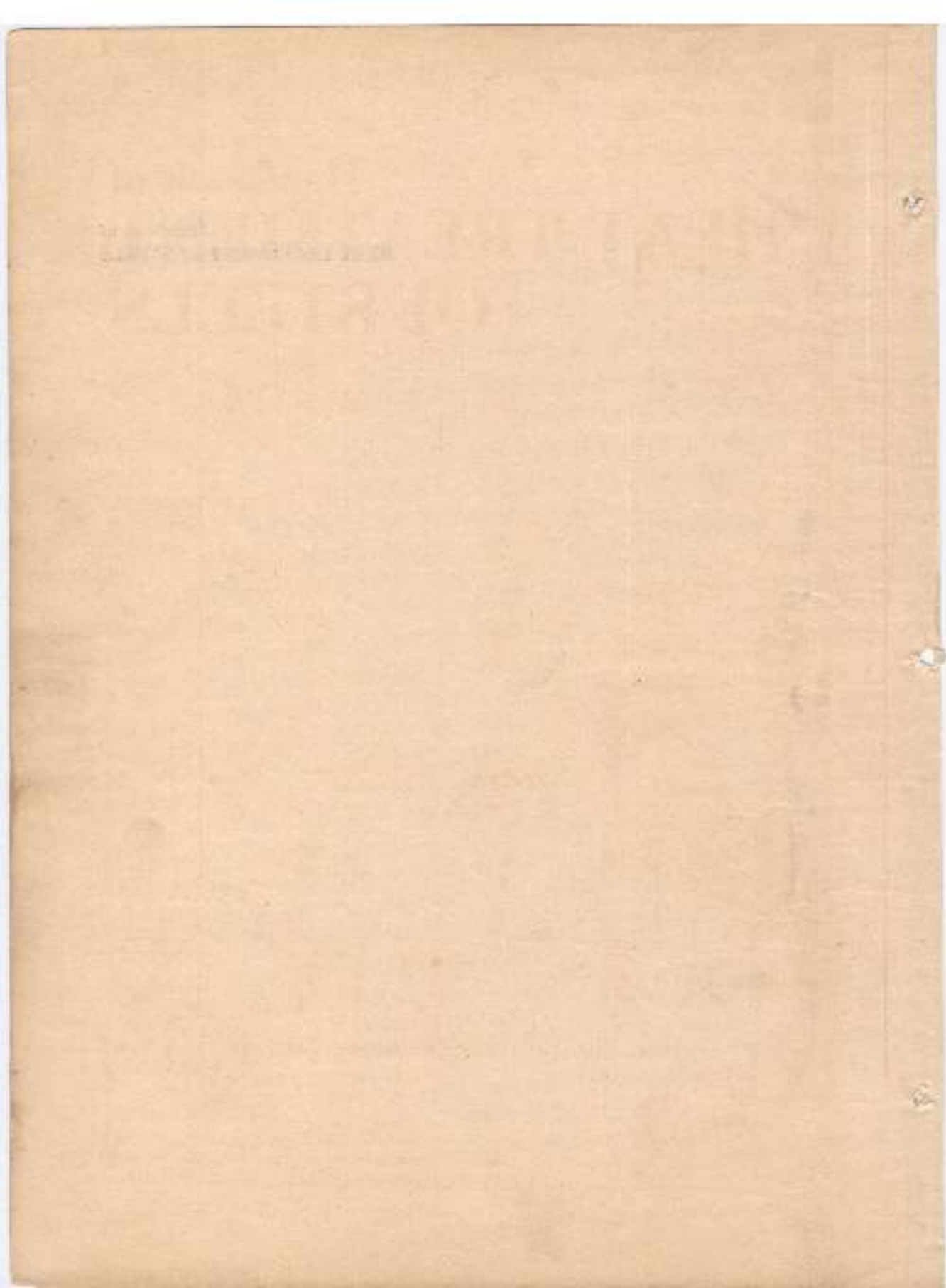


Handbook of HEAT TREATMENT OF STEELS



K H PRABHUDEV

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K H PRABHUDEV

*BMT Limited
Bangalore*



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*Dedicated
to
My Mother*

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Preface

The purpose of writing this handbook is to provide theoretical as well as practical knowledge of heat treatment of steels and application of steels in engineering industries to technocrats, namely designers, planning engineers, material engineers, heat treaters and to students of engineering.

This book deals with varieties of steels, their heat treatment and their applications. Exhaustive descriptions on heat treatment operations, such as annealing, normalizing, stress relieving, hardening, etc. for different types of steels are given in this book. The different types of furnaces required for carrying out heat treatment operations are also described. The book deals with the control of heat treatment processes, right from incoming inspection of steels to be heat treated, process control during heat treatment, to quality control of finished parts by adopting different types of testing methods such as Vickers, Microhardness, Rockwell hardness and Brinell hardness.

The different types of case hardening methods such as gas nitriding, ion-nitriding, nitro-carburizing, tufftriding, sursulf, sulfinaizing, different types of carburizing, cyaniding, carbo-nitriding with their practical applications are outlined along with shop problems and solutions. It also covers both flame and induction hardening of steels, with their practical applications.

Separate data compilation is provided for each of the international standard grades of engineering alloy steels, free-cutting steels, spring steels, stainless steels, different types of tool steels such as carbon tool steels, cold work alloy steels, hot work steels and high speed steels, details of their applications, mechanical properties, heat treatment procedures, sequences of manufacturing operations are also given. This will be helpful to the materials engineer or design engineer to examine both the technical and economic feasibility of available materials while going for a new product or improving the old one since the economics of production are determined, to a large extent by the cost of the materials, plus the cost of converting them into the finished product.

Data sheets present the chemical composition, mechanical and physical properties, general characteristics of steels and their corresponding international standard grades such as ISO (International Standards Organisation), IS (Indian Standards), DIN (German Standards), BS (British Standards), AISI (American Iron and Steel Institute), NFA (French Standards), GOST (USSR) and JIS (Japanese Standards).

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India Ltd, India for providing the necessary information in bringing out this book.

I am thankful to the management of HMT Limited and to my many friends who have rendered their invaluable help in bringing out this handbook. I also gratefully acknowledge the assistance of my wife Mrs. Sunanda and son Arvind.

K H PRABHUDEV

Foreword

In the field of heat treatment of steels, this handbook is unique. It has been designed for practical everyday use by designers, heat treaters, material engineers and production engineers. Both principles and methods of application have been presented keeping in mind the soundness of engineering concepts, their dependability for important decisions where heat treatment of steels is concerned, and their usefulness as a source of information for all who are concerned with heat treatment methods and processes. In short, the aim has been to make available a handbook on heat treatment of steels to all those in manufacturing, and to the students of engineering who aspire for a career in the important field of heat treatment of steels.

Mr Prabhudev, the author of this handbook, has succeeded in setting forth the guiding principles in every topic, and the details are meticulously provided to cover the full gamut of heat treatment processes, their application and control, and the selection of equipment and its use in the manufacturing shop. The author has painstakingly screened a large amount of information for preparing and compiling data for each of the international standard grades of steels.

Mr Prabhudev has relied heavily on his rich experience of over 17 years in HMT to write this handbook to enrich the knowledge of practising engineers, designers and students of engineering.

M R NAIDU

*Chairman & Managing Director
HMT Limited
Bangalore*

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The first part of the paper is devoted to a general discussion of the problem of the existence of solutions of the system of equations (1) for arbitrary values of the parameters α and β . It is shown that the system has solutions for all values of the parameters α and β if the function $f(x)$ is continuous and has a bounded derivative. The second part of the paper is devoted to the study of the properties of the solutions of the system of equations (1) for arbitrary values of the parameters α and β . It is shown that the solutions of the system of equations (1) are unique and depend continuously on the parameters α and β . The third part of the paper is devoted to the study of the properties of the solutions of the system of equations (1) for arbitrary values of the parameters α and β . It is shown that the solutions of the system of equations (1) are unique and depend continuously on the parameters α and β .

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Introduction

Heat treatment of metals and alloys is one of the many wonderful processes discovered by man to mould materials to desired properties for making implements in his ascent to modern civilization. Heat treatment of steels alone covers a very wide range of processes. It is used in a variety of ways ranging from stress relieving of parts for reducing fabrication stresses and full annealing for softening steels for easy shaping to hardening and tempering for developing high strength and toughness. Even in this hardening process which involves phase transformations, there are several refinements and tempering treatments to develop a series of combinations of strength and toughness in steels for different engineering applications. Again heat treatment is a process by which micro-structural refinement is achieved. There are a variety of surface heat treatments to convert chemically and physically surface material ranging in thickness from a few microns to substantial depths of the cross-sections in order to impart enhanced hardness and wear resistance properties.

Although a large variety of published literature is available on the subject, there are very few comprehensive compilations on the subject. In this regard, Mr Prabhudev has done an excellent job of compiling most of the information related to heat treatment of steels. This book deals in great detail with the principles and practices of heat treatment of steels and associated heat treatment furnaces and other equipments and applications. It also covers various types of steels and specific treatments adopted for each variety of steel. I feel that this book will be very useful as a reference book on heat treatment of steels not only for metallurgists and engineers engaged in heat treatment, but also for designers and engineers working in industry involved with applications of steels for various engineering structures.

I congratulate the author for bringing out such a useful publication.

KRISHNADAS NAIR

Group Executive

Hindustan Aeronautics Ltd

Bangalore

Introduction

The purpose of this study is to investigate the effects of the proposed system on the performance of the system. The study is divided into two main parts: a theoretical analysis and an experimental evaluation. The theoretical analysis is based on the principles of the system and the results of previous studies. The experimental evaluation is based on the results of a series of experiments conducted under controlled conditions. The results of the study are presented in the form of a series of tables and graphs. The results show that the proposed system has a significant positive effect on the performance of the system. The results also show that the proposed system is more efficient than the existing system. The results of the study are discussed in the context of the literature and the implications for future research are discussed. The study is limited by the scope of the experiments and the results may not be generalizable to all systems. The study is a preliminary study and further research is needed to confirm the results and to investigate the effects of the proposed system on other systems.

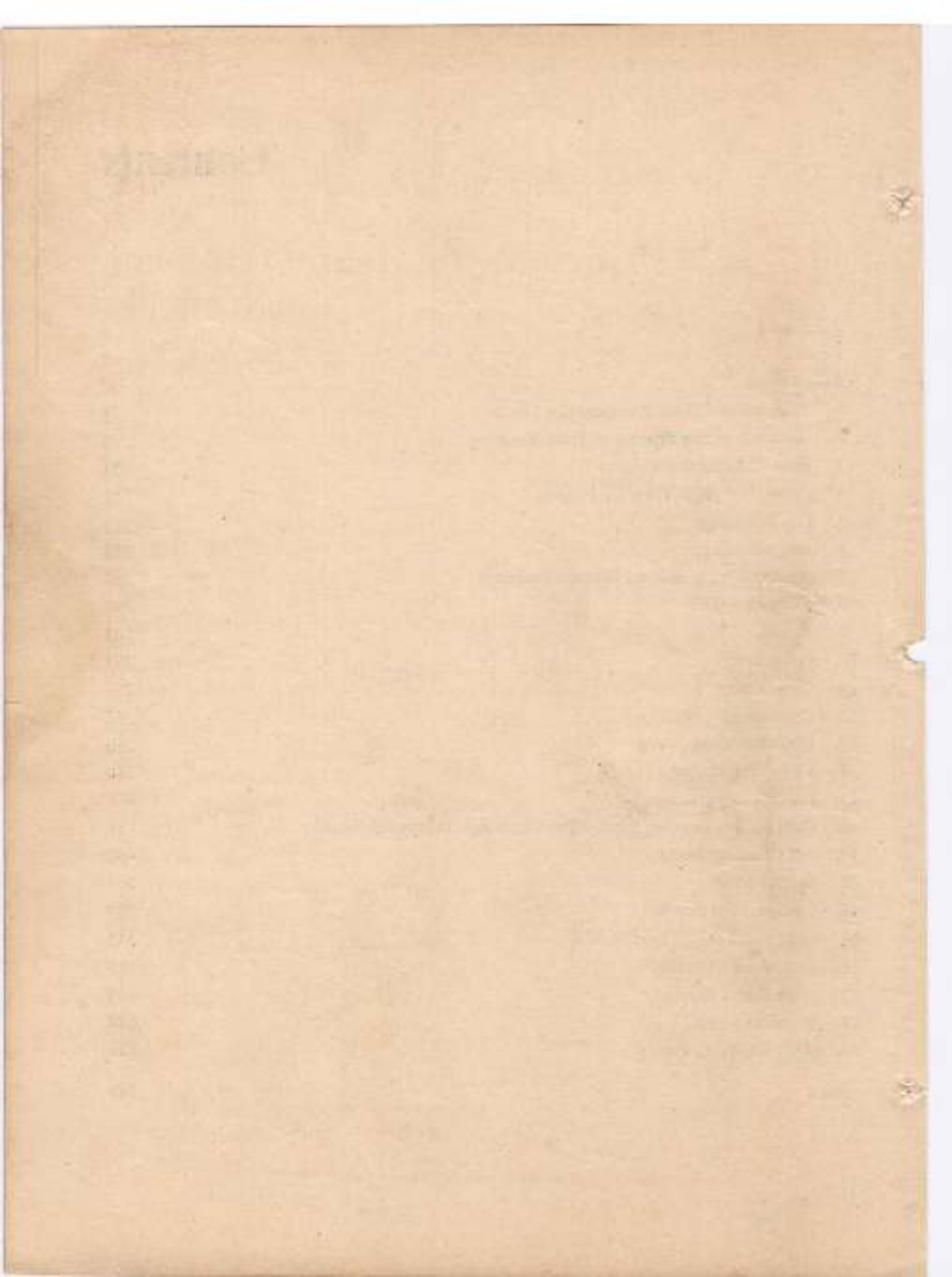
1.1. Background

1.2. Objectives

1.3. Scope

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Principles of Heat Treatment of Steels

1.1 Iron and Its Transformation

(Iron is the most important of all metals. It is the primary metal used to make a variety of steels which are the most popular engineering materials of our times. The allotropic property of iron is responsible for obtaining different microstructures on the various forms of steels. Iron is also an excellent solvent for many metals.)

The essence of allotropic transformation is that the atoms of a crystalline solid are converted from one crystalline form to another, i.e. they form a new crystal lattice.

Iron is stable at low temperatures and this condition is designated by the Greek letter alpha (α). A second form of the same iron stable at a higher temperature is known as the gamma (γ) stage, and at still higher temperatures prevail the delta (δ) stage.

The allotropy of iron is of special practical importance. It has essentially two crystalline forms. At ambient temperature pure iron is in a body-centered cubic system. There is an iron atom at each of the eight corners of the cube with another atom at its centre. This arrangement, shown in Fig. 1.1, is the alpha iron, metallurgically termed as ferrite. When pure iron is heated no change takes place in the structure of alpha iron up to 910°C. Hence, there will be no change in the arrangement of atoms up to this temperature, usually

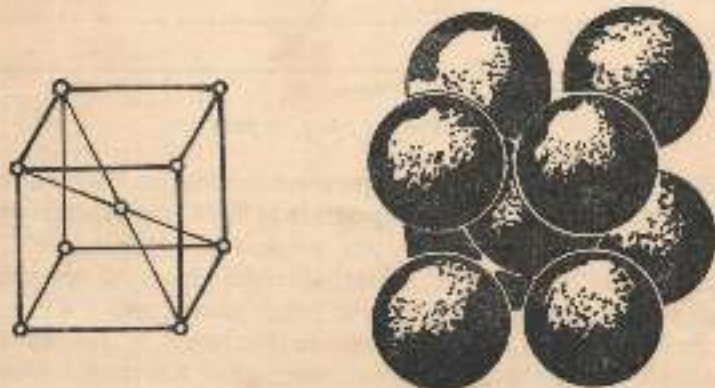


Fig. 1.1 Crystal lattice of iron (body-centered cubic)

known as the transformation point Ac_3 (Fig. 1.2). If the iron is heated above 910°C , the atomic arrangement is modified and transformed into a face-centered cubic system, with an atom at the centre of each face (Fig. 1.3). This is called the gamma (γ) iron, the metallurgical term being austenite. The austenite, thus formed, has a relatively high solvent power for carbon. If the heating is continued, the gamma form is changed at 1392°C into a body-centered cubic structure again. It is now known as delta (δ) iron. Further heating causes an increase in the thermal vibration of atoms. Finally, at 1536°C , the crystalline cohesive forces are no longer present. The metal passes into the liquid or molten stage. On cooling the molten iron to the ambient temperature, the transformation occurs in the reverse order, at approximately the same temperature. Iron is ferromagnetic at room temperature; its magnetism decreases with increase in temperature and vanishes completely at 769°C , which is called the Ac_2 point (Fig. 1.2).

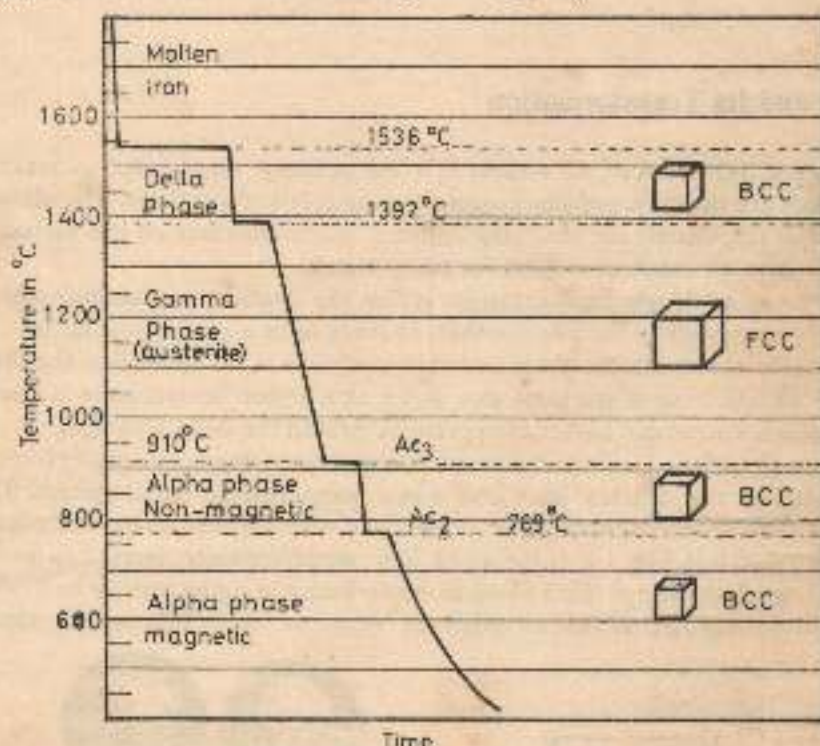


Fig. 1.2 Cooling curve for pure iron

Figure 1.2 illustrates a typical time-temperature cooling curve. It has critical points at 769°C , 910°C , 1392°C and 1536°C . The temperature of 769°C corresponds to the curie point, 910°C to the Ac_3 point and 1392°C to the Ac_4 point. The point at 1536°C corresponds to the melting point of pure iron. The Ac_1 point, corresponding to a temperature of 723°C , exists only when iron is alloyed with carbon or other metals, and not in its pure form.

The usage Ac for defining the points of transformation is derived from the French expression *Arrêter chauffage*, where A denotes arresting and c denotes heating. When iron is cooled from its molten state, the critical points are the same in the reverse order, except that they are denoted by the letter r instead of c (for example Ar_2 , Ar_3 etc.). The letter r

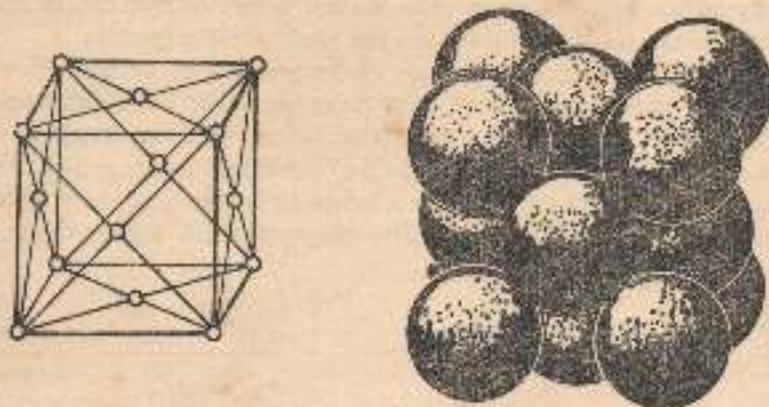


Fig. 1.3 Crystal lattice of iron (face-centered cubic)

denotes the first alphabet of the French word *refroid*, meaning cooling.

Data on the lattice structure transformation on heating and cooling are given in Table 1.1. The table lists specific temperatures, called critical points, at which solid phases occur in iron and its alloys.

Table 1.1

On heating		On cooling	
Stable lattice	Temperature range, °C	Stable lattice	Temperature range, °C
Body-centered cubic alpha iron	≤ 910	Body-centered cubic alpha iron	1536–1392
Face-centered cubic gamma iron	910–1392	Face-centered cubic gamma iron	1392–898
Body-centered cubic delta iron	1392–1536	Body-centered cubic delta iron	≤ 898

Note: The difference in the structure of alpha and delta iron is attributed only to the distance between the atoms, the mutual arrangement of atoms of both structures being identical.

The addition of alloying elements to iron, especially carbon, facilitates the manufacture of a variety of steels which, when subjected to various heat treatment methods, make the steel suitable for a particular application.

1.2 Iron-Carbon Phase Diagram

The versatility of steel depends on its different properties, imparted through suitable alloying and appropriate heat treatment measures. The mechanical properties of steel

depend chiefly on its microstructure. The microstructure of steel can be advantageously changed by heat treatment to obtain the desired mechanical properties.

Many steels owe their special properties to the presence of certain alloying elements. Carbon is the most important element controlling the properties of all steels. When iron is alloyed with carbon, the transformation that takes place over a temperature range is related to the carbon content. According to the conditions under which an iron-carbon alloy is formed, carbon is present either in solution or in the elementary form of graphite, or in combination as iron carbide (Fe_3C). The diagram which depicts the temperatures at

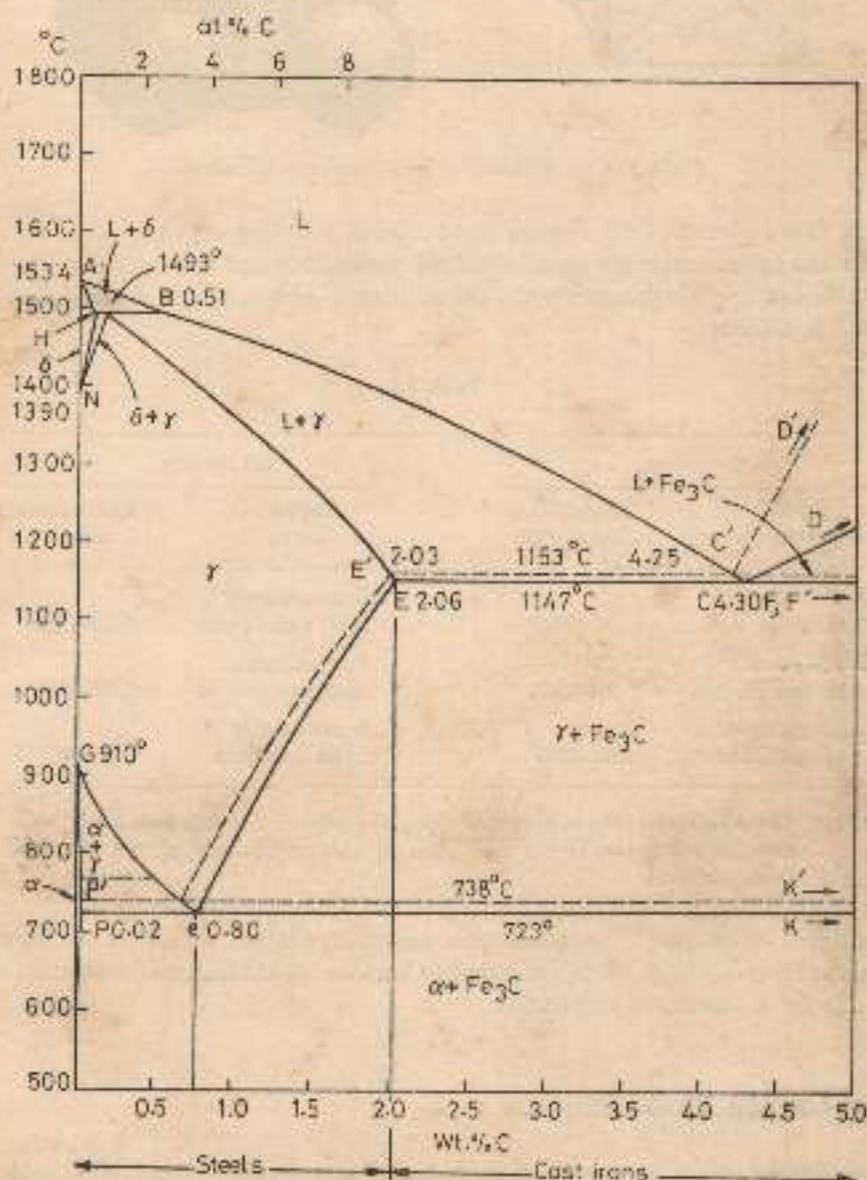


Fig. 1.4 Thermal equilibrium diagram for iron-iron carbide alloys¹

which phase changes occur during very slow cooling or heating, and in relation to the carbon content, is called the iron-carbon phase diagram. This diagram is the basis for a correct understanding of all heat treatment operations. Figure 1.4 illustrates the iron-carbon phase diagram which includes the whole range of iron-carbon alloys, namely carbon-less iron, carbon-steel and cast irons. The carbon varies from zero to about 6 per cent.

Figure 1.5 illustrates the various microstructures appropriate to that part of the iron-carbon diagram which applies to the heat treatment of steels. Steels are iron alloys with

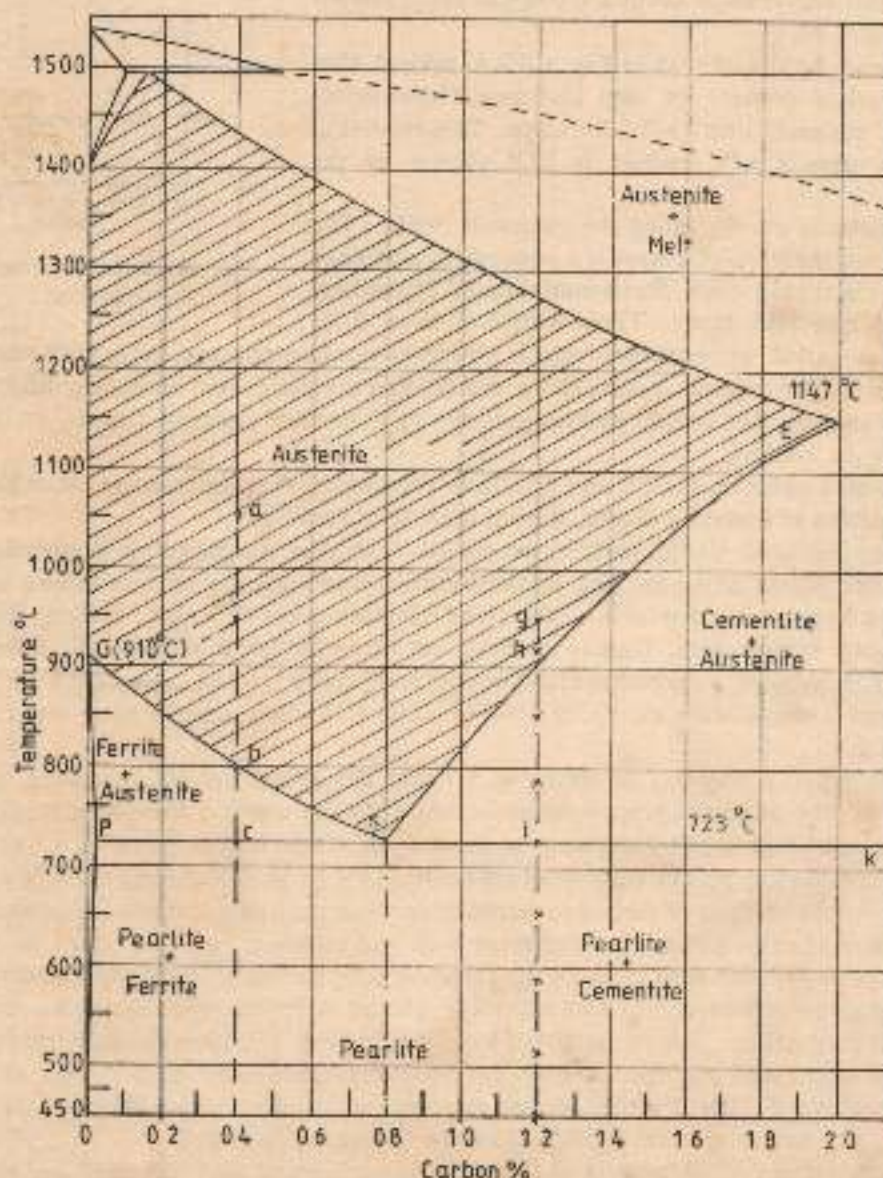


Fig. 1.5 Steel portion of iron-carbon equilibrium diagram²

relatively low carbon (up to about 2% carbon) by weight. Alloys with carbon above this level are generally classified as cast irons.

Carbon is an element that stabilizes austenite by increasing the range of austenite formation in steel. The maximum solubility of carbon in austenite is about 2.06% (E) at 1147°C. The percentage of carbon capable of going into solution in ferrite increases from zero at 910°C to a maximum of 0.02% at 723°C. On further cooling, this decreases to around 0.008% at room temperature (Fig. 1.6).

As shown by the line GS in Fig. 1.5 it is evident that as the carbon content of iron increases, the transformation of austenite into ferrite decreases. This reaches a minimum value of 0.8% carbon at 723° shown by the point S.

This point is usually called the eutectoid point. The eutectoid composition of a steel is a convenient reference point for classifying steels. Steels containing 0.8% carbon are called eutectoid steels. Those with less than 0.8% carbon are called hypoeutectoid steels. Hypereutectoid steels are those with more than 0.8% carbon. The critical points along the GS line are designated as A_{c1} on heating and as A_{r1} on cooling. The critical points along the PSK line are designated as A_{c1} on heating and as A_{r1} on cooling.

Thus, each point on the GS and SE lines represents the temperature at which the transformation of austenite begins, during heating or cooling.

If eutectoid steel (0.8% carbon) is cooled from the austenitizing temperature on reaching the points along the line, it transforms into an eutectoid mixture known as pearlite. When hypoeutectoid steel is cooled (steel containing less than 0.8% carbon) from the austenitizing temperature, ferrites separate out along the grain boundaries following the line GS. For instance, a carbon steel containing 0.4% carbon, when austenitized and cooled slowly from a temperature shown by point *a* (Fig. 1.7) starts transforming on reaching the point *b*.

At this point, it may be seen from Fig. 1.7 that the grains of solid solution (ferrite) nucleate at the austenite grain boundaries, and the alloy enters a two-phase field. If slow cooling is continued to point *c* it leads to the growth of the ferrite grain size. At 723°C the steel structure at point *c* consists of austenite (0.8% carbon) and ferrite (0.02% carbon). Since the solubility limit of carbon in ferrite is very low and its growth is associated with the rejection of carbon from the interphase back into austenite becomes richer in carbon. Further cooling of this steel through the eutectoid temperature leads to the transformation of the remaining austenite into a fine lamellar mixture of ferrite and cementite which is nothing but pearlite. This is indicated by point *d* in Fig. 1.7. Now the 0.4% carbon steel consists of ferrite and pearlite. The ratio of ferrite to pearlite is the same as that of ferrite to austenite at point *c*. Further cooling to room temperature has no effect on the microstructure. The reverse process holds good while the steel is heated.

The amount of pearlite present in the various structures of steel depends on the percentage of carbon present. For instance, a steel containing 0.20% carbon will possess 25%

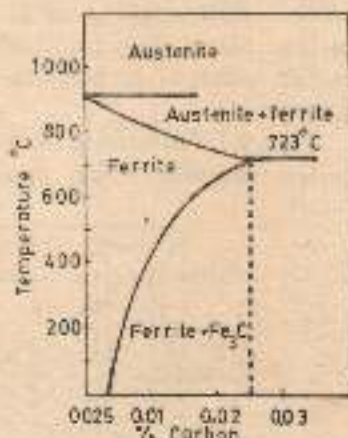


Fig. 1.6 Solubility of carbon in alpha iron.

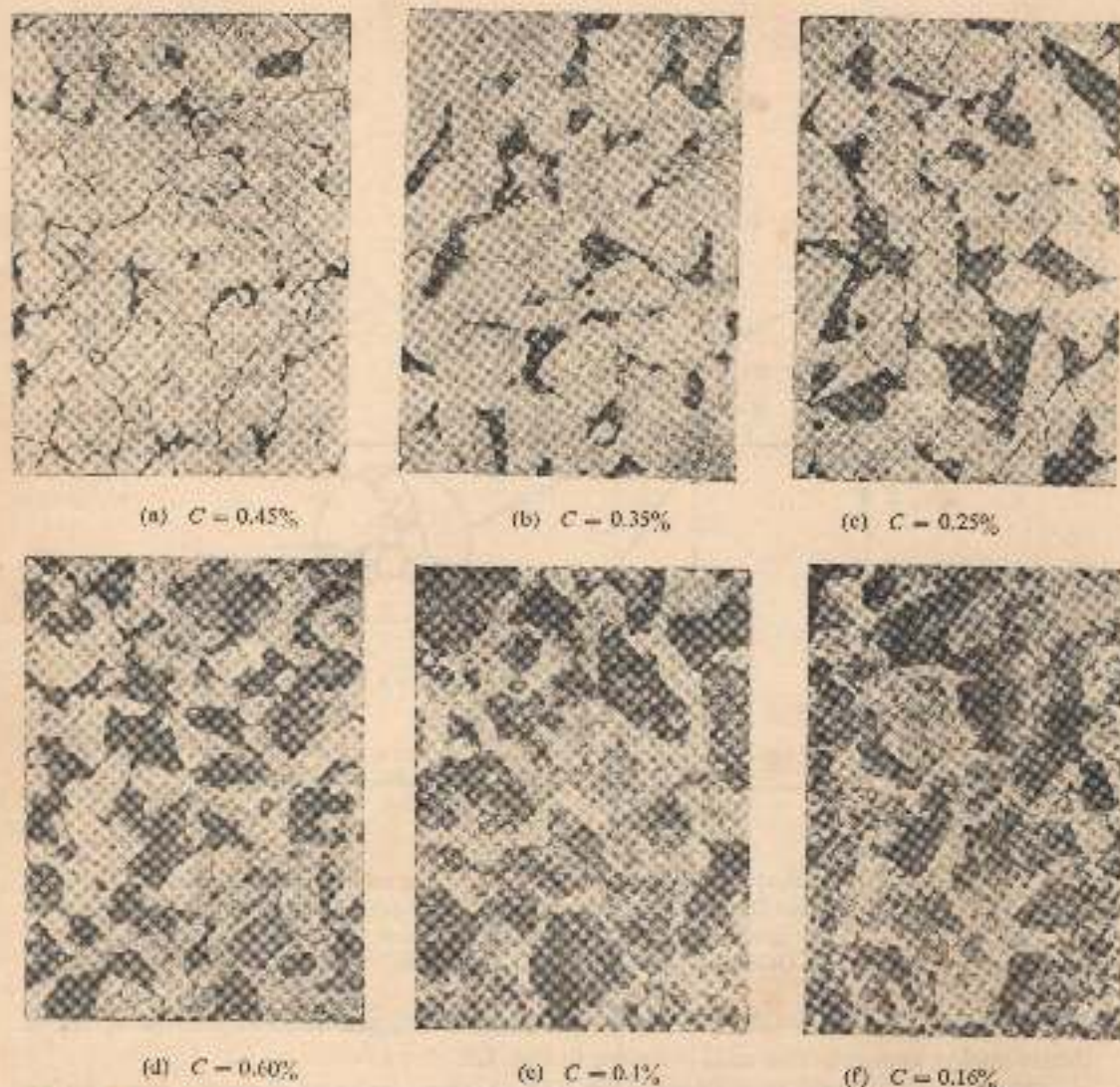


Fig. 1.8 Microstructures of hypoeutectoid steels (dark areas represent pearlite structure and white areas ferrite structure)

temperature does not change the microstructure. The microstructure of slowly cooled hypereutectoid steel is shown in Fig. 1.10.

These explanations help surmise that depending on the carbon content, the structure of the slowly cooled (annealed) carbon steels at room temperature will be:

1. 0.007–0.025% carbon, ferrite.
2. 0.025–0.8% carbon, ferrites and pearlites.
3. 0.80–2.06% carbon, pearlites and carbides precipitated from austenite.
4. 2.06–4.2% carbon, pearlite and graphite.

With the help of the iron-carbon equilibrium diagram, it is possible to select the temperature of heating for annealing, normalizing and hardening.

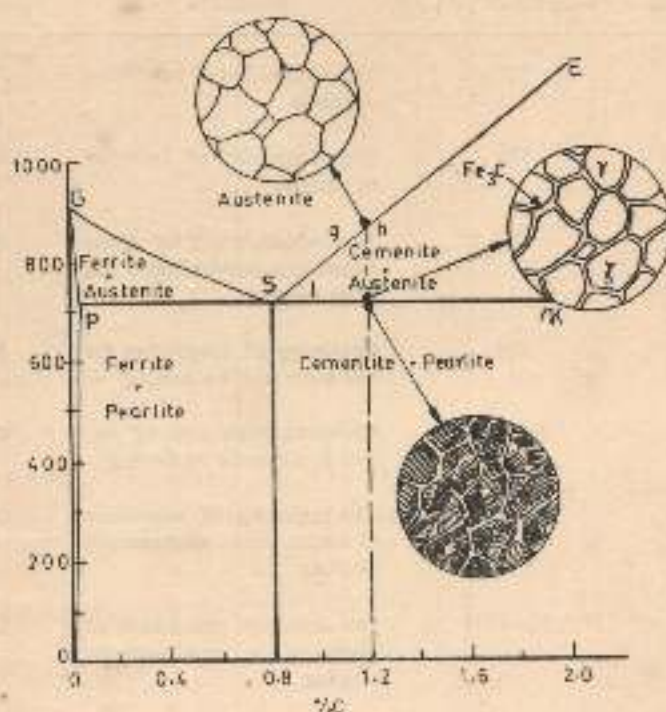


Fig. 1.9 Diagrammatic representation of transformation phenomena when cooling an iron-carbon alloy with 1.2% C.



(a) C = 1.5%

500x



(b) C = 1.1%

500x

Fig. 1.10 Microstructures of pearlite and cementite (dark areas are pearlite and white areas cementite)².

The temperature at which the solid phase changes occur in iron and its alloys are called critical points, as shown in Table 1.2.

Table 1.2

Arrest points on heating	Transformation temperature, °C	Nature of transformation	Line of transformation
A_{c1}	723	Transformation of pearlite to austenite	FSK
$^{11}A_{r1}$	723	Transformation of austenite to pearlite	PSK
A_{c2}	768	Loss of magnetism for steels containing approx. upto 5% C on heating	MO
$^{11}A_{r2}$	768	Regaining of magnetism for the same steel on cooling	MO
A_{c3}	910-723	Complete dissolution of ferrite in austenite on heating	GOS
$^{11}A_{r3}$	910-723	The beginning of separation of ferrite from austenite on cooling	GOS
A_{cm}	723-1147	The complete dissolution of cementite in austenite on heating	SE
A_{cm}	723-1147	The beginning of separation of cementite from austenite on cooling	SE
—	—	The beginning of melting of C.I. on heating	IE
—	—	The end of solidification of steel on C	IE
—	1147	The beginning of melting of C.I. on heating	ECP
—	1147	The end of solidification of C.I. on cooling	ECP
—	—	The end of melting of steel and C.I. on heating	$ABCD$
—	—	The beginning of solidification of steel and C.I. on cooling	$ABCD$

1.2.1 EFFECT OF ALLOYING ELEMENTS ON THE IRON-CARBON PHASE DIAGRAM

Addition of alloying elements to iron-carbon alloys influences the phase boundaries so that the transformation range is either narrowed or expanded. Figure 1.11 shows the change in the eutectoid temperature with increasing amounts of alloying elements. The eutectoid temperature is considerably raised by the addition of most alloying elements, but the addition of nickel or manganese lowers the eutectoid temperatures.

Figure 1.12 shows that the addition of alloying elements lowers the percentage of carbon in the eutectoid. For example, a steel containing 5% chromium has its eutectoid point at 0.5% carbon. The influence of chromium and manganese is depicted in Fig. 1.13 and Fig. 1.14 respectively. Here, it can be seen that the eutectoid transformation temperature A_{c1} is lowered by the addition of manganese, whereas it is raised by the addition of chromium.

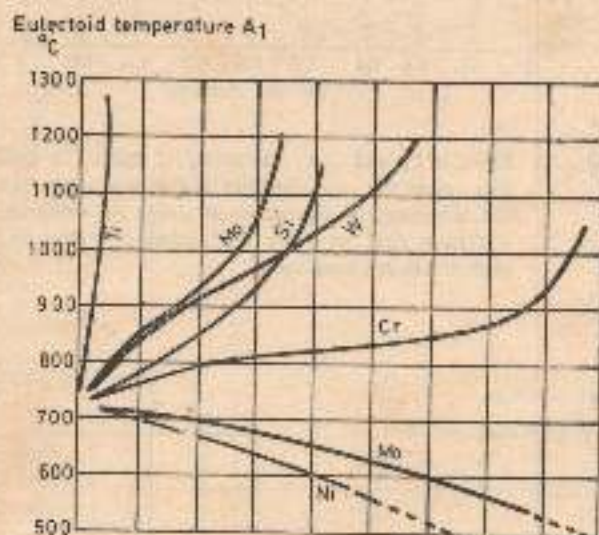


Fig. 1.11 Influence of alloying element on eutectoid temperature²

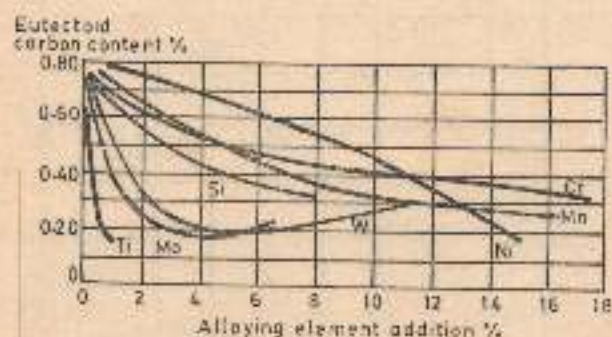


Fig. 1.12 Influence of alloying element addition on eutectoid carbon content²

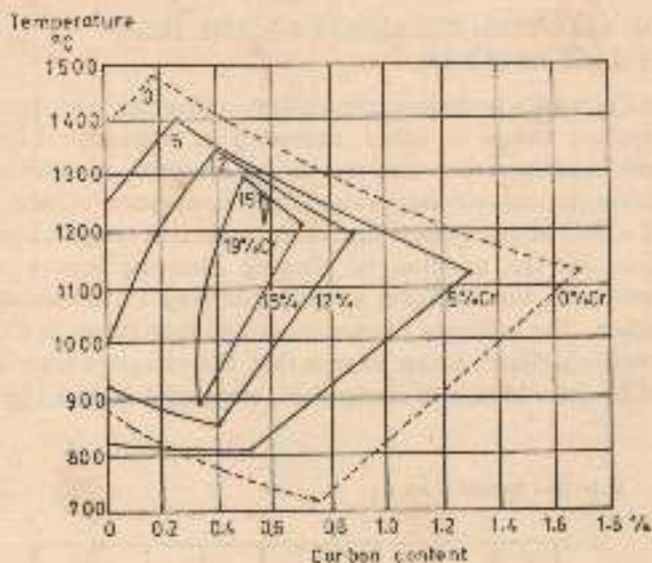


Fig. 1.13 Effect of Cr and C on the austenite field. The dark line traces the austenite field of the base alloy. The displacement of the eutectoid point, for instance, indicates that an alloy containing only iron and carbon has not been used¹

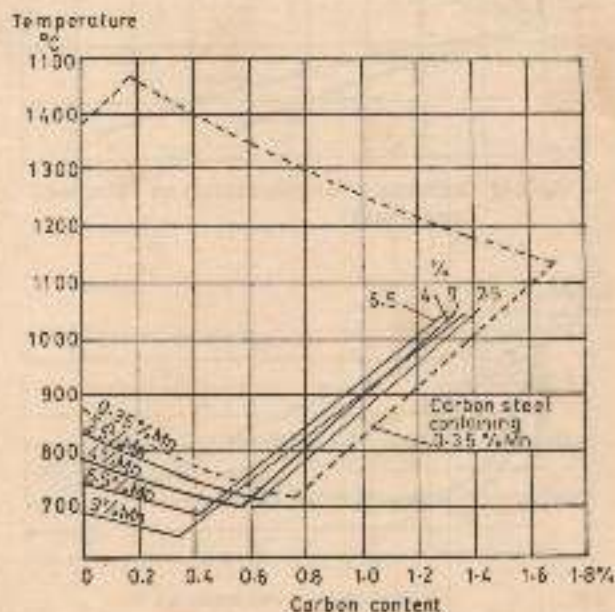


Fig. 1.14 Effect of Mn and C on the austenite field¹

1.3 Time-Temperature Transformation Diagram

The main purpose of heat treatment of steels is to obtain the most desired structure of the steel to suit a particular application. It is possible to accurately predict the formed structure of the steel by employing a specific heat treatment process. The obtained structure is the result of a particular transformation from the original condition. These transformations are read from phase diagrams. The iron-carbon phase diagram is the most useful to predict many transformation conditions, but it does not provide much information on the non-equilibrium state of steels. Under each condition, transformations can be best described by *Time-Temperature-Transformation* diagrams, usually called the TTT diagrams. They relate the transformation of austenite to the time and temperature conditions to which it is subjected. Other names for these diagrams are S curves and C curves. These help to understand clearly the behaviour of steel at various stages of heat treatment. These diagrams are used mainly to predict the structure and mechanical properties of steels quenched from the austenitizing region and held at a constant elevated temperature below the eutectoid point A_{c1} .

The influence of cooling rate on the transformation of austenite may be illustrated by considering the TTT diagram for a particular steel. For instance, Fig. 1.15 illustrates the TTT curves for a 1.0% carbon steel. In this diagram the ordinate is the temperature and the abscissa is the time plotted on a logarithmic scale. This diagram is a summary of the various microstructures obtained as a result of a series of experiments conducted on small test pieces heated to austenitic condition and quenched in a salt bath maintained at different temperatures below the eutectoid point A_{c1} , and holding it at each temperature for various lengths of time until the decomposition of austenite is completed. The transformation of austenite in these steel pieces may be studied under a microscope.

The products formed by the transformation of austenite may be classified into three groups. At the temperature range from A_{c1} to about 550°C, pearlite is found to be formed. However, the pearlite formed will be coarser at or near 700°C, and will be finer at temperatures nearing 550°C. Below this temperature, at around 450°C, upper bainite is formed; and at a temperature around 250°C, just above M_s , the structure is that of lower bainite. The hardness levels corresponding to the above structures can be read from a scale given on the right side of the curve.

In the TTT diagram, the curve *B* indicates the beginning of austenite transformation and the curve *E* indicates the time required for the complete transformation of austenite. The region to the left of curve *B* indicates the incubation period when the transformation of austenite has not yet commenced. It may be seen that the transformation is most rapid at about 550°C, where it commences in less than one second and is completed after about five seconds. This shows that the rate of cooling should be relatively fast to attain either martensite or bainite. This may be achieved by water quenching.

Pearlite formed in the higher range is less hard than the fine pearlite. This is due to the fact that cementite is precipitated from austenite diffusion.

Bainite, formed at a higher temperature, has a lower hardness compared to the bainite formed at a lower temperature. The structure may have either a feathery or a circular needle-like appearance, depending on whether it was formed at a relatively high or a relatively low temperature.

The formation of martensite differs from that of pearlite or bainite. It is practi-

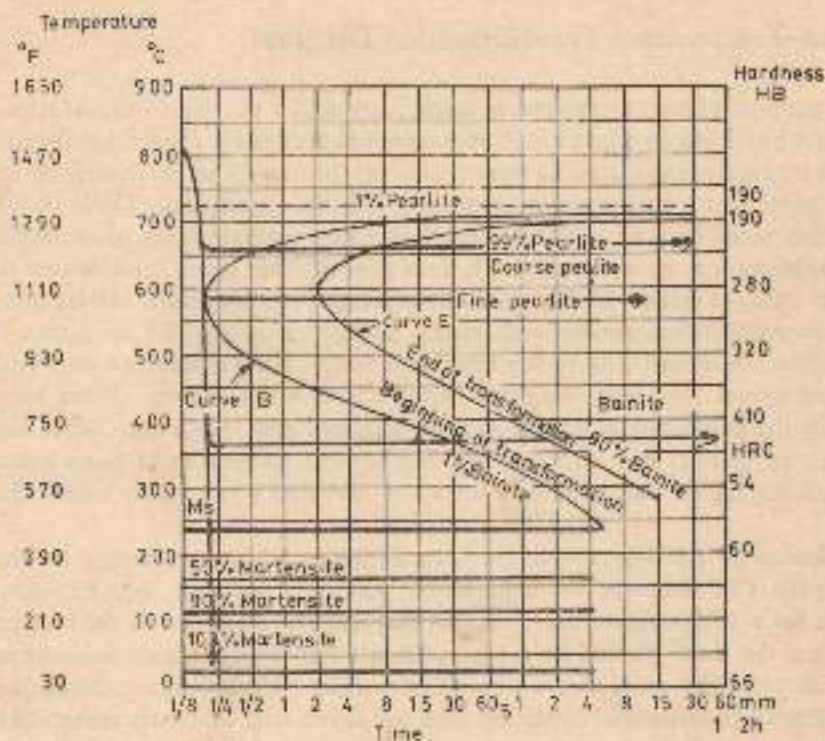


Fig. 1.15 (a) Isothermal transformation diagram for 1% carbon steel (Courtesy: Uddeholm Steel Corp., Sweden)

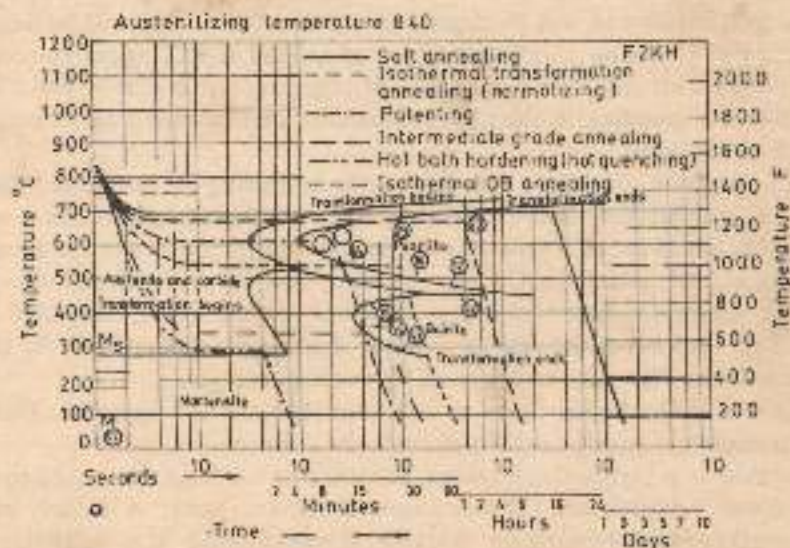


Fig. 1.15 (b) Isothermal TTT curve and methods of heat treatment

only independent of time. In this example, it starts at about 200°C (M_s) and continues as the temperature falls until at about 29°C when it is nearly 100% martensite (M_f). The formation of martensite, in relation to time, is illustrated by the horizontal line in the graph. At 99°C about 90% martensite is formed. This proportion does not change with time as long as the temperature is kept constant.

Figure 1.15b illustrates the application of isothermal heat treatment for different types of heat treatment, such as soft annealing, isothermal OB-annealing, patenting, hardening, etc.

1.3.1 EFFECT OF ALLOYING ELEMENTS

The shape of the S and C curves is influenced by the chemical composition of steel. Almost all the alloying elements, with the exception of cobalt, titanium and aluminium, move the curves of the isothermal transformation diagram to the right, i.e. they delay the initiation of transformation and reduce the rate at which that reaction proceeds. An increase in carbon content up to the eutectoid percentage retards the pearlite reaction, but any further increase in the carbon content shortens the incubation period and accelerates the rate of reaction. Depending on the particular alloying element, there is a marked influence on the isothermal transformation of steels. For example, nickel and manganese retard the pearlite and bainite transformations almost uniformly at all temperatures. The presence of molybdenum and chromium strongly retard the pearlite reaction but affect the bainite reaction to a much smaller extent. These alloying elements also raise the temperature range over which the pearlite reaction occurs and lowers that over which the bainite

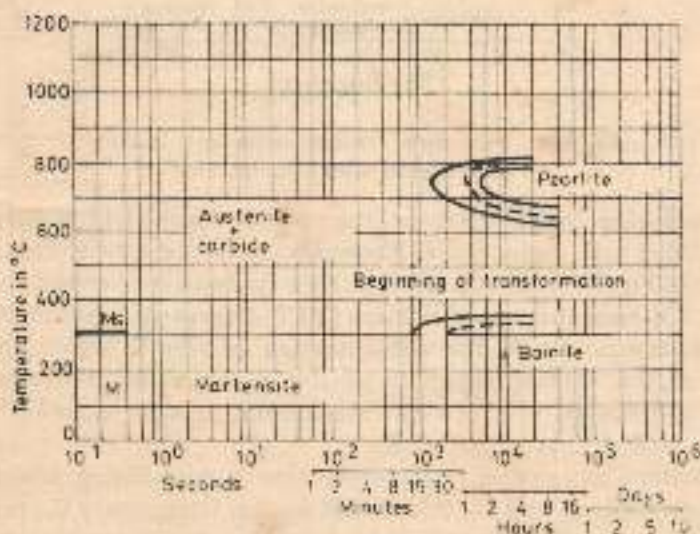


Fig. 1.16 Isothermal TTT curve of AISI H13 (Courtesy: Roehling-Stahlexport GmbH, W. Germany)

reaction takes place. As a result, the TTT diagram of steels containing appreciable amounts of either of these alloying elements frequently shows a stability 'bay' of austenite between two reaction zones (Fig. 1.16) which is most common with the high speed, hot-worked and cold-worked steels.

1.3.2 TRANSFORMATION UPON CONTINUOUS COOLING

The information from TTT diagrams is quantitatively valid only for isothermal transformations at constant temperature. In practice, TTT diagrams are not applicable, since under real conditions of heat treatment, the transformation occurs in most cases on continuous cooling. Hence these diagrams can be modified to be quantitatively useful for continuous cooling conditions. Continuous cooling diagrams are similar to the isothermal transforma-

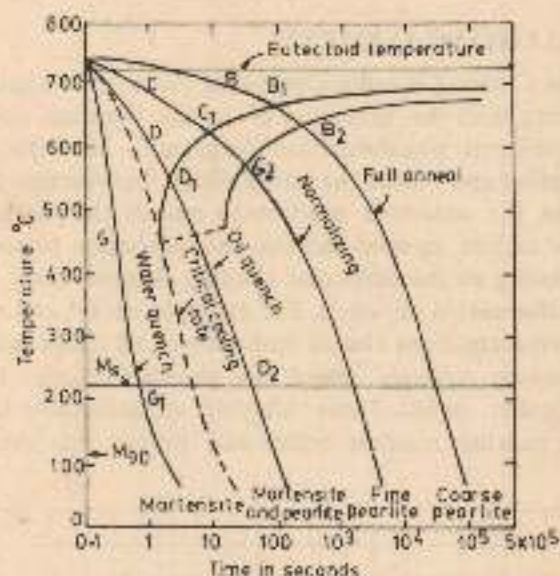


Fig. 1.17 Variation of microstructure as a function of cooling rate of an eutectoid steel²

tion diagrams requiring longer time for completion. Figure 1.17 illustrates a modified diagram that includes both isothermal and continuous cooling curves (Figs. 1.18 and 1.19).

For example, in Fig. 1.17, curve B represents the steel specimen cooled at a very slow rate as in annealing. It crosses the transformation (TTT diagrams) curves at B_1 and B_2 . When the steel reaches temperature B_1 , the transformation of pearlite begins; and when it cools to temperature B_2 , the transformation to pearlite is completed. It may be noted that the pearlite formed at point B_1 will be somewhat coarser, having been formed at a slightly higher temperature than that formed at B_2 .

Curve C indicates a more rapid rate of cooling, as in normalizing. It also intersects the transformation curves at C_1 and C_2 . When steel reaches temperature C_1 , pearlite formation begins and it will be somewhat finer than that formed at B_1 . On reaching temperature C_2 , transformation to pearlite is completed. Pearlite formed at C_2 will be still finer, since it is formed at a relatively low temperature.

Curve D represents a still more rapid rate of cooling. It intersects only the curve corresponding to the beginning of the transformation at point D_1 , and does not cross the curve representing the end of the transformation. This means that the transformation of pearlite begins but does not reach completion. In other words, a certain volume of austenite

nite is first transformed to pearlite at a higher temperature, but since the time is not sufficient to allow the transformation to be completed, the remaining volume of austenite undergoes transformation into martensite on reaching the M_s point, at point D_3 . Thus the structure of the cooled steel at this rate is a partially hardened structure.

The curve G represents a very rapid rate of cooling as in a water quench. Steel cooled at this rate does not undergo transformation until it reaches the temperature G_2 . At this point the austenite begins to form martensite. Figures 1.18 and 1.19 illustrate the continuous cooling curves of BS 708 M40 and AISI H13.

1.4 Metallographic Structure and Associated Properties

Steel can be heat treated to produce the desired micro-structure and properties. The desired results are accomplished by heating and cooling at the specified temperatures. If the surface of a steel specimen is properly prepared and examined under a microscope, it will be found to possess different structures. The type of structure present mainly depends on the chemical composition of the steel and heat treatment applied. The different structures present in steels are ferrite, pearlite, bainite, martensite, cementite, carbides.

1.4.1 FERRITE

A solid solution of carbon and other alloying elements in a body-centered cubic iron is called ferrite. This is formed on slow cooling of austenitized hypoeutectoid steel below A_{r1} . This is the so-called alpha (α) iron. It is soft, ductile and possesses a hardness of 70–100 BHN and has a fairly high conductivity.

When austenitized steel is cooled below A_{r1} , the carbon-free austenite gets transformed into ferrite which is basically a pure iron (maximum percentage of carbon is 0.021%). The ferrite present in the steel may have other elements as residual elements in addition to the small amount of carbon in solid solutions. Figure 1.20 illustrates a pure iron. The ferrite grains are polygonal and of regular shape and size.

1.4.2 CEMENTITE

Cementite is a compound of iron and carbon, known chemically as iron carbide having the approximate chemical formula Fe_3C (carbon percentage 6.67%). It is characterized by an orthorhombic crystal structure. Cementite is a hard and brittle compound possessing a hardness of 65–68 HRC. It may be found in the round form, either in an annealed or a hardened structure. In the annealed structure, the carbides embedded in a soft ferritic matrix create chip breakers and render the steel more machinable. The presence of carbides in hardened steels and particularly in high speed steels and cold-work steels, increases the wear resistance of tools. Figure 1.21 shows the microstructure, consisting of spheroidized cementite in a ferritic matrix.

1.4.3 PEARLITE

Pearlite is a eutectoid mixture of cementite and ferrite possessing a hardness of RC 10–30 depending on the type of steel. For example, when a eutectoid steel (0.8% carbon) is austenitized and rapidly cooled below A_{r1} to about 700°C, and allowed to transform isothermally, the decomposition of austenite to form pearlite occurs by nucleation and growth. The



Fig. 1.20 Microstructure of ferrite



annealed

500x

Fig. 1.21 Microstructure of cementite (Courtesy: VEW, Austria)



$C = 0.85\%$

500x

Fig. 1.22 Microstructure of lamellar pearlite¹

resultant product is a mixture of ferrite and cementite, and the eutectoid structure is a mixture of these phases. This constituent is called pearlite, consisting of alternate plates of cementite (Fe_3C) and ferrite (Fig. 1.22).

The pearlite formed just below the eutectoid temperature possesses a lower hardness and requires more time to form. A further decrease in temperature leads to the formation of a pearlite, which takes a lesser time to form and therefore possesses increased hardness (Fig. 1.15). An example of pearlite structure is shown in Fig. 1.22. In the case of hypoeutectoid steels (less than 0.8% carbon), the structure consists of pearlite areas surrounded by white ferritic areas. In the case of hypereutectoid steels (more than 0.8% carbon), on cooling from the austenite, a certain amount of proeutectoid cementite starts forming before the pearlite, as a continuous network at the austenite grain boundaries. It may also have an infill of lamellar pearlite. This structure may be observed in annealed or normalized steels.

1.4.4 BAINITE

Bainite is named after its discoverer, E.C. Bain. It is a metastable aggregate of ferrite and pearlite resulting from the austenite transformation at a temperature below which pearlite is produced and above which martensite is formed. For example, when an austenitized steel of eutectoid composition is held isothermally in the temperature range of 250–500°C for the transformation of austenite, the resultant product will be one having a ferrite and cementite structure, known as bainite. Bainite, as contrasted with pearlite, has a definite orientation relationship between ferrite and the parent austenite.

The produced hardness, after complete transformation, may vary between RC 45–55, depending on whether it was formed at a relatively high or low temperature. Depending on the temperature of formation of bainite, it is classified as upper or lower bainite. The structure may have a feathery appearance if formed in the upper part of the bainite transformation range, or a circular profile, resembling the tempered martensite, if formed in the lower part.

1.4.5 MARTENSITE

Martensite is named after the metallographer, A. Martens. It is the supersaturated solid solution of carbon and other elements in alpha iron with a distorted lattice. This is a hard constituent produced when a steel is cooled from the hardening temperature at a rate greater than the critical cooling rate.

In iron-carbon alloys and steels, austenite is the parent phase and transforms to martensite on cooling. The martensitic transformation is diffusionless and has exactly the same composition as its parent austenite up to 2% carbon (Figs 1.4 and 1.5) depending on the alloy composition. The resulting structure is an orderly change from face-centered cubic lattice to the body-centered tetragonal lattice. The carbon atoms can be considered to strain the lattice into a tetragonal configuration; the extent of tetragonality which occurs may be deduced from Fig. 1.23. The solubility of carbon in the bcc structure is greatly exceeded when martensite forms; hence martensite assumes a body-centered tetragonal (bct) unit cell in which the c parameter of the unit cell is greater than the other two parameters pertaining to 'a' axes. With a higher carbon concentration of the martensite, more interstitial sites are filled, and the tetragonality increases. In Fig. 1.24, the lattice parameters are plotted as a function of the carbon content in both austenite and martensite.

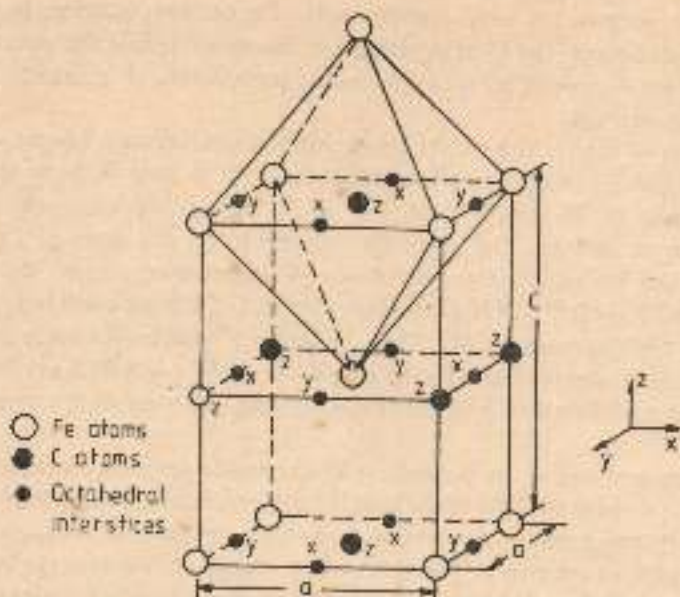


Fig. 1.23 Body-centered tetragonal crystal structure of martensite in Fe-C alloys. Carbon atoms are trapped in one set (Z) of interstitial octahedral sites—the X and Y sites are unoccupied*

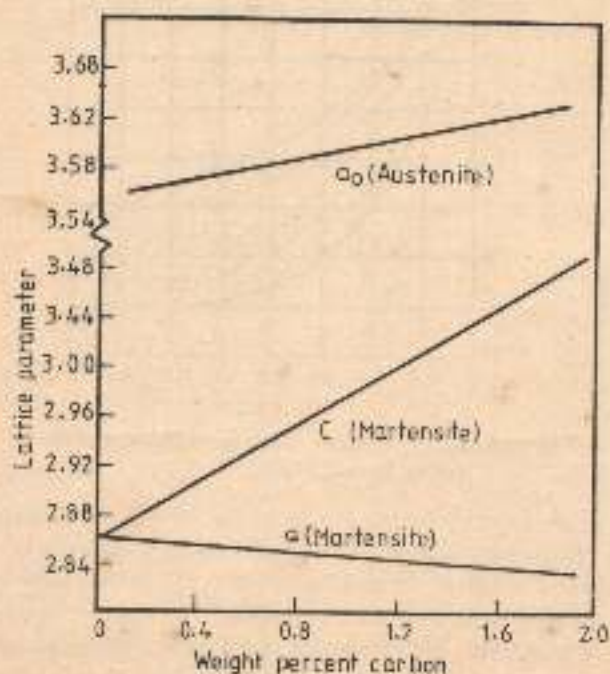


Fig. 1.24 Variation of the lattice parameters of austenite and martensite as a function of carbon content*

In each case, the parameters vary linearly with the carbon content. In martensite, with increasing carbon content, the C -axis parameter increases while the parameter associated with the two a axes decreases, whereas the cubic parameters of austenite increase with the increasing carbon content.

The formation of martensite differs from those of pearlite and bainite, being practically independent of time. From the transformation diagram it may be seen that the formation of martensite begins at M_s temperature (Fig. 1.15). As cooling continues austenite begins to transform into martensite. The lower the temperature, the more will be the martensite formed and at the M_f point, the formation of martensite stops. In this example, it starts at about 390°F ($\sim 200^\circ\text{C}$) (M_s) and continues as the temperature falls until about 85°F, when it is nearly 100% martensite M_f . That the formation of martensite is dependent on time is illustrated by the horizontal line in the graph. At 210°F ($\sim 100^\circ\text{C}$) about 90% martensite is formed; this proportion does not change with time, as long as the temperature is kept constant.

The beginning and end of the formation of martensite depends on the chemical composition of the steel and the condition of the austenitizing treatment. In carbon steels, the temperature of the start and finish of martensite formation, M_s and M_f respectively, depend on the carbon content, as shown in Fig. 1.25. The higher the percentage of carbon in steel, the lower the temperatures of the beginning and end of martensite formation. It is clear from

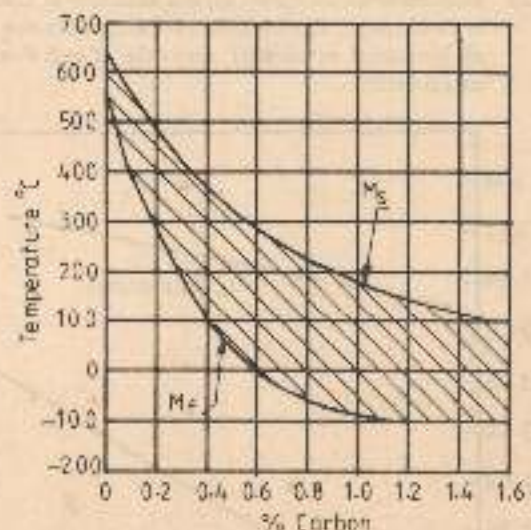


Fig. 1.25 Effect of carbon content on the martensite points M_s and M_f .

Fig. 1.25 that the martensitic transformation in steels with carbon contents exceeding 0.5% is completed below room temperature. This fact enables us to draw an important conclusion. When the carbon content in steel exceeds 0.5%, it contains both martensite and retained austenite at room temperature. The higher the carbon content in the steel, the greater the amount of austenite. This austenite is called the residual or retained austenite. Such steels should be subjected to the subzero treatment to convert the retained austenite into martensite.

Apart from carbon, elements such as manganese, silicon, nickel, chromium, molybdenum and tungsten 'tend to lower the M_s point of steel'. The decrease in the M_s point is proportional to the amount of the element dissolved in austenite (Fig. 1.26). Of all the elements carbon has by far the greatest effect in depressing the M_s point; manganese, chromium and nickel follow in that order. Silicon, molybdenum and tungsten are less effective (Fig. 1.26). Martensite has a characteristic acicular or needle like structure (Fig. 1.27). The

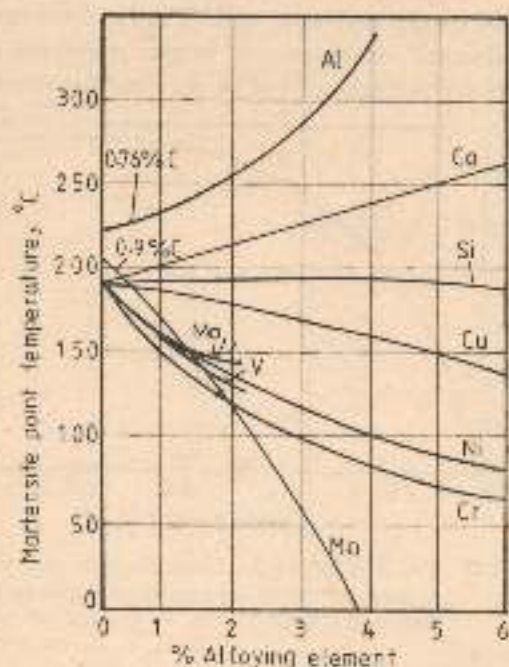


Fig. 1.26 Effect of alloying elements on martensite points M_s and M_f .



Fig. 1.27 Microstructure of hardened steel (Courtesy: VEW, Austria)

degree of acicularity of martensite depends on the size of the original austenite grains. The larger the austenite grain, the bigger the needles of martensite. Martensite formation is accompanied by an increase in the specific volume of about 3%. This is the main reason why large stresses are set up during hardening. They distort the component being hardened, resulting in cracks.

The cause for the extreme hardness of martensite is that the lattice is under a high state of internal strain due to the presence of carbon atoms in the iron lattice. Hence, the hardness obtained depends on the carbon content. The hardness ranges between 20 and 67 HRC (Fig. 1.28). The higher the carbon content in martensite, the greater is the distortion of the space lattice, and hence the greater will be the resulting hardness.

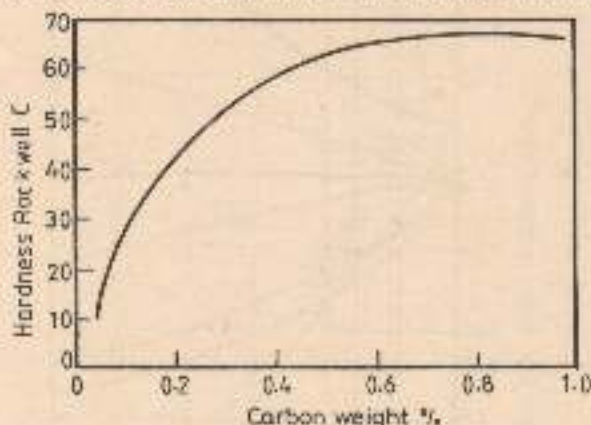


Fig. 1.28 Variation of the hardness of martensite as a function of carbon content, as measured on the Rockwell-C Scale

1.4.6 CARBIDES

Alloying elements such as carbon, manganese, chromium, tungsten, molybdenum and vanadium are used in tool steels (cold work steels, hot work steels, high speed steels) to increase wear resistance and thermal stability. The presence of these alloying elements in steel leads to the formation of alloys of carbides, such as M_3C , $M_{23}C_6$, M_6C , M_7C_3 where M represents the metal atom and C represents the carbon content. These carbides possess very high hardness (Fig. 1.29). They increase the wear resistance of the tools in proportion to the volume of carbide, depending also on the hardness of the carbide. Figure 1.29 illustrates the approximate hardness of different carbides. Table 1.3 gives the general classification and lists the properties of carbides found in tool steels.

The quantity of carbide in a tool steel depends on the percentage of carbon and alloying elements present and the type of carbide phases formed in the structure. They may be present in the hardened structure, say 5–12 per cent in hypereutectoid steel. The annealed structure will have more carbide. During austenitizing, these carbides saturate the austenite with carbon and alloying elements. Saturation of austenite with carbide-forming elements, such as chromium, tungsten, molybdenum or vanadium can result in a favourable condition for the development or precipitation of carbides on hardening and during tempering. This leads to an increase in thermal stability, and an increase in hardness of 3–5 HRC.

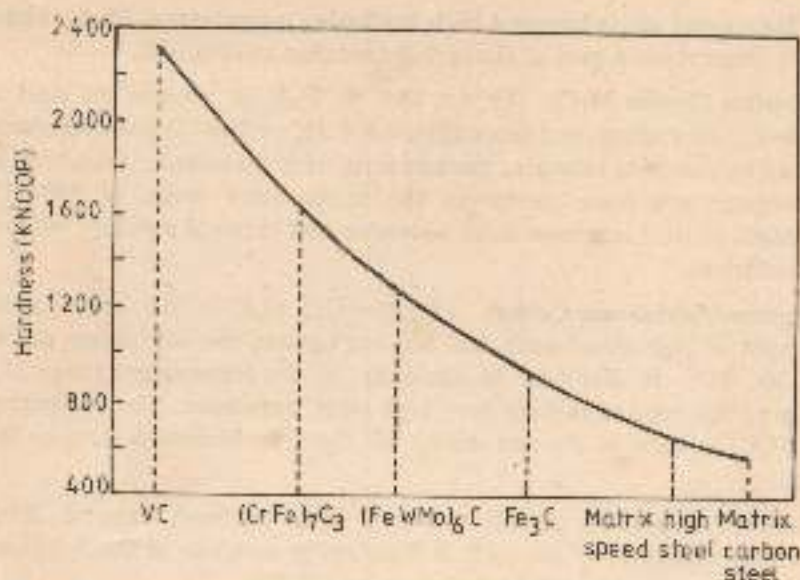


Fig. 1.29 Comparative hardness of carbides found in tool steels. (Adapted from data in Roberts, G.A., Hanaker, J.C. and Johnson, A.R., *Tool Steels*, 3rd edn. ASM, 1962)

Table 1.3 General classification and properties of carbides found in tool steels

Type of carbide	Lattice type	Remarks
M ₃ C	Orthorhombic	This is a carbide of the cementite (Fe ₃ C) type. M, maybe Fe, Mn, Cr with a little W, Mo, V.
M ₇ C ₃	Hexagonal	Mostly found in Cr alloy steels. Resistant to dissolution at higher temperatures. Hard and abrasion resistant. Found as a product of tempering high-speed steels.
M ₂₃ C ₆	Face-centered cubic	Present in high-Cr steels and all high-speed steels. The Cr can be replaced with Fe to yield carbides with W and Mo.
M ₆ C	Face-centered cubic	Is a W or Mo rich carbide. May contain moderate amounts of Cr, V, Co. Present in all high-speed steels. Extremely abrasion resistant.
M ₂ C	Hexagonal	W- or Mo-rich carbide of the W ₂ C type. Appears after temper. Can dissolve a considerable amount of Cr.
MC	Face-centred cubic	V-rich carbide. Resists dissolution. Small amount which does dissolve reprecipitates on secondary hardening.

Cementite Carbide Iron carbide, symbolized as M₃C, is present in all types of steels. Its hardness may vary between 910 and 1050 HV depending on the condition of formation.

Complex Chromium Carbides M₂₃C₆ (Cr, Fe, Mo, W, V)₂₃C₆, designated as M₂₃C₆, will be present in steels containing more than 3-4% chromium and less than 0.8-1.0 per cent carbon. Its hardness may vary between 1000 and 1100 HV. During austenitizing, in the range of 950-1000°C, these carbides saturate the austenite with vanadium, molybdenum and

tungsten. In high speed steels having a high hardening temperature, $M_{23}C_6$ dissolves fully on heating. In other steels a part of the carbide remains undissolved.

Complex Chromium Carbide M_7C_3 (Fe, Cr, Mo, W, V) $_3C_3$ is present in steel containing more than 3–4% chromium and more than 0.8–1.1% carbon. It has a hardness of 1600–1800 HV. The M_7C_3 carbide saturates the austenite with chromium, vanadium and molybdenum and tungsten to a lesser extent in the temperature range of 950–1150°C. The presence of M_7C_3 in steel increases wear resistance and thermal stability, while decreasing the friction coefficient.

Complex Tungsten-Molybdenum Carbide (W, Mo, Cr, V) $_6C$ is the main carbide (M_6C) found in all types of high-speed steels and hot-work steels, the hardnesses of which vary from 1200–1300 HV. It dissolves in austenite in the temperature range 1150–1300°C. Steels containing this type of carbide have high wear resistance. On tempering at 500–600°C, the M_6C carbide is formed owing to the transformation from an intermediate carbide phase.

Vanadium Carbide (MC) This carbide has very high hardness, around 2000 HV, and increases the wear resistance of the steel. It dissolves in austenite in the temperature range 1100–1150°C and saturates the solid solution up to 1.5–2%.

1.5 Effects of Specific Alloying Elements in Steel

The mechanical properties attained in the heat-treated steel depend mainly on its chemical composition. Steel is a combination of iron and carbon. Apart from these, it contains varying amounts of other elements, principally Mn, P, S and Si, which are always present, even if only in trace amounts. The steel containing carbon alone may not possess the desired mechanical properties. Addition of alloying elements, such as Mn, Ni, Cr, Mo, V, W, etc., individually and in various combinations, helps in attaining the ultimate properties and characteristics of the particular steel. The effects of commonly specified chemical elements on the properties of the steel are discussed hereby, considering each element individually.

1.5.1 CARBON

Carbon is the principal hardening element in steels. It combines with iron to form iron carbide (Fe_3C) or cementite which is hard in nature. Further addition of carbon increases the hardness and tensile strength of steel with a corresponding reduction in impact strength. As the carbon content increases above 0.85%, it leads to a lowering of strength, and the hardness remains almost constant. Upon quenching, the maximum hardness attainable also increases with the increasing carbon content, but above a value of 0.6%, the rate of increase is very small (see Fig. 1.28). Commonly used constructional steel has a carbon content ranging from 0.1 to 0.6%. The carbon content varies from 0.5 to 1.4% in plain carbon tool steels. Case hardening steels have a carbon content varying from 0.5 to 0.025%.

1.5.2 MANGANESE

Manganese is present in all commercial steels. It contributes significantly to increase the strength and hardness in the same manner as carbon, but to a lesser extent. It reduces the

critical rate of cooling, thereby increasing the hardenability of the steel, and also increases considerably the resistance to abrasion. A steel with a higher manganese content, i.e. above 0.8%, is called a manganese-alloyed steel.

Manganese-alloyed steels are sensitive as far as overheating is concerned. They tend to become coarse-grained. The presence of manganese in steel also helps to obtain a better surface quality because it combines with sulphur, thereby minimizing the formation of sulphide which is responsible for the hot-shortness or susceptibility to cracking and tearing at rolling temperatures. Manganese steels are used for springs, crossing rails, crusher and dredger parts. The presence of manganese in non-distorting steels is 12%. In rust-proof steels manganese is in combination with chromium and nickel.

1.5.3 SILICON

Silicon and manganese are companions in steels and may be present up to 0.35% in almost all constructional steels. Silicon is used in greater amounts in some steels such as the silico-manganese steels. Silicon develops hardness and elasticity in steel, but diminishes tensile strength and ductility. When hardened and tempered, silicon steels possess high strength combined with good ductility and shock resistance. They are used in low hysteresis steels, spring steels and in acid-resisting plants.

1.5.4 CHROMIUM

Chromium, after carbon, is perhaps the most important element in steels. It forms several carbides, depending on the treatment and the amount of chromium present. Chromium is present in most constructional steels and in high-grade tool steels. It is one of the main elements in high-speed steels.

Chromium increases the austenitizing temperature. It increases the corrosion resistance in steel considerably by creating a tenacious chromium-rich oxide film on the surface in stainless steels and heat resisting steels.

Chromium is used primarily to increase the hardenability of steels. It increases the tensile strength, toughness and resistance to abrasion.

1.5.5 NICKEL

Nickel is one of the most important alloys for increasing the strength and toughness of steel, influencing to a great extent its structural transformation. When present in appreciable amounts, it improves the mechanical properties. The presence of sufficiently large amounts of nickel renders the steel austenitic even at room temperature.

Nickel lowers the eutectoid temperature of steel. Lowering of the temperature leads to a suitable alloy for effective quenching. Nickel does not form carbides and does not have a marked effect on hardenability. It improves corrosion resistance. Nickel alloyed steels are used for structural and engineering purposes (2-4%) in bridges, machine parts, case hardening steels, etc.

1.5.6 MOLYBDENUM

Molybdenum exhibits a greater effect on hardenability per unit added than any other commonly specified alloying elements except manganese. As a result of this, it increases the depth of hardening by reducing the critical cooling rate. Molybdenum, in combination with other elements, increases toughness and creep strength as well as the hot strength of the steel. The

presence of molybdenum reduces the susceptibility of steel to temper brittleness as apparent in nickel-chrome steels, when rapid cooling from tempering temperature is desired.

In tool steels, molybdenum like tungsten is mainly used in the hot work and high speed steel grades. It forms carbides and improves the resistance to wear, toughness and hot strength.

Molybdenum alloyed steels are used in constructional steels for case-hardening, in direct hardening steels, hot-working tool and constructional steels, high speed steels, rust-proof steels and in combination with chromium and nickel.

1.5.7 TUNGSTEN

Tungsten and molybdenum are related elements. Tungsten forms complex carbides. Tungsten alloyed steel is distinguished by high cutting hardness, resistance to abrasion, good hot strength and high red hardness. Tungsten renders the transformation of austenite to martensite very sluggish. It also inhibits the grain growth. Tungsten alloy steels are insensitive to overheating. In austenitic chromium nickel steels, the addition of tungsten increases the yield point.

Tungsten alloyed steels are used in high speed steels, tool steels, hot work steels, magnet steels, valve steels, rust-proof steels, etc.

1.5.8 VANADIUM

In constructional steels, vanadium increases the tensile strength and the yield point. It improves the ratio between them. It is a strong carbide-former, and its carbides are very stable. Hardenability of medium carbon steels is increased with vanadium additions up to 0.04-0.05%. Above this value, the hardenability decreases with normal quenching temperature due to the formation of insoluble carbides.

Vanadium is useful when a higher austenitizing temperature is needed. Due to its carbide-forming properties vanadium is used in tool steel. It increases the hot hardness and, when present in sufficient amount in tool steels, increases the wear resistance of tools.

Vanadium with chromium, nickel and molybdenum is often used in constructional steels which are likely to be subjected to high stresses. It is also used in tool steels for punching and blanking dies, cold working and forming dies and in high speed steels.

1.6 Hardenability

Hardenability refers to the property of steel which determines the depth of the hardened zone induced by quenching from the austenitizing temperature. It is not concerned with the maximum hardness achievable with a particular type of steel. Whereas the quenched surface hardness of a steel part depends primarily on the carbon content and the cooling rate, the depth at which a certain hardness level is maintained under a given quenching condition is a function of hardenability. Hardenability is largely dependent on the percentage of alloying elements, austenitic grain size, austenitizing temperature, time, and the microstructure prior to hardening.

Hardenability required for a particular part depends on many factors such as size, design, and service conditions. For highly stressed parts, particularly in tension, the best combination of strength and toughness is obtained by thorough hardening to a martensite

structure, followed by adequate tempering. Quenching such parts to a minimum of 80% martensite is generally considered adequate. Carbon steel can be used for thin sections, but as the section size increases, steels of better hardenability are required. Where only moderate stresses are involved, quenching to a minimum of 50% martensite is sometimes appropriate.

The difference between hardenability and hardness may be illustrated by considering the response to hardenability of two steels *A* DIN 42 CrMo4 and *B*. Steel *A* contains 0.4% carbon and 0.7% chromium. Steel *B* is a plain carbon steel containing 0.45% carbon.

A series of bars of different sizes of each of these steels is quenched under identical conditions, sectioned and tested for hardness from the surface to the axis. If the hardness of each bar is then plotted in the form of a curve of hardness against distance from the axis, two sets of hardness curves are obtained which are shown in Fig. 1.30(a). Similarly, Fig. 1.30(b) shows that the alloy steel *A* has a greater hardenability than steel *B* since steel *A* is fully hardened up to 40 mm diameter, whereas steel *B* can be fully hardened only up to 20 mm diameter with the same quenching conditions.

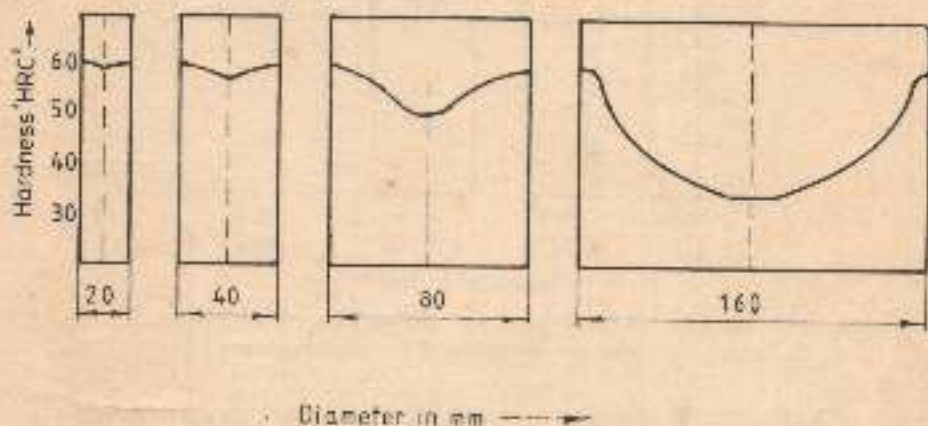


Fig. 1.30 (a) Hardenability curves for steel grade DIN 42 CrMo4 after quenching in water, for different diameters¹⁹

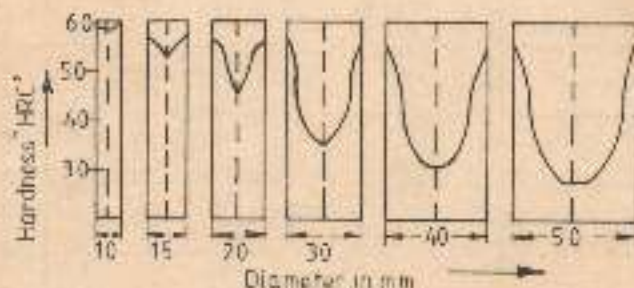


Fig. 1.30 (b) Hardenability curves for steel grade 0.45% C after quenching in water with considerable agitation of bars; diameters 10, 15, 20, 30, 40 and 50¹⁹

1.6.1 QUANTITATIVE HARDENABILITY

Hardenability is expressed quantitatively in terms of *critical diameter* or *quenching section*. The critical diameter of steel may be defined as the maximum diameter which, when quenched in a selected medium, will develop at the axis a specified hardness or a structure containing a specified proportion of martensite. Usually, it will be 50% martensite and 50% pearlite. Figure 1.31 illustrates the typical hardness plot on a cross-section of successively large diameters. As the diameter of the test bar increases, the centre hardness decreases. But at a particular diameter, say 1 inch (25.4 mm), it possesses 50% martensite and 50% pearlite. Test bars of less than one inch diameter are effectively hardened throughout, while bars bigger than one inch have a soft core containing pearlite. This diameter, viz 1 inch, is the *critical diameter*.

The hardenability of steel can be increased by the addition of alloying elements. There

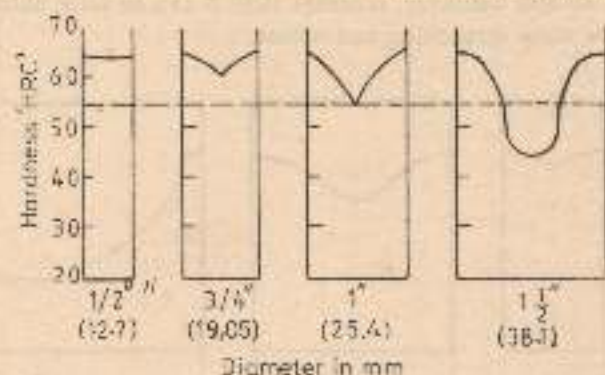


Fig. 1.31 Typical hardness test survey made along different diameters of quenched cylinders.

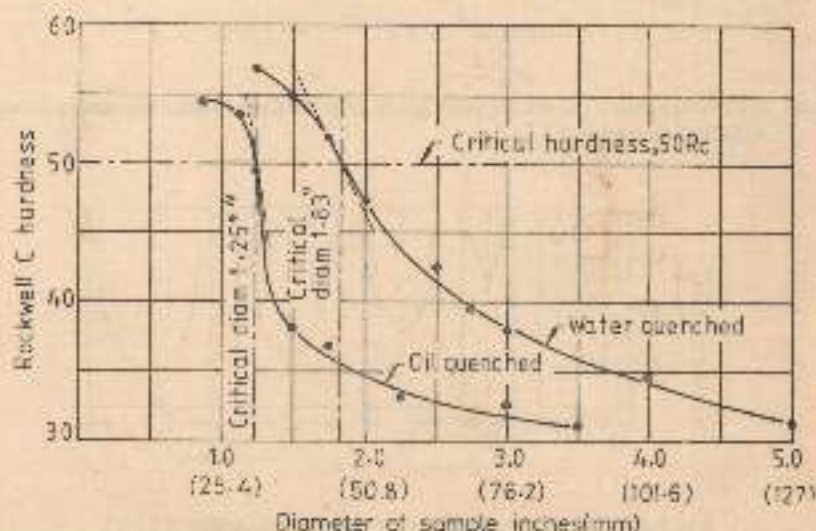


Fig. 1.32 Hardness at the centres of water and oil quenched bars of SAE 3140 steel of various diameters¹¹

will be a corresponding increase in the critical diameter. Apart from this, the critical diameter also depends on the severity of the quench. For example, different critical diameters are associated with the same grade of steel, of the same diameter, depending upon whether it is quenched in oil or water. It is clear from Fig. 1.32 that the critical diameter is greater when quenched in water because of the increased severity of the quench. However, ideal size, on the other hand, is defined as the size of the bar hardened to 50% martensite by a theoretically perfect quench in which it is assumed that the surface of the bar cools instantly to the temperature of the quenching medium.

The 'ideal critical diameter' will clearly be greater than the critical diameter for a quench in, say, oil or water. The ideal size is a true measure of the hardenability associated with chemical composition, and it can also be used to determine the critical size of steels quenched in media of different quench severities.

1.6.2 CRITICAL SIZE

It is possible to determine the critical size of a bar by using a diagram (Fig. 1.33) where the ideal critical diameter D_i is plotted as the abscissa, and the critical diameter D_c is plotted as the ordinate for various quench severities (H). A number of different curves are plotted on this chart, each corresponding to a different rate of cooling (measured by a number known as the H value or the severity of the quench). The values of H are given in Table 1.4. The straight line identified by a quench severity of infinity shows that the critical size far equals the ideal size for a theoretically perfect quench. In practice, it is not possible to get an ideal quench. The ideal quench is approached by quenching into a violently agitated brine bath designated 5.

Table 1.4 Severity of quench (H) for various quenching media*

	Air	Oil	Water	Brine
No circulation of fluid or agitation of piece	0.02	0.25-0.30	0.9-1.0	2
Mild circulation (or agitation)	—	0.30-0.35	1.0-1.1	2-2.2
Moderate circulation	—	0.35-0.40	1.2-1.3	—
Good circulation	—	0.4-0.5	1.4-1.5	—
Strong circulation	0.05	0.5-0.8	1.6-2.0	—
Violent circulation	—	0.8-1.1	4	5

Using Fig. 1.33 and knowing the diameter of bar (D_i) and the severity of the quench (H), the critical diameter D for a particular steel may be determined. Let us consider a typical example. Take a test bar, with a 2-inch diameter (D_i value) quenched in oil. The H value under this condition is 0.41 which would yield a D -value of 0.8 inch.

1.6.3 END-QUENCHING HARDENABILITY TEST

The most commonly used method of determining the hardenability is the end-quench test developed by Jominy Boegehold of USA. This method has been introduced with certain modifications in numerous countries as the standard end-quench hardenability test. At present, its importance is considerable in the classification of steels.

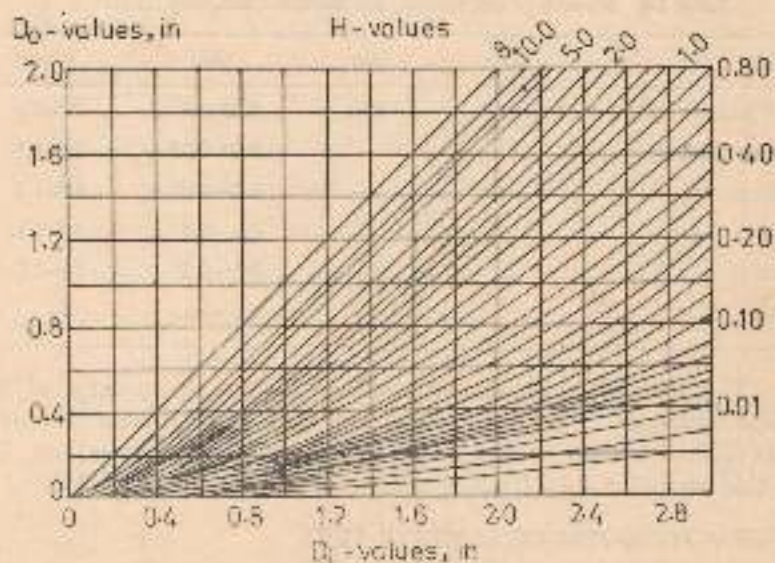
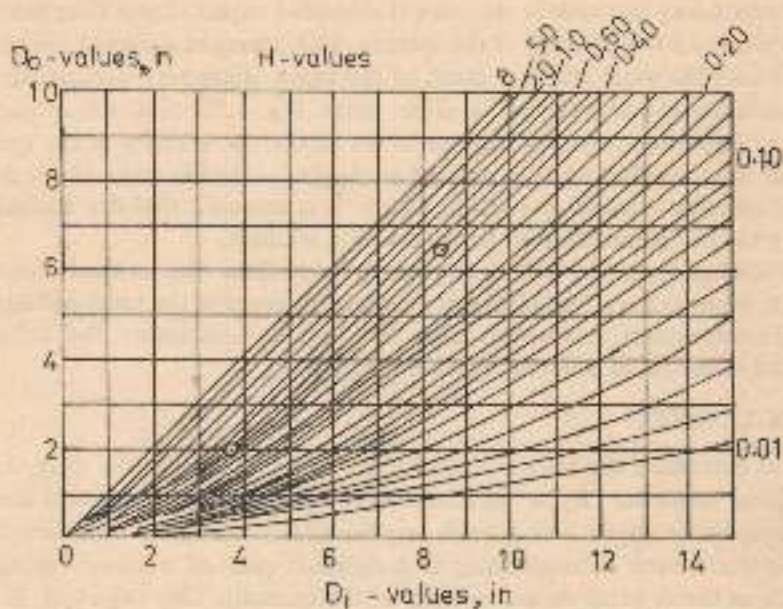


Fig. 1.33 Charts showing the correlation between critical diameter D_0 , ideal diameter D_1 and H -value. The lower diagram is an enlargement of the lower left-hand portion of the upper diagram.

To conduct this test, a bar of 25 mm diameter and 100 mm length is required, with a collar or groove for holding it in the quenching bath. It is usually machined to size from a previously normalized stock to remove the decarburized layer. Also the end of the specimen, which will be water-cooled, is ground to have a smooth finish.

The test piece is now held in a furnace maintained at the specified austenitizing temperature for 30–35 minutes. It is most important that the furnace atmosphere is neutral in order to avoid scaling and decarburization. After the desired soaking time, it is dropped into a holding fixture (Fig. 1.34) and then quenched at its end by only using a water jet maintained at 25°C. This procedure is covered in an Indian standard. The water jet should be about 12 mm in diameter and should rise to a free height of about 65 mm above the 12-mm orifice.

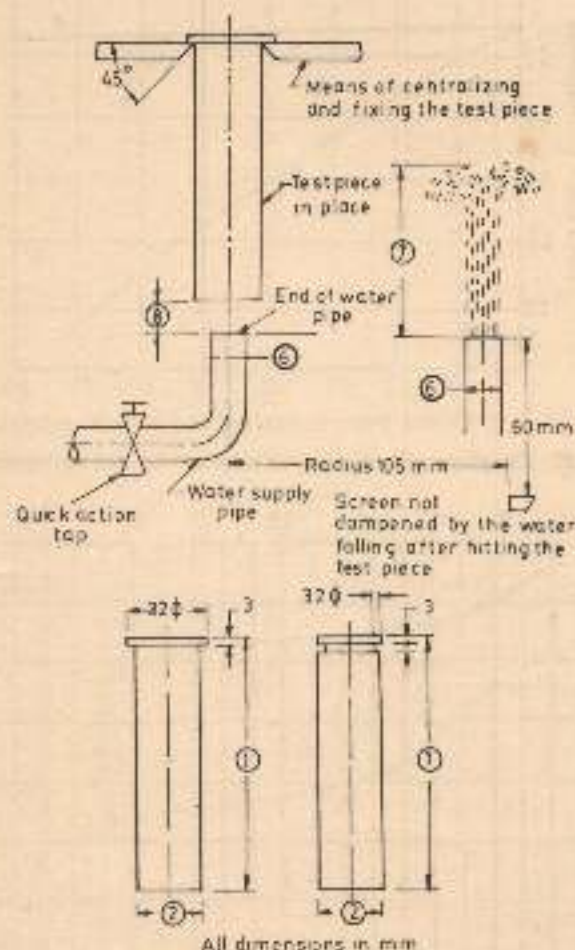


Fig. 1.34 Schematic diagram of Jominy test¹²

The time between the removal of the specimen from the hardening furnace and the beginning of the quench should not be more than 5 seconds. Immediately after placing the test piece, the water supply must be opened rapidly to direct the stream of water with full force against the face of the specimen for not less than 10 minutes. As a result of this, the

piece cools very rapidly at the quenched end, but the rate of cooling decreases progressively towards the opposite end. Therefore, a variety of continuous rates prevail along the length of the bar. After this time, the cooling of the test piece shall be completed by immersing it in cold water.

The hardened end is then ground to different dimensions as set out in standards (1.5, 2, 2.2, 2.2 mm to a total of 15 mm), checking the hardness in Rockwell C scale at each stage.

Test results should be plotted on a standard hardenability chart prepared for this purpose, in which ordinates represent Rockwell C readings and the abscissa represent the distance from the quenched end of the test piece at which the hardness determinations were made (Fig. 1.35).

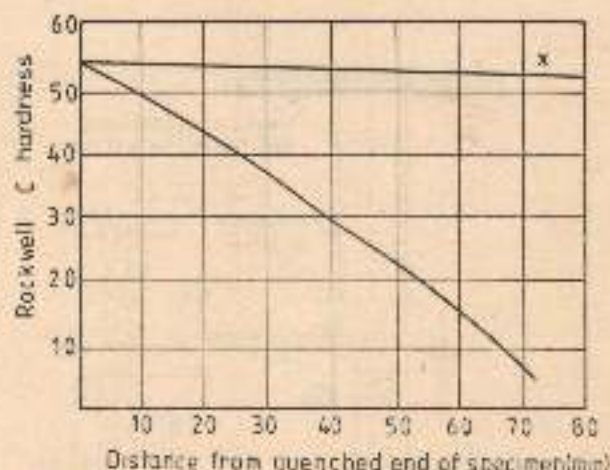


Fig. 1.35 Diagrammatic representation of the Jominy end-quench test

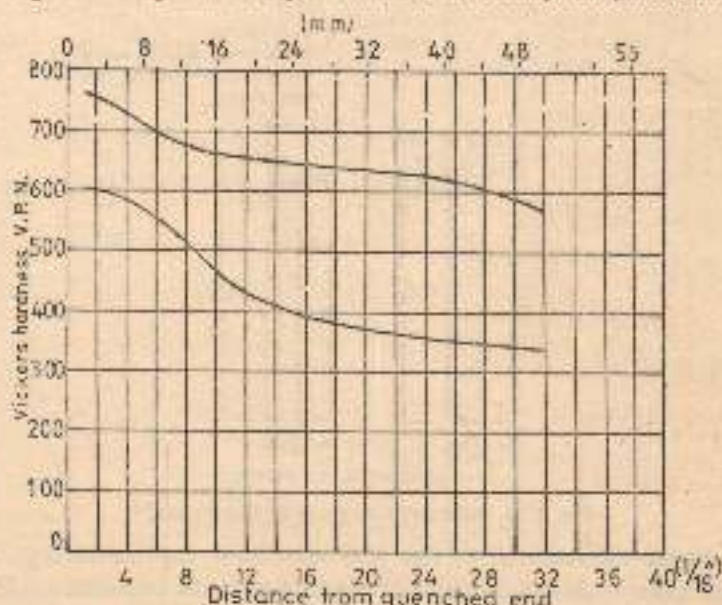


Fig. 1.36 Hardenability band of DIN 40 Cr4Mo3 (Courtesy: Roehling Stahlexport GmbH, W. Germany).

A deep-hardening steel will give an almost horizontal end-quench curve, similar to *X*, which indicates that the steel will develop a substantially martensitic structure when cooled at any desired rate within the range covered by the end-quench test. A steel of medium hardenability, however, will give a curve similar to *Y*.

The hardenability of the same steel may vary over a considerable range depending upon the chemical composition and grain size of the given grade of steel, as shown in Fig. 1.36. The upper curve shows the maximum hardness values corresponding to the upper composition limit of the steel; and the lower curve gives the minimum hardness values corresponding to the lower limit of the composition range. The two curves together form what is called the Jominy hardenability curve or the hardenability band.

1.6.4 CALCULATION OF END-QUENCH HARDENABILITY BASED ON ANALYSIS

It is possible to predict the end-quench hardenability curve of steel without subjecting it to testing. In 1942 M.A. Grossman had devised a system for the mathematical prediction of hardenability, from composition and grain size in a variety of carbon and low-alloy steels.

Grossman determined a series of multiplying factors for the major alloying elements in steels including silicon, manganese, chromium, nickel, vanadium, molybdenum and boron. For carbon he determined a series of factors representing the critical diameter of plain carbon steels of a given carbon content which would just through-harden when subjected to an "ideal quench". The outside of the bar is assumed to cool instantaneously to the quenchant temperature. This diameter is then represented as the ideal critical diameter D_i .

Example of Calculation of Hardenability

FIRST STEP Consider a steel, 8640 (AISI), having grain size No. 8 at the quenching temperature, and the following chemical composition:

C	Mn	Si	Ni	Cr	Mo
0.39	0.91	0.25	0.54	0.56	0.20

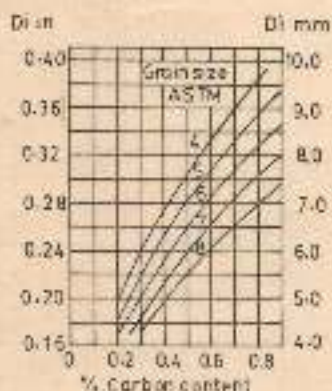


Fig. 1.37 The ideal critical diameter as a function of the carbon content and austenite grain size for plain carbon steel²¹

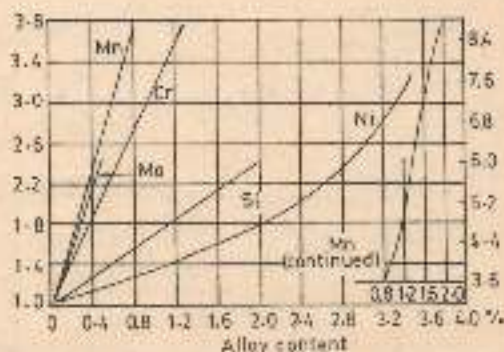
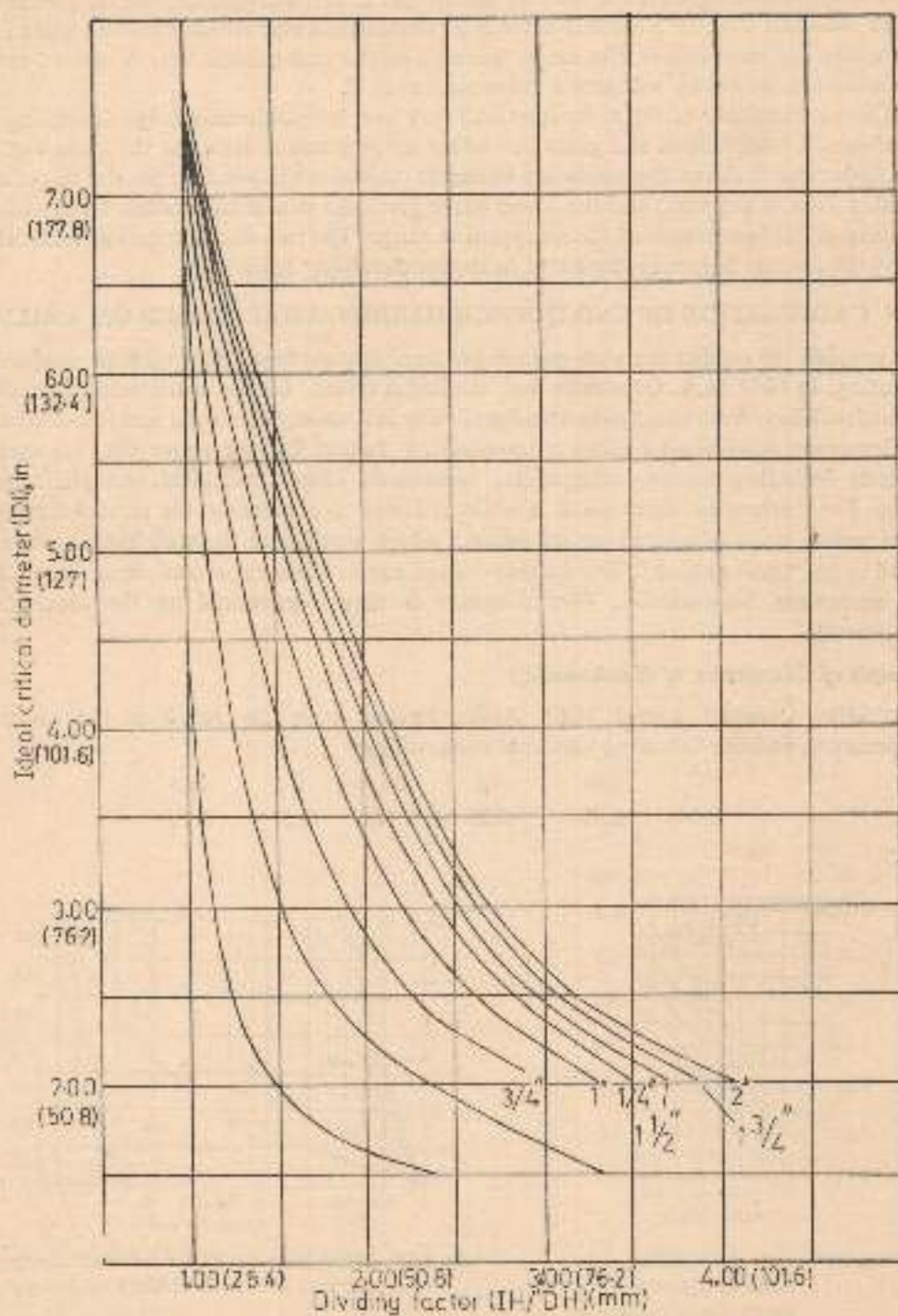


Fig. 1.38 Multiplying factors for different alloying elements for hardenability calculations²¹

Fig. 1.39 Relation between D_I and dividing factors for various distances from quenched end²³

From Fig. 1.37 the base value of the ideal critical diameter D_i is 0.195. On multiplying this value with the appropriate factors indicated in Fig. 1.38 the final D_i value as calculated below is obtained:

$$D_i = 0.195 \times 4.03 \times 1.18 \times 1.20 \times 2.21 \times 1.60 = 3.93$$

SECOND STEP From Fig. 1.39 determine the dividing factor known as IH/DH ratio for a given D_i (ideal critical diameter). The IH/DH ratio gives the ratio between the maximum hardness obtainable (IH) and the hardness actually obtained (DH).

The IH/DH ratio is based on the observation that with a D_i of 7.30, or greater, an end-quench curve will almost be a straight line, and when the ideal critical D_i is less than 7.30, it will produce a falling curve. The IH/DH ratio for different end-quench distances for a calculated D_i of 3.93 is given below as read from Fig. 1.39.

Distance (in.)	Dividing Factor
1/16	0.00
1/4	1.03
1/2	1.21
3/4	1.41
1	1.61
1 1/4	1.75
1 1/2	1.84
1 3/4	1.92
2	1.96

THIRD STEP Determine the initial hardness (IH) from Fig. 1.40. This indicates the hardness at 1/16 inch on the end-quench specimen and is a function of the carbon content.

The initial hardness for 0.39 carbon is HRC 55.5. Calculate the Rockwell C hardness for each distance by dividing the IH (55.5) by each respective dividing factor.

Distance (in.)	Dividing factor	Calculate HRC
1/16	—	55.5
1/4	1.03	54
1/2	1.21	46
3/4	1.41	39.5
1	1.61	34.5
1 1/4	1.75	32
1 1/2	1.84	30
1 3/4	1.92	29
2	1.96	28.5

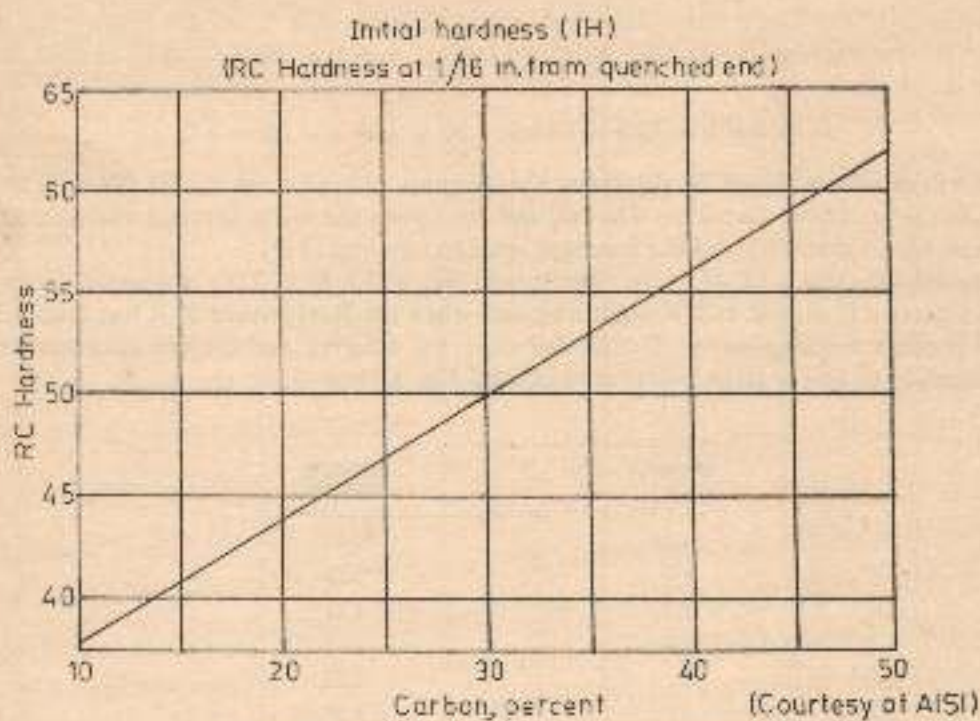
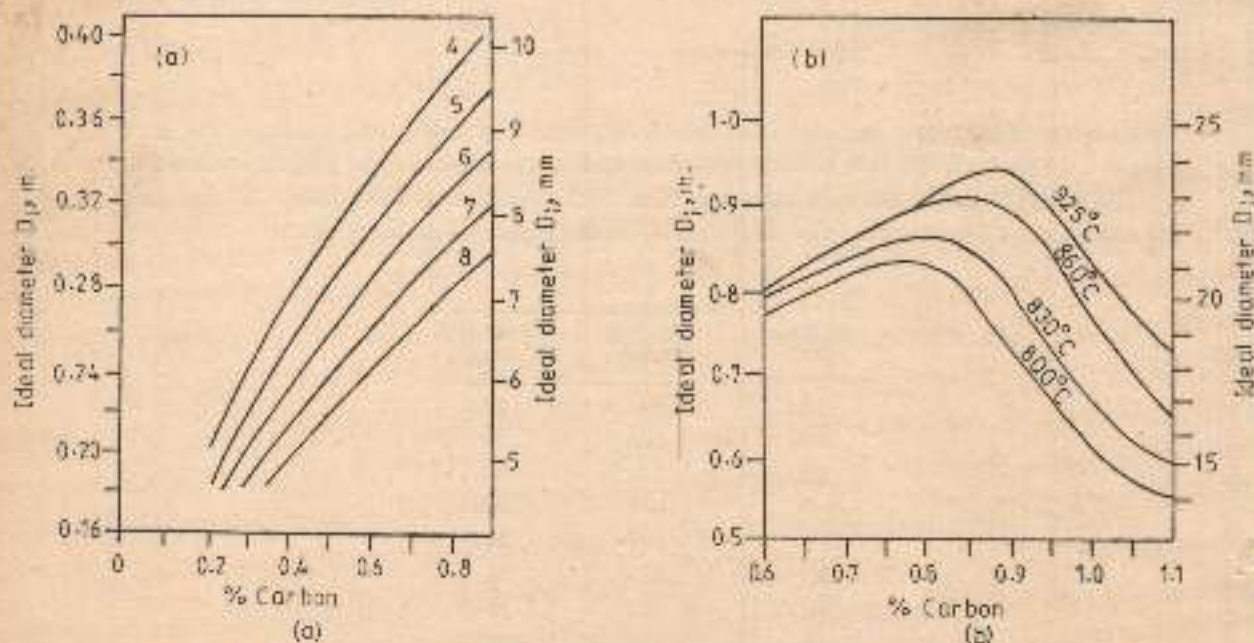


Fig. 1.40 Dependence of hardness on carbon content

Fig. 1.41 Ideal diameter for base carbon content: (a) for grain sizes from 4 to 8 ASTM, (b) at four austenitizing temperatures¹³

Using the hardness values obtained as calculated, a plot of end-quench hardenability curve may be got, plotting the hardness values on the y-axis and the distances on the x-axis.

Recent Developments Recently, it has been found that the method of calculation using certain multiplying factors, as given by Grossman for determining hardenability, holds good for carbon and low alloy steels.

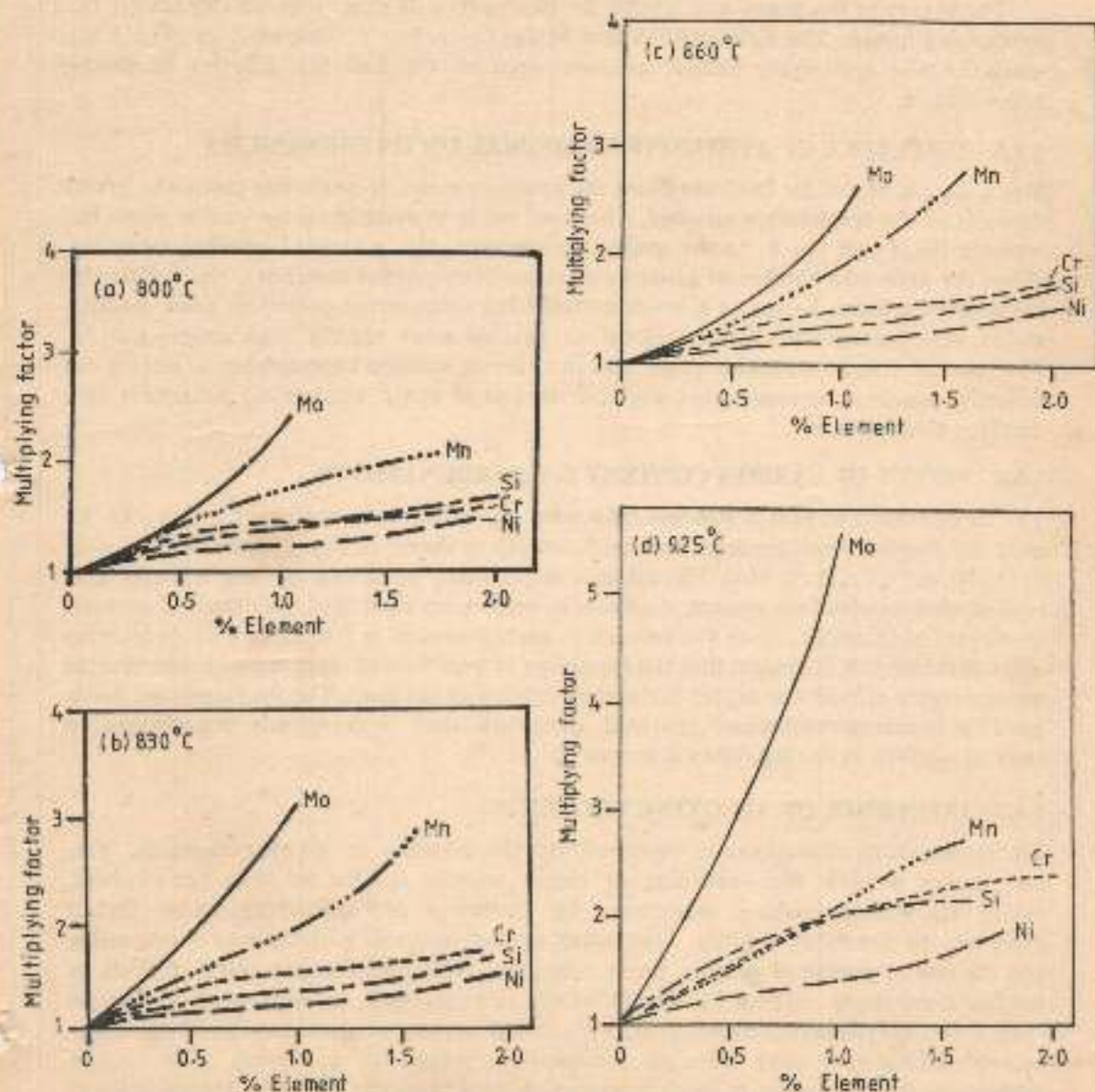


Fig. 1.42 Multiplying factors for major individual alloying elements at four austenitizing temperatures: (a) 800°C, (b) 830°C, (c) 860°C, (d) 925°C¹⁴

Jateczak^{14, 15} et al. have re-examined these multiplying factors and redetermined the values of D_1 for pure carbon steels (Fig. 1.41) and multiplying factors for the major alloying elements (Fig. 1.42). Jateczak has also published multiplying factors for steels with a carbon range of 0.60 to 1.10% which also take into account the hardening temperature. For these cases, calculations can proceed straight from the composition of the steel without the necessity for applying any correction for such alloying elements, as they are not in solution in the austenite.¹⁴

The factors of Grossman and Jateczak for base carbon D_1 differ considerably, as do the multiplying factors. The differentiation base D_1 due to carbon is illustrated in (Fig. 1.40), while the alloy multiplying factors are compared in Fig. 1.42 for different hardening temperatures.

1.6.5 INFLUENCE OF AUSTENITE GRAIN-SIZE ON HARDENABILITY

When steel is heated for hardening into the austenite stage, its grain-size (austenite grain) depends on the temperature adopted. The usual range of austenite grain sizes in steels lies between No. 1 and No. 9. As the grains get smaller, the grain-size number increases. When the grain-size number of austenite increases (fine-grained austenite), the hardenability decreases. Steels heated to a lower austenitizing temperature possesses lower hardenability, since austenite tends to transform to pearlite more rapidly than coarse-grained. The use of coarse austenite grain size in order to increase hardenability of steel is not generally practised because it also results in the loss of other mechanical properties like ductility, toughness, etc.

1.6.6 EFFECT OF CARBON CONTENT ON HARDENABILITY

The hardenability of steel is strongly influenced by its carbon content. Carbon can be used to increase both hardness and hardenability as shown in Fig. 1.43 for an 8600 steel (0.5% Ni, 0.5% Cr, 0.2% Mo). This effect is substantially enhanced by the quantity and type of alloying elements present. Addition of carbon, up to at least the eutectoid content, improves hardenability, since the increase in carbon content is associated with an increase in hardenability. It is evident that the formation of pearlite and proeutectoid constituents becomes more difficult the higher the carbon content of the steel. The statement also holds good for hypereutectoid steels, provided that each steel is completely transformed to austenite before its hardenability is measured.

1.6.7 INFLUENCE OF ALLOYING ELEMENTS

The hardenability of steel can be increased by the addition of alloying elements. This also makes possible the hardening of larger sections and the use of molten salt bath, rather than water-quenching, minimizing the distortion and quenching cracks. Cobalt decreases hardenability slightly. Also, cobalt in steel increases both the rate of nucleation and the rate of growth of pearlite. Steels containing this element are more difficult to harden than those without it. The alloying elements such as manganese, chromium (Fig. 1.44), molybdenum, nickel (Fig. 1.45), tungsten, etc. increase hardenability, either as single addition, or more often in combination, where the increasing alloy content suppresses the formation of high temperature transformation products. The presence of boron up to about 0.003% leads to a marked increase in hardenability, but further increase leaves the hardenability unchanged.

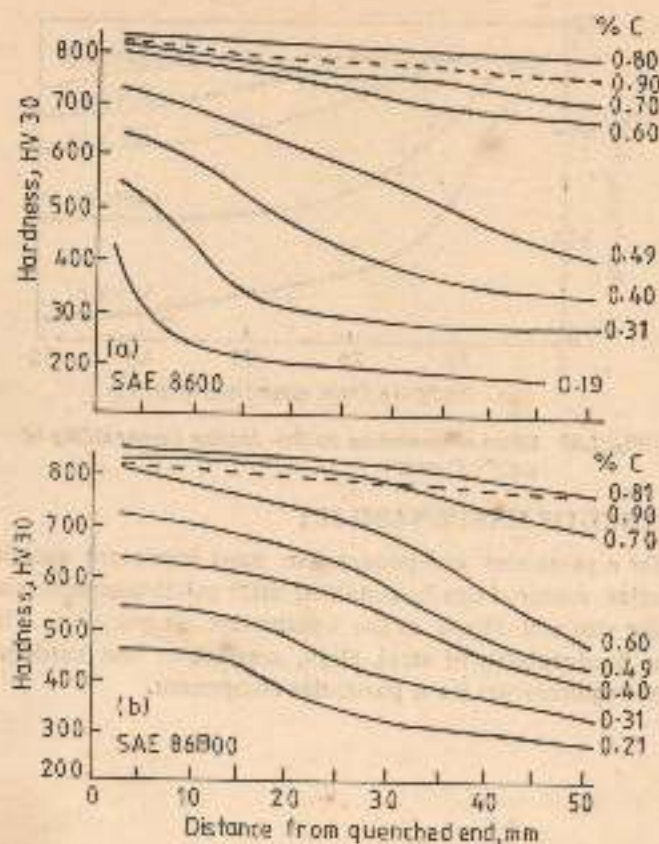


Fig. 1.43 The effect of carbon on the hardenability of (a) SAE 8600 and (b) SAE 86B00 base steels¹⁶

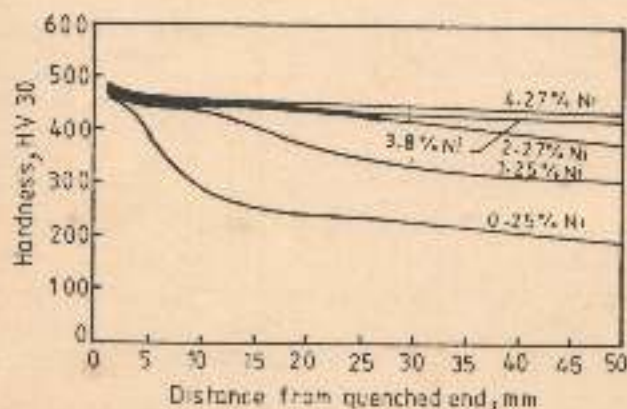


Fig. 1.44 Effect of nickel on the Jominy hardenability of a 0.2% C/1% Cr steel¹⁶

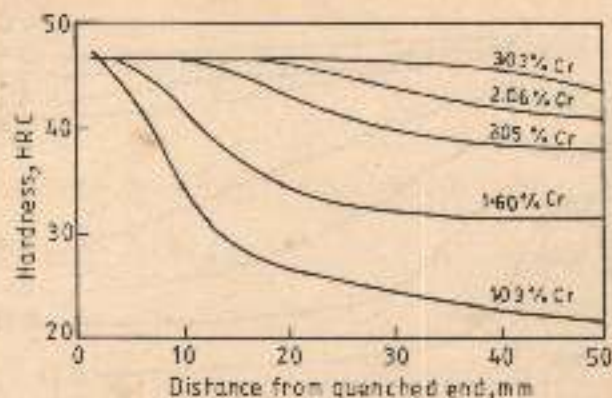


Fig. 1.45 Effect of chromium on the Jominy hardenability of a 0.2% C steel¹⁴

1.6.8 SIGNIFICANCE OF HARDENABILITY

In selecting steel for a particular component, the most important question is whether the mechanical properties required can be obtained after suitable commercial heat treatment with regard to the size and shape of the component in question. The answer to this question lies in the hardenability of steel. High, medium or low hardenable steels may be adopted, as per the requirements for a particular component.

Elements of the Process of Heat Treating

2.1 Annealing

Annealing is carried out to improve machinability and cold formability, to restore ductility, to reduce or eliminate structural non-homogeneity, to refine the grain size, to relieve internal stresses and to prepare the structure of the steel for subsequent heat treatment. Annealing is not applied to improve the mechanical properties of alloy steels of the pearlitic class and tool steels. The mechanical properties of structural steels are improved by hardening, followed by tempering. There are different types of annealing which are applied for different purposes.

2.1.1 FULL ANNEALING

Full annealing consists of austenitization of the steel followed by slow cooling in the furnace. The temperature to be adopted depends on the carbon content of the steel (Fig. 2.1). For hypoeutectoid steels, the temperature is just above A_{c3} temperature; for hypereutectoid steels the temperature is above A_{c1} . The critical temperature will vary somewhat, depending on the alloy content of the steel; but the objective of heating into the single-phase austenite field for low and medium carbon steels and into austenite and cementite field for high-carbon steels remain the same, irrespective of the steel composition.

Full annealing of hypoeutectoid steel consists of austenitizing the steel at 10–30°C above the A_{c3} line and holding it at this temperature for a desired length of time, followed by slow furnace cooling. At this temperature the formation of austenite destroys the structures that existed before heating and leads to the formation of a fine grained austenite structure. The subsequent slow cooling in the furnace enables the austenite to decompose at low degrees of supercooling so as to form pearlite plus ferrite. Heating the steel too much above A_{c3} leads to austenite grain growth which impairs the properties of the steel.

Annealing of hypereutectoid steel is done by heating the steel above A_{c1} to spheroidize the proeutectoid cementite. If the hypereutectoid steel is heated above A_{cm} temperature and cooled slowly, proeutectoid cementite would form at the grain boundaries, resulting in a network of carbides on the austenite grain boundaries. Retarded cooling facilitates ferrite precipitation as a separate cluster. The formation of separate ferrite regions in the structure of a steel is undesirable. This may result in soft spots during hardening and render the steel brittle to forming or service stresses. Therefore, it is the general practice

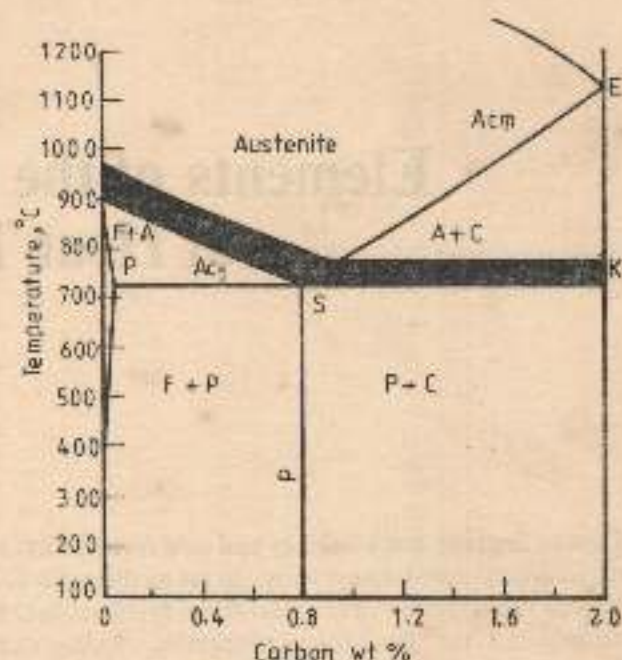


Fig. 2.1 Iron-carbon equilibrium diagram showing temperature region for full annealing

to use spheroidized annealing.

However, full annealing may be adopted for castings of carbon and alloy steels and hypereutectoid hot-worked steels (forging rolled stock, sheet, etc.). For larger castings, particularly those made of alloy steels, full annealing improves machinability and also increases the strength because of a fine grain structure. Full annealing can also be applied for steels containing more than 0.5% carbon to improve machinability. In low-carbon steels, the effect on machinability may be the opposite, on account of excessive softening.

Full annealing is normally carried out in all types of batch furnaces.

2.1.2 SPHEROIDIZED ANNEALING

Spheroidized annealing is done by heating the steel just above or slightly below A_c1 , critical temperature for a prolonged time, followed by a slow cooling, in order to soften the steel as much as possible (Fig. 2.2).

This annealing treatment is adopted to spheroidize the carbides of lamellar pearlite or secondary cementite. This is also done to transform structures such as martensite, troosite, sorbite, etc., that are produced by quenching. Figure 2.3 shows a typical, fully spheroidized structure of a tool steel.

The purpose of this treatment is to improve machinability and, in some cases, to improve cold formability. For example, the machinability of high-carbon tool steels is at its best when the structure is globular. All alloy tool steels, including those of the carbide class, as well as ball bearing steel should have a globular structure in suitable condition for the best machining results. The methods that are adopted to obtain a globular structure are listed in the succeeding paragraph.

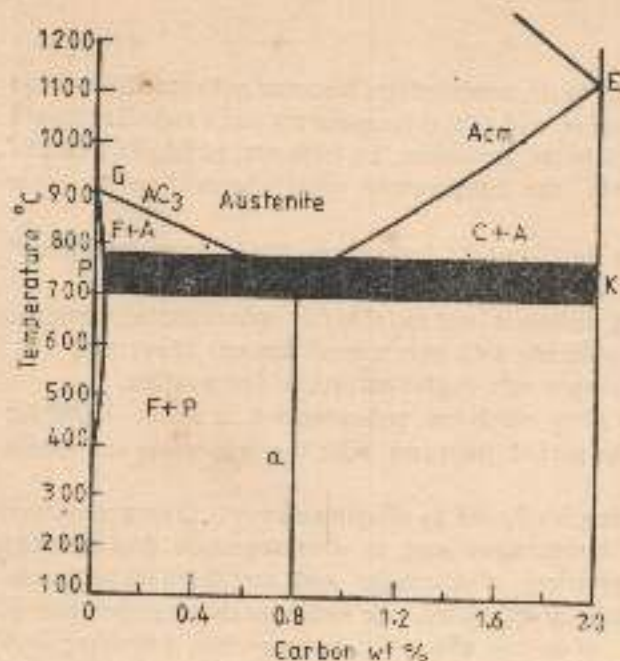


Fig. 2.2 Iron-carbon equilibrium diagram showing temperature region for spheroidized annealing

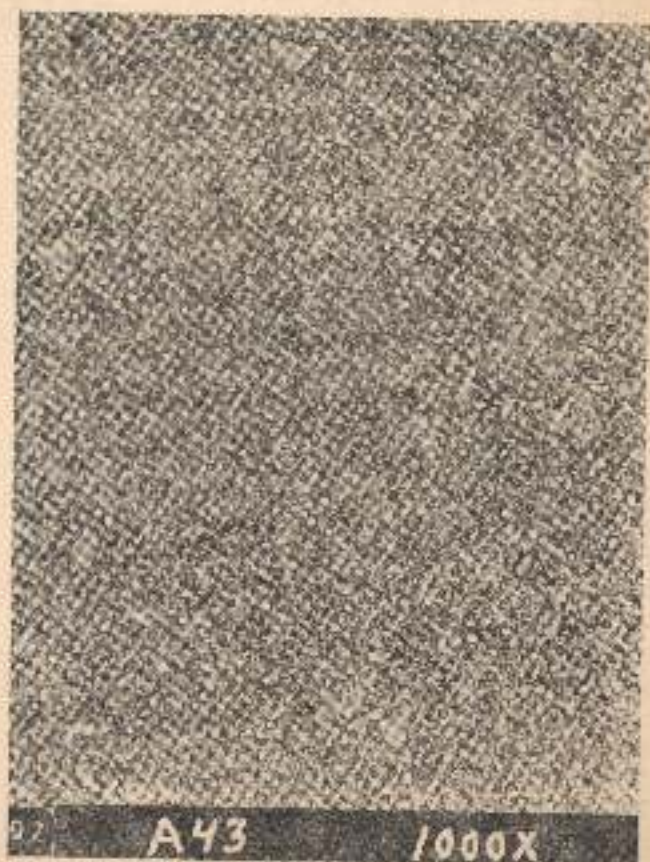


Fig. 2.3 Spheroidized annealed structure of high-speed steel

First Method The steel is heated nearer to A_{c1} temperature. It should not exceed this range to avoid formation of austenite. The steel is held at this temperature for a sufficient length of time for the formation of coarse globular cementite. To obtain a satisfactory rate of formation of coarse globular cementite, the temperature should be as close to A_{c1} as possible.

The temperature employed and the holding time for spheroidized annealing depends on the previous structure and chemical composition of the steel.

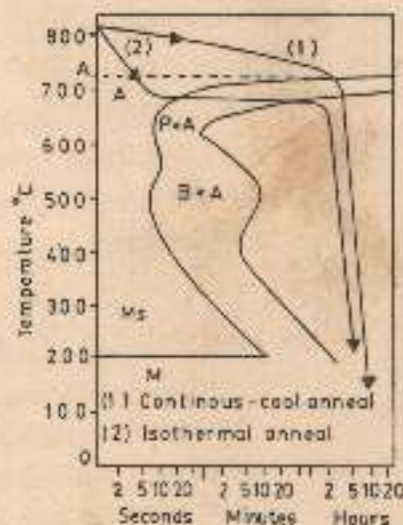
(i) A steel containing less than 0.3% carbon is not suitable for spheroidizing, since the structure of low-carbon steels consists of ferrite with only a small amount of pearlite.

(ii) Coarse pearlite coagulates at a slower rate in comparison to fine pearlite.

For example, plain carbon and low alloy steels are soft-annealed at about 700°C for periods ranging from 4–6 hours. But the period increases with the increasing coarseness of pearlite.

(iii) The temperature of soft annealing is affected by alloying elements. The presence of nickel or manganese decreases the A_{c1} temperature and, as a consequence, decreases the soft annealing temperature. But the presence of chromium and molybdenum raises the A_{c1} temperature. Thus for steels containing 4% nickel, the soft annealing temperature is as low as 670°C. A lower temperature, of course, affects the process-time, extending it to 8–10 hours. On the contrary, high-speed steels, highly alloyed by tungsten, vanadium and molybdenum and further by chromium and vanadium, have to be soft-annealed at a temperature above 800°C. The presence of strong carbide-forming elements increases the stability of carbides in steels. They, therefore, reduce the coagulation and increase the time for annealing at the particular temperature considered.

Second Method The steel is heated slightly above the critical temperature A_{c1} (Fig. 2.4) and held at this temperature for a prolonged time, followed by slow cooling at a rate of 10–20°C per hour up to 550–600°C. Subsequent cooling to room temperature may also be done in still air. During slow cooling, the carbon dissolved in the austenite will separate out as carbide spheroids. This will ensure low hardness after annealing the steel. If the annealing temperature is higher, a greater amount of carbide will dissolve, and the cementite will separate out in a lamellar form. This method is mainly adopted for eutectoid and hyper-eutectoid steels. For example, the annealing procedure (Fig. 2.5) for fully spheroidizing the carbides in a ferritic matrix, for steel DIN 100 CrMo involves austenitization at 825/830°C, followed by holding at 775/780°C. This leads to the precipitation of carbides. Afterwards, it is cooled slowly through the range of 740–680°C, and subsequently cooled in air to the room temperature.



Transformation time
Fig. 2.4 Typical process curves for continuous cooling and isothermal spheroidized annealing treatments superimposed on the time-temperature transformation diagram for 534A99 bearing steel¹⁷

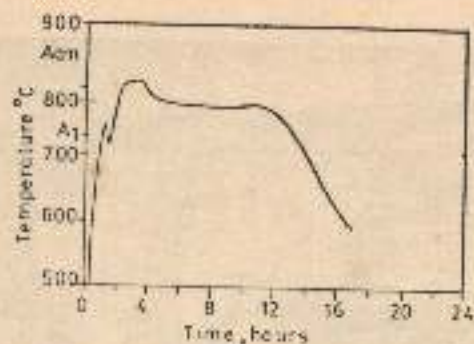


Fig. 2.5 (a) Spheroidize annealing cycle for DIN 103 CrMo07-3 steel

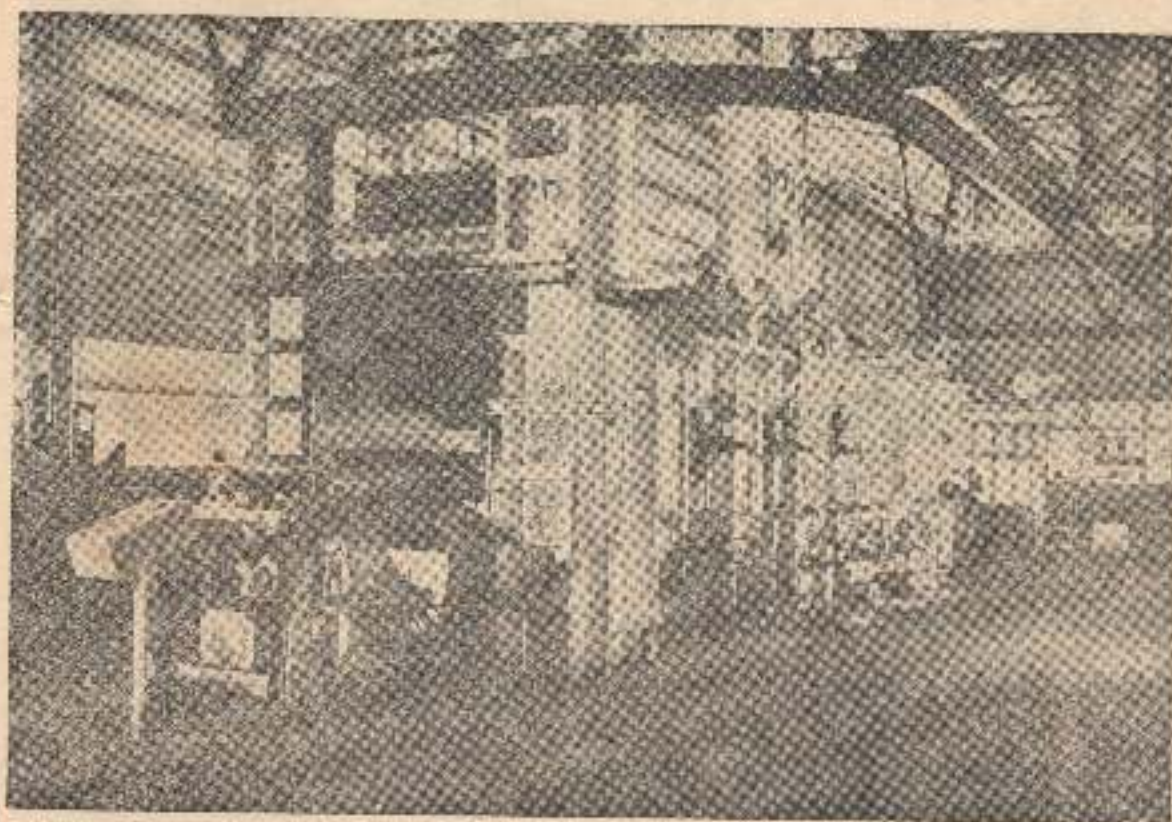


Fig. 2.5 (b) Oil-fired pusher-type annealing furnace (Courtesy: Mys Wellman Incandescent India Ltd, Calcutta)

Third Method In this method, the steel is heated slightly above the critical temperature A_{c1} , and held at this temperature for a pre-determined time, it is then followed by furnace cooling or holding just below the critical temperature A_{c1} for a prolonged time, and subsequently cooled to the room temperature. Holding should not be done at 50° more or 50°

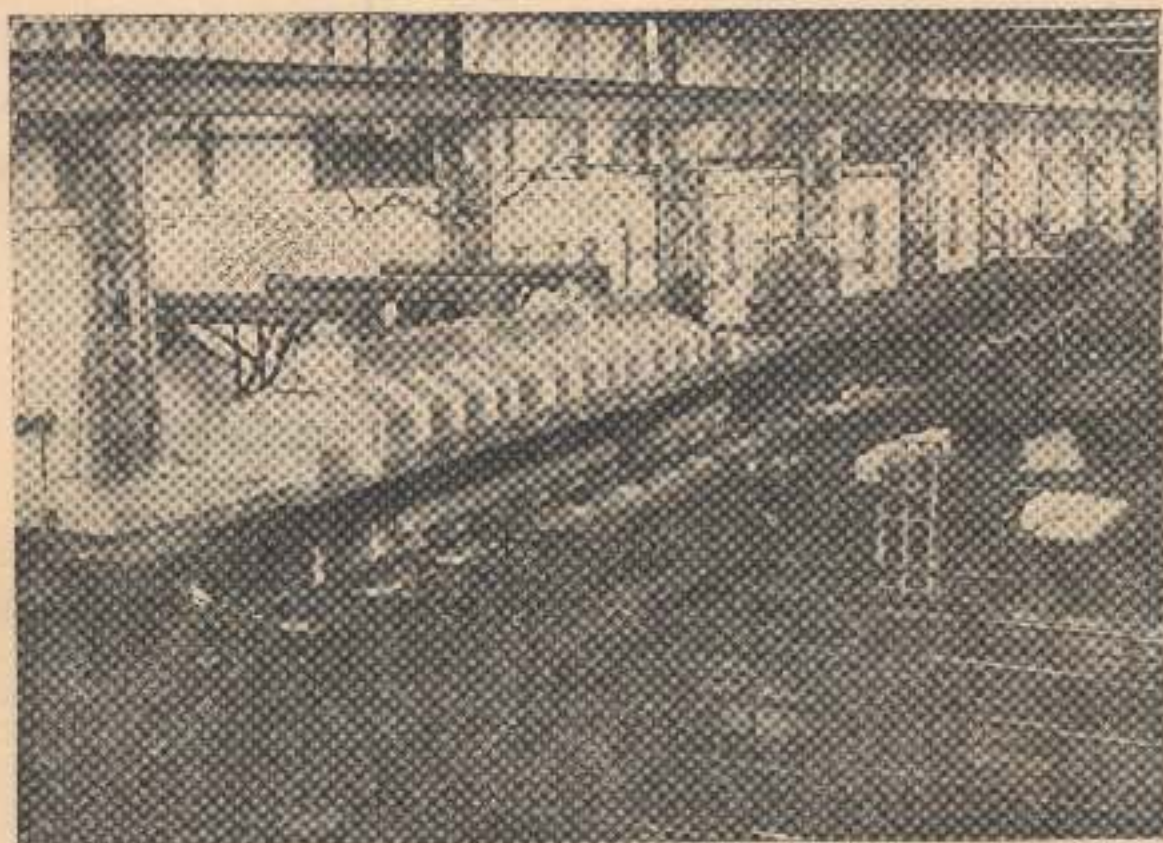


Fig. 2.5 (c) Electrically heated roller hearth tube annealing furnace (Courtesy: M/s Wellman Incandescent India Ltd, Calcutta).

less than the A_{c1} temperature. Nearer the A_{c1} temperature, the spheroidized structure will be coarser and softer. Further below A_{c1} temperature, for example at about 680°C , the resulting structure will be lamellar and harder. This method, however, has a lesser process time compared to the other methods of spheroidizing. This method is mainly adopted for plain carbon and low alloy steels.

Fourth Method Spheroidizing is also done by repeatedly heating and cooling just above and below the A_{c1} critical temperature. During heating above the temperature A_{c1} , only the small-sized grains of cementite will dissolve in the austenite, but there is insufficient time for the larger cementite grains to dissolve. In the subsequent cooling cycles, the molecules of cementite are deposited mainly on the cementite grains that are not dissolved in the austenite. Hence a coagulation process occurs. This method of spheroidizing takes less time compared to the previous methods for the formation of globular pearlite, but it is difficult to perform.

The rate of spheroidization depends on the previous structure. The finer the carbide in the original structure (i.e., before heating), the better will be the spheroidization. Fine

pearlite is a better starting point than coarse pearlite; bainite is still better. Sorbite, resulting from tempering of martensite, is probably the best. Cold working, which breaks up the cementite and distributes it more uniformly, also facilitates spheroidizing.

Strong carbide-forming elements, particularly chromium, tungsten, molybdenum, and vanadium, increase the stability of carbides in steels. Therefore, they reduce the rate of coagulation and increase the time for soft annealing at the particular temperature considered.

The hardness obtained after spheroidizing depends on the chemical composition of the steel. Steels containing low carbon show a lower hardness of 160–190 HB; alloyed and high-carbon steels show a higher hardness of about 200–230 HB.

To increase the machinability of high-carbon tool steels, highly alloyed steels, spring steels, ball-bearing steels, wear-resisting steels, tool steels, etc., spheroidizing is done after the forging operation. This is done by heating the steels above A_{c1} temperature and then either by cooling very slowly in the furnace or holding at a temperature just below A_{c1} for a prolonged time, followed by cooling in air to the room temperature. It should be borne in mind that for obtaining the globular structure, the steel should be heated uniformly and the temperature distribution should be maintained accurately in the furnace. Steels containing inter-granular cementite lattice are particularly difficult to machine.

In this case, normal spheroidizing does not improve the conditions. First, it is necessary to eliminate cementite by *homogenizing* or *normalising*, or by slight quenching at a temperature above A_{c1} . After that, an ordinary spheroidizing treatment can follow.

Furnaces for Soft Annealing The choice of furnaces for spheroidized annealing is determined by the following:

1. Temperature of spheroidized annealing is relatively low and has to be maintained within close limits. Therefore, electric furnaces are more suitable than gas or oil fired furnaces. The time consumed by the process is relatively long.
2. For these reasons electrically heated batch furnaces are commonly used and the continuous furnaces do not offer any advantage.
3. Vacuum furnaces and salt bath furnaces may be used where the charge is less. They are more advantageous for re-annealing of hardened tools.

2.1.3 ISOTHERMAL ANNEALING

Isothermal annealing is derived from the exact knowledge of temperature-time diagrams. This type of annealing is useful for softening steels for the subsequent machining operations. This treatment consists of austenitizing the steel at the normal annealing temperature (full annealing) and then cooling rapidly to the appropriate temperature below A_{r1} , usually about 50–60°C below A_{r1} (isothermal holding in pearlite range). This temperature is held for a predetermined time (Fig. 2.4), enabling the complete austenite decomposition to take place for producing a structure having optimum machinability. After the transformation is complete, the steel is cooled in a furnace, or air-cooled, or rapidly cooled. There is no metallurgical reason for slow cooling during the change from the austenitizing to the transformation temperature, or after the transformation is completed.

The hardness obtained after isothermal annealing depends on holding the steel below A_{r1} . If the steel after austenitizing is held just below A_{r1} , it will decompose slowly. The product then may contain relatively coarse spheroid carbides or coarse lamellar pearlite depending on the austenitizing temperature. This product tends to be very soft. At the

transformation temperature the austenite generally decomposes more rapidly, and the resultant product is harder, more lamellar, and less coarse than the product from just below A_{r1} . Alloy case-hardening steels are normally subjected to isothermal annealing. After carburising the steels at 900–930°C, they are held at 630–680°C for 2–4 hours for the completion of austenite transformation and then cooled. The structure obtained consists of ferrite and pearlite, suitable for most machining operations. Usually, isothermal holding is extended beyond the end of transformation for 1–2 hours. So, additional improvement of machinability is obtained as a consequence of partial spheroidization of pearlitic cementite.

Isothermal annealing is best suited for applications in which full advantage can be taken of the rapid cooling to the transformation temperature. The cooling is continued from this temperature to the room temperature.

Furnaces for Isothermal Annealing Isothermal annealing may be carried out in salt baths or vacuum-hardening furnaces most conveniently for high loads and also for rehardening tools, if necessary. Annealing can be carried out by austenitizing in a salt-bath maintained at the austenitizing temperature, then transferring to the bath maintained at the isothermal temperature. In vacuum furnaces, the tool is first heated to the austenitizing temperature, and later quenched to the isothermal temperature. Subsequently, at the isothermal temperature, the gas is evacuated and held at this temperature to allow a complete transformation to pearlite. Finally, it is gas-quenched. Isothermal annealing can also be carried out for light loads in batch type or continuous type, where adequate arrangements are made for cooling the load from the austenitizing temperature. Isothermal annealing facilitates large savings in time vis-a-vis conventional cooling. It may not be advantageous for applications such as the batch annealing of large furnace loads in which the rate of cooling at the centre of the load may be so slow as to preclude rapid cooling to the transformation temperature. For loads of such type, conventional annealing is advantageous. (see Figs. 2.5(a) and (b)).

2.1.4 HOMOGENIZING

This process is carried out in the temperature range 1100–1200°C (Fig. 2.6). The diffusion

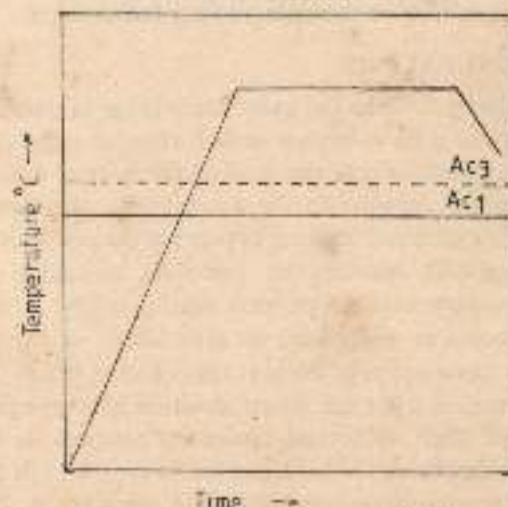


Fig. 2.6 Diagram representing homogenizing operation

which takes place at this temperature equalizes the composition of steels. This process is adopted to alloy steel ingots which, when solidified after pouring, have an inhomogeneous structure. This lack of structural homogeneity is removed to a large extent during forging and rolling of steel ingots. Where homogeneity has not been effected completely, the structural homogeneity is to be corrected by homogenizing or diffusional annealing treatment. In this case, the phenomenon of diffusion brings about a uniform concentration of primary grains.

The homogenizing treatment is carried out for several hours at temperatures between 1150–1200°C. After the treatment, the charge is cooled to 800–850°C, and then further cooled in air. After this treatment, the steel may undergo either normalizing or annealing to refine the over-heated structure. This treatment is applied only in very special cases, since the treatment cost is very high.

2.1.5 INTERMEDIATE ANNEALING

This treatment is carried out after case-hardening in order to carry out further machining such as turning, drilling, milling, etc. It consists of holding components below the A_{c1}

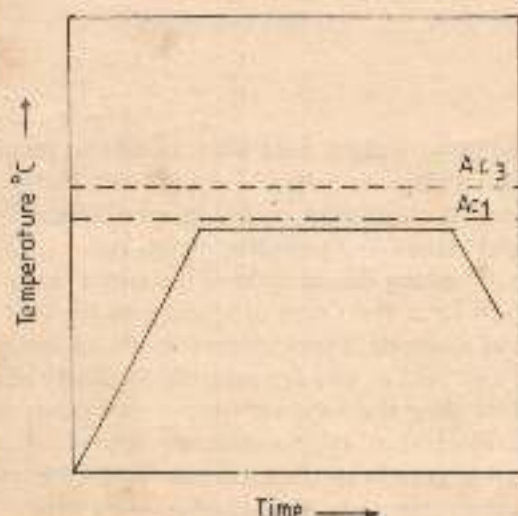


Fig. 2.7 Diagram representing intermediate annealing

temperature, i.e., around 630–680°C, for 4–6 hours, followed by slow cooling (Fig. 2.7). The object of this treatment is the same as that of spheroidizing, viz., improved machinability through the formation of globular cementite.

1.2.6 BRIGHT ANNEALING

This treatment is carried out to obtain a bright surface free from oxides. Protection from oxidation during heat treatment is usually obtained by blanketing the charge with a suitable gas atmosphere. The atmosphere gases, however, must be such as to avoid undesirable effects on the treated metal such as sulphiding, embrittlement, decarburization, etc.

Bright annealing is done in a variety of ways on a wide range of ferrous and non-ferrous materials. The material can be in the form of wire, strip, sheet, tube pressing, etc.

The selection of gases used for bright annealing depends on the type of steel. The gases employed are pure nitrogen, cracked ammonia, exothermic gas, pure hydrogen, etc. Appropriate gases and furnaces used for bright annealing of various workpieces is given in the Table 2.1.

Table 2.1

Material	Type of work	Furnace	Gas used
Carbon steel	Strip and wire in coils	Bell or pit type furnace	Dry burnt ammonia or lean exothermic stripped of carbon dioxide and H ₂ O
Mild steel	Strip and wire in coils, sheets and strips or tubes in lengths	Bell or pit type furnace roller hearth	Rich exothermic
Stainless steel	Strip and wire strands, small pressings, etc., straight small bore tubes	Pusher type or mesh belt	Cracked NH ₃ and pure hydrogen

2.2 Normalizing

Normalizing is one of the most widely used heat treatment processes applied on almost all castings, over-heated forgings, very large forgings, etc. Normalizing is done to refine the grain structure, improve machinability, relieve internal stresses and to improve mechanical properties of structural carbon and low-alloy steels, etc.

Normalizing consists of heating the steel above the critical temperature A_{c1} or A_{cm} and holding at this temperature for a short time depending on the type of steel (Fig. 2.8). To achieve homogenization of austenite, hypoeutectoid steels are heated to 30–40°C above the critical temperature A_{c1} , and held at this temperature for 20–40 minutes depending on the chemical composition. Exceeding the indicated temperature range might result in excessive austenite grain growth. Holding at the normalizing temperature for a longer time may also result in excessive grain growth or the exceeding of the tolerated limit.

After the desired holding time has elapsed, the components are cooled in air. The resultant metallurgical structures are composed of fine pearlite with ferrite in hypoeutectoid steels. It will be noticed that the newly formed grain boundaries do not correspond to the old ones. If the initial structure is coarse-grained or irregular, normalizing leads to a considerable improvement of the structure, together with improvement in mechanical properties.

In the same way, normalizing of hypereutectoid steel is done by heating the steel to 30–40°C above the critical temperature, A_{cm} , holding at this temperature for a short period, until the complete phase transformation has taken place, and subsequently cooling in air. This operation is done not only to refine the grain size but also to dissolve the networks of carbides that may have developed during forging, rolling, or in some instances, during case-carburizing. At room temperature, the newly formed structure consists of fine-grained pearlite with cementite. The normalized structure is more suitable for spheroidizing treatment to obtain good machinability.

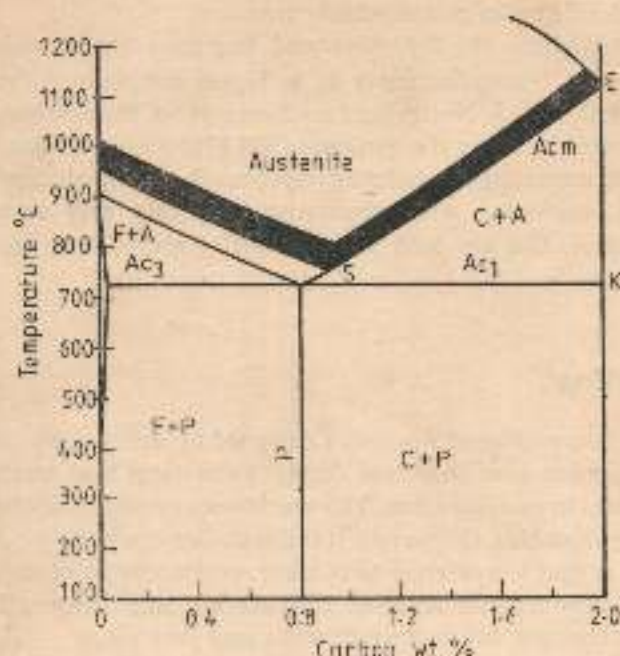


Fig. 2.8 Iron-carbon equilibrium diagram showing temperature range for normalizing

The mechanical properties obtained after normalizing depend on the rate of cooling in air. A faster rate of cooling may result in a higher strength and greater hardness than otherwise. Hence, when increased strength and hardness are required, the cooling rate may be enhanced by using fans.

Normalizing is mainly adopted on plain carbon and low-alloy steels. The hardness resulting from this treatment depends on the dimensions and composition of the steel and the rate of cooling. Normalizing treatment is not adopted for the air-hardening variety of steels.

Cooling in air after austenitizing the alloy steels may result in higher hardness. In such instances, they may be tempered at 600–650°C to render them machinable. Instead of adopting a lengthy annealing treatment, certain alloy steels may be subjected to normalizing, followed by tempering, so that the treatment time is reduced.

ADVANTAGES

1. Normalizing is used to eliminate the coarse grain structure obtained in the previous working operations such as rolling, forging, etc. The temperature employed for forged components may be in the upper range of the normalizing temperature.
2. Normalizing also avoids the coarse structure that would result from slow cooling of regular annealing.
3. Carburizing steels and carbon tool steels may be normalized to break up the continuity of the cementite network surrounding pearlite, since slow cooling would re-establish the network.
4. Refinement of the size of ferrite and pearlite.

5. Modifying and refining of cast dendritic structure.
6. Normalizing minimizes the distortion and improves the machinability of alloyed carburizing steels. Normalization is at a higher temperature than the carburizing temperature (950–970°C). Normalized medium carbon, high carbon, and alloyed steels are then tempered to lower the hardness (200 BHN) for purposes of machining.
7. Compared with annealing normalizing improves the mechanical properties.
8. In many cases, annealing with subsequent tempering may be substituted for normalizing. Furnaces that are used for normalizing are of both batch type and continuous type.

2.3 Stress Relieving

Stress relieving is a heat treatment operation designed to relieve the stresses induced in the component, minimize the distortion during subsequent heat treatment and to avoid the formation of cracks in extreme cases. This treatment consists of heating the components to a temperature approaching the lower transformation temperature A_{c1} , and holding it for a sufficient time at that temperature to achieve uniformity throughout the component, and subsequently cooling it to the ambient temperature in a furnace. This treatment will not cause any phase changes, but recrystallization may take place.

2.3.1 DEVELOPMENT OF STRESSES

There are many reasons for the development of stresses in metals employed for making engineering parts. Some of the most frequently encountered conditions for the build-up of stresses in components are given below:

Machining When components are subjected to heavy machining operations, certain stresses are induced in the component. The generated internal stresses can cause either cracking during the subsequent heat treatment or result in an instability of size and shape. This is mainly due to the change induced by machining in the equilibrium stress pattern.

Forming Operations Internal stresses are also developed during some forming operations such as bending, coining, deep-stamping, drawing, etc.

Heat Treatment Heat treatment is one of the causes for the development of internal stresses in components. This is either due to uneven heating and cooling, or due to a fast rate of heating to the hardening temperature. On certain occasions, internal stresses are developed during the phase transformation that occurs during cooling, since the formation of pearlite, bainite and martensite are all accompanied by an increase in the specific volume.

Casting Stresses are usually present in all castings in the *as cast* condition because of the non-uniform cooling of the surface compared to its centre, and due to a difference in cooling rates between sections of the same casting.

Welding Stresses are also induced when a component is subjected to welding, soldering and brazing. This happens due to the expansion and contraction in the weld-affected zone and also at the weld itself.

Others Other notable reasons for the development of internal stresses include exposure of the metal to severe atmospheric conditions such as marine or corrosive liquids.

2.3.2 STRESS-RELIEVING TEMPERATURE

The residual stresses that are induced in the material by any of the conditions listed earlier should be removed to impart the desired properties to the finished component or material. The stress relieving operation is carried out normally by heating the component below A_c1 temperature. Heating decreases the yield strength of the material. When it is warm and plastic, the stresses are relieved.

Stress-relieving is done by heating the steel to a temperature of 550–700°C, depending on the type of material. At temperatures above 500–600°C, steel almost entirely ceases to be elastic, and becomes ductile. For this reason, the internal stresses developed in the steel at such temperatures are gradually relieved as a result of local plastic deformations caused by them. The remaining stresses become negligible.

After heating to the desired stress-relieving temperature, the components should be held at this temperature for a considerable time to attain a uniform temperature throughout the section or charge. It is then cooled in a furnace, to 300°C and subsequently cooled to the ambient temperature. Care must be taken to ensure slow, uniform cooling, to avoid the formation of any new internal stresses. Typical stress-relieving temperatures to be employed on some of the materials are given in Table 2.2.

Table 2.2

Steels	Temperature
High speed steels	650–700°C
Hot-worked steels	650–670°C
Cold-worked steels	650–700°C
Nitriding steels	550–600°C
High temperature steels	600–650°C
Bearing steel	600–650°C
Free-cutting steel	600–650°C

If the greatest possible freedom from internal stresses is required, the stress-relieving treatment should be carried out near the upper limit of the appropriate temperature range. But this may lead to a superficial oxidation or excessive softening in hardened and tempered steels. In such cases, it is necessary to employ a lower temperature range for stress-relieving. The higher the temperature of stress-relieving, the lower the residual stresses. Figure 2.9(a) illustrates the temperature and time required to minimize the induced stresses.

Hardened and tempered components may be relieved at a temperature of about 25°C below the tempering temperature employed for tempering. Components to be heat-treated should be provided with sufficient machining allowance to compensate for any distortion resulting from stress-relieving.

Internal stresses induced by welding can be relieved by heating the components to 600–650°C, and holding at this temperature for a predetermined time. Normally, the holding time is about 3 to 4 minutes per mm of the maximum thickness of the sheet. It is

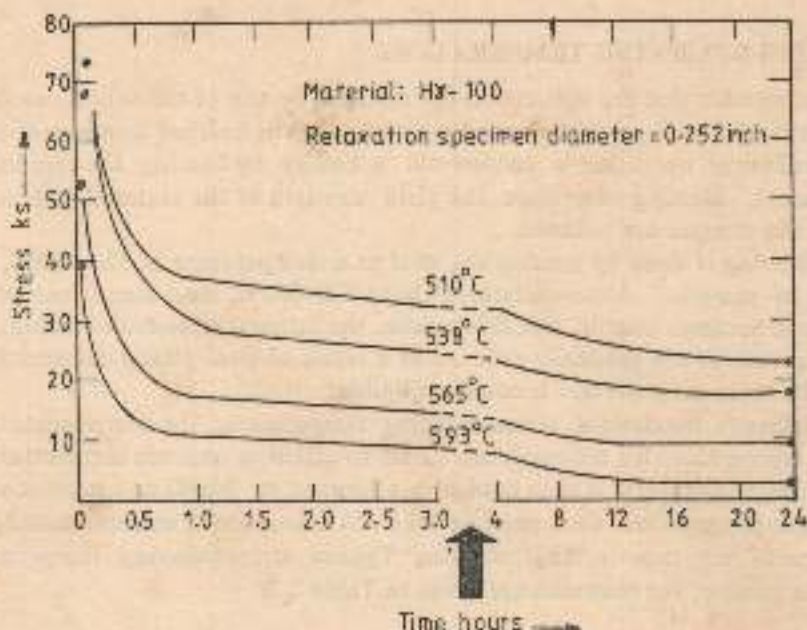


Fig. 2.9 (a) Stress as a function of time after stress relieving at various temperatures¹⁷

subsequently cooled at a rate of 50-100°C per hour to a temperature of 300°C. This slow and uniform cooling is necessary to prevent the addition of new internal stresses on cooling and to avoid the formation of cracks in stress-relieved, welded components.

Induced stresses may also develop in the hardened component due to faulty grinding. It may lead to cracks during or after grinding. Components in such conditions can often be salvaged by stress-relieving between 150 and 400°C at or below the tempering temperature immediately after grinding.

Tools also develop high residual stresses during usage. It is sometimes advantageous to relieve such stresses by heating the steel below the tempering temperature.

2.3.3 FURNACES FOR STRESS RELIEVING

Because the stress-relieving cycle is strongly temperature-dependent, it is essential to use a proper furnace.

In most cases an electric batch type furnace is employed (Fig. 2.9 (b)). Furnace cooling is adopted to prevent new residual stresses that may arise due to rapid cooling.

2.4 Hardening

Hardening is a heat-treating operation necessary to impart hardness to any component. This treatment consists of heating the steel to a selected hardening temperature (austenitizing temperature), and holding it at this temperature, followed by cooling or quenching at a rate fast enough to develop the desired hardness (Fig. 2.10). When the steel is austen-

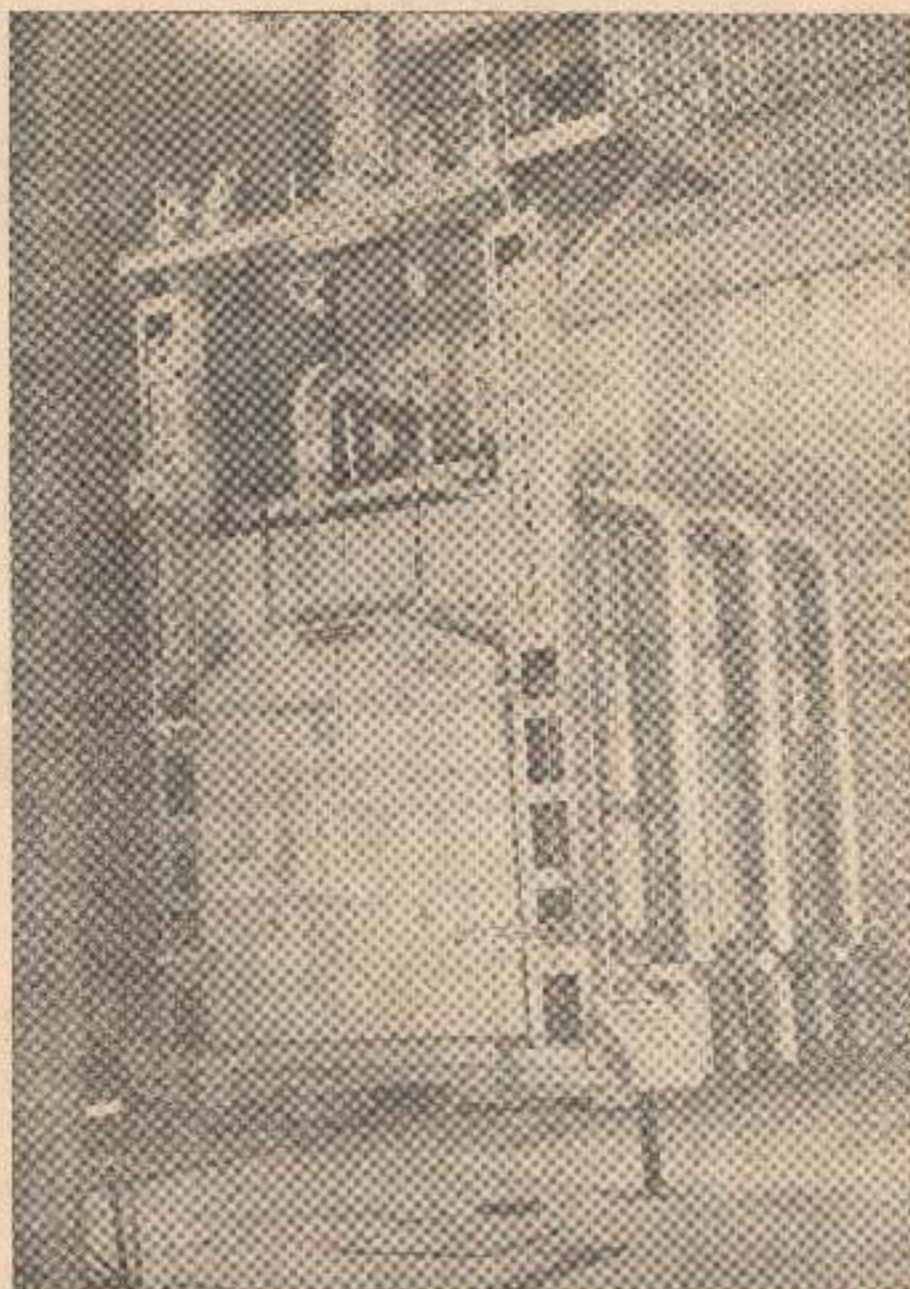


Fig. 2.9 (b) Electrically heated stress-relieving furnace (Courtesy: Wellman Incandescent India Ltd, Calcutta).

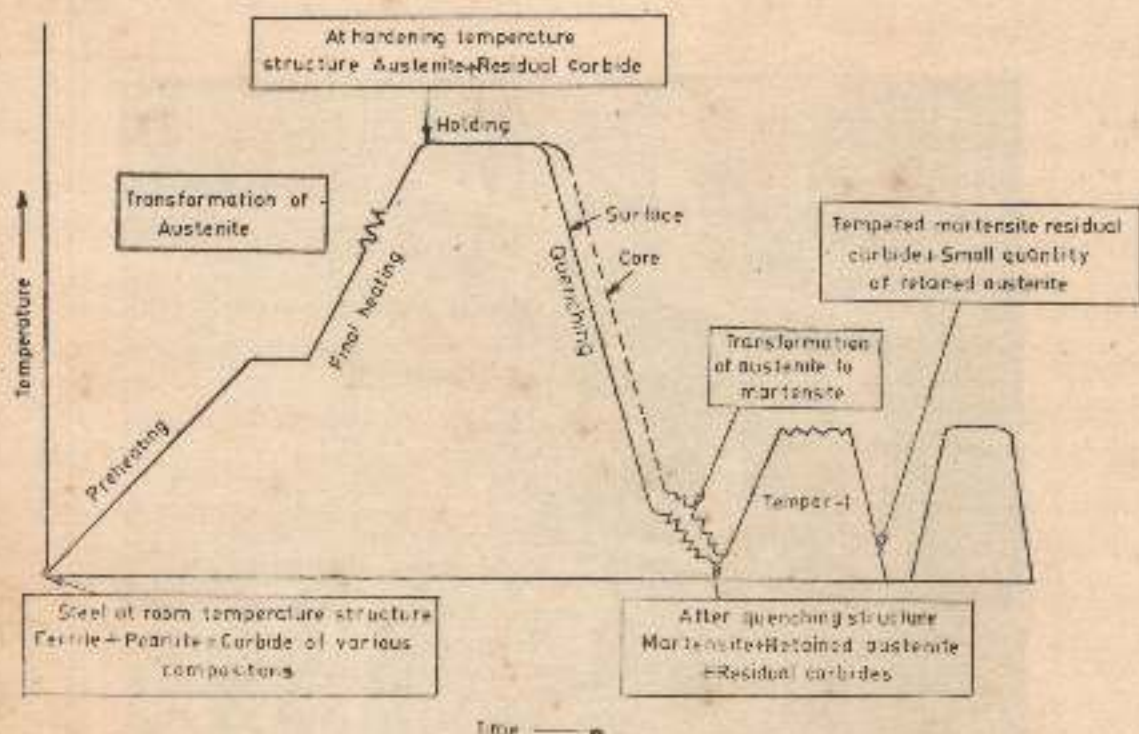


Fig. 2.10 Schematic representation of heating, quenching and tempering processes of tool steels¹⁴

nitized, its lattice structure is a face-centered cubic. The reason for heating and holding the steel in the austenite range is to dissolve carbides cementite into a matrix; then the steel is

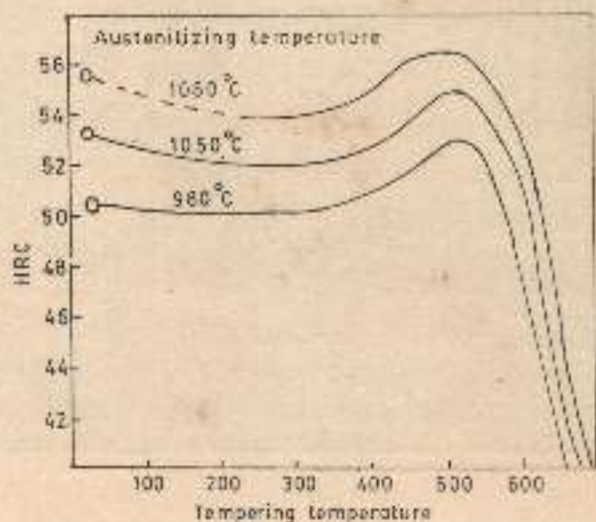


Fig. 2.11 Hardness obtained at different hardening temperatures AISI-H13 Steel¹⁴

quenched. At this stage, the trapped carbon causes a shift in atoms to form a body-centered tetragonal structure. The shift of atoms and the trapped carbon creates a stressed lattice structure. This stressed structure, called martensite, is hard and brittle. It is responsible for the high hardness of the steel. The hardness finally achieved depends on how much carbon was available, how much of this was dissolved, the temperature adopted (Fig. 2.11) and the rate of cooling. It is subsequently tempered to reduce the induced quenching stresses caused by the formation of martensite.

The main object of hardening is to develop high hardness and to increase the wear life of parts. The higher the hardness, the higher will be the wear resistance of the components. For example, spindles, gears, shafts, tools and dies, high speed steel tools, etc., need high hardness. It is also necessary for structural steels to have the required mechanical properties such as tensile strength, ductility, elasticity, etc. These properties can be obtained by hardening, followed by tempering. Hardened and tempered components possess better mechanical properties compared to the annealed and normalized components. Since hardening is the last operation, the component is almost close to the finished state. Hence, it should not be attempted without proper equipment, facilities and suitably trained operators.

The hardening temperature for specific grades of steels, obtained on the basis of a series of practical trials, is given in the manuals of most steel manufacturers. Recommended practices giving ranges of hardening temperature relevant to steels, listed in international standards, may also be adopted.

2.4.1 HARDENING TEMPERATURE FOR HYPOEUTECTOID STEELS

The hardening temperature to be employed depends on the chemical composition, carbon content and section thickness of the steel. The temperature employed for hypoeutectoid steel will be in the range of 20–50°C above the A_c1 critical temperature, and for hyper-eutectoid steels 30–50°C above the A_c1 critical temperature (Fig. 2.12). If a steel containing, for instance, 0.5% carbon (ferrite and pearlite structure) is heated to a temperature below

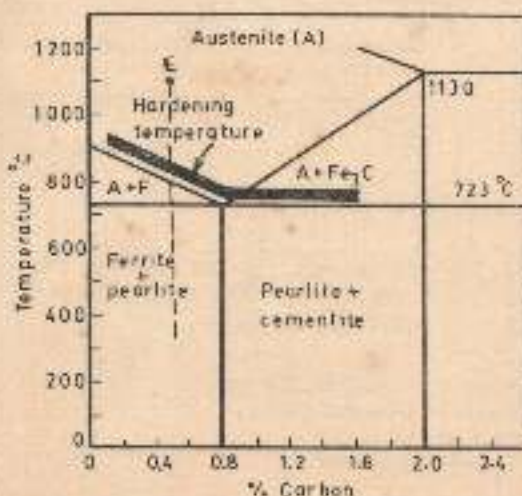


Fig. 2.12 Hardening temperature of steels¹

the lower critical temperature A_{c1} , it will not change the original structure of the steel containing pearlite and ferrite. Heating to a temperature above the lower critical temperature A_{c1} but below the upper critical temperature will change pearlite to austenite, without affecting the free ferrite. Quenching from this temperature produces a semi-hard steel, since the austenite is transformed to martensite, but the free ferrite remains unchanged. The presence of ferrite in addition to brittle martensite does not give appreciable toughness. If the steel is heated slightly above the A_{c2} critical temperature and held at this temperature for a sufficient time to bring about complete diffusion and equalization, the steel will be transformed, giving the smallest austenite grain size possible. An effective quenching from this range will produce martensite and the maximum hardness possible. Heating to a temperature E (considerably above the higher range of critical temperature) will tend to increase the grain size. Subsequent quenching will produce a martensite structure, whose properties, even after tempering, will result in a low impact strength. This may lead to warping and cracking during the quenching operation.

2.4.2 HARDENING OF HYPEREUTECTOID STEELS

This process consists of heating the steel to 30–50°C above the critical temperature A_{c1} (Fig. 2.12) which is the austenite plus carbide region. This is followed by rapid quenching to produce a fine-grained martensite with sufficient undissolved carbides. The quenched

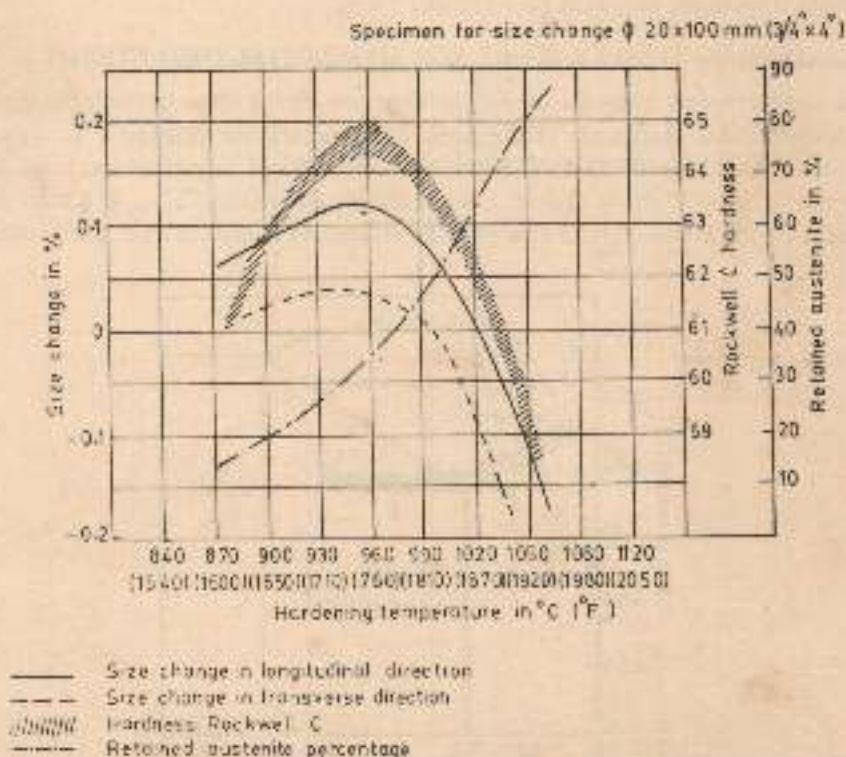


Fig. 2.13 Size change, hardness and retained austenite content in relation to hardening temperature (AISI) D3 steel (Courtesy: Bobler Bros., Austria).

structure has a higher hardness compared to the martensite, since the hardness of carbides is greater. If too little carbide is dissolved in austenite, the resultant hardness will be low. The amount of carbide that can be dissolved in austenite is proportional to the austenitizing temperature. The amount of carbide increases progressively as the temperature is raised; the grain size of the steel also increases. If too much carbide is dissolved, grain growth may occur with a corresponding decrease in hardness as well as toughness (Fig. 2.13). If the steel is heated above the A_{cm} temperature, the resultant structure will have only austenite grains. In such a case, the grain growth is larger; consequently, the martensite becomes coarser. The resultant hardness will be low due to the presence of an excessive amount of retained austenite in the quenched structure and also because no more carbide will be present in the steel structure.

Hence, proper precautions may be taken to obtain a fine grained martensite with sufficient undissolved carbides. The treatment temperature for specific grades of steels is given in the manuals of all steel manufacturers. This information is based on a series of practical trials. In addition, the recommended practices in international standards may also be used. They contain a hardening temperature range to which the steel is to be heated.

2.4.3 OPERATIONS BEFORE HARDENING

It is most important that the components to be hardened should be free from scales, grease, oil, etc., in order to achieve the desired hardness. Hence, such components should be cleaned thoroughly. Components having holes, particularly tool steels, may be packed with clay, asbestos and steel inserts wherever necessary, so that no hardening can occur in the holes. Special attention may not be required where holes are relatively large and tools should be quenched in such a manner that the internal surfaces of the holes harden completely.

The components should be placed in suitable fixtures before placing them in the hardening furnace. This is done to avoid distortion. Small components may be heated in a suitably designed basket to ensure uniform hardness.

Plain carbon and low-alloy steels may be heated right up to the hardening temperature in one step, without any pre-heating. Components of large size and complicated shapes may be pre-heated to avoid distortion and cracking due to uneven temperature differentials between the core and the surfaces. This is more common, particularly in tool steels, since the thermal conductivity of tool steels is very low. For this reason, these components are preheated to 500–600°C. At this temperature, the internal stresses generated by uneven heating between the core and the case are gradually relieved as a result of local plastic deformations. The remaining internal stresses become negligible. Therefore, at temperatures above 500–600°C components may be heated faster. Pre-heating is also necessary when the hardening temperature is high, since the shortest possible time at high temperatures minimizes scaling and decarburization. Complicated components or tools made of highly alloyed steels should be pre-heated in two steps before subjecting them to the austenitizing temperature.

It is also very important that components should have a homogeneous and fine-grained structure before hardening. For instance, if the component has a coarse-grained structure before hardening, it may lead to a non-uniform hardness, a greater degree of distortion, and quenching cracks may also develop during hardening. Prior to hardening, the

components possessing a coarse-grained structure should be normalized for a short period. Normalizing refines the grain structure of steels, and helps to avoid the previously mentioned defects. To ensure the development of a high and uniform hardness in tool steels in the as-hardened condition, the steel, prior to hardening should have a lamellar-pearlite structure instead of a globular structure. The reason for this preference is that the transformation of globular structure into austenite occurs at a considerably slower rate than the lamellar pearlite. Yet another reason is that steels of this type may not possess a higher depth of hardness. If it is necessary to harden a tool steel to a greater depth, it is then necessary to have a lamellar pearlite structure. For this, a normalizing operation may be done in the temperature of 780–800°C.

Before hardening, the component should also be free from the cementite network because that leads to a further increase in brittleness of the hardened steel. Such a steel should be subjected to the normalizing operation to overcome this defect.

2.4.4 HOLDING TIME IN HARDENING BATH

The time taken to reach the hardening temperature depends on several factors such as the heating equipment and the hardening bath. The rate of heating in a salt bath is considerably faster than it is possible in a furnace with atmosphere because the heat transfer from a liquid to a solid body occurs at a faster rate. When the desired hardening temperature is reached, sufficient soaking time should be given. A visual inspection may be done through a small hole in front of the furnace to assess whether the component has reached the desired hardening temperature in relation to the walls of the furnace. If the surface of the component is darker, its temperature is lower, and it should be allowed to remain in the furnace for some more time. When the component attains the furnace temperature throughout, the colour of the component will be indistinguishable from that of the furnace wall. When the surface of the component has reached the required temperature, the holding time should be counted. The same principle applies to salt bath heating. If the salt bath is maintained properly, it should be possible to match easily the colour of the component to the colour of the transparent liquid salt.

After the component has reached a uniform temperature, it should be held at this temperature and subsequently quenched to get the martensite structure.

The time of holding at the hardening temperature depends on the type of steel and the selected temperature within the prescribed range for plain shaped parts. In most cases, the upper limit of the hardening temperature is selected. However, if the cross-section shows large differences, the lower temperature range is preferred. Holding times are, therefore, longer in the first instance than in the latter. To offset the risk of overheating worsening of grain, unalloyed and low-alloy steels must be kept for a far shorter period at the hardening temperature than, for instance, for high-alloy, special hot working of steels containing carbides which require more time for the dissolution of carbides essential for the optimum retention of hardness.

The diagram in Fig. 2.14 can serve as a guide to determine the holding time to be applied to construction and tool steels after reaching the hardening temperature, or the immersion period (period from start of immersion until removal) in the salt bath.

2.4.5 HARDENING FURNACES

The hardening treatment requires a suitable furnace which serves as a heating equipment.

The furnaces used for hardening should have accurate temperature control and a suitable atmosphere to assure an accurate treatment. It is important that the atmosphere used should be neutral during the hardening operation; it should not cause decarburization or carburization on the surface of the component. A decarburized layer gives a lower hardness which may result in the choice of an incorrect tempering temperature. Decarburization may lead to cracking in tool steels. In certain cases, the decarburized layer may be removed by grinding, if the component displays adequate tolerance. However, many tools are usually finished to size and hence the same should be maintained throughout the hardening operation. Scaling and decarburization cannot be tolerated in such instances. To obtain an optimum hardening on components, it is necessary to select the best furnace with suitable heating media.

The types of heat treatment furnaces available for hardening are: (i) Salt bath furnace, (ii) Muffle furnace, (iii) Vacuum furnace and (iv) Fluidized bed furnace. These furnaces derive their names because of the particular heating medium used. For instance, various salts are used as a heating media in a salt bath furnace, whereas a vacuum or a fluid bed is used in the case of the vacuum furnace and the fluidized bed furnace respectively. In all these furnaces, heating is normally done with electrical energy using electrodes, coils, or heating elements housed in a suitable container, depending on the particular heating media, namely salt, gas, etc.

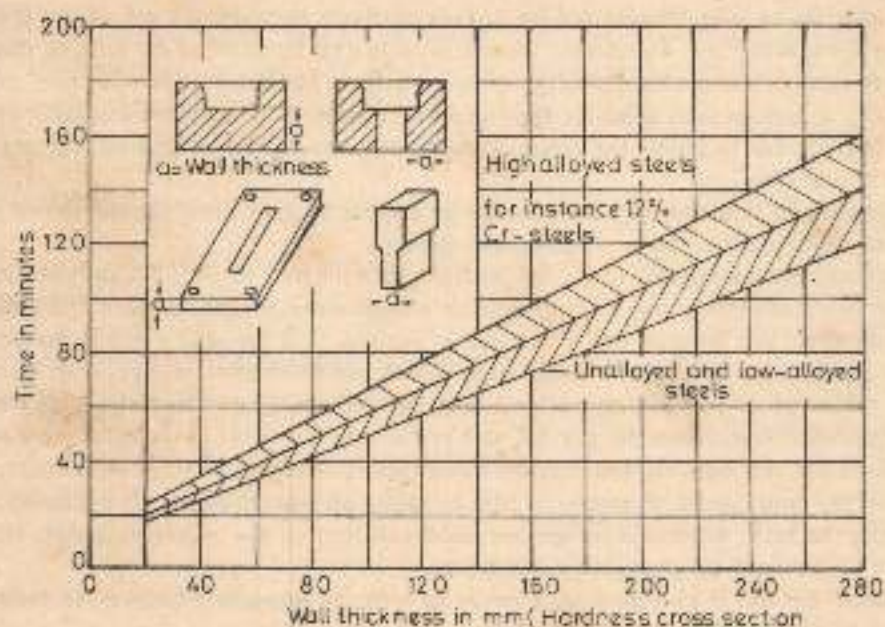


Fig. 2.14 Soaking period in salt bath after reaching hardening temperature on the surface of the workpiece, as a function of wall thickness⁵

Since the hardening process depends very much on the correct preparation of the hardening media, a brief description of the different media employed is given in the following paragraphs.

Salt Baths Neutral salts are used for hardening steels.^{15,20,21,22,23,24} These salts are required

to heat the steel without causing either carburization or decarburization. Salts are available in the market as proprietary salts. They can be used for the medium temperature and high temperature range of hardening.

MEDIUM TEMPERATURE SALT BATHS Salts used for hardening different types of steel at medium temperature are chlorides of sodium, potassium, barium and calcium. They vary widely in composition. There is no single mixture that can cover the whole range of temperatures required for all types of steels. Three or four combinations of salts, usually sold under trade names, will cover the entire heating range required for all steels. Salt manufacturers of heat treatment salts do not specify the composition of salts; on the other hand, they give detailed information on properties and applications. Typical compositions, suitable for various operating temperatures, are listed in Table 2.3.

Although chloride salts are inert to steel, they provide the best protection to steel when first melted. In the course of operation, molten salts gradually react with air and form oxychlorides and oxides, resulting in decarburization on the workpiece. Decarburization will be aggravated in the higher temperature range, if held for a longer time in the bath. Salt baths must, therefore, be periodically rectified, the frequency being determined by the cleanliness of the work being treated. Rectification may be done in several ways; for instance, by the addition of boric acid (2.4%), which will convert the oxychlorides into a sludge that can be periodically removed.^{20,21,22}

Decarburization may be detected by surface hardness tests, by the use of test files or by microscopic examination. The degree of rectification can be checked by heating and quenching high-carbon test-pieces. Any sign of low surface hardness indicates the need for rectification. Since the salts used for the medium temperature bath are available commercially, it is advisable to follow the recommendations given by the salt manufacturers for the addition of rectifiers.

It is important that the bath be covered by a layer of pure graphite powder to prevent heat losses, insuring thereby a reducing atmosphere.

A salt containing a mixture of 20–30% sodium chloride and 70–80% barium chloride, with a melting point of 640°C, may be employed at temperature ranges between 750 and 950°C. This salt mixture can be used for treatment of carbon and low-alloy steels, hardening of precision tools, dies, gauges and other parts which are finished to size prior to hardening, and not subjected to further operations. It is recommended to cover the bath with pure graphite powder to increase the pot life and reduce the amount of rectifiers to be added. To maintain the salt bath in the original condition it is necessary to remove scales or rust present on the component. Presence of rust or scales on work leads to an excessive amount of oxides in the melt, necessitating an increased addition of the rectifying agent. However, it may be de-oxidized by the addition of borax.

Activated carbon is also used as a cover to form an insulating blanket, to reduce heat losses and to prevent decarburization.

A salt containing a mixture of 80% barium chloride and 20% sodium chloride, with a melting point of 750°C, is used in the temperature range of 815–1095°C for hardening high alloy steels. Rectification or deoxidation of the bath is done by adding 4–5% borax.

A salt mixture of 50% barium chloride and 50% sodium chloride, having a melting point of 660°C, can be used in the working range of 700–1000°C for hardening of tool steels and constructional steels. This salt can also be used as a pre-heating salt for hot-work steels and high-speed steels. De-oxidation of the bath is done by adding borax.

Salt mixtures of 50-60% barium chloride, 15-25% sodium chloride and 20-30% potassium chloride with a melting point of 620°C, are used in the temperature range of 650-1000°C. Such mixtures may be used for hardening, high temperature tempering, normalizing and also along with a carburizing salt for the preparation of the bath. Carburized components can be annealed for machining purposes using this salt bath.

Table 2.3*

Chemical composition %			Temperature °C	
NaCl	BaCl ₂	KCl	Approx. melting	Operating range
20-30	70-80	—	700	760-930
10-20	80-90	—	750	810-1090
50	50	—	670	700-1000
30	68	(MgF ₂)	710	780-950
30	40	22	660	720-960
15-25	50-60	20-30	600	650-1000

HIGH TEMPERATURE SALT BATHS (1000-1300°C) Barium chloride salts with a melting point of 960°C are usually used in the temperature range of 1000-1300°C; barium chloride and 3-5% magnesium fluoride having a melting point of 950°C, can be used in the temperature range of 1050-1300°C. The details of composition are given in Table 2.4. The rectifiers used for de-oxidation are borax, ferrosilicon, and magnesium fluoride. In the first 6-8 hours of operation, there will not be a tendency towards oxidation of the molten salt. Sometimes these salts are mixed with a sufficient quantity of rectifiers; however, for rectification of bath the salts in the course of the operation, it is necessary to add 0.6-0.8% borax, 1-2% ferrosilicon or 0.6-0.8% magnesium fluoride per shift of 8 hours.^{21,22,23} The addition of magnesium fluoride provides full protection to the bath, the electrodes and also to the bath-lining. In fact, ferrosilicon can cause erosion of bath-lining and electrodes. For this reason it is better to add both ferrosilicon and borax in identical proportion. Table 2.4 indicates salts used for high-speed steels. They can also be used for treatment of hot-work steels. The decarburizing tendency of the bath is aggravated by high temperatures. Decarburizing can be checked by treating a test piece, quenching it in oil and examining it with a file. A *file soft* surface indicates the need for more rectification.

Table 2.4 (After Smolinikov)²⁴

Types	Chemical composition	Approx melting °C	Operating range
1.	100% BaCl ₂	960	1050-1300°C
2.	95% BaCl ₂ + 5% MgF ₂	940	1200-1300°C
3.	97% BaCl ₂ + 3% MgF ₂	950	1050-1300°C
4.	94% BaCl ₂ + 5% Na ₂ B 407 + 1% SiV ₂	950	1050-1300°C
5.	96% BaCl ₂ + 6% Na ₂ B 407	950	1050-1300°C
6.	90% BaCl ₂ + 10% NaCl	850	950-1000°C

Advantages and Disadvantages of Salt Baths

ADVANTAGES The initial investment cost of a salt bath furnace is low compared with the other heating methods.

Salt bath provides uniform heating for all the workpiece in the furnace, whereas in atmospheric furnaces, the parts in the centre of the charge lag considerably behind those on hearth or on the outer edges of the charge in reaching the desired temperature.

The heat-transfer rate from salt to metal is much higher than that obtainable by heat radiation in atmospheric furnaces.

When the charge is withdrawn, it is coated with a thin film of liquid salt to protect the metal oxidation while being transferred to the quench.

Conduction heating in salt bath is more rapid and uniform than radiation heating. Yet, no thermal shock is encountered.

Work handling in salt bath is especially well supported because of the high density of the medium. It lowers the apparent weight of the workpiece; therefore, the tendency towards bending distortion is reduced.

Long, slender components can be hung and quenched vertically; this helps to prevent distortion.

Due to the stirring action of the salt bath, the temperature throughout the bath is uniform. The salt-bath temperature can be controlled accurately²⁴.

Salt baths are ideal for the hardening of die steels and high-speed steel, since they are capable of being quenched very rapidly below the pearlitic nose, thus assuring high hardness.

DISADVANTAGES The disadvantage in salt baths is the disposal of dross and effluent containing barium waste.

A separate room has to be provided for storing the salts.

Salt baths are very corrosive. Corrosion leads to the deterioration of the plant, since the salts are hygroscopic. Salt fumes condensed on the equipment produce thin films which, when cooled, rapidly hydrate and cause accelerated rusting.

Salt baths call for a good ventilation system. Furnaces should be provided with a separate exhaust system to suck the fumes from the bath during operation.

Operating personnel should be subjected to periodical medical examination.

An electrically heated preheating furnace is necessary to preheat the work in air to remove the water which may be present, and to eliminate the risk of salt spitting.

Endothermic Atmospheres Muffle furnaces and sealed quench furnaces mainly employ either an endothermic or exothermic atmosphere. An endothermic atmosphere is produced through a suitable generator using an appropriate gas and air. The product obtained consists of mainly nitrogen, hydrogen, and carbon-monoxide, with small quantities of carbon-dioxide and methane.

The gas normally used is propane which is mixed carefully in a balanced proportion with air, and passed into a chamber that is filled with a nickel-bearing catalyst. The chamber is heated externally to a temperature of around 1040°C. The reaction takes place in an endothermic atmosphere which is also called the carrier gas. The carrier gas has a carbon potential of 0.4%; hence a majority of constructional steels can be heated in direct contact with this gas, without any risk of change in the carbon content on their surface. Steels containing a higher percentage of carbon, such as carbon tool steels and high-speed

steels, may be hardened by increasing the carbon potential by the addition of propane directly into the furnace. The required potential of the carrier gas should be the same as that of the carbon dissolved in the steel at the hardening temperature. It is very important to carefully control the carbon potential in the furnace, using either the dew point or infra-red radiation method to avoid decarburization or carburization.

Exothermic Gas The exothermic atmosphere is produced by combining a fuel gas (natural gas, LPG, etc.) with varying amounts of air in a suitable generator to obtain a range of gas mixtures.

Heat is developed due to the reaction of the gases and hence it is called exothermic. The resultant gas contains a mixture of hydrogen and carbon monoxide (accounting for 25%), 5–12% carbon dioxide, and the balance is made up by nitrogen plus water vapour.

In cases where carbon dioxide and water vapour are detrimental, it is necessary to remove them, usually either by absorption or through molecular sieves. The resultant gas is chiefly dry nitrogen, with or without controlled residues of hydrogen and carbon monoxide.

NITROGEN Nitrogen is generated mainly from air by liquefaction. It can also be prepared in an exothermic generator by burning a mixture of air and fuel gas. This gas can be used as a neutral atmosphere in muffle furnace, sealed-quench furnace, fluidized furnace, etc.

Fluidized Beds Fluidized bed furnaces can also be used for the hardening operation.^{25,26,27} The parts to be treated are heated in a fluidized bed. The furnace consists of a refractory-lined sheet-shell carrying a retort, which is usually filled with particles of fine-grained aluminium oxide. Aluminium oxide particles are fluidized by a controlled flow of gas blown upwards through the base of the retort. The controlled flow of gas blown upwards through a porous bottom of the retort creates a fluidizing effect such that the bed acts like a fluid. When heat is applied the bed provides a rapid heat transfer medium, almost similar to that of molten salt. The fluidized gas performs two tasks simultaneously; it creates the operating conditions of the fluidized bed, and also determines the furnace atmosphere.

Heating of the furnace can be external or internal, by electricity or gas. The heating medium used for hardening is neutral gas (nitrogen). Use of nitrogen provides a bright surface which does not require decarburization. Fluidized furnaces are more ideal for production situations such as those needed in tool rooms.

Vacuum Hardening Hardening, using a vacuum medium, is gaining importance, particularly for hardening tool steels and super-alloys because the vacuum medium confers better hardening properties on components, together with less distortion and a brilliant surface appearance.^{29,30,35-37}

The essential difference between vacuum hardening and other hardening methods is that it provides absolute neutral conditions with little effort, and prevents the occurrence of surface reactions such as oxidation, decarburization, carburization, etc. during hardening. A vacuum pressure range of 1 to 500 microns is required for the hardening treatment.

2.4.6 METHODS OF QUENCHING

After the component is held at the hardening temperature for a desired length of time, it is taken out for cooling, or quenching, in order to obtain a hard martensite structure. The

rate of cooling must be controlled, so that the formation of soft pearlite or bainite is prevented.

The medium used for quenching depends upon the chemical composition of the steel, the hardness required, permissible degree of distortion and the complexity of the component. Water, oil, brine, molten salt and polymer quenchants are some of the quenching media in use.

The grade of steel, section thickness, distortion allowed and the properties to be imparted to the component govern the method to be adopted. The various quenching methods are:

1. Direct quenching
2. Martempering
3. Austempering
4. Delay quenching
5. Time quenching
6. Die quenching

Direct Quenching In this method, components held at the hardening temperature for the required length of time are directly quenched in water or oil, to get the hard martensite structure (Fig. 2.15).

The disadvantages of this method are, firstly, the higher distortion and, secondly, the presence of cracks due to the very high rate of cooling in the martensite range. However,

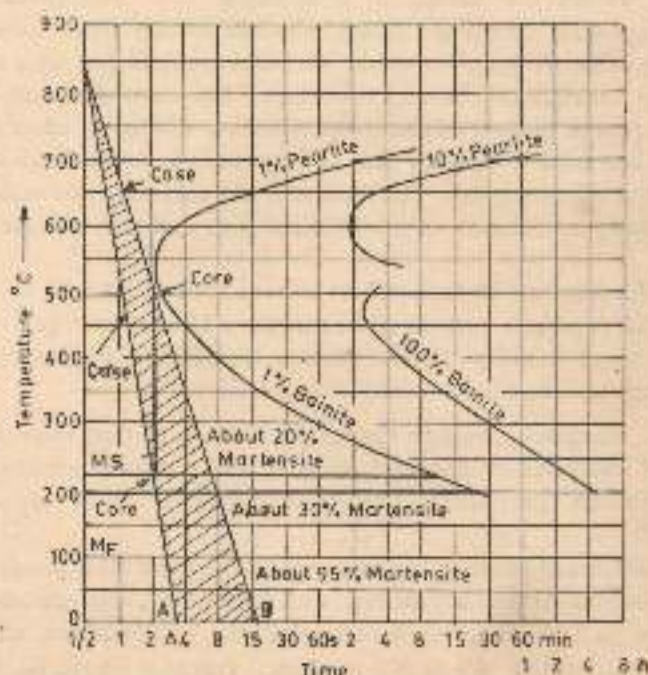


Fig. 2.15 TTT diagram showing, in principle, the temperature conditions on the surface and in the core of a specimen subjected to direct quenching (Courtesy: Uddeholm Steel Corporation, Sweden)

this method is deemed suitable for mild steels, low-carbon and medium-carbon steels.

Martempering The main object of martempering is to minimize distortion and to eliminate cracking during hardening.^{32,33,34} It should be noted that martempering cannot prevent volume changes which are inevitable in any hardening treatment. However, it can help to reduce erratic changes to a minimum, so that the minimum finishing allowances can be maintained on the components. In this method, the component is heated to the hardening temperature in the usual manner, and quenched in a molten salt-bath, instead of employing water or oil. The temperature of martempering bath is kept a little above the martensitic starting point of steel being treated (Fig. 2.16). The component is soaked in the bath until its temperature is uniform throughout; but the component is not kept long enough for transformation into softer bainite. The component is then taken out of the bath and allowed to cool in air.

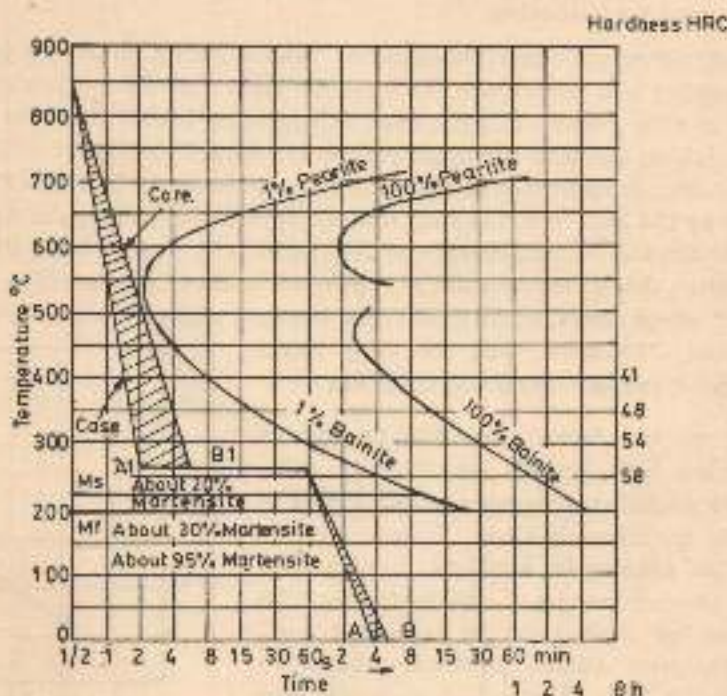


Fig. 2.16 TTT diagram showing, in principle, the temperature conditions on the surface and in the core of a specimen subjected to martempering (Courtesy: Uddeholm Steel Corporation, Sweden)

Figures 2.15 and 2.16 illustrate the difference in temperature distribution on the component during quenching in water or oil and in molten salt-bath maintained a little above the M_s temperature of steel.

It is clear from Fig. 2.15 that in direct quenching, the surface of the component gets hardened before the onset of transformation in the centre. The martensite structure commences to form at the outside of the component when its temperature falls below the M_s point. As cooling continues, martensite forms and continues inside, until the tempera-

ture of the quenching oil pervades the section. The formation of martensite, first on the outside and later inside a component, causes an increase in volume and a loss of ductility. This sets up stresses which cause distortion and, sometimes, cracking.

As compared to the transformation process discussed above, the effect of martempering can be seen in Fig. 2.16. The temperature across the section reaches a uniform value of that of the martempering bath A_1B_1 before the martensite transformation begins. The internal stresses will develop during martensite transformation, and proceed almost simultaneously in both the core and the case (thick and thin section) of the component being hardened. As a result, there is less residual stress, minimum distortion and less danger of quenching cracks appearing in the component.

The martempering method may be further modified in order to harden a greater range of steels. In this method the components are quenched 10–20°C below the M_s temperature. This will accelerate the working speed of the component. Hence a lower hardenability of steel can be adopted for hardening.

STEELS FOR MARTEMPERING Steels subjected to martempering must be judged on the basis of hardenability and section size. To form the martensite for a given section size, the carbon content or alloy content or both, must be somewhat higher than for convention a quenching. Therefore, this heat treatment process is adopted mainly for oil hardening and air hardening steels. It requires a suitable salt bath, the capacity of which should be large enough to take up the heat from the steel without appreciably raising the temperature of the bath. Although the M_s temperature of steel varies with composition, the most important factor affecting the M_s temperature is the carbon content. In practice, a quenching temperature of about 250°C is satisfactory for hotwork steels. For carburized, hardened steels it is about 180–200°C, and for alloy steels (structural steels) it can be from 200°C to 250°C.

HOLDING TIME IN THE BATH The holding time in the martempering bath depends on chemical composition, section thickness, temperature and degree of agitation of the quenching medium. Agitation of the bath increases the obtainable hardness considerably. To utilize fully the advantages of martempering, the quenching in the hot bath must be continued until the whole component attains practically the same temperature as the bath. Figure 2.17 gives an idea of the time required for this. Within the mentioned limits this equilization time is rather independent of the hardening as well as the bath temperature. Excessive holding time lowers the final hardness due to the formation of bainite.

The martempering time for temperature equalization in oil is about four to five times that required in an anhydrous salt at the same temperature.

The addition of 1 to 2% water to the molten salt results in accelerating the cooling capacity of the bath.

MARTEMPERING MEDIUM Martempering is carried out either in a hot oil bath (at a maxi-

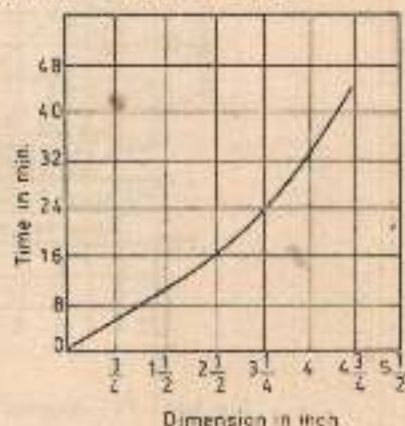


Fig. 2.17 Minimum holding time required for the equalization of temperatures in cylindrical steel specimens of different diameters (Courtesy: Uddeholm Steel Corporation, Sweden)

imum temperature of 230°C) or in a nitrate-nitrite salt bath. The oil bath, on account of its instability and inflammability, is less favoured than the more costly salt bath which is simple, safer and can be operated in a wide operating temperature range of 150–400°C. The components quenched in salt bath can be easily washed with plain water after treatment.

The quenching properties of the nitrate-nitrite salt bath is equivalent to that of a well-agitated oil quenching. An increase in quenching rate can also be achieved by the addition of 1% water to the salt bath.

Since the molten salts contain nitrates, they should never be mixed with cyanide because they react violently if heated together. Components quenched in oil should be washed before tempering.

EXAMPLES OF APPLICATIONS Martempering is mainly applied for tools of intricate design and non-uniform cross-section, high-speed steel cutters and die steels, etc., where minimum distortion, freedom from cracking and a high degree of dimensional accuracy are required. Almost all high-speed steels, hot-work tool steels and high-alloy steels are subjected to martempering. Martempering is also appropriate for carburized parts such as gears, shafts, spline shafts, spindles, cams, etc., since martempering causes minimum distortion. As a result of this, the costly grinding operation time is reduced, apart from avoiding scrap due to heavy distortion.

Components such as shafts, drills, reamers, washers and springs can be easily subjected to straightening or reforming operation either by hand pressure or in a die press, since the steel is still austenitic when removed from the bath. This is not possible in direct hardening.

Austempering Austempering may be employed for certain grades of high-strength steels which require a remarkable degree of toughness and ductility. Components that are subjected to this process possess a higher toughness, improved impact strength, higher endurance limit and ductility compared to conventional hardening and tempering to the same hardness.^{25, 26, 27, 28} Hence, austempering usually replaces conventional quenching and tempering to obtain improved mechanical properties and to decrease the likelihood of cracking and distortion. Austempering is done by quenching the steel from the austenitizing temperature in the molten bath, the temperature of which is kept just above the level of martensite transformation. The holding time in the bath is such that the austenite is fully transformed to bainite. The steel is then cooled in air to the room temperature (See Fig. 2.18). Bainite is hard and tough. The resultant hardness depends on the temperature. The higher the austempering temperature, the shorter is the soaking time; the resultant hardness is lower (see Fig. 2.18). The soaking time varies from 5 minutes at the higher austempering temperature of 350–380°C to 30 min. or one hour at 250–270°C. However, the correct treatment temperature and soaking time should be chosen from the relevant transformation diagram of the particular steel. The hardness of bainite, obtained at a particular temperature of transformation, is roughly equal to that of martensite tempered at the same temperature. At a given hardness the bainite structure is more ductile and tougher than tempered martensite. The endurance limit of austempered springs is the same as that of springs hardened and tempered to the same tensile strength. Hardening temperature has a significant effect on the time at which transformation begins. As the hardening temperature is increased above normal, the nose of the TTT

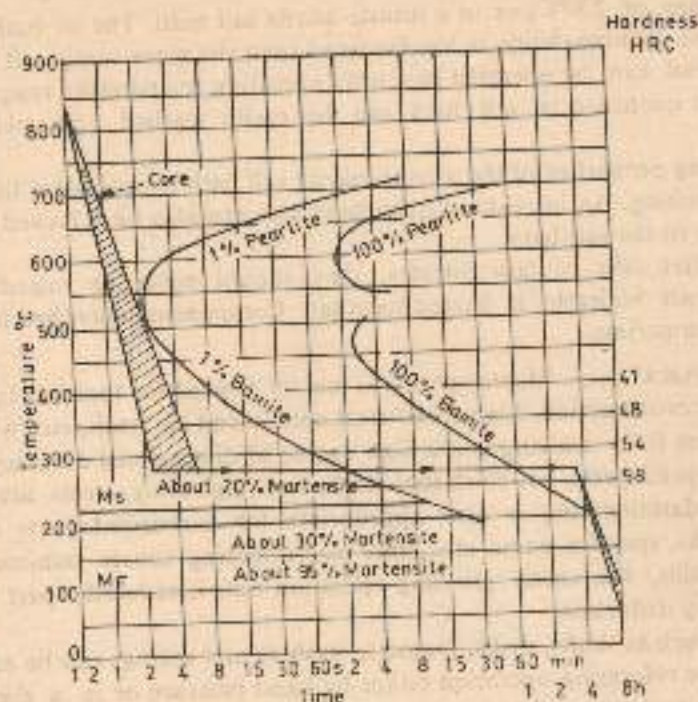


Fig. 2.18 TTT diagram showing, in principle, the temperature conditions on the surface and in the core of a specimen subjected to austempering (Courtesy: Uddeholm Steel Corporation, Sweden).

curve shifts to the right because of grain coarsening. Consequently, more time is needed before transformation begins. The hardness of bainite is influenced by the chemical composition of the steel and by the temperature of the bath and can, therefore, be governed to some extent by temperature. The time-temperature diagram indicates (Fig. 2.18) usually the right side, the hardness that can be expected after 100% transformation into bainite. The method of cooling after the heat treatment has no influence; the one usually adopted is air-cooling. Tempering is also not required.

AUSTEMPERING MEDIUM Austempering is carried out in a molten salt bath, since it permits more accurate temperature control, thereby producing a uniform degree of hardness. The lower the temperature of the salt bath, the higher is the cooling capacity. Addition of 1-2% water increases the cooling capacity of the molten salt bath at 400°C, and is approximately four times higher than that with water. A salt mixture of 45-55% sodium nitrate and 45-55% potassium nitrate is used. These salts are completely soluble in water, hence it is easy to wash the components. These salts can be effectively used in the temperature range of 200-500°C.

APPLICATIONS Applications of austempering are limited to small-sized, low-alloy steel components and medium sizes of alloy steels restricted to components of small sizes. For high-alloy steels the length of time necessary for complete transformation to bainite is too long, thus rendering the process uneconomical.

Austempering reduces the distortion due to the slow transformation of austenite to bainite, and as a result, the subsequent machining time will be reduced. In some applications, austempering is less expensive than conventional quenching, since it avoids tempering.

Austempering is applied to small components requiring exceptional toughness combined with reasonable hardness. The components mainly adopted for austempering are: springs and clips of all shapes and sizes, hack-saw blades, spanners and wrenches, compressor valve plates, cultivator sweeps, scraper blades, needles for stitching boots and shoes, shoe chunks, toe caps for safety boots, pen nibs and clips, garden shears, conveyor sprockets, chain shackles, paint-scraper blades, etc.

Delay Quenching Delay quenching is the term applied to a quenching process in which the components, after removal from the hardening bath, are quenched in a suitable medium after some lapse of time. This allows the quenching to be done at a relatively low temperature, resulting in a minimum of distortion. This method may be applied to high speed steels, hot-worked steels and case-hardened steels.

Time or Interrupted Quenching This method is mainly adopted for steels of low hardenability which require water-quenching, and for those of higher hardenability when the tools are big. It minimizes internal strains, resulting in reduced distortion and breakage during or after hardening. Components subjected to this method yield a soft and rough core, with a progressively tougher and hardened outer zone.

Components treated by this method are quenched from the austenitizing temperature in a suitable quenching medium until the temperature is $60-80^{\circ}\text{C}$ below the M_s temperature. They are withdrawn after a fixed time before they attain the bath temperature throughout their section. Finally, they are quenched in an oil bath or cooled in air. The initial quench produces a martensite structure to a depth depending on the time allowed in the quenching bath. Since cooling continues at a much reduced rate after the component is withdrawn, the core gets transformed into a non-martensite structure. The martensite formed at the outer rim is tempered by the heat stored in the interior of the component. The process yields a soft and tough core, with a progressively toughened and hardened outer part. The structure of the hardened surface is like that obtained in continuous hardening.

After interrupted quenching, air cooling alone is sometimes not sufficient to reduce cracks. In such cases, the parts should be transferred immediately from the quenching bath to the tempering furnace maintained at $160-200^{\circ}\text{C}$. The net result of the procedure is the reduction of the rate of cooling through the range where martensite forms. Residual heat in the component immediately tempers the martensite which was formed in the quench. In order to obtain consistent results under varying conditions, the time required for immersion in the quenching bath for a component of given size must be determined by experiment, and strictly adhered to. However, more control is involved than with martempering, since fractures can occur if the part is left too long in the first quench.

Tools made of carbon or low-alloy steels are dipped in water for 5-20 seconds, depending on their size, until their surfaces become dark. Alloy steels are quenched in oil for 30-60 seconds to 10-15 min. depending on their cross-sectional area. Then, without allowing further cooling, the parts are transferred to a tempering bath maintained at $150-180^{\circ}\text{C}$ to relieve the stresses, and to temper the martensite.

This method is versatile and can be adopted with a large variety of steels. Typical applications are given below:

1. Tools made of carbon steels.
2. Simple shape of ball-bearing steels.
3. Steels of low hardenability.
4. Crankshafts made of fairly high-alloyed steels.
5. Connecting rods, their combination of light and heavy sections are frequently time-quenched to prevent breakage.
6. It may be adopted in place of more expensive martempering or austempering because the process is simple.

Die Quenching This method may be employed for thin disks, gears, flats, long slender rods and other delicate parts that got excessively distorted when they are quenched in a conventional liquid medium. The process is best adopted for symmetrical objects.

Generally, in components having irregular sections, the transformation to martensite in quenching tends to produce warping. If good contact can be made between the hot austenite steel and anything else that will abstract heat rapidly, quenching may be accomplished. By pressing the austenitized component between closely fitting dies some of the warpage can be mechanically removed.

There are two principal types of quenching machines; the gear press, and the pinion and shaft machines. In the case of the former, the correction is accomplished by means of properly designed dies; and in the case of the latter, by means of the action of spinning the shaft between rollers. In both types, a suitable die surface should be available as in the component. The pressure used for straightening the hot piece is low and it is so applied as not to restrain the normal contraction once the quench has begun. It is the normal practice to allow a short interval of time between mechanical contact of the die with the gear and commencement of the heating cycle. Once the part is trued by assembly, it acts as a guide for the flow of oil, the greatest flow being directed to the heaviest section and vice-versa.

Die quenching is mainly adopted for gears, thin disks, delicate parts and similar components. Even though this method increases the cost of the actual quenching operation, the overall cost is reduced, since it avoids the straightening operation, and minimizes the expensive grinding and scraping operation.

Hardness Obtained after Quenching Hardness obtained after quenching depends mainly on the carbon content and alloying elements in the steel. It mainly depends on:

1. The grade of steel used.
2. The hardening temperature used.
3. Holding time at hardening temperature.
4. Quenching media used.

The hardness after quenching can be seen in the steel manufacturer's tempering diagrams, or standard sheets in which typical hardening temperatures are given.

2.4.7 QUENCHING MEDIA

The primary objective of hardening is to obtain a hard martensite structure, at least on the surface layers of the steel. This can only be achieved by using an effective quenching medium, so that the steel is cooled at a rate that prevents the formation of a softer product like pearlite, sorbite or bainite. Since the majority of components are already in

a finished stage and finish-machined to size, the quality of the quenching medium used should assure lesser distortion on the component after quenching. This may be achieved by using different quenching media, depending on the type of steel, section thickness, and allowable distortion. For plain carbon steels the medium used is water; for alloyed steels the preferred medium is oil, polymer quenchant or salt bath, and for highly-alloyed steels the medium mainly preferred is the salt bath.

Mechanism of Quenching Selection of a cooling medium for hardening the steel depends on the rate of cooling required for the desired hardness. In order to understand the rate of cooling of any cooling or quenching medium, it is necessary to examine a typical cooling curve of the type shown in Fig. 2.19. This curve represents the changes in temperature of a component being cooled or quenched from the hardening temperature.^{35, 40, 41} Cooling occurs in three different stages marked A, B and C, each of which has different cooling rate characteristics.

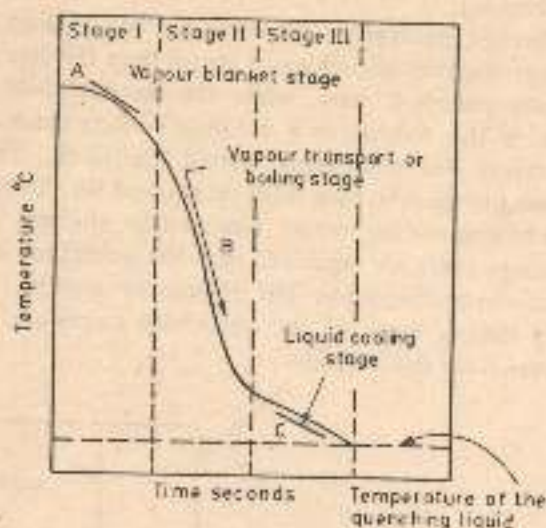


Fig. 2.19 Three stages of the normal cooling curve³⁹

When a component is quenched in a cooling medium, the liquid layer immediately surrounding it will be almost instantaneously heated up to the boiling point and vaporized. At this stage (stage A), the component is surrounded by a blanket of vapour formed by the liquid. This prevents further access of the cooling liquid to the surface of the component. The surface layers of the component will be cooled very intensively before the formation of vapour coating. This slows down the cooling rate, since the vapour envelope acts as an insulator, and cooling occurs principally by radiation through the vapour film.

The vapour-coating formed is continuously washed off by the surrounding layers of liquid. The more pronounced is this effect, the less is the viscosity of the liquid.

When the component is cooled further, and the heat evolved is not sufficient to maintain a continuous blanket of vapour, the second stage 'B' begins. During this stage, the liquid has access to the surface of the component, and a stream of bubble rises and disperses the vapour film, giving rise to a very fast cooling rate.

The third stage 'C' begins when the boiling ceases and the quenching liquid is in contact with all parts of the surface. Cooling, during this stage of the operation, is by convection; the rate therefore is slow. The cooling rate decreases as the temperature of the metal falls.

To obtain a hard martensite structure of carbon steels and alloy steels, conditions should be created which enable the cooling rate to exceed the critical cooling rate of the component being quenched. Where the stability of austenite is at its lowest value (650–550°C), the transformation of austenite into pearlite and bainite is prevented, resulting in the formation of martensite.

The ideal fluid for quenching steels to get a completely martensitic structure should:

1. Remove heat fast enough in the high temperature zone to prevent pearlite formation.
2. Cool more slowly in the lower temperature range, i.e. below 350°C, to prevent distortion or cracking.

The occurrence of thermal cracking or distortion can be attributed to the fact that the exterior of a component during quenching is cooler than the centre, and the surface is the first to reach a fully quenched state, while the interior cools more slowly. Subsequent volume changes in the interior as a result of cooling results in thermal stresses or cracks in the outer layers. The component should, therefore, not pass through the martensite transition zone too quickly; time must be allowed for the release of stresses.

In practice, in order to disperse the vapour film and to shorten the duration of the vapour blanket stage, components are agitated and the quenching medium is circulated. This promotes more uniform cooling rates. The differential cooling rate curve (Fig. 2.20), illustrates what happens during each of the quenching stages and the effect of factors such as agitation and quenchant temperature.

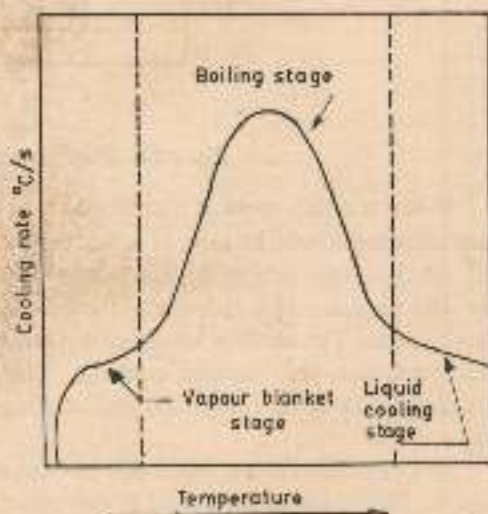


Fig. 2.20
Differential cooling rate curve (Courtesy of
Edgar Vaughan and Co. Ltd., Birmingham,
U.K.)

The cooling media used for hardening components depend on the chemical composition of the steel, size or section thickness of the component, amount of distortion allowed, and the complexity of the component. The different types of quenching media

used are: water, oil, salt bath, etc. Figure 2.21 shows the cooling curve at the surface and at the centre of a steel cylinder with comparisons of quenching in water, oil, hot salt and air.

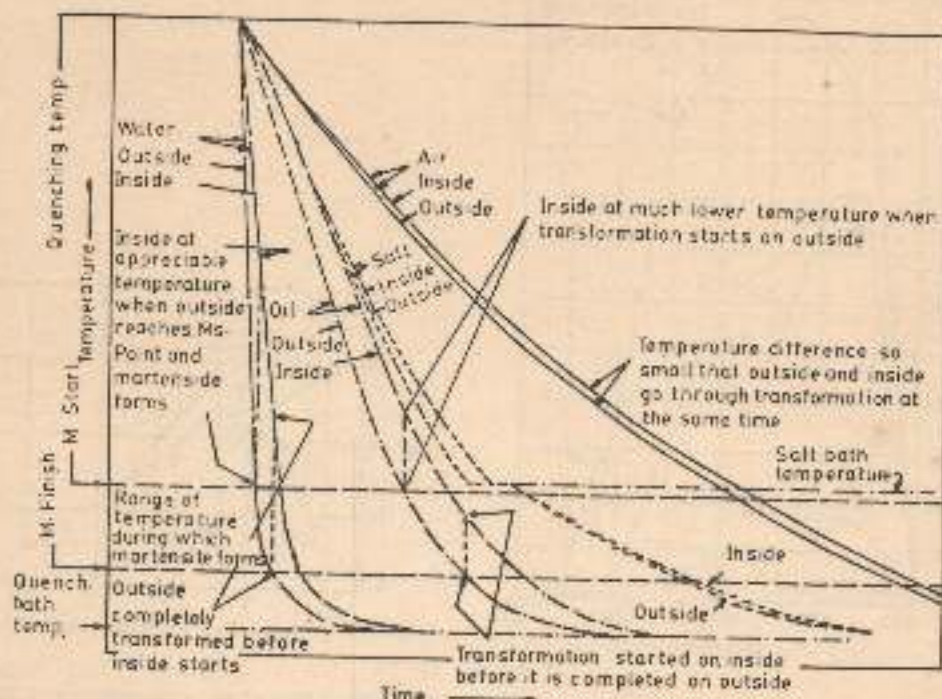


Fig. 2.21 Cooling curves at surface and centre of steel cylinder, comparing quenches in water, oil, hot salt and air (After Houghton, USA).

Water Quenching Water is used as the quenching medium for many applications. It is mainly used for hardening steels of low hardenability, such as plain carbon steels, certain low-alloy steels, non-ferrous metals, stainless steels, etc. The chief merit of water is that it is cheap, readily available, easy to handle without problems of storage and has a high cooling power in the vapour transport or boiling stage, making it very useful for shallow hardening steels, plain carbon steels, mild steels after carburizing, etc.

By virtue of its high specific heat and high thermal conductivity, water has a high cooling power and, consequently, gives a fast rate of quench.^{4,5,8} This can be seen from Fig. 2.22. Water, however, has a pronounced vapour blanket that leads to soft spots in the component. It cools the components so rapidly that in the third stage, the rate of cooling is doubled throughout the lower temperature range where the steel is undergoing transformation, (i.e., between M_s and M_f) which may lead to distortion or cracks. Consequently, water is usually restricted to the quenching of simple, symmetrical parts made of shallower hardening steel. Another disadvantage of using plain water is that, due to the sharp reduction of cooling capacity at higher temperature ranges, the duration of vapour blanket increases with the water temperature and naturally becomes very prolonged as boiling point is approached. This results in uneven hardening (depending on the complexity of the component), and may lead to unfavourable distribution of

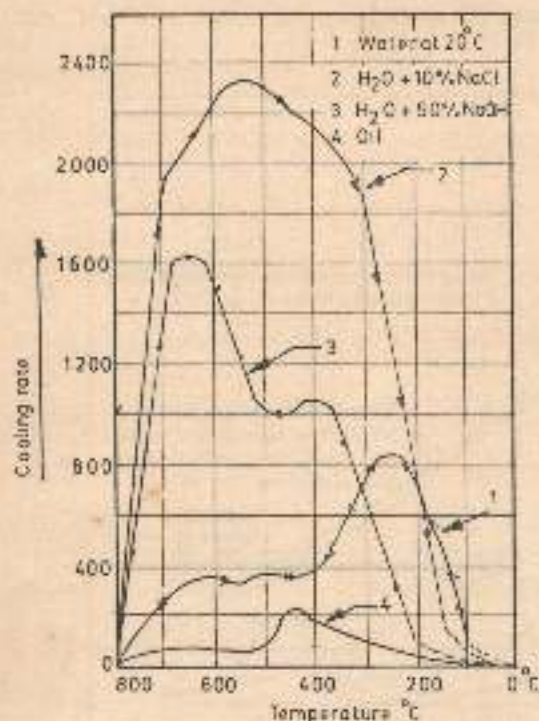


Fig. 2.22 Variation in cooling capacity with temperature, for various quenching media (After Gulf)

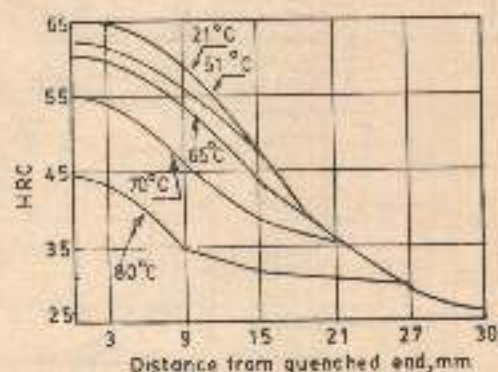


Fig. 2.23 Effect of water temperature on hardenability of steel with 1% C and 1.5% Cr (end-quench test)⁴²

stresses. This may cause distortion, cracking or soft spots. Figure 2.23 illustrates the rapid fall in cooling capacity as the temperature of water rises above 60°C. The best results may be obtained when the temperature of the bath is between 15 and 30°C. The great drawback in water quenching, as mentioned earlier, is that the rate of cooling is high in the temperature range of martensite formation. This may lead to heavy distortion or cracks. The danger of cracking may be reduced, if the steel is removed from water when it has cooled to about 200–300°C and is rapidly transferred to an oil-bath.

Agitation is especially important in water quenching because it disperses vapour bubbles from the component and directs the cooler water towards it. To obtain reproducible results in water quenching, temperature, agitation and contamination must be controlled.

The cooling rate of water can be increased by the addition of caustic soda, common salt, sulphuric acid, etc. (Fig. 2.22). It is believed that the movement of quenching crystals of the dissolved salts are precipitated round the component and these tend to dissipate the vapour blanket, thus shortening the stage 'A' (vapour blanket) and boosting the stage 'B' (boiling stage). For an effective cooling rate of these solutions it is necessary to maintain a 10% NaCl (common salt) in the brine quenchant and a 5–10% NaOH (caustic soda) in aqueous quenchants.

In actual practice, brine and caustic soda quenchants are used only when oil or water quenchants do not provide the desired results. They provide a low cooling rate in the martensitic transformation temperature range due to their high boiling point (Fig. 2.22). Hence, the distortion is less than in water-quenching. The disadvantage of caustic soda solution quenchants is their high alkalinity which is harmful to the skin. Figure 2.22 illustrates the cooling capacity of (1) pure water at 20°C, (2) $H_2O + 10\%$ NaCl, (3) $H_2O + 50\%$ NaOH, (4) oil.

The demands for ever-increasing mechanical properties in components and the associated development of sophisticated high-alloy steels have rendered water-quenching of limited applicability. Consequently, quenching techniques involving the use of products with a mineral oil base predominate.

Oil Quenching Oil quenching is most widely adopted now. A wide range of quenching characteristics can be obtained with oil-based products through careful formulation and blending. The advantage of oil cooling is that the cooling rate in the initial vapour blanket stage can be controlled to give uniform quenching characteristics. The cooling rate for the steel quenched in oil is relatively low due to its high boiling point. The cooling efficiency of mineral oil is many times lower than that of water because the specific heat, latent heat of vaporization and thermal conductivity are lower than that of water.

Warming of the oil (up to 40 to 100°C) prior to quenching increases the cooling rate (Fig. 2.24). This increase in temperature makes the oil more fluid and hence increases its

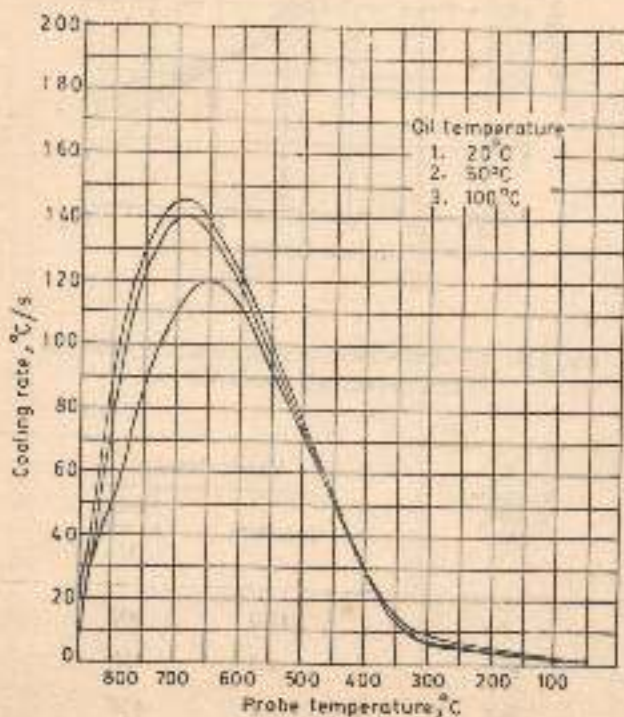


Fig. 2.24 Effect of oil temperature on quenching speed¹⁹

cooling capacity. The cooling capacity of oil may be further enhanced by agitation because it breaks the vapour blanket formed in the first stage of cooling, and directs the cooler oil against the component.

The factors governing the dissipation of heat from the component or charge are specific heat, thermal conductivity, latent heat of evaporation and the viscosity of oil used. In general, the lower the viscosity the faster is the quenching rate (Fig. 2.25). There is a wide range of viscosities from which to choose and, as a rule, the lower viscosity oils are more volatile. This factor must be taken into consideration. High volatility can prolong the vapour blanket stage in quenching and, in addition, the loss of volatile matter brings about an increase in the viscosity of oils, thus reducing the rate of cooling after a short period of use. On the other hand, oils of higher viscosity and lower volatility can shorten the vapour blanket

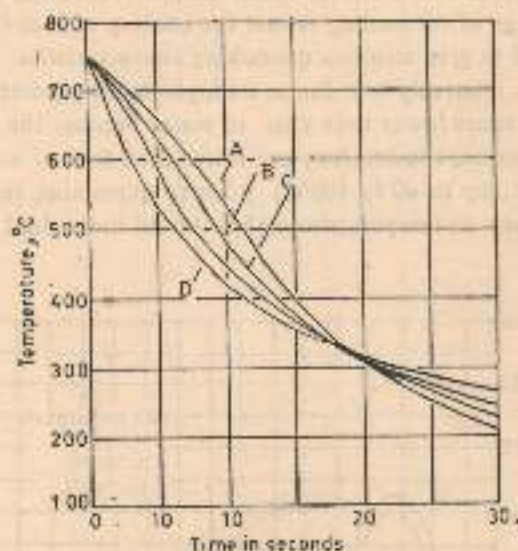


Fig. 2.25 Effect of oil viscosity on quenching speed (oil at 55°C, silver ball specimen)⁴⁴

Oil	Viscosity at 60°C cSt	Vapour blanket		Temp. after 30°C
		Duration	Temp. at end °C	
A	9.4	11.0	500	210
B	14.2	8.5	550	235
C	38.9	5.2	630	245
D	152	2.4	710	270

stage and provide a faster quench. The maximum temperature of the employed working oil should be 25°C below the flash point of oil.

Based on its composition, quenching effect and temperature, quenching oil is categorized as conventional, fast, martempering or hot-quenching oil.

CONVENTIONAL QUENCHING OILS Conventional quenching oils are mineral oils, sometimes containing antioxidants. However, these are free from additives that alter their quenching effects. The typical viscosity of conventional quenching oils is 100 to 110 SSU at 40°C but can occasionally reach about 200 SSU.

FAST QUENCHING OILS Fast quenching oils are blended mineral oils, usually with a viscosity between 50 and 100 SSU at 40°C, but for the majority of applications, it is between 85 and 105 SSU at 40°C. They contain specially developed proprietary additives that provide faster quenching effects (Fig. 2.26). In addition, they can be compounded further with antioxidants, wetting agents and other additives. Certain additives in mineral oils suppress the formation of a vapour blanket around the component. When these additives are incorporated into mineral-based oils of low viscosity, very fast quenching rates can be obtained. This effect can be seen by comparing the cooling rates of a plain quenching oil and an accelerated oil (Figs. 2.26 and 2.27). Wetting agents are added to

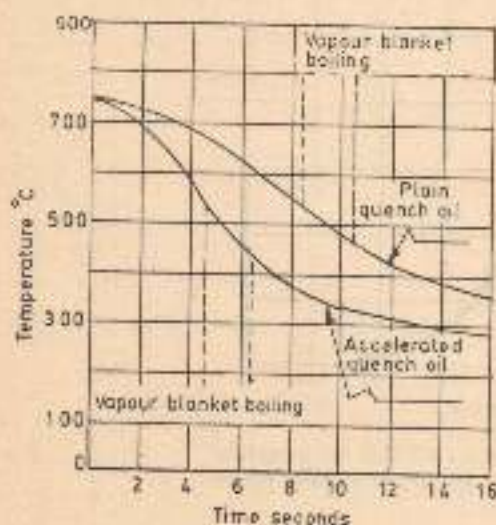


Fig. 2.26 Effect of additives on silver ball cooling curves*

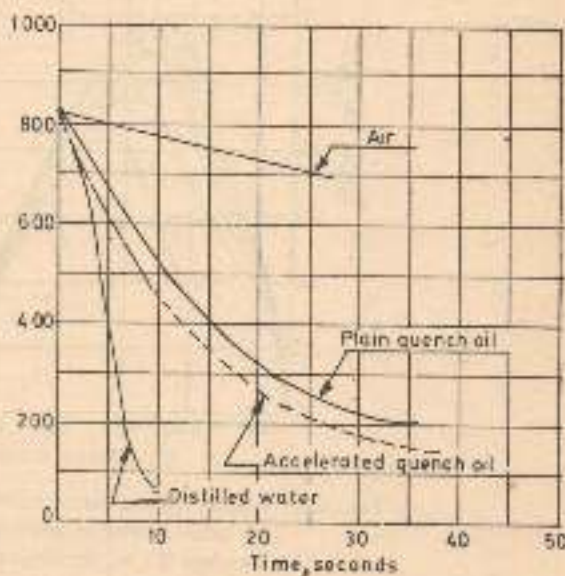


Fig. 2.27 Cooling curves (steel cylinder) for various media*

oils to increase their wetting ability. These oils may be suitable where the distortion of component is not a problem.

MARTEMPERING OR HOT QUENCHING OIL Martempering or hot quenching oils are solvent-refined paraffin-type mineral oils. They provide uniform quenching characteristics with high oxidation resistance, together with thermal stability during prolonged use at elevated

temperatures. They are used at temperatures between 100–200°C for modified and actual martempering of ferrous materials. Since these oils are mixed with special additives, they minimize the slow-cooling, vapour-blanket stage, to give a quenching speed intermediate between the accelerated and slow speeds. The cooling rate increases with oil temperature up to 150°C, but above this temperature, there is a slight decrease (Fig. 2.28). Martempering oils may contain antioxidants to improve their aging stability. Martempering oils are available with fast, normal and slow quenching speeds to suit specific requirements even at higher temperatures. Components of complex shapes, varying sections, etc., and precision components on which the distortion should be minimum are all subjected to hot oil quenching at a temperature of 150–200°C.

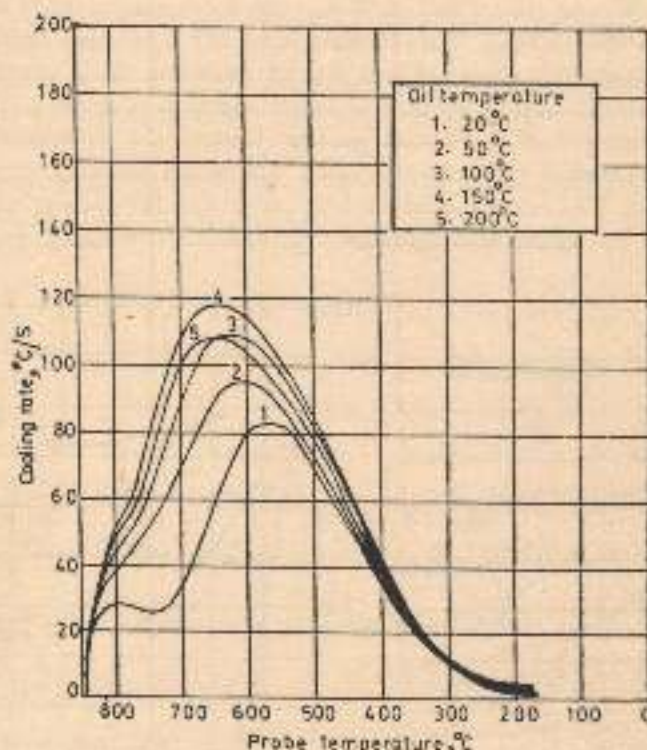


Fig. 2.28 Typical cooling curves showing the effect of martempering oil temperatures on quenching speed¹⁰. (Courtesy: Edgar Vaughan & Co., Birmingham)

QUENCHING SYSTEMS Quenching fluids cannot be considered in isolation, since the furnace and the quench tank also play a major role. The size of the tank used must be capable of accepting the largest component, and it should contain sufficient fluid to quench out the load without an excessive rise in the temperature of the quenching fluid. In an un-cooled tank, the quantity of oil required for a single quench is about 10 litres of oil for each kilogram of steel. This will give an acceptable rise in oil temperature. However, with successive quenches, some form of cooling is necessary to prevent the oil from overheating.

COOLING SYSTEMS The size range of equipment used in oil quenching can vary considerably from tanks of a few gallons capacity using static oils, to installations holding several thousand gallons of oil and equipped with pumps, etc., for the circulation of oil through a cooler to control the temperature. Tanks with static oil cooled by water jackets or internal water cooling coils are adequate for small hardening shops, but where the throughput of work is considerable and work places are larger, it may be desirable to pump the quenching oil round an external circuit containing a cooling equipment. This may be either an ordinary tubular heat exchanger using water as the cooling medium, or an atmospheric cooler in which oil passes through pipes cooled by an air-blast. In addition to the cooler, the external circuit will include a pump and a strainer to remove large solid contaminants, such as scale, from the oil. It may be advisable on certain occasions to provide a scum tank to serve as a reservoir for cooling oil, to facilitate cleaning of the system and to help recover lost components. In order to obtain maximum efficiency from the cooler, the direction of circulation should be such that hot oil is removed from the top of the tank, either by direct outlet or over weir, then passed through the heat exchanger and returned via the bottom of the tank. Circulation of the quenchant is necessary in order to disperse the vapour blanket, to ensure that hot oil at the surface of the tank is replaced by cold oil, and to maintain a uniform temperature of the quenchant throughout the tank. Circulation can be by a pump or an impeller. Compressed air is not recommended, since this can reduce the life of oil by promoting oxidation. Agitation of the component is also very effective in dispersing the vapour blanket. It replenishes the surface of the component with oil, and helps to maintain a uniform temperature of the quenchant.

Salt Bath Mixtures of nitrates and nitrites are mainly used for components quenched at a low temperature. These salts are available as proprietary items, properly balanced for applications at different temperatures (Table 2.5). They may be used in the temperature range of 150–500°C. At temperatures above 500°C, strong oxidation may cause pitting on the surface of the steel, apart from causing an explosion. Hence, great care should be taken not to exceed the recommended safe working temperature.

Table 2.5 Quenching Salts

Composition	Temperature approx. melting	Operating range
40–50% NaNO_3 + 50–60% NaNO_2	143°C	160–500
40–50% NaNO_3 + 50–60% KNO_3	225°C	230–550
100% KNO_3	337°C	350–500
100% NaNO_3	370°C	400–600
50% BaCl_2 + 20% NaCl + 30% KCl	540°C	570–900
80% NaOH + 20% KOH + 6% H_2O	140°C	160–200
40–50% KOH + 50–55% NaOH	400°C	300–400
45–55% CaCl_2 + 25–38% BaCl_2 + 15–25% NaCl	530°C	550–650

Tempering salts contain nitrates and should never therefore be mixed with cyanide, since they react violently if heated together. For the same reason any combustible material like oil or wood should not be brought into contact with the molten salt.

These salts can be used for martempering, austempering, isothermal treatment and also for tempering. The bath may be prepared by melting the salts in a pot type furnace. The pot may be heated with gas or electricity. A salt mixture containing 40–50% sodium nitrite and 50–60% sodium nitrate, and having a melting point of 145°C, may be used for tempering and quenching in the range of 150–500°C. It also used to produce a blue or black finish on steel parts. The salt will not adhere to the parts after quenching because there is no precipitation. It can be used over and over again, adding only enough fresh material to take care of the drag-out losses.

A mixture of 40–50% sodium nitrate and 50–60% potassium nitrate salts with a melting point of 225°C is intended for use where a low melting point is not required. This mixture, with a higher melting point, does not have the same liquidity as the previous mixture, even though it is heated to a higher temperature. However, it is found to yield satisfactory results in the working temperature range of 260–600°C.

These salts are mainly used for tempering after hardening and also in quenching baths used for martempering⁴² and austempering. They can also be used for annealing of non-ferrous metals and to produce a blue oxidized layer on steel. Moreover, these salts, being water-soluble, can be stripped off freely, leaving the surfaces clean.

Potassium nitrate, having a melting point of 337°C, can also be used for salt baths in the temperature range of 350–500°C. It is used for martempering of hot-work steels and high-speed steels.

Sodium nitrate, having a melting point of 370°C, can be employed in the temperature range 400–600°C to temper and temper hot-work steels and HSS.

A mixture of 80% sodium hydroxide and 20% potassium hydroxide with 6% water having a melting point of 140°C, can be used in the temperature range of 160–280°C for bright hardening, to obtain a bright surface of the metal upon quenching. This will help avoid subsequent cleaning operations.

A mixture of 40–50% potassium hydroxide and 50–55% sodium hydroxide can be used for working temperatures from 300–400°C for bright hardening.

AGITATION The quenching speed will be accelerated by agitating the salt bath. The quenching speed is lowered if the molten salt-bath temperature increases; therefore, there is an advantage in using a salt which will be fluid at the lower range of temperature, say around 150–180°C. In addition, if the bath is properly agitated the cooling capacity of the bath will increase.^{46,47} This is illustrated in Fig. 2.29. The parts took 48 seconds to cool to 350°C in an agitated bath at 300°C, but took 37 seconds in an agitated bath at 200°C.

ADDITION OF WATER TO SALT BATH This increases the rate of cooling.⁴⁸ Addition of approximately 1% water enhances the rate of cooling in the pearlitic transformation range, and helps to increase the hardenability and hardness of the component. (see Fig. 2.30). With 1–2% addition of water, the rate of cooling at 600–450°C increases 4–5 times, and at 300°C by a factor of two, as compared to the normal quenching bath at 170°C. The addition of more than 2–3% water has a lower cooling effect (see Fig. 2.30). It is also clear from Fig. 2.30 that the cooling capacity of the bath with 1–2% water will be very high compared to an oil bath maintained at 50°C.

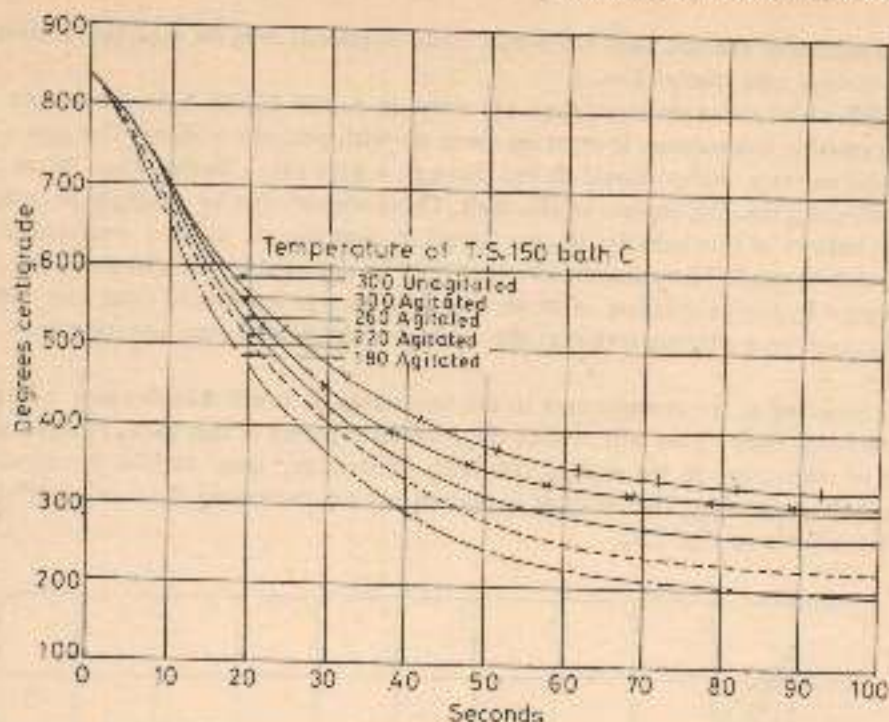


Fig. 2.29 The effect of the temperature of the 50% NaNO_2 + 50% NaNO_3 martempering bath on the rate of cooling of a stainless steel cylinder, 19 mm diameter, 102 mm long, quenched from 830°C**

Figure 2.30 illustrates that the quenching capacity of a salt bath is approximately 4-6 times higher in the range of 700-550°C when the addition of water is maintained at 0.68% at 300°C and 0.09% at 400°C compared to a bath without water. This is an added advantage for increasing the hardenability and hardness of the machine parts (Fig. 2.31).

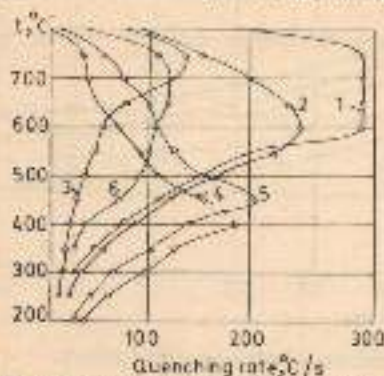


Fig. 2.30 Cooling rates in the centre of a silver ball, 20 mm in diameter, in quenching bath at 170°C with various contents of water (%): 1—0.68; 2—0.93; 3—no water; 4—3.9; 5—4.3. Curve 6 shows for comparison the cooling rate in oil at 50°C**

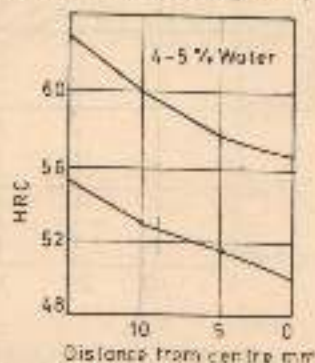


Fig. 2.31 Effect of adding water to a mixture of NaNO_2 and 50% NaNO_3 (at 160-180°C) on the hardenability of steel, grade 64C (C—0.9%, Si—1.4%, Mn—1.1%), as a 30 mm cylindrical specimen**

These properties of the salt bath (to which water is added) may be used for austempering of small springs and special dies.

It is difficult to maintain more than 1% water in a 150–200°C bath, since the added water gradually evaporates. It must be made up with periodic addition through a special device; alternatively, water should be fed through a pipe into a baffle. This forms a fan-like jet flowing into the surface of the melt. There should also be a supply of compressed air at the bottom of this bath for proper agitation. Sometimes, certain mechanical agitators can also be used. The presence of water may be detected by the characteristic sizzling sound caused by the production of steam when the charge is lowered into the salt. This steam also sets up a stirring action at the surface of the bath; hence agitation may not be necessary.

Salts adhering to the components in the hardening bath will dissolve and contaminate the quenching bath. This will reduce the cooling capacity of this bath. Foreign particles are kept in suspension in the molten salt bath. Therefore, they should be removed by using a salt separator. The effect of contaminants on decreasing the cooling efficiency of the bath is shown in Fig. 2.32.

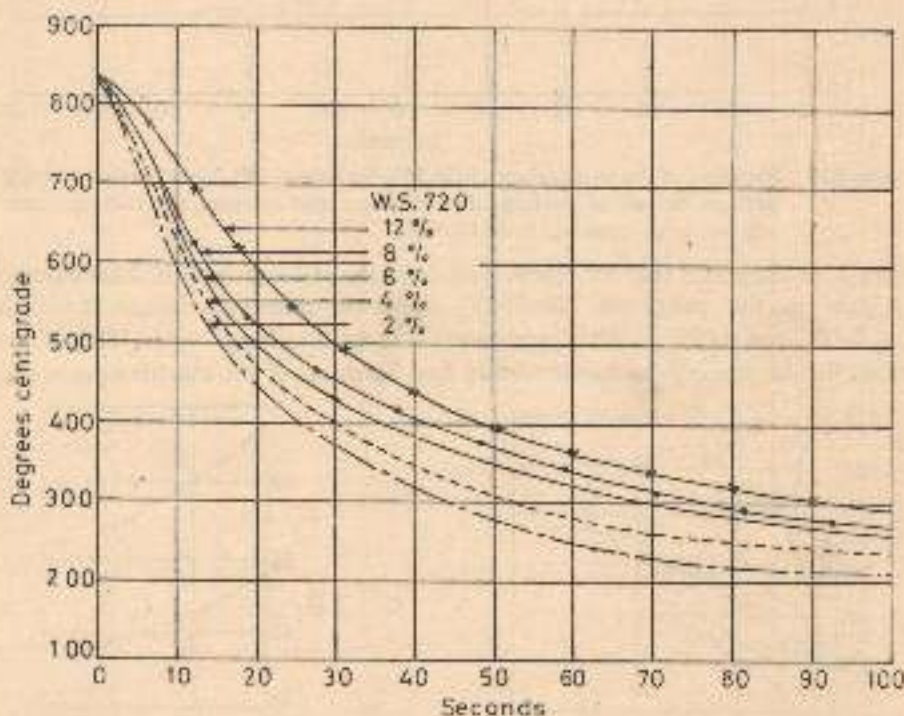


Fig. 2.32 The effect of contaminating a quenching bath with a neutral bath (varying from nil to 12%) on the rates of cooling of a specimen of stainless steel, 1.9 cm diameter \times 10 cm length, heated to 830°C then quenched in the bath.

A salt mixture containing 50% barium chloride, 20% sodium chloride and 30% potassium chloride, having a melting point of 540°C, may be used in the range of 570–700°C. This mixture may be used for quenching hot-work steels, high-speed steels after

austenitizing, and for the secondary hardening of high speed steels. This can also be used for tempering of other types of steels.

Gas Quenching The media used for gas quenching are hydrogen, helium and nitrogen in the decreasing order of quench efficiency. The danger inherent in the use of hydrogen and the high cost of helium make their application rare. Nitrogen is more commonly used as a quenching medium for hardening various grades of hot-work steels and high-speed steels. Gas quenching is commonly used to harden large forgings for obtaining a more uniform cooling of heavy sections, to prevent cracking and to assure thermal stability. Gas quenching also provides uniform mechanical properties in large parts of intricate shape and in those of varying section thickness. Gas quenched components reveal less distortion. In gas quenching, the austenitized component is placed directly into the gas zone or chamber, and heat is rapidly extracted from the metal by a fast-moving stream of gas. The cooling rate of the metal is related to surface area, mass, type of metal and velocity of cooling.

Polymer Quenchant Polymer quenchants are organic chemicals of high molecular weight known as polyalkylene glycols.⁴⁸⁻⁵⁴ They dissolve in water at room temperature. When the solution temperature rises above 77°C during immersion of the hot component, it becomes insoluble. When the solution is cooled, the polymer goes back into solution and is fully miscible.

These polymer quenchants are available as proprietary items and are incorporated with a corrosion inhibitor. When the hot component is immersed in the quenchant, the solution in immediate contact with the metal is heated above 77°C. The polymer becomes

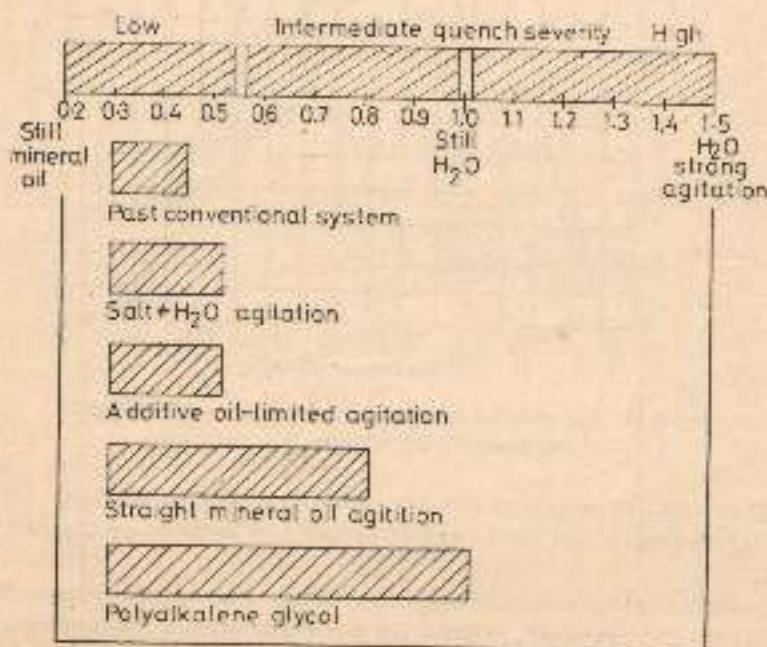


Fig. 2.33 Approximate quench severities for quenching mediums containing additives to improve cooling capacity**

insoluble in water. Depending on the type of quenchant, the polymer either forms a sedimentary layer or a thin layer is deposited on the surface of the component. This is a period of slow cooling analogous to the vapour blanket stage in oil quenching. The polymer layer thus formed on the surface in the vapour blanket stage slows down the cooling rate in the lower temperature range (martensitic range). When the temperature falls below the inversion temperature of the polymer, the layer redissolves and heat is taken away by the liquid phase (analogous to liquid-cooling).

The cooling rate of the polymer quenchant depends on the percentage of additives such as polyalkylene glycol present in water. They can be made to span the quenching severity range from oil to water (Fig. 2.33).

The lower the percentage of concentration in water, the higher will be the cooling capacity (Fig. 2.34). The ideal cooling rate for different purposes can be obtained to suit

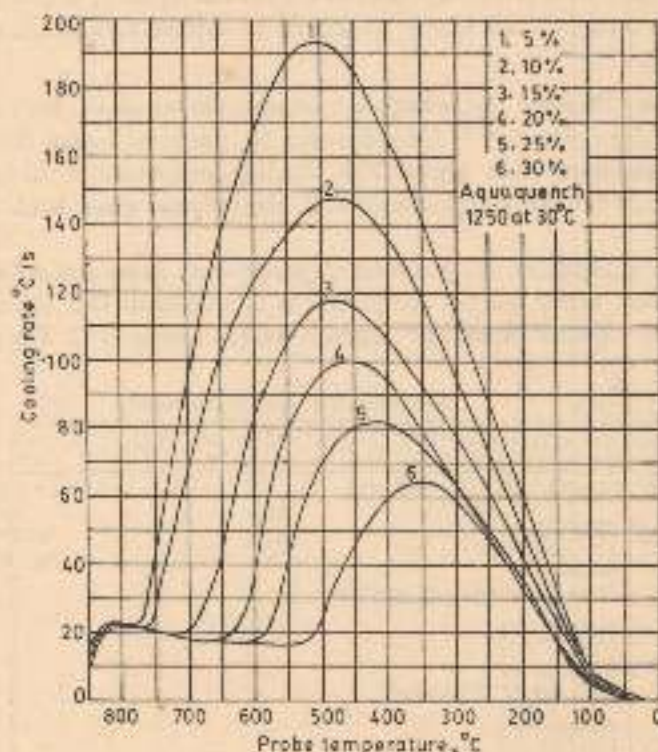


Fig. 2.34 The effect of concentration upon the quenching speed of Aquaquench 1250 solutions⁴¹

individual requirements by changing the concentration of the solution. Solutions with 3-4% concentration possess the same cooling capacity of brine or nitrate solution without any soft spots.

12 to 15% solutions achieve quenching rates better than those obtainable with fast quenching oils, and are, therefore, suitable for low hardenability applications.

15 to 30% solutions are suitable for case-hardening and through-hardening steels.

The flexibility of quenching speed obtainable by varying the concentrations of polymer

solutions makes possible the selection of the most appropriate cooling rate for specific requirements. This offers a means of developing mechanical properties in low-alloy steels and larger sections of high-alloy steels which fast-quenching oils are unable to achieve, avoiding thereby the unnecessary use of expensive steels.

Quenching in polymer quenchants helps to avoid cleaning before tempering because the residual films of polymer will not adhere, as with oils, but will volatilize fully and decompose at high temperatures to form water vapour and oxides of carbon.

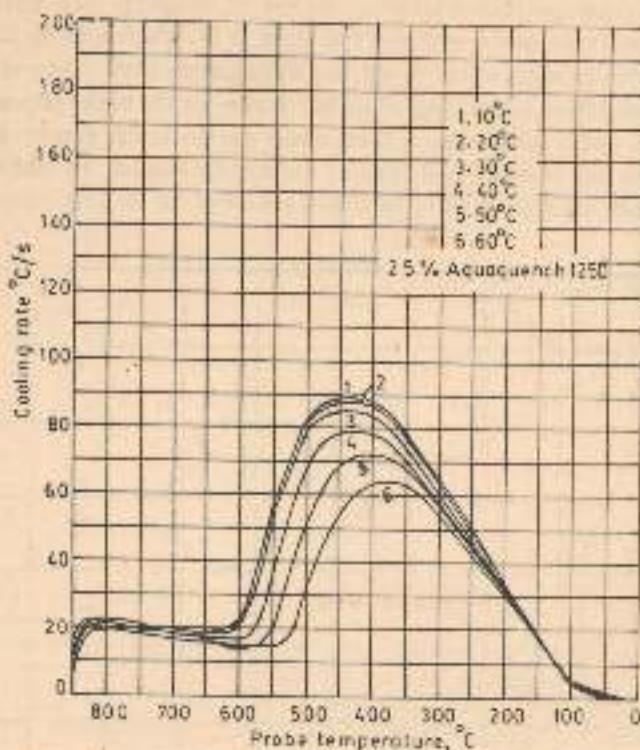


Fig. 2.35 The effect of temperature upon the quenching speed of 25% Aquaquench 1250⁴¹

The recommended working temperature for polyglycol quenchants is 35 to 50°C, although a range as wide as 15°C can be adopted to suit specific requirements (Fig. 2.35).

The cooling rate of polyglycol quenchants can be accelerated by agitation. Variable rates of agitation provide the needed flexibility, where parts of different sizes, mass, geometry, etc. are processed. Further, the rate of agitation alone is not the total answer. Direction and uniformity are equally critical, particularly in the case of induction hardening.

Fluidized Bed A fluidized bed can also be used as a quenching medium for many applications. It is mainly used for quenching highly alloyed cold-work steel, hot-work steel, high speed steel, air-hardening steel, etc. The cooling rate in fluidized beds is faster compared to air cooling, and about 10% slower than molten salts quenching. It is also possible

to increase the severity of the cooling rate compared to molten salts, since the fluidized bed can operate at any lower temperature without solidifying.

The fluidized bed consists of fine-grained aluminium oxide particles in a retort which may be heated externally or internally. The aluminium oxide particles are fluidized by a continuous stream of gas blown upwards through the base of the retort. They move about in a liquid-like manner. Nitrogen can be used to form the fluidized bed to obtain an inert protective atmosphere for quenching.

A comparison of various quenching media for 5" diameter steel bars quenched from about 780°C to room temperature, given in Fig. 2.36. It is clear from Fig. 2.36 that the fluidized bed quench is slower than water or oil, but significantly faster than air. These beds are suitable for low temperature quenching of air hardening steels, high temperature quenching, patenting, etc. The main advantage is that when the parts are removed from a fluidized bed, they contain no salt residues and require no post-treatment. In addition, there are no fumes and no hazards associated with the introduction of oil or water into the medium.

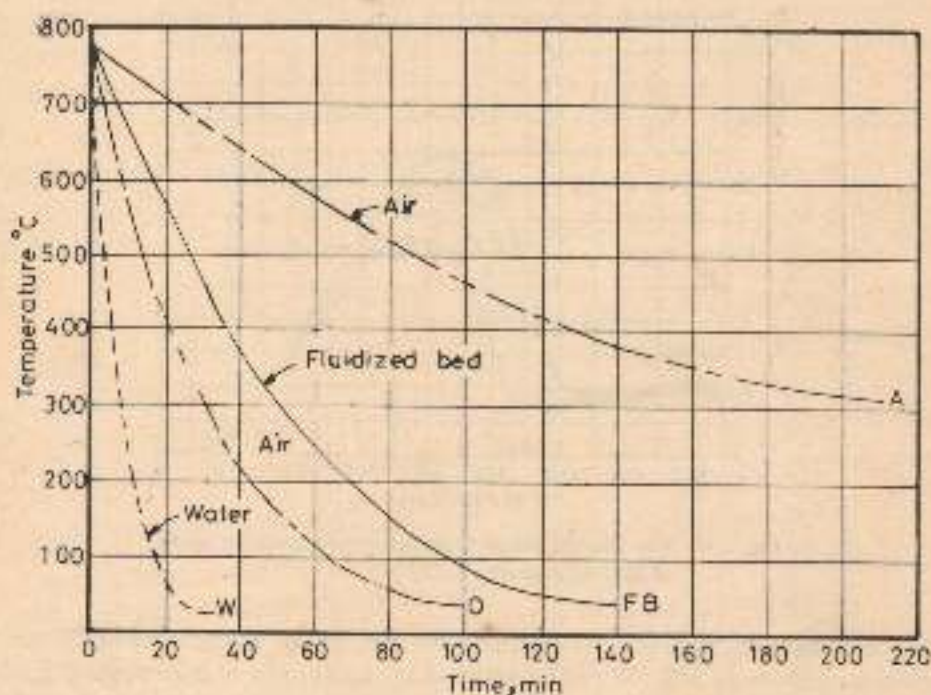


Fig. 2.36 Comparison of cooling rates in various quenching media

Quenching Equipment The hardness obtained after quenching the steel depends on the cooling medium employed, the temperature of the bath and the degree of agitation. Hence, it is very important that the selected quenching equipment should maintain the desired temperature; it must be provided with a suitable impeller or pump for the agitation of the quenching medium. The different types of quenching equipment are described below:

BATCH QUENCHING SYSTEM WITH PUMP Figure 2.37 illustrates the quenching equipment used for conventional quenching. It has a built-in pumping system for agitating. When the

components are quenched, the surface of the component is surrounded by heated oil. This oil is replaced by continuously pumping cold oil from the storage tank to the bottom of the quench tank, leading to the flow of liquid upward through the component. The heated oil is passed from the top of the tank to the storage tank through the cooler. The quench tank is normally fitted with a heating coil to maintain the minimum operating temperature of oil ($60\text{--}80^{\circ}\text{C}$). This type of quenching equipment is used for batch type quenching.

INTEGRAL QUENCH FURNACE This type of quenching equipment is used in a sealed quench furnace. Figure 2.38 shows a schematic drawing of a propeller-agitated sealed quench system with shroud tubes and directional baffles. Cooling is accomplished by

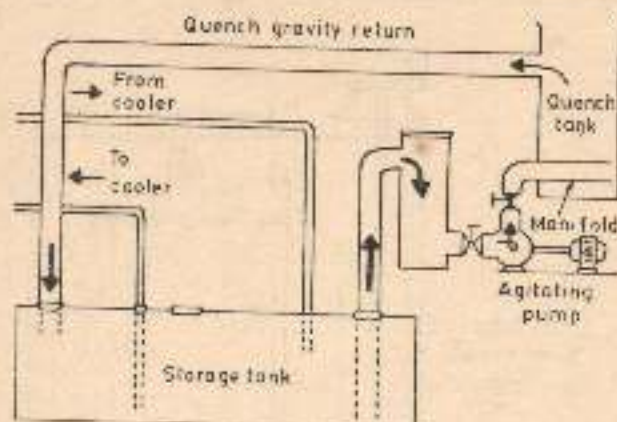


Fig. 2.37 Batch quenching with pump agitation

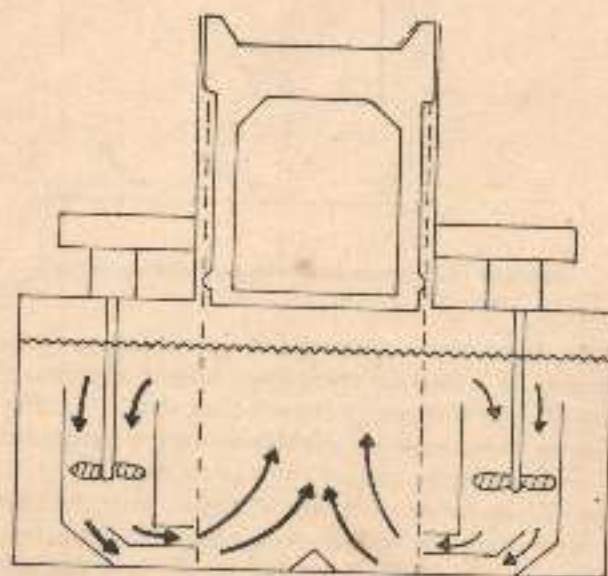


Fig. 2.38 Integral quench furnace with draft tube and directional flow manifold*

the circulating oil. The impeller directs the oil upwards through the charge, so that the heated oil is replaced by fresh oil. The tanks are normally fitted with immersed electric heaters and heavy gauge cooling coils, so that the cooling oil is maintained at the desired temperature.

PIT QUENCH TANK This type of quenching tank can be used for high volume production. Figure 2.39 shows a pit quench tank using a propeller for agitation. This system ensures a continuous upward movement of the fluid stream, unlike some pumped manifold system which induces a tangential flow pattern at intermediate levels. These quench furnaces are fitted with a heating coil to maintain the minimum operating temperature and a cooling system to bring down the temperature during quenching of the component.

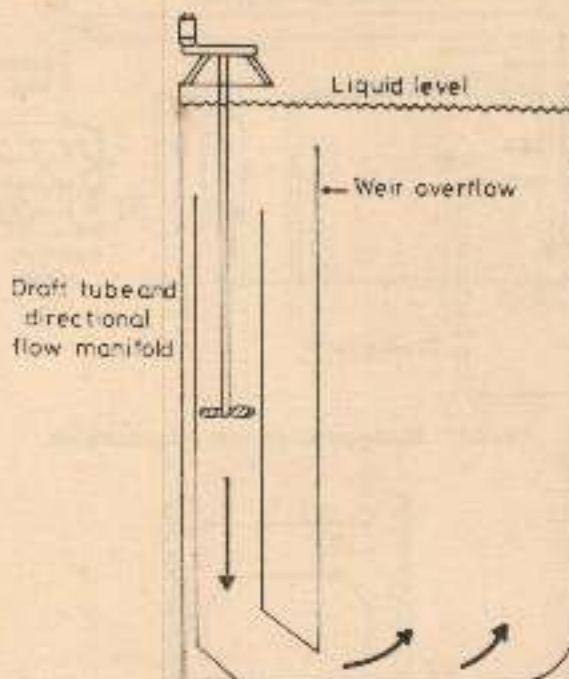


Fig. 2.39 Pit quench tank with propeller agitation

CONTINUOUS QUENCHING EQUIPMENT This type of quenching tank can be adopted for continuous type furnaces. It is used for those quenching components that can be dropped into the quenching liquid. The continuous quench tank shown in Fig. 2.40, has built-in baffles and an impeller to assure vigorous circulation during the quenching of components. A weir above the oil level inside the quench chute prevents the oil from splashing into the heating chamber. Components that are dropped from the heating chamber to the quenching tank fall on the conveyor belt through a quenching medium. This belt carries the cooled components to the unloading platform or on to the belt of the next process operation. Such quench tanks are normally limited to components having simple shapes because a free fall of the component into the tank can result in distortion.

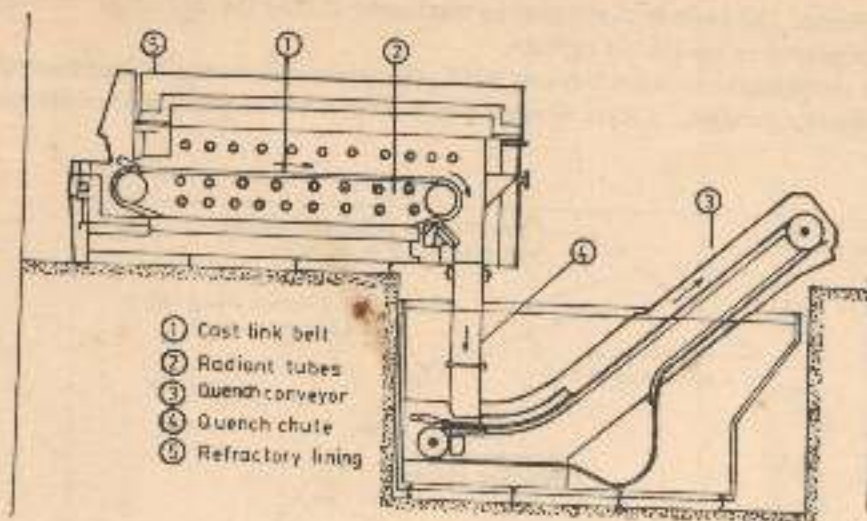


Fig. 2.40 A typical arrangement of a quenching system in a continuous belt or cast link furnace

2.5 Tempering

When steel is hardened it acquires the structure of tetragonal martensite and a certain amount of retained austenite. Steel in this condition is hard, brittle, highly stressed and liable to develop quench cracks, particularly in tool steels. Thus steels in the 'as-hardened' condition are of limited usefulness. To overcome this, the hardened steel should have a potential tendency to pass into a stable condition. But this equilibrium or stable state cannot be achieved at room temperature because of the low mobility of atoms. As the temperature rises, the mobility of atoms increases due to the accelerated diffusion rate, and this results in a structural change of the hardened steel to give rise to a stable state. This, in effect, is the process of tempering. By tempering, ductility can be increased, and hardness and strength decreased. In the majority of structural steels, the purpose is to obtain a combination of high strength, ductility, and toughness. Thus, the tempering process, after hardening, makes the steel more useful by providing a stable structure.

2.5.1 STRUCTURAL CHANGES ON TEMPERING

Tempering consists of heating the steel to some temperature below the critical range (A_{c1}), and holding it for the desired length of time and subsequently cooling it in air. Investigations by various physical methods have established that as the temperature is increased, the hardened carbon steel passes through four stages (Fig. 2.41).⁵⁵⁻⁶¹

1. At a temperature between 80 and 200°C, a carbon-rich transition product known as carbide is precipitated from the tetragonal martensite (Fig. 2.42a) reducing the lattice to cubic ferrite (Fig. 2.42b). This reaction is called the first stage of tempering. During this period, due to the release of carbon, the martensite lattice contracts

in volume. The carbide that forms in martensite during the first stage of tempering is designated as epsilon (ϵ) carbide.

- At a temperature between 200 and 300°C, the retained austenite is decomposed into a bainite-like product, a state of aggregation similar to tempered martensite; and this

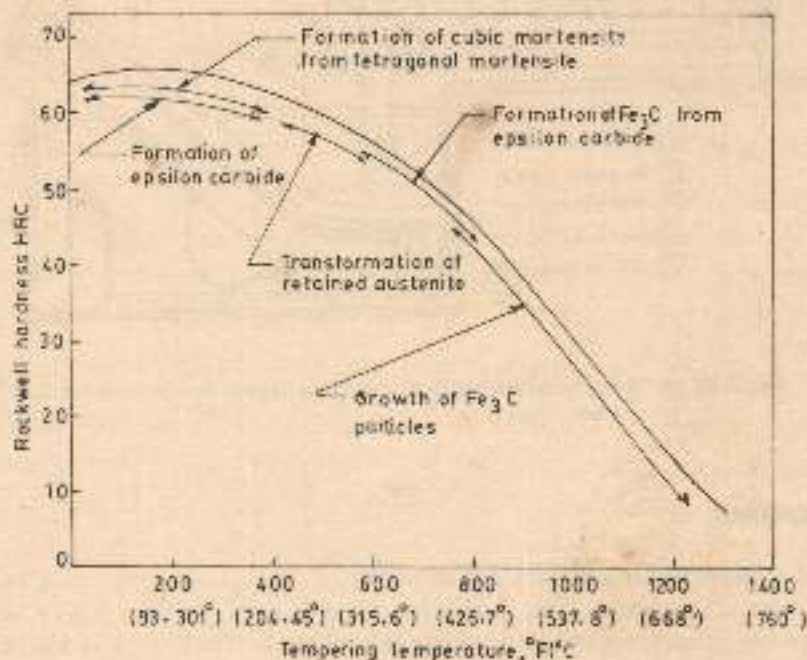


Fig. 2.41 Change in hardness and structure during tempering of eutectoid steels

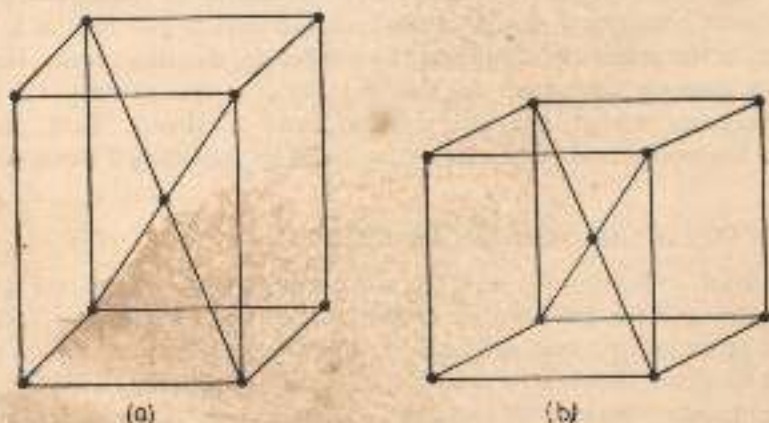


Fig. 2.42 (a) Body-centered tetragonal structure (b) Body-centered cubic structure

transformation is called as the second stage of tempering. At this stage, there is an increase in the volume of steel.

3. At a temperature between 300 and 400°C, there is the formation and growth of cementite from the carbide precipitated during the first and second stages. This conversion is regarded as the third stage of tempering. It is marked by a considerable decrease in volume and overlaps the austenite decomposition reaction of the second stage.
4. (a) At a temperature between 400 and 700°C the growth continues and spheroidization of cementite takes place.
5. At still higher temperatures, the formation of more complex carbides takes place in steels in which strong carbide forming elements are present. This process is designated as the fourth stage.

It may be mentioned that the temperature ranges specified in each of the above stages of transformation are typical. In practice, they vary to a certain extent since they depend on the rate of heating, time of tempering and type of measurement and sensitivity. They also depend on the chemical composition of steel.

Effect of Alloying Elements on Tempering When steels are alloyed, the interval between tempering stages shifts towards higher temperatures which means that the martensite becomes more resistant to tempering.^(2,6) The carbide forming elements, especially chromium, molybdenum, tungsten, titanium and vanadium, retard the loss of hardness and strength with increasing tempering temperatures. With certain types and amounts of these elements, it is possible that this drop in hardness may occur between 400 and 600°C, and in certain instances, an increase in hardness also takes place. Figure 2.43 illustrates the

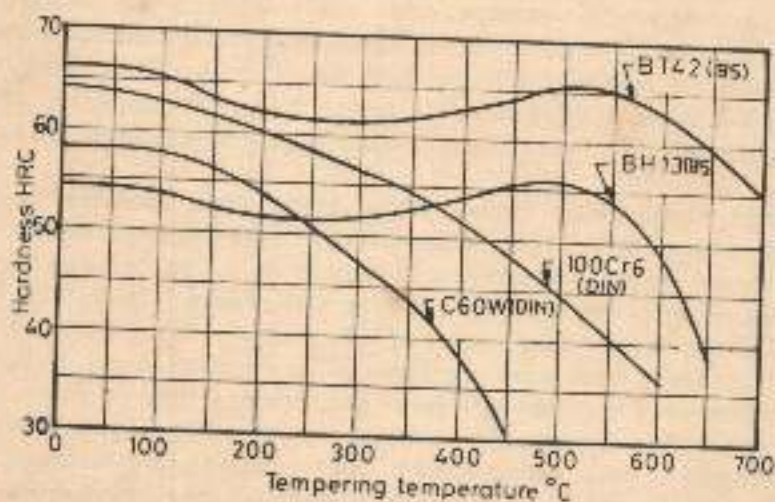


Fig. 2.43 Effect of tempering on alloyed steels

above phenomenon. The effect of alloying elements on the reduction of hardness is explained by the fact that they retard precipitation of carbon from martensite at higher tempering temperatures. On the other hand, the increase in hardness, at high tempering temperatures,

in steels containing large amounts of tungsten, molybdenum and vanadium, may be due to the transformation of retained austenite into martensite.^{63,64}

For highly alloyed tool steels, such as hot-work steel and high-speed steels, a sluggish austenite is encountered which does not undergo transformation in the 200–300°C range. By tempering at 450–600°C, however, the austenite is conditioned and as a result, a secondary martensite is formed on cooling. As the co-existing martensite in such steels does not soften too much at the tempering temperatures, a method of decomposing of the retained austenite is thus made available. The conditioning of austenite depends on time and temperature. It is the precipitation of carbides that reduces the carbon and alloy contents of austenite, thereby raising the martensitic temperature range. The formation of martensite from the retained austenite and the precipitation of carbides together create an increase in hardness, which is a characteristic feature of highly alloyed steels and high speed steels. In high speed steels and in high-alloyed chrome steels, the retained austenite is transformed to martensite during cooling from the tempering temperature of about 500°C. Therefore, such steels should be tempered again for the purpose of toughening the secondary martensite that forms during the tempering treatment.

The increase in hardness, as a result of the austenite decomposition, is common to all steels, but it is scarcely noticed in carbon steels and low-alloy steels because the amount of retained austenite is small. On the other hand, the amount of retained austenite is 5 to 30% more in highly alloyed steels.

2.5.2 MECHANICAL PROPERTY CHANGES

Tempering accomplishes its purpose through a combination of temperature and time. It is not sufficient to merely heat a hardened steel to some definite temperature. It must be soaked for a definite length of time. Since it is associated with diffusion processes, the tempering cycle consists of heating to a temperature well below A_c1 and holding for a period, usually around 2–4 hours, to bring about the desired changes in properties. As the temperature employed is relatively low, the heat transfer is very poor, and the diffusion process is slow.

Carbon steels, medium alloy steels and high carbon steels, upon heating up to 200°C, may lower the hardness by 1–3 HRC on tempering owing to the martensite decomposition of tetragonal martensite into an aggregate consisting of ferrite and epsilon carbide. A further increase in tempering temperatures lowers the hardness, tensile strength and the yield point, while the relative elongation and reduction of area are increased. Figure 2.44 illustrates the change in mechanical properties of hardened steels in accordance with the tempering temperature. Impact strength varies in a somewhat different manner. Tempering between 250 and 300°C is not advisable as tempering within this range will seriously reduce the impact strength. As steels are subjected to this tempering to a certain extent embrittlement of the first order is prevented by rushing through the dangerous temperature regions or by quenching from the tempering temperature.

In general, the higher the tempering temperature, the greater is the reduction in hardness and strength, and greater the increase in ductility and toughness. The as-quenched hardness and the mechanical properties of 817 M 40 (BS) steel for selected tempering treatments as a function of bar size are listed in Table 2.6. The strength properties for a given treatment decreases with increasing bar diameter.

Table 2.6 Typical Results Obtained on Production Tests on Various Sized Bars of BS for Steel 817 M 40

Analysis				Treatment		Size		Yield stress		Tensile strength		Elongation		R.A. Test			
C	Si	Mn	Ni	Cr	Mo	Oil harden °C.	Temper °C.	inches	mm	tons/sq. in.	kg./mm ²	tons/sq. in.	kg./mm ²	$\frac{\sigma_u}{(4\sqrt{A})}$ %	$\frac{\sigma_u}{(5D)^{1/2}}$ %	fl. lbs.	
40	.20	.60	1.55	1.11	.30	850	200	.564 T.P.	—	—	—	116.0	182.7	14.0	10.5	—	27
40	.28	.65	1.55	1.11	.25	850	600	1 sq.	25	(58.6)	92.3	70.0	110.2	20.0	15.5	—	55
40	.23	.62	1.57	1.07	.30	850	555	1 1/2 dia.	41	73.0	115.0	80.0	126.0	19.0	14.5	52.2	39
36	.18	.68	1.59	1.19	.29	850	660	2 dia.	51	44.7	70.4	53.3	83.9	24.0	18.5	64.8	103
40	.18	.64	1.35	1.15	.31	850	600	2 1/4 dia.	64	66.0	103.9	74.0	116.5	18.0	14.0	50.0	47
37	.28	.59	1.42	1.11	.27	850	660	2 1/4 dia.	64	50.8	80.0	59.3	93.4	24.0	18.5	63.6	96
40	.27	.59	1.44	1.09	.26	850	620	3 1/4 dia.	83	55.0	86.6	66.0	103.9	20.0	15.5	57.0	61
42	.23	.63	1.35	1.07	.26	850	640	3 1/4 dia.	83	53.0	83.5	63.0	99.2	24.0	18.5	58.1	66
38	.23	.66	1.54	1.00	.26	850	650	4 dia.	102	(46.2)	72.8	58.5	92.1	25.0	19.5	—	86
41	.19	.63	1.55	1.16	.25	850	640	6 dia.	152	50.0	78.7	60.4	95.1	21.0	16.0	60.0	73
39	.25	.60	1.38	1.05	.35	850	620	8 1/4 dia.	210	48.8	76.9	59.8	94.2	20.0	15.5	57.0	45

Figures in parentheses are 0.1% proof stress values obtained in accordance with allsort material testing procedure. Approximate figures (see Conversion Graph).

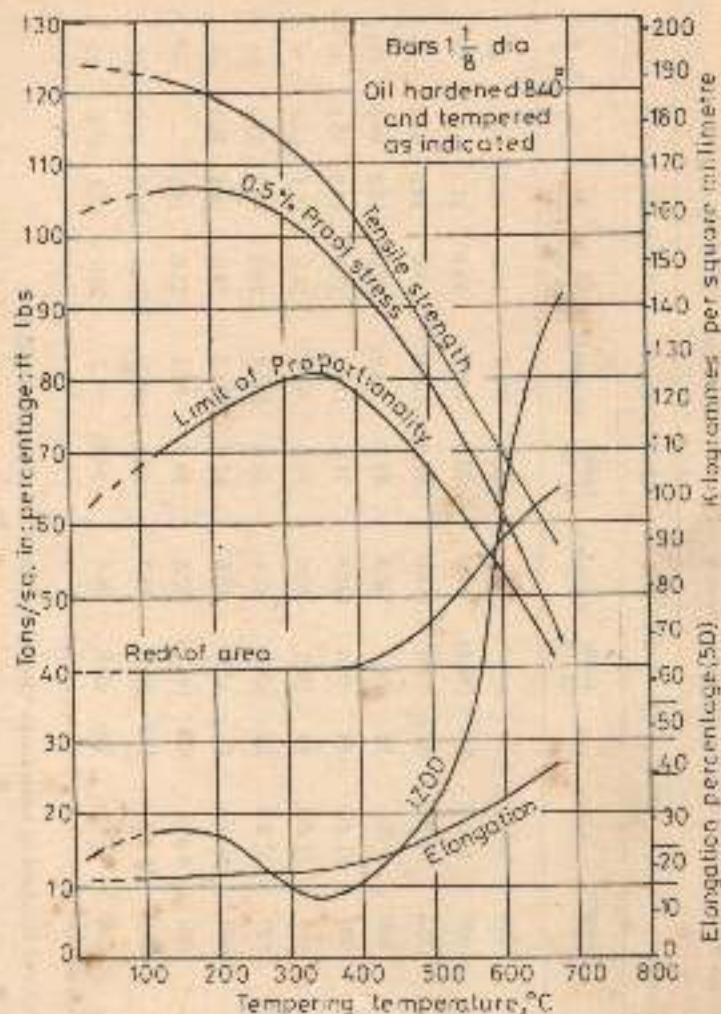


Fig. 2.44 Typical curves showing effect of tempering on mechanical properties of steels 817 M40⁴

2.5.3 TEMPERING PROCEDURE

Tempering may be carried out in forced air circulation furnaces, oil baths, salt baths (salts with low melting point) and vacuum furnaces. If a forced-air circulation or muffle furnace is used, components hardened by using salt-baths must be cleaned, preferably in boiling water or steam. If a component having salt on its surface is put into the furnace, both the furnace coil and the steel may be easily attacked by corrosion. These problems can be avoided by tempering in salt baths. The salt-bath furnace used for martempering may also be used for tempering. Tempering furnaces should be equipped with automatic temperature control within $\pm 5^\circ\text{C}$. Accurate control of the tempering operation is essential. Tempering is essential to assure the successful working of a tool.

It is necessary to refer to the appropriate tempering curve for guidance in selecting

the tempering temperature. The curves show average results, but in practice, there may be a slight deviation from the indicated values due to:

1. Variation in the as-quenched condition.
2. Mass effect and the need to extend soaking times to allow for the extra mass.
3. Slight variations in chemical analysis of the steel.
4. Inaccuracies in temperature measurement, considering the above reasons it is advisable to use a lower range of tempering temperature to obtain the desired hardness.

To obtain a uniform distribution of temperature within the component and to prevent the non-uniform relief of hardening stresses that could cause cracking or warping, heating to the tempering temperature should be slow. Satisfactory results may be obtained by charging the components into a freely circulating medium at the desired tempering temperature. A faster rate of heating to the tempering temperature may result in the cracking of tools due to an increase in volume of the surface layer. Hence, a fast rate of heating should be avoided. The rate of heating transfer is most rapid in molten lead baths, less in salt baths and oil baths, and the slowest in still air. For instance, to attain a tempering temperature of 200°C on a hardened component measuring $\phi 40$ mm by 80 mm length will require one hour in a hot air oven; 40 minutes in a circulating atmosphere furnace; 30 minutes in a hot oil bath. It will be still faster in lead baths. Table 2.7 gives the approximate time needed to heat various sizes of tools to 400°F (200°C). It is necessary that enough time be allowed during tempering for the temperature to be distributed uniformly throughout the tools before measuring the tempering time. It is known from experience that the full effect of tempering can be brought out only if the holding time is sufficiently long. For this reason, it is not advisable to use lead baths for tempering highly alloyed steels.

Table 2.7 (Courtesy of the Carpenter Steel Division of Carpenter Technology of Corporation, Reading, Pennsylvania, USA)

Size of piece	Time required to heat		
	In quiet hot-air oven	In hot oil bath	In circulating-atmosphere furnace
1" Rd \times 2" Lg	At least $\frac{1}{2}$ h	At least $\frac{1}{2}$ h	20'
1½" \times 3" Lg	1 h	$\frac{3}{4}$ h	40'
3" \times 6" Lg	2 h	1 h	70'
6" ϕ \times 12" Lg	5 h	2½ h	3 h

The time for tempering varies from half an hour to two hours for every 10 mm thickness. Since tempering is a precipitation process, the time at constant temperature is in the order of minutes at a fairly high temperature, and may produce the same effect in an hour or so at lower temperatures. However, a minimum of half an hour to one hour at any temperature is usually required. Longer periods are sometimes specified for large parts to ensure that all areas of the parts are actually exposed to the required temperature for the

required time. After the tempering time is elapsed, the tools should be allowed to cool slowly in air. A faster rate of cooling or quenching from the tempering temperature will produce stresses of a value close to that produced by hardening.

In many shops it is customary to check the Rockwell hardness on quenched tools before deciding the tempering temperature to attain the required hardness. There are many instances on record of *as-quenched* tools having cracked during handling. Tools should be tempered immediately for safety, using a low temperature so that the hardness is not reduced below the desired point. The hardness is to be determined, and a temperature selected for retempering to the desired hardness. If, for any reason, it is not possible to temper tools immediately after quenching, a *holding* furnace should be used to keep them warm until tempering can be carried out. The furnace temperature should be below the tempering temperature, normally in the range of 100–150°C. If the *as-quenched* tools are held at the ambient shop temperature for extended periods of time, they may crack.

2.5.4 TEMPERING AT DIFFERENT TEMPERATURES

The tempering procedure adopted depends on the required hardness and other mechanical properties. The temperature, and the time adopted, depend on the chemical composition of steel.

Low temperature tempering is performed in the range of 150–200°C for about 1–2 hours. The main purpose is to relieve the induced stresses that are developed during hardening, and to increase the toughness without any loss in hardness. Tempering in the range 100–130°C may be applied when high hardness values are assigned for tools to operate under heavy wear and practically no dynamic loads. The duration of tempering will be 2–4 hours. This type of tempering is mainly adopted in the case of carburized, induction-hardened, flame-hardened components, cutting tools of high-hardness steels, measuring tools, ball bearing steels, razors, etc.

Medium temperature tempering (350–450°C) is adopted only when the steel is to have better elastic properties, or if it is to operate under dynamic loads. It is mainly adopted for spring steels and wood cutting tools, surgical tools and hammer dies.

High temperature tempering (500–650°C) is mainly adopted to eliminate internal stresses and to provide the desired ratio of strength to toughness for structural steels. High tempering temperature is also adopted to improve machinability.

2.5.5 SELF TEMPERING

Tempering, according to this method, takes place by the residual heat in the interior of the component, when cooling has not been allowed to proceed to the ambient temperature. After austenitizing at the desired temperature, components are cooled in the normal manner in the quenching bath until the M_s temperature, or a temperature a little below it is reached. The component is then withdrawn from the bath and cooled in air. Thus no tempering process is used; instead the heat left in the interior portion of the components will gradually re-heat the quenched surface and temper the martensite in the quenching stage. Obviously the stored heat will vary with the mass of the component, making the tempering effect very sensitive to mass. In order to obtain identical results under varying conditions, the number of seconds required for the immersion of a component of a given size in oil or water must be determined by experiment, and strictly adhered to. To avoid quenching cracks, it is sometimes necessary that the component, after it being quenched, nearer to the M_s temperature

is withdrawn and placed in the tempering furnace. The net result of this procedure is to reduce the ratio of cooling through the martensite range. This results in reduced internal stresses in martensite and allows for the production of tempered martensite by the stored heat as it raises the temperature of the outside layer. This will avoid cracks in the component.

This process may be applied to small symmetrical components and to large forgings of uniform sections such as heavy axles. They are heated as usual for hardening and then quenched for a specified number of seconds, followed by air cooling. Forgings treated by this process have a characteristically soft or untempered core, with a progressively toughened outer part. Even though the process is strictly controlled, the results may be erratic; however, this process may be used where more precise results are not required.

2.5.6 SELECTIVE TEMPERING

Selective tempering techniques are employed in fully hardened parts for tempering the selectively hardened areas. The purpose is to obtain different degrees of hardness in the same part with a consequent improvement in quality, or to meet a design requirement, as, for instance, an increase in toughness in the shank portion of tools by reducing the hardness, or an increase in hardness of the spring portion of collets, or to carry out machining operations like tapping, drilling or thread cutting in a particular area.

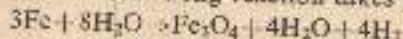
Selective tempering is done by reheating the hardened portion of the selective area, followed by a slow cooling of the section required to be soft. Reheating may be done by induction, with flame, or possibly in molten lead or salt. The temperature chosen for tempering should be in the higher range.

2.5.7 SUPER-HEATED STEAM TEMPERING

This treatment consists of tempering the steel in super-heated steam, adopted as an additional treatment for conventionally hardened and tempered tools. Steam-treated components yield a higher hardness and exhibit higher resistance to mechanical abrasion compared to the non-steam treated components.

The parts to be treated are thoroughly cleaned before treatment in the furnace. Steam tempering is carried out in an electrically heated, gas-tight, channel-type furnace. The furnace is closed by a tightly fitting cover on to which a fan is installed, so that all parts of the charge can be quickly heated to a uniform temperature. The temperature adopted for treatment may vary between 350 and 600°C, depending on the chemical composition of the steel. The holding time is between 30 and 60 minutes. The recommended pressure for steam tempering is 100 mm water column.

At the operating temperature the following reaction takes place (above 300°C)



The blue iron oxide Fe_3O_4 that is deposited on the component during the steam treatment is a hard porous oxide which is usually about 0.005 mm thick and is very receptive to coolants. It possesses a satisfactory corrosion resistance.

The treatment outlined above may be adopted for steels, cast irons and sintered products because it increases the life of components. Life of cutting tools is increased by 50 to 100% by the oxide film. It is believed that this is because the cutting oil is absorbed and retained in the pores of the oxide layer, thus reducing the friction of the chip against the edge of the tool.

2.5.8 FLUIDIZED BED FURNACES FOR TEMPERING TREATMENT

Fluidized bed furnaces can also be used for the tempering operation. In this treatment, the components to be treated are thoroughly cleaned before loading to the furnaces. During tempering the furnace is fluidized with nitrogen in order to maintain the bright surface. On completion of tempering the total charge cools down in a fluidized bed. The heat-treated parts are made available immediately after the tempering process.

Fluidized bed furnaces are mainly used for tempering of tool steels in conjunction with vacuum furnaces, since the surface brightness is maintained even after tempering. There is no need for post-treatment.

2.5.9 TEMPER BRITTLINESS

When the hardened steel is tempered, it passes through a series of transformations that affect not only its hardness but also its toughness. When the steel is tempered at a particular temperature, it suffers a marked reduction in impact strength. This phenomenon is called tempered brittleness.

In practice, this loss occurs most frequently when a susceptible steel is slowly cooled after tempering at a high temperature. It can also happen on heating it in the embrittling range. According to popular opinion,^{65-67,69,70} this may be due to the precipitation of compounds containing trace elements such as phosphorus, arsenic and tin along with chromium or manganese. The inter-granular nature of the fracture suggests that the embrittlement occurs at the austenite grain boundaries. However, temper brittleness depends on tempering conditions and the chemical composition of the steel, even though the exact mechanism of occurrence still remains to be discovered.

Temper brittleness occurs when the steel is heated or cooled through the critical temperature range of 375–675°C. The embrittling kinetics follow a C-curve behaviour with tempering time and temperature. It takes a minimum time for embrittlement around 550°C and, as the temperature decreases, more and more time is required. Temper embrittlement is reversible; and de-embrittlement may occur on heating to about 575°C after holding for only a few minutes at that temperature. Hence temper embrittlement can be eliminated or prevented by suitable heat treatment with the addition of certain alloying elements.

It is predominantly the presence of specific impurities that causes temper embrittlement, and they are antimony, phosphorus, tin, arsenic, etc. The presence of silicon and manganese in steels, avoids temper brittleness as long as their content is low. However, if they are present in large amounts, it leads to detrimental effects. The presence of Mn should not exceed 0.5%. Steels containing chromium-nickel are more susceptible to temper brittleness. Temper brittleness may be eliminated by the addition of molybdenum. Addition of tungsten also avoids temper embrittlement to a lesser extent. Cr-Ni-Mo and Cr-Mn-Mo steels sharply differ from Cr-Ni and Cr-Mn steels in that they are completely free from the defect of temper brittleness.

2.6 Retained Austenite

In steels austenite is stable at temperatures above the A_{c3} and A_{cm} phase boundaries. On cooling from these temperatures, it becomes unstable and gets decomposed into some new

products. The new constituents formed are related to the rate of cooling and the chemical composition of the steel. If the rate of cooling is slow, the transformation results in the formation of pearlite or bainite or sorbite. As a result of this, austenite will not be formed. If, on the other hand, the steel is cooled in such a way that the intermediate transformations are avoided, the structure may consist of martensite and untransformed austenite.

During quenching from the austenitizing temperature, martensite begins to form at the M_s temperature and ends at the M_f temperature (Fig. 2.45). This temperature depends on the presence of carbon and on the alloy content in steel. It is clear from Fig. 2.45 that the steel containing more than 0.5% carbon, contains retained austenite along with martensite at room temperature. The higher the proportion of carbon content in the steel, the greater is the amount of retained austenite and lower is the temperature of the start and finish of the martensite transformation. In tool steels, martensite begins to form in the temperature range of 200–300°C, and martensite transformation ends in the range of –70 to 120°C, depending on the carbon and alloying elements in steel. This fact enables us to draw some important conclusions. If the steel is not cooled below room temperature, it contains both martensite and some amount of austenite. The austenite present is called the *retained austenite*. For instance, in tool steels, it will be in the range of 5–30%.

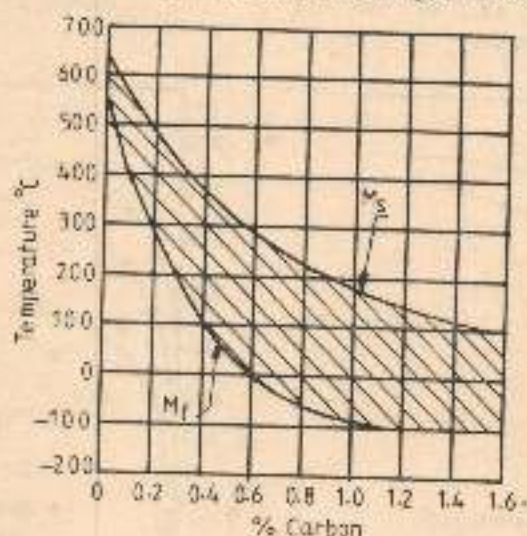


Fig. 2.45 Effect of carbon content on the martensite points M_s and M_f .

If the steel is kept after hardening for a long time at the ambient temperature, it will result in the stabilization of retained austenite. This leads to the presence of more retained austenite after sub-zero treatment than would otherwise be the case.

Cohen⁶⁴ has illustrated the effect of arresting the hardening quench of 1.0% carbon and 1.5% chromium steel for 30 minutes at various temperatures (within the martensite range) before cooling to room temperature (Fig. 2.46). It will be noted that when the arresting takes place at 53°C (130°F), the steel contains 51 per cent martensite. After holding for 30 min, the cooling transformation is completely inhibited to about 46°C, where transformation recommences and follows parallel to the normal curve. But,

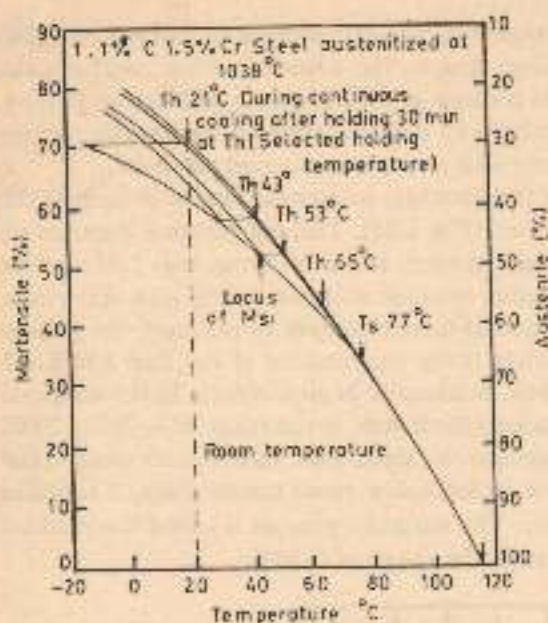


Fig. 2.46 Martensite transformation in 1.1% carbon, 1.5% chromium steel⁴⁴

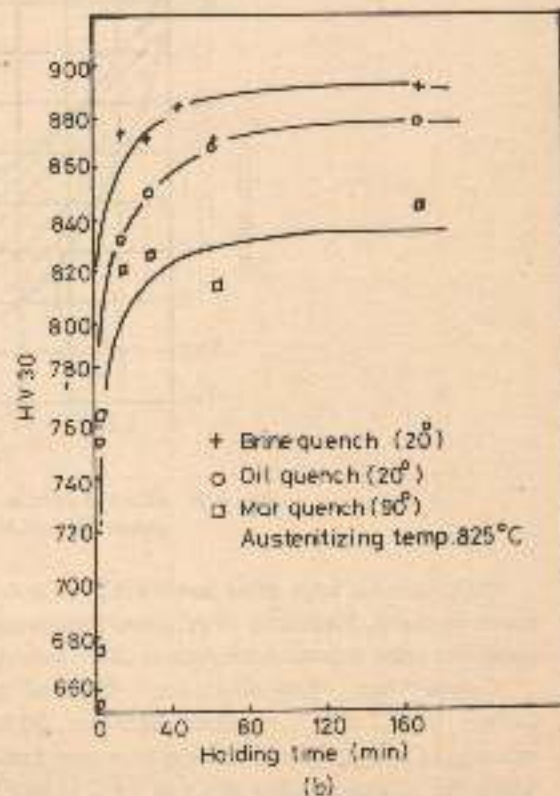
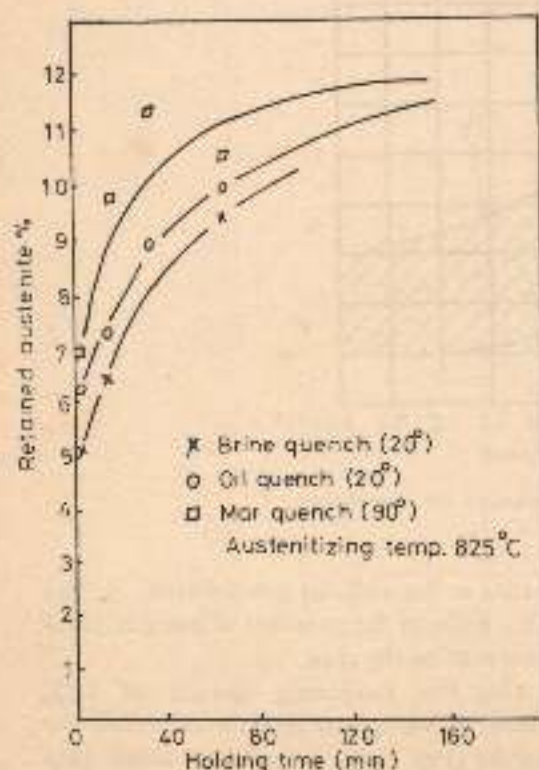


Fig. 2.47 The effect of austenizing time and quench rate of steel⁴⁴ 1% carbon, 1% chromium (a) retained austenite, (b) hardness.

after transformation is completely inhibited, on further cooling until a temperature of 46°C (115°F) is reached, it sets in and follows parallel to the normal curve. During the cooling between 53°C (T_r -holding temperature) and 46°C (M_r) approximately 6 per cent austenite would have been transformed to martensite, were it not for the stabilization during the arrest at temperature T_r .

Cooling below the martensite point (M_r) also affects the amount of retained austenite. The lower the cooling rate, the more austenite will be retained in the hardened structure. It is clear from Fig. 2.47(a) and Fig. 2.47(b) that decreasing the cooling rate by quenching in different media leads to an increase in the proportion of retained austenite and reduction in hardness of the steel by as much as 50 HV. This result appears to confirm the fact that a faster rate of cooling promotes martensite formation and a harder structure. The lowering of the hardness level is most probably due to the stabilization of the untransformed austenite which is both time and temperature dependent.

The amount of retained austenite present in the hardened steel also depends on the austenitizing temperature (Fig. 2.48). A higher austenitizing temperature results in a higher percentage of retained austenite in the hardened structure. This is due to the effect of lowering the M_s temperature, and depressing M_f below room temperature in the hardened

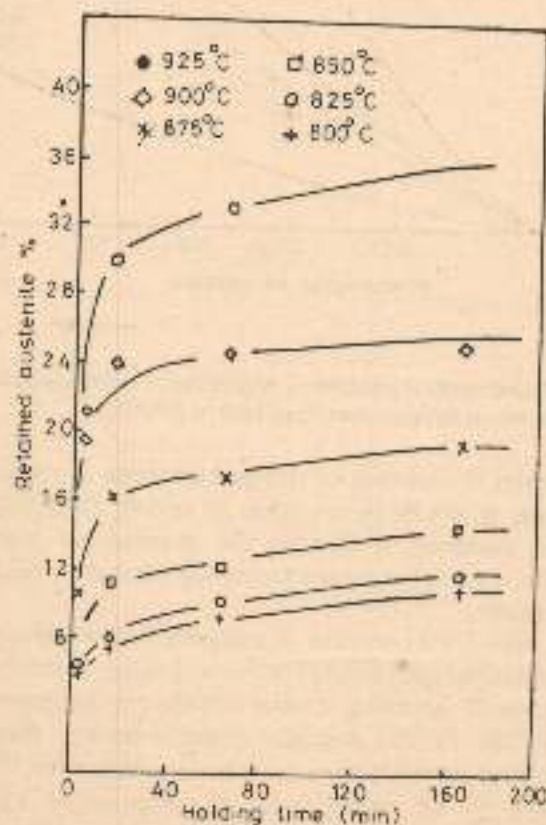


Fig. 2.48 The effect of austenitizing temperature and holding time on retained austenite⁷¹

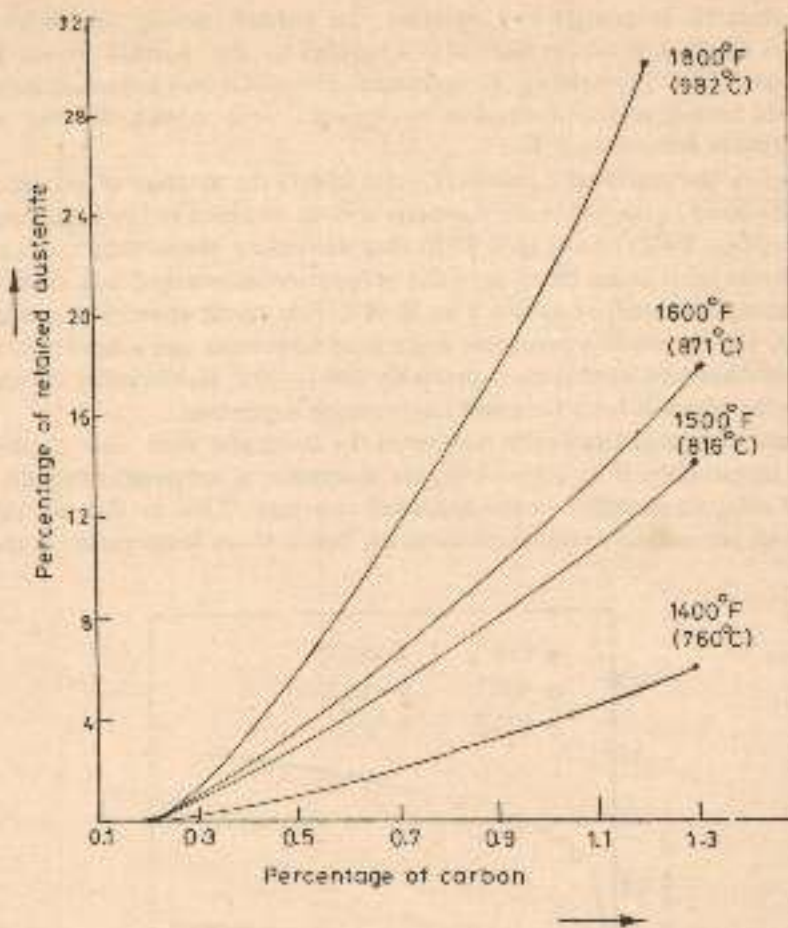


Fig. 2.49 Percentage of retained austenite v. percentage of carbon in plain carbon steels, for austenitizing temperatures from 1400 to 1800°F.

steel, Figure 2.49 illustrates the amount of retained austenite in the steel depending on the austenitizing temperature. It will be in the range 10 to 34% from 800 to 982°C. A higher percentage of retained austenite is due to the presence of high carbon and alloying elements in the austenite at a higher austenitizing temperature which is responsible for lowering the M_s temperature.

The presence of an undesirable amount of austenite in the hardened steel has a detrimental effect on its mechanical properties.^{71,72} For one thing, it reduces the hardness. There is also a tendency towards grinding cracks uneven cutting properties and an inherent dimensional instability due to the austenite transformation during use and storage. Hence it is desirable to transform retained austenite to martensite.⁷⁴ To obtain the martensitic structure, steel has to be cooled to the M_s temperature. This may be achieved by sub-zero treatment of the hardened steel containing retained austenite at ambient temperature. In highly alloyed, hardened steel (HSS), retained austenite may be reduced to the desired level by repeated tempering. In the case of high carbon steels, ball bearing steels,

carburized steels, etc., tempering results in a lower hardness. Retained austenite may be lowered by hardening from the lower range of the austenitizing temperature.

2.7 Subzero Treatment

This treatment consists of cooling the hardened component to the subzero temperature to transform the retained austenite into martensite. The mechanical properties of steels, such as hardness, wear resistance and strength, are a function of composition and heat treatment. In order to produce very high hardness and wear resistance as required in tools, dies, gears, gauges, etc., the subzero treatment may be employed. Figure 2.50 illustrates the typical heat treatment curve that may be adopted for subzero treatment.

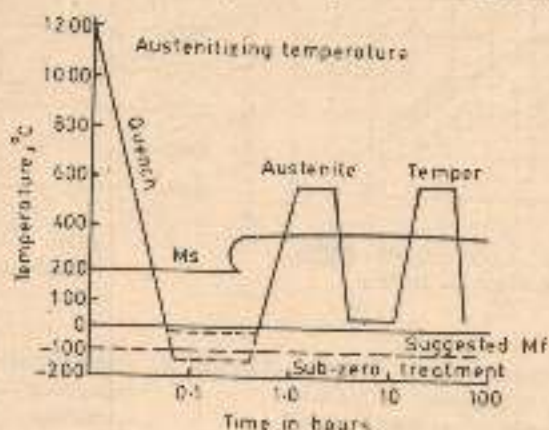


Fig. 2.50 Schematic representation of a conventional hardening and tempering treatment and a sub-zero treatment superimposed on the isothermal transformation diagram for an M2-type high-speed tool steel¹⁵

The method consists of cooling the steel to the subzero temperature. The temperature required to transform the retained austenite to martensite depends on the chemical composition. It is usually conducted in the temperature range of -30 to -140°C . Holding time at the M_f temperature is from 1 to 1.5 hours. Cooling below this temperature results in no additional transformation of the retained austenite. Subzero treatment is more effective. If it is carried out soon after the quenching operation, before the phenomenon known as stabilization occurs, it makes the retained austenite resistant to further transformation.

Subzero treatment is effective on any steel which is susceptible to retained austenite, either as a remedial step or as an integral part of the heat treatment cycle. The treatment may be applied to ball-bearing steels, carburized steels, cold work steels, high speed steels, etc. After this treatment, there will be an increase in hardness by 2-4 RC. Except highly alloyed steels for which the subzero treatment temperature is -140°C , the remaining steels are treated in the range of -80 to -90°C .

Subzero treatment must be followed by a tempering cycle to ensure that there is no

brittle, untempered martensite when the component is put into service. It also helps to increase abrasion resistance, induces better fatigue, and eliminates the possibility of grinding cracks during subsequent grinding. Besides it produces a highly ductile and more stable structure. Tempering for a long time and refrigeration cycles may be applied either in the as-quenched condition or martempered condition which will result in equivalent dimensional stability, along with higher hardness and increased wear resistance as compared to the straight quenching-tempering treatment.

The transformation of austenite does not proceed to completion and is practically

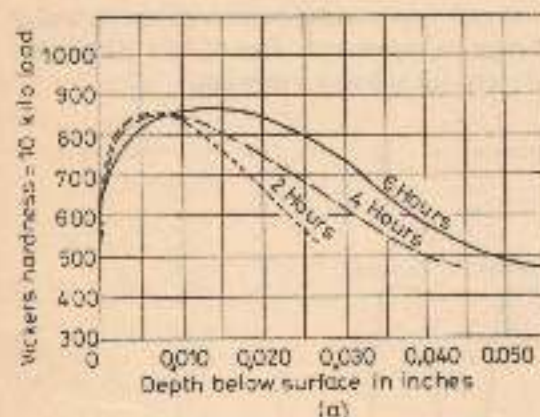


Fig. 2.51 (a) Nickel-chromium steel BS659H15 carburized in 'Rapideep'-H 2, 4 and 6 hours respectively at 900°C, reheated to 770°C and oil quenched (ground in steps)

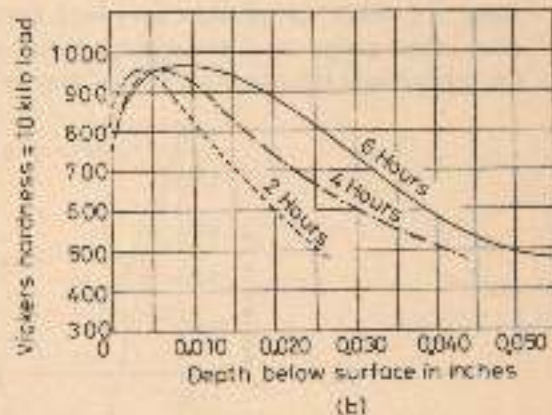


Fig. 2.51 (b) Same specimen immersed in 'Drikold' mixture at -76°C for $\frac{1}{2}$ hour after oil-quenching (ground in steps)

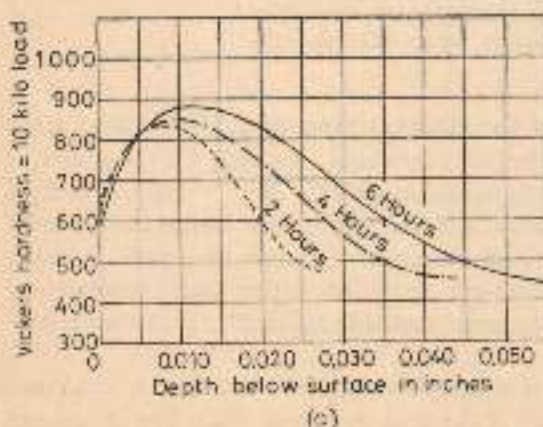


Fig. 2.52 (a) Nickel-chromium steel BS659H15 carburized in 'Rapideep'-H 2, 4 and 6 hours respectively at 950°C, reheated to 770°C and oil quenched (ground in steps)

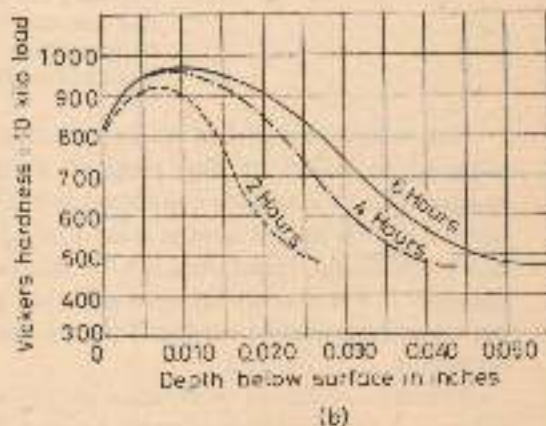


Fig. 2.52 (b) Same specimen immersed in 'Drikold' mixture at -76°C for $\frac{1}{2}$ hour after oil-quenching (ground in steps)

stopped on attaining the M_s temperature; the steel will, therefore, retain a certain amount of austenite even on being cooled to the subzero temperature. Hence, it is necessary to repeat the treatment at subzero temperature to effect an additional transformation of austenite.

For complicated components, it is advisable to temper around 150°C to 160°C immediately after quenching to avoid microcracking. Subsequently subzero treatment may be carried out.

Subzero cooling is valuable in salvaging tools that have become soft due to excessive retained austenite, resulting from the use of high austenitizing temperature or due to the higher range of carbon potential in the carburized component. Figure 2.51 (a) and Fig. 2.52 (a) show the decrease in hardness due to retained austenite; Figures 2.51 (b) and 2.52 (b) show the increase in hardness after the subzero treatment. In salvage work, subzero cooling is more positive than multiple tempering of alloyed tool steels because it is difficult to select the optimum tempering temperature to produce the desired transformation. In the case of carburized steel and ball bearing steel, tempering alone does not help transform the retained austenite to martensite, unless it is also followed by a subzero treatment. Some of the important methods of subzero treatment are mentioned in the succeeding paragraphs.

2.7.1 SOLID CARBON DIOXIDE METHOD

In this method, the oldest in practice, the component may be cooled to -80°C. Carbon dioxide is used to lower the temperature of the organic liquid mixture, such as trichloroethylene or alcohol, contained in an insulated tank. The achievable temperature is only -80°C and may not be sufficient for some applications. Also, there is a lack of control of the cooling rate and temperature.

2.7.2 MECHANICAL REFRIGERATION

This method may be capable of cooling to about -100°C. The most commonly used convection fluids are: methylchloride (-97°C), feron (-111°C), methylalcohol or methanol (-97°C) and pentane (-129°C). These fluids facilitate good temperature control; and the cooling rates can also be regulated. Besides, running costs are low. However, the capital cost and maintenance costs may be high.

2.7.3 LIQUID NITROGEN SYSTEM

In this method, components can be cooled to around -196°C. Liquid nitrogen system compared to other methods is more advantageous since it can be adopted for a wider temperature range. In this method, components can be cooled to a desired temperature at a controlled rate. This method was developed by the British Oxygen Company. There are two techniques for utilizing liquid nitrogen in a controlled manner:

1. The "Ellenite" gas-cooled system (Fig. 2.53) which cools the components by forced convection of cold nitrogen gas through the workpiece (-196°C).
2. The "Ellenite" liquid-cooled system (Fig. 2.54) which cools the components indirectly by immersion in a bath of alcohol or trichloroethylene which is cooled by a submerged liquid nitrogen spray (-150°C), temperature and cooling rate controls are possible. The equipment is relatively inexpensive compared to other systems.

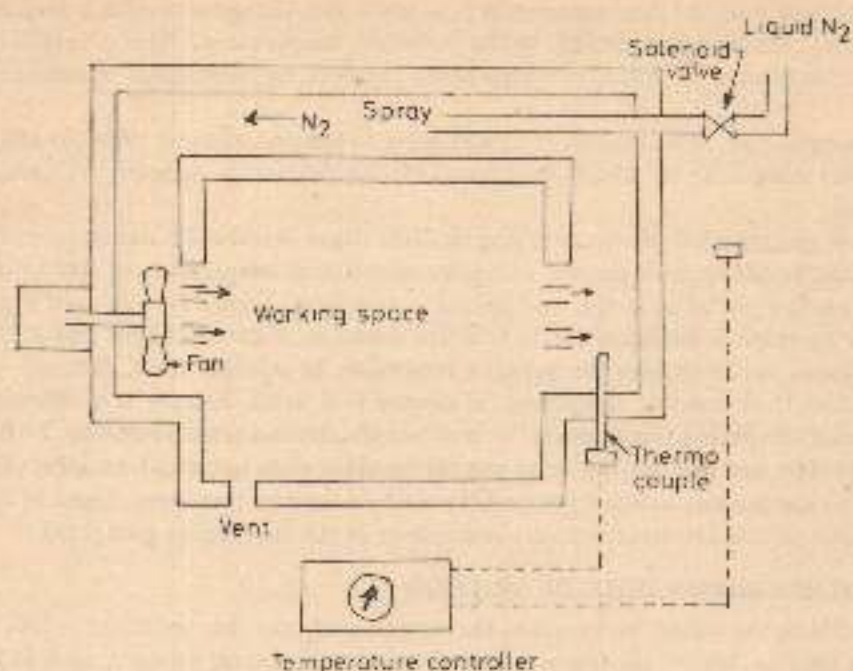


Fig. 2.53 Liquid nitrogen system (gas cooled)¹²

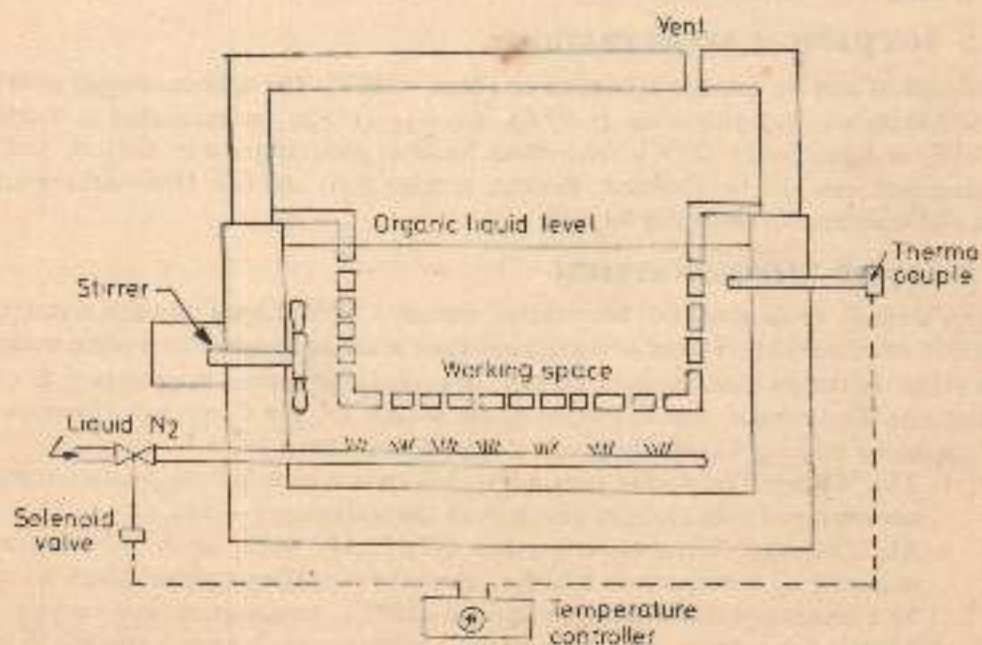


Fig. 2.54 Liquid nitrogen system (liquid cooled)¹²

2.8 Shop Problems and Remedies

The basic heat treatment of steels involves simply heating and cooling at a rate fast enough to develop the desired properties. Despite the fact that professional heat treaters are highly competent, there are countless ways in which component failure may take place. This may be due to improper heat treatment, faulty design or steel, improper machining, improper grinding, etc.

2.8.1 DISTORTION

No steel is totally free from distortion during hardening. Distortion may be defined as a permanent and generally unpredictable change in the shape or size of a component during processing. It is probably the biggest problem in the heat treatment operation; as such, it deserves careful attention. Distortion can occur both before and during heat treatment; hence it is not advisable to carry out the machining operations directly to the final finished dimensions. No matter how the heat treater is instructed to "avoid distortion", he cannot meet this request, since heat treatment of steel may produce a variety of structures, the specific volume of which are different because of the varying lattice of components. It is for this reason that the majority of components or tools are machined with an allowance to take into account the possible changes in dimensions during heat treatment. The desired final dimensions are then produced normally by grinding.

When the component is quenched in such a way from the austenitizing temperature as to form martensite, it undergoes basic dimensional changes. First, there is the normal thermal contraction during cooling, but superimposed on this is the expansion of steel as it gets transformed from austenite to martensite. Since austenite has the smallest and martensite the largest specific volumes, volumetric changes can produce very high internal stresses. If these stresses become large enough and exceed the yield point of steel, they can produce plastic deformation. This will result in distortion or warping. The setting up of internal stresses during hardening cannot be fully avoided. They can be only mitigated. For this reason, various methods of quenching have been evolved, depending on the chemical composition of the steel.

Distortion arising during heat treatment can be of the following forms: (1) size distortion or movement, (2) shape distortion or warping during heating or quenching. The factors that influence the amount of distortion in heat treatment are the size and the shape of the tool itself. It is very difficult to accurately predict in advance the changes that take place.

Volume Change due to Transformation of Structure The component undergoes expansions and contractions during hardening due to thermal expansions and contractions during heating and cooling. The structural changes in steel during heat treatment produce a volume change on the component. Hardening of the component results in greater volume than is the case in the soft condition.

Volume change depends on the chemical composition of steel, hardening temperature employed, soaking time and quenching rate. The volumetric expansion of the metal increases with an increase in the carbon content. Figure 2.55 illustrates the change in specific volume of carbon steels when heat-treated. Figure 2.55 gives the increase in volume for different types of steels. It is clear that the volume change in respect of water-

hardening carbon steel is about 0.55–1.0%; 0.3–0.5% in the case of medium alloy hardening steel, and about 0.1–0.3% in the case of higher carbon, high-chromium, dimensionally stable steel.

It must be noted that the volume increase in the hardened component depends on the depth of hardness. This is explained by the fact that with increasing dimensions of the component, the degree of penetration of hardness is reduced. So, the volume change that takes place in the component is confined to the hardened zone. Therefore, volume changes of the whole piece are much less than what is shown in Fig. 2.56 (which applies to the shallow and fully-hardened condition). Volume increase in tool steels of different dimensions is consequently dependent to a great extent on hardenability. This, however, varies depending on the chemical composition of tool steels. In the case of surface hardening, volumetric changes are practically nil.

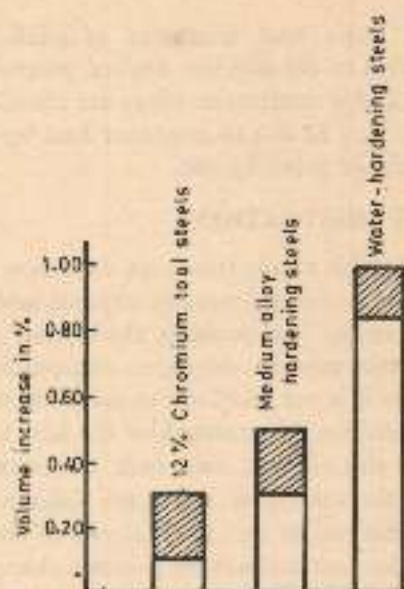


Fig. 2.55 Typical volume change in hardened steels*

Deformation due to Thermal Stresses Deformation resulting from thermal stresses is fairly regular in symmetrical bodies of uniform thickness. When the steel is heated or cooled, compressive stresses as well as torsional stresses are developed in it due to the differences in temperature between the core and the case. These stresses mainly induce a change in size, and it must be said that they seldom receive attention in the evaluation of dimensional stability. A distinction must be made between heat stresses that are relieved during cooling in the plastic stage (which are responsible for deformation), and stresses that remain in the material but are of secondary importance for the occurring size change. The general rule is that all spherical bodies tend towards a shape of a sphere due to the stresses which develop on cooling. A cube of a carbon steel with 0.10% carbon will, after repeated heating and sudden cooling, lead to a spherical shape. Even bodies deform in the same direction; the more violent the cooling, the greater is the depth of deformation. The degree of thermal stresses (and deformation) are not only dependent on the cooling rate, but also on the temperature difference between the steel and the cooling medium. Increase in the hardening temperature, from which the steel is cooled, results in an increase in thermal stresses and, therefore, in greater deformation.

Figure 2.57 illustrates the change in length caused by the heating and rapid cooling of a eutectoid carbon steel. It can be seen how the steel expands during heating. At the austenite transition point of about 750°C the steel shrinks, leading to the conclusion that austenite has a smaller volume than ferrite. But, as the temperature increases due to the expansion of grain growth, there will be a further increase in length. During cooling, the austenite size remains the same up to about 250°C, when the martensite begins to form, resulting in expansion. After the formation of martensite is complete or nearly so, the volume is

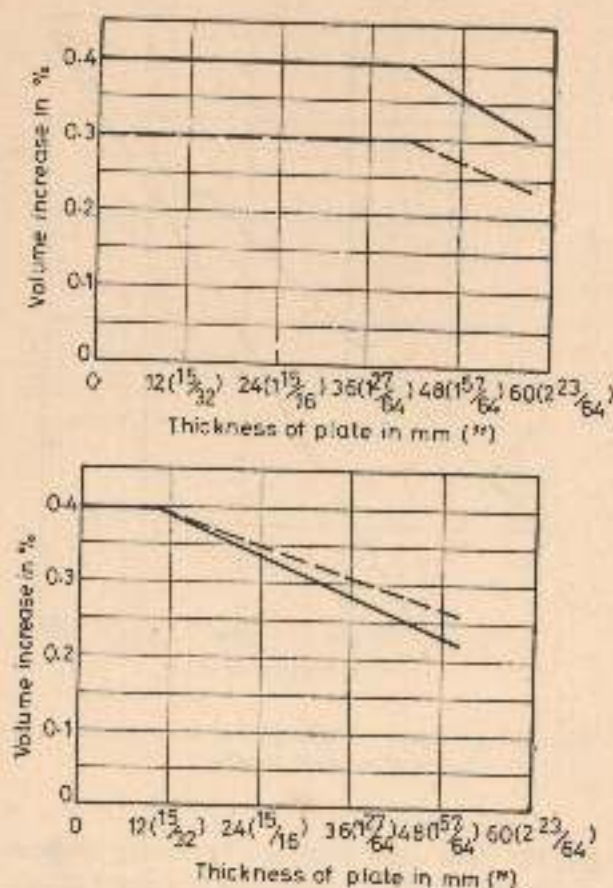


Fig. 2.56 The effect of varying hardenability on volume increase in die plates of different thicknesses¹⁴
Top: Deep hardening steels, Bottom: Shallow hardening steels

greater than that before hardening.

If a tool being hardened undergoes a volume change only due to martensite formation, then all dimensions would have to increase by the same percentage according to the depth of hardening. However, upon hardening, cylindrical and prismatic bodies grow more in thickness than in surface dimension. Only cubes show a uniform growth in each direction. This shows that the bodies tend to attain spherical shape and deform under heat stresses previous to hardening. Upon the formation of martensite, the resulting increase in volume is superimposed on the form affected by the action of the aforementioned heat stresses. The volume increases by the same percentage in each direction, but not in comparison with the original size of the annealed stage.

In some high alloy steels, for example (AISI) D3, in which the amount of retained austenite after hardening is rather big, it can be reduced to some extent by adjusting the

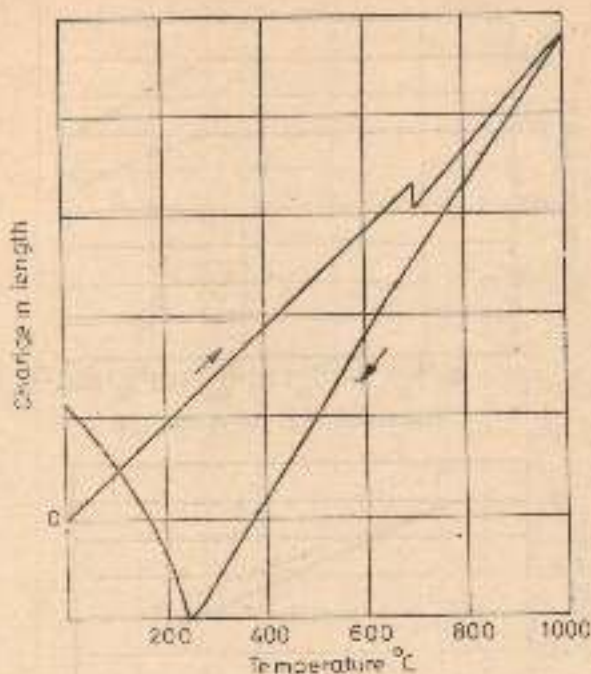


Fig. 2.57 Change in length during heating and rapid cooling of a carbon steel²⁷

hardening temperature. For these steels there is a hardening temperature which will theoretically give no change in volume, i.e., the increase in volume caused by the formation of martensite is balanced by the decrease in volume caused by the retained austenite (hardening from 1020°C followed by oil quench).

Remedies for Distortion The distortion may be observed as a change in dimensions (size distortion) or a change in configuration or contour. Several factors contribute to the total distortion during hardening, such as, residual stresses that may be present as a result of heavy machining or cold working operations, method of placing component in the furnace, rate of heating, non-uniform heating or the normal volumetric changes that occur with phase transformation. Uneven cooling during quenching and also the geometry of the component are responsible for distortion. Hence it is necessary that the parts to be hardened be stress-relieved, after heavy machining. There should always be proper loading, since the strength of all steels diminishes rapidly as the temperature rises, and the parts are likely to deform under their own weight.

The thermal conductivity depends on the chemical composition of steel, and it decreases as the alloying elements increase. Hence it is necessary to preheat the component around 500°C to 600°C to avoid thermal stresses. It is also important that the component be placed in a suitable fixture to avoid distortion. Apart from these precautions, suitable quenching media will also play a greater role in reducing the distortion.

Since it is not possible to meet the desired norms of accuracy in finished components during hardening, a conventional procedure is to provide an allowance for finish grinding which is large enough to compensate for the distortion.

2.8.2 CRACKS

Quench cracks are developed in a component due to stresses produced during the structural transformation from austenite to martensite with its accompanying increase in volume. In the as-quenched condition, the steel is hard, brittle and exhibits virtually no ductility.

When the steel is hardened it undergoes two basic dimensional changes: firstly, thermal stresses develop in the rapidly cooled steel as a result of unequal cooling on the cross section of the cooled part. This causes a non-uniform volumetric change where the surface layers of the article contract more rapidly than its internal surface. Secondly, expansions of the steel occur due to the transformation to a martensitic structure. These volumetric changes result in the generation of high internal stresses. If these internal stresses exceed the tensile strength of steel, it will then result in cracks.

For instance, when the component is quenched in such a way as to form the martensite structure throughout the section, the transformation occurs first at the surface when its temperature falls below the M_s point. As cooling proceeds and the material near the centre reaches the M_s point, the expansion accompanying the newly formed martensite is restricted by the outer layer of martensite formed earlier. This results in an internal stress and places the surface in tension inducing loss of ductility. Cracking occurs when the martensite formed sets up internal stresses sufficient to exceed the ultimate strength of the as-quenched martensite at the outer surface. Quench cracks start from the surface, moving towards the centre of the component in a relatively linear fashion. It may be noted that during quenching, austenite does not get completely transformed to martensite at room temperature, but occurs over a range of temperatures starting at the M_s temperature. The martensite from the higher austenitizing range of temperature will cause less expansion. Steels containing higher carbon and higher alloying elements have a tendency to form quench cracks, apart from lowering the M_s temperature.

Some of the most common causes for quench cracks are as follows:

1. Time delay between quenching and tempering.
2. Over-heating and burning.
3. Improper selection of quenchants.
4. Cracks due to faulty design.
5. Improper selection of steel.

Time Delay between Quenching It is a common practice on the shop floor to check the hardness of the tool in the as-quenched condition. This is done to decide the tempering temperature according to design requirements. Checking the hardness immediately after hardening is not advisable. A common misconception is that quench cracks occur only while the work is in quenchant. Actually quench cracks can occur, particularly in tool steels, even after an hour, a day, or a week after the quenching, if the tool is allowed to stand after hardening without tempering. Figure 2.58 illustrates the cracks developed at the corners due to the delay in tempering. Figure 2.59 illustrates the cracks developed as the tool is not tempered after hardening. This is mainly due to the isothermal transformation of

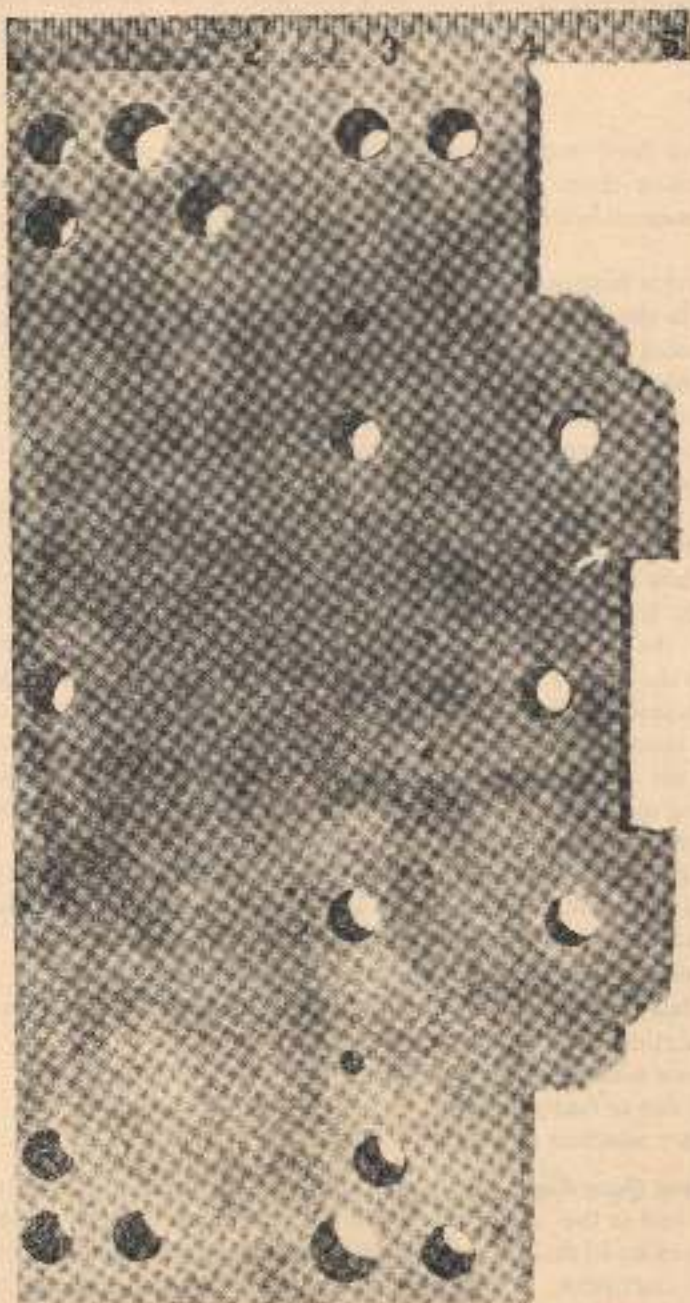


Fig. 2.58 This die, made of type D1 tool steel, cracked in sharp corners because it was not tempered immediately after quenching. Identical corners in the lower half did not crack!"

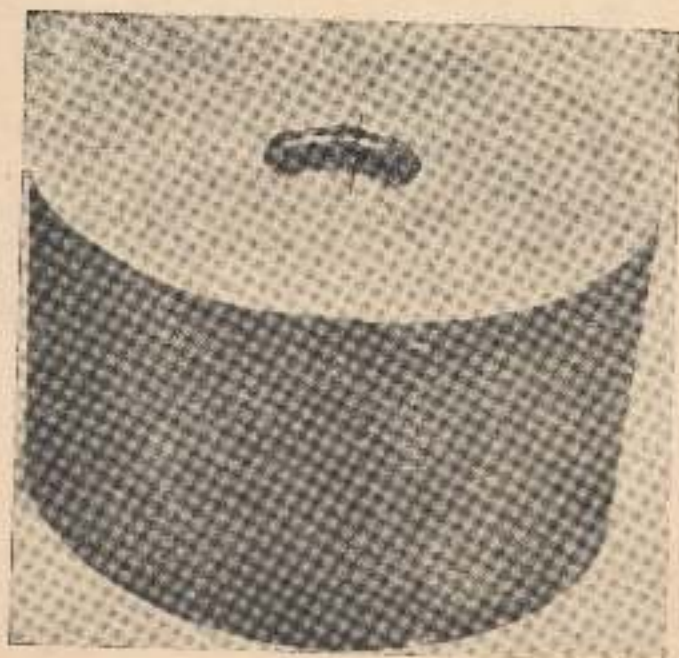
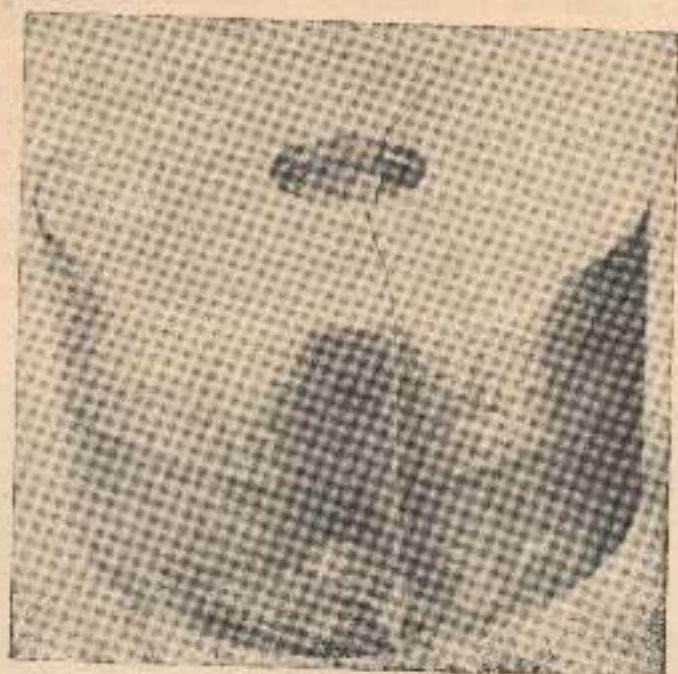


Fig. 2.59 These coinage dies were made of Type D2 tool steel and cracked during use after a short period of service. A laboratory investigation showed that the dies had not been tempered, thus explaining their brittle behaviour in service²³

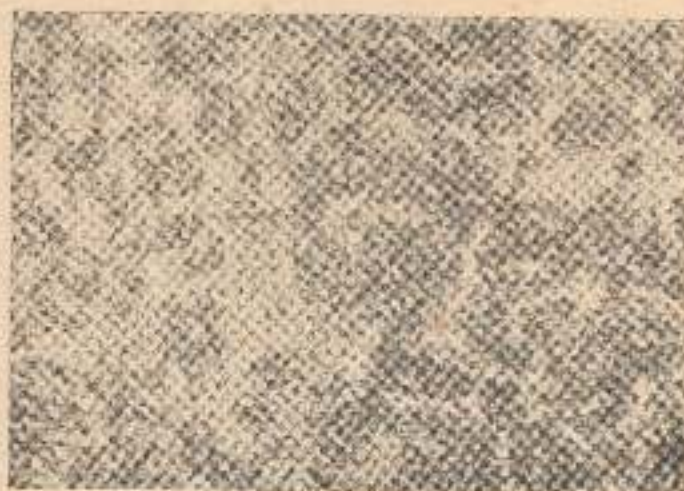
retained austenite to martensite. The formation of isothermal martensite adds an additional volumetric strain to an already badly quenched tool, thereby increasing the probability of crack formation.

Hence it is important that the hardened parts should be tempered as soon as possible to release the internal stresses formed during quenching. A good rule-of-the-thumb is to draw the parts from the quenchant while it is still warm (60 to 80°C) and transferring it to a tempering furnace. The temperature adopted for tempering should not reduce the hardness below the required point. The hardness is then checked and the temperature selected on the basis of the hardness required. If, for any reason, it is not possible to temper parts immediately after quenching, a holding furnace should be used to keep them warm around 100°C until tempering can be carried out.



Fig. 2.60 This die insert made of type O1 tool steel is of relatively simple design and should not be troublesome in hardening if the holes are packed, as there were. Cracking occurred in the quench due to the use of an excessively high quenching temperature of 1020°C.

Tools and dies made of high carbon steels, high chromium steels, air-hardening steels and high-speed steels contain an excessive amount of retained austenite in the as-quenched condition, because of the high quenching temperature. Since these steels are sluggish in their hardening transformation, it is important to temper them two to three times to convert the retained austenite to martensite. In particular, tempering should be applied on these steels when they attain a temperature of around 60°C during cooling because the transformation of austenite to martensite at or near the room temperature may induce



Overheated structure

x500



Overheated structure

x1000

Fig. 2.61 Overheated structure shows reprecipitated carbide-eutectic and grain boundary carbide in a matrix of coarse high-speed steel (Courtesy: VEW, Austria)

cracking. Between tempering operations tools should be air-cooled to room temperature.

Carburized parts (highly alloyed nickel steels), medium and high alloy steels are susceptible to retention of excess austenite after quenching. It is helpful to use subzero cooling as an aid for transforming the retained austenite.

Subzero treatment should be followed immediately after quenching. However, complicated parts should be tempered before subzero treatment to avoid cracking. This treatment is also considered to be essential for stabilizing tools, such as gauges, templates, master gauges, etc., where dimensional stability is of utmost importance.

Overheating and Burning Hardening of components at a very high temperature causes overheating of the steel. This may happen either due to a wrong selection of temperatures or due to the failure of the thermocouple which gives a wrong temperature indication. Overheating of steel causes grain growth, formation of coarse martensite and excessive amounts of retained austenite, all of which cause brittleness in components. Heat treatment operations to harden parts normally produce a refining effect upon the grain size of the component. That is why fractures of a properly hardened tool show a fine grain, whereas the parts overheated during hardening display a coarsening of grains that is readily visible on a fractured surface. The microstructure of overheated steel can provide a conclusive proof for an excessively high quenching temperature.

Overheating of highly alloyed steels may result in cracks or very low hardness after quenching. Figure 2.60 illustrates the cracks developed in a simple die due to a very high hardening temperature. When high speed steel is overheated, its structure will become coarse-grained, with massive austenite at the grain boundaries and with an evidence of eutectic reformed (Fig. 2.61) from the liquid; whereas the normal structure has a random distribution of globular carbides. The steel may crack during heat treatment if overheated. If it survives the heat treatment operations, it will easily develop grinding cracks, and, in all likelihood, be brittle in service. Burnt high speed steel tools cannot be reworked; they are scrapped. The overheated structure of carbon and low alloy steels may be corrected by annealing at or just above the A_1 or A_{cm} temperatures to refine the grain-size, followed by a spheroidized annealing, in an attempt to globularize some of the less refractory carbides. In the case of highly alloyed tool steels, it is not advisable to rework, since it is impossible to restore the mechanical properties of burnt steel by further heat treatment.

Improper Selection of Quenchants It is most important that a suitable quenching medium is used in order to avoid cracks, depending on the chemical composition of the steel and the geometry of the job. It is more common in parts that are subjected to water or brine solutions for quenching. For instance, in high speed or air hardening steels quenched directly in oil from the austenitizing temperature, it may lead to cracks if allowed to cool to the oil temperature of around 60°C (Figs. 2.62 and 2.63). In such a case, it is advisable to remove the tool when it attains the temperature of around 500°C, and then cool in air. Another alternative to overcome the quench crack on high speed steel and other highly alloyed tool steels may be to subject them to martempering.

Cracks Due to Faulty Design Most of the failures of hardened components are due to overload or internal stresses, set up by non-uniform cooling of the parts during the hardening process. This may be due to the unfavourable shape or dimensions. The ideal shape evolved by a rational design is a well-balanced distribution of mass within the component, in such a way that each surface point should receive and give back the same quantity of heat, and

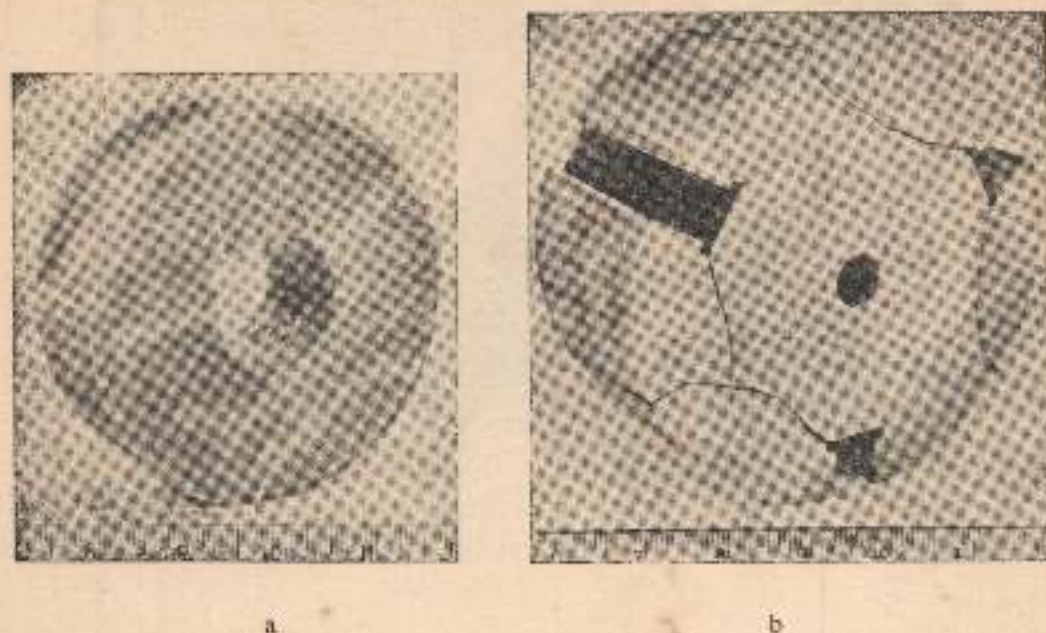


Fig. 2.62 (a) Air-hardening tool steels are also subject to cracking in sharp corners in the quench—when they are quenched in oil. The thread roll shown above was made of Type A2 tool steel and was hardened to Rockwell C63 by oil quenching and tempering at 350°F. The crack initiated at sharp corner in the keyway. If this part had been air quenched it would not have cracked in the sharp corner or, if the keyway had been half-round, the part would not have cracked during oil quenching. (b) This tool holder, made of Type A2 tool steel, was found to have cracked after heat treatment. The cracks are exaggerated by the magnetic particle test and were found to originate in the sharp corners of the dovetails. The type of cracking indicates that liquid quenching was involved although the exact treatment practice was not available. Air-hardening tool steels that are actually air hardened do not crack in this manner. Parts such as this one should be air hardened or redesigned to make them suitable for liquid quenching¹⁴.

at the same rate, on heating and on cooling. Of course, such a shape does not exist in reality, but it is the designer's task to come as near it as possible.

There are many empirical design rules in handbooks covering procedures for the development of tool geometry.

The importance of good design cannot be over-emphasized. Inadequate design affects the service life of the component in two ways. Improperly designed tools may crack in heat treatment or may fail prematurely in service.

The most common design faults which cause cracking in heat treatment are:

- (1) heavy sections adjacent to a thin section,
- (2) sharp corners and transitions between sections (Fig. 2.64).

When hardening the components in liquid quenching media, thin cross sections are cooled more quickly than the heavy sections. Therefore, the latter are still red hot, whereas the thin sections are hardened fully. The resulting stresses between the thin and heavy

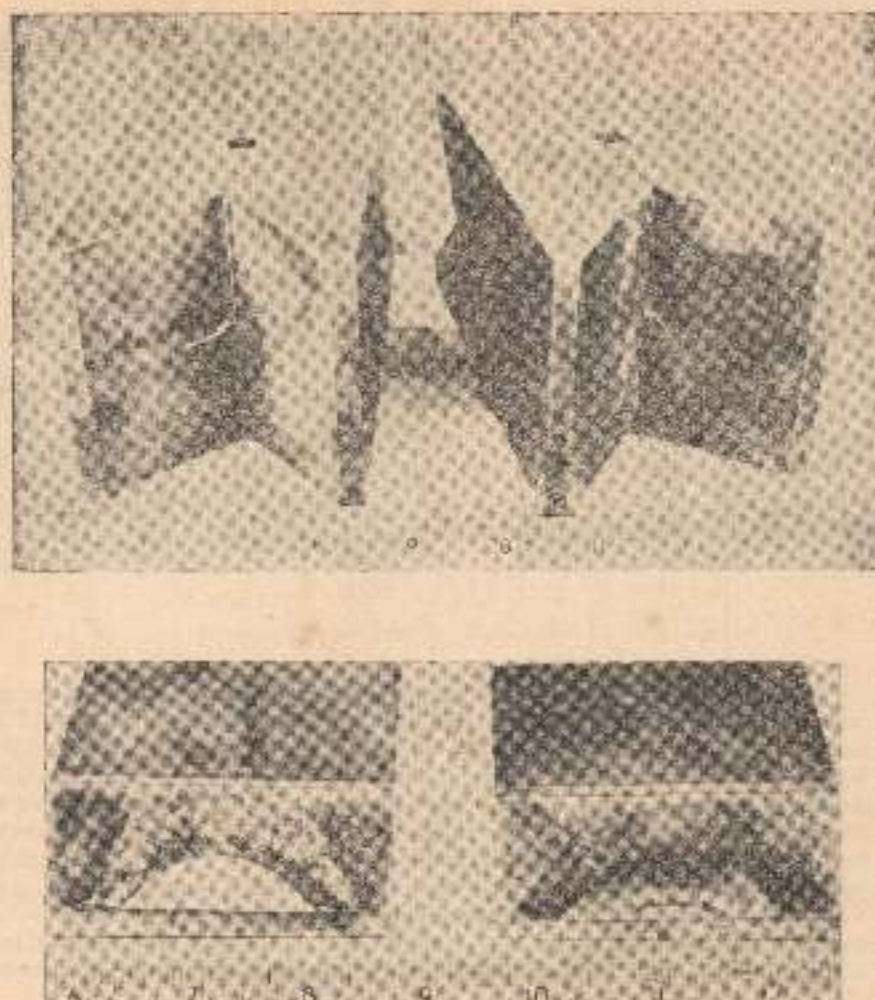


Fig. 2.63 Two V-dies made of Type B1 tool steel cracked in the quench because they were quenched too cold and not tempered immediately after the quench. Each crack originated at the bottom of the V, in spite of the presence of a radius. The photograph of the fracture face of each die indicates the origin of the crack at the bottom of the V and shows that the crack was open during the temper (oil residue and temper colour). The circular gray are on each piece indicates the fresh fracture needed to break the die pieces apart.

sections readily cause dimensional changes or cracks, if these stresses become higher than the tensile strength of the steel employed.

One way of overcoming these difficulties is to design the tool, if possible, in separate parts of relatively uniform section. If this is not possible, it is advisable to use a hardening steel that may be successfully hardened by step-hardening (salt bath quenching). This

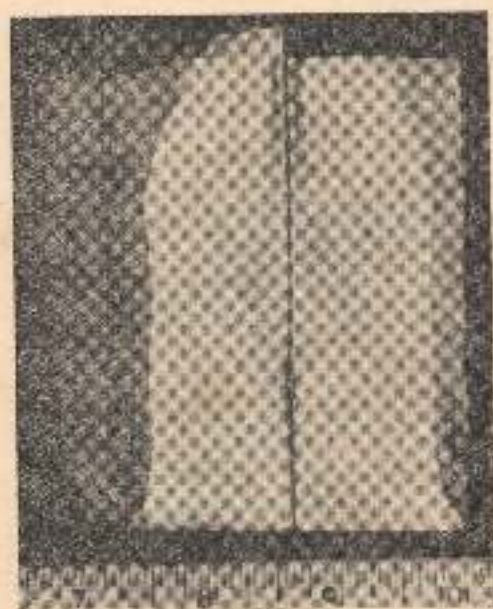


Fig. 2.64 This die insert made of Type S1 tool steel cracked at a section change through a sharp internal corner during heat treatment. The crack was broken open and the fracture is illustrated (bottom). The light portion represents a fresh fracture while the darker portion shows temper colour from exposure to the tempering furnace atmosphere. Sharp corners greatly increase the cracking hazard. Extreme care must be used to remove the tool from the quench while warm, and to temper immediately to avoid cracking through the corners!¹⁹

hardening process starts the transformation to martensitic structure simultaneously throughout the section of the tool. The risk of cracks and deformation is thereby reduced.

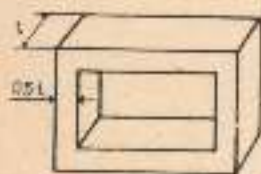
Figure 2.21 illustrated the effect of different quenching media on the temperature distribution in the core and surface areas of the steel during the hardening process when the tool of the same size was quenched. It is clear that the difference in temperature within the martensite transformation zone is the smallest when the part is quenched in air or in a salt bath. In this case, the core and surface areas transform to martensite structure almost simultaneously, whereas with water quenching, the core retains a relatively high temperature when the transformation in the surface layer begins, resulting in high internal stresses. Compared to this, water quenching or oil quenching shows a much smaller temperature difference. It is, therefore, clear that the cracks that may increase due to the quenching



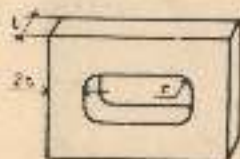
Wrong: uneven section if teeth are opposite.



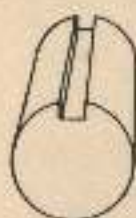
Better: Staggered teeth give more even section.



Wrong: wall section too thin and internal corners too sharp.



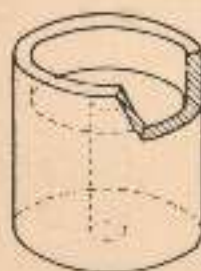
Right: thicker section and rounded corners.



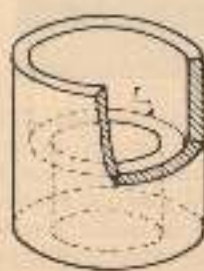
Wrong: groove on one side only, and with sharp corners.



Better: grooves on either side, and with radius.



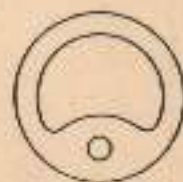
Wrong: big differences in section and no radius in fillet.



Right: more even section and radius in fillet.



Wrong: sharp corners and big differences in section.

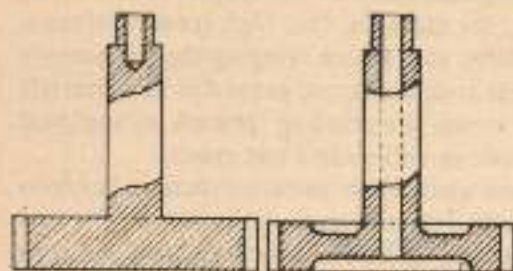


Right: radius in corners and more even section.

Fig. 2.65 (Contd.)¹⁸

media may be controlled by (1) using the most suitable quenching media, (2) using an appropriate type of steel.

Sharp internal corners, sharp edges and angles should be avoided because they show differences in the cooling rate at different portions of the workpiece, and these become the focal points of concentration of stresses. Therefore, it is necessary to avoid sharp corners, inadequate radii, etc. In those places where it is not possible to avoid sharp corners because

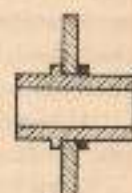


Wrong: sharp corners and big differences in section.

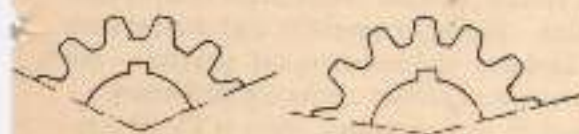
Right: radius in corners and more even section.



Wrong: big differences in section.

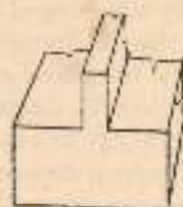


Right: tool made in two parts of more even section.

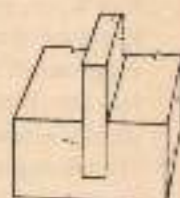


Wrong: keyslot opposite gap between teeth.

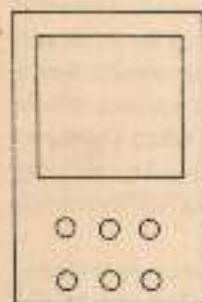
Right: Keyslot moved half a pitch.



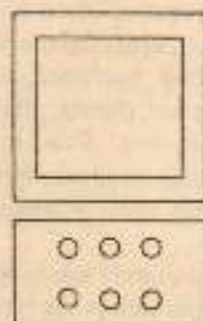
Wrong: big differences in section (in some cases unavoidable).



Right: tool made in two parts of more even section.



Wrong: big differences in section.



Right: progressive die plates can be divided into two.



Wrong: deep blind hole hinders quenching.



Right: hole continues right through.

Fig. 2.65 Illustrates right and wrong approaches to component designs¹⁷

the function of the component demands them, relief notches in the corners corresponding to the sharp edges are to be provided. Figure 2.65 lists the right and wrong approaches of component design involving hardened steels.

2.8.3 GRINDING CRACKS

Many parts or tools are designed to have smooth, hard surfaces for resistance to wear in service and to increase the life of the component: for example, dies, high speed steel tools, journals in crankshafts, piston pins, bearing surfaces, etc. Before bringing the components to this stage, they are machined, hardened (by heat treatment), and ground to an extremely close finish tolerance. At this stage, if for any reason the grinding process of hardened parts are not done carefully, they are likely to result in undesirable end results.

Although all grinding operations produce some changes in surface structure, hardness and residual stresses, these changes are usually within the tolerance limit.

Grinding cracks are the inevitable result of excessively localized heating. This is due to unsatisfactory grinding practice (Fig. 2.66). Common grinding faults are: (1) grinding with a wheel of grit size that is too fine or of too high hardness, (2) grinding with a dull or loaded wheel, (3) too rapid removal of metal due to excessive feed or wheel speed, and (4) insufficient cooling during grinding due to lack of adequate supply of coolant. It may also result sometimes in a temperature rise in the hardened steel to cause a rehardening of a surface layer, accompanied by softening of the immediately adjacent material (Fig. 2.67).^{26,33,34} Research work indicates that the energy required for grinding is 30 times as much as the other machining processes to remove a given volume of steel. The surface temperature reaches from 1100°C to 1650°C during grinding. The development of high temperature during grinding will lead to (1) changes in hardness and metallurgical structure, and (2) development of high internal stresses to a level where surface cracks can be formed.

During hardening the austenite is transformed to martensite and there is a sizable increase in the lattice parameter. Heating the martensite to the tempering temperature reduces the hardness and results in a corresponding decrease in the lattice parameter until the martensite is tempered completely to a microstructure of finely dispersed carbides in a matrix of ferrite. The contraction accompanying tempering of martensite is a natural phenomenon and must be taken into account when dealing with hardened parts.

For instance, during grinding, the surface temperature of the hardened parts is increased and will result in lowering the hardness of the steel, apart from a shrinkage in its structure. But this contraction is restricted by the surrounding hardened, stronger martensite which has not been heated during grinding since it is not plastic. Shrinkage of an area whose parameter is rigid, sets up tensile stresses in that area. Cracking occurs when the stress generated by grinding, together with other existing residual stresses, reaches the ultimate strength of the material. Grinding cracks are usually shallow, ranging from a few thousands to fifteen thousands of an inch.³¹

Retained austenite in the hardened part is exceedingly sensitive to grinding operations. If the surface temperature rises and is sufficient to allow the transformation of retained austenite to alpha martensite, cracks may develop at the surface. If cracks do not occur during grinding due to the newly formed structure, they may tend to crack under additional stresses encountered in service. The presence of retained austenite may be reduced before grinding by adopting double tempering or subzero treatment.

If the grinding is done with heavy feeds, it is sometimes possible to generate the heat

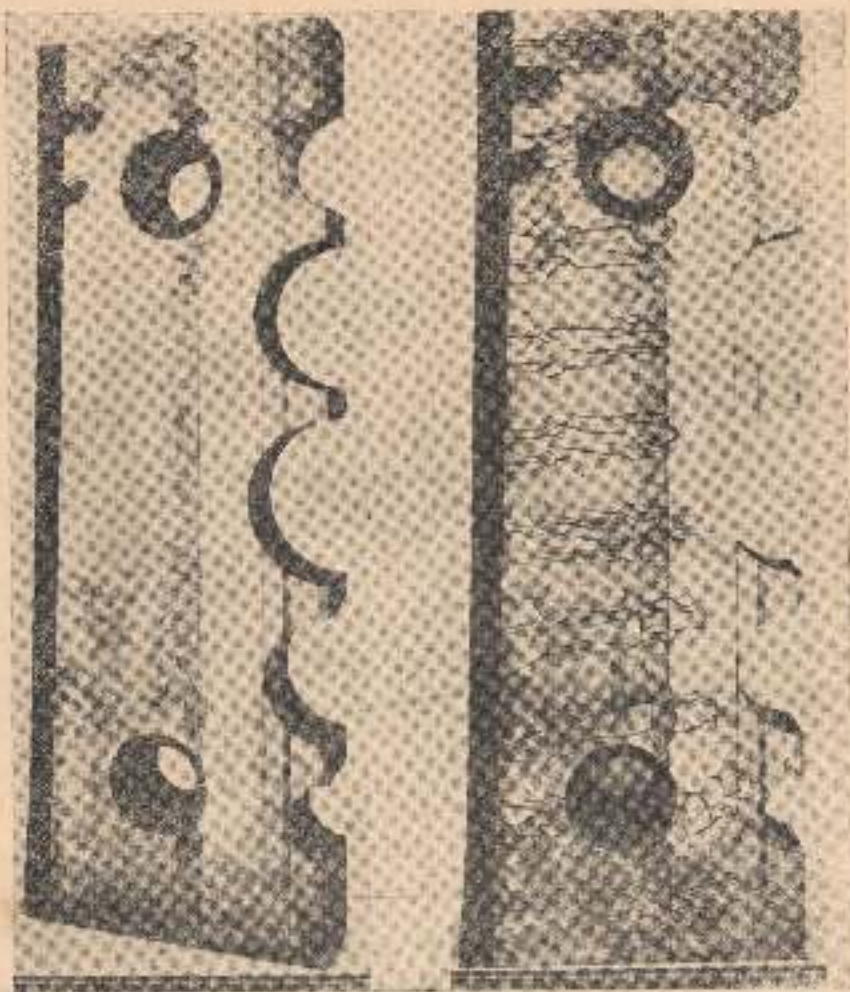


Fig. 2.66 (Left) Visual surface appearance of shear blade made of Type S1 tool steel after grinding operation. Note the network-type cracks and spalled areas.

(Right) Surface appearance after magnetic particle test. Note the severe grinding cracks and spalled areas.

(Micro 100X) The heat generated in grinding this tool was so intense that a rehardened martensitic zone about 0.007 inch deep was formed. The grinding practice used on this part would not be satisfactory on any type of hardened tool!"



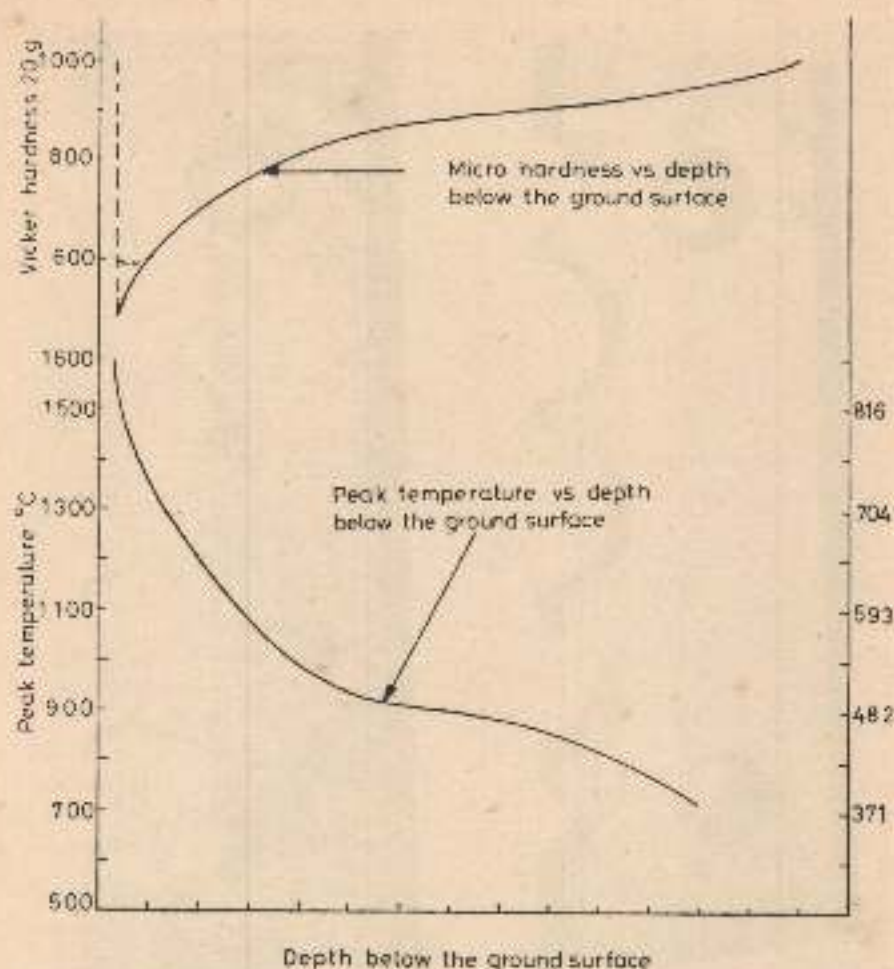


Fig. 2.67 Effect of temperatures on the corresponding micro-hardness distribution made on a taper section of the sample after grinding. The dotted line shows the probable hardness distribution near the surface when the steel hardness gradient made values inaccurate¹¹

at the surface above the hardening temperature. This results in rehardening of the surface layer which will then comprise of a mixture of untempered and tempered martensite together with some retained austenite. As a result of encountering heavy stresses, grinding cracks will develop, and it may even lead to flanking or fragmenting the steel.

It is also possible that when grinding is severe the temperature on the surface of the metal rises to the hardening temperature. The cooler metal below the surface extracts heat from the hot surface at an extremely rapid rate, leading to quenched martensite. The next pass of the grinding wheel will meet a structure specially prone to cracks. Parts containing *as-quenched* martensite on the surface are prone to failure in service in a relatively short time. Improper grinding is not always the sole cause of grinding cracks; heat treatment deviations can also produce extreme sensitivity towards grinding cracks, no matter how

carefully the grinding is done. The deviations are: (1) leaving the tool for a long time without tempering, (2) overheated steel, (3) case having a carbide network during carburizing, and (4) an improper tempering procedure.

Grinding cracks are usually superficial at the time they are produced. Components having this type of cracks may be salvaged by removing the metal with utmost care. But earlier to the removal of material, it is advisable to temper the component for 4-6 hours in the temperature range of 150 to 200°C depending on the chemical composition of the steel.

The detection of cracks may be done by using a magnetic flaw detector or by the fluorescent powder testing method, or by the ultrasonic method.

Considering the drawbacks, mentioned earlier, it is important that grinding is carried out with great care, especially in the case of hardened tools or components. A summary of essential points to bear in mind in this connection are listed below:

1. Make sure that there are no vibrations on the grinding machine and that the workpiece is firmly fixed.
2. Grind the tool only in the tempered condition.
3. Rough grinding should be carried out with a heavy feed (0.01-0.05 mm per revolution), and the finishing operation with a small feed. A carefully sharpened wheel should be used. Avoid too many soft cuts.
4. Use only sharp, tapered diamonds for sharpening the wheels.
5. To ensure a free-cutting grinding, use wheels that are at least one grade softer than normally used for tool grinding. For correct choice of wheel, consult the manufacturer's handbooks or his local agents.

2.8.4 SOFT SPOTS

Soft spots on the surface of the component will result in lower hardness. This may be due to the following reasons:

1. By quenching too many parts at a time or due to an insufficient quenching medium.
2. If the quenching temperature is above the specified range or if it is too warm.
3. Vapour accumulation on the surface of the quenched parts reducing the cooling rate on the area.
4. Oil of high viscosity may also cause soft spots by giving too slow a quench. Any scale adhering to the parts being treated will also delay the quench and may cause local softness.

The following measures may avoid soft spots:

1. Use of a sufficient quantity of water or oil (oil should be 8-10 litres/kg) and a suitable quenching equipment.
2. The temperature of water should be around 25°C. In the case of oil, it should be as per the specification.
3. Quenching tank should be provided with a good agitation system together with the use of effective quenching medium.
4. Suitable oil should be used as per standards.
5. Components should be free from scale or decarburization before they are hardened.

2.8.5 PITTING, SCALING AND CORROSION

A salt bath free from cyanide, but containing carbonate in which cyanide is exhausted, will decarburize and deposit a thin coating of oxide layer on the steel surface. The parts treated in salt bath and cooled slowly in air from the hardening temperature will also reveal pitting. Hence it is necessary to cool the parts in a closed chamber with a neutral atmosphere or by quenching the parts immediately after the treatment. Parts containing nitrate salts and treated in a neutral salt bath are prone to pitting. To avoid this, parts should be thoroughly cleaned before further heat treatment.

Parts containing salts heated in a muffle furnace exhibit a heavy scale compared to similar components free from salt. Treatment of such parts in a salt bath would avoid this trouble, or the components should be thoroughly cleaned.

Component coated with neutral salts, on tempering in a muffle furnace, will tend to suffer from surface corrosion. To avoid this, parts may be tempered in a salt bath or subjected to thorough cleaning before treating in muffle furnace.

Scale may be produced by preheating in a muffle furnace or air-preheater to a temperature in excess of 550°C before immersing in a salt bath.

A thick layer of scale may form on the surface of the component if the components are treated in a muffle furnace without a neutral or reducing atmosphere. This may be avoided by using an endothermic atmosphere, or nitrogen as a heating medium, or by treating in a molten salt bath.

2.8.6 LOW HARDNESS

This may be due to the following reasons.

Too Low a Hardening Temperature If the hardening temperature chosen is very much below the suggested temperature, it will result in low hardness after quenching. It may also be due to a faulty measuring device.

To avoid this, the selected hardening temperature should be accurate, and the temperature measuring instruments should be checked regularly.

Too Short a Holding Time A short holding time in the hardening temperature will lead to insufficient dissolution of carbides in the austenite which will result in low hardness after quenching. To avoid this defect, the holding time in the bath should be of the correct duration.

Too High a Temperature or Too Long a Holding Time Treating the component in high hardening temperature or holding the parts for a very long time will result in low hardness due to the presence of excess retained austenite. By using the correct temperature and the specified holding time for hardening this defect may be avoided.

Decarburization A decarburized layer will also lead to low hardness. Treating parts in a muffle furnace without a neutral atmosphere, or the nondeoxidation of parts during treatment in a molten salt bath, leads to surface decarburization. The decarburized layer will have a lower carbon compared to the inside layer. This will result in low hardness and a reduced tool life. Hence it is advisable to use a controlled atmosphere furnace. The molten salt baths should be deoxidized with borox or ferrosilicon, etc., regularly.

Slow Quenching Speed If the components are cooled slowly, it results in an unwanted transformation into pearlite or bainite—both softer than the desired hard martensite.

structure. This may be due to the wrong choice of quenching medium, contaminated bath, insufficient agitation, or a very high bath temperature.

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Heat Treatment Furnaces

Furnaces used for different heat treating operations depend on the temperature employed, which in turn depends on the amount of components to be treated. Furnaces available to suit the heat treatment requirements may be classified as follows:

1. 150–700°C—used for nitriding, tempering, stress relieving, annealing, etc.
2. 650–1000°C—used for hardening, normalizing, carburizing, annealing, etc.
3. Over 1000°C—used for hardening of hot work steel, high speed steel, sintering, etc.

Furnaces that are used for different types of heat treatment processes may be divided into batch-type and continuous type furnaces.

3.1 Continuous Furnaces

Continuous furnaces are suitable for the production of a large volume of similar parts, made of the same grade of steel and subjected to the same treatment. In continuous furnaces, the parts to be treated are charged at one end of the furnace and discharged at the other end after the treatment is over. Since the continuous furnaces operate on mass production, it is essential to determine well ahead the working parameters such as the desired temperature, the conveyor required and its speed, etc., to obtain uniformity of heating. Quenching and cooling are done in a fixed fashion.

In particular, these furnaces are designed for a specific treatment and operate at a predetermined temperature. They may be operated with or without atmospheric control. These furnaces may be designed to carry out annealing, normalizing, hardening, carburizing and similar treatments.

Capital and installation costs of continuous furnaces are very high compared to batch-type furnaces, although running costs are usually considerably lower due to the efficiency of work flow and the reduced amount of labour. To be more economical, continuous furnaces should be operated 24 hours, for otherwise the interest on idle capital employed would be high.

By definition, continuous furnaces incorporate a method of moving the charge from the charging end, through the furnace, to the discharge end, in a controlled manner. The type of mechanism employed decides the basic design and gives the furnaces its generic name, such as shaker hearth, pusher type, rotary retort, belt conveyor, rotary hearth, and

so forth. Furnaces most commonly used are explained below.

3.1.1 SHAKER HEARTH FURNACES

This furnace is used for direct hardening with atmosphere control, tempering, carbonitriding and case-hardening (smaller case depth). The hearth design incorporates a serrated cast hearth. The serrations are at right angles to the direction of flow (Fig. 3.1).

In a typical automated installation, the components are fed on to the hearth by means of a hopper or a vibrating feed. They are moved along the hearth by means of a reciprocating shaker motion at a predetermined and adjustable rate until the quenching chute is reached. Components are austenitized or carburized before they reach the quenching chute, avoiding thereby all exposure to atmosphere which may cause scaling. The quenching media are usually oil or water-based quenchants. It can also be provided with a molten salt bath in order to carry out austempering treatment. After quenching, the parts are conveyed automatically through the quenching bath to a washing and drying set-up.

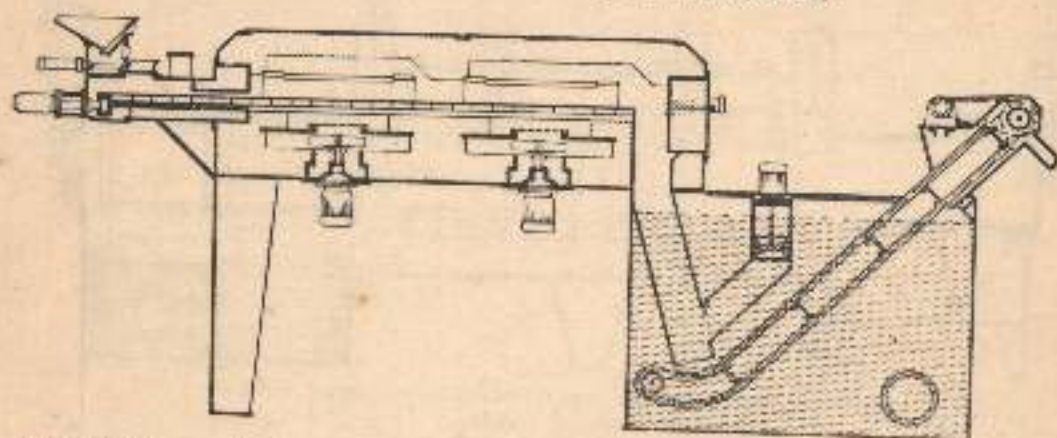


Fig. 3.1 Shaker hearth furnace with forced circulation and sealing of the charging end to improve atmosphere circulation and controllability (Courtesy: Ipsen Industries International, GmbH, W. Germany)

This type of furnace is more suitable for handling small components. The process is mainly used for the production of components such as bolts, springs, screws, clips, bearing races, sewing needles, etc. A protective atmosphere ensures a bright finish.

3.1.2 ROTARY DRUM FURNACE

This furnace can be used for controlled atmosphere hardening, carburizing, and carbonitriding of small parts such as fasteners and bearings. The drum is made of cast nickel-chrome and may be heated by electrical resistance elements or gas-fired.

The furnace drum is mounted horizontally, rotating around the horizontal axis or an inclined axis. Usually, such furnaces are charged through a hopper. A steady flow of the charge through the drum is maintained by a spiral thread on the inside wall of the drum throughout its length. The spiral rib can move the charge in a forward or backward direction. The frequency and duration of the forward or reverse motion can be varied over any desired range. Since the charge is advanced at a controlled rate and exposed

uniformity to the furnace atmosphere, uniformity of charge temperature is possible. The load is heated and finally discharged into a liquid quench via a chute at the far end of the furnace. Special provisions may be made in the quenching chute and tank to allow for the use of water-based quenchants and the treatment of a wide variety of part sizes and configurations.

3.1.3 **PUSHER-TYPE CONTINUOUS FURNACE**

On the basis of tonnage, pusher-type furnaces are by far the most widely used of continuous furnaces (Fig. 3.2 to 3.4). They may be used for hardening, tempering, normalizing

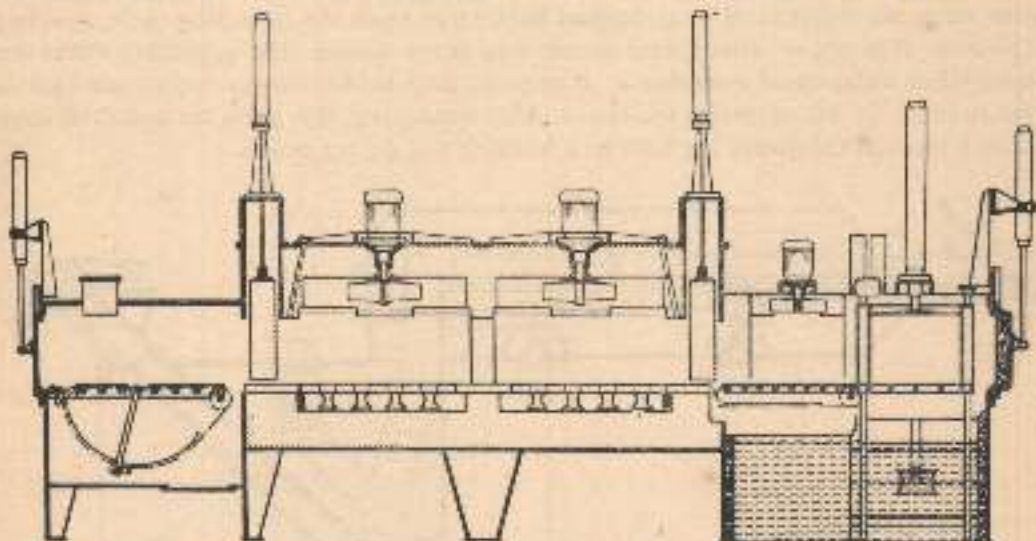


Fig. 3.2 Continuous pusher-type furnace (Courtesy: Ipsen Industries International GmbH, W. Germany)

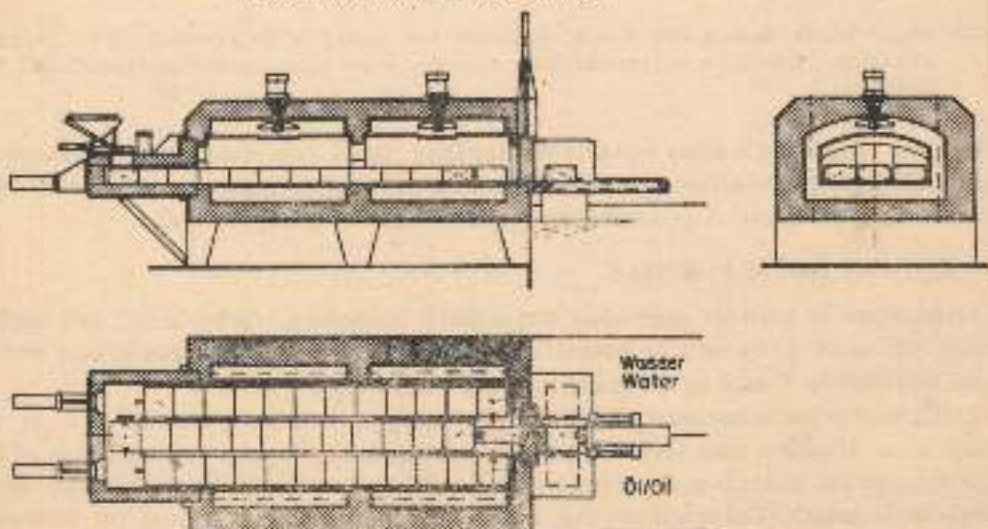


Fig. 3.3 Return pusher furnace (Courtesy: Ipsen Industries International, GmbH, W. Germany)

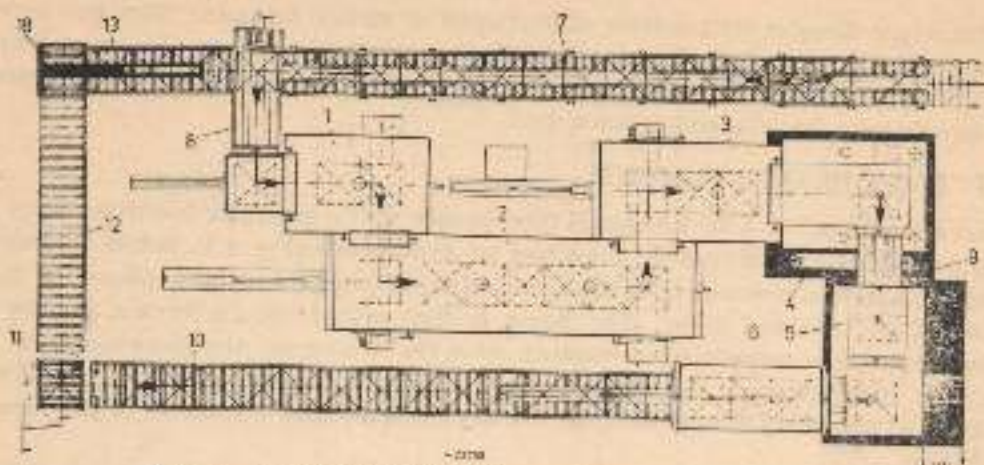


Fig. 3.4 Pusher-type continuous furnace (Courtesy: Ipsen Industries International GmbH, W. Germany).

or carburizing. In this method, parts are placed on the robust heat-resisting trays which are pushed through the working chamber at pre-determined time intervals by means of a pusher operated by a hydraulic or mechanical drive. After completion of the treatment, the discharge end may be equipped for quenching or slow cooling, as required. Heating or pusher furnaces are mostly heated by gas. When controlled atmospheres are used, gas lock chambers may be used to minimize air ingress.

3.1.4 ROTARY HEARTH FURNACE

It comprises essentially of a ring-like bottom rotating around the vertical axis. Rotary hearth furnaces are heated electrically. These furnaces are employed to heat for forging, end-stamping and for hardening.

3.2 Batch-type Furnaces

Batch-type furnaces are mainly used for the treatment of low volumes of parts. They are designed to carry out different types of treatment in the same furnace. They may be used for different grades of steel and for different types of components. Some furnaces are of the universal type, suitable for many types of heat treatment. For instance, the same furnace can be used for carburizing, hardening, annealing, normalizing, stress-relieving and similar treatments. In a batch-type operation, a batch of parts charged into the furnace are heated to the desired temperature, soaked for the desired length of time and withdrawn from the furnace as a whole batch. Subsequently, the next batch is treated in the same way. The batch may differ from one another in size, grade of steel or the type of heat treatment required. Consequently, different heat treating durations and temperatures are to be employed. The initial cost of investment for batch type furnaces is lower compared to continuous furnaces. They may be operated with or without a controlled atmosphere.

Batch-type furnaces are better for long cycles required to produce a deep case.

Batch-type furnaces are available as horizontal or vertical furnaces. They may be used for annealing, hardening, carburizing, nitriding, nitrocarburizing, etc. The most important furnaces include the sealed quench, rotary drum, salt bath and vacuum furnaces, bell-type furnace, bogie hearth furnace, etc.

3.2.1 BOGIE HEARTH FURNACE

This is a modification of the horizontal type furnace with a moveable hearth mounted on wheels to facilitate loading and unloading of components (Fig. 3.5). Before loading the bogie, the hearth is removed from the furnace and the components are placed in it by means of an overhead crane. The bogie is then pushed into the furnace, keeping the furnace atmosphere airtight when required. After the treatment, the discharging of the charge is done through the entrance only. These furnaces may also be provided with loading and unloading at opposite ends to carry out quenching operations in the case of hardening.

The bogie hearth furnace is mainly used for hardening large components and for annealing alloy steel forgings, stress relieving, etc.

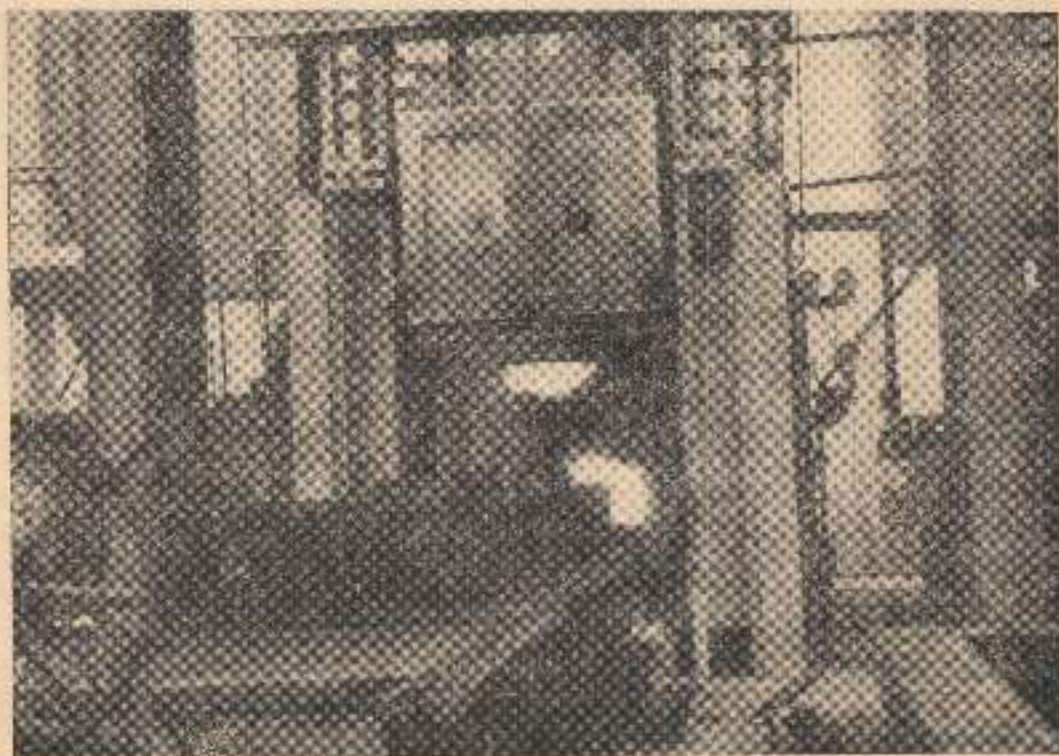


Fig. 3.5 Gas-fired high-temperature bogie hearth furnace (Courtesy: M/s Wellman Incandescent India Ltd, Calcutta)

3.2.2 MUFFLE FURNACE

This is a horizontal-type batch furnace, the simplest and cheapest for carrying out

many of the heat treatment operations. This furnace can be used for the treatment of stress relieving, annealing, pack carburizing and for hardening of low alloy steels. The standard muffle furnace consists of a furnace chamber which is rectangular in section (Fig. 3.6). The charging and discharging is done through hinged doors. The furnace of the chamber is made of high alumina refractory bricks with grooves for supporting the heating elements. Heating is effected by means of a resistance wire made out in coil form and placed inside the refractory groove. The temperature of the heating chamber is controlled by a thermocouple, usually entering through the rear wall of the chamber which, in turn, is connected to the pyrometer for automatic temperature control.

This type of furnace is used for the treatment of small and medium sized components. Loading and unloading is done manually, and for heavier components, a zig-crane or an overhead crane may be used.

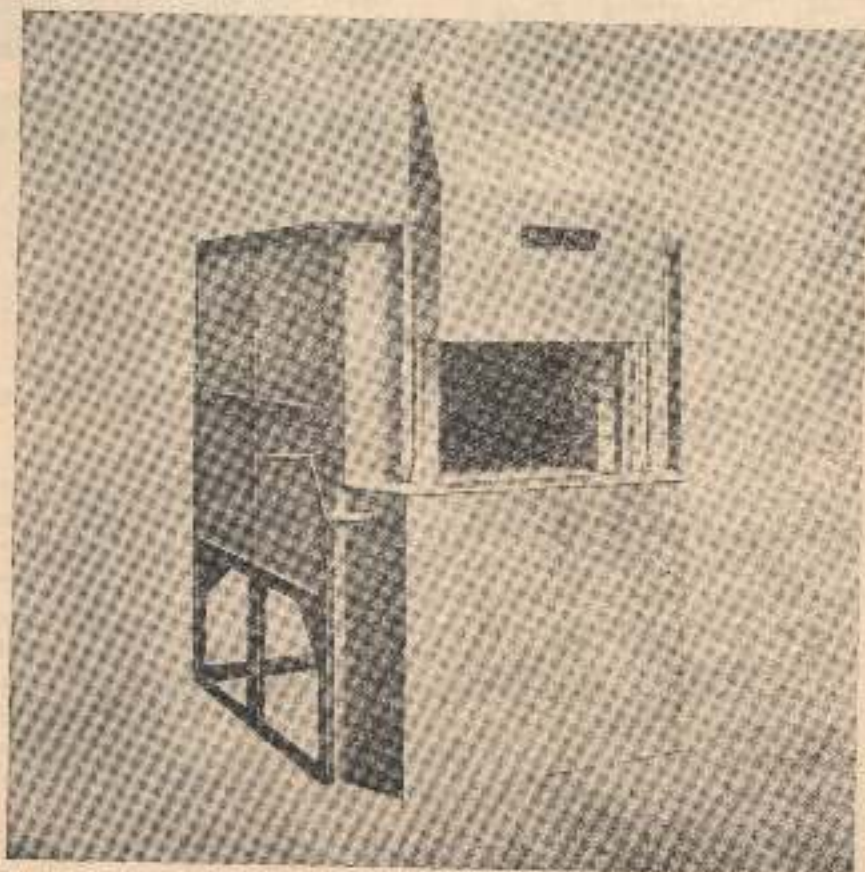


Fig. 3.6 Muffle furnace (Courtesy: Degussa, W. Germany)

3.2.3 SEALED QUENCH FURNACE

This type of furnace can be used for various types of components and for diverse heat

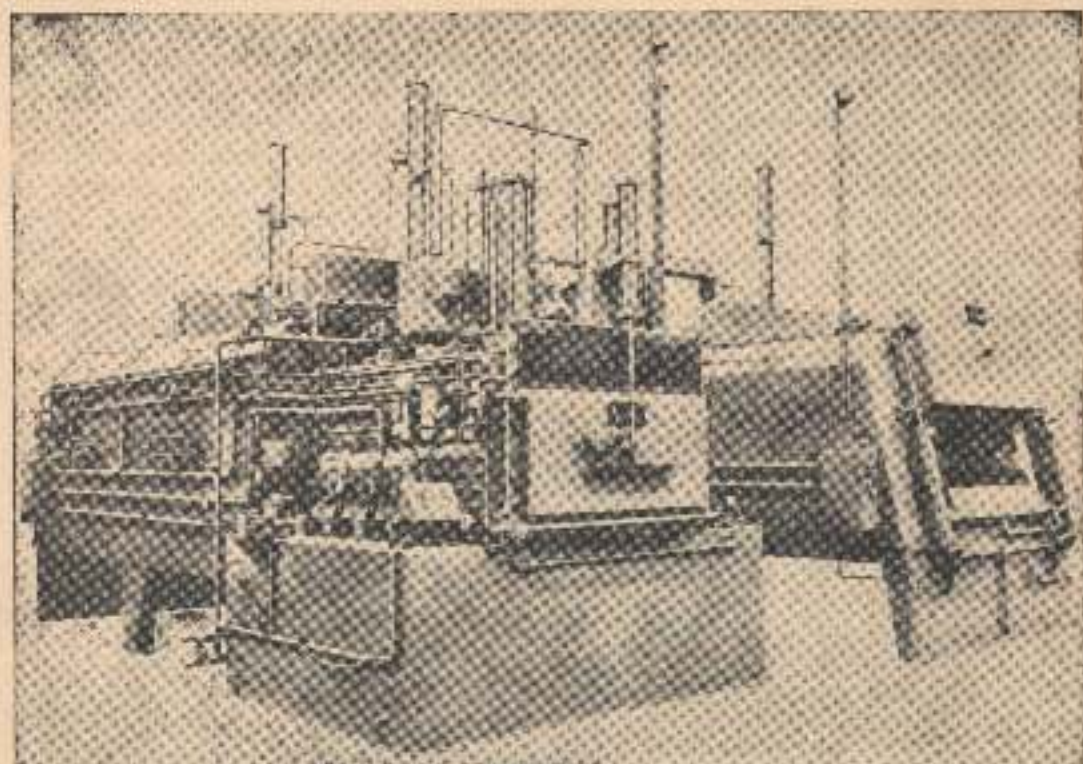


Fig. 3.7 Ipsen sealed-quench, twin-chamber, multipurpose atmosphere furnace (Courtesy: Ipsen Industries International GmbH, W. Germany)

treatments (Fig. 3.7). It can be employed for bright hardening, bright normalizing, carbonitriding, and carburizing. These furnaces are of a well-known design—electrically heated, arranged horizontally, and incorporating an integral tank and an atmosphere lock. Furnaces may be provided with fans for the purpose of heating by conduction and also for distributing the atmosphere around the work to ensure uniformity of heat treatment during the treatment of the parts. After the charge has been at the given temperature for the required length of time, it is passed to the quenching chamber. The desired atmosphere is maintained during the process with the help of the atmosphere panel, comprising of a flow meter and valves for butane or propane, ammonia and endogas, etc.

The quench tank is provided with a suitable cooling system in which a pump circulates the oil through an external cooler.

Temperature control is effected by an automatic temperature control system.

Although it operates as a batch type furnace from the work handling point of view, it is a continuous furnace atmosphere-wise. Under working conditions its furnace and ante-chamber doors operate alternatively so that the atmospheric condition in the treatment chamber remains constant and control is possible. Since quenching is carried out under sealed atmosphere conditions, the charge is produced completely free from scale.

The sealed quench furnace is an expensive equipment, the principal merit of which

is that by quenching under atmosphere completely scale-free finish is achieved. So, a sealed quench furnace is necessary when the foremost requirement is freedom from scale. However, it is not suitable for long slender parts, such as camshafts, drilling spindles, long main spindles and similar components, since the components are to be quenched individually which takes time, apart from the tendency to warp.

The sealed quench furnace system comprises:

1. Loading and unloading table
2. Sealed quench furnace
3. Power-operated charging machine
4. Endogas generator or suitable gas
5. Atmosphere control and distribution panel
6. Gas analyser
7. Cleaning machine.

3.2.4 PIT-TYPE FURNACE (VERTICAL TYPE FURNACE)

This type of furnace may be used for hardening, bright normalizing, bright annealing, carburizing, nitriding, etc. The main advantage of using a pit-type furnace is that it reduces

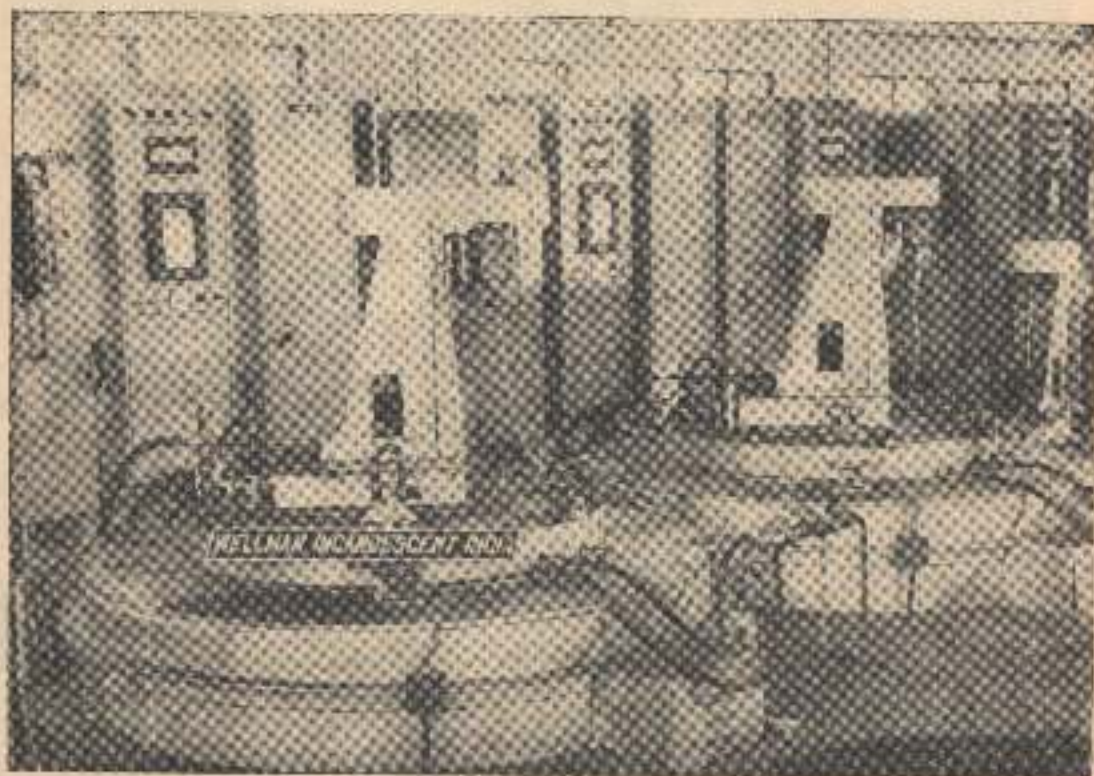


Fig. 3.8 A battery of electrically heated pit-type nitriding furnaces (Courtesy: M/s Wellman Incandescent India Ltd., Calcutta)

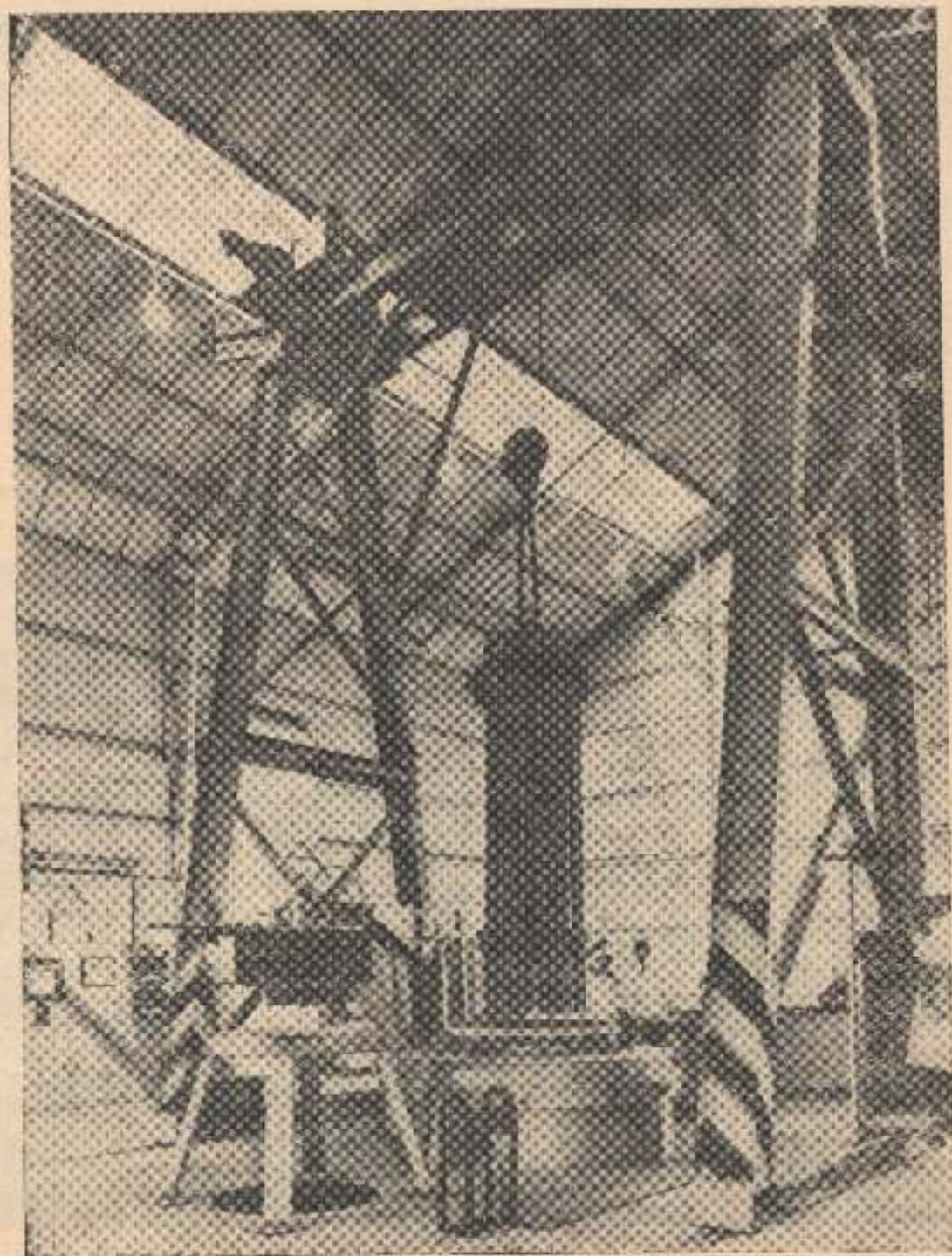


Fig. 3.9 Gas-carburizing, pit-mounted, 3-zone furnace designed for gas carburizing rock-drill extension shafts in a suspended retort (Courtesy: Wild Barfield Ltd, England)

distortion in the case of long, slender parts like spindles and cam shafts, as they can be hung vertically in a suitable fixture and can be removed from the hearth without the need for taking out each component separately, as is the case with horizontal type furnaces. This also avoids the need for individual quenching of components and likely heat losses due to repeated opening and closing of the furnace door, as is usually done on any horizontal type furnaces. The pit-type furnace enables feeding of the complete charge of components suspended in a suitably designed heat-resistant alloy fixture. Quenching can be effectively done by lowering this entire fixture in the quenching bath. Loading and unloading of the charge can usually be done by an overhead crane.

The standard pit-type furnace consists of a chamber that is cylindrical in shape (Figs. 3.8, 3.9). The outer casing is made of mild steel sheets. The casing is supported by a mild steel channel framework. The steel casing encloses the refractory chamber which can withstand the desired temperature and also the insulation brick in between. Suitable refractories are used for the heating chamber; and the innermost lining will have special grooved refractories to carry the heating coils. The hearth of the furnace is made of heavy duty refractory brick-work suitable to carry the load.

Heating is effected through coil-type resistance heaters, suitably designed and supported in the refractory grooves, which in turn are connected to the electrical control equipment of the furnace. The furnace can be sealed with suitable doors so that a controlled atmosphere is obtained within it. The furnace door is equipped with a switch which acts as a protective device, cutting off supply to the element when the door is opened.

Pit-type furnaces may also incorporate a retort for charging the components. The use of metallic retorts allows a high degree of control over the process atmosphere operating under batch conditions, where rapid restoration of the correct composition is essential after each loading of the furnace. Fans are often incorporated to promote both uniformity of temperature and gas circulation.

For hardening and case-hardening treatments, either a sealed quench or a pit-type furnace can be used. A choice of atmosphere between endogas and drip-feed liquids can be made with the pit-type furnace. Also, the pit-furnace is cheaper and will give a better payload-cost ratio. In cases where complete freedom from scale is required, a sealed quench furnace is necessary, but in many cases, a pit type furnace may well be the better all-round choice. For long components a pit type furnace has necessarily to be used.

3.2.5 BELL FURNACE

The bell furnace (Fig. 3.10) is a vertical batch furnace used for bright annealing, stress relieving, nitriding, bright normalizing and ion nitriding. It consists of a bell-shaped heating furnace with electrical heating elements. This is used to serve several insulated hearths in which the charge is held. When one hearth has been heated, the furnace can be moved to a fresh hearth and the first hearth is left to cool in its protective atmosphere. Generally, the hearths are either circular or rectangular in section. They are surrounded by sealing troughs which are filled with a suitable sealing medium, such as sand, low-melting metal, etc.

Bell furnaces offer many advantages. They enable the transfer of the heating furnace from one hearth to another immediately on the completion of the heating cycle. This results in an economical heating procedure, as the furnace body is not continuously cooled

and reheated. However, this requires more floor space and needs an overhead crane of sufficient capacity to deal with the bell and the particular charge being processed.

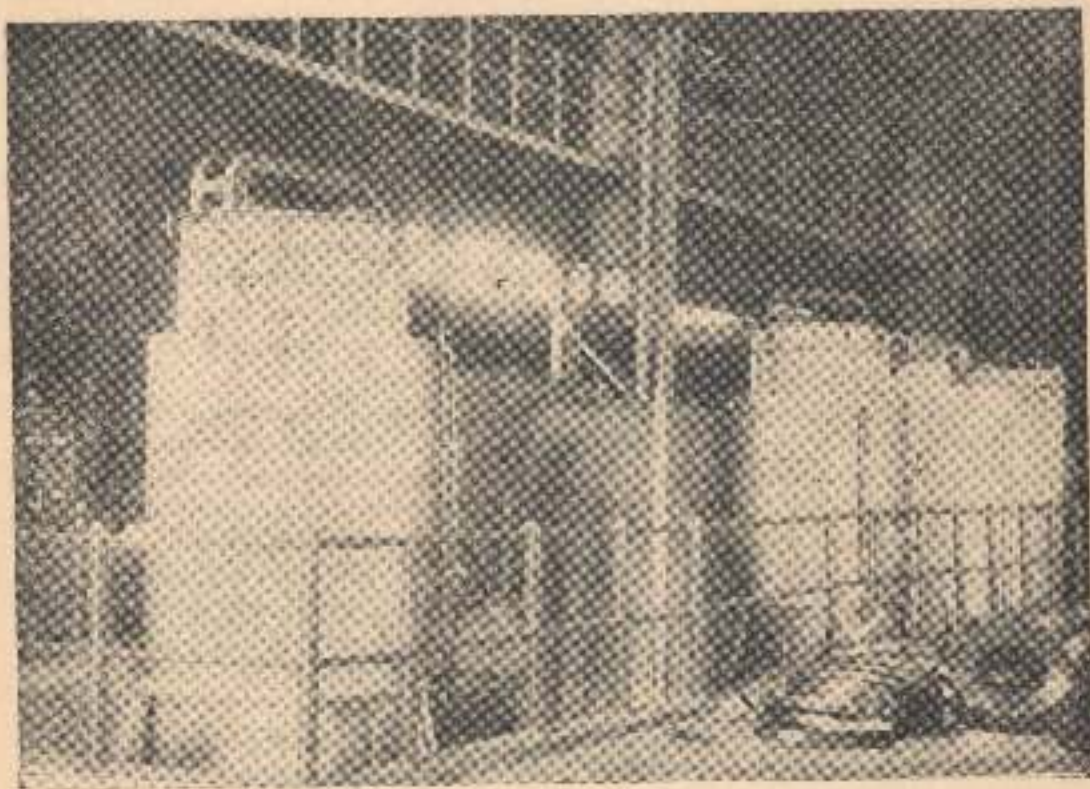


Fig. 3.10 Electrically heated strip-coil bell-type annealing furnace (Courtesy: M/s Wellman Incandescent India Ltd, Calcutta)

3.2.6 IMMERSE ELECTRODE SALT BATH FURNACE

This furnace is suitable for hardening, carburizing, annealing and similar treatments. Heat efficiency of the bath is more compared to the other conventional furnaces. This type of furnace is suitable for mass production of medium and small-size components (Fig. 3.11).

In this method, a component to be heat-treated is immersed in a molten salt contained in a steel or refractory pot and is heated by conduction. The salt is melted by passing an A.C. supply through the immersed electrodes. As a result of the resistance built up by the passage of current through the salt, heat is generated within the salt itself, and this results in molten salt. The molten salt is electrodynamically stirred because of the magnetic field induced around the electrodes, giving a high thermal uniformity in the bath. It prevents overheating of the salt near the electrodes (Fig. 3.12).

The furnace consists of a casing, which is fabricated with a mild steel sheet of suitable

thickness. The steel casing will have sufficient strength and structural rigidity. It encloses a refractory chamber which can withstand the high temperature and the resistivity to chemical bath, and also the insulation brick in between. A pot is provided inside the chamber. Three electrodes are immersed in the pot. The cross-section of the electrodes is

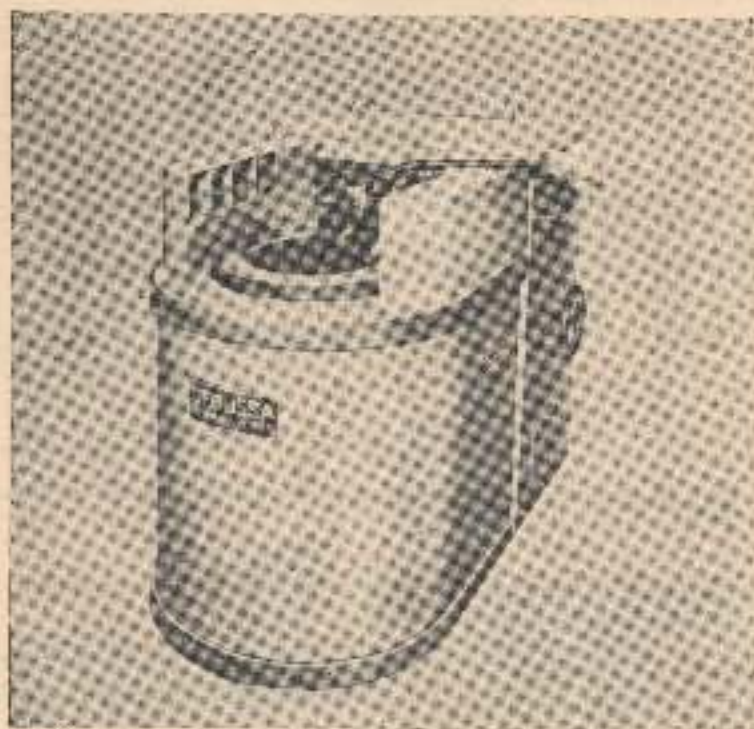


Fig. 3.11 Electrode metal pot salt-bath furnace (Courtesy: Degassa, W. Germany)

square or rectangular, because flat, opposing surfaces afford a better concentration of the magnetic flux than that offered by curved surfaces. The electrodes will be of a suitable cross-section and made of mild steel. They are connected to the secondary of the transformer by means of copper or aluminium bus bars of adequate capacity (Fig. 3.12).

For heating the salt, current is supplied by the transformer which converts the line voltage to furnace voltage (10–15 volts), together with a necessary tap to adjust the rate of input. In view of the large cross-section of the salt, low voltages and high currents are required.

A fume hood is mounted on to the furnace and connected to an exhaust for suction of all fumes produced during operation.

The temperature of the bath is automatically controlled by means of a system consisting of a thermocouple, pyrometer, relay and a magnetic contactor.

Refractory pots are preferred for use with neutral salts, free from cyanide or carbonate.

Steel pots are suitable both for hardening and carburizing. The shape of the pot may be oval or rectangular.

It is most important that the room in which the furnace is installed should have a high roof, be well-ventilated, and used only as a hardening shop.

Compared to the other conventional furnaces, the initial investment for the salt bath furnace is very low. The floor space and maintenance is minimum. The worn-out electrodes can be replaced while the furnace is in operation and do not necessitate costly shutdowns.

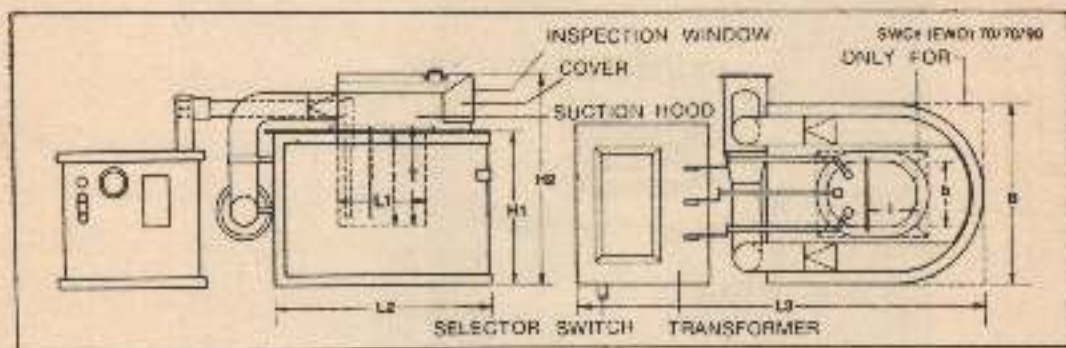


Fig. 3.12 Sectional view of electrode salt-bath furnace (Courtesy: Degussa, W. Germany)

The main disadvantage is the removal of the worn out pot which requires considerable force and may damage the surrounding area.

Starting of the Bath Solid salt is so good an electric insulator that it does not carry significant amounts of current subjected to the normal operating voltage of the furnace. Due to the above reason, salt has to be melted first by means of an auxiliary device or blow torch, until there is enough melt between the electrodes.

The heating-up device consists of an U-shaped steel frame equipped with copper connection pieces. This device is put into the preliminary heating chamber provided on the electrodes, and the other end is immersed in the bath. The electrical connection is then given. Salt is now added to the bath and the furnace is started at low taps of the transformer. After sufficient melting, the heating device is taken out as the resistance path for the current is now through the molten salt.

Before shut down of the furnace the heating device should be again placed inside the electrode chamber and the same procedure given above should be followed when starting the furnaces again. It is necessary to ensure that the device should be dry before inserting as otherwise spurting may take place. While the above procedure employs electrodes for initial melting, the salt may also be melted by using an oxyacetylene blow torch.

The torch should be of sufficient capacity and melting should start near the electrodes to permit the electrodes to assume the energy supply as early as possible through the liquid medium. A liquid pool may surround and connect all electrodes over their entire length, but the salt at the far end from the electrode may still be solid. Then the voltage must be cut down to avoid overheating of the salt.

3.2.7 HIGH TEMPERATURE SALT BATH FURNACE

The furnace can be used for hardening of high speed steels and hot work steels. The hardening furnaces are refractory lined and resistance heated using the salt as the resistor current being fed from three massive electrodes set into the furnace walls (Fig. 3.13). The bath is electro-dynamically stirred by the magnetic field induced around the electrodes, giving a high degree of thermal uniformity within the bath. The temperature of the bath may be maintained within plus or minus 5°C and this leads to uniformity of hardness on quenching.

The casing of the equipment is of mild steel fabrication with suitable thickness. It has the requisite strength and structural rigidity. It will be usually placed on suitable channels

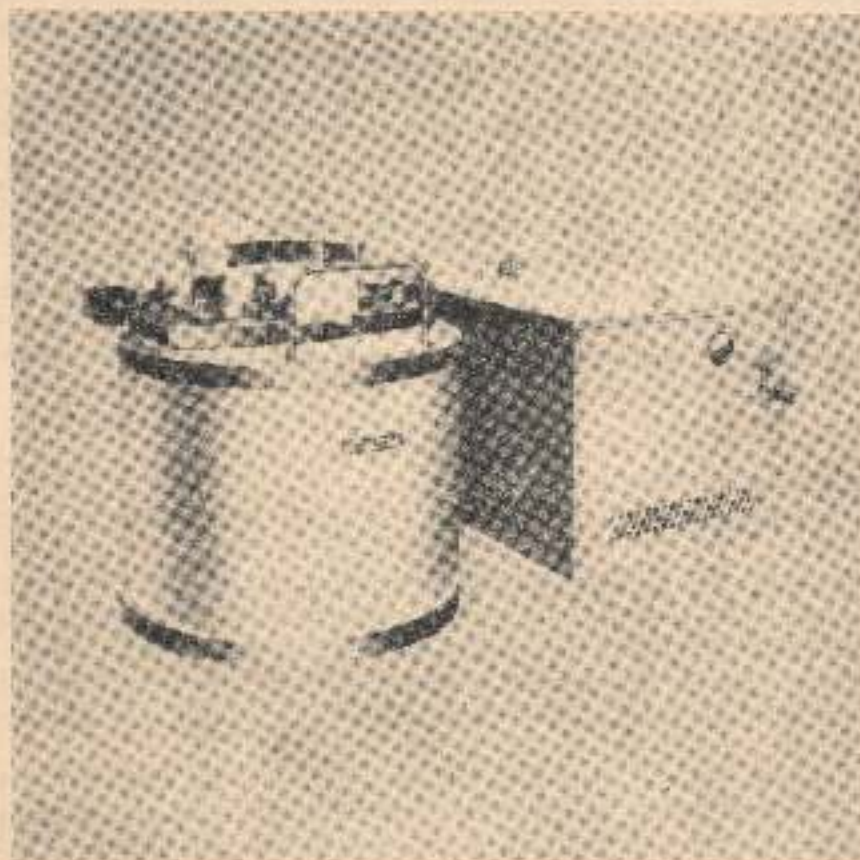


Fig. 3.13 High-temperature salt-bath furnace (Courtesy: Degussa, W. Germany)

for a convenient working height. The steel casing encloses a refractory chamber, and insulation brick work in between, which can withstand the high temperature and display resistivity to chemical salts. A high alumina-content silimanite pot, the inside of which is in the form of segments, will form the actual working area. Necessary grooves are provided around the diameter of the pot for inserting the three electrodes.

Heating is effected through three electrodes provided inside the bath. The electrodes are of a suitable cross-section and made of low carbon steel or steel containing 28% chromium and 2% nickel. These electrodes are connected, by means of copper or aluminium bus bars of adequate capacity, to the secondary of the transformer to enable the furnace to be heated rapidly to the working temperature. The transformer is equipped with a range of tappings and a tap changing switch, enabling accurate manual control of the bath temperature. Alternatively, an automatic control can also be fitted. A fume hood is provided at the rear of the bath to suck the fumes and expel them through the exhaust system.

It is most important that the temperature control system should be in the range of $\pm 5^{\circ}\text{C}$ to avoid the ruining of costly tools.

Starting of the Bath Salt in the cold condition does not carry current. It has to be melted by an auxiliary device until there is enough melt between the electrodes. The necessary heating device or auxiliary electrodes are supplied with the furnace itself.

Three auxiliary electrodes supplied with the plant are bolted to the legs prepared for them on three of the main electrodes, the ends of which are dipping into the bottom of the pot. A small amount of salt is spread at the bottom. A graphite disc is placed between the three electrodes and pressed against the ends of the auxiliary electrodes. Now the transformer is switched on and the maximum voltage supplied. The graphite disc becomes incandescent and melts the adjacent salt forming a pool through which the electric current now flows. Small quantities of salt are periodically added to the pool. After sufficient melt is prepared, the auxiliary electrodes are removed. The temperature may now be raised; the transformer tapping can be adjusted to increase the flow of current for a faster rate of heating to the desired temperature.

3.2.8 TEMPERING FURNACES

Tempering may be carried out in a molten salt bath, air furnace or oil bath.

Oil Bath Tempering The furnace is suitable for tempering up to 250°C . It consists of a steel tank surrounded by a suitable sturdy casing and refractory lining. The bottom of the casing is provided with a suitable grooved refractory brickwork in which coiled wire heating elements are placed. The furnace should be provided with a suitable temperature control system. It is also provided with a section hood if the bath is operated above 150°C .

Salt Bath Tempering Furnace Such furnaces are widely used for tempering steels of all types. They are employed for temperatures above 150°C . Since molten salt surrounds the parts, it promotes a faster rate of heating compared to conventional tempering furnaces (Fig. 3.14).

Components to be treated should be free from oil or grease and free from moisture to avoid spurting of the salt, because molten salt reacts violently with moisture. The salt mixture that is used for tempering is mentioned in Table 2.5. These salts are commercially available. To avoid violent explosions it is most important that the part treated in the cyanide bath should not be placed directly in it.

The furnace consists of a fused salt in a steel pot or cast iron pot. The pot is surrounded by a suitable sturdy sheet casing. The pot is provided with a refractory brickwork in which

coiled wire heating elements are placed. These are backed by suitable layers of insulating media. The furnace is heated by means of heating coils and provided with an automatic temperature control system. The temperature range that can be used is about 150 to 600°C.

This furnace can be used to temper all types of steels and for stress relieving.

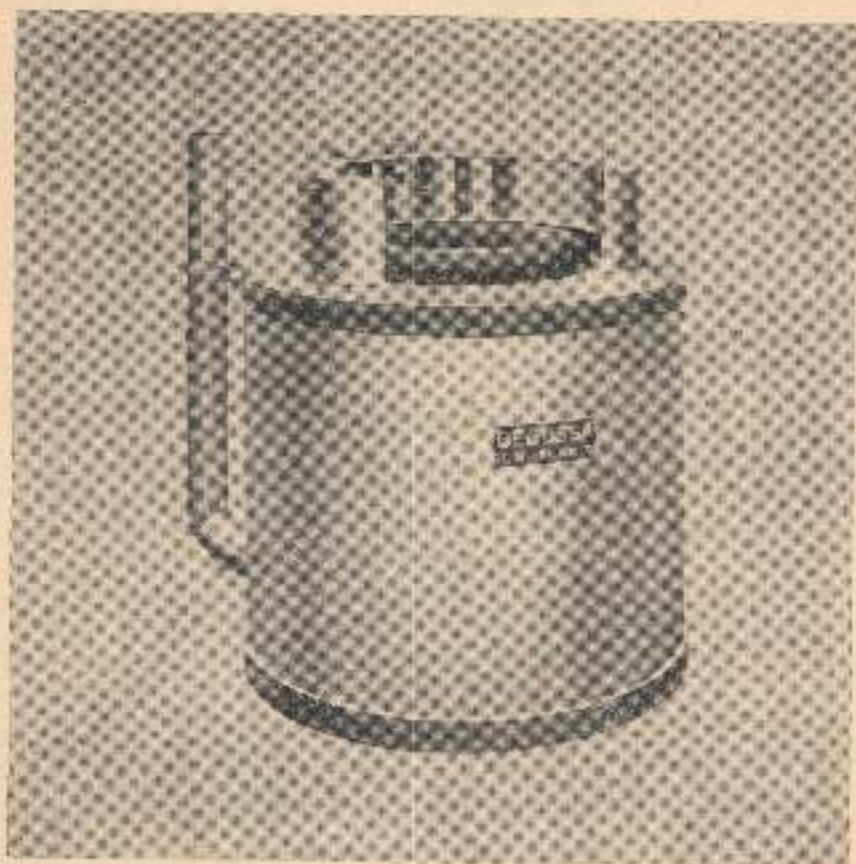


Fig. 3.14 Salt-bath tempering furnace (Courtesy: Degussa, W. Germany)

Convection Furnace Tempering may be carried out with the help of forced air circulation in a furnace (Fig. 3.15). The advantage of a forced air circulation furnace is the penetration of the heat transfer medium (air, etc.) into the interior spaces of the charge, if the latter is composed of many small parts. It is known that, at low temperatures, heat transfer is mainly dependent on the circulation of air in the form of convection currents. Hence, it is necessary to have forced air circulation at lower temperatures.

The furnace essentially comprises a heat-insulated chamber of cylindrical dimensions with an inner, concentric metal liner of baffle which serves to prevent direct radiation from the elements on to the charge and confines the air to a definite path. Specially design-

ned heating elements are mounted in the annular space formed by the chamber walls and the liner. The inner liner is supported in the chamber by the throat which in turn is carried on pillars secured to the baseplate.

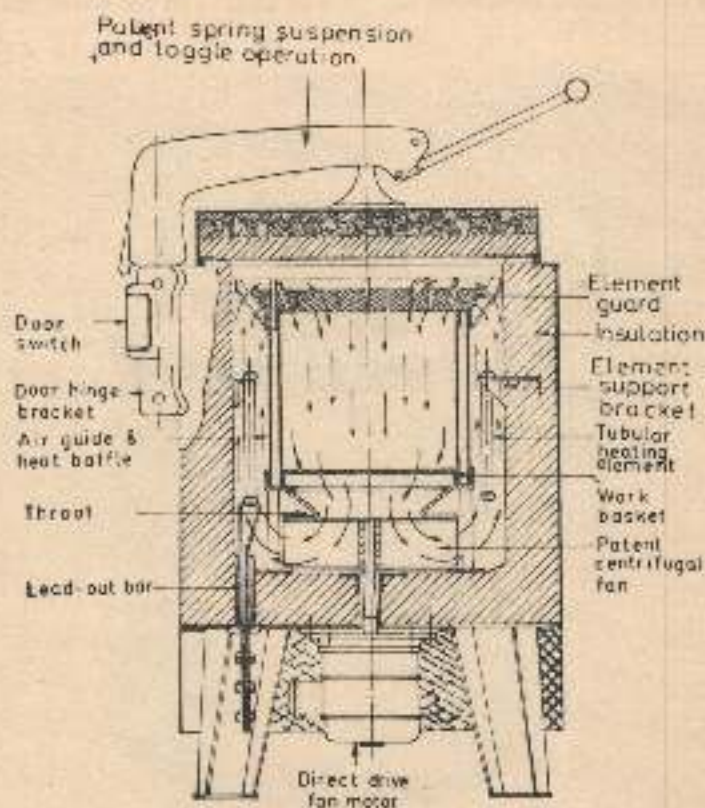


Fig. 3.15 General arrangement of vertical forced-air-circulation furnace.

While in operation, the centrifugal fan at the base of the chamber beneath the throat creates a vigorous and high velocity air circulation. Due to the design of the furnace interior, this circulation is restricted to a definite and closed circuit in which the only material resistance to air flow is offered by the charge itself. It will be clear that the circulating air first passes upwards over the heating elements from which it absorbs heat, and then down through the charge to which the heat is imparted. The components to be tempered are placed in a work basket provided with a perforated base which, when charged into the furnace, rests inside the inner lines upon the throat.

3.2.9 VACUUM FURNACES

The development and application of vacuum heat treating of metals has been going on for the last 30 years. Vacuum furnaces can be used for heat treating steels and non-ferrous alloys as well as super alloys in the place of conventional methods such as controlled atmo-

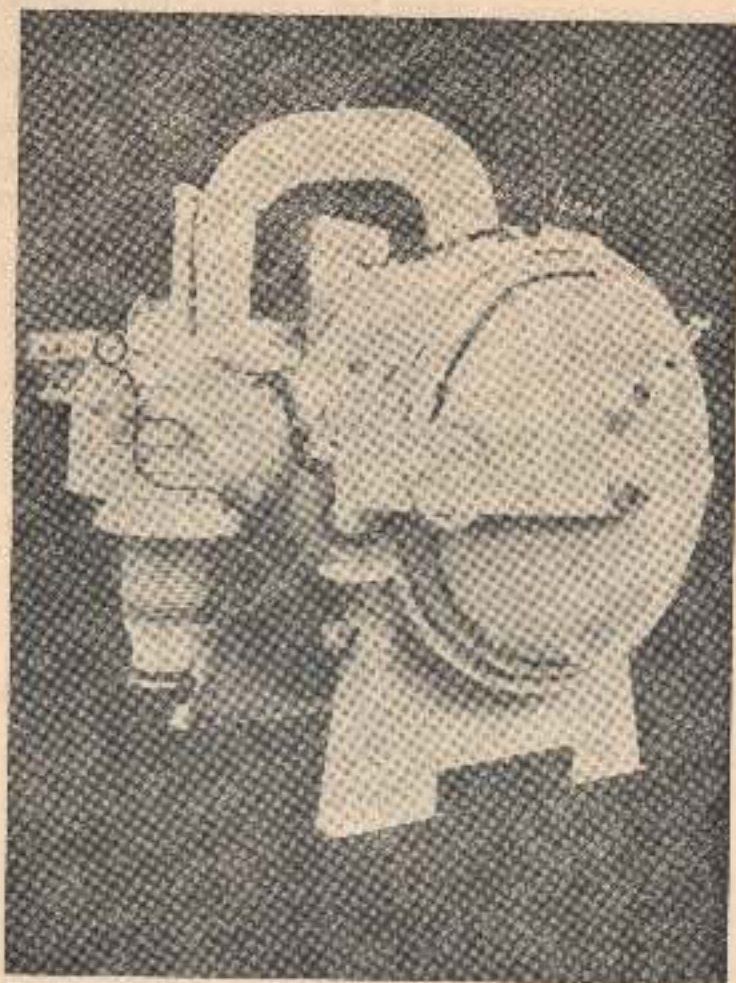


Fig. 3.16 Ipsen single-chamber vacuum furnace with high-pressure gas quenching (Courtesy: Ipsen Industries International, GmbH, W. Germany)

sphere or molten salt bath (Fig. 3.16). Vacuum furnaces provide the necessary conditions for clean atmosphere without which the heat treatment of various sophisticated aircraft engine components would not be possible. Vacuum heat treating is gaining more application since it ensures consistent metallurgical characteristics on the components together with less deformation and brilliant surface. Vacuum furnaces are now available in a modern design which has eliminated the limitations of the previous models.

Unlike conventional atmosphere heat treatment, vacuum heat treatment does not require control of the carbon potential of prepared atmosphere and related furnace-conditioning requirements. In atmosphere heat treating, the water vapour content or dew point of a protective gas atmosphere is often the most critically controlled variable in addition to the temperature and time of processing during heat treating.

The essential difference between vacuum heat treating and other heat treating methods is the evacuation of the heating chamber during heating-up and holding. Subsequently, the components are cooled or quenched depending on the specific process requirement. The evacuation of active gases provides an absolute neutral condition and prevents the occurrence during heat treating of surface reactions such as oxidation, decarburization, etc.

The term *vacuum* as applied to vacuum heat treatment, is a misnomer if interpreted in its literal sense, because the process is usually carried out within a pressure range of 10-

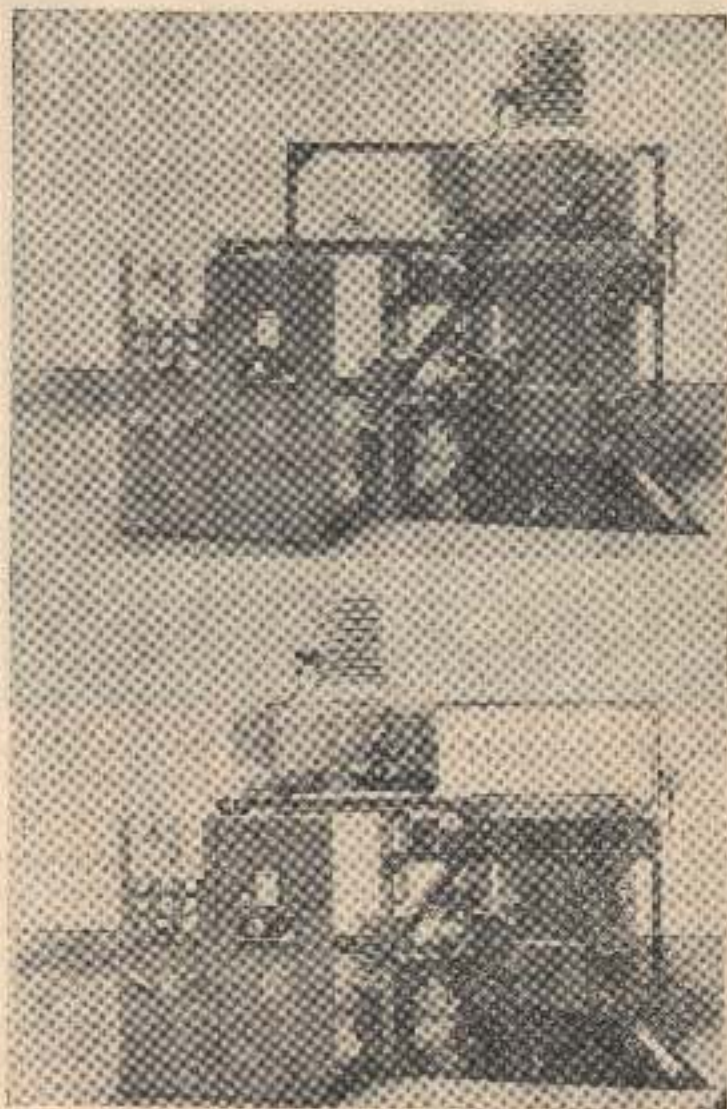


Fig. 3.17 Top-loading cold-wall vacuum furnace (Courtesy: Ipsen Industries International, GmbH, W. Germany)

500 microns and hence can be designated as partial pressure treatment. However, at this level of vacuum, chemical activity is negligible and, for all practical purposes, the atmosphere may be considered inert.

Absolute vacuum is technically neither attainable nor necessary. Vacuum conditions therefore always represent a certain gas pressure which is usually expressed in either 'torr', 'micron' or 'Pascal'. One torr corresponds to 1 mm of mercury at 1/760 atmosphere or 1.3×10^{-3} bar, 1 micron corresponds to 1.3×10^{-6} bar.

Types of Vacuum Furnaces Vacuum furnaces are usually cylindrical and may be constructed horizontally or vertically. The size and shape of the component usually determines the type of furnace best suited for the heat treatment application. They may be grouped into three basic designs.

(i) **PIT TYPE FURNACE** These furnaces are used for processing long slender components as well as light components. The components to be treated are suspended vertically in a suitable alloy fixture (Fig. 3.17).

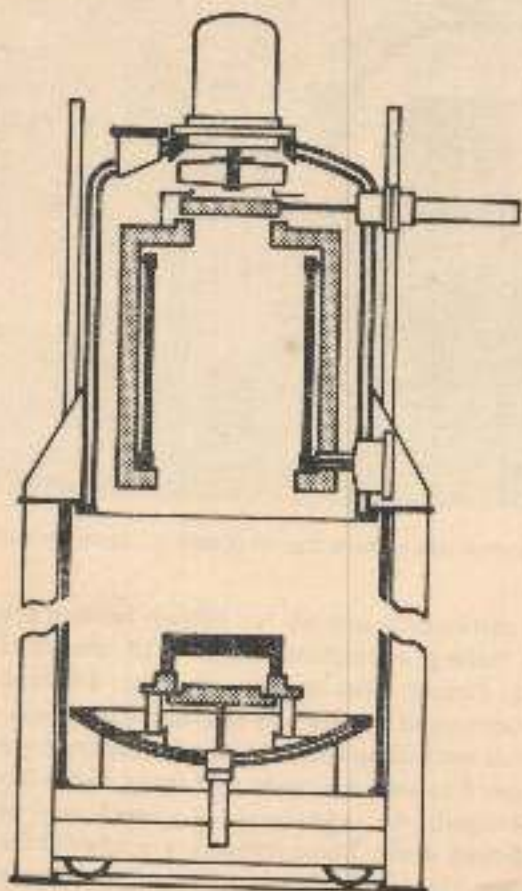


Fig. 3.18 Bottom-loading cold-wall vacuum furnace
(Courtesy: Ipsen Industries International,
GmbH, W. Germany)

(ii) **BELL TYPE FURNACE** The furnaces are suitable for handling large heavy components. Here the work to be treated is loaded in a suitable fixture or trays and are placed on the hearth when the bottom is in the lowered position (Fig. 3.18).

(iii) **HORIZONTAL TYPE FURNACE** Horizontal type furnaces are more commonly used. They are available both as batch type and continuous type vacuum furnaces with several zones for loading, high temperature processing and cooling by gas or liquid (Fig. 3.19).

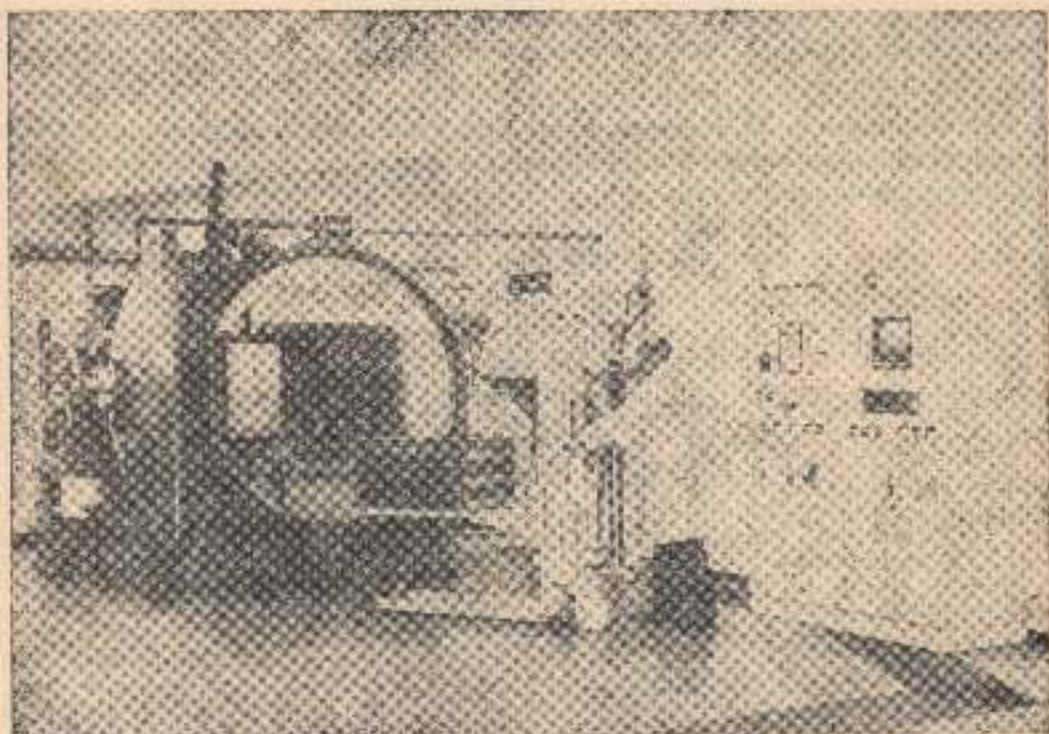


Fig. 3.19 Horizontal-type cold-wall vacuum furnace (Courtesy: Ipsen Industries International, GmbH, W. Germany)

These furnaces are particularly suitable for difficult loading conditions for heat treating of heavier loads and brazing operations. Figure 3.19 illustrates the type of horizontal multi-chamber vacuum furnace that may be used for different types of heat treatment. These furnaces are advantageous particularly in those cases where single-chamber furnaces do not ensure a sufficient quenching speed. Use of a separate gas quench chamber to increase the quenching speed to such an extent that many high-alloyed, oil-hardening steels can now be vacuum-treated. An additional oil quench tank renders possible vacuum-treating of all oil-hardening steels. These furnaces are applied for the treatment of bright-hardening, annealing, sintering, degassing, brazing, stress relieving and carburizing.

Heating System Even though heat treating furnaces are available in many configurations (horizontal, vertical, bottom load, etc.), vacuum furnaces fall into two categories, hot wall and cold wall.

For treatment of steels normal temperatures do not exceed 1300°C. For this purpose, furnaces may be built with molybdenum, tungsten, tantalum and graphite. Using Mo, W, and Ta as a heating element will result in high cost and higher power consumption compared to graphite. But they are mainly useful for treating materials such as titanium and other super alloys. The shape of heating elements from these metals is either a rod or a ribbon.

Now-a-days most of the steel heat treatment furnaces are provided with graphite heaters available in the form of tubes or flat bars, and capable of being arranged in many configurations. Graphite in the form of cloth is also available. It has the advantage that it can be cut with scissors and arranged in the work zone to give large surface areas for heating at extremely low watt densities. Graphite is also less expensive compared to other elements.

Cooling Media As the materials heat-treated in vacuum furnaces require cooling at different rates, these are built with gas cooling facility, gas cum oil quenching facility and multiple quenching facility in gas, oil or water and salt.

Gas cooling facilities are designed for different pressures, depending on the cooling rate required for a particular heat treatment. The pressure may vary between 1-6 bar depending on the type of materials.

The gas quenching media used are hydrogen, helium and nitrogen. Nitrogen is more commonly used since hydrogen and helium are costlier. The grade of nitrogen is important if oxidation of furnace parts and work is to be avoided.

Vacuum ranges Depending on the requirements of materials to be treated and the heat treatment process, vacuum furnaces are provided with a medium vacuum pump set consisting of rotary plus Root pump to give an ultimate vacuum of 10^{-2} m bar or a high vacuum pump set consisting of Rotary plus diffusion pump to give an ultimate vacuum of 10^{-5} m bar.

When high degassing rate is involved, Roots pump is additionally provided. Table 3.2 outlines the types of pumps available, their approximate pressure range, and how they might be used.

Table 3.2 Vacuum Pump Types

Pump Type	Pump Fluid	Approx. Press Range—Torr	Use
Mechanical	Oil	ATM- 10^{-3}	Work horse, roughing and backup for booster pump
Booster-Roots type (Mech) ejector	None Oil	$50-10^{-4}$ $1-10^{-4}$	To increase efficiency in 10^{-3} - 10^{-4} range
Diffusion	Oil	10^{-3} - 10^{-5}	High speed in high vacuum range
Molecular	None	10^{-3} - 10^{-7}	Specialized; used when oil must be excluded
ION	Electrodes and getter chemicals	10^{-5} - 10^{-10}	To maintain the high vacuum level for long periods

Vacuum Heat Treating Applications Applications of the vacuum furnace in the metal processing industry include 1. hardening, tempering or annealing of steel, stainless steel, alloy and other metal products, 2. brazing, 3. degassing particularly titanium, 4. diffusion bonding, 5. sintering, 6. carburizing, and 7. nitriding (ION nitriding).

Some of the vacuum heat treating processes which require special consideration are discussed below:

AIRCRAFT ALLOYS Of concern here are the special alloys containing titanium and aluminium. These alloys are usually processed at a high temperature (1095°C-1260°C for solution treating) and thus are highly susceptible to oxidation. This means maintaining a tight vacuum system and utilizing high-vacuum pumping to operate below 1×10^{-4} torr (.1 micron).

The aircraft alloys most often heat treated are the titanium-based alloys. These alloys are so prone to contamination, particularly hydrogen pick-up, that they must be processed in vacuum or argon. While solution-treating many of these alloys, it is necessary to drop the temperatures below 10°C to achieve complete transformation. Vacuum offers distinct advantages in that the material can be cooled without exposure to atmospheric conditions. By chilling the fluid in the heat exchanger within the vacuum vessel, the requisite temperature decrease can be brought about. Aging of these alloys can take place in the same system, again without exposing the alloy to atmospheric contamination.

TOOL STEELS Tool steel heat-treating is simplified in the vacuum furnace. The tool maker can finish the tool to very close tolerance since subsequent grinding to remove scale, etc. would not be required. Heating of the tools can be closely controlled by varying cross section to avoid distortion. Cooling rates can be very fast for some tool steel grades; distortion problems can be avoided by proper placement of the work in the gas flow.

When heating the high speed grades for hardening, it is necessary to prevent vaporization of surface constituents, particularly chromium. To degas the surface, the parts can be raised to preheat temperature under high vacuum. Then, when heating to hardening temperature, the furnace chamber may be backfilled to 200-400 microns with nitrogen. This higher pressure level is maintained until the furnace is backfilled for cooling. The partial backfill forms a blanket of gas molecules which retains the metallic vapor so that it does not come in contact with the cooler surface where it can condense.

Advantages of Vacuum Heat Treatment

1. It is possible to obtain a clean bright finish surface thus reducing polishing time considerably.
2. Negligible carburization or decarburization.
3. Distortion is minimum, thus eliminating the costs and risk of subsequent finishing operations.
4. Constant reproducible quality of products due to automation of process parameters; eliminates expensive unexpected failures.
5. Ideal labour conditions, no heat exposure, no ecological problems, no cooling water contaminations.
6. Programmed, automatic cycle, instant availability for operation and the flexible heat-treating cycles allow considerable savings in labour costs.

7. Almost instant starting and shut down, unlike in the case of the salt bath and atmosphere control furnaces where in addition to heat treatment cycle time, considerable time, power, labour and salt or gas are spent in preparing and shutting down the furnace.
8. The slightly higher heat treatment costs compared to other methods are amply compensated for by indirect savings and by the improvement of the quality of the products.

Disadvantages

1. Higher initial investment cost.
2. The power input to maintain the temperature of the hot zone is lost in every quench cycle.
3. The hot zone and internal construction undergo several thermal shocks during the gas quench cycle with resultant higher replacement of expensive material.
4. The longer time cycle due to slow rate of heating since heat transfer is by radiation.

3.2.10 FLUIDIZED BED FURNACES

Fluidized bed furnaces are used for neutral hardening, annealing, carburizing, carbonitriding, nitriding, ferritic nitrocarburizing, tempering, patenting, mar-quenching, etc.

Figure 3.21 illustrates the basic arrangements usually employed for fluidized bed furnaces. The furnace consists of an outer shell lined with a heavy ceramic-fibre blanket insulation which surrounds the electrically heated or gas-fired heating chamber. The heating chamber encloses a retort and diffusion plate constructed of heat-resistant alloys which is welded into the bottom of the retort. This plate is termed as the distributor plate and uniformly distributes the gas phase from the plenum chamber below the distributor plate. Above the porous plate, the bed of fine particles such as sand, aluminium oxide, zirconium oxide or other similar material is held. Pre-mixed air and gas is blown upward into the furnace at a certain velocity, through the distributor plate. This fluidizes the bed of sand or alumina particles and makes it behave remarkably like a liquid.

The standard range of fluidized bed furnaces now commercially available can be externally heated by gas or electricity, internal combustion or submerged combustion.

External Electric-heating Figure 3.21 illustrates an electrically heated furnace. The furnace is heated indirectly by electric elements located outside the retort containing the bed. Thus, any desired gas mixture can be passed through the bed. Typically, air is used for fluidization during heating with a rapid change-over to a neutral or active atmosphere for the heat treatment process, for which the desired gas must be supplied separately. The main

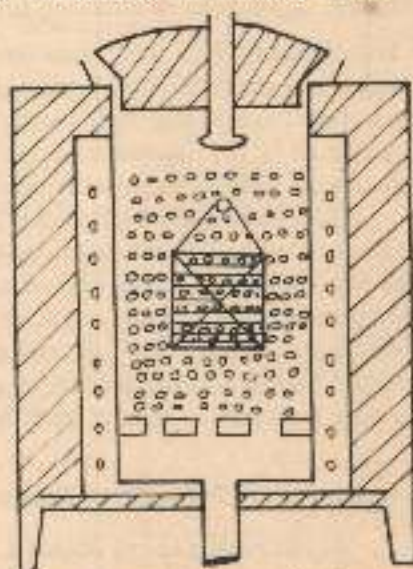


Fig. 3.21 Typical externally heated, fluidized-bed, electric furnace

advantage of this type of heating is the tightly controlled atmospheres and stable fluidization during heating and processing. A further benefit is the wide range of operating temperatures, from ambient up to the maximum design temperature.

Externally Heated Gas This is similar to an electric unit except that gas burners replace heating elements. In addition, recuperators are used to preheat the incoming combustion air.

Submerged Combustion Here, the gas burner is placed directly in the fluidized bed. The combustion products heat up the bed and are re-routed via a compressor to fluidize the bed itself.

Internally Gas Fired (Active Atmosphere) (Fig. 3.22). In this type of unit, the air-gas mixture flows through the bed to maintain the desired fluidization for the operating temperature. Additional air or air-gas mixture (submerged combustion) is added at the top of the bed to complete combustion and maintain the bed temperature. The advantage of this type of unit is that the active atmospheres of carburizing/carbonitriding, etc. can be generated in the bed by controlling the air-gas ratio to suit the operating temperature.

Special Features of Fluidized Bed Furnaces A fluidized bed can be fluidized by air, any gas or a mixture of gases. Depending on the requirement of the process, any desired gas or combination of gases can be used. For neutral hardening or tempering, N_2 is used. For carburizing, a mixture of methanol, N_2 and propane or a mixture of propane and air, is used. By adopting the externally heated type furnace, different types of heat treatment such as carburizing, carbonitriding, nitriding, nitro-carburizing with a suitable gaseous medium in the fluidized bed, can be used.

Heat transfer in the fluidized bed is 8-25 times greater than forced convection furnaces.

Because of the inherent temperature uniformity and high thermal conductivity of fluidized beds, it is possible to quench many parts that are normally air cooled in a fluidized bed with lower distortion and no cracking.

These furnaces can be operated at any temperature between ambient and $1000^{\circ}C$. Capital costs are considerably lower for all the system, except the salt bath.

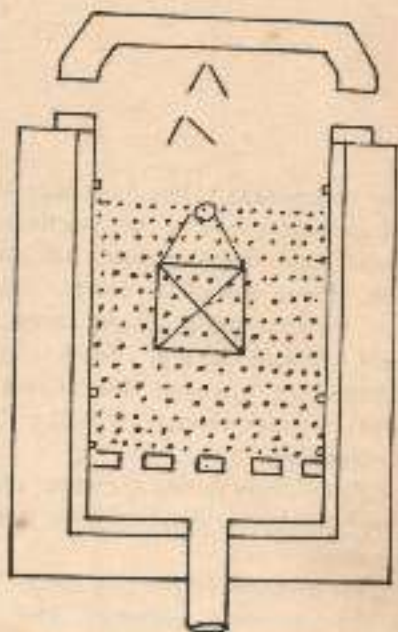


Fig. 3.22 Internal-combustion, fluidized-bed furnace

Control of Heat Treating Process

Any component, after final heat treatment, should conform to the specified standards for the particular type of heat treatment. These standards are often stringent and any deviation would result in components not conforming to the desired specifications, resulting in rejection. Hence, it is of the utmost importance to follow the established standard procedures. For instance, adopting an excessive hardening temperature results in overheating of the steel, whereas too low a hardening temperature results in low hardness. In some instances, maintaining a wrong dissociation rate during nitriding may lead to an insufficient case depth and, conversely, a higher nitriding temperature may lower the hardness of the component.

Apart from these, the steel used for a particular component may not be the correct type. Moreover, even when the steel is correct in composition, it may not possess the desired structure.

To overcome these and similar defects, and to obtain the best results, adequate control of the process is required. The following are hence important in any heat treatment process.

1. Incoming steel inspection.
2. Process control during heat treatment.
3. Quality control of finished product.

4.1 Incoming Steel Inspection

In order to avoid use of the wrong grade of steel for components subjected to heat treatment, it is necessary to inspect the incoming steel to check the following:

1. Chemical composition of the steel.
2. Microstructure (to ascertain conformity to standard).

Normally the checking is done by the steel manufacturers themselves and a test certificate issued at the time of supply of the steel. In the absence of such information a test is essential.

When different types of steel are procured they should be stored with proper identification in order to avoid mixing up. It is advisable to paint the steels in different colours. A board should be displayed in front of each grade.

Despite these precautions, a mixing up may occur; or sometimes the paint applied may fade. It is then necessary to carry out a chemical analysis. In such cases, complete chemical

analysis is not necessary but a check need be made to determine the content of carbon and chief alloying elements. This will establish the characteristics of the steel. Either spark or spectroscopy testing can be employed for this purpose.

4.2 Control of Manufacturing Process

In order to maintain quality and to avoid rejection of components in any heat treating process, the most important factor is the temperature, and its control. For instance, a close control of the gas supply, dissociation rate, and proper use of equipment for gas supply is the most essential requirement in case hardening.

Also, the thermocouple used for a particular temperature range should be the correct one. The most commonly used thermocouples in heat treating shops are:

- (a) Chromel-alumel (up to 1000°C)
- (b) Ferri-constant (up to 600°C)
- (c) Platinum-rhodium-platinum (up to 1300°C)

When the thermocouple is used for measuring the temperature, it is desirable that its hot junction touch the surface of the heated components or at least be placed as near them as possible; otherwise the thermocouple will give wrong readings. Apart from this, it is necessary to counter-check the temperature every day with the help of a standard thermocouple or by using a voltmeter.

Apart from the above process controls, the importance of the 'human' element in heat treatment operations should not be neglected. The man at the furnace is the ultimate key to the situation and at the same time the weakest link in the chain. He is the one who controls the final metallurgical property of the components under treatment. It is his skill, experience and judgement that may frequently determine the nature of the quality. Hence it is necessary to impart proper training and an understanding of the principles governing heat treatment.

4.3 Quality Control of Heat Treated Components

Quality control of heat-treated components is accomplished by measuring the dimensions, properties or other characteristics and comparing the measurements with predetermined standards. Thus, quality control determines whether the heat-treated components conform to established specifications and standards. In actual practice, it consists of determining whether the given components are within the specified limits of variability.

Various methods have been developed for accurate and reliable quality control of heat-treated components. Many of these are indirect methods. Nevertheless, they have gained acceptance both by the management and by the production personnel as a means of reducing cost and improving product quality.

Specifications are developed on the basis of the following sources:

1. Standards for typical components.
2. Plant technical requirements, i.e., for non-typical components for which no standards have been developed.
3. Drawings.

To conform to the technical requirements formulated in the standards, specifications and drawings, the components should be tested for:

1. Hardness.
2. Mechanical properties.
3. Physical properties (e.g. magnetic properties for steel, corrosion resistance of nitride components, etc.)
4. Depth of case of case hardening steels.

Inspection standards should be established so that decisions to accept or reject the component depend on certain conditions. It is advantageous to have the inspection immediately after every operation rather than having it at the end of the final process because in many instances, it is the easier, more reliable and more economical option.

It is most important that the heat-treated components be visually inspected to see whether the components are free from surface defects, distortion, warpage, scales, etc.

The chief methods adopted for inspection are complete screening and sampling inspection methods. In complete screening inspection, each manufactured component is subjected to inspection individually. Sampling inspection is performed on samples taken at random (3 to 5) from lots of small and similar types of components made of the same material. These samples may be considered as a representative of the lot when it is not practical to inspect each component.

Hardness testing is the most commonly applied method in inspection since it is most easily obtained. The details of the process and equipments are given in the following section.

4.3.1 SPARK TEST

This method consists of visual observation of the spark thrown off when the steel is held against a high speed grinding wheel. This method is one of the quickest for identifying different types of steels (Fig. 4.1). This test is found accurate if done by an experienced person.

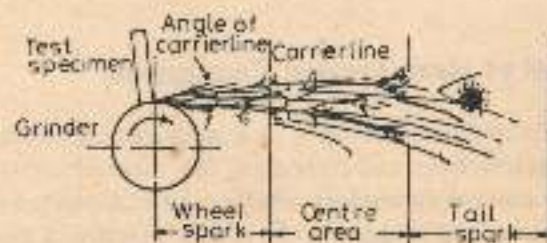


Fig. 4.1 (a) Form of characteristic spark

Instructions for Spark Testing (a) The steel to be identified should be free from decarburization, since the decarburized layer may result in sparks different from those which are the characteristics of that particular steel.

(b) The grinding machine used should be driven either electrically or pneumatically.

(c) The test should be carried out in a suitably darkened room.

(d) Only that amount of pressure should be applied as will maintain a steady contact between the steel and the grinding wheel. A 500 mm long spark is the standard on a 0.2% carbon steel.

(e) The spark must be directed horizontally or in a slightly upward direction. The observation should be made in the receding direction of the spark or from the direction at right angles to the stream.

(f) Observation should be made on each section of the wheel spark—the centre area and the tail of the spark, taking particular care to note on the following characteristics:

1. Streamline (colour, number, brightness and length)
2. Bursting (colour, number, shape and size)
3. Resistance to grinding felt by hand.

The specimen may be identified on the basis of its stream, carrier lines, spark burst and the characteristics of spark. The carrier lines will vary in length, breadth, colour, shape and distance from the wheel end. The presence of alloying elements in steel influence the nature of the sparks. Figure 4.1 (b) illustrates the different types of sparks produced by different types of carbon steels and Fig. 4.1 (c) by different types of alloy steels. The effects of some alloying elements on the spark are given below:

CARBON This causes bursts. The greater the amount of carbon, the more plentiful and complicated the bursts.

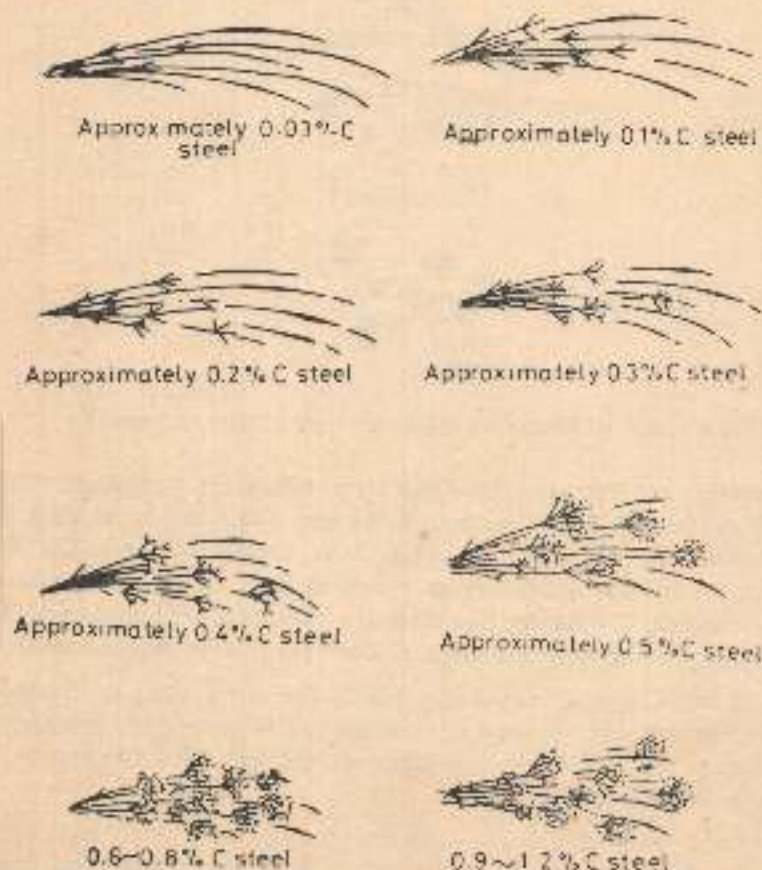


Fig. 4.1 (b) Illustration of carbon steel sparks

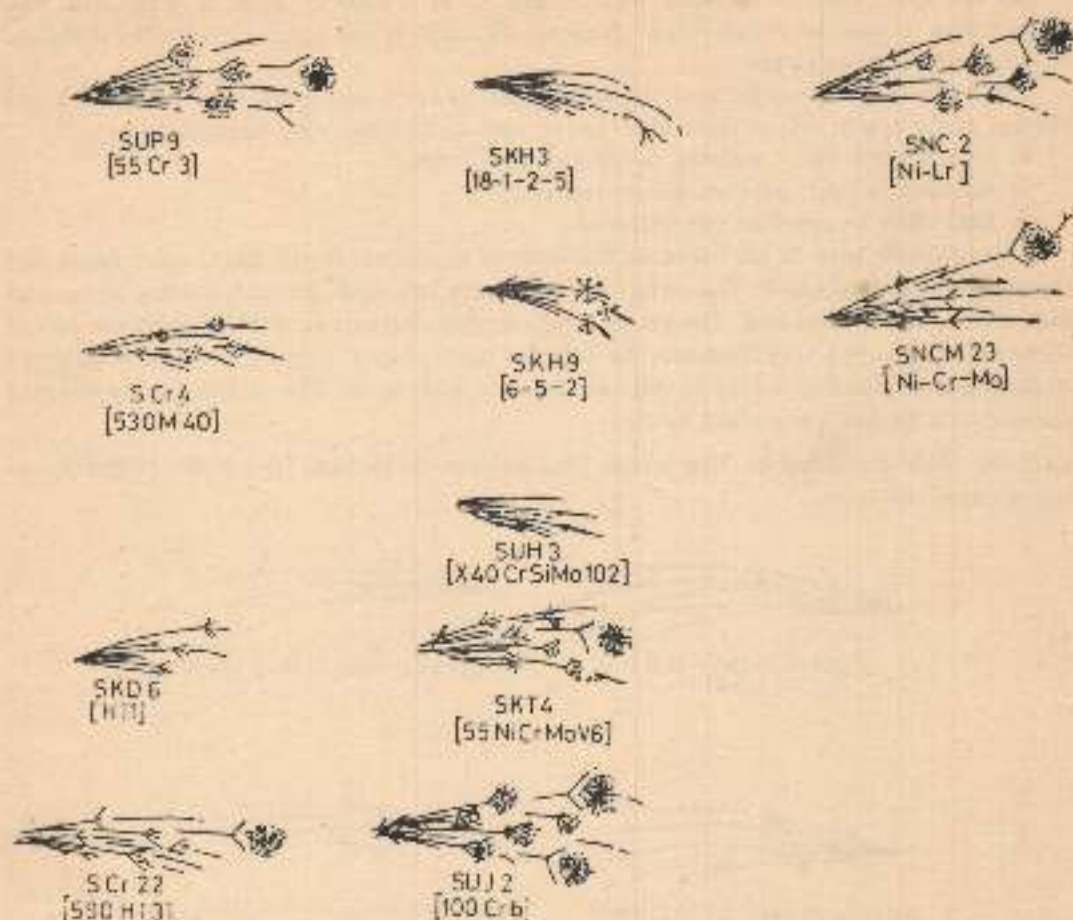


Fig. 4.1 (c) Illustration of different types of alloy steel sparks

The plain carbon steels produce long and large yellow carrier lines with easily discernible springs. With steels of higher hardness forks may also form at the ends of the carrier lines. With medium carbon steels the carrier lines usually end in a star. The colour of sparks is golden yellow. The spark stream produced from higher-carbon steels consists of groups of short bursts. The harder the steel the shorter the spark stream. The colour of these sparks is less red and these are more brilliant than lower carbon steels.

MANGANESE In steels where manganese forms the main alloying element, it tends to brighten the sparks and increase the spread of the sparks around the grinding wheel. With increasing amounts of other alloying elements the effect of manganese on the spark characteristics becomes less visible.

SILICON Significant amount of silicon suppresses the carbon sparks. Steels with low carbon content and high silicon content (1%) produces a dense, condensed and luminous spark stream without bursts. The spark stream has long, pointed carrier lines that have no oxidation parts.

CHROMIUM At the grinding wheel chromium produces carrier lines which are finer and more spaced than those from carbon steels. Relatively higher amounts of this metal retard the spark stream. It imparts an orange-red colour to the stream.

NICKEL Presence of nickel produces characteristic tiny blocks of white light in the spark stream. Forked tongues in the sparks are noticed. It also retards bursts but to a much lower extent compared to chromium.

TUNGSTEN The presence of tungsten can be easily detected since it tends to suppress the effect of all the other alloying elements on the spark. The spark stream produced is red in colour. When tungsten content is high (between 1 and 15%) single bright-orange tongues are produced at the end of carrier lines. In higher tungsten steels the bursts are suppressed altogether.

VANADIUM The spark testing for vanadium steels can be only applied for its detection. The estimation of vanadium content by this test is not at all accurate. Generally vanadium tends to brighten the spark stream.

MOLYBDENUM In molybdenum-dominated steels, there is a characteristic spear point at the end of the carrier lines. Presence of other alloying elements mark the spear points.

4.3.2 THE FILE TEST

This is one of the oldest methods of testing the hardness of components and it is still one of the most useful methods practiced on the shop floor. An experienced heat treater can tell almost as much with a file as a laboratory man can tell with a hardness testing machine. Usually all that the file treater has in his memory is a 'feel' which has obvious limitations.

Standard test files are heat treated to a 'file hardness' of about 67-70 HRC. For testing, the edge of the file is pressed firmly against and drawn across the surface to be tested. If the file does not bite, the material is said to be file hard. The personal skill of the man handling the file, the angle at which it is held, the force applied, etc. are the variables. By frequently checking for himself by filing standard blocks and discarding test files as soon as they wear out, the tester can make accurate comparisons about the hardness of the steel.

The testing file will not 'touch' quenched steel of 64-68 HRC, but will bite quenched and tempered steel of 64-66 HRC. The result obtained will be fairly accurate only at the highest hardness levels.

Advantages and Disadvantages The results may be obtained very fast and this method is readily adaptable for all types of odd shape and size which are difficult to test by other methods. The decarburized layer or soft spots on the surface can be easily identified.

Thin hard surface layers produced by special surface treatments, such as tuffriding, carbonitriding, nitriding, cyaniding, etc., also require file testing if other hardness testers tend to penetrate through the case.

The disadvantage is that its ability to give reproducible hardness values is rather limited. Also, it requires highly skilled personnel and the results obtained for low hardness may not be accurate.

4.3.3 BRINELL HARDNESS TEST

The Brinell hardness tester is employed for determining the hardness of comparatively soft

components which have been subjected to annealing, normalizing, hardened and tempered components, etc.

This method consists of pressing a hardened standard steel ball or sintered carbide under a constant load into the surface of the specimen to be tested. After removing the load, an indentation remains on the surface of the specimen. The Brinell number BHN is the ratio of the load applied to the ball during the test to the area of indentation produced by pressing the ball into the specimen.

The Brinell Number, BHN, will be:

$$\text{BHN} = \frac{P}{X} \text{ kg/mm}^2$$

where P = applied load in kg

X = area of indentation in mm^2

If the indented area X is expressed by ball diameter d , the Brinell Hardness Number may be determined from the following formula:

$$\text{BHN} = \frac{2P}{\pi D(D - \sqrt{D^2 - d^2})} \text{ kg/mm}^2$$

where BHN = Brinell Hardness Number kg/mm^2

P = applied load in kg

D = diameter of ball in mm

d = diameter of indent in mm

The test load applied varies in magnitude and time of application as indicated in Table 4.1.

Table 4.1 Brinell Test Conditions

Standard Test Conditions							
Metal and thickness requirement, if any	Penetrator diameter (mm)	Load (kg)	Full load hold time	Minimum Distance from:		Thickness of test piece $\times h$	For any other penetrator size, adjust the load applied so that F/D^2 equals:
				Edge $\times d$	Next mark $\times d$		
Steel	10	3000	10-15	2.5	4	8	30
Grey cast iron							
Greater than 15 mm	10	3000	15-20	2.5	4	10	10 (for HB less than 140)
Between 5 and 15 mm	5	750	15-20	2.5	4	—	30 (between HB 140 and HB 500)
Less than 5 mm	2	120	15-20	2.5	4	—	—
Light metals and alloys	10 mm preferred and 1 mm minimum		30 \pm 2; for magnesium alloys 120 \pm 2	3.0	6	8	5 (for HB less than 55) 5-15 (between HB 55 and HB 80) 15 (for more than HB 80)

Note: D = diameter of penetrator; d = diameter of indentation;
 h = depth of indentation; F = applied force

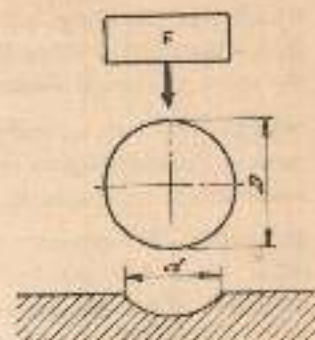


Fig. 4.2 Indentation after Brinell hardness test

When testing the specimen for hardness, the following conditions are to be met.

1. The specimen should be free from pit, scale or grease before testing. A satisfactory surface finish may be obtained by grinding or filing with a smooth file.
2. The test surface of the specimen should be plain.
3. Rounded surfaces should be so machined as to present a plane to the indenter.
4. The specimen to be tested should have a thickness of at least 8 times the depth of impression or as per the Table 4.1.
5. The minimum distance between the centre of two adjacent impressions or from any edge should be 4 to $2\frac{1}{2}$ times the impression diameter respectively.
6. The load should be applied perpendicular to the test surface. The specimen should be brought into solid contact with the penetrator before applying the load.
7. The load should be slowly increased without impact to reach the specified magnitude.
8. The time duration maintained for the specified magnitude of load shall be as per the Table 4.1.

The diameter of the impression is read by a special microscope usually available along with the testing machine. It has a magnification of 20X and an eyepiece scale graduation in millimetres from 0 to 7 with a resolution of 0.05 mm. A number of measurements should be taken across different diameters of the indentation.

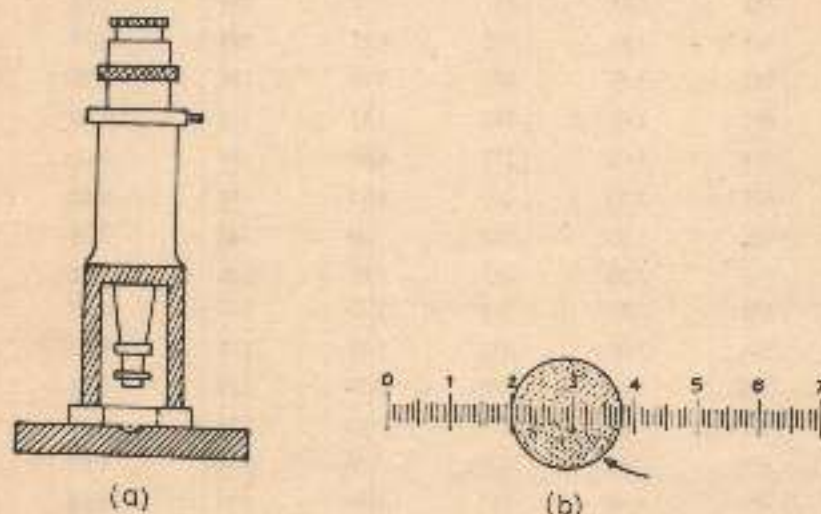


Fig. 4.3 (a) Brinell Microscope, (b) Eyepiece scale

The average diameter is then calculated and the Brinell Hardness Number determined. Table 4.2 is used to read the Brinell Hardness Number directly from the diameter of indentation under normal test conditions, thus avoiding the calculations of the spherical area of indentation and then the hardness number. In the event the table fails to serve the purpose, it is necessary to calculate the hardness by the fundamental principle relationship previously given.

Limitations It is not advisable to apply the test for materials having hardness greater than 450 BHN, as otherwise the ball may be deformed and will result in wrong readings. For materials with a BHN exceeding 450, a tungsten carbide penetrator should be used. It may be used up to about 650 BHN. The Brinell test cannot be applied in the case of small or thin parts.

Table 4.2 Brinell hardness determination from impression size
Diameter of steel ball 10 mm

Diameter of ball impression d	Hardness for a load of 3000 kg	Diameter of ball impression d	Hardness for a load of 3000 kg	Diameter of ball impression d	Hardness for a load of 3000 kg	Diameter of ball impression d	Hardness for a load of 3000 kg
2.00	945	3.25	352	4.50	179	5.75	105
2.05	899	3.30	341	4.55	174	5.80	103
2.10	856	3.35	331	4.60	170	5.85	101
2.15	817	3.40	321	4.65	167	5.90	99.2
2.20	780	3.45	311	4.70	163	5.95	97.3
2.25	745	3.50	302	4.75	159	6.00	95.5
2.30	712	3.55	293	4.80	156	6.05	93.7
2.35	682	3.60	285	4.85	152	6.10	92.0
2.40	653	3.65	277	4.90	149	6.15	90.3
2.45	627	3.70	269	4.95	146	6.20	88.7
2.50	601	3.75	262	5.00	143	6.25	87.1
2.55	578	3.80	255	5.05	140	6.30	85.5
2.60	555	3.85	248	5.10	137	6.35	84.0
2.65	534	3.90	241	5.15	134	6.40	82.5
2.70	514	3.95	235	5.20	131	6.45	81.0
2.75	495	4.00	229	5.25	128	6.50	79.6
2.80	477	4.05	223	5.30	126	6.55	78.2
2.85	461	4.10	217	5.35	123	6.60	76.8
2.90	444	4.15	212	5.40	121	6.65	75.4
2.95	429	4.20	207	5.45	118	6.70	74.1
3.00	415	4.25	201	5.50	116	6.75	72.8
3.05	401	4.30	197	5.55	114	6.80	71.6
3.10	388	4.35	192	5.60	111	6.85	70.4
3.15	375	4.40	187	5.65	109	6.90	69.2
3.20	363	4.45	183	5.70	107	6.95	68.0

4.3.4 ROCKWELL HARDNESS TESTING

The Rockwell hardness test measures the property of the material in terms of its resistance to penetration. Hardness is determined by impressing a penetrator of known geometry, and placed under a known static load, into the component resting on a rigid platform. It employs a *minor load* which is applied first on the surface of the component being tested. Following this the *major load* is applied, and the actual depth measured is that which results from this load (Table 4.3). After removing the major load, hardness is read directly from the dial; the softer the material, the more is the penetration and lower the hardness.

Table 4.3 Rockwell Test Methods and Field of Application

Symbol	Penetrator	Minor load KP	Remaining load KP	Major load KP	Field of application
HRC	Brake (cone)	10	140	150	Hard steel, deeply case hardened steels, tools
HRA	Brake (cone)	10	50	60	Tungsten carbide, parts with thin hardened layers ≥ 0.4 mm, cemented carbides, ceramics and cermets
HRB	1.5875 mm ball	10	90	100	Soft steel, copper alloys, aluminium alloys
HRF	1.5875 mm ball	10	50	60	Brass, annealed copper alloys, soft sheet metal
HRN 15	Brake (cone)	3	12	15	} Thin hardened layers, thickness ≥ 0.12 mm, thin hardened steel sheets
HRN 30	Brake (cone)	3	27	30	
HRN 45	Brake (cone)	3	42	45	
HRN 15	1.5875 mm ball	3	12	15	} Deep drawing steel sheet thickness ≥ 0.2 mm
HRN 30	1.5875 mm ball	3	27	30	
HRN 45	1.5875 mm ball	3	42	45	

There are several Rockwell tests, the most commonly used being the Rockwell hardness test (HRC), Rockwell 'N' superficial hardness test (HR 30N), Rockwell 'B' hardness test (HRB) and Rockwell 'A' hardness test (HRA). Table 4.3 indicates the field of application of different Rockwell testing machines.

Rockwell Machines There are two types of Rockwell testing machines: normal and superficial hardness testing machines. They are operated manually. Most modern machines are now equipped with digital displays and also, the load application is motorized to obtain the most accurate results. Hence the entire operation is carried out automatically by the simple activation of a push button. The measured values are indicated on a large luminous figure (Fig. 4.4).

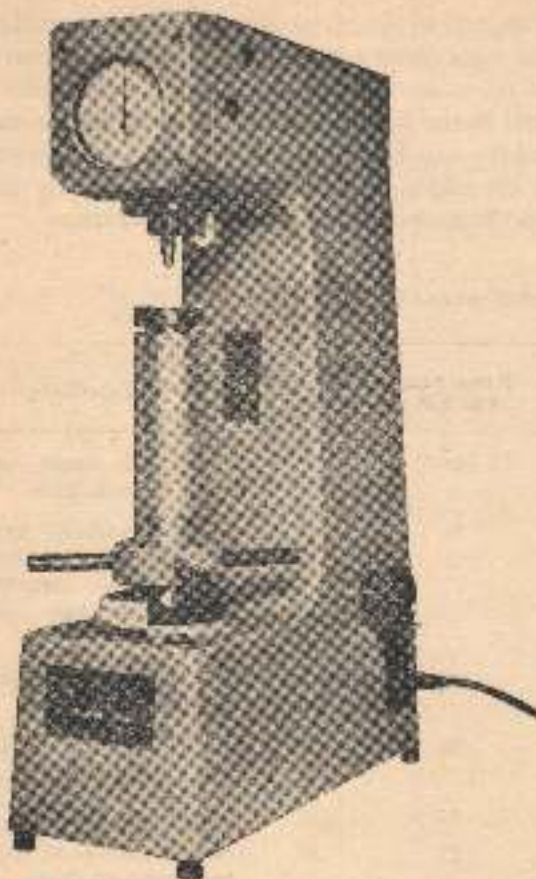


Fig. 4.4 Rockwell hardness tester, motorized (Courtesy: Matsuzawa Seiki Co., Japan)

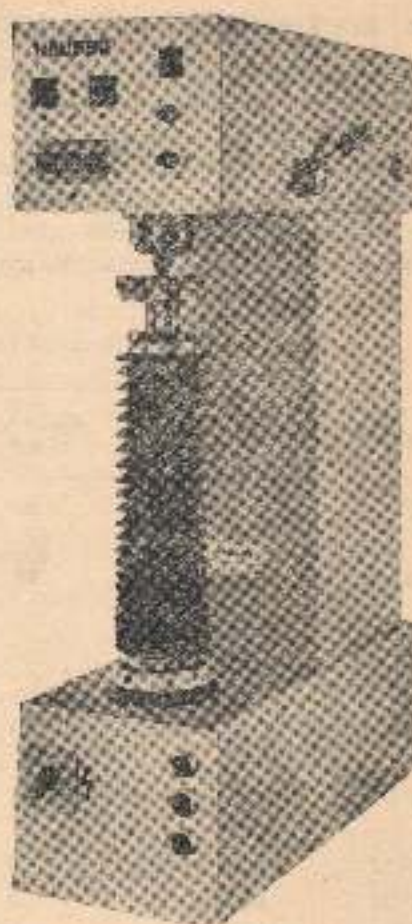


Fig. 4.5 Rockwell hardness tester, digital type (Courtesy: Henri Hauser, Switzerland)

Of the two, the normal Rockwell hardness testing machine uses heavier loads of 60, 100, 150 kg. These loads are normally stored in the same machine. Depending on the type of material, and the method of heat treatment, a particular load may be applied. These machines have a wide variety of applications.

The superficial Rockwell hardness testing machine uses lower test loads of 15, 30 and 45 kg. This machine is used for special applications, e.g. for testing the hardness on shallow case depth of nitrided and carbonitrided steels etc., and also for testing thin materials.

In both the machines two types of penetrators are used. A diamond cone known as a *brale* for hard materials and a *hardened steel ball* for testing the soft materials. In either case a variety of different loadings can be used, each designated by a letter.

Rockwell Scales The most commonly used scales are the Rockwell A, B and C on the normal hardness tester. A single letter, used as the scale symbol, denotes the size of the

major penetrating load on the normal Rockwell testing machine, whereas the superficial machine indicates the scale with a letter and a number equal to the size of the major load. When a Rockwell hardness measurement is recorded it should show the letter R for Rockwell and the scale symbol to indicate the major load applied.

Usually, specifications for a material will indicate which of the scales to use on a given material. If such specifications are not available, the initial choice depends on whether the material is hard or soft. The different types of Rockwell hardness tests adopted are:

Rockwell Hardness Test HRC This test is somewhat similar to the Brinell Test and is based on the indentation of a Brale indenter with an apex angle of 120° (the apex being somewhat rounded, $r=0.2$ mm). This indenter is first seated on a component by a minor load of 10 kg (10 ± 0.2) KP which can be read on a dial and then the dial graduated on the hardness scale is set to zero. After this the major load of 140 kg (140 KP) is applied for a specified period of about 3 seconds. The hardness is then read directly after relieving the major load on the hardness dial (C scale) without counting the minor load. Figure 4.6 illustrates the mechanism of the Rockwell hardness test.

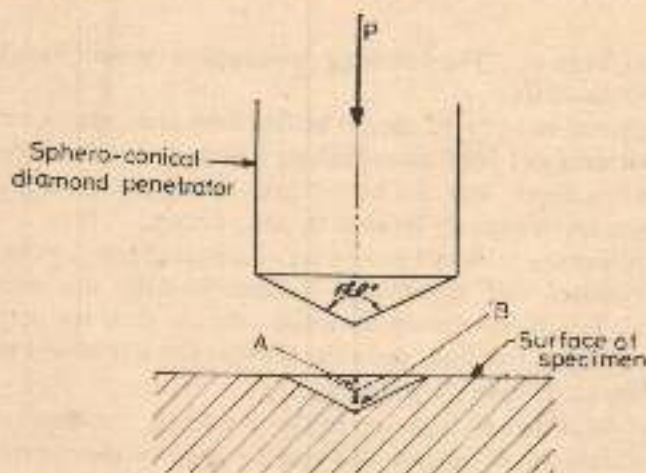


Fig. 4.6 Diagram of mechanism of the Rockwell hardness test: (a) Depth of penetration with minor load, (b) Remaining depth of penetration, with major load, that forms the basis for the Rockwell hardness tester reading.

ADVANTAGES OF THE HRC METHOD Rockwell tests are widely applied in industry due to the rapid rate of operation and the facility of direct readings on the machine. This method is most suitable for testing hardened and tempered metals, and also flame and induction-hardened components whose hardness normally lies in the range of 30-70 HRC.

LIMITATION OF THE HRC METHOD The HRC testing method is not suitable for soft materials and also components which are having case depths less than 0.5 mm. This is because all standard machines are designed with high load capacities in the range of 140 kg. However for testing components with lesser case depths special machines with a load rating of 1-30 kg are available.

Rockwell Hardness Test HRB This method employs a hardened steel ball $1/16''$ diameter instead of the Brale indenter. The total test load applied will be 100 kg ($10 \pm 0.2 + 90$ KP)

It consists of a minor or initial load of 10 kg and a major load of 90 kg. This test can be used to measure hardness in the range of 35–110 HRB.

This method may be adopted for checking hardness of annealed steel, brass, bronze and magnesium hard alloys as well as hardened and tempered components. However, it is not suitable for hard metals and is not as accurate as the Brinell or the Vickers hardness tests.

Rockwell Hardness Test HRA This is similar to the Rockwell hardness test HRC and the same indenter is used. The only difference is that the method employs loads of 60 kg ($10 \pm 0.2 + 50$ KP) only. The hardness is read directly on the dial in A scale after releasing the major load recorded as HRA.

Rockwell 'N' Test This test employs the same diamond cone indenter as Rockwell 'C'. The load applied for testing the components will be 5, 30 and 45 kg (3 kg minor load), depending on the type of material, thickness and the case depth. This machine is used mainly for special applications, e.g. for testing thin materials on nitrided and carbonitrided steels etc., where the superficial layer is less than 0.5 mm. The decarburized layer can also be tested.

PRECAUTIONS BEFORE TESTING The following precautions should be taken before testing the hardness of any material:

- The component to be tested should be free from scale, grease, or traces of machining. A difference of 1 HRC during testing corresponds to a difference of 0.002 mm in penetration depth. Hence a high degree of surface finish is necessary and also the opposite surface should be smooth and parallel.
- Every hardness tester should have a set of standard test blocks, and these should be used regularly and properly to indicate whether the testing machine is in calibration. Test blocks should be tested only on their top surfaces. They should be kept free from rust and dirt. The test on the test blocks should be done 4–5 times before calibrating the machine.
- As for the location and spacing of the Rockwell test-impression, the distance between the centre of the indenter and the edge of the component should be at least two times the diameter of the indenter, and at least four times the diameter from a previous indentation made if any.
- Corrections need be made for surface curvature, as curved small parts will give a different reading for hardness compared to the reading on a flat surface of the same material. Similarly hardness test made on convex surfaces will read lower and those made on concave surfaces higher than the true hardness. For surfaces whose curvatures are known, such as cylindrical surfaces, correction Tables 4.4 and 4.5 can be used to convert the direct readings into the corrected values. As the diameter of curvature increases, the correction factor decreases. For diameter measurements above 25 mm, the correction is negligible.

4.3.5 VICKERS HARDNESS TEST

This is a highly accurate testing machine used for testing both soft and hard steels. The test measures resistance to penetration and is similar to the Brinell test which is based on the principle of geometrical similarity of impression.

The indenter used is a square based diamond pyramid with an apex angle of 136° .

Table 4.4 Correction Values for Cylindrical Surfaces

HRC	Bending radius of tested surfaces, mm								
	3	5	6.5	8	9.5	11	12.5	16	19
20				2.5	2.0	1.5	1.5	1.0	1.0
25			3.0	2.5	2.0	1.5	1.0	1.0	1.0
30			2.5	2.0	1.5	1.5	1.0	1.0	0.5
35		3.0	2.0	1.5	1.5	1.0	1.0	0.5	0.5
40		2.5	2.0	1.5	1.0	1.0	1.0	0.5	0.5
45	3.0	2.0	1.5	1.0	1.0	1.0	0.5	0.5	0.5
50	2.5	2.0	1.5	1.0	1.0	0.5	0.5	0.5	0.5
55	2.0	1.5	1.0	1.0	0.5	0.5	0.5	0.5	0
60	1.5	1.0	1.0	0.5	0.5	0.5	0.5	0	0
65	1.5	1.0	1.0	0.5	0.5	0.5	0.5	0	0
70	1.0	1.0	0.5	0.5	0.5	0.5	0.5	0	0

Table 4.5 Curvature corrections with 1.5875 mm ball penetrator

	B.F.G. scales	Specimen Diameter (mm)						
		6	10	13	16	19	22	25
Observed dial reading	100	3.5	2.5	1.5	1.5	1.0	1.0	0.5
	90	4.0	3.0	2.0	1.5	1.5	1.5	1.0
	80	5.0	3.5	2.5	2.0	1.5	1.5	1.5
	70	6.0	4.0	3.0	2.5	2.0	2.0	1.5
	60	7.0	5.0	3.5	3.0	2.5	2.0	2.0
	50	8.0	5.5	4.0	3.5	3.0	2.5	2.0
	40	9.0	6.0	4.5	4.0	3.0	2.5	2.5
	30	10.0	6.5	5.0	4.5	3.5	3.0	2.5
	20	11.0	7.5	5.5	4.5	4.0	3.5	3.0
	10	12.0	8.0	6.0	5.0	4.0	3.5	3.0
	0	12.5	8.5	6.5	5.5	4.5	3.5	3.0

Note: Corrections greater than 5 points of Rockwell hardness are not generally acceptable. They should be considered for approximations only.

The hardness value obtained when using this indenter is frequently referred to as the diamond pyramid hardness, DPH. The correct terminology now used is Hardness Vickers, HV.

In general the applied load varies between 10 and 60 kg, but both higher and lower loads may be used. After applying the desired load, the average length of the diagonals of the impression is measured and the Vickers pyramid number read off from the table like HV.

Vickers hardness is defined as the coefficient of dividing the load by the pyramid area of the impression, kg/mm^2 , and may be calculated from the following formula:

$$\text{HV} = \frac{2P \sin \alpha/2}{d^2} = \frac{1.8544 \times P}{d^2}$$

where HV = Vickers hardness in kg/mm^2

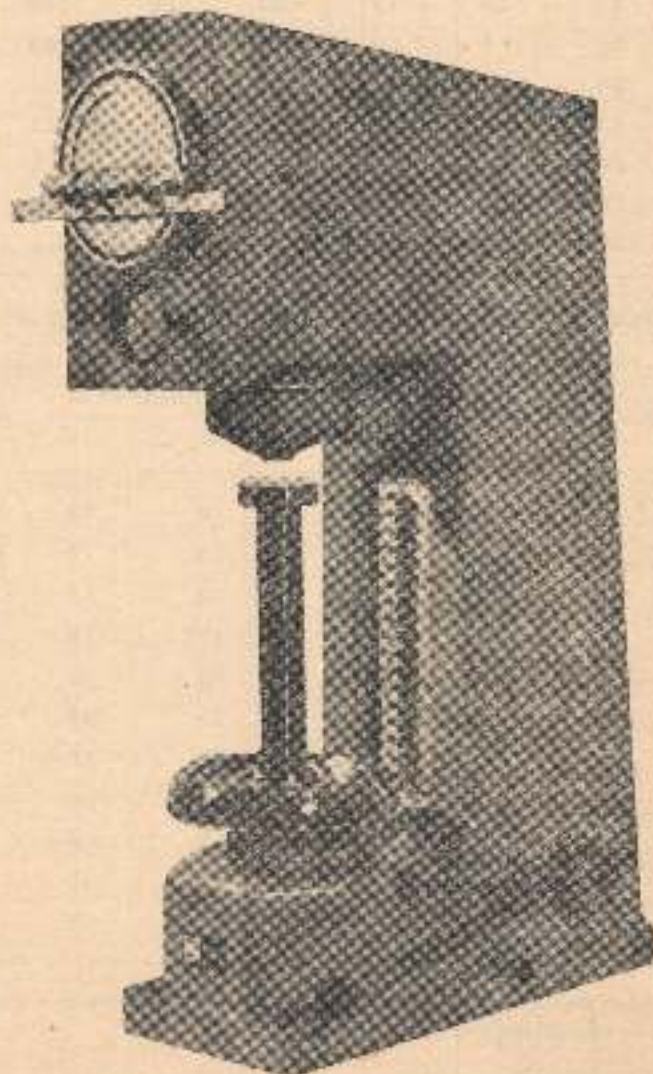


Fig. 4.7 Vickers hardness tester (Courtesy: Karl-Frank, W. Germany)

P = Load in kg

d = Average diagonal length of the impression in mm $[(d_1 + d_2)/2]$

α = Angle between the opposite faces of the pyramid ($\alpha = 136^\circ$)

Precautions The following precautions should be taken before testing the specimen: (a) The surface to be tested should be free from scales, decarburization layer and rough traces of machining. The surface finish is to be achieved up to an accuracy of 0.0002 mm. (b) The minimum section thickness of the specimen should be not less than 1.5 times the diagonal length of the indentation. In any case the imprint of the indentation should not appear at the back of the specimen. (c) The minimum distance between the centres of adjacent impressions or between the centre and edge must be $2\frac{1}{2}$ times the length of the diagonals of the impression. (d) The components to be tested should be firmly clamped horizontally, usually in the vice placed on the anvil of the machine.

Method of Testing The load is selected in accordance with the size and hardness of the specimen. Thinner the specimen lesser is the load required. Loads of 100 kg and above are however liable to fracture the diamond if used on hard materials.

For maximum accuracy, the largest load consistent with the diameter of the test sample should be used. The load is to be applied slowly and progressively to the test specimen.

The time duration of loading should be 30 seconds according to specified standards.

The diagonal length of the indentation should be measured after removing the load

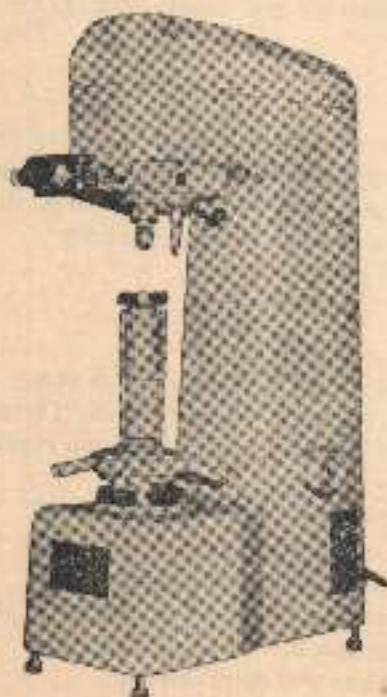


Fig. 4.8 (a) Vickers hardness tester (Courtesy: Matsuzawa Seiki Co. Ltd., Japan)

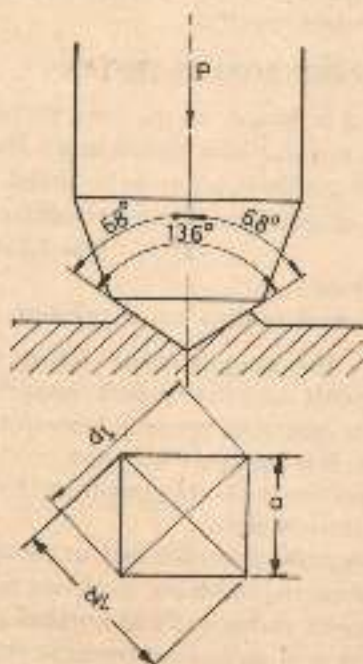


Fig. 4.8 (b) Schematic illustration of the Vickers indenter and the impression formed on the test surface

completely and the average value of the two diagonals should be taken as the final diagonal length, with the help of the microscope provided on the machine (Fig. 4.8 (a)) $\left(\frac{d_1 + d_2}{2}\right)$. The average values are converted to the Vickers hardness number HV (kg/mm^2) by the use of charts supplied along with the machine.

Advantages The advantage of the Vicker's hardness method is that, by varying the loads, hardness determinations of the softest and hardest alloys can be undertaken. Also, the results are expressed on a single scale without the necessity of shifting from one scale to another, as in most other methods.

Due to the small depth of indentation, this test is particularly well-suited for testing the hardness of superficial layers. Even small parts and thin pieces can be subjected to this test. It is also possible to determine whether a steel surface has been unintentionally carburized or decarburized during the course of heat treatment. If the hardness indicated at a lesser load is lower than that obtained at a higher load, it indicates that the surface is decarburized.

Limitations of the Method This test cannot be applied for the testing of cast iron and sintered metals. Also, direct reading is not possible as in the Rockwell testing method. It is tiresome to work with a measuring microscope over a long period. It calls for a ground and polished surface for testing the specimen.

The Vickers hardness number corresponds closely to the Brinell hardness number up to values of about 450 BHN. Beyond this, the values are not comparable as the Vickers number increases rapidly.

4.3.6 MICROHARDNESS TESTER

This method is based on the same principle as the Vickers hardness testing method. It involves the pressing of a square-based diamond pyramid with an included angle of 136° into the well-polished surface to be tested. The load applied will be 10–1000 g, depending on the type of specimen. The microhardness is determined from the formula

$$H = 1.8544 P/d^2 \text{ g/mm}^2$$

where P = load in g

d = length of diagonal in microns.

Advantages The microhardness testing (Figs. 4.9 and 4.10) method is widely used for testing materials and parts which require close hardness characteristics. These include items used in aircrafts, research laboratories and various types of precision machine tool components. It is suitable for testing

1. Ferrous materials, ranging from the extremely soft to the extremely hard.
2. Non-ferrous metals.
3. Non-metallic materials such as ceramics, plastics, jewels and glass.
4. Hardness and hardness gradients across the deeper surface treatments of induction-hardened, carburized and nitrided and very thin layers.
5. Hardness of surface treatment in electroplating and paint coatings.
6. Depth of decarburized layers.
7. Hardness by phases in the structure of metals.
8. Hardness of items which cannot be measured by Rockwell type machines which use heavier loads.

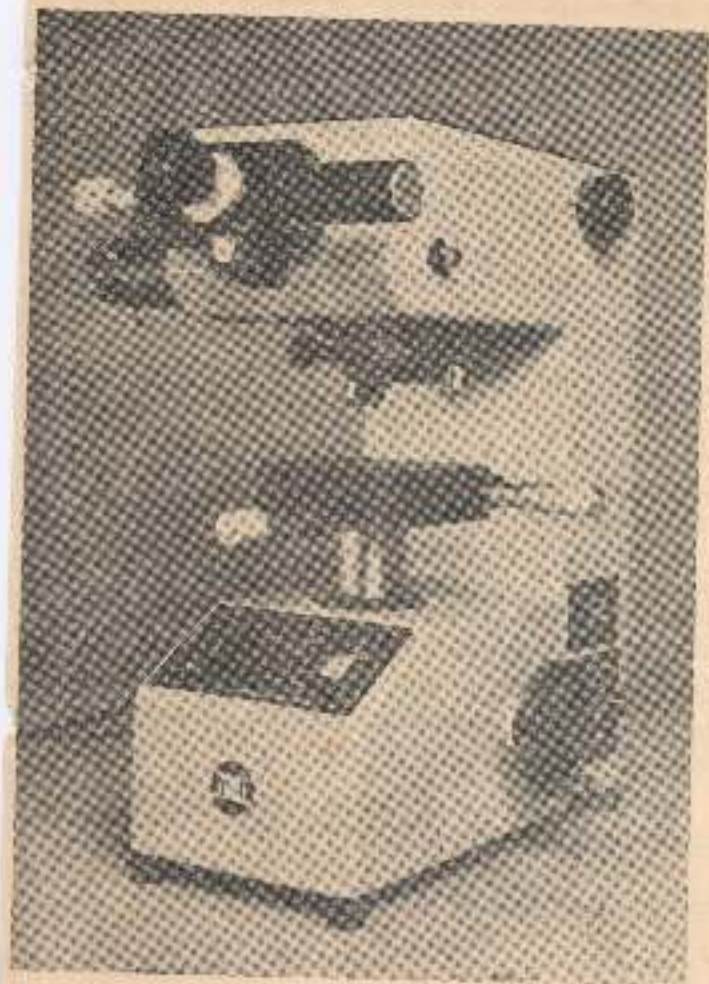


Fig. 4.9 Micro hardness tester (Courtesy: Matsuzawa Seiki Co. Ltd., Japan)

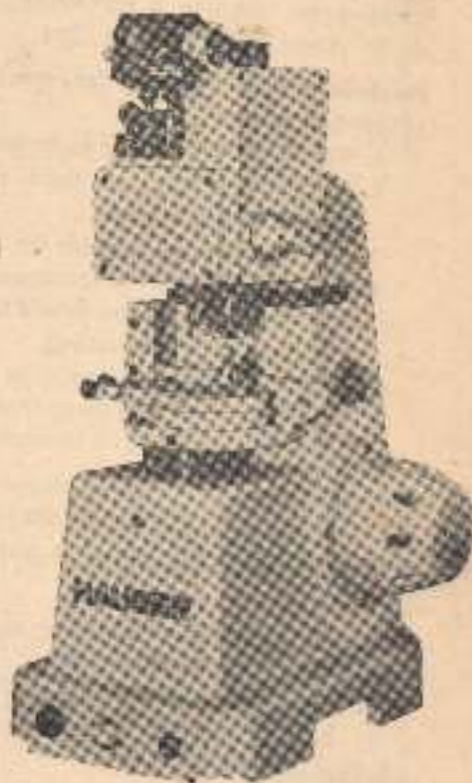


Fig. 4.10 Vicker hardness tester, 50 to 100 g (Courtesy: Henri Hauser Ltd., Switzerland)

These items include small parts, minute parts, thin plates, metal foils, fine drawn wires, etc.

Disadvantages

1. It calls for a highly polished surface.
2. It needs skilled persons to operate the machine.
3. It is not suitable for use on the shop floor.

4.3.7 SHORES SCLEROSCOPE TEST

This test does not depend on the resistance to indentation to the same extent as the other

hardness testing methods. The shores scleroscope test consists of dropping a diamond-tipped hammer from a definite height upon the surface to be tested. The height of rebound of the hammer is taken as a measure of the specimen's hardness.

The maximum rebound height in this test, obtained in quenched high carbon tool steel, is set as the standard. This height is divided into a suitable number of equal divisions. The number of divisions may vary according to the manufacturer (100 or 120 divs). The scleroscope number is accordingly defined. Quenched high carbon tool steel therefore shows values near to 100 or 120.

Precautions When testing the specimen for hardness the following conditions are to be adhered to:

1. The specimen surface to be tested should be plain.
2. It should be free from scale and dirt and the surface should be well polished to get the correct hardness.
3. This test is more suitable for large castings, heavy axles, ingots, massive dies, etc.
4. The thickness of the specimen should be minimum 10 mm.
5. Four to five readings should be taken and the average reported as the hardness value, unless otherwise specified.
6. The hardness test should be performed at a position on the surface of a specimen not less than 4 mm away from the edge of the specimen. The centre-to-centre distance should be more than twice the diameter of the dent made.

Procedure The shores scleroscope must be held firmly in a horizontal position, and the hammer must fall exactly vertical from a fixed height on the test specimen. The height to which the hammer rebounds is read off from the graduated scale.

Advantages

1. It is specially suitable for testing huge components. This instrument can be transported to the work spot.
2. The depth of penetration is very small, so that the instrument can be used on case hardened components.

Limitations

1. It requires a fine surface finish for testing.
2. It is only suitable for testing large components.
3. This test cannot be applied for very accurate hardness measurements.

4.3.8 POLDI HARDNESS TESTER

Poldi hardness (Fig. 4.11) test may be employed for testing the hardness of large casting as well as annealed and normalized components.

Principle of Operation In this test, impressions are obtained simultaneously on a standard specimen of known hardness and the test piece using a steel ball indenter. By measuring the diameter of the two impressions, the hardness of the test piece can be obtained by the rule of proportion.

The hardness of the specimen is calculated from the following formula:

$$Ha = Hs \left(\frac{ds}{da} \right)^2$$

where H_s = Hardness of specimen
 H_s = Hardness of standard specimen
 d_s = Diameter of indentation on specimen
 d_s = Diameter of indentation on standard specimen.

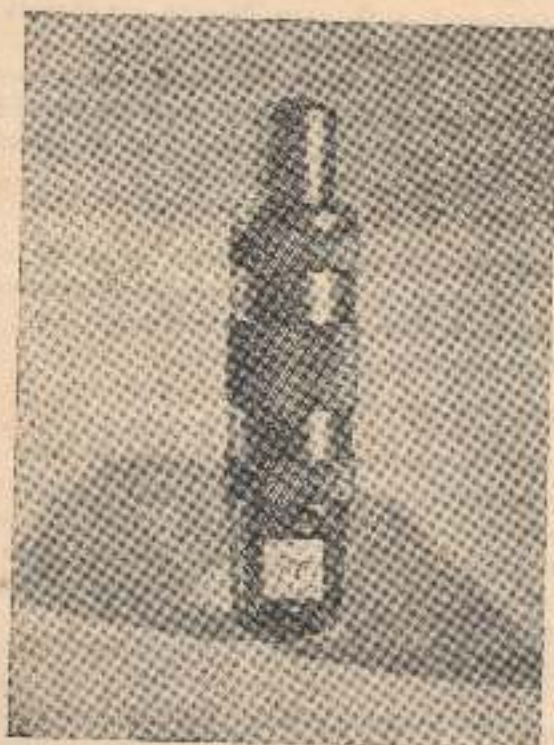


Fig. 4.11 Poldi hardness tester (Courtesy: Karl-Frank, W. Germany).

Procedure The relevant portion of the piece to be tested is ground, filed or polished so as to produce a plain and smooth surface on a small area.

The apparatus fitted with the standard test piece is placed on the component whose hardness is to be tested. A short blow is then given with a hammer. The diameter of indentations on the component and the standard specimen are measured as accurately as possible with the enclosed adjustable magnifying glass having graduations of tenth of a millimeter. The hardness is then read off from the standard charts supplied along with the tester using the diameter readings.

Precautions

1. The apparatus must be held vertically over the surface.
2. The blow rendered should not be too heavy and should be as vertical as possible. This avoids a rebound and thus a double blow which may damage the sharp edge of the ball impression.

3. The diameter of the impression on the standard specimen should not exceed 4.2 mm. If a larger impression is obtained, then the standard rod is liable to give away laterally thereby indicating wrong results.
4. If small pieces are to be tested, they should be placed firmly on larger pieces.

Advantages

1. The test can be performed on the shop floor on components which are too big to be taken to the material testing section.
2. High surface polish is not essential. Medium surface conditions prove sufficient.
3. Usually for testing the hardness of component a sample has to be cut off from it and then tested. When the cutting of the component is not permitted, this test can be easily applied to measure the hardness.

Limitations

1. In measuring hardness with this tester, errors up to 5% may occur. But on the actual shop floor, this degree of accuracy is considered sufficient for large articles.
2. This test is suitable for testing of large materials only.
3. Very hard materials cannot be tested accurately.

4.3.9 LIQUID PENETRANT METHOD

In this method the parts to be tested are treated with a dye solution in which the solvent has a high degree of penetrating power. The dye is drawn into the cracks or fissures by capillary action. The excess penetrant is then removed from the surface by washing or wiping. After this, the part is usually treated with another fluid which, after drying, tends to draw the dye solution out of the cracks. The surface is then visually examined for indications of penetrant bleed back from surface opening.

To make the dye more visible, it may be coloured red to contrast against the white dried second coating.

The liquid penetrants are available commercially in three main systems and they are designated by the type of penetrant used (1) water washable, (2) post emulsifiable, (3) solvent removal.

Water washable visible dye system is the fastest and simplest of all the penetrant techniques. It is more useful in those applications where shallow and relatively wide flaws are not significant.

Past emulsifiable visible dye system is more sensitive but is costlier than the first type.

Solvent removal visible system can be adopted for a wide range of applications both in the shop and in the field. This method is generally confined to spot inspection or for inspection under circumstances that prohibit the use of the first two methods.

4.3.10 MAGNETIC PARTICLE FLAW DETECTION

Magnetic particle flaw detection is a non-destructive method of detecting cracks or other discontinuities at or near the surface in ferro-magnetic materials.

The magnetic particle flaw detection is based on the principle that if a ferro-magnetic object is magnetized, the discontinuities in the material, such as cracks and inclusions, lying at an angle to the magnetic lines of force, cause an abrupt change in the path of magnetic flux flowing through the object. This results in a local flux leakage at the surface over the discontinuity. If at this stage, fine particles of ferro-magnetic material, either dry

or suspended in a liquid, are applied over the surface, some of these particles attracted towards the leakage field, will pile up and bridge the discontinuity, setting up a magnetically held pattern outlining the discontinuity.

This method may be adopted for detecting the cracks and other discontinuities at or near the surface in ferro-magnetic materials. It is mainly adopted for final inspection, receiving inspection, process inspection and quality control. It may also be used for examination of castings, forging, welding defects, etc. The only limitation is that beyond a depth of 2 mm from the surface are not detectable. It is also comparatively expensive.

Gas Nitriding

Development of sophisticated equipment and machine tools with high operating parameters warrants the use of highly reliable and durable components that go to make the products. The durability of a machine part in general depends on its fatigue strength, wear resistance and corrosion resistance. These can be increased considerably in components through special heat treatment processes. Nitriding is one such process which is being widely used at present.

The earliest information on nitriding dates back to the days of the iron pillar at Qutab (415 A.D.). The higher corrosion resistance of this iron pillar can be explained by the formation of a nitride film on its surface. It is believed that a high concentration of ammonia in the atmosphere in combination with the subtropical climate of India produced a protective layer of iron nitrides on the surface of the column.¹

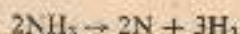
The nitriding process was first used around 1920, and since then its application has continuously widened. The process has been further developed and it can now be applied to a much larger number of steels than was originally thought possible.

Nitriding is a process of case-hardening in which steel is heated in an atmosphere of ammonia gas at a temperature of 490°–550°C, usually (500–520°C), for a prolonged period. At this temperature range, ammonia gas dissociates to produce atomic nitrogen. The atomic nitrogen diffuses into the steel forming nitrides, thus producing a hard wear resistant surface free from scale containing the minimum of distortion.

Steels containing any of the nitride forming elements such as Al, Cr, Mo, V, Ti, W, etc., can be nitrided. The atomic nitrogen combines with these alloying elements and produces nitrides like Cr_3N , Mo_3N , AlN , VN , W_2N , etc. Highly dispersed particles of these nitrides interlock the slip planes on the material and thus increase the hardness of the nitrided layer. The obtained hardness depends on the amount of alloying elements present. The highest hardness obtained by the nitriding process ranges from VH 1000 to 1300.

5.1 Mechanism of Nitriding

When ammonia is heated to the nitriding temperature between 500 and 520°C, very little dissociation occurs on the surfaces capable of catalyzing its decomposition. Since steel has such a surface, the following reactions will occur at the gas-solid interface during nitriding.²



It is assumed that the atomic hydrogen thus formed passes immediately into the molecular state. A part of the atomic nitrogen is absorbed by the steel and the rest reacts to form molecular nitrogen which is inert.

Since the life of atomic nitrogen is short, it is necessary to replenish it continuously by supplying fresh ammonia to the steel surface. It is thus necessary to circulate ammonia in such a way that the atomic nitrogen produced through dissociation is continuously made available to the whole area of the part to be nitrided.

It is important to maintain a predetermined rate of dissociation of ammonia as it influences the mechanical properties of the treated components. Normally a 20 to 50% dissociation rate would suffice.

The hardness of the nitrided case develops primarily during cooling, after the completion of the nitriding process. The high hardness of the nitrided case on steels, alloyed with nitride forming elements (Al, Mo, W, V, etc.) is the result of the overall hardening effect of.^{3,4}

- (a) Formation of nitrides of alloying elements in the process of nitriding.
- (b) Precipitation and pre-precipitation of dispersed nitrides of alloying elements in the process of intermediate gamma to alpha transformation.
- (c) Precipitation or pre-precipitation of nitrides of alloying elements due to the lower solubility at decreasing temperature.

5.2 Operations Before Nitriding

The following sequence of operations may be applied for nitriding of nitroalloys as well as other steels.

5.2.1 ROUGH MACHINING

The components are rough-machined in the as annealed condition, keeping sufficient machining allowance for further machining operations.

5.2.2 HARDENING AND TEMPERING

Since the nitrided case is extremely thin and very hard, it should be supported by the core which is strong and tough. Further, the properties of the nitrided case depends on the prior microstructure. As nitriding is carried out below the first critical temperature the core properties should be developed prior to nitriding. In order to ensure optimum results, it is necessary to see that the metallographic structure of the steel being treated is suitable. It has been established that a uniformly distributed sorbite structure in steel is best for nitriding.² This is the type of structure produced by oil or water quenching followed by a suitable tempering treatment.

If the steel is having an annealed or normalized structure the possibility is that the nitrided case obtained will be excessively brittle and not particularly hard. Large nitride particles are also formed in any decarburized layer that may be present on the surface of the steel. The outer decarburized layer may flake off while still in the nitriding furnace.

The hardness and depth of case obtained is low in the annealed and normalized steels with a ferrite-pearlite structure than for quenched and tempered steels with a sorbite struc-

ture. The temperature chosen for austenitizing should be in the lower range of hardening temperature, capable of inducing satisfactory core properties with a fine-grained sorbite structure. If the temperature is too high grain coarsening takes place, which is detrimental not only to the core properties but also to the quality of the case. If the grain size is too large, coarse filaments of nitride form at these grain boundaries during nitriding. The alloying elements used in nitriding steels have a profound effect on these properties. The core properties of any one steel may be varied by adjusting the tempering temperature, but the case hardness of any particular steel will suffer if an excessively high tempering temperature is used. The tempering temperature should be higher than the nitriding temperature and preferably not below 550°C.

The test piece used for nitriding should be hardened and tempered to check the hardness, depth of case, and the microstructure of the charge loaded to the furnace.

5.2.3 FINAL MACHINING

The hardened and tempered components are then machined, keeping a close tolerance of 0.3 mm to 0.5 mm on all areas. All corners or edges should be rounded to avoid the effects of cumulative growth during nitriding. The components are subsequently stabilized.

Caution When designing components for nitriding sharp corners or edges should be avoided whenever possible; because the projections formed at the sharp corners as a result of the growth that takes place are high in nitrogen content and are susceptible to chipping. Similarly sharp edges are nitrided throughout the section and have no supporting core. When sharp corners are unavoidable, brittleness may be reduced by nitriding one side only, if the other side is not a wearing surface.

5.2.4 STABILIZING (STRESS RELIEVING)

If freedom from distortion is of paramount importance, the internal stresses produced by machining or heat treating should be removed before nitriding. This is achieved by heating the part to a temperature of 550–570°C soaking it for at least 2 to 4 hours thoroughly and allowing it to cool in air. As the stabilizing temperature is below the tempering temperature, this will not affect the final mechanical properties of the core and the microstructure; but it is above the nitriding temperature, and will ensure the removal of stresses imposed during the machining cycle. Stress relieving may not be necessary for short components.

5.2.5 FINISH MACHINING

After the stabilizing treatment the components may be finish machined, taking utmost care to see that no stresses are imposed during machining. During the nitriding process the formation of nitrides produces a growth on the surface of the component to an extent of 0.02 to 0.05 mm.⁵ This growth is purely a surface phenomenon and has no marked effect on the overall dimensions of the part.

The growth will be somewhat greater if the steel is not fully hardened. With hollow cylinders, the growth increases as the wall thickness decreases. However, if no subsequent machining is involved after nitriding, allowances must be maintained for this growth on the surface in components which have to retain the highest accuracy after nitriding.

5.2.6 PROTECTION AGAINST NITRIDING

On nitriding a component, the entire surface becomes hard unless precautions are taken.

It is often desirable that screw threads, keyways, etc. are kept soft. This can be done by any of the following methods:

Electrolytic deposition using not more than 0.01 mm to 0.02 mm of suitable metal such as tin, nickel, etc. are very effective but are generally costly. Hence a thin coating of copper plating is done as a stop-off for nitriding.

During the prefinal machining operation, extra allowance may be provided to remove the nitrided case after nitriding (normally 0.8-1 mm). This may be economical for some components that are finish machined after nitriding.

Soluble glass paste of sufficient thickness may be applied and allowed to dry at a temperature of 100 to 120°C. However, the water glass coating is likely to deliquesce on the surface of the component during nitriding and cannot be used where an exact separation line between the nitrided and non-nitrided areas are required.

In many cases, fine threads and blind holes may be protected by plugging them tightly with copper plugs.

5.3 Nitriding Operations

The surface of the steel prior to nitriding should have a fine machined and ground finish since the nitriding process is based on the affinity of nascent nitrogen for iron and certain other metallic elements. At the nitriding temperature of 500-550°C nascent nitrogen is produced by the dissociation of gaseous ammonia in contact with the hot steel parts. The nascent nitrogen thus formed produces a nitrided case. The nitriding of parts is carried out in a gastight retort placed in an automatic temperature control furnace. The following operations are carried out during nitriding process.

5.3.1 SURFACE PREPARATION

It is most important that the surface preparation of the components to be nitrided is done properly. Especially some of the finish machining processes such as buffing, finish-grinding, lapping and burnishing may produce surfaces that will retard nitriding, thus resulting in uneven nitriding and distortion. In such a case the following methods are employed to prepare the surface for nitriding.

1. The components to be nitrided are de-greased in a de-greasing tank or by cleaning the surface with trichloroethylene. Although this removes the oil and dirt present on the surface, it does not facilitate removal of any oxide layer that may be formed during the grinding operation.

2. Vapour de-greasing can also be used for surface preparation.

5.3.2 LOADING

Nitriding is usually done in an electric furnace equipped with precise temperature control. The cleaned and dried components are properly placed in the furnace with the help of suitable fixtures in such a way that the ammonia gas envelops all the surfaces of the component (Fig. 5.1). Care should be taken to avoid distortion of the component during supporting and holding in the fixture. Since the tensile strength of the component at the nitriding temperature is relatively low, an incorrect supporting and holding will result in sagging and twisting of the component.

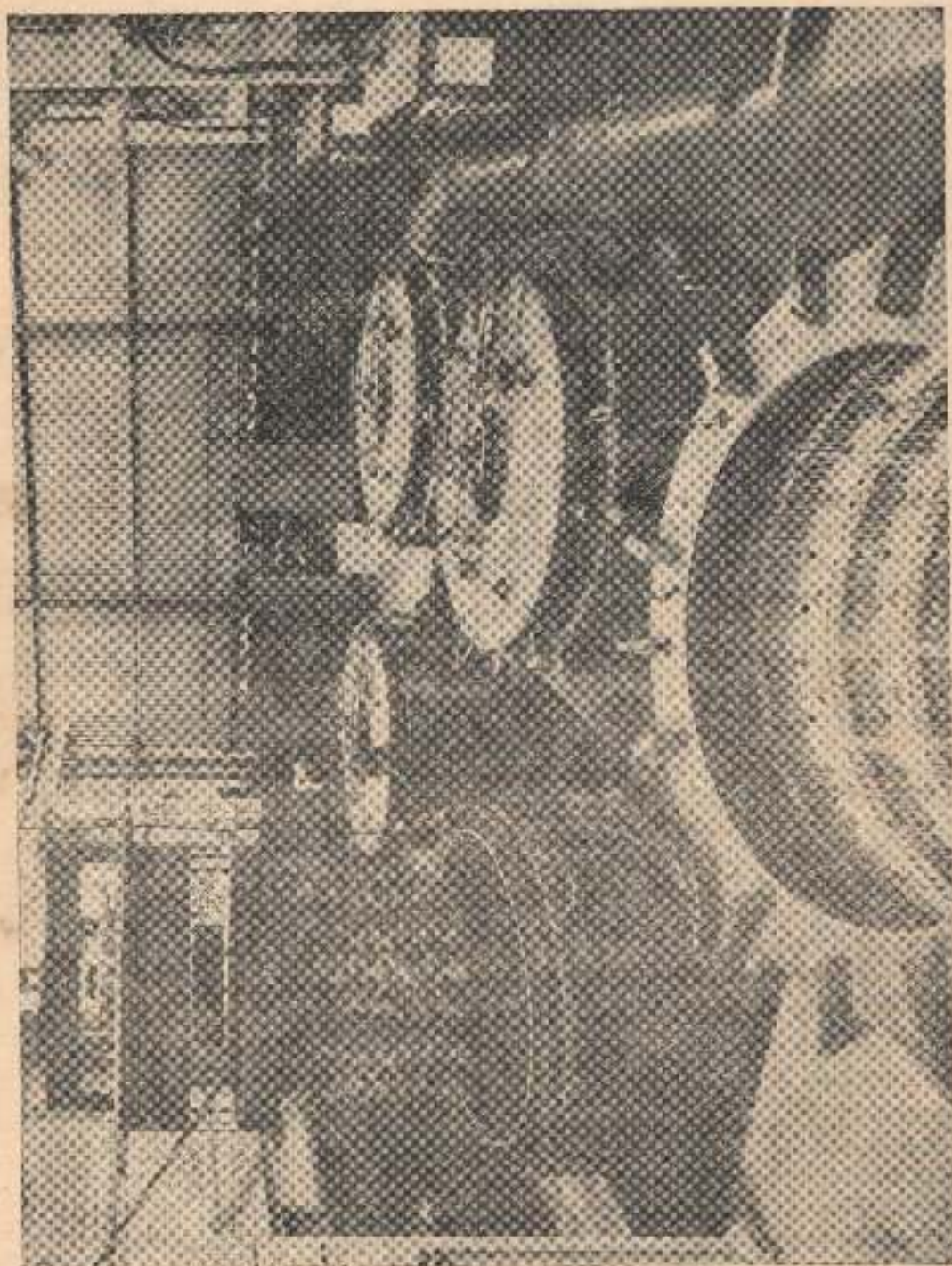


Fig. 5.1 Nitriding installation comprising 3 nitriding furnaces, 2 cooling stations (water-cooled) with 2 spare retorts and 5 charge-supporting jigs. Ancillary equipment consists of control cabinets, control panel with feedlines to removal retorts fitted with quick-release self-sealing cranes. The whole — Nitriding crumb-shaft (top left) industrial vehicles (Courtesy: Wild Hufeldt Ltd, Frankfurt)

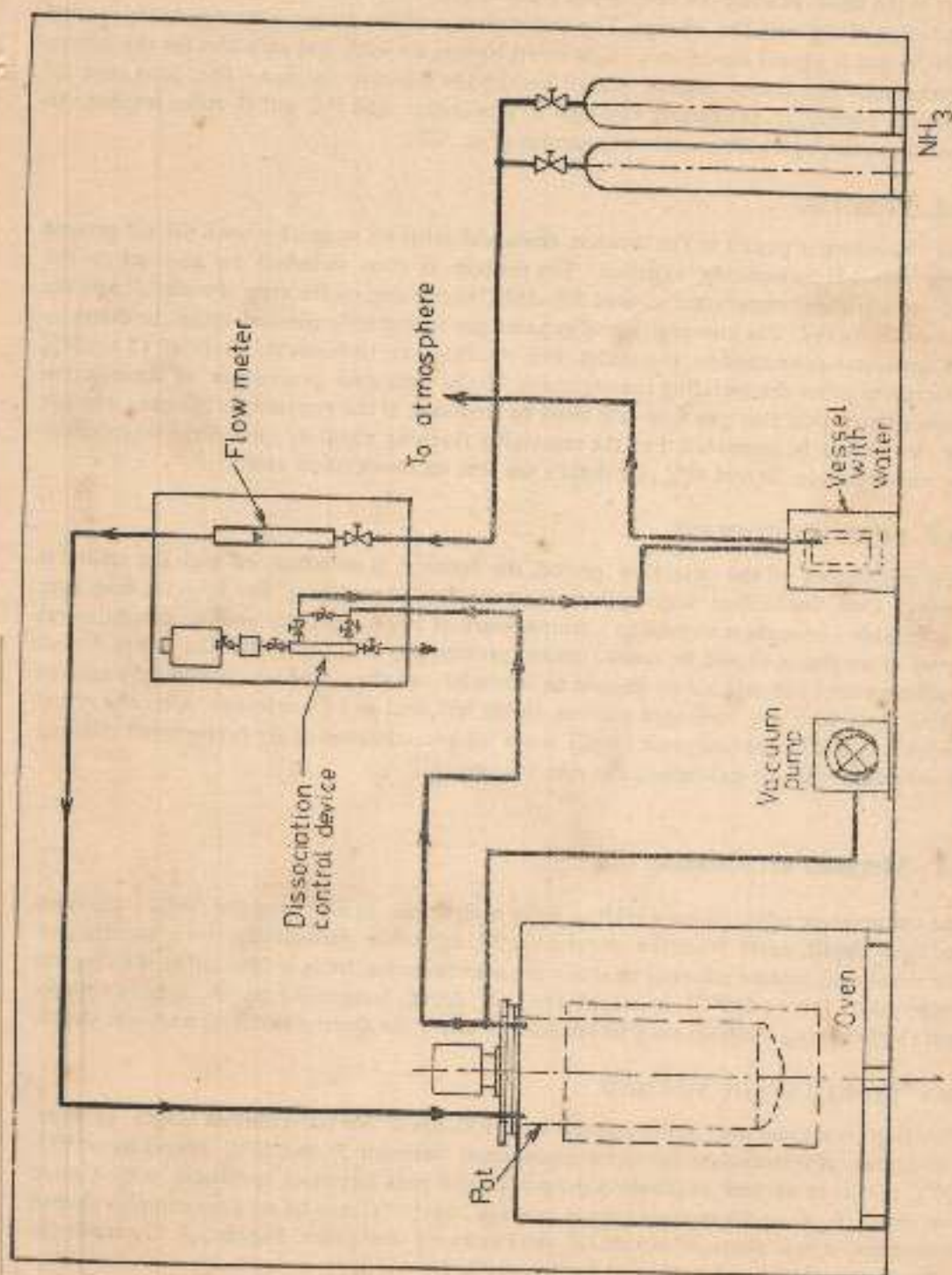


Fig. 5.2 Nitriding crucible furnace plant

It is the usual practice to keep a test piece of the same material as the components to be nitrided along with the charge. The entire charge of the group of components carried in the fixture is placed inside an airtight retort having an inlet and an outlet for the supply of ammonia. The retort is then placed inside the electric furnace. The inlet tube of ammonia supply is connected through a flow-meter and the outlet tube is taken to atmosphere through a dissociation apparatus (Fig. 5.2).

5.3.3 PURGING

After the retort is placed in the furnace, ammonia gas is let in quickly until the air present in the retort is completely expelled. The furnace is then switched on and set to the required nitriding temperature around 500–550°C depending on the type of material and the hardness required. The composition of exhaust gas is regularly checked using the dissociation apparatus connected to the outlet. For the first 5 to 10 hours it is kept at 15 to 20% dissociation (after the nitriding temperature). If the indicated percentage of dissociation is lower than this, the gas flow rate must be reduced. If the converse is the case, the gas flow rate should be increased. For the remaining reaching nitriding period the dissociation may vary between 20 and 60% (for details see text on dissociation rate).

5.3.4 FURNACE COOLING

After completion of the nitriding period, the furnace is switched off and the retort is removed from the furnace without disturbing the flow of ammonia. The retort is now kept in a suitable atmosphere to cool to a temperature of 100°C. During cooling a continuous supply of ammonia should be maintained to prevent any air getting into the retort. Under no circumstances should air or oxygen be admitted into the retort for cooling purposes, as mixing them with the hydrogen present inside will lead to an explosion. After the retort is cooled to 100°C, the ammonia supply is cut off and compressed air is employed to expel the residual ammonia gas before the retort is opened.

5.4 Methods of Nitriding

The temperature adopted for nitriding plays a vital role in attaining the desired hardness and case depth, apart from the percentage of ammonia dissociation to be maintained. The usual temperature adopted to attain the maximum hardness is 500–510°C. Raising the temperature (above 500°C) increases the case depth. Depending on the type of component the following methods may be adopted to attain the desired hardness and case depth.

5.4.1 SINGLE-STAGE METHOD

Nitriding is carried out in this method at 500–530°C for the required length of time. The degree of dissociation has to be maintained between 20 and 50%. Nitriding at 500–530°C results in optimal antifriction properties and peak hardness consistent with a good case depth.^{5,6} A nitriding temperature range of 500–510°C may be used for complex shaped thin-walled components of structural steel to avoid distortion. Figure 5.3 illustrates the depth of case that may be attained by this method.

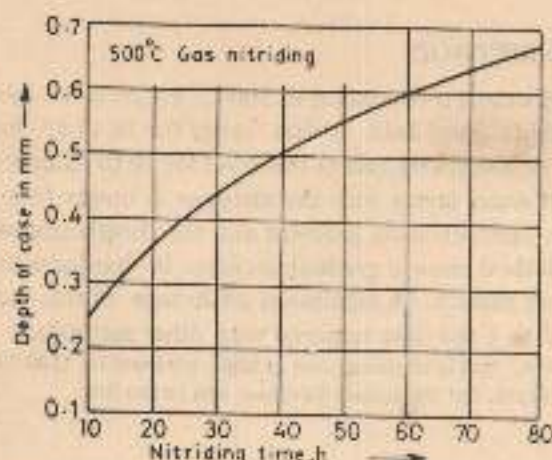


Fig. 5.3 Depth of case depending on nitriding time

5.4.2 TWO-STAGE METHOD

In this method nitriding is carried out at about 500–510°C for the first 15 to 20 hours, and then the temperature is raised to 550°C for the remaining period of the nitriding cycle. The degree of dissociation is maintained between 20 and 50% during both the stages.

At 550°C a high nitrogen content is built up at the surface and the rate of diffusion into the material is accelerated. This results in an increased case depth^{6-7,8,9} but at the same time, the case becomes toughened. The advantage of this method is that it considerably reduces the total time required for the process, because a higher case depth associated with a higher temperature is made possible, even while the high hardness obtained at the lower temperature at the first stage is retained. Figure 5.4 illustrates the variation in case depth attained by single stage and the two stage method.

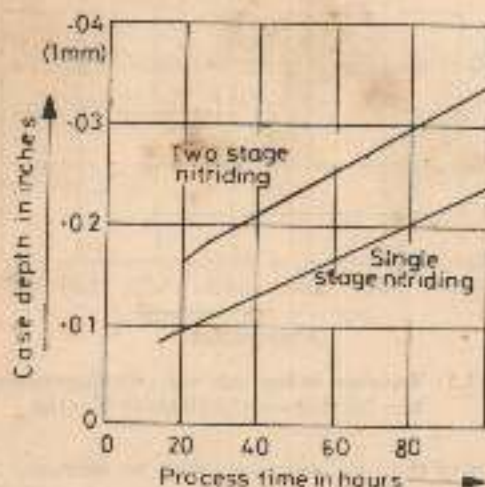


Fig. 5.4 Rates of case development for steel—40NiCr1Mo28 (AISI 4340)*

5.4.3 THREE-STAGE METHOD

Nitriding is first carried out in this method at 500°C for 10 to 15 hours; the temperature is then raised to 550–570°C and held in that range for 10 to 15 hours. Thereafter, the temperature is reduced to 500°C and held at this level for 10 to 15 hours. At this temperature the rate of saturation of outer layers with the nitrogen is slower than the rate of diffusion; hence this reduces the concentration gradient and the brittleness of the surface. Components treated by this method show a gradual decrease in hardness from the surface to the core and possess tougher surface. A significant advantage of this method is that the total process time is reduced to $\frac{1}{3}$ the time required with other methods.¹⁰

Note Reversing the cycle, that is nitriding first at high temperature (550–570°C) and soaking at 500–510°C, gives the same case depth, but the surface hardness will be too low.

5.5 Effect of Nitriding Temperature

The temperature at which gas nitriding is performed ranges from 490–550°C depending on the type of steel used. Contrary to the results obtained in regular case hardening, the hardness of the nitrided case does not increase with the nitriding temperature. Figure 5.5

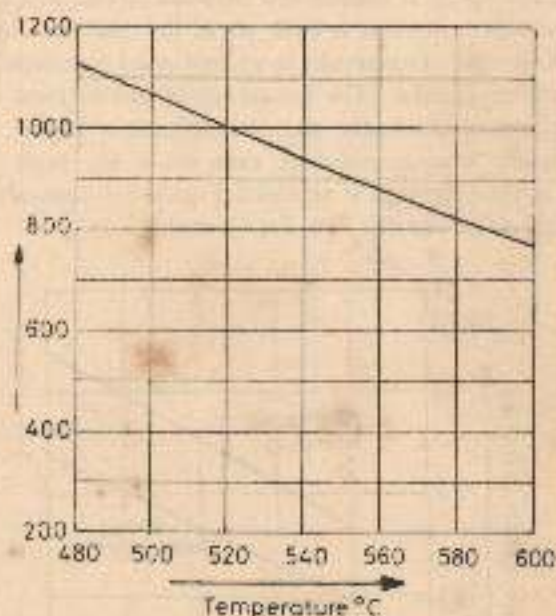


Fig. 5.5 Variation in hardness with nitriding temperature for steel—40Cr2AlMo18 (En418)

indicates that the hardness of the case decreases with an increase in temperature and also the depth of penetration is greater. At a lower temperature surface hardness is higher, but at the same time, the case depth is smaller. Figure 5.6 illustrates the variation in case depth and hardness.^{4,11} The best temperature for nitriding treatment is determined by

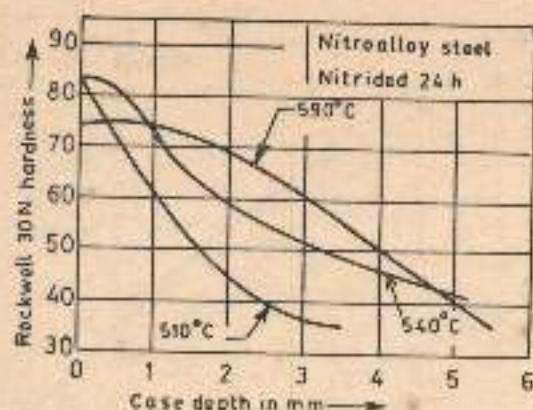


Fig. 5.6 Influence of temperature on hardness and depth of nitriding¹¹

the interaction of ammonia dissociation, diffusion rate and the precipitate size. Below 450°C, diffusion is so slow that it will take an inordinately long time to form a case. Above 540°C the dissociation of ammonia increases, and the nitrogen potential concentration gradient becomes low; moreover, the alloy nitride particles grow coarser, reducing the dispersion hardening effect.¹³ Higher temperatures yield a smaller white zone, a lower surface hardness, and a greater diffusion zone. The commonly used nitriding temperature of 500–530°C for structural steels is a compromise between good hardness and a satisfactory case depth.^{5,12}

5.6 Dissociation Rate

Rate of dissociation is an important process parameter in nitriding. The rate of dissociation has to be monitored throughout the process because it determines the supply of a sufficient amount of atomic nitrogen. This is achieved by regulating the flow rate of ammonia gas into the retort so as to maintain the required concentration ratio of ammonia to give the needed atomic nitrogen. Though the rate of dissociation required in the process may be in the range of 20–65%, it is advisable that a rate of 20–25% is maintained for several hours (10 to 15 hours) at the start of the cycle, keeping the temperature at 500 to 520°C. Afterwards the rate of dissociation may be raised further.

It can be noted that it is possible to use different levels of dissociation at a particular nitriding temperature. The nitriding media needs only sufficient active nitrogen and beyond this point, it will only serve to increase the depth of white layer and will not affect the depth of the useful nitrided case.

The relationship between hardness and case depth remains unchanged for dissociation rates from 15 to 65%, and it gets altered only beyond 65%² (Fig. 5.7). It is to be noted that the formation of white layer increases at decreased dissociation rates. This effect is more predominant at dissociation rates below 15%. Though the formation of the white layer is a common phenomenon in nitriding it is noted that the white layer disappears when

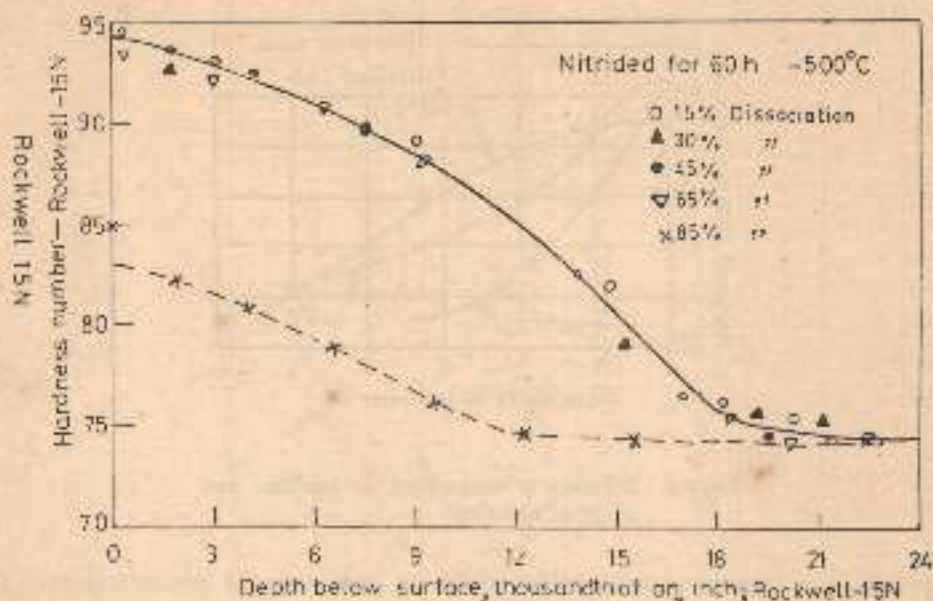


Fig. 5.7 Hardness characteristics of samples nitrided for 60 h at the shown dissociation of ammonia²

dissociation rates are above 85%; but above this point de-nitriding takes place.² It is therefore generally recommended that the dissociation rate be kept at about 20 to 25% at the start for 15 to 20 hours, after which the rate is to be raised to 55 to 60% to reduce the formation of a white layer and also to cut down ammonia consumption.

If a higher degree of dissociation (60–80%) is used, it is essential to have furnaces with fans to provide a turbulent atmosphere. Only a low dissociation can be treated even without fans. In actual practice it has proved feasible to operate with a degree of dissociation of roughly 50 to 60% even in furnaces without fans. Ammonia consumption can be reduced by 25% by raising the degree of dissociation from 30% to 50%.⁴

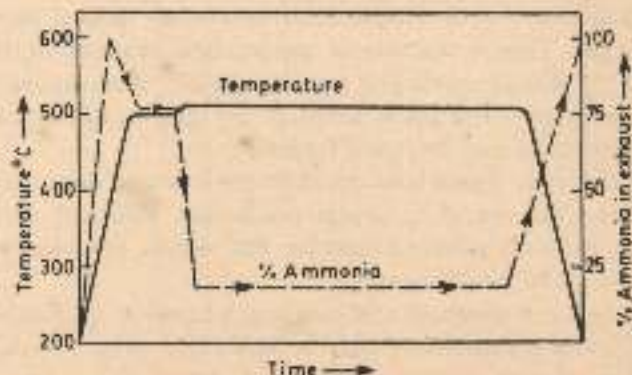


Fig. 5.8 Nitriding cycle to produce a nitrided case with a controlled white layer¹³

Adopting the higher degree of dissociation helps to reduce the white layer, but the corrosion resistance of the produced case is not as good as that obtained with a lower degree of dissociation. At higher values of dissociation, especially at more than 85%, the denitriding action starts due to the higher concentration of hydrogen and hardness also reduces. The lower percentage of dissociation of 25 to 30% may be used if maximum resistance to corrosion is desired. If the components are subjected to grinding after nitriding, higher dissociation rates may be used. For some applications where it is impracticable to grind or lap the parts after nitriding, it is desirable to decrease the depth of white layer as much as possible. This can be done by first adopting 25 to 30% dissociation for 5 to 6 hours in order to establish the white layer followed by an increased dissociation of 80% for the remaining period^{2,7} (Fig. 5.8).

5.6.1 MEASUREMENT OF DEGREE OF DISSOCIATION

The percentage of ammonia dissociation in the container is measured with a *dissociation meter*. This instrument consists of a dissociation pipette with a scale graduated in 100 divisions and a water container at the top (Fig. 5.9).

This instrument is connected to the exhaust pipe of the retort. During nitriding the valves *I* and *O* are opened and as the exhaust gas passes through them the degree of dissociation is measured. After a brief interval of time valves *I* and *O* are closed and subsequently valve *W* is opened to admit water. Water thus introduced into the dissociation pipette, absorbs all the ammonia that has not been decomposed, whereas hydrogen and nitrogen do not dissolve in it. The amount of water sucked into the pipette is equal to the amount of non-decomposed ammonia. The remaining amount indicates the percentage of ammonia dissociated in the container.

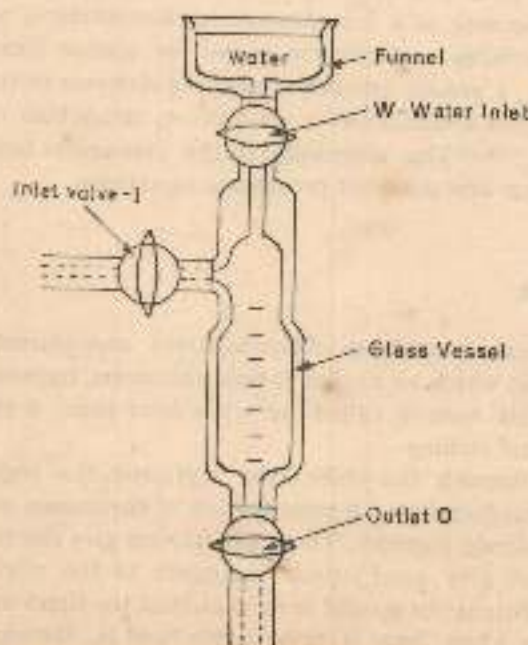


Fig. 5.9 Dissociation pipette for nitriding

5.7 Effect of Tempering Temperature

The tempering temperature is also an important factor in the attainment of peak hardness of nitrided components, although it is not the case with all nitriding steels. For example, steels containing aluminium do not show an appreciable change in peak hardness. On the other hand the hardness of steels containing chromium and molybdenum are quite markedly affected by the tempering temperature. It may be seen from Fig. 5.10 that the tempering

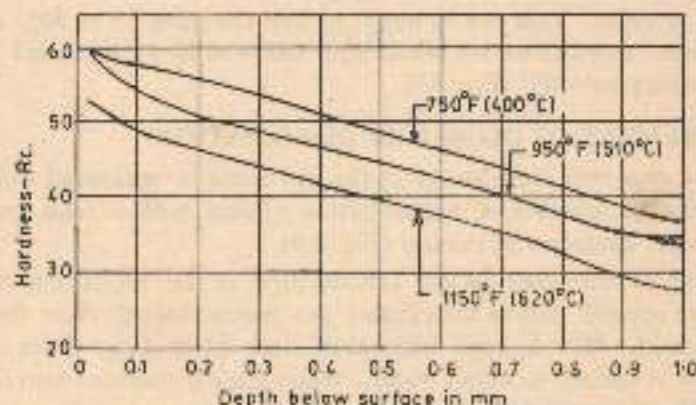


Fig. 5.10 Effect of tempering temperature on steel 4137 (AISI)
Mod. nitrided for 72 h at 500°C¹³

after hardening should be at a lower range in order to get the peak hardness. This peak hardness is obtained because, at a low tempering temperature, a smaller amount of the alloy is locked up in carbides leaving more alloys for nitride formation. With a higher tempering temperature, a greater amount of alloying elements in the steel are precipitated as carbides; there is thus a reduction in the amount of carbide that should be available for nitride formation.^{74,12,16} The aluminium in the aluminium bearing steels remains in solid solution in the iron and does not precipitate as carbide.

5.8 Nitrided Case

In general, a nitrided case is made up of two separate and distinct zones. The outer zone represents the region in which all nitride forming elements, including iron, have been converted to nitrides. This zone is called the *white layer* since it appears white under the microscope, after a nital etching.

The second zone beneath the white layer represents the region in which most of the special elements are hardened by the precipitation of chromium, molybdenum, aluminium, vanadium, etc., into nitride particles. These precipitates give rise to compressive stresses in the surface layer which give good fatigue resistance to the nitrided component. Under normal nitriding conditions the second zone is at least ten times as deep as the first.

The outer zone or white layer is very brittle and is, therefore, usually removed by grinding before a nitride case is put into service. Sometimes the white layer is not removed

when corrosion resistance is of primary importance, since nitrogen ferrite, as well as nitrides, possess a relatively high corrosion resistance. This fact determines the application of the nitriding process to protect steel against corrosion. The constitution of the nitrided layer consists of a series of phases of progressively decreasing nitrogen content from the outside towards the core as follows: 4.17

1. $\text{Fe}_2\text{N}/\text{Fe}_3\text{N}$ —epsilon nitride (ϵ)
2. Fe_4N — γ nitride
3. $\alpha(\text{N})$ —nitrogen-rich ferrite.
4. α ferrite.

Note It should be noted that a thick case is not required to obtain the best properties. A thick case will not only reduce the fatigue limit but will also increase the deformation of the components.

5.9 Hardness of the Nitrided Case

Hardness of the nitrided case depends on the structure, chemical composition of the steel and the temperature employed for nitriding.

The hardness of the case decreases with increasing nitriding temperature, as illustrated by Fig. 5.5. The maximum hardness consistent with a good case depth is obtained in most of the constructional steels by operating at 490–500°C. Much softer cases, but considerably deeper for a given nitriding cycle, may be obtained by nitriding at 550–560°C. The commonly used temperature of 520°C is a compromise between a good hardness and a satisfactory case depth. However, for parts requiring extreme hardness with some sacrifice in case depth, a temperature of 500°C is recommended.

It may be seen from Table 5.1 that higher hardnesses are obtained in constructional steels containing primarily aluminium and chromium.

Table 5.1

IS	AISI	Nitriding temp, °C	Hardness HRC	Case depth, mm	Time, h
40Cr2Al1Mo18	135-M	525°C	65–70	0.5–0.6	48
40Cr3Mo1V20	—	520°C	60–62	0.5–0.65	48
25Cr3Mo55	—	500°C	65–67	—	—
40Ni2Cr1Mo28	4340	525°C	50–55	0.6–0.7	48
40Cr1Mo28	4140	525°C	55–60	0.6–0.7	48
C45	1045	500°C	30–32	—	—
T35Cr5Mo1V30*	H11	515 & 550	70–75	0.4–0.5	15 + 55
T35CrMoV1*	H13	525 & 550	70–75	0.3	60
T83MoW6Cr4V2*	M2	525 & 550	70–75	0.15–0.2	2 + 35
Stainless Steel*	300 Series	550 & 550	65–75	0.03–0.07	16 + 20

*Data refers to a two-stage cycle of nitriding.

The hardest and toughest nitrided case is obtained only if the steel is in sorbite condition, i.e. the carbide phase is uniformly distributed through the ferrite. Preliminary heat treatment affects the properties of the nitrided case on aluminium-free steels containing carbide forming elements. For annealed and normalized steels with a ferrite-pearlite structure the depth and hardness of the nitrided case are lower than for quenched and tempered steels with a sorbite structure.

5.9.1 DEPTH OF CASE

The case depth obtained depends on duration of nitriding, temperature adopted, composition of the steel, microstructure, availability of active nitrogen and the method of nitriding. Nitrogen from the nitriding reagent diffuses into the steel, forms nitrides with the special alloying elements at the treatment temperatures and are precipitated along the crystal planes of the iron. These precipitates of alloy nitrides harden the case. Hence the depth of case depends on how far beneath the steel surface nitrogen has been able to diffuse during the nitriding period. The depth of case produced in a given time will therefore depend upon the amount of alloying elements that must be precipitated in a given time before the nitrogen can diffuse further.

The higher the nitriding temperature the greater will be the case depth attained in a given time. Similarly, the lower the alloy content the greater the case depth produced in a given time. Higher alloying elements reduce the case depth. This is due to the higher solubility of nitrogen in the alloyed alpha phase. Apart from this the presence of nickel and silicon further decreases the diffusion rate of nitrogen. Also steels in the annealed and normalized structures have a lower case depth.

The depth of the nitrided case specified in practice varies with the application. Major factors that determine case depth are as follows:

1. Maximum amount of allowable wear.
2. Amount of distortion, which governs the maximum amount of case that must be removed after nitriding.
3. Size and shape of the section.

5.10 Testing of Nitrided Case

Testing of the nitrided case includes the examination of the surface hardness and the determination of its appearance.

The hardness test can be carried out by the Vickers hardness method, applying a load of 1, 5, 10 or 15 kg or by using super-Rockwell 15N. Ductility and brittleness may be judged according to the appearance of the impression caused by the Vickers hardness test. If the impression is sharp edged, it is a sign of non-brittleness. If, however, cracks occur in the surrounding area of the impression and the impression itself is not very pronounced, it is a sure sign of brittleness.

5.11 Furnaces

Furnaces used for gas nitriding are pit type or conventional muffle type furnaces. Pit type

furnaces are used for large-scale nitriding. Muffle type furnaces are used for small scale nitriding.

The containers used for nitriding should be made of materials such as Inconel, or heat resisting steels with 25% chromium and 20% nickel which do not react with the gases.

Although special nitriding furnaces are desirable such an equipment is not absolutely necessary in many instances. These special furnaces are constructed in such a manner that they can be used for general heat treating purposes when not used for nitriding. The most essential point is that the furnace must be well equipped for precise control of temperature. This is needed to prevent uneven heating so that distortion of components and variation in hardness are avoided. The components are finish machined prior to nitriding. In addition, nitriding containers should be provided with fans for a uniform circulation of nitriding gases.

5.12 Shop Problems, Causes and Remedies

The common problems encountered on the shop floor are as follows.

5.12.1. DISTORTION

Since the nitriding process is carried out at a relatively low temperature on finished or nearly finished components, it is often presumed that the distortion is minimum. But this assumption, however, is only true if all the conditions during nitriding and cooling are favourable.

Distortion is mainly caused by the release of residual stresses imposed during machining, straightening and also by the nitriding process itself.^{18,19,20}

1. Distortion may be negligible in short components machined from a heat treated bar, but items such as shafts, spindles and leadscrews of appreciable length should always be hardened and tempered with sufficient machining allowance to machine them without straightening. Before nitriding, distortion can be corrected by straightening but this does not prevent distortion during nitriding because the internal stresses generated during straightening are not removed. Straightening and subsequent removal of residual stresses by stabilization at 550°C helps to reduce distortion to a minimum during nitriding. The higher the temperature and longer the tempering time, the greater is the reduction of distortion after nitriding.
2. It is known that residual stresses occur during any machining operation. It may be due to heavy machining or improper machining. This can normally be avoided by applying a stabilizing treatment prior to finish-machining or grinding, and then nitriding. This consists of heating to 550°C, through soaking (2-4 hours) and cooling in air.
3. Distortion caused by the nitriding process itself is difficult to correct.¹⁸ For example, in dealing with thin-walled cylinders, this can be a problem, because there is only a general increase in diameter, but due to the greater freedom of movement at the ends of the cylinder, there can also be considerable 'bell-mouthing'. This can be usually avoided by leaving the cylinder considerably thicker and finishing the outside after nitriding. Alternatively collars can be left on the ends of the cylinder for subsequent removal. Stabilizing for a longer time is essential to avoid distortion or bell-mouthing.

Sometimes, when hollow cylinders, bushes, spacers and rings are nitrided, the dimensional changes affect both internal and external surfaces.²⁰

Figure 5.11 demonstrates that up to a certain cylinder thickness during nitriding, there will be an increase in the outside as well as the inside diameter. When a certain definite relationship between the outer and the inner diameter is reached only the

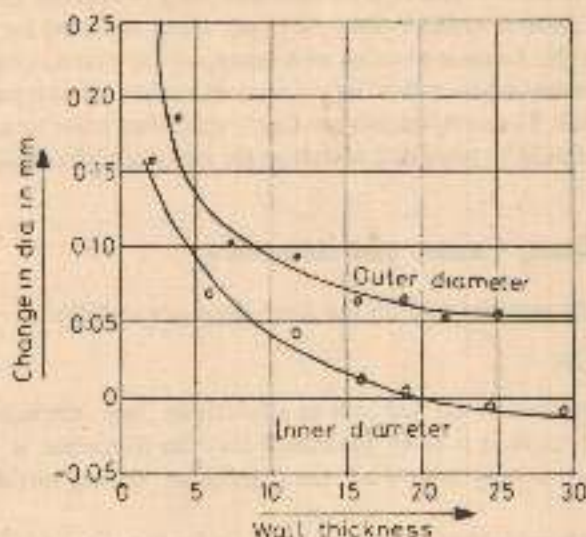


Fig. 5.11 Diameter changes as a function of wall thickness of rings of 50 mm height, 70 mm outer diameter and varying wall thickness, after nitriding for 72 h at 525°C. Steel—40Cr2Al1Mo18 (En41B)²⁰

inner diameter will shrink further. It is advisable to use a lower nitriding temperature of 500 to 510°C for thin-walled, complex form cylinders, spacers, rings, etc.

4. As the nitrided case forms, it expands in an attempt to stretch the core. After nitriding and cooling, compressive stresses will be present in the case, and tensile stresses persist in the core. If the component and nitrided case are not symmetrical, some distortion is inevitable, particularly in slender components like racks, wheel spindles with different cross section, etc. For this reason nitriding is considered suitable only for parts which are rigid or symmetrical such as shafts, cylinders, gears, etc.

Sometimes distortion is caused by the part geometry itself. This can be overcome by straightening them either in hot (500°C) or cold condition, and then grinding or lapping to the finish size. Hence in such cases, it is necessary to provide an allowance for grinding or lapping after nitriding.

5. Keyways in shafts, screws, etc., can be a source of trouble, and wherever possible, it is recommended that they be duplicated at diametrically opposite positions on the component.
6. When components are ground, local distortion occurs because of a slow buildup of residual stresses in the core. If extremely close dimensional stability is required, it

is advisable to reheat to the nitriding temperature for a minimum of one hour, depending on the section and finishing to size by lapping.

7. Uneven case depth: The most exclusive cause of distortion, however, has been traced to uneven case depth caused by an inadequate surface preparation. Certain finishes such as those produced by buffing, finish-grinding or lapping develop irregular cases when nitrided. When this occurs in thin cylindrical or delicate sections, they will get severely distorted because of unbalanced stresses in the case. This can be usually prevented either by phosphating or vapour degreasing prior to nitriding or, by a careful preparation of the surface of the components.
8. To avoid distortion or warping, it is also of utmost importance that a uniform heating and cooling of parts in the furnace during nitriding be adopted.

5.12.2 NETWORK AND MINIMUM DEPTHS

The presence of iron nitride around grain boundaries can result in spalling.^{19,20} Since this condition occurs specially at the sharp corners, such components should be chamfered before nitriding. This undesirable grain boundary condition can be traced to a higher nitriding temperature which was employed during the 2nd stage of the process to get a higher case depth and to reduce the white layer. Use of a lower temperature during the 2nd stage will eliminate or minimize the grain boundary condition, and at the same time, it will also increase the hardness.

5.12.3 WHITE LAYER

White layer is the common term given to the iron nitride skin that forms up to a depth of 0.05 mm on the surface of the nitrided parts.^{19,20} This layer is not as hard as the case immediately underneath it, but it develops brittleness and spalling in service. This layer can be removed most economically by careful grinding, lapping, buffing, polishing, shot blasting, alkali treatments, sulphuric acid, etching, etc.

The white layer can also be removed by soaking the nitrided parts for about 8 hours in a hot cyanide solution consisting of one pound of sodium cyanide in a gallon of water and heated up to 75 to 80°C. Removal of the white layer can be speeded up by a shorter soaking followed by cleaning with 220 mesh aluminium oxide grit of 80. Tests have shown that the process does not affect the fatigue life or the impact resistance of the component and also the grain boundaries are not attacked.²¹

A white layer deeper than the permitted limit may be caused due to very low temperatures or, alternatively, due to a very low percentage of dissociation (15%) coupled with fast purging with raw ammonia instead of cracked ammonia above 480°C during cooling. Proper control of dissociation by adjusting the flow of ammonia gas to the chamber, nitriding at a correct temperature and avoiding fast purging with ammonia will reduce the formation of white layer.

5.12.4 VARIATION IN PERCENTAGE OF AMMONIA DISSOCIATION

This may be caused by a change in gas flow due to a pressure build-up in the furnace, or the charge supplied in the furnace may be too small for the furnace area. Use of good pipe fittings and suitable materials for the valves will avoid the building up of pressure in the furnace.

5.12.5 LOW CASE HARDNESS OR SHALLOW CASE

This is mainly due to a faulty processing or due to the characteristics of the nitrided material. Low hardness is caused if the material is not suitable for nitriding or if the nitriding is done on a low core-strength material. Low hardness or a shallow case may be caused if the nitriding is done at too high or too low a temperature, or by a non-uniformity in the furnace temperature. This can be prevented by a close control of the temperature and by checking the temperature control system periodically during nitriding.

Insufficient ammonia gas and insufficient nitriding time also cause a low hardness or shallow case. Maintenance of an adequate supply of ammonia, proper dissociation rate and nitriding time will avoid the defects of low case hardness or a shallow case.

5.12.6 DISCOLORATION OF THE COMPONENT

Discoloration of the component occurs mainly due to an improper surface preparation before nitriding or by the presence of moisture in the retort due to the seepage of water into the retort from the cooling chamber. Presence of air in the retort is due to improper sealing of the lid or leakage due to inadequate sealing around the pipes. Discoloration of the workpiece can be avoided by proper surface cleaning by using exceptionally good quality pipe fittings and also by the proper sealing of the lid. However, discoloration of the component in no way affects its hardness.

5.13 Precautions for Nitrided Parts

1. Maximum resistance to corrosion is exhibited in those steels which are put into service in the as-nitrided condition, that is, without the removal of the outer layer. If this layer is removed there will be an appreciable fall in the corrosion resistance of the steel.
2. If maximum hardness and toughness is required and resistance to corrosion is not of major importance then it is advisable to remove the thin brittle white layer on the surface, which is undesirable on the surface. Removal of this layer normally calls for grinding or lapping to a depth of 0.025 mm to 0.05 mm from the surface after nitriding. In no instance should more than 0.12 mm of surface layer be removed in final grinding, and it is preferable to specify a maximum removal of 0.08 mm.
3. Even though the hardness of the nitrided steel is considerably high and greatly improves the usefulness of the steel, it cannot withstand the abrasive action of solid particles such as sand or grit. Therefore nitriding should not be applied for components such as sand and shot-blasting nozzles.
4. During nitriding a surface growth is likely to take place, which is primarily dependent upon the size of the section, depth of the case and the shape of the component. The amount of this growth is constant for a given nitriding cycle and must be determined for each component by experiment. Based on this, proper allowances can be introduced during finish machining. The amount of growth on the surface of the component usually ranges between 0.02 and 0.05 mm.
5. It is not practicable to nitride a component already nitrided. Renitriding may lead to brittleness in the case and spalling. However, if the first nitriding attempt has

been unsuccessful the case may be ground off and the component then re-nitrided.

5.14 Special Features and Advantages of Gas Nitriding

1. Nitriding offers an extremely valuable combination of properties which justify the cost of treatment for components exposed to severe service conditions.²¹
2. Nitriding provides a very hard surface on a component with a tough core.
3. Since nitriding is carried out at a comparatively low temperature, distortion is reduced to an absolute minimum and except in parts of a very thin section or intricate design, it is practically eliminated.
4. In a majority of cases, the nitrided parts can be put straight to work after treatment, thus eliminating the straightening and final grinding procedures necessary in the other methods of hardening components; this helps save valuable time.
5. No quenching is necessary as in the ordinary methods of case hardening and, consequently, the problem of quenching cracks is obviated by this process.
6. Nitriding is less sensitive to stress raisers caused by a poor surface finish, sharp changes in cross-section holes etc.
7. Greater hardness obtained by nitriding compared with the methods of other case hardening (Table 5.2).

Table 5.2 Hardness of nitrided and case-hardened steels

Steel IS	Case hardness VHN	Treatment
C10	800	Carburized
15Ni4Cr1	750	Carburized
15Cr55	710	Carburized
15Cr3Mo55	850	Nitrided
25Cr3Mo55	900	Nitrided
40Cr2Al1Me18	1000	Nitrided

8. One of the most valuable functional properties of the nitrided case is its high wear resistance. Wear resistance of the nitrided case is of the order of 10 times more than the carburized case.^{11,21} The big advantage of high wear resistance as components lies in the fact that frequent replacement of the machine elements can be avoided thus bringing down the maintenance cost.

Table 5.3 illustrates the wearing properties of nitrided steels in response to tests carried out with an Amsler Machine. It can be seen that whereas in the case of different case hardened steels the loss in weight for loadings between 20 and 80 kg is considerable, nitrided steels showed no loss in weight even when loaded with 80 kg. It may be seen from Fig. 5.12 that the wear resistance of the nitrided case after the shot-blasting test is very low, the least abrasion being taken compared to the case hardened and un-nitrided steels.

Table 5.3 Relative wear on nitrided and carburized steels¹¹,
Amsler Test

Load kg	Carburized steel loss in weight (centigrams)				Nitrided case
	Cr steel	Ni-Mo steel	Cr-V steel	Cr-Ni-Mo steel	Nitro alloy steel
20	0.48	0.19	0.16	0.16	Nil
30	1.55	0.60	0.44	0.38	Nil
40	2.24	1.15	1.15	1.11	Nil
50	2.35	1.49	1.60	1.71	Nil
60	2.43	1.98	2.06	2.35	Nil
70	2.62	2.58	2.00	2.40	Nil
80	2.98	2.47	2.08	2.79	Nil
200	—	—	—	—	0.26

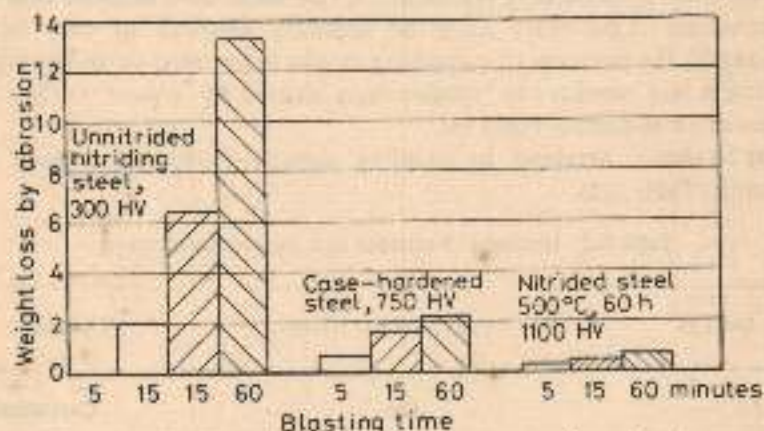
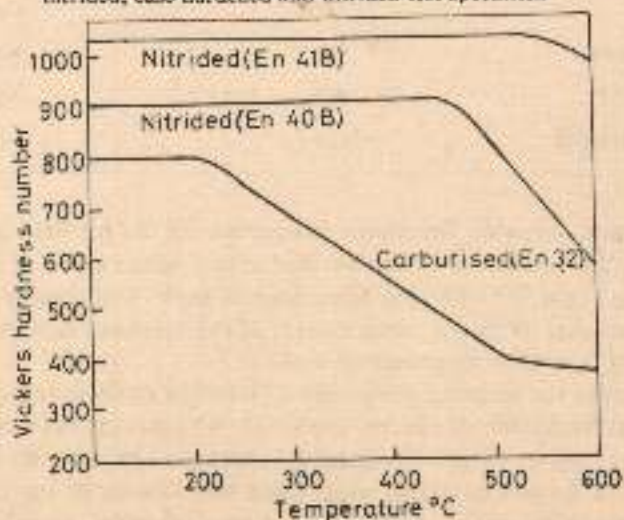
Fig. 5.12 Abrasion loss occurring during blasting with steel grit on un-nitrided, case hardened and nitrided test specimens²⁸

Fig. 5.13 Effect of temperature on the hardness of carburized and nitrided steels

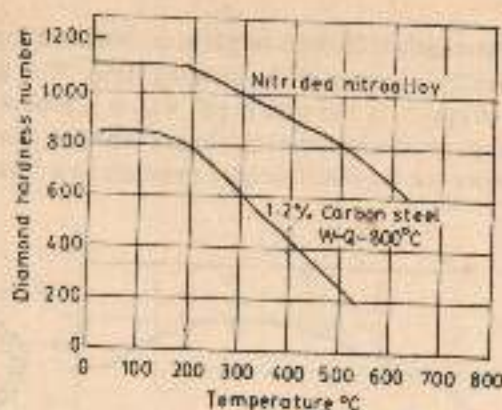


Fig. 5.14 Hardness at elevated temperatures¹¹

9. The nitrided case retains its hardness even if it is heated to the nitriding temperature, and in some cases to an even higher temperature revealing no loss of hardness at room temperature.^{11,22} This is the greater advantage over the other methods of case hardening such as carburized, induction hardening and flame hardening cases which soften above 200°C. Hence nitriding is desirable for components where lubrication is critical or non-existent. At the same time nitriding provides excellent wear resistance to components operating at high temperatures. Figure 5.13 illustrates the effect of temperature on case hardened and nitrided case. Carburized steels begin to lose their hardness at a comparatively low temperature with an appreciable drop in hardness at 300°C. Figure 5.14 shows that the hardness at elevated temperatures is also relatively high compared with 1.2% carbon steel. It can also be observed that at 500°C, the nitrided steel has a hardness above 800 VH while the hardness of carbon steel is only 300 VH. This softening is only temporary in the case of nitrided steels which regain the original hardness on cooling. On the other hand, carbon steel will not regain its hardness after cooling.
10. Lubrication failure, or other factors which lead to high surface temperature, will not result in softening as readily as with other methods of surface hardening.
11. Although nitrided steels cannot be included in the stainless steel category, they are, nevertheless, extremely resistant to the corrosive action of fresh water, sea water, super-heated steam, etc. This is ascribed to the formation of the high nitrogen Eta phase in a continuous layer on the surface of a component. Corrosion resistance is greatest for polished surfaces. However, by grinding off a layer of about 0.03 mm thickness, the white layer is removed and corrosion resistance is reduced. Nitriding also increases the fatigue strength under corrosive media. High corrosion resistance may be obtained by raising the nitriding temperature from 520–580°C.⁴² This is mainly due to improvement in the nitrided layer.
12. Nitrided surface can be polished to acquire a handsome metallic lustre.
13. The formation of the high nitrogen phase on the surface of the nitrided component is associated with large volume changes which lead to the appearance of compressive stresses in the hardened layer. These stresses substantially increase the fatigue limit of the component as a whole.¹⁷
14. Nitriding is also an effective means of increasing resistance to fatigue strength. The

increase in fatigue strength is highest in plain carbon and low alloy steels (see Table 5.4), and this generally increases with nitriding time. The important parameter for improving fatigue strength is the case depth which is reported to be effective up to 0.30 mm depending on the material thickness and the shape. This is illustrated in Fig. 5.15 which shows the torsional fatigue strength as a function of nitriding depth

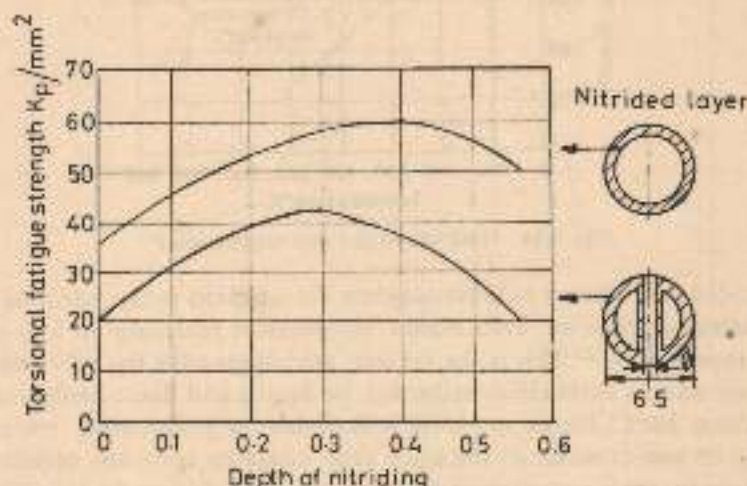


Fig. 5.15 Torsional fatigue strength as a function of depth of nitriding of a smooth test specimen and a drilled test specimen, respectively, made from a Cr-Mo-V steel of the following composition: C-0.3%, Cr-2.5%, Mo-0.2%, V-0.25. OB 110 K_p/mm^2 .

after the gas nitriding of test bars of 6.5 mm diameter. One test bar has a traversed hole of 1 mm diameter, which reduces the fatigue strength. With this bar the maximum fatigue strength is obtained with a nitriding depth of 0.30 mm. For undrilled bars it is at a depth of 0.40 mm. Normally the fatigue properties of the component increase after nitriding between 30 and 40%. If the components have stress raisers (sharp notchers) the fatigue limit will be 2 or 3 times more than in un-nitrided components.

Table 5.4 Improvement in fatigue strength in nitriding steel

Material	Tensile strength	Fatigue strength			
		Original		Improvement in %	
		Plain	Notched	Plain	Notched
CrMoV	90	49	10.5	+5	+142
1.7% Cr + 1.3% Al	62	22.9	—	+2	—
CrMoV	68	38.2	12.5	+36	+300
CrMoV	85	47.5	17.7	+20	+189
CrMoV	90	41.5	18.7	+24	+170
Stainless Steel 18.7% Cr + 9.3% Ni	40	15	—	+30	—
Stainless Steel 12.3% Cr	58	28	5	+15	+750

15. High dimensional stability due to absence of retained austenite.

5.15 Disadvantages of Gas Nitriding

1. The process time required is very long (typically 20 to 80 hours) and this makes nitriding expensive. The following table provides the details;

Table 5.5 Time required to produce a comparable case depth in Gas Carburizing and Nitriding.

Method	Time in hours for different case depths		
	0.010 (in)	0.02 (in)	0.03 (in)
Carburizing En 32 at 925°C	0.25 h	0.75 h	1.5 h
Nitriding En 40 B at 575°C	20 h	40 h	80 h

2. A brittle *white layer* is formed on the surfaces which may exfoliate and damage bearing surfaces.
3. Special steels have to be used in nitriding and this adds to the cost.
4. Standard nitriding steels are 25Cr3Mo551S and 40Cr2Al1Mo28. The aluminium containing steels, i.e. 40Cr2Al1Mo28 should be avoided for gears because of low resistance to spalling.²²
5. The fatigue strength of the nitrided case decreases when the case depth exceeds 0.3 mm. Under more severe loading conditions the fatigue life of nitrided components will be even shorter than that of hardened and tempered components.
6. Nitrided steels cannot be used for highly concentrated loads and shock loads.
7. Gas nitriding takes more time to attain the required case depth compared to salt bath nitriding and ion-nitriding.
8. Compared to ion nitriding, consumption of ammonia gas is greater.

5.16 Steels for Nitriding

Nitriding steels are primarily intended for use where components require maximum resistance to abrasion or resistance to fatigue or both. Sometimes, when a higher surface hardness than can be obtained with other case hardening steels is required, nitriding steels are preferred. They resist scuffing or galling where there is rubbing of metal against metal, and are particularly useful where lubrication is difficult.

Since nitriding itself appreciably improves fatigue resistance, nitrided steels are particularly useful for parts subjected to high alternating stresses.

Since nitriding is applied primarily to increase the surface hardness for the purpose of minimizing the wear, special steels (nitriding steels) have been developed which contain elements enabling the highest possible surface hardness to be obtained. Aluminium is the most important element in common use. The conventional nitriding steels contain about 0.8 to 1.20% aluminium. Aluminium has a very pronounced tendency to form nitrides resulting in peak hardness. Other nitride-forming elements are chromium, molybdenum, vanadium, titanium, tungsten, etc. Chromium and molybdenum in particular, apart from forming nitrides, also improve hardenability. This in turn favourably influences the core properties and the conditions for the formation of a sound nitrided layer.

Nitriding can be usefully applied to a number of other steels for special applications, and it is possible to obtain a large range of both case hardness and core properties. For

example, the 3% chromium-molybdenum and the 3% chromium-molybdenum-vanadium steels develop softer cases than nitro alloy, and have the advantage of higher hardenability and resistance to tempering. Certain nickel containing steels are useful because nickel improves the properties of the core, which therefore gives better support to the case. Although nickel reduces the case it increases its toughness.

Typical applications are aircraft, automobile and machine tool components such as crankshafts, gudgeon pins, shackle pins, pistons, cylinder liners, shafts and thrust collars and precision gears, particularly where the development of play cannot be tolerated. Table 5.6 indicates the different types of steels that are mainly used for nitriding.

Data Sheet 5.1—Type-1 (ISO)

CHARACTERISTICS

Possesses excellent hardenability and may be used to develop wide range of tensile strength combined with excellent ductility and resistance to shock.

APPLICATIONS

Components requiring medium to high tensile properties in the nitriding condition. Crankshafts increase the fatigue strength and wear resistance, cylinder liners, valves, slides, internal combustion engine cylinders, as well as superheated steam fittings, etc. Table 5.7 indicates the equivalent steels of International Standards.

PROCESS CHART

Rough Machine → Harden 890-910°C → Temper 570-650°C → Machine →
Finish Machine ← Nitriding 500-520°C ← Final Machine ← Stress relieve 550°C ←

Refer Fig. 5.16 for typical hardness depth curve.

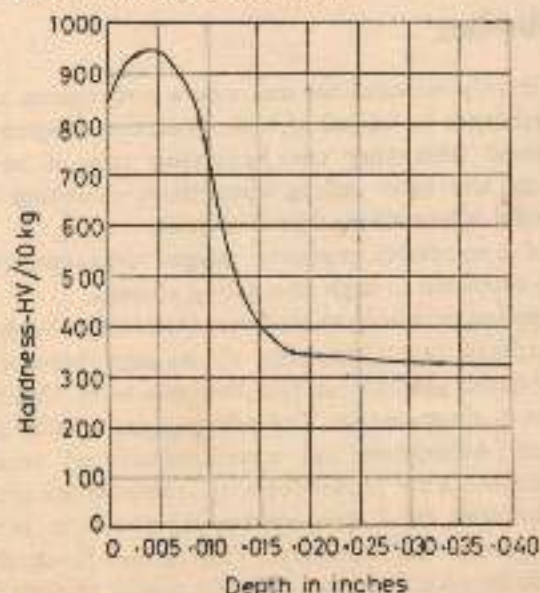


Fig. 5.16 Nitriding of steel—25Cr3Mo55 (BS 722M24) for 80 h at 500°C (gas nitriding)

Table 5.6. Nitriding steels^{a, b}

Country	ISO	INDIA	DEU	USA	GBR	FRA	USSR	JP
Standard	ISO	IS	DIN	AISI	BS 970	NFA 35	GOST	JIS
1	Type-1	25Cr3Mo55	31Cr-Mo12	—	722M24	30CD12	—	—
2	Type-2	40Cr3Mo1V20	39Cr-MoV139	—	897M39	—	—	—
3	Type-3	—	34Cr-AlMo5	Class D	905M31	30CAD612	—	—
4	Type-4	40Cr2AlV-Mo8	41Cr-AlMo7	Class A	905M39	40CAD612	38ChM10A	SACM1
5	—	—	34Cr-AlNi7	Class C	—	40CAD612	—	—
CONSTRUCTIONAL STEELS								
6	Type 3	40Ni12Cr1Mo28	34CrNiMo6	—	817M40	35NCD6	38Ch2N2MFA	SNC8
7	Type-3 (VIII 70)	40Cr4Mo3	42CrMo4	4140	708M40	42CD4	—	SCM4
HOT WORK STEELS								
8	40CrMoV5	T35Cr-MoV7	X40Cr-MoV51	H13	BIH3	24DCDV5	40C35MF15	SKD61
COLD WORK STEELS								
9	—	T160Cr12	155CrV-Mo214	D2	BD2	—	—	—
HIGH SPEED STEELS								
10	HS6-3-2	X19TW1Mo-3Cr4V2	S-6-5-2	M2	BM2	285WDCV 09-04-02	R6M5	SKH9

Table 5.7^a

Steel	Standard	ISO	IS	DIN	AISI	BS	NFA	GOST	JIS
	Designation	Type-1	25Cr3Mo55	31CrMo12		722M24	30CD12		
Chemical Composition	C %	0.28-0.35	0.28-0.35	0.28-0.35	—	0.20-0.28	0.28-0.35	—	—
	Si %	0.15-0.40	—	0.15-0.40	—	0.1-0.035	0.10-0.40	—	—
	Mn %	0.40-0.70	0.40-0.70	0.40-0.70	—	0.45-0.70	0.40-0.70	—	—
	≤ P %	0.03	—	0.03	—	0.025	0.035	—	—
	≤ S %	0.035	—	0.035	—	0.025	0.035	—	—
	Cr %	2.8-3.3	2.8-3.3	2.8-3.3	—	3.0-3.50	2.8-3.3	—	—
	Mo %	0.3-0.5	0.3-0.5	0.3-0.5	—	0.45-0.65	0.3-0.5	—	—
	Ni %	0.30	—	0.30	—	—	—	—	—
	Others	—	—	—	—	—	—	—	—
Mechanical Properties	Dimensions	40-100 101-160	—	40-100 101-160	—	152 max	40-100 101-160	—	—
	0.2% Proof Stress N/mm ² min	785 735	—	785 735	—	745	770 730	—	—
	Tensile Strength N/mm ²	980-1180 930-1130	—	980-1180 930-1130	—	920-1080	980-1180 930-1130	—	—
	Elongation % min.	11 12	—	11 12	—	11 12	11 12	—	—
	Reduction of area % min	—	—	—	—	—	—	—	—

Data Sheet 5.2—Type-2 (ISO) 40Cr3Mo1V20 (IS)

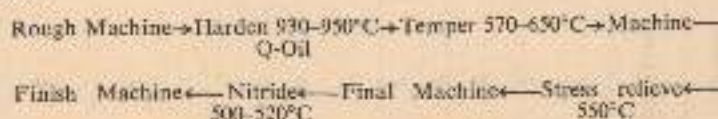
CHARACTERISTICS

A high tensile strength nitriding steel of excellent hardenability which can be heat-treated to give high core strength 140 kg/mm²; on nitriding it develops a hard wear-resistance case. Exhibits hardness around 800 HV after nitriding.

APPLICATION

Used for components requiring high tensile properties and subjected to severe wear after nitriding. Table 5.8 indicates the equivalent steels of International Standards.

PROCESS CHART



(a) Refer Fig. 5.17 for typical curves showing effect of tempering on mechanical properties.

Table 5.8

Steel	Standard	ISO R683/X-75	IS	DIN	AISI	BS	NFA	GOST	JIS
	Designation	Type-2	40Cr3Mo1V20	59CrMoV135		897M39	—	—	—
Chemical composition	C%	0.35-0.42	0.35-0.45	0.35-0.42		0.35-0.43	—	—	—
	Si%	0.15-0.40		0.15-0.40		0.10-0.35	—	—	—
	Mn%	0.4-0.7	0.4-0.7	0.4-0.7		0.45-0.70	—	—	—
	≤P%	0.03	0	0.03		0.025	—	—	—
	≤S%	0.035		0.035		0.025	—	—	—
	Cr%	3.0-3.50	3-3.5	3.0-3.50		3.00-3.50	—	—	—
	Mo%	0.8-1.1	0.9-1.1	0.8-1.1		0.8-1.1	—	—	—
	V%	0.15-0.25	0.15-0.25	0.15-0.25		0.15-0.25	—	—	—
	Others						—	—	—
Mechanical properties	Dimensions	70 max	—	70 max		64 max	—	—	—
	0.2% Proof stress N/mm ² min	1080	—	1080		1110	—	—	—
	Tensile strength N/mm ²	1270-1470	—	1270-1470		1310 min	—	—	—
	Elongation % min	—	—	—		—	—	—	—
	Reduction of area % min	—	—	—		—	—	—	—

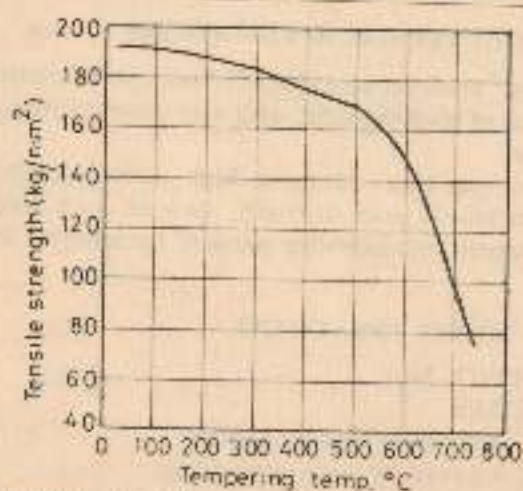


Fig. 5.17 Typical curve showing effect of tempering on tensile strength. Bar diameter—1.8", oil quenched from 970°C.

(b) Refer Fig. 5.18 for typical hardness depth curve.

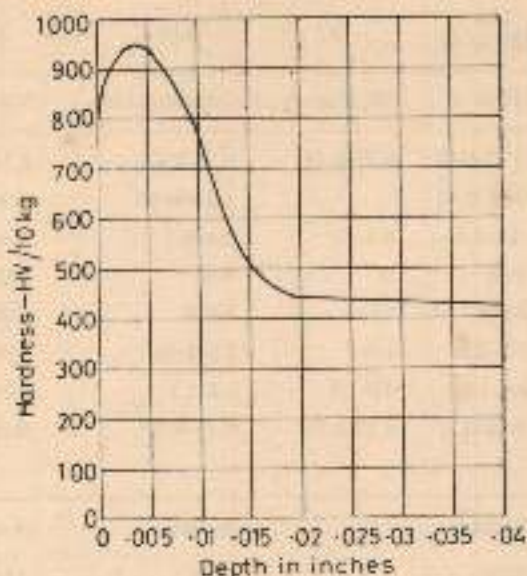


Fig. 5.18 Gas nitriding of 40Cr3Mo1V20 (BS 897M39) for 80 h at 500°C

Data Sheet 5.3—Type-3 (ISO), 34CrAlMo5 (DIN)

CHARACTERISTICS AND TYPICAL APPLICATIONS

This steel, after nitriding, produces an extremely hard, wear-resistant case. It develops a core strength of the order of 80–90 kg/mm², with very good ductility and resistance to shock in medium-sized sections.

Used for components requiring extremely high surface hardness, of nitrided case, combined with medium tensile core strength, such as lead screws, spacers, spindles, racks, etc. Table 5.9 indicates the equivalent steels of International Standards.

HOT WORKING AND METAL TREATMENT

Forging—Commence—1050°C Max.

Finish—850°C Min.

Annealing—650–700°C, followed by furnace cooling.

Hardening—900–930°C, followed by water quenching.

910–940°C, oil quenching.

Tempering—570–650°C.

Figure 15.19 shows a typical curve of the effect of tempering on tensile strength, and Fig. 15.20 shows the typical hardness-depth curve of 905M31 (Type 3).

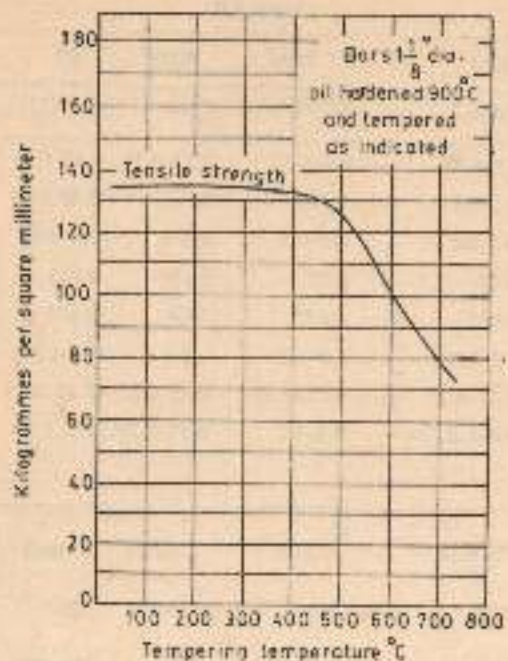


Fig. 5.19 Typical curve showing effect of tempering on tensile strength of steel—90SM31 (Type 3)

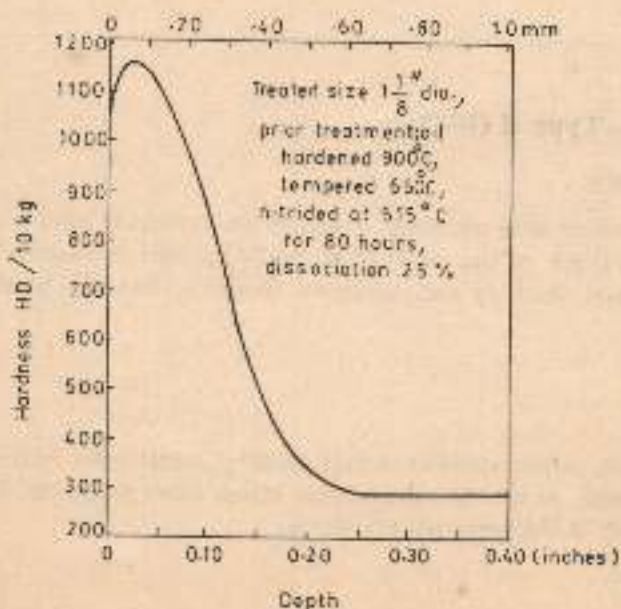


Fig. 5.20 Typical hardness-depth curve of steel—90SM31 (Type 3)

Table 5.9

Steel	Standard	ISO	IS	DIN	AISI	BS	NFA	GOST	JIS
	Designation	Type-3	—	34CrAlMo5	Class 0	905M31	30CAD612	—	—
Chemical composition	C %	0.3-0.37	—	0.3-0.37	0.33-0.38	0.27-0.35	0.28-0.35	—	—
	Si %	0.2-0.5	—	0.2-0.5	0.2-0.4	0.10-0.45	0.2-0.4	—	—
	Mn %	0.5-0.8	—	0.5-0.8	0.5-0.7	0.4-0.65	0.5-0.6	—	—
	≤P %	0.03	—	0.03	0.035	0.025	0.035	—	—
	≤S %	0.025	—	0.035	0.04	0.025	0.035	—	—
	Cr %	1.0-1.3	—	1.0-1.3	1.0-1.3	1.4-1.8	1.5-1.8	—	—
	Mo %	0.15-0.25	—	0.15-0.25	0.15-0.25	0.15-0.25	0.25-0.40	—	—
	Al %	0.8-1.2	—	0.8-1.2	0.95-1.30	0.9-1.3	1.0-1.3	—	—
	Others								
Mechanical properties	Dimensions	70 max	—	70 max	—	64 max	16-40 41-100	—	—
	0.2% Proof stress N/mm ² min	590	—	590	—	570	635 590	—	—
	Tensile strength N/mm ²	780-930	—	780-980	—	770-920	830-980 780-920	—	—
	Elongation % min	14	—	14	—	15	15	—	—
	Reduction of area % min	—	—	—	—	—	—	—	—

Data Sheet 5.4—Type-4 (ISO)

CHARACTERISTICS

An alloyed steel which after nitriding produces an extremely hard wear-resistant case. It develops a core strength of the order of 80 to 90 kg/mm² in medium sized sections combined with very good ductility and resistance to shock. Exhibits hardness around 950 to 1150 HV.

APPLICATIONS

Spindles, wormshaft, cutter spindles, wheel spindles, small bolts, bushes, gauges, and precision measuring tools, as well as superheated steam valve parts, etc. Table 5.10 indicates the equivalent steels of International Standards.

PROCESS CHART

Rough machine → Harden 900-930°C → Temper 550-650°C → Machine →
Finish machine → Nitride 500-520°C → Final Machine → Stress relieve 550°C →

(a) Figure 5.21 for typical hardness depth curve.

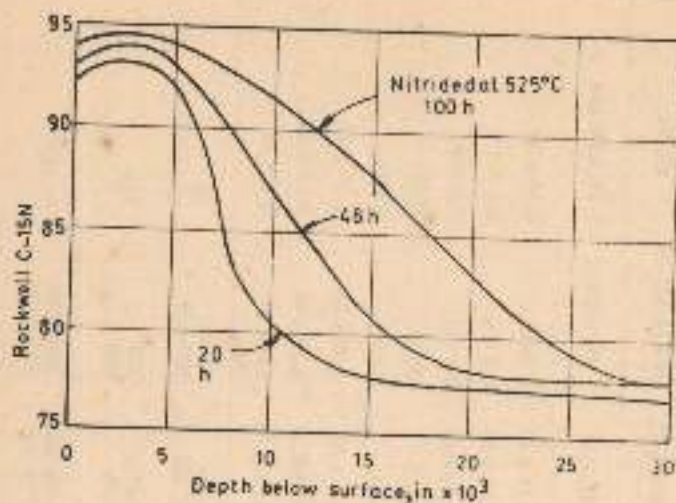


Fig. 5.21 Typical hardness-depth curve of gas-nitrided steel—90SM39 (Type 4)

(b) Figure 5.22 for typical curves showing effect of tempering on tensile strength.

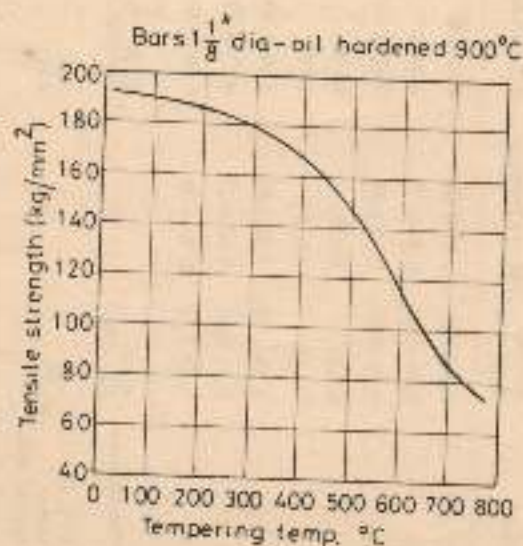


Fig. 5.22 Typical curve showing effect of tempering on tensile strength, steel 90SM39(BS)

Table 5.10

Country	ISO	INDIA	DEU	USA	GBR	FRA	USSR	JPN
Standard norm	ISO	IS	DIN	AISI	BS970J1-72	NFA35-551-75	GOST	JIS
Designation	R683X Type-4	40Cr7Al10Mo2	41CrAlMo7	ASTM355-70 Class A	905M39	40CAD612	38Ch2MJuA	
Chemical composition								
C	0.28-0.45	0.35-0.45	0.38-0.45	0.28-0.43	0.35-0.43	0.38-0.45	0.35-0.42	—
Si	0.20-0.50	0.40-0.70	0.20-0.50	0.2-0.4	0.10-0.45	0.2-0.4	0.2-0.45	—
Mn	0.50-0.80	0.10-0.45	0.50-0.80	0.5-0.7	0.40-0.65	0.5-0.8	0.3-0.6	—
P	0.030	0.030	0.030	0.035	0.025	0.035	0.025	—
S	0.035	0.035	0.035	0.040	0.035	0.035	0.025	—
Cr	1.50-1.80	1.50-1.80	1.50-1.80	1.4-1.8	1.4-1.80	1.50-1.80	1.35-1.65	—
Mo	0.25-0.40	0.10-0.25	0.25-0.40	0.3-0.4	0.15-0.25	0.25-0.40	0.15-0.25	—
Al	0.80-1.20	0.90-1.30	0.80-1.20	0.95-1.40	0.90-1.30	1.0-1.30	0.7-1.10	—
Mechanical properties								
Dimensions	≤100 100-150	—	≤100 100-160	—	≤64 ≥102	40-100 100-160	80	—
0.2% Proof stress N/mm ² min	735 635	—	735 635	—	665 570	720 670	835	—
Tensile strength N/mm ²	940-1130 830-980	—	930-1130 830-1030	—	850-1000 770-920	900-1100 850-1000	≥980	—
Elongation % min	12 14	—	13 14	—	13 15	13 14	14	—
Reduction of area % min	—	—	—	—	—	—	—	—

Data Sheet 5.5—34CrAlNi7 (DIN)

CHARACTERISTIC AND APPLICATION

This steel possesses a very high core strength, of the order of 80–100 kg/mm². It is used mainly for higher section thickness requiring high or ultra-high tensile properties in the nitrided conditions, e.g. components such as wheel spindles, hobber spindles, cutter spindles, etc. Table 5.11 indicates the equivalent steels of International Standards.

HOT WORKING AND METAL TREATMENT

Forging—Commence—1050°C—Max.

Finish—850°C—Min.

Annealing —650–700°C, followed by furnace cooling.

Hardening —850–900°C, followed by oil quenching.

Tempering —580–660°C

Nitriding —500–520°C

Hardening —950 HV (nitrided condition).

Table 5.11

Steel	Standard	ISO	IS	DIN	AISI	BS	NFA	GOST	JIS
	Designation			34CrAlNi7	Class C	—	40CAD612	—	—
Chemical composition	C %	—	—	0.3–0.37	0.22–0.27	—	0.35–0.45	—	—
	Si %	—	—	0.15–0.40	0.20–0.40	—	0.2–0.4	—	—
	Mn %	—	—	0.40–0.70	0.50–0.70	—	0.5–0.8	—	—
	≤P %	—	—	0.03	0.035	—	0.035	—	—
	Cr %	—	—	1.5–1.8	1.0–1.35	—	1.5–1.8	—	—
	Mo %	—	—	0.15–0.25	0.20–0.30	—	0.25–0.4	—	—
	Ni %	—	—	0.85–1.15	3.25–3.75	—	—	—	—
	Al %	—	—	0.8–1.2	0.95–1.30	—	1.0–1.30	—	—
Mechanical properties	Dimensions	—	—	700–250	—	—	100–160	—	—
	0.2% Proof stress N/mm ² min	—	—	590	—	—	670	—	—
	Tensile strength N/mm ²	—	—	780–980	—	—	850–1000	—	—
	Elongation % min	—	—	13	—	—	14	—	—
	Reduction of area % min	—	—	—	—	—	—	—	—

Data Sheet 5.6 Constructional Steels—Type-3, R683/VIII-70 (ISO), 34CrNiMo6 (DIN)

CHARACTERISTICS

This may be used in the range of 100–135 kg/mm² tensile strength after heat treatment.

After nitriding it possesses a high wear resistance and develops a higher fatigue strength. Exhibits surface hardness of about 650–700 HV after nitriding. Table 5.12 indicates the equivalent steels of International Standards.

APPLICATIONS

Used for high tensile strength machine parts, spindles, screws, pinion axle, shafts, crank-shafts, connecting rods, etc. Table 5.12 indicates the equivalent steels of International Standards.

PROCESS CHART

Rough machine → Harden 830–850°C → Temper 550–650°C → Machine

Finish machine → Nitriding 500–520°C → Final machine → Stress relieve 550°C →

Refer Fig. 5.23 for a typical hardness depth curve.

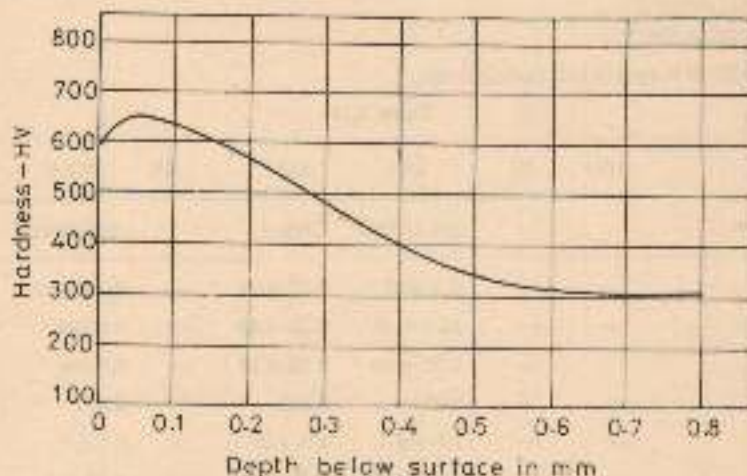


Fig. 5.23 Nitriding of steel—40Ni2Cr1Mo28 (817M40BS)—for 60 h at 510°C (gas nitriding)

Data Sheet 5.7—Type-3 (ISO), 42CrMo4(DIN)

CHARACTERISTICS

This may be used in the range from 70 to 110 kg/mm² tensile strength after heat treatment. After nitriding it possesses a good wear resistance even though hardness is low. Apart from this it develops a higher fatigue strength after nitriding. Exhibits hardness of about 650HV after nitriding. Table 5.13 indicates the equivalent steels of International Standards

APPLICATIONS

Face plates, screws, connecting rods, gears, propeller shaft joints, hydraulic parts, crank-shafts.

PROCESS CHART

Rough machine → Harden 850–870°C → Temper 550–650°C → Machine

Finish Machine → Nitriding 500–520°C → Final machine → Stress relieve 550–570°C →

Table 5.12

Steel	Standard	ISO R683/VIII-70	IS 5517-78	DIN 17200-84	AISI	BS 970/1-83	NFA 35/552-83	GOST 4543-71	JIS G4103-79
Designation	Type 3	40Ni12Cr1Mo28	34CrNiMo6	35NCD6	36Cr2Ni2MoFA	SNCM8			
C %	0.32-0.39	0.35-0.45	0.30-0.38	—	0.36-0.44	0.30-0.37	0.33-0.40	0.36-0.43	
Si %	0.15-0.40	0.15-0.40	0.15-0.40	—	0.10-0.35	0.10-0.40	0.17-0.37	0.15-0.35	
Mn %	0.50-0.80	0.40-0.60	0.40-0.70	—	0.45-0.70	0.60-0.90	0.25-0.50	0.60-0.90	
Cr %	0.035	0.035	0.035	—	0.040	0.035	0.025	0.030	
Mo %	0.035	0.035	0.030	—	0.040	0.035	0.025	0.030	
Ni %	1.30-1.70	0.90-1.30	1.40-1.70	—	1.00-1.40	0.85-0.15 0.85-1.15	1.30-1.70	0.60-1.00	
Others	0.15-0.30	0.20-0.35	0.15-0.30	—	0.20-0.35	0.15-0.30	0.30-0.40	0.15-0.30	
	1.50-1.70	1.25-1.75	1.40-1.70	—	1.30-1.70	1.20-1.60	1.30-1.70	1.60-2.00	
Mechanical properties									
Dimensions	16-40 41-100	100	40-100 41-100	—	29	16-40 41-100	25	25	
0.2 % Proof stress N/mm ² min	885 785	800 1300	800 685	—	940 855	835 735	930	—	
Tensile strength N/mm ²	1080-1280 980-1180	1000-1150 1550 min	1000-1200 900-1100	—	1080-1240 1000-1610	1070-1230 930-1130	1080	980 min	
Elongation %, min	10 11	13 11	11 12	—	11 12	10 11	12	16 g/in	
Reduction of area %, min	—	—	45 50	—	—	—	50	45 min	

Table 5.13

Steel	Standard	ISO R683/II 68	IS 5517 78	DIN 17200-84	AISI	BS 970/1 83	NFA 35/552 84	GOST	JIS G4105-79
	Designation	Type-3	40Cr4Mo3	42CrMo4	4140	708M40	42CO4		SCM4
Chemical composition	C %	0.38-0.45	0.35-0.45	0.38-0.45	0.38-0.43	0.36-0.44	0.39-0.46	—	0.38-0.43
	Si %	0.15-0.40	0.10-0.35	0.15-0.40	0.15-0.30	0.10-0.35	0.10-0.40	—	0.15-0.35
	Mn %	0.50-1.00	0.50-0.80	0.50-0.80	0.75-1.00	0.70-1.00	0.60-0.90	—	0.65-0.85
	≤P %	0.035	0.035	0.035	0.075	0.040	0.035	—	0.030
	≤S %	0.035	0.035	0.035	0.040	0.040	0.035	—	0.30
	Cr %	0.90-1.20	0.90-1.20	0.90-1.20	0.80-1.10	0.90-1.20	0.90-1.20	—	0.90-1.20
	Mo %	0.15-0.30	0.20-0.35	0.15-0.30	0.15-0.25	0.15-0.25	0.15-0.25	—	0.15-0.30
Mechanical properties	NE %	—	—	—	—	—	—	—	—
	Others	—	—	—	—	—	—	—	—
	Dimensions	16-40 41-100	450 100	16-40 41-100	13 100	29 63	41-100 160-250	25	—
	0.2% Proof stress N/mm ² min	765 735	540 600	705 635	1110 685	755 675	770 600	—	—
	Tensile strength N/mm ²	980-1180 880-1080	700-850 800-950	980-1180 880-1080	1155 885	920-1080 850-1000	880-1080 780-930	985 min	—
	Elongation % min	11 12	18 16	11 12	15.4 19.5	12 13	12 13	12 min	—
	Reduction of area % min	—	—	45 50	—	55 60	—	45 min	—

Refer Fig. 5.24 for a typical hardness depth curve.

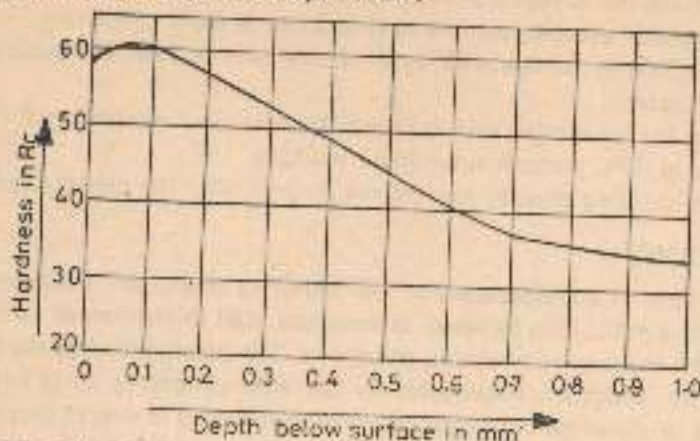


Fig. 5.24 Gas nitriding of steel-40Cr1Mo28 (AISI 4140) at 500°C for 70 h

5.17 Other Structural Steels

Unalloyed case hardening steels, plain carbon steels, (CK-45, CK-40, CK-30) and alloyed case hardening steels are nitrided at 500 to 510°C to increase the fatigue limit and corrosion resistance. The approximate hardness values for some of these steels are given in Table 5.14.

Table 5.14

	VH
CK-45	300-350
CK-30	300-350
CK-35	300-350
CK-15	350-400
En 352-(637 M17)	650-700
20MnCr5	700-750

5.18 Stainless Steels

Nitriding is widely used to improve the wear resistance of stainless steel machine parts. In some cases, abrasive wear is reduced by a factor of 300 after nitriding. This treatment increases the hardness and by changing friction characteristics, prevents galling and scoring. Stainless steel parts should be annealed and stress-relieved prior to nitriding with the exception of the hardenable grades.

The martensite grade can be hardened and tempered at a temperature above the nitriding temperature.

Surface preparation prior to nitriding should include the removal of oil, grease, etc. This is accomplished by removing any oxide film present, because this creates a passive

condition preventing the nitrogen penetration. Mechanical methods (wet blasting) or acid pickling are acceptable procedures. The acid pickling is done as follows:

1. Pickling in 50% by volume with hydrochloric acid at 70°C and subsequent thorough rinsing in water.
2. Pickling in 1% by volume with orthophosphoric acid containing 0.7% primary zinc phosphate at 70°C without subsequent washing.

In both cases nitriding must be carried out directly after the pre-treatment.

5.18.1 NITRIDING

This is accomplished at a temperature of 530–550°C for martensite steels and for the austenitic steels at 570–620°C. The increase in hardness and improvement in wear resistance is obtained at the expense of corrosion resistance. The precipitation of the finely dispersed chromium nitrides which are responsible for the wear properties tends to deplete the surrounding matrix of dissolved chromium, affecting a lowering of overall corrosion resistance. Hardness attainable after nitriding depends on the type of stainless steel. Normally the hardness ranges from 900 to 1150 HN.

Data Sheet 5.8—Hot Work Steels—40CrMoV5(ISO)

CHARACTERISTICS

Nitriding of hot work steels will help to prevent the metal from sticking and improves wear resistance especially on dies. It will also reduce the ill effects due to rubbing in certain cases. For example piston and cylinders in die casting machines, dies with thin sections which are more rapidly attacked due to their high working temperature, etc. Table 5.15 indicates the equivalent steels of International Standards.

APPLICATIONS

Nitriding can have beneficial effects on certain parts of die casting dies, such as spreaders, fixed inverters, covers, sprue parts, nozzle, ejector pins plungers, shot sleeves, etc.

PROCESS CHART

Rough machine → Harden 1000–1040°C → Temper 520–600°C →
Polish ← Nitriding 520–540°C ← Finish machine ← Stress relieve 530°C ←

Note: Nitriding is done in ammonia gas at 520 to 540°C. Length of time depends on the case depth required. Nitriding at higher temperature say 540°C is advisable to avoid brittleness even though hardness obtained may be little low (1000 HV). Wear resistance mainly depends on the nitride forming elements. The depth of case obtained for different treatment time is given below.

Nitriding time	Depth of case, mm
10	0.125
20	0.180
40	0.250
60	0.300

Table 5.15

Standard norm	ISO	INDIA	DEU	USA	GBR	FRA	USSR	JPN
	ISO 6957-80	IS 3479-78	DIN 17350-80	AISI	BS4659-71	NFA35-590-78	GOST	JIS 4004-72
Designation	40CrMoV5	135CrMoV1	X40CrMoV51	H13	BH13	Z40CDV5	40X5MP1S	SKT961
C	0.35-0.45	0.3-0.4	0.47-0.43	0.30-0.40	0.32-0.42	0.36-0.44	0.37-0.44	0.32-0.42
Si	0.90-1.20	0.8-1.2	0.9-1.2	0.80-1.20	0.85-1.15	0.8-1.2	0.80-1.20	0.80-1.20
Mn	0.25-0.55	0.25-0.50	0.3-0.5	0.20-0.40	0.4	0.2-1.5	0.15-0.40	0.50
P	0.030	0.030	0.030	0.03	0.03	0.025	0.030	0.03
S	0.030	0.030	0.03	0.03	0.03	0.025	0.030	0.03
Cr	4.5-5.5	4.75-5.25	5.0-5.50	4.70-5.50	4.75-5.25	4.8-5.5	4.50-5.50	4.50-5.50
Mo	1.2-1.7	1.2-1.6	1.2-1.5	1.25-1.75	1.25-1.75	1.2-1.5	1.20-1.50	1.00-1.50
V	0.85-1.15	1.0-1.2	0.9-1.1	0.80-1.20	0.9-1.1	0.85-1.15	0.80-1.10	0.80-1.20

Chemical composition

Other hot work steels that are nitrided are H11, H12, etc.

Data Sheet 5.9—Cold Work Steels—T160Cr12(1S)

CHARACTERISTICS

High chromium steels such as A₂, D₂, D₃ and D₆ can also be nitrided to increase the wear and corrosion resistance. After hardening the tempering should be done at a lower temperature of 200°C if they are to be nitrided for a lesser period of time, e.g. 10 hrs or less. Nitriding will reduce their core hardness to a tempering temperature of about 550°C.

APPLICATIONS

Mainly applied for dies in plastic industries since the hardness formed by nitriding significantly increases the wear resistance compared to the martensite structure formed by hardening. Table 5.16 indicates the equivalent steels of International Standards.

PROCESS CHART

Rough machine → Stress relieve 550°C → Machining → Hardening 1020–1040°C
 Polish → Nitriding 510–520°C ← Final machining ← Tempering 180–250°C

Refer Fig. 5.25 for a typical hardness depth curve.

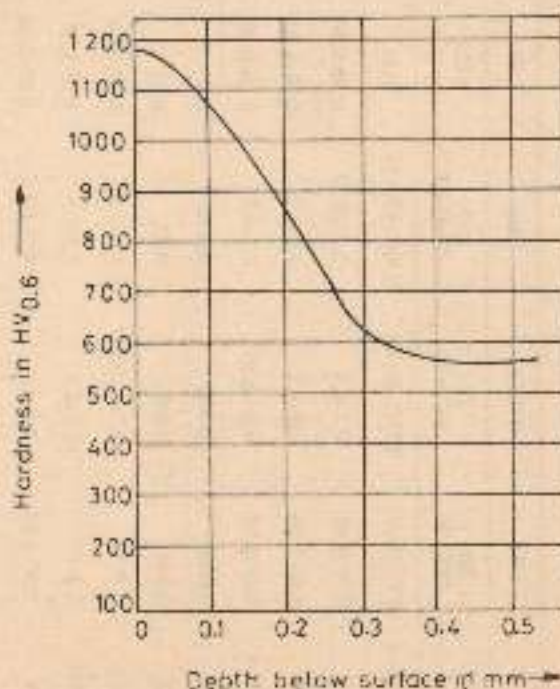


Fig. 5.25 Nitriding of steel—T160Cr12 (DIN X155 CrVMo121) for 80 h at 520°C (gas nitriding)

Table 5.16

Standard norm		ISO	IS	DIN	ASTI	BS	NFA35-551-75	GOST	JIS
Designation			T160Cr12	X155CrMa121	D2	8D2		C	SKD11
Chemical composition	C	—	1.55-1.70	1.5-1.6	1.4-1.6	1.4-1.6	1.45-1.70	—	—
	Si	—	0.1-0.4	0.1-0.4	0.3-0.5	0.6	0.1-0.4	—	—
	Mn	—	0.3-0.5	0.1-0.4	0.3-0.5	0.6	0.15-0.45	—	—
	Cr	—	11-13	11.5-12.5	11-13	11.5-12.5	11-13	—	—
	Mo	—	0.8	0.6-0.8	0.7-1.2	0.7-1.2	0.7-1.1	—	—
	V	—	0.8	0.9-1.1	0.8	0.25-1.0	0.7-1.1	—	—

Data Sheet 5.10—High Speed Steel—HS6-5-2 (ISO)

CHARACTERISTICS AND APPLICATIONS

Nitriding of HSS tools increases the wear resistance and the service life substantially. Although gas nitriding of tool steels has not been as widely used as salt bath nitriding, considerable success has been achieved recently. The best results have been obtained with high speed steel mandrels and drawing dies used for cold drawing or cold pressing of brass and aluminium. Hardness values above 1300 HV are obtainable after nitriding. These may be too high for many purposes; in such cases the tools are tempered at 350 to 400°C after nitriding, thereby increasing the toughness. For cutting tools the case should consist only

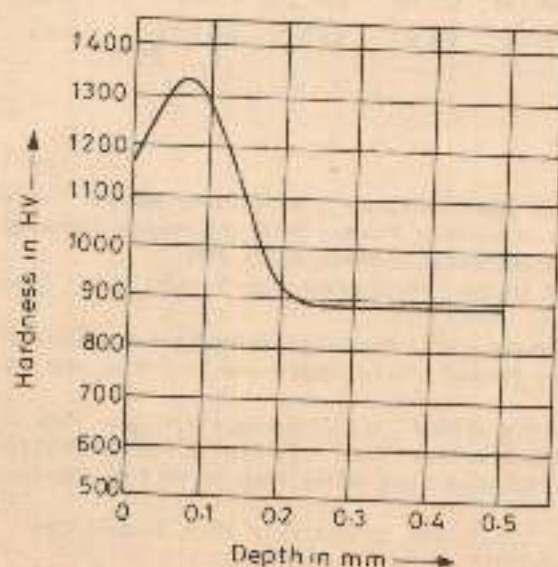


Fig. 5.26 Gas nitriding of Steel—T83MoW6Cr4V2 (ASTI—M2) for 35 h at 530°C

of the diffusional layer without brittle nitrided phases on the surface, since they impair the cutting properties of the tool. For tools that will operate under dynamic loads, the case depth should be 0.01 to 0.02 mm. Nitriding increases the durability of cutting and knurling tools by 50 to 100%. The duration of nitriding for cutting tools will be 15 to 60 minutes at 510 to 520°C or 10 to 12 minutes at 560°C.

Other types of high speed steels that are normally nitrided are T1, T7, M42, etc. Table 5.17 indicates the equivalent steels of International Standards.

PROCESS CHART

Rough machine → Stress relieve 660°–650°C → Machine → Hardening 1200–1230°C
 Temper 350–400°C ← Nitriding 520–560°C ← Finish machining ← Temper 530–570°C ←

Refer Fig. 5.26 for a typical hardness depth curve.

Table 5.17

Standard norm	ISO 4957-80	IS	DIN 17450-80	AISI	BS4659-71	NFA35-590-78	*GOST	JIS 4403-68
Designation	HS6-5-2	XT8TW6	56-5-2	M2	BM2	Z85WDCV06-05-04-02	R6M5	SKH9
Chemical composition	C	0.82-0.92	0.82-0.92	0.86-0.94	0.78-0.88	0.8-0.9	0.8-0.87	0.8-0.88
	Co	—	—	—	—	≤0.6	≤1.0	—
	Cr	3.5-4.5	3.75-4.50	3.8-4.5	3.75-4.50	3.75-4.50	3.5-4.5	3.8-4.4
	Mn	4.6-5.3	3.75-5.50	4.7-5.2	4.50-5.50	4.75-5.50	4.6-5.3	5.0-5.5
	V	1.7-2.2	1.75-2.05	1.7-2.0	1.60-2.20	1.75-2.05	1.7-2.2	1.2-2.10
	W	5.7-6.7	5.75-6.75	6.0-6.7	5.5-6.75	6.0-6.75	5.7-6.7	5.5-6.7

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Ion Nitriding

The nitriding process is a well known method of improving the surface properties of engineering components; for this reason it plays a vital role in engineering industry. The process may be carried out in solid, liquid or gaseous media. Apart from these three states of matter, there is a much more active state of matter known as the plasma state, and the development of modern techniques has facilitated its use for nitriding. This method is called *ion nitriding* or called as *plasma nitriding* (the term being coined in accordance with other nitriding processes).

Ion nitriding is carried out in a low pressure container in which a mixture of hydrogen and nitrogen gases becomes ionized. When the parts to be treated are subjected to this ionized discharge, the nitrogen ions formed bombard the surfaces of the parts, which become heated and allow diffusion of nascent nitrogen inwards to form nitrides. The diffusion layer thus formed has a ductile compound layer and a high wear resistance, apart from possessing a higher hardness and a higher resistance to point loads, impact, etc., compared to other methods of nitriding. Apart from this the compound layer formed is very less. Hence components can be directly used without any refinishing or cleaning operation. Also the improvement in properties brought about by ion-nitriding frequently allows cheaper, lower alloyed materials to be used.

Ion nitriding offers many control advantages over other forms of nitriding. The great number of treatment parameters which can be arbitrarily selected and precisely preset within wide limits, make it possible to produce specific structures with properties not found in normal nitrided steels. For this reason ion nitriding is, in many cases, superior to the conventional nitriding processes.^{1,2}

Ion nitriding is suitable for the complete range of ferrous materials from cast irons and plain carbon steels to the high alloy content materials such as tool steels and stainless steels. The nitrided steels now dominate the range of steel currently being introduced.

6.1 Glow Discharge Process

The ion nitriding process is carried out in an evacuated chamber containing low pressure gas in which two electrodes are immersed. If a sufficiently high DC voltage is applied between the two electrodes, a current will flow between them. This current consists of two factors: negatively charged electrons moving towards the positive electrode (anode) and

positively-charged ions moving towards the negative electrode (cathode) (Fig. 6.1). These ions are gas atoms from which one or more electrons have been detached and they bombard

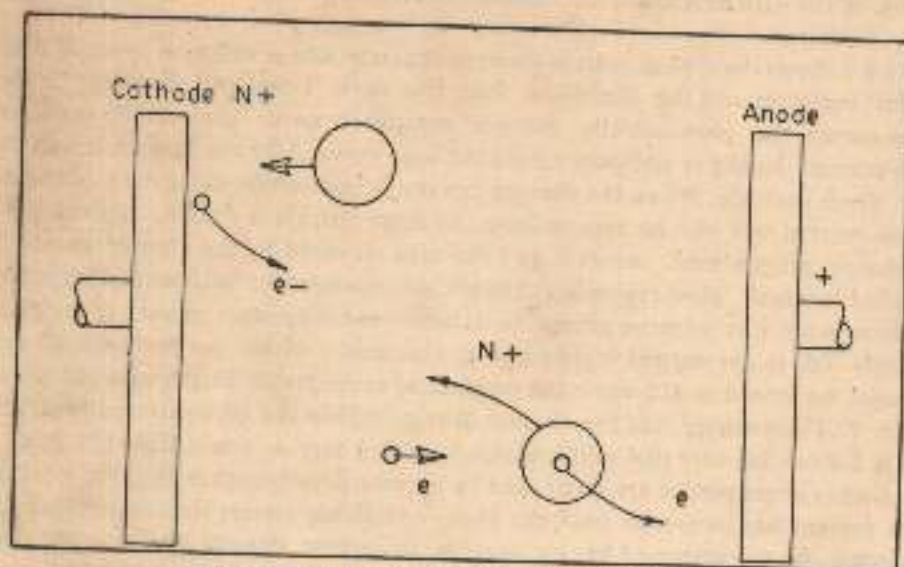


Fig. 6.1 The ion-electron discharge mechanism¹

the cathode with considerable energy. Part of this energy is converted into heat, thereby raising the temperature of the cathode while the remaining part is used for displacing the secondary electrons from the cathode surface. These secondary electrons gain energy from the applied voltage (potential). The gas atoms then gain sufficient force to cause either:

1. The detachment of further electrons (the process of ionization), or

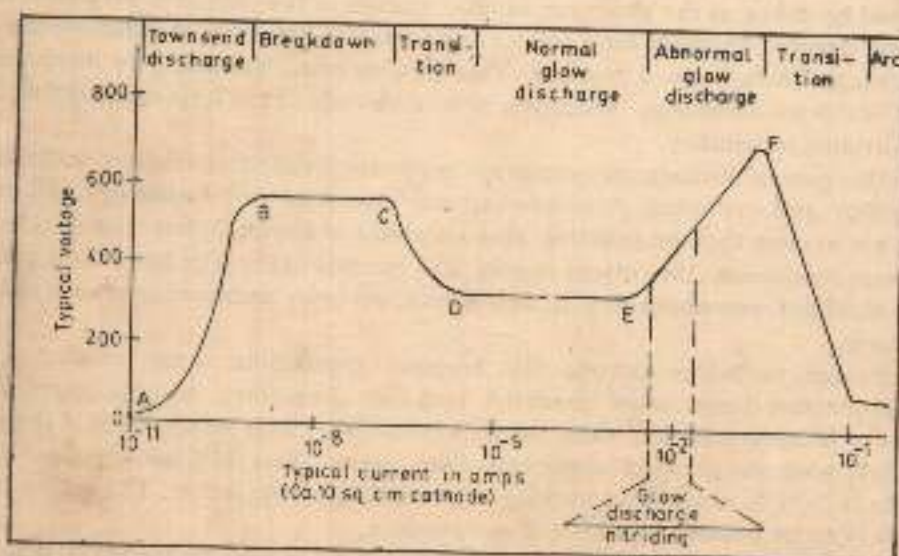


Fig. 6.2 Voltage-current characteristic of the electric discharge²

2. Changes in the energy states of electrons within each gas atom (excitation) which leads to the emission of light.

Because of the light emitted by the excited gas atoms, this electrical phenomena is known as a glow discharge.

Figure 6.2 shows the typical voltage-current characteristic of different types of discharge. As current increases and the transition from the dark Townsend discharge to the glow discharge occurs, the glow initially will not completely cover the cathode surface. Thus, although current density is uniform within the area covered by the glow, it is non-uniform over the whole cathode. When the current density is non-uniform, heating of the cathode by the ion current will also be non-uniform. As more current is drawn, the voltage across the discharge stays almost constant and the area covered by the glow increases. This is the so-called 'normal' glow region—a historical nomenclature with somewhat misleading implications, since it is no more normal in its behaviour than other regions of the discharge. The cathode fall in the normal region is a characteristic of the gas and cathode material. For nitrogen on iron it is 215 volts; the product of cathode fall length and gas pressure is 0.17-torr (0.4 cm-torr); and the current density within the glow-covered portion of the cathode is $2.6\text{ mA/in}^2\text{-torr}$ ($0.4\text{ milliamps/cm}^2\text{-torr}^2$; $1\text{ torr} = 1\text{ mm Hg} = 133\text{ Pa}$).

The discharge properties are controlled by current density rather than by total current. After the current has increased until the glow completely covers the cathode, any further increase must be accompanied by an increase in current density, and now the discharge voltage begins to rise. This is the *abnormal* glow region, and is characterised by a uniform current density everywhere on the cathode. It is the region used for glow-discharge nitriding, in order to achieve uniform heating and case development.

Transition from the normal to abnormal glow can occur at quite high currents; for the traditional laboratory discharge experiments the electrode area may be only a few square centimetres, but a nitriding cathode might be several square metres in area. For a reasonable working calculation a figure of 0.4 amps/ft^2 can be used. It is easy to note the achievement of the abnormal region by increasing the voltage until current increases (see Fig. 6.2). Care should be taken as the glow can rapidly change in the region of very high voltage and current density. This calls for a greater control and command of the unstable abnormal glow discharge. There is also a possibility that the abnormal, unstable glow discharge may turn into stable arc-discharge, which is a serious obstacle to the large-scale application of the ion nitriding in industry.

Two other general discharge properties are important for nitriding discharges: the hollow-cathode effect and sputtering. A hollow-cathode discharge exists when opposed cathode surfaces are so close that the negative glows coalesce as shown schematically in Fig. 6.3. Under those conditions, the current density can increase markedly; for nitriding this can result in localized non-uniformity of case depth, or even overheating above transition temperatures.

For nitrogen, the hollow-cathode effect becomes appreciable as the product of cavity width and pressure drops below about 0.8 inch-torr (3 cm-torr), and the current density continues to increase until the width becomes comparable with the thickness of the normal cathode fall, when the glow no longer enters the cavity. This last condition allows the possibility of simple mechanical masking to prevent nitriding action. The hollow-cathode effect can often be avoided by choice of gas pressure.

Sputtering is the ejection of cathode atoms from the surface by the ion bombardment

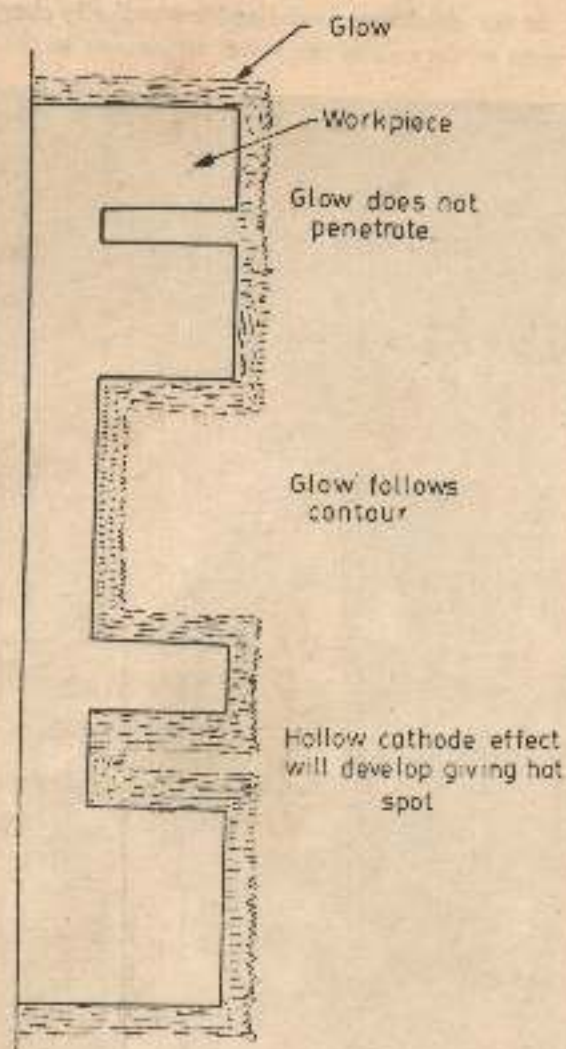


Fig. 6.3

of the discharge. The rate of ejection increases with ion energy (starting at some threshold energy, typically below 100 volts), ion mass (though early elements in each group of the periodic table have exceptionally low yield), and more approximately with the number of electrons in the outermost 'd' shell of the target atoms. Very few experiments have been conducted using nitrogen; for 1 KEV (kiloelectron-volt) ions a yield of 0.78 iron atoms/ion has been reported, so that yields at typical glow discharge voltages will be much less. Furthermore the effective loss of cathode material at low pressures and large electrode distances is greatly reduced by back diffusion. Some surface modification takes place on a micro-inch scale, and there may be slight differences between sputtering yields for alloying elements, but the effects are minor as far as nitriding is concerned.

To obtain this glow discharge phenomena in the nitriding process, the components to

be treated are placed in the discharge vessel and cathodically charged to a potential of 400 to 1000 V, with respect to the wall of the vessel which acts as the anode of the circuit.

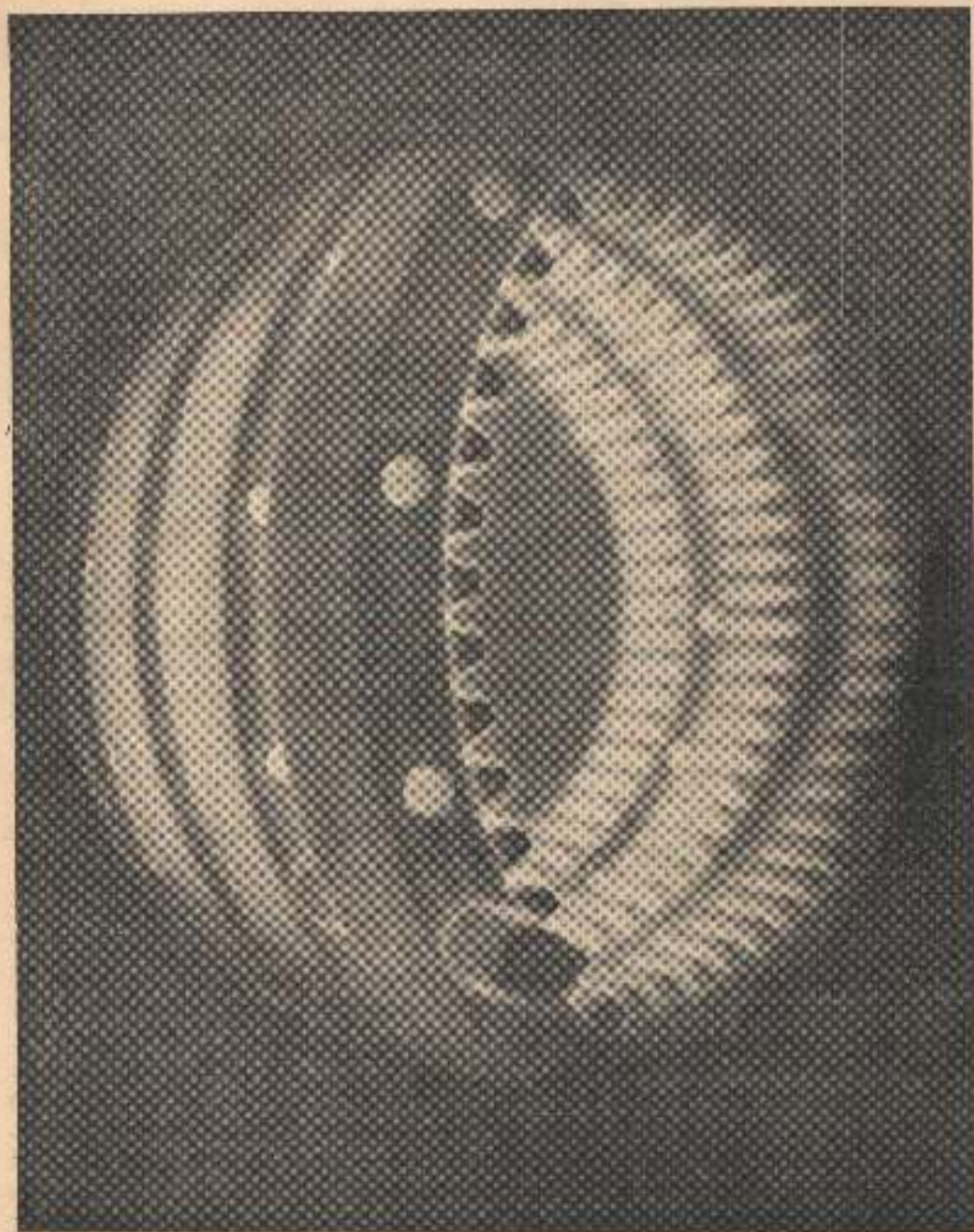


Fig. 6.4 View from a sight glass during the nitriding process, where the plasma can be observed evenly distributed over the surface of helical gears (Courtesy: Consare Engineering Ltd, Scotland.)

At the working pressure of 0.1 to 10 torr (13.3 to 1333 N/m²) plasma discharge of the reaction gases (H and N) is effected. Nearly all the potential drop across the vacuum occurs within a few millimetres from the surface of the workpiece and this region appears as a luminous glow fringe (Fig. 6.4) and is uniform all over the surface of the component, irrespective of the distance from the chamber. The positive nitrogen ions so produced are attracted by the cathode (component) and hit its surface with tremendous kinetic energy. The release of this energy heats the work-piece up to the desired nitriding temperatures, while some of the nitrogen ions diffuse into the metal and combine with the nitride-forming elements, as in conventional ammonia gas nitriding. Ion nitriding is carried out using either pure nitrogen or mixtures of nitrogen with hydrogen or suitable hydrocarbons in the temperature between 350 and 600°C depending on the type of material.

6.2 Operations before Ion Nitriding

Ion nitriding is done after all the machining operations are carried out. Prior to finish machining, tool steels and alloy steels are hardened and tempered to the required toughness. They are then stress relieved at 10 to 20°C above the nitriding temperature for 1 to 2 hours to avoid distortion. After this treatment, components are finish machined. In the case of carbon steels they are normalized and cast irons are stress relieved at 550°C prior to finish machining operation.

Areas where nitriding is not required may be masked with mild steel sheets or stainless steel foil. For an outer diameter, protection is done by means of a bush and the internal surface area by means of a plug. Cavities to be protected are filled with conductive plugs and so on. Masks are fixed on surfaces not to be nitrided with a small gap up to 0.8 mm.

The state of the component surface is of decisive importance to the success of ion nitriding. It must be free from oil, oxide, rust and other foreign materials. The presence of high vapour pressure materials will make it more difficult to obtain the desired vacuum, but of more concern is the influence of hydrocarbon oils or greases in modifying the process to give uncontrolled carbo-nitriding. Also of concern is the presence of metallic contaminants such as copper, which can get redistributed over the surface of the work by sputtering action, leading to a non-uniform case development, or in extreme cases, to a complete blocking of the nitriding action. Vapour degreasing is generally used to remove oils or sometimes chemical cleaning may also be employed to remove rust.

6.3 Fixtures

Where a large number of smaller parts are required to be nitrided and fixturing is used, certain precautions have to be taken. Care must be taken to see that the supports do not pass near other parts and mask them nor cause the hollow cathode effect.

To enable a uniform temperature to be achieved, it is important that sufficient distance be left between the parts. A distance of approximately 25 to 75 mm is usually appropriate. In addition to making the spacing large enough to avoid the hollow cathode effect, the possible differences in temperature caused by radiant heat transfer must also be taken into account. Thus in a concentric arrangement of small parts, where those at the centre will

tend to get a little hotter than those at the edge, sufficient gaps between the outer parts will minimize this difference.

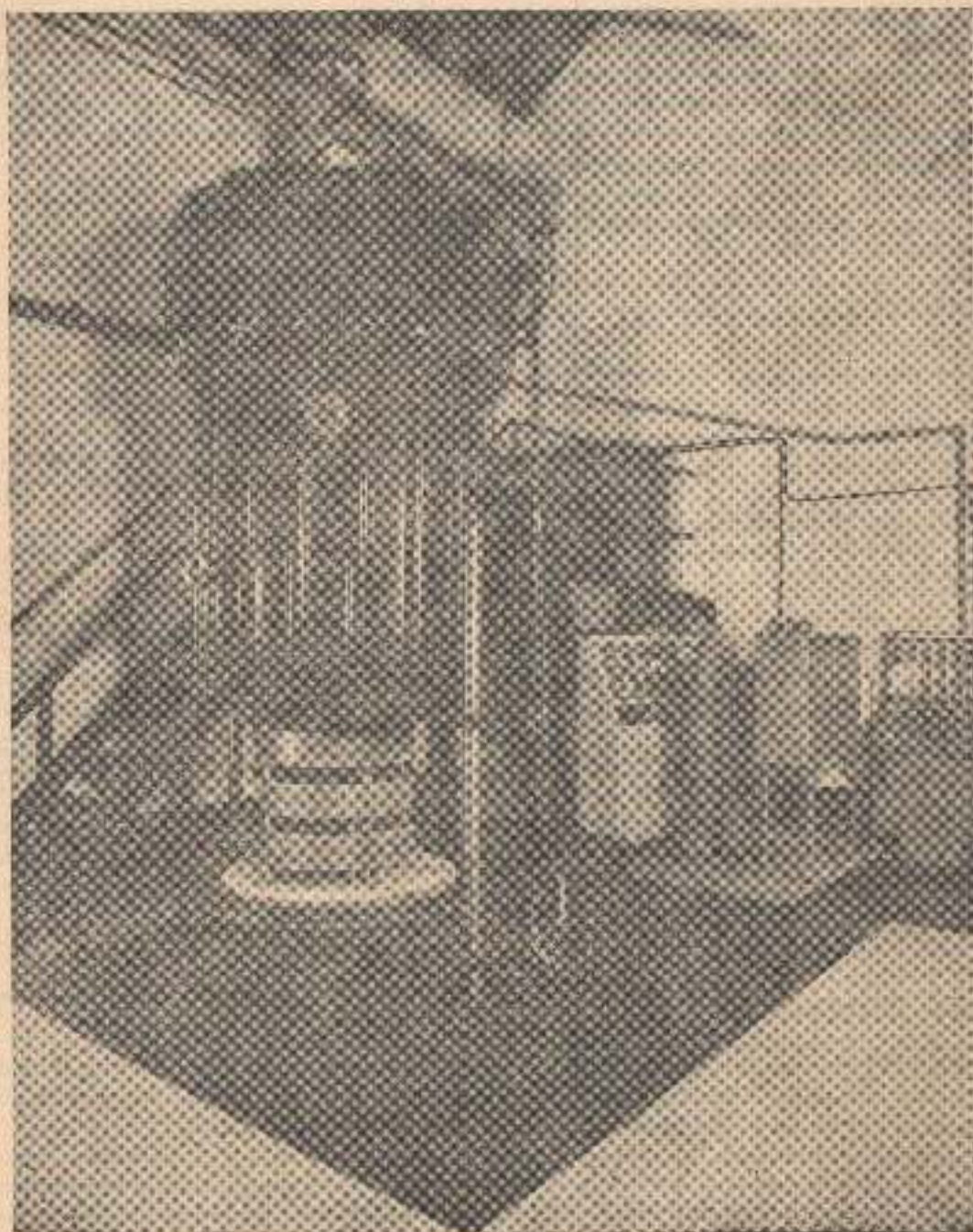


Fig. 6.5 Ion nitriding furnace loaded with gears, with the bell chamber about to be lowered to complete the vessel. (Courtesy: Consare Engineering Ltd, Scotland.)

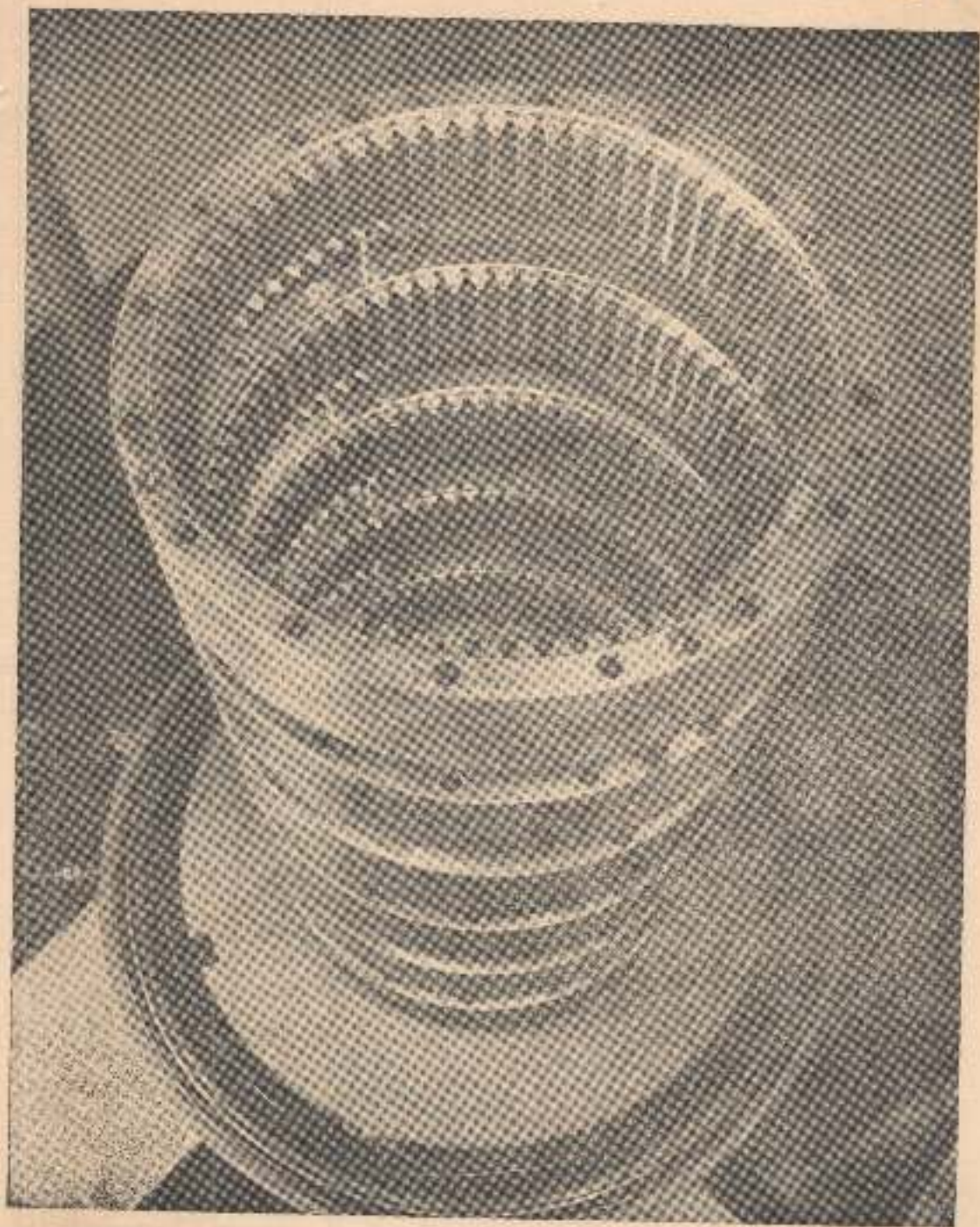


Fig. 6.6 A charge of six helical gears in position on the furnace hearth prior to the lowering of the external chamber. (Courtesy: Consare Engineering Ltd, Scotland.)

6.4 Applications of Ion Nitriding

The glow-discharge nitriding chamber consists of a stainless steel, double-walled water cooled bell chamber (Fig. 6.5) with a viewing window and supported by a structural steel base (Fig. 6.6). The vacuum pumping equipment, the control and the necessary power supply are mounted separately. Access is provided to the base of the chamber for easy maintenance.

After thorough cleaning, the components to be treated are mounted on a steel table supported by the base of the vacuum chamber. This forms the cathode for the glow discharge. The walls of the chamber are ground and form the anode. After sealing, the working chamber is evacuated to a pressure of about 100 microns. Then the working gas mixture of nitrogen and hydrogen is allowed to enter the chamber through a flow control valve until a pressure of 0.2 torr is recorded. As the working gas passes to the chamber, moisture

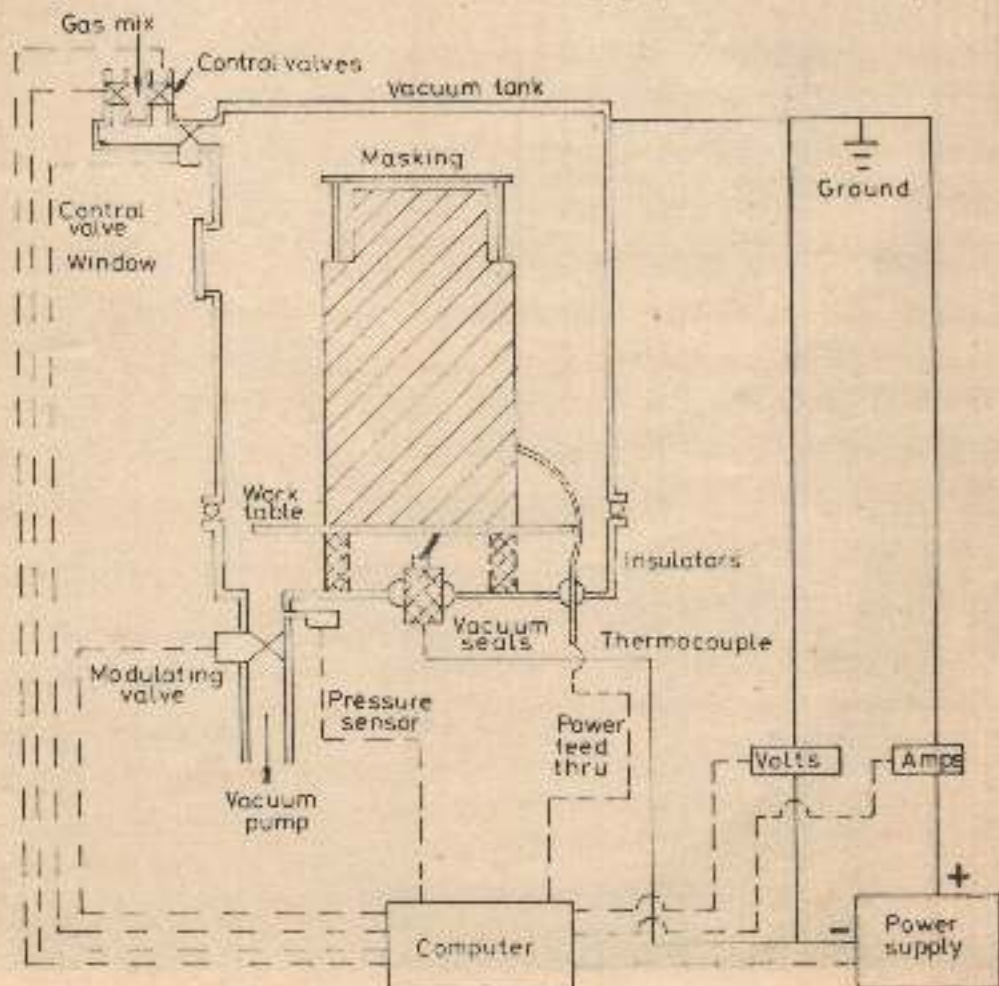


Fig. 6.7 Schematic diagram of the ion-nitriding process (Courtesy: Consare Engineering Ltd., Scotland.)

and oxygen are removed by means of a filter. Power is fed from a DC supply source, which increases smoothly to 1000 volts, on the components, which serve as the cathode. A glow discharge is ignited at a pressure of 200 microns between the components and the internal surface of the working chamber which ionizes the gaseous medium.

The positive nitrogen ions, produced in the glow discharge, are accelerated towards the negatively connected component and hit the surface with a high kinetic energy. This energy is transferred to the component which results in a heating of the component to the nitriding temperature, and removes the possible contaminants and oxides. With a smoothly increasing gas pressure and current strength, the surface of the component is saturated with nitrogen. The working voltage in the chamber is normally between 300 and 550 volts. At the end of the assigned holding time, cooling gas is admitted until the chamber pressure reaches atmospheric pressure—at which point the entire system closes down. The whole system is completely automatic, with the instruments displaying at all times what part of the cycle the furnace is in, plus the time elapsed, temperature, and pressure in the chamber. The control system is shown schematically in Fig. 6.7.

The temperature in the setup is measured by means of a thermocouple introduced into the vacuum chamber and electrically insulated from the sheath; it is recorded automatically by an electronic potentiometer with an accuracy of $\pm 3^\circ\text{C}$.

6.5 Process Consideration

In order to obtain the desired hardness and case depth, the following process consideration may be adopted.

6.5.1 GAS MIXTURE

The gas mixture used for ion nitriding will be usually a 25% nitrogen with 75% hydrogen. Raising the nitrogen concentration to 50% during processing will increase the rate of case development. Using higher range of nitrogen concentration (above 50%) will result in the formation of an excessive white layer. If too low a percentage of nitrogen is used, case development rates are reduced.

6.5.2 PRESSURE

Gas pressure can be chosen to optimize the penetration of the glow into cavities (to give a uniform case development on gear teeth, for example). While avoiding the hollow cathode effect, a low pressure enhances glow uniformity, but this becomes a consideration only if the discharge conditions are approaching 'normal' that is if there are signs of the glow contracting away from portions of the work hard surface.

Ignition of the discharge at 0.2 torr (0.2 mm Hg) or less will normally give a good uniformity. This is maintained as the computer controller brings the pressure up to the full process value, with increasing temperature at the same time. A pressure of 2 torr is suggested as a typical value for most applications though pressures of up to 5 torr are frequently used. Only in special cases is pressures above this value recommended.

6.5.3 ION NITRIDING TEMPERATURE

The temperature adopted for ion nitriding will be in the range of 350–580°C depending

on the type of material used. The temperature adopted for carbon steels is between 550 and 580°C and for cast iron it is between 540 and 550°C. For alloy steels it will be in the range of 400–550°C depending on the grade of steel and the desired hardness.

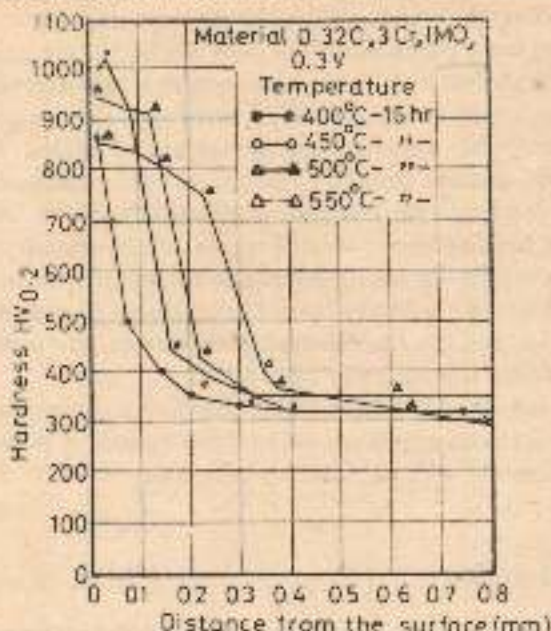


Fig. 6.8 Influence of treatment temperature on the hardness profile of steel—32CrMoV12²

The higher hardness attained depends on the type of steel, the temperature and the time duration. For example, Figs. 6.8 and 6.9 show the maximum hardness for quenched

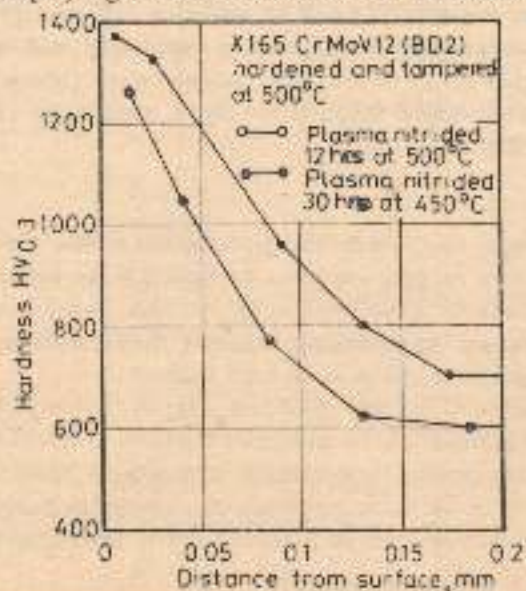


Fig. 6.9 Hardness profiles of BD2-type steel after plasma nitriding²

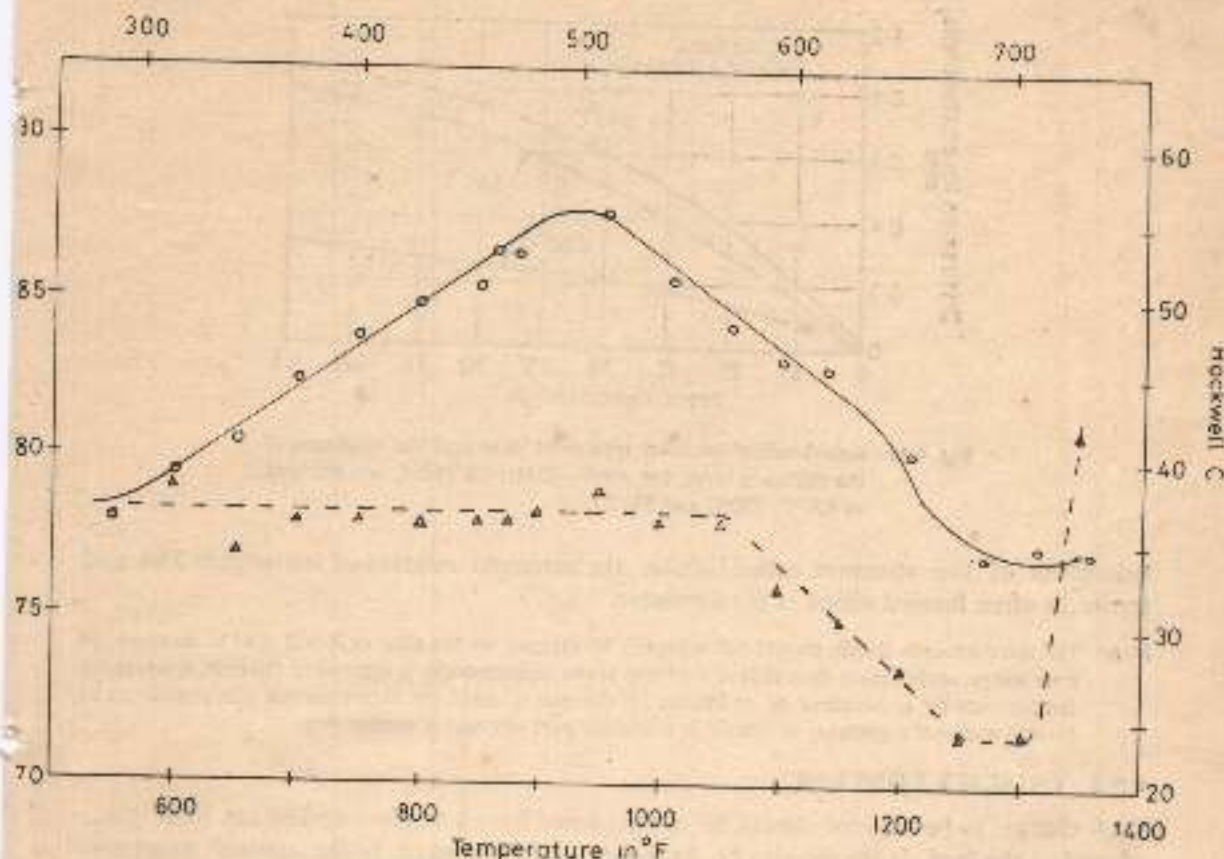


Fig. 6.10 Case and core hardness as functions of temperature for steel (AISI) 4340.

and tempered alloy steel 32CrMoV12 (0.32% C, 3% Cr, 1% Mo, 0.3% V) is 450°C. Further increase in the temperature reduces the hardness. Figure 6.10 shows both case and core hardness of AISI 4340 steel plotted against temperature. From these two curves, it is clear that the optimum condition for a 0.02 in (0.5 mm) case can be obtained by ion nitriding at 500°C for 16 hours without any loss of core hardness. Further increase in duration of ion nitriding leads to a decrease in hardness.

Figure 6.11 illustrates the relationship between the treatment time and thickness of the diffusion layer for the steel DIN42CrMo4 ion nitrided at 450°C, 530°C and 570°C. As the temperature increases case depth also increases; but hardness decreases at higher temperatures. When a higher case depth and a higher hardness are both required it is necessary to carry out the treatment for a longer time at the optimum temperature adoptable for higher hardness. Adopting a higher temperature also results in greater thickness of the compound layer and an increase in the volume per surface depending on the chemical composition of the steel.

Temperatures above 580°C are not used because of a structural change which occurs at 592°C, the eutectoid temperature of the binary Iron-Nitrogen system. In particular, the

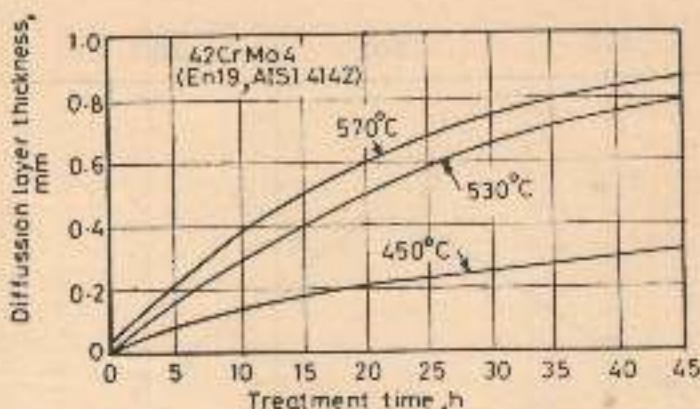


Fig. 6.11 Relationship between treatment time and the thickness of the diffusion layer, for steel—(DIN) 42CrMo4, ion nitrided at 450°C, 530°C and 570°C*

brittleness of the structure called bainite, the eutectoid mixture of iron nitride Fe_4N and ferrite, is often formed which is not advisable.

Note The thermocouple sheath should not normally be exposed to the glow or it will tend to measure its own temperature rather than that of the load. If the thermocouple is internal to the part, it senses the temperature by conduction or radiation. If the part is solid, the thermocouple can sometimes be located within the masking or placed in a dummy part of roughly similar size.

6.5.4 QUALITY CONTROL

Each charge to be nitrided should be accompanied by a test piece and be the same grade of steel as the load. It should also be hardened and tempered to the desired toughness adopted for the charge. After treatment, the test piece can be sectioned and metallographically examined for the case depth, and the extent of white layer. Hardness measurements of the case and also core should be made using Vickers hardness testing machine by applying a low load of 0.2 to 0.5 kg/mm².

6.6 Ion Nitriding Case

The main advantage of ion-nitriding has led to the application of producing specific structures with properties not found in normal nitriding processes. For this reason, ion nitriding is in many cases, superior to conventional nitriding processes. The desired case depth with specific structure may be attained by adopting the specified atmospheric pressure and temperature. The nitrided case thus produced consists of two zones, i.e., the compound layer and the diffusion zone, the details of which are as follows:

6.6.1 COMPOUND LAYER

The ion-nitrided surfaces usually are made up of two layers: a very thin and compact compound zone (white layer) and a continuous diffusion zone. The structure and thickness of the two layers can be varied according to the treatment parameters chosen.

The ion nitriding process can produce different structures of compound zones which are

completely homogeneous. They are either a single-phased Fe_4N γ -phase structure or the single-phased $\text{Fe}_{2-3}\text{C}_x\text{N}_y$ (ϵ -phase) structure. Also a mixture of the two structures is sometimes desired. The compound zone formed depends on the composition of the working gas, i.e., nitrogen or carbon content in the plasma.

The thickness of the compound zone obtained depends on the temperature and the treatment time. It increases with increasing temperature and time (Fig. 6.12). However its thickness does not exceed a value of 10 μm even for very long treatment times. This is probably due to the small solubility range of nitrogen in this phase.^{3,4,5,6}

These mono-phase compound zones are the main reason for the excellent properties of ion-nitrided surfaces. The γ compound layer combined with a brittle nitride suppressed diffusion zone is very wear-resistant and exhibits good ductility. The ϵ compound zone is extremely resistant to wear and corrosion.

6.6.2 DIFFUSION ZONES

The depth of the diffusion zone obtained depends on the ion nitriding temperature. It is clear from Fig. 6.10 that as the temperature increases the thickness of the diffusion layer also increases.

The hardness of the diffusion zone depends on the chemical composition of the steel. It also depends on the temperature employed for ion nitriding. From Fig. 6.7 it can be seen that at 450°C, the hardness obtained is the highest (1000 HV 0.2) for the steel 32CrMoV12 (DIN). The hardness obtained will be low either below or above this temperature. Hence the hardness and the depth of diffusion zone depend on the alloy content and the nitriding temperature.

6.7 Special Features and Advantages of Ion Nitriding

Ion nitriding offers many advantages over other types of nitriding because of the possibility of close control not only of the temperature, but also of the gas composition, pressure, heating rate and process time.

1. The white layer formed is much slower even after a longer processing time and it remains almost constant at 6 μm (Fig. 6.12). It is also possible as explained earlier the degree of control of the process allows full exploitation of the non-brittle layer. In gas nitriding the compound layer formed on the surface of the component is typically 0.02 mm thick—such a layer is very brittle and must be removed before the component is put to use. In the case of intricately shaped components of a surface with fine details, the removal of the white layer formed by gas nitriding is a very tedious and expensive operation. By applying the plasma process to such intricately shaped components, it is possible to control the formation of the compound layer within the tolerance limit. However, the compound layer formed in low-nitriding is very ductile and it provides good lubricating characteristics to the surface, hence it should not be removed from the components if it does not affect the functioning.
2. One of the advantages of ion nitriding is the extremely small changes in the dimensions of the components resulting from saturation with nitrogen. The reason for this is that the sputtering effect which detaches atoms from the surface tends to reduce the volume of a component which compensates the natural growth in diameter of

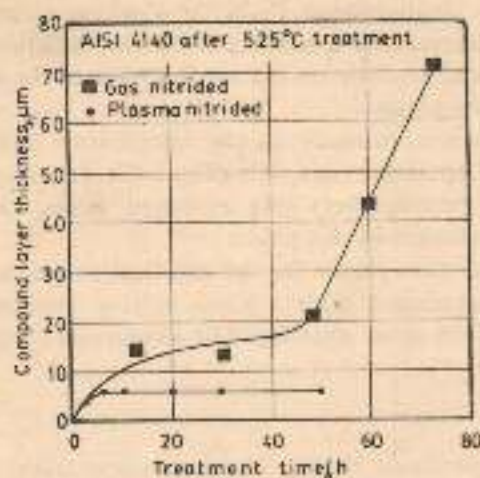


Fig. 6.12 The kinetics of compound-layer formation during nitriding²

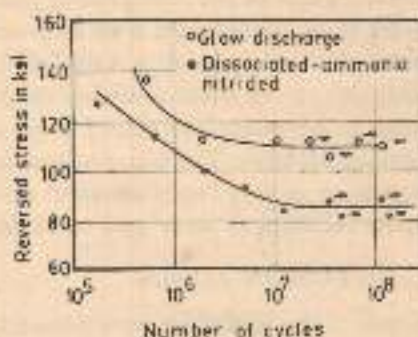


Fig. 6.13 Fatigue strength of steel—(AISI) 4140 subjected to dissociated-ammonia nitriding and glow-discharge nitriding⁴

the part during ion nitriding. Thus, the change in dimension of experimentally nitrided components did not exceed 8 to 10 μ . Measurement of the profile deviation of seven worms showed (Table 6.1) that the distortions arising in ion nitriding are significant and are within the field of allowances of the technical requirements of the drawing for finish machining of the components. Moreover the surface finish after ion nitriding is retained at the same level as before. This clearly indicates that the components can be directly used without any further machining operation.

Table 6.1³

Profile deviation mm	Play in thread turns mm	Play in shank (mm)	
		Long	Short
0.003/0.005	0.025/0.025	0.02/0.05	0.004/0.004
0.003/0.002	0.005/0.01	0.06/0.01	0.008/0.015
0.003/0.004	0.008/0.015	0.1/0.015	0.008/0.015
0.003/0.005	0.003/0.005	0.003/0.003	0.008/0.005
0.003/0.003	0.004/0.005	0.005/0.005	0.01/0.025
0.003/0.004	0.01/0.015	0.03/0.03	0.002/0.005
0.003/0.004	0.004/0.01	0.004/0.004	0.015/0.15

Note The numerator shows the profile deviation, the play in the third turns and shanks of the components before ion nitriding and the denominator after nitriding.

3. The fatigue properties of the ion-nitrided components are markedly increased by ion nitriding. Some results measured on smooth krouse fatigue bars of AISI 4340 steel are shown in Fig. 6.13. It can be seen that the ion-nitrided components have improved fatigue strength as compared to gas-nitrided ones. Improvement in fatigue strength of quenched and tempered steel is 80% in the case of 30CrMoV1 steel, whereas in case of plain carbon steel a greater percentage of about 130% was observed.
4. The power required is very low, because the work is maintained at temperatures by a glow discharge at a low pressure. Heat loss to the furnace walls is mainly by radiation and small losses may be further reduced by radiation shields, which increases the heating efficiency without impairing the nitriding action. As a result the total power requirement is very low, and the accessible furnace walls may be kept at a comfortable temperature by water cooling.
5. Low gas consumption and cost is another advantage associated with ion nitriding.
6. Shorter process time because of the more rapid formation of the nitrided layer in ion-nitriding which in turn is due to the higher nitrogen concentration produced on the surface. Figure 6.14 illustrates the speed of the case development in ion nitriding using AISI 4340 steel compared with other nitriding processes.
7. Mechanical masking is a feature of the ion nitriding process. Such a mask can be made of mild steel sheet, which would be fitted at a distance of approximately 0.5 mm from the area to be masked. These masks have almost indefinite life and can be fitted easily. Accordingly there is no need to apply and then remove protective electro-deposited coatings as in conventional nitriding. In the case of a single component, it is possible to mask with a stainless steel foil or may be with ceramics. Stop-off points containing tin should be avoided to prevent contamination of the tank.
8. Work pieces made from carbon steels, low alloy steels, tool steels, nitriding steels, heat resistant steels, high speed steels, and stainless steels can be ion nitrided. Different types of cast iron and sintered materials can also be ion nitrided.
9. Ion nitriding lends itself to total process automation, ensuring repetitive metallurgical results.
10. Since ion-nitriding can be carried out at lower temperatures, cold work steels can be successfully ion nitrided to get high absolute wear resistance. Such steels are subjected to high loads or high punching stresses as such a high core strength is essential to support the nitrided layer. A prerequisite for retaining a high core strength is that the nitriding temperature is set well below the tempering temperature. For example extruder dies are hardened and tempered at 500°C to a hardness of 58 HRC.

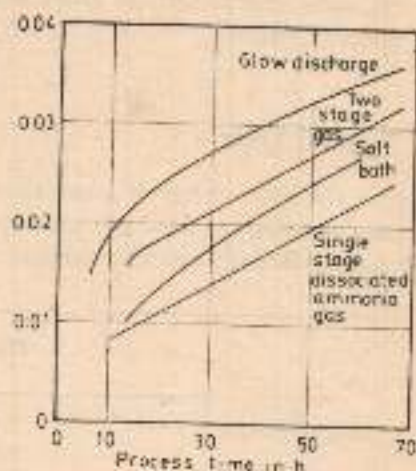


Fig. 6.14 Case depth obtained for different types of nitriding processes

Ion nitriding may be carried out at 450°C; as a result there will not be any effect on core strength. Hence higher hardness may be attained.

As against this, ion nitriding has the following disadvantages:

1. Complexity of nitriding deep surfaces.
2. The relative complexity of equipment.
3. The necessity of strictly following the parameters of the process.
4. The case depth attainment will be slow compared to salt bath nitriding.
5. Highly skilled labour is required.
6. High initial investment cost.
7. The difficulty of combining parts in one load that are greatly different in shape and weight.
8. No quenching facility (to attain better fatigue strength) for component made out of unalloyed steels.

6.8 Typical Data

Because of the wide range of conditions of temperature, pressure gas mixtures available, it is common to use a fixed gas pressure and mixture varying the time and temperature. The standards initially recommended are:

	During warm up	Processing
Gas mixture	75% Hydrogen 25% Nitrogen	50% Hydrogen 50% Nitrogen
Gas pressure	2 Torr	

Typical times and temperatures are as follows:

Case depth required	Material	Time	Temperature °C
0.008–0.012	Nitr alloys	10	525
	4140 steel	3	510
	4340 steel	4	510
	NI-CR-MO-V steel	4	510
0.015" min	Nitr alloys	30	525
	4140 steel	10	510
	4340 steel	12	510
	NI-CR-MO-V steel	12	510
0.025" min	Nitr alloys	—	—
	4140 steel	30	510
	4340 steel	30	510
	NI-CR-MO-V steel	30	510

6.9 Typical Applications

The variety of components which can be ion nitrided is almost unlimited and vary in size between very large gears to balls in ball point pens. Highly complex shaped parts, as well as simple, present no problems. Table 6.2 indicates the obtainable hardness after ion nitriding.

Table 6.2 Ion Nitriding Data for Steels and Cast Irons

Type of iron material DIN	British standard BS	Results of the most commonly produced ionnitrided cases				
		Core hardness	Surface hardness (HV _{0.05} -ph)*	case depth (in)†	White layer thickness (in)	White layer phase‡
1	2	3	4	5	6	7
<i>Constructional and carbon steels</i>						
5160 (1.0540)	En8 En9	~170 HB	250-400	0.015-0.030	0.0004-0.0006	c
C45 (1.0503)		~150 HB	250-600	0.015-0.030	0.0004-0.0006	c
C60 (1.0601)		~180 HB	250-400	0.015-0.030	0.0004-0.0006	*
<i>Cast irons</i>						
GG25	lamellar	~250 HB	350-500	0.005	0.0004-0.0006	c
GGG42	nodular	~250 HB	400-600	0.005-0.010	0.0004-0.0006	*
GGG60	nodular	~300 HB	450-650	0.005-0.010	0.0004-0.0006	*
<i>Carburizing steels</i>						
C15 (1.0401)	En2E	~140 HB	250-400	0.015-0.030	0.0004-0.0006	c
16MnCr5 (1.7131)	—	~180 HB	600-700	0.015-0.025	0.0003-0.0004	γ ¹
14NiCr14 (1.5752)	En36B	~200 HB	550-700	0.012-0.015	0.0003-0.0004	γ ¹
<i>Heat-treatable steels</i>						
34Cr4 (1.7933)	En18C	240-300 HB	500-600	0.015-0.025	0.0002-0.0003	γ ¹
42CrMo4 (1.7225)	En19	240-320 HB	550-650	0.015-0.025	0.0002-0.0003	γ ¹
37MnSi5 (1.5122)	—	240-300 HB	400-500	0.015-0.025	0.0002-0.0003	γ ¹
32CrMo12 (1.7361)	623 Grade 47	240-300 HB	800-900	0.012-0.015	0.0002-0.0003	γ ¹
34CrNiMo6 (1.6582)	En24	250-350 HB	550-650	0.015-0.025	0.0002-0.0003	γ ¹
<i>Nitriding steels</i>						
34CrAlNi7 (1.8550)	—	260-330 HB	900-1100	0.015-0.020	0.0002-0.0004	γ ¹
34CrAlMo5 (1.8507)	En41A	260-330 HB	900-1100	0.015-0.020	0.0002-0.0004	γ ¹
31CrMo12 (1.8515)	~En40B	300-360 HB	780-880	0.012-0.015	0.0002-0.0003	γ ¹
39CrMoV13 9 (1.8523)	En40C	330-420 HB	800-900	0.012-0.015	0.0002-0.0003	γ ¹
<i>Hot working steels</i>						
X40CrMoV5 1 (1.2344)	H13	30-50 HR _c	900-1150	0.010-0.015	0.0001-0.0002	γ ¹
X37CrMoV5 1 (1.2606)	H12	30-50 HR _c	900-1150	0.010-0.015	0.0001-0.0002	γ ¹
X30WCrV9 3 (1.2581)	H21	35-53 HR _c	900-1150	0.005-0.010	0.0001-0.0002	γ ²
56NiCrMoV7 (1.2714)	—	30-40 HR _c	600-700	0.010-0.020	0.0002-0.0003	γ ²

(Contd.)

Table 6.2 Ion Nitriding Data for Steels and Cast Irons (contd.)

1	2	3	4	5	6	7
<i>Cold working tool steels</i>						
X155CrVMo12 1 (1.2379)	D2	55-60 HR _c	950-1200	0.005-0.010	—	—
X165CrMoV12 (1.2601)	—	~58 HR _c	950-1200	0.005-0.007	—	—
X210Cr12 (1.2080)	D3	~50 HR _c	850-1100	0.003-0.007	—	—
90MoV8 (1.2842)	O2	~40 HR _c	450-600	0.010-0.025	0.0002-0.0003	—
<i>High speed steels</i>						
S6-5-2 (1.3343)	M2	63-66 HR _c	900-1200	0.001-0.004	—	—
S12-1-4-5 (1.3202)	T15	64-66 HR _c	900-1200	0.001-0.004	—	—
S18-0-1 (1.3355)	T1	64-66 HR _c	900-1200	0.001-0.004	—	—
<i>Maraging steels</i>						
X2NiCoMo 18 85 (1.6359)	~U110	52-55 HR _c	800-950	0.005	0.0001-0.0002	γ^{\dagger}
N2iCoMo 18 2 4 (1.6356)	—	59-62 HR _c	800-1000	0.005	0.0001-0.0002	γ^{\dagger}
<i>Stainless steels</i>						
X15Cr 13 (1.4024)	En56A1	250-300 HB	900-1100	0.005-0.010	—	—
X35CrMo17 (1.4122)	—	280-340 HB	950-1150	0.005-0.010	—	—
X12CrNi18 8 (1.4300)	En58A	~170 HB	950-1200	0.003-0.005	—	—
X10CrNiNb 18 9 (1.4550)	305819	~170 HB	950-1200	0.003-0.005	—	—
<i>Heat resisting steels</i>						
X15CrNiSi25 20 (1.4841)	310824	~170 HB	900-1300	0.002-0.004	—	—
X50CrMnNi22 9 (1.4871)	349854	250-400 HB	700-1000	0.001-0.002	—	—

*Measured with a load of 5 kg (11 lb).

†Depth where the hardness has declined to a value which is equal to core hardness plus 50 dph. Larger case depths can be produced if necessary.

‡The mentioned white layer phases are most suitable for the normal applications of these steels. For special cases other white layer phases are also produced.

Different types of materials that can be ion nitrided successfully are given below:

- Al—Containing low alloy steels
- Cr—Containing medium-carbon low alloy steels
- Tool and die steels
- High speed tool steels
- Austenitic stainless steels
- Ferritic and martensitic stainless steels
- Constructional steels
- Precipitation-hardening stainless steels
- Plain carbon steels
- Heat resisting steels
- Carbon nitriding steels
- Carburizing steels
- Maraging steels.

Iron nitriding has been achieved with the following cast irons:

- Grey cast iron
- Malleable iron
- Ductile iron
- Alloy iron

In the non-ferrous field:

- Titanium and titanium alloys
- Tantalum
- Molybdenum
- Sintered alloys

Examples for Application:

- Food industry in general
- Sausage machines-housing
- Bakery machines
- Machine construction in general
- Gearwheels
- Primary shafts
- Guide bead
- Machine basin
- Driving gears
- Machine construction for textile industry
- Thread guide roller
- Hydraulic cylinder
- Internal toothed ring
- Car industry
- Percussion tools
- Press tools
- Crankshafts
- Distance rings for gears
- Cam disks
- Secondary shafts
- Axle guide bar
- Pump industry
- Rotors
- Stators
- Housings
- Links
- Tool
- Drill of HSS
- Reamer of HSS
- Milling cutter of HSS
- Screw tap of HSS
- Lathe chuck
- Injection moulded tools
- Barrel extruder
- Injection nozzle

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Nitempering (Gaseous Nitrocarburizing)

Nitempering is the widely used heat treatment process for the purpose of increasing the service life, wear resistance and scuffing properties of steel. It is carried out in a sealed quench furnace in an atmosphere of endothermic gas and ammonia at a temperature of about 560 to 580°C. This process results in the transfer of both carbon and nitrogen to the surface of the steel so that a compound layer is formed on the surface of the component supported by a nitrogen-rich ferrite surface diffusion zone. The compound layer thus formed has excellent tribological properties, while the nitrogen in the diffusion zone, when retained in solid solution in the ferrite, provides a considerable increase in fatigue.^{1, 2} These improvements are maximized when the treatment is applied to non-alloy steel components. Of late nitempering is more widely used in general engineering and automobile industries.

7.1 Method of Operating and Control

The nitempering process is normally performed in a standard sealed-quench furnace (Fig.

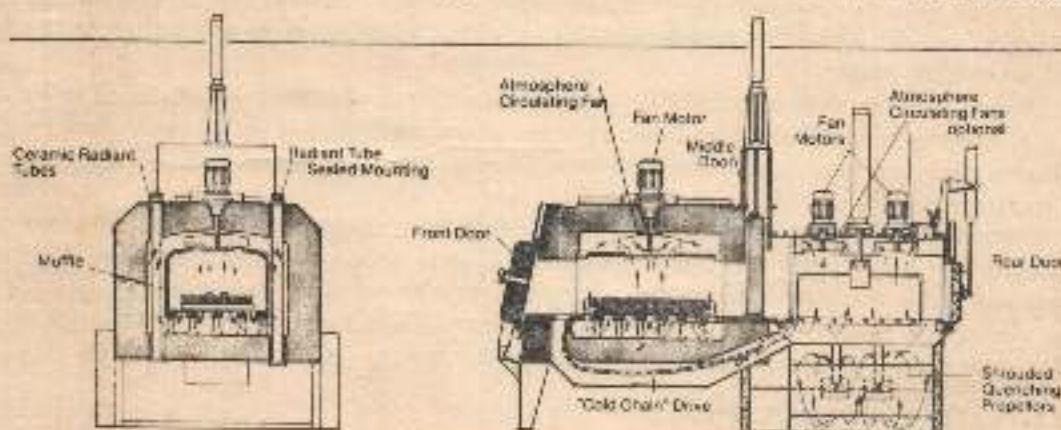


Fig. 7.1 Cross and longitudinal section through the Ipsen single-chamber, atmosphere-sealed quench furnace, type TQ (Courtesy: Ipsen Industries International, GmbH, W. Germany)

7.1)³. Before the process starts, the furnace is heated to a temperature of 750°C before being filled with the mixture of endogas and ammonia.^{3,4} The furnace temperature can now be lowered, preferably to about 600°C, and then purged with the said gas until a degree of ammonia dissociation reaches about 35–40%, which is measured in the sample gas taken from the furnace chamber. Purging will be done for 3–5 hours depending on the furnace walls. After the desired degree of dissociation is reached, first the charge is introduced after preheating the parts to about 350°C in air; the actual process begins when the temperature is held at 550 to 580°C depending on the type of material (Fig. 7.2). The process time varies

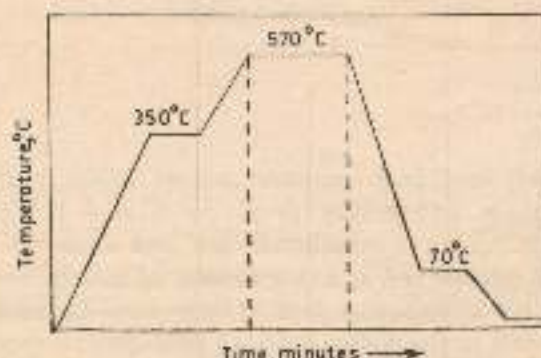


Fig. 7.2 Nitrotempering process cycle

between 1 and 4 hours, depending on the desired depth of case and the compound layer. After the elapse of the process time the components are quenched to raise fatigue strength. Quenching in oil increases the fatigue strength by about 25% as compared to air cooling. Tool steel components are quenched in forced gas cooling. Finally the parts are washed to remove any remaining oil.

Control of the process is done by means of checking the ammonia content in the furnace atmosphere (degree of dissociation of ammonia). The dew point of the carbon dioxide content of endogas should be monitored with a suitable, continuous measuring, recording and controlling device.

However, when working at 570°C, some extra safety devices must be employed, such as a flame curtain at the charging door, nitrogen purge, and ignition safeguarding system. It is also necessary to provide a temperature control system, so as to guarantee an adequate temperature control during the process.

Components which for any reason have not produced a nitrotempered layer of adequate thickness can be retreated without any difficulty so as to obtain better results. However it is not possible in those cases where, for example, a breakdown of the temperature controlling device has caused the load to be treated at too high a temperature. In this case a subsequent second treatment would not be successful.

7.1.1 SAFETY PRECAUTIONS

To avoid explosion hazards when using endothermic gas below 750°C, it is necessary that the furnace doors of the nitrotempering plant be equipped with flame curtains, which, when the door is opened, ignite the gas air mixture to maintain the flame front.^{3,4} The pilots which

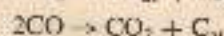
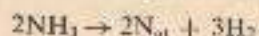
light the flame curtains also heat a safety device, interlocked with the door operating mechanism, to prevent any door being opened without the presence of a flame curtain. The safety of the operation is therefore comparable to that when operating at higher temperatures, as for instance when gas carburizing or carbonitriding are being carried out.

7.2 Furnaces

The nitriding process is normally performed in a standard sealed quench furnace (Fig. 7.1). Here quenching is possible without the load coming into contact with air. Such units are also suitable for gas carburizing, carbonitriding and bright hardening, and therefore additional investment can be avoided if such a plant is already available.

7.3 Nitempered Structure

The gaseous mixture used in nitempering will be about 50% ammonia and 50% endothermic gas. At the operating temperature the following reactions occur.



The atomic nitrogen and carbon formed saturate the surface of the steel. This results in the formation of epsilon carbonitride phase on the surface, which contains approx. 8% nitrogen, carbon and oxygen (Fig. 7.3).⁵ Underneath this there is a *diffusion zone* in which the ferritic structure is retained and enriched in nitrogen. The nitrogen produces a strain in the ferritic structure. This strain increases both the hardness and the fatigue strength of the material.

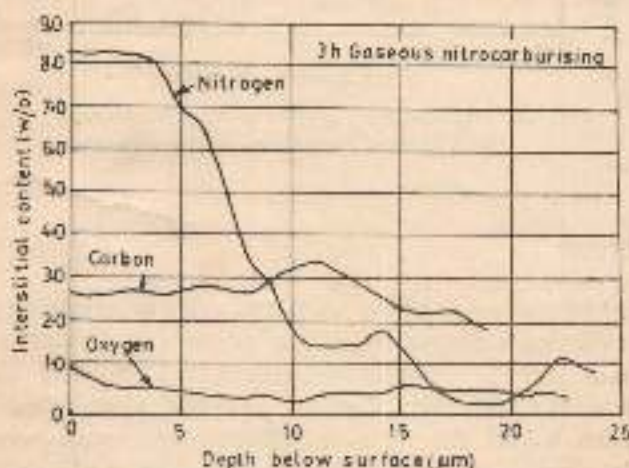


Fig. 7.3 Electron microprobe traces of nitrogen, carbon and oxygen in the compound layer formed by three hours of gaseous nitrocarburizing treatment in an ammonia/endothermic gas mixture⁵

Improvement in wear and scuffing resistance is due to the presence of epsilon compound (ϵ -carbonitride) layer on the surface.^{3,6} The thickness of the compound layer increases with time and is temperature dependent. A temperature difference of 10°C can cause a 10 to 15% improvement or reduction in the thickness of the compound layer. At the same time the variation in ammonia percentage in the furnace can also affect the formation of a compound layer. It is possible to substitute up to 50% of the ammonia by an endothermic gas without adversely affecting the atmosphere of nitriding and the formation of the compound layer.

Since the formation of the compound layer is very thin and if the wear resistance is the principal criteria, then the component should be finish machined before nittempering or at the most subjected to only light operation after heat treatment. The outer thin layer will have a hardness of 600 to 1200 HV depending on the alloy content of the steel (Fig. 7.4).⁵

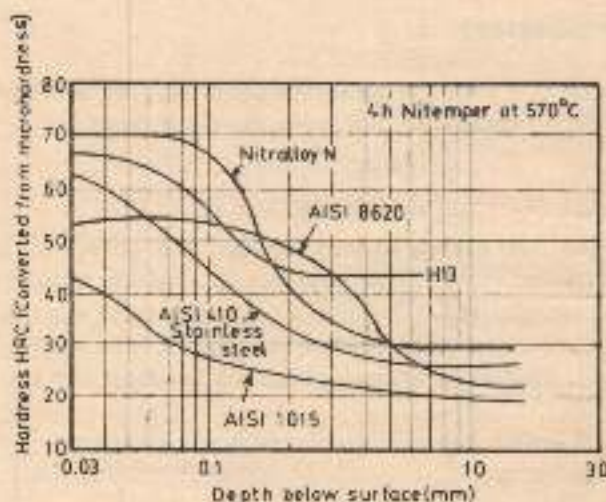


Fig. 7.4 Microhardness profiles of the diffusion zone for a series of steels after nittemper treatment⁵

7.4 Prior Treatment

The components must be stress-free before treatment and if necessary they should be stress-relieved. The stress relieving is done at 600°C and subsequently cooled in the furnace.

It is most important that the components should be completely clean and free from grease, oil, rust and surface decarburization for successful nittempering as in the case of gas nitriding. These can inhibit the nitrogen diffusion and hence washing in trichloroethane is preferable. Passive surfaces can be reactivated by anodizing them lightly before treatment.

As in the case of gas nitriding there will be a slight growth on the surface of the treated components and this in most cases can be compensated by 'prediction' during the final machining operation.

Before charging the components to the nitempering furnace, they should be pre-heated to 350 to 400°C in air.

7.5 Post Treatment

Components made of unalloyed steels and alloyed steels are quenched in oil to improve the fatigue strength of the components, so that the nitrogen is held in solution.

Hot work steels do not require oil quenching and they are cooled by forced gas cooling.

7.6 Quality Control

Random testing of the nitempered components from a given batch is effected by means of surface hardness measurements with appropriate graduated loading of 10, 0.5 and 0.03 kg and hardness distribution measurements on an edge layer (HV-0.3) of a cut polished specimen. An additional random check by microscopy for determination of the thickness of the compound layer is recommended. It is most important that the polished section be carefully prepared.

7.7 Properties of the Nitempering Components

Nitempered components possess a very high resistance to wear under friction with similar or other metals, even with dry-running.^{1,2,5,7} This effect is mainly produced by the compound layer on the work piece surface, which consists of epsilon carbonitride phase. Figure 7.5 illustrates the improvement in wear resistance under dry running conditions relative to

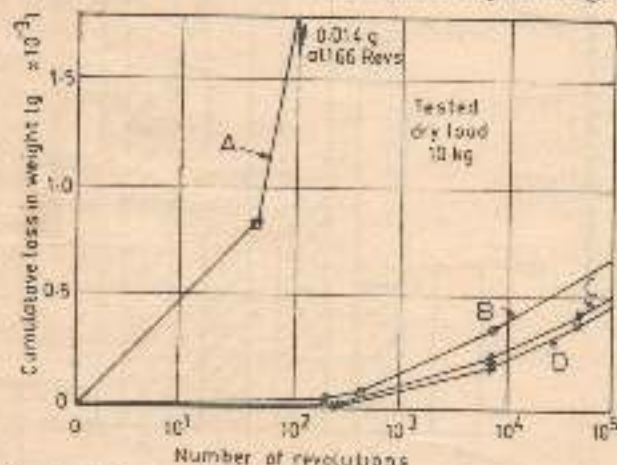


Fig. 7.5 Dry-running wear measurements using 'four-ball' wear test on 15-steel: A—Untreated, B—Nitempered 3 h and air cooled, C—Nitempered 3 h and oil-quenched, D—Nitempered 8 h and oil-quenched, tested dry load 10 kp.

untreated material and shows the results of modified four ball wear tests on gaseous nitrocarburized En-32 steel after various treatments.

A comparison of scuffing resistance of 080M40 (DIN C45) steel after different surface treatments is presented in Fig. 7.6. It can be seen that the wear rate is improved compared to an untreated steel after adopting tuffriding, nitrotempering, salt bath nitriding or case

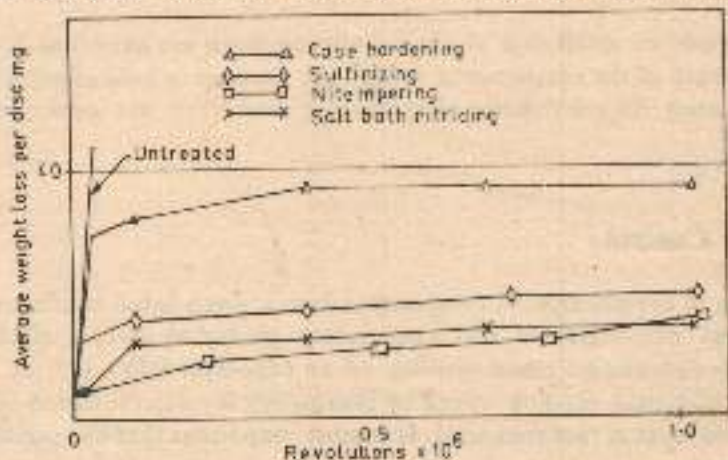


Fig. 7.6 Lubricated scuffing wear results*

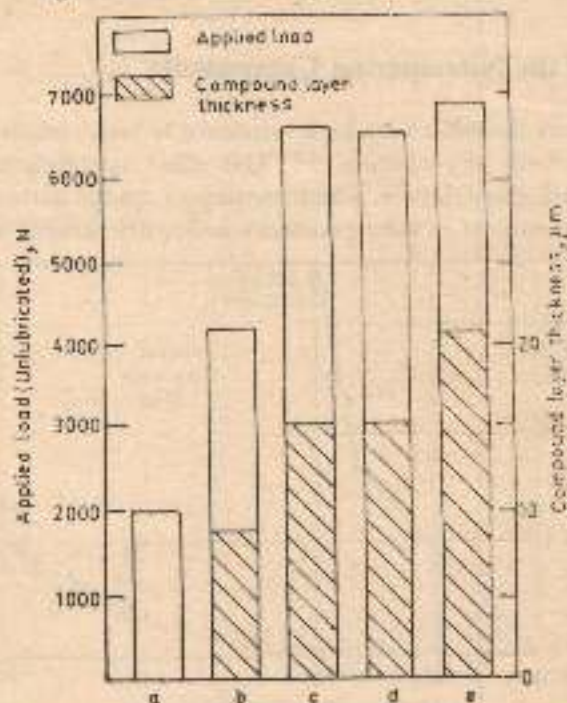


Fig. 7.7 Faville-Levalley test results for nitrocarburized, low-carbon, non-alloy steel: (a) Untreated, (b) 9 μm compound layer OQ, (c) 15 μm compound layer OQ, (d) 15 μm compound layer AC, (e) 21 μm compound layer OQ

hardening.⁴ Among the above processes the nitempered or tufftrided components show better results.

Nitempered components are less prone to scuffing or seizure and possess excellent tribological properties. Figure 7.7 illustrates the resistance to scuffing as indicated by a test using Faville-Levally testing machine on low carbon non-alloyed steel air-cooled after nitempering. The test is conducted in dry condition. It can be seen that the untreated non-alloy steel did not show any significant scuffing resistance and seized at an applied load of 2000 N, whereas the nitempered component had no sign of scuffing.

With respect to the thickness of the compound layer, Fig. 7.7 shows that a 9 mm thick compound layer failed to develop maximum anti-scuffing resistance compared to that of a 21 mm thick compound layer. Hence it may be concluded that a 15 mm thick compound layer is ideal for developing maximum anti-scuffing resistance on low carbon non-alloy steels.

7.7.1 FATIGUE STRENGTH

Nitempered components possess an improvement in fatigue strength due to the nitrogen being held in solid solution, producing a strain on the ferritic lattice structure. This strain increases the hardness and fatigue strength of ferrous materials.⁵

Figure 7.8 illustrates the improvement in fatigue strength for different types of steels

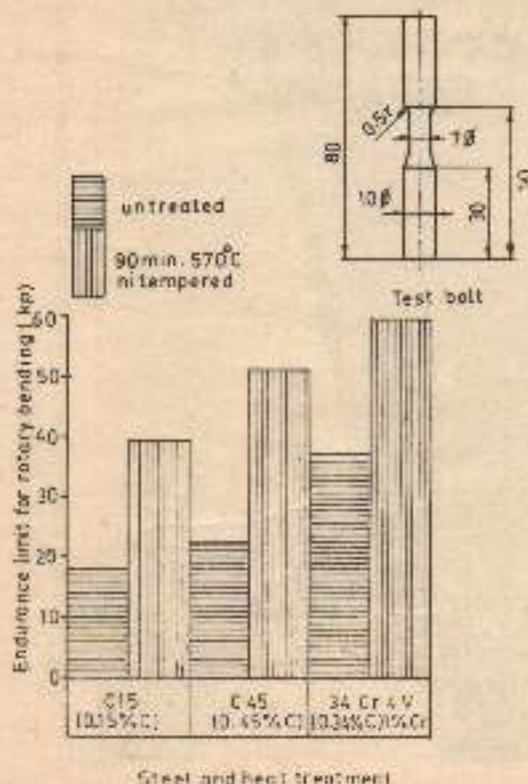


Fig. 7.8 Fatigue strength of C15-steel, steels C45 and 34Cr4V, prior to and after nitempering for 90 minutes at 570°C and after oil-quenching

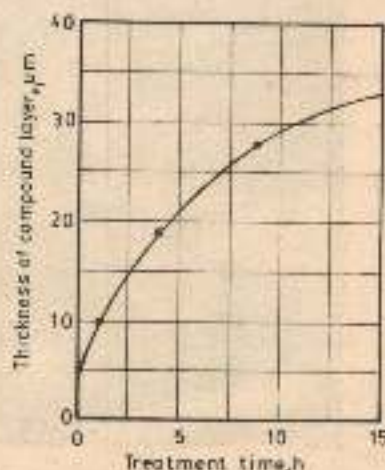


Fig. 7.9 (a) Depth of compound layer v. treatment time^{5,6}

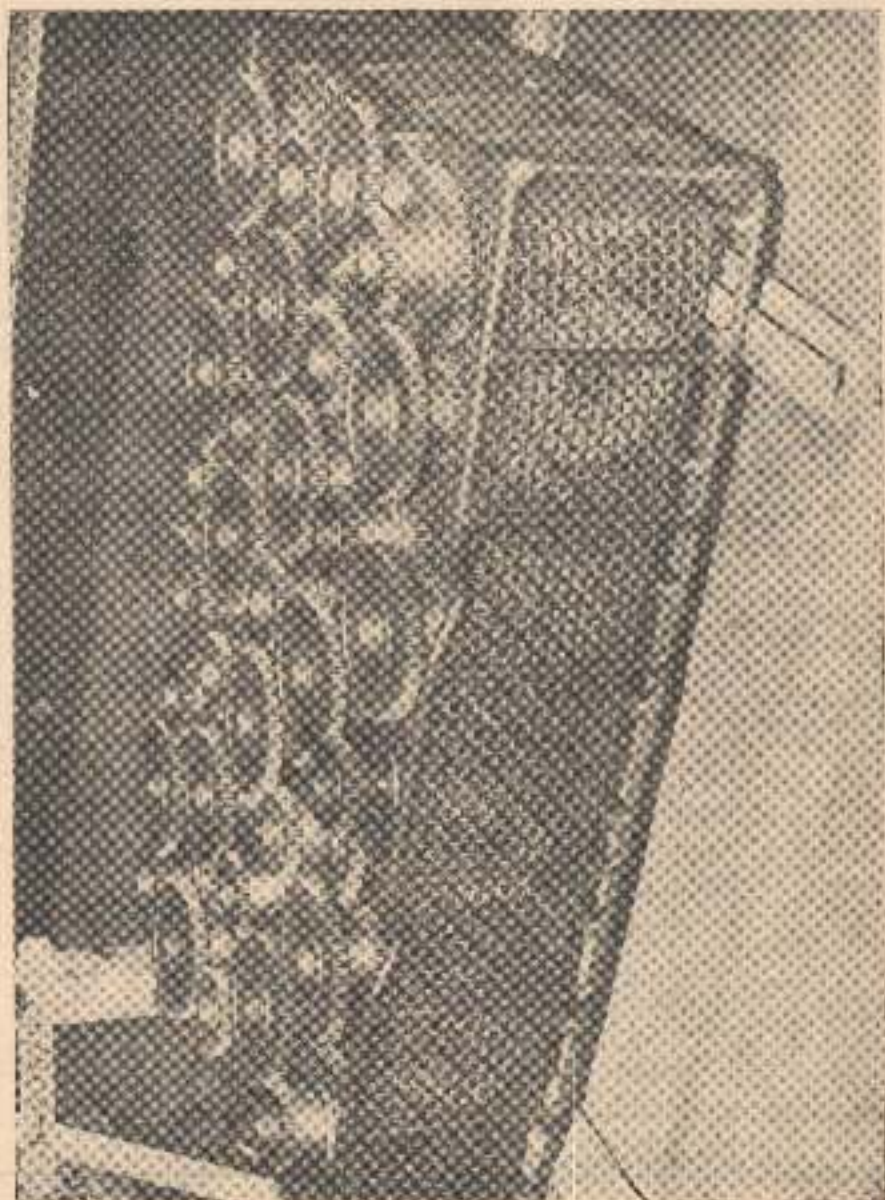


Fig. 7.9 (b) Nitrocarburized load of pinions approximately 40 kg (Courtesy: Ipsen Industries International GmbH, W. Germany)

after 90 minutes, treatment time. Quenching the components in oil produces an optimum fatigue strength, because the nitrogen in the diffusion zone remains in solid solution compared to the air or gas cooled. However, the components that are subjected to higher temperatures in internal combustion engines are not oil quenched.

The improvement in the fatigue strength is achieved only because of the diffusion zone, and remains, therefore, even if the compound layer is removed.

Nitempering improves the corrosion resistance of ferrous materials with the exception of stainless steel. A series of corrosion tests including the salt spray test, exposure to industrial atmosphere and exposure to tropical conditions indicated that nitempering enhanced the corrosion resistance of mild steel, cast iron, carbon steel, etc. Better results are obtained compared to phosphated and oiled, chromium plated, nickel plated and zinc plated samples.

7.7.2 DIMENSIONAL CHANGES

There will be a gradual growth in the dimensions of the components after nitempering treatment. This depends on the nitempering time and temperature. Figure 7.9 illustrates that at 570°C there is a direct relationship between total compound depth and dimensional growth. This is caused by the atomic lattice volume expansion and has proved to be very consistent. Hence it is necessary that, before final machining, allowances should be made to avoid further machining operation. However, with this practice the dimensional changes are negligible.

7.8 Applications

Nitempering has a wide and vastly differentiated range of applications covering the whole process industry.

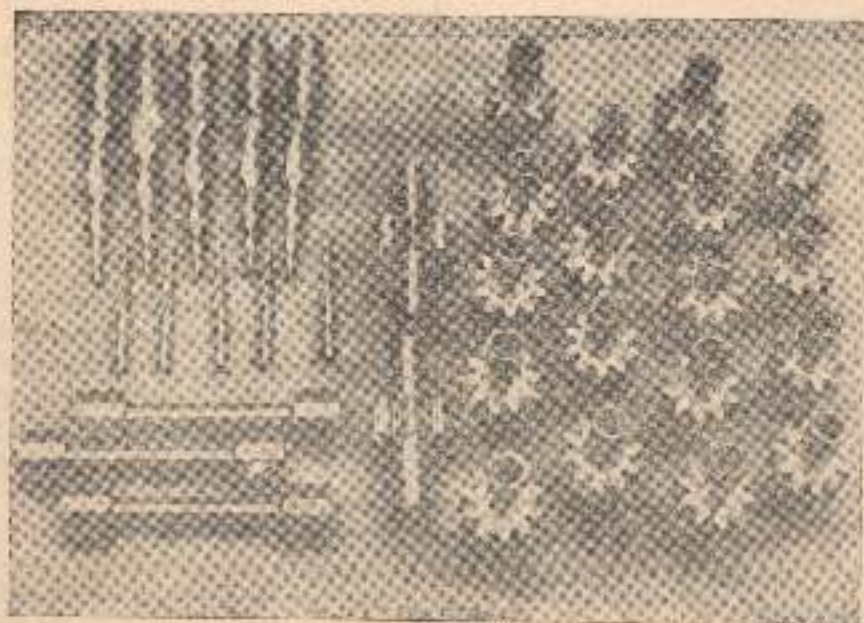


Fig. 7.9 (c) Nitrided parts

1. The process is amenable to single or mass production items made of carbon steel and cast iron. It leads to the possibility of replacing alloyed steels with carbon steels, hence saving both material and finished costs.
2. Since the dimensional changes after treatment are negligible the components may be treated after finish machining.
3. Nittempering yields outstanding improvements in wear and fatigue resistance compared to conventional surface hardening methods. The process is free from some of the adverse effects associated with carburizing, where it is often difficult to eliminate the occurrence of retained austenite especially when high alloy steels are used.
4. The applicability of the process in the case of high-quality precision components such as tools and machine components, is of particular importance because the improvement in wear characteristics and fatigue strength is achieved with a minimum of distortion and dimensional changes thus avoiding expensive re-finishing operations and the risk of scrap.

However, the fact that carbon and low alloy steels treated at a temperature of 570°C have reduced core strengths should be taken into consideration. Hence the application of this process in the case of components subjected to high, local surface loading or substantial mechanical stresses (as for example in the case of gear wheels subjected to high stress), is less advantageous.

5. Nittempering may be employed as a substitute to nitriding and sursulf treatment. This makes it possible to avoid the use of salts containing cyanide and helps solve the environmental problems connected with their use. This process may be employed for unalloyed steels, alloyed steels, tool steels, steel castings, spheroidal/malleable castings and grey cast iron.
6. The nittempering furnace may be used for hardening, carbonitriding, carburizing, annealing, etc.

7.8.1 NITEMPERING CYCLES FOR DIFFERENT TYPES OF STEELS

1. **Non-Alloy Steels** First the non-alloy steels are normalised, then rough machined. They are then subjected to stress relieving treatment at 580 to 600°C for 2 to 3 hours and subsequently cooled in the furnace. This treatment is done to relieve the heavy stresses that are developed during machining, and to avoid the distortion after nittempering.

Normalizing \rightarrow Rough machining \rightarrow Stress relieving 600°
 Oil quenching \rightarrow Nittempering 570°C \leftarrow Cleaning \leftarrow

2. **Alloyed Structural Steels** Alloyed structural steels used for nittempering should be hardened and tempered to the desired toughness after rough machining, keeping 3 to 4 mm allowances. The parts are then stress relieved at 580 to 600°C for 2 to 3 hours in order to relieve the machining stresses and to avoid distortion after the nittempering treatment. After this treatment, parts are machined to the final dimensions, considering the growth of the compound layer. The finished components are then subjected to the nittempering treatment for 1 to 2 hours depending on the required case depth (Fig. 7.9 a).

Rough machining \rightarrow Hardening and tempering \rightarrow Machining \rightarrow
 Quenching \leftarrow Nittempering 570°C \leftarrow Finish machining \leftarrow Stress relieving \leftarrow

3. **Tool Steels and Dies** Tool and die steels used for nittempering are rough machined by keeping the 2 to 3 mm allowance in mind. Therefore, in order to relieve the stresses that are developed during heavy machining, the components are subjected to stress relieving

treatment at 600 to 620°C for 2 to 3 hours. The parts then are machined almost to the finish machining or to the final dimensions depending on the type and size of tools. The tools are then hardened and tempered to the desired hardness. Finally the tools are finished to the requisite dimensions and then nittempered (Fig. 7.9b).

Rough machining → Stress relieving 600-620°C → Prefinal machining
 Nittempering 570°C ← Final machining ← Tempering ← Hardening

7.8.2 PRODUCT APPLICATIONS

Drive Transmission Assembly For reasons of corrosion resistance the drive transmission

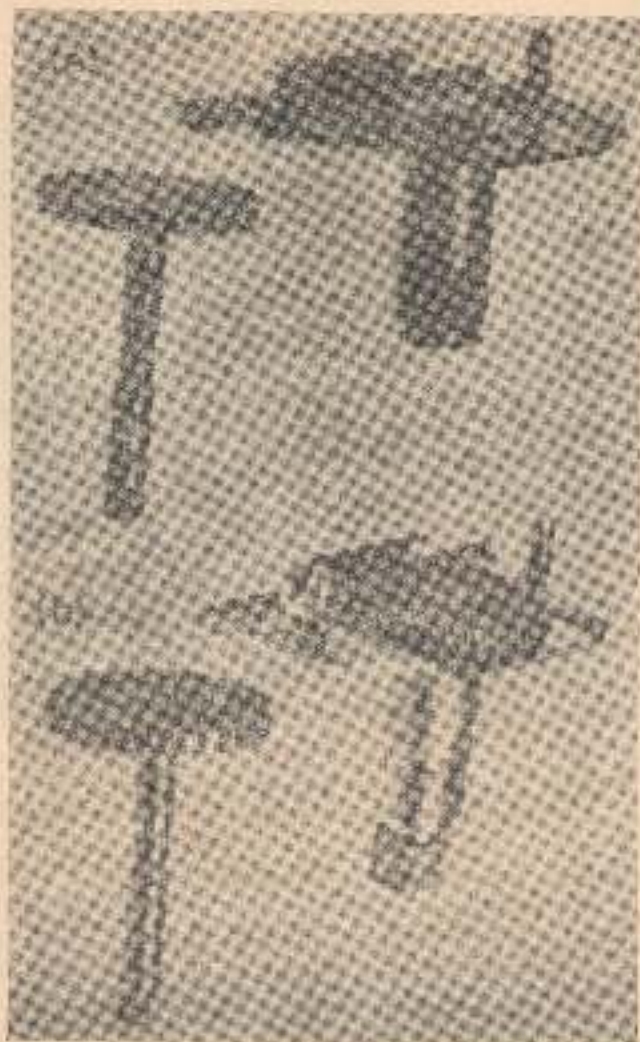


Fig. 7.10 Drive transmission assembly: (a) Modified design made entirely from non-alloy steel and nitrided, (b) Original design with 13% Cr iron shaft, aluminium bearing sleeve and zinc-plated cover plate (Courtesy: Ipsen Industries International GmbH, W. Germany)

assembly shown in Fig. 7.10² was made originally with a stainless steel shaft running in an aluminium bearing sleeve (Fig. 7.10b). The redesigned unit (Fig. 7.10a) consists entirely of nitrided low-carbon non-alloy steel. The components are welded to form two subassemblies and then heat treated. It has been possible to eliminate the stainless steel shaft and the aluminium bearing sleeve, and to remove the need to line the gear cover plate with zinc.

Bearing Bush The pinion illustrated in Fig. 7.11¹ was specified originally to operate in conjunction with an expensive bronze bearing bush. Proving tests showed that it was possible to replace the bronze bearing bush with a thinner nitrided low-carbon non-alloy steel bush. This allowed the root section of the pinion to be increased, thereby improving its performance.



Fig. 7.11 Drive pinion and bearing bush assembly (Courtesy: Ipsen Industries International GmbH, W. Germany)

Bearing Shaft and Sleeve The bearing shaft and sleeve shown in Fig. 7.12¹ illustrate the advantages which may be obtained when nitriding is considered at the design stage of a new product. The shaft and sleeve are manufactured in low carbon non-alloy steel, and then nitrided and assembled without any bearings. In addition, manufacturing schedules do not specify any corrective machining or sizing after heat treatment to compensate for distortion, although the assembly is 7 cm long.

Helical Drive Pinion Figure 7.13¹ illustrates a constant-mesh helical drive pinion which requires a very close tolerance tooth profile to operate with minimum noise. Nitriding enables these very close tolerances to be maintained during heat treatment. In addition, fatigue strength and wear resistance are improved, thereby enabling the engineering perfor-

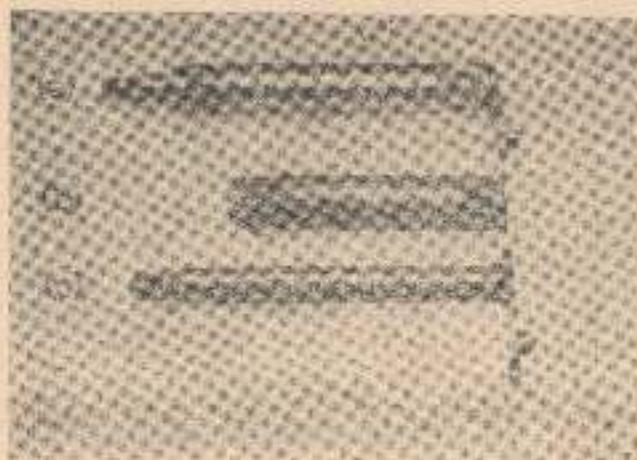


Fig. 7.12 Nitrided, non-alloy shaft and bearing sleeve (Courtesy: Ipsen Industries International GmbH, W. Germany)

formance to be achieved with an inexpensive medium carbon non-alloy steel.



Fig. 7.13 Nitrided, medium-carbon, non-alloy, helical-drive pinion (Courtesy: Ipsen Industries International GmbH, W. Germany)

Output Shaft Assembly Figure 7.14¹ illustrates an output shaft assembly which is required to transmit a torque of 50 Nm minimum at the spline end of the shaft. The shaft was originally designed in low carbon non-alloy steel, but it failed during product proving owing to:

1. Corrosion attack
2. Slip at low torque values of 34–47 Nm caused by collapse of the splines as illustrated in Fig. 7.15a.



Fig. 7.14 Nitrided, non-alloy, transmission-shaft assembly
(Courtesy: Ipsen Industries International GmbH, W. Germany)

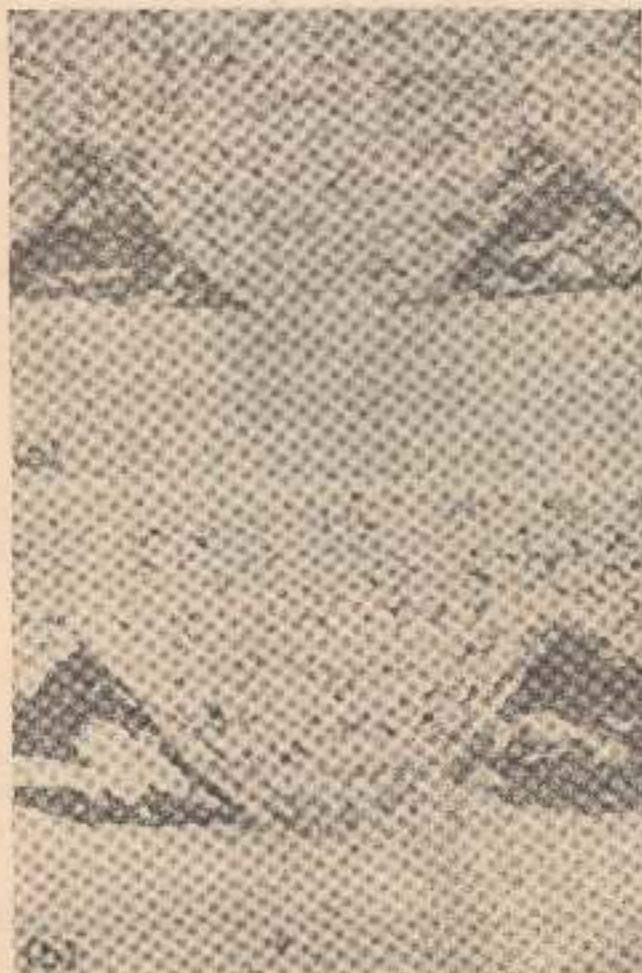


Fig. 7.15

Low-carbon, non-alloy steel shaft
(a) Unnitrided, showing collapse of
splines during assembly, (b) Nitrided,
showing undamaged spline profile
after driving on to transmission link
(Courtesy: Ipsen Industries Inter-
national GmbH, W. Germany)

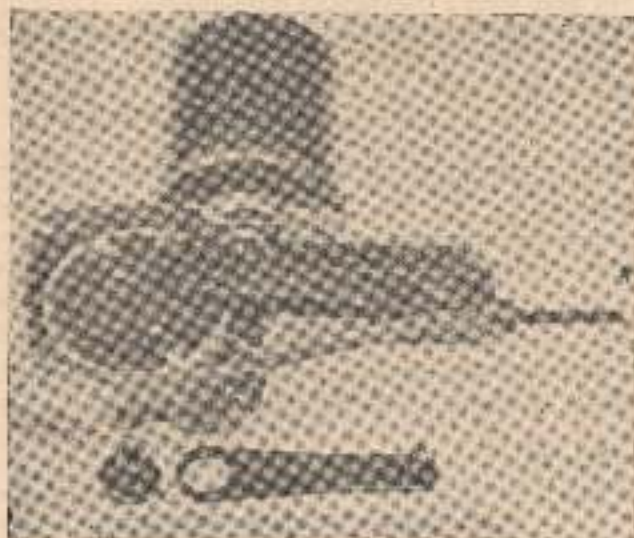


Fig. 7.16 Nitrided, non-alloy eccentric-drive assembly (Courtesy: Ipsen Industries International GmbH, W. Germany)

Nitriding the shaft provides ferrite strengthening of the splines, which prevents their collapse when driven into the transmission link as illustrated in Fig. 7.15b. Thus, nitriding enables the specified torque to be transmitted and, in addition, provides resistance to corrosion.

Drive Assembly Figure 7.16¹ illustrates a con-rod which is actuated by an eccentric pin located on a shaft and plate assembly; eight wearing surfaces are involved. Nitriding has allowed this assembly to be manufactured without the need for any bearing bushes.



Fig. 7.17 Nitrided non-alloy, steel-actuator assembly (Courtesy: Ipsen Industries International GmbH, W. Germany)

Actuator Unit Figure 7.17¹ illustrates an actuator unit designed specifically to utilize the advantages associated with nitriding, in this case the elimination of distortion and the need for zinc plating, stainless steel shafts, and sintered bearings. All the components are made in low carbon non-alloy steel, and are welded and Taumel riveted into two subassemblies before being heat treated. If this product had been constructed using traditional design

methods, it would not have been a commercial proposition.

Apart from the above listed applications, it has been successfully used in the following applications (Table 7.1).

Table 7.1

Application	Requirement
Precision gear wheels up to 650 mm	Wear resistance, distortion free
Hydraulic elements	Wear resistance, distortion free
Precision components (camera, sewing machines)	Wear resistance, non-fretting, distortion free
Internal combustion engine crank shafts and compressor components. Drive shafts, tractor equipment.	Higher fatigue strength, avoid refinishing
Spindles for friction welding machines	High fatigue strength
Ball bearing cages, sliding plates for conveyor systems	To avoid resistance, to wear with no distortion
Components for domestic applications	Wear and rust resistant
Gear lever templates	Wear resistant at the unfinished cutting edge, no fretting of the gear lever
Door hinges	Wear resistant, rust resistant
Valve rocker shafts	Wear resistant, no distortion
Moulds for moulding compound	Wear resistant, extension of useful life several times over
Continuous casting tools and hot extrusion dies for aluminium	Wear resistant, extension of useful life several times over
Silicon-iron cores of solenoid contactors	Wear resistant on contact surface

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Tufftride—TF1

This is a cyanide free salt bath process developed by the Degussa Company (Germany) as an alternative to a tufftride process involving cyanide. The process differs from the conventional tufftriding process inasmuch as only 3 to 4% cyanide is present in the working bath.

Tufftride TF1 is a molten salt nitrocarburizing process carried out at 580°C, in which nitrogen and a small amount of carbon are liberated in the presence of a steel surface. Nitrogen thus produced diffuses deep into the surface of the component and along with carbon forms a rich compound layer on the surface of the component. The compound zone consists mainly of a ductile carbon bearing epsilon iron nitride and is responsible for the wear and galling resistance of tufftride treated components. The thickness of the layer formed will be in the range of 8–20 microns depending on the material treated and the process time. The compound zone has a microhardness ranging from 400 to 1200 HV, depending on the base material.

Components after the treatment are cooled in an oxidizing bath ABI maintained at 350 to 400°C. This results in a combination of high corrosion resistance and a cosmetic black finish. This eliminates the additional surface treatment process such as bluing etc.

The tufftriding treatment can be applied successfully to most ferrous materials and is now more widely used by the automotive and general engineering industries. Tufftriding TF1 is also known as Melonite in U.S.A. and as carbonitriding in U.S.S.R.

8.1 Process Requirements

The equipment required for the process are as follows (Fig. 8.1):

1. A degreasing plant for cleaning the components.
2. Heating chamber for preheating the components to 350 to 450°C.
3. Electrically heated furnace for heating the tufftride TF1 salt with automatic temperature control system with a tolerance of $\pm 5^\circ\text{C}$.
4. The nitriding pot made of titanium and pipes for air inlet into the melt made of the same material.
5. ABI salt bath cooling furnace.
6. Cold water tank.
7. Hot water tank.

8. Dewatering fluid.
9. Manometer.
10. Air gauge.
11. Compressor.
12. Suitable jigs and fixtures for handling the components and to avoid distortion.
13. First aid treatment kit.

Note: It is most important that the tufftride bath, AB1 quenching bath and cold water tank should be equipped with good exhaust systems. The room should be well ventilated.

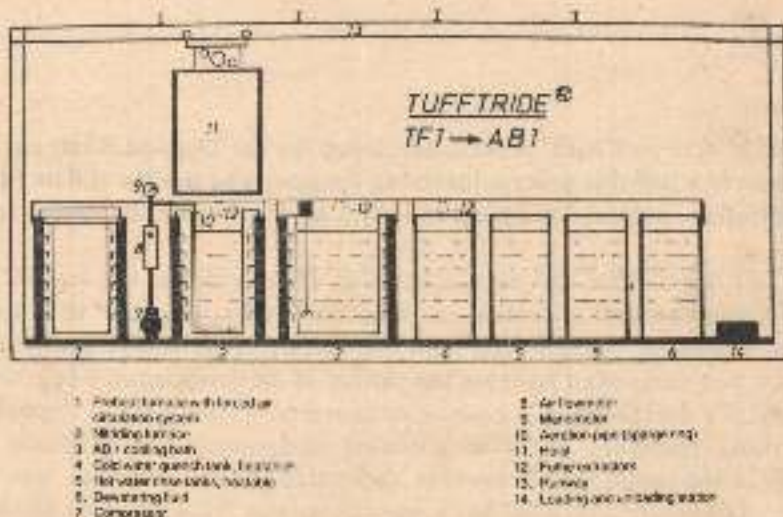


Fig. 8.1 Schematic diagram of an automatic salt-bath plant (Courtesy: Degussa, W. Germany).

8.2 Special Precautions

Since most of the components after treatment can be sent readily to the assembly, it is necessary that prior to tufftriding all the machining operations must be carried out. Complicated components which are liable to deform must be stress relieved at or above 570°C for one to two hours. Alloy steels should be properly tempered after hardening. The tempering temperature should be greater than 550°C.

It is of the utmost importance that the components should be free from any oxide film, decarburization, grease, etc.

Components after stress relieving should be finish machined.

8.3 Operating Procedure

The desired properties attained by the tufftrided components depend mainly on the operating procedure employed. Hence, the following procedure may be followed:

is often quite sufficient, whereas big gears and parts of cast iron may require 3 to 5 hours. After the treatment time has elapsed, the components are transferred directly into a bath containing AB1 salt at 350 to 400°C and immersed for 10 to 20 minutes. Subsequently the

8.3.1 PREPARATION OF THE BATH

A new tufftride bath is prepared by melting out the single base salt (containing sodium and potassium cyanate and carbonate salts) in a titanium lined pot. Salt is added for melting only after the furnace is on and the thermocouple is inserted in the pot. The bath is thereafter heated to a temperature of 580°C. After melting completely to liquid, the aeration of the bath is started using a dry flow of air through the salt to maintain a uniform temperature and to get consistent results.

Once the bath is completely melted down and has reached the temperature 580°C, a sample is taken out with the help of an iron spoon and poured on a dry, cold aluminium sheet, on which the sample will immediately solidify. This uniform sample should be immediately subjected to a chemical analysis or kept in an air-tight glass jar. After the analysis the regenerator (REG1) is added if necessary to bring the cyanate content up to the required concentration of 34 to 36%.

During the process, the cyanate content reduces and the carbonate content increases. Addition of a small amount of cation-free (cyanide-free) regenerator (REG1), upon reaction with the carbonate, forms fresh cyanate. Addition of the regenerator does not increase the bath level.

The addition of base salt depends on the throughput of the work and the amount of dragout which varies according to the shape and nature of the components being treated; but it is normally found to be in the range of 2% of the weight of the parts treated in 24 hours.

Although the base salt and regenerator are free from cyanide, a small amount, typically between 1 and 3%, develops in the bath during the treatment of components. In contrast to the current tufftride process no iron complex, for instance $\text{Na}_4[\text{Fe}(\text{CN})_6]$, is formed at the normal operating temperature. Hence it eliminates the need for a high temperature desludging. The only material that needs to be removed is iron oxide (Fe_2O_3), which can be done at the operating temperature.

Note 1. Local overheating of the pot or the bath must be prevented. The temperature of the bath should not exceed more than 650°C, since it reduces the life of the pot. Hence the bath temperature has to be continuously controlled by a thermocouple. Overheating can occur if an appreciable amount of sludge has accumulated at the bottom of the pot. Regular and careful removal of all sludge is therefore imperative.

2. The bailed out sludge contains a small amount of cyanide and must therefore be treated as cyanide containing waste salts according to the local regulations.

8.3.2 PRE-TREATMENT

The components to be treated should be free from oxide, grease, oil, etc., before being inserted into the bath. Degreasing is imperative on parts thickly coated with grease, while thin grease films evaporate either during preheating or within a few minutes after insertion of the parts into the bath. The presence of sulphurized machining oil on the component is undesirable since sulphur has a detrimental effect on the bath properties. The components should therefore be held in suitable fixtures or hung vertically by wiring in order to avoid distortion. After this the components are preheated in a pre-heating furnace to about 400 to 450°C in air, both to ensure they are dry and to limit the temperature fall in the tufftride bath to less than 540°C. (This ensures the formation of a ductile epsilon carbonitride compound zone and not the brittle γ' layer produced in conventional gas nitriding.)

In particular, massive tools should be preheated up to 450–500°C depending on the grade of steel, especially when the nitriding treatment is short and a large temperature difference between the profiles on the component is likely.

8.3.3 NITRIDING TREATMENT

After preheating the components are charged into the tuffride bath maintained at 580°C (Fig. 8.2). The treating time depends on the size of the components and the material, usually in the range 10–180 minutes. With very thin parts, a treating time of 10–30 minutes

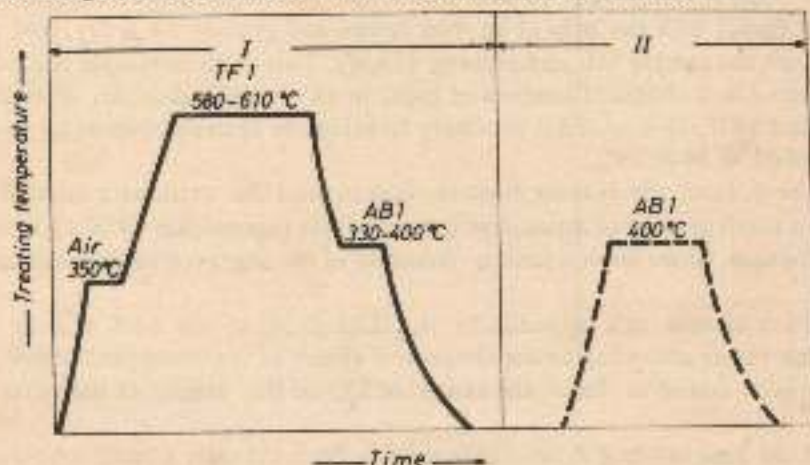


Fig. 8.2 (a) Treating cycle.



Fig. 8.2 (b) Loading jig for automated tuffride plant
(Courtesy: Degussa, W. Germany).

components are quenched in cold water and then washed in hot water. Quenching in salt bath completely destroys all forms of cyanide and cyanate generated by the nitriding process.

8.3.4 QUENCHING

Components after treatment may be cooled or quenched in water, oil, air or salt bath ABI maintained at 350 to 400°C, depending on the type of material and the properties required. Subsequently the components are quenched in cold water and then washed in hot water.

Cooling in hydroxide bath ABI reduces the distortion compared to the effect of quenching in oil or water. All types of materials may be cooled (Fig. 8.2). Apart from this the detoxification of waste water is not necessary, since the nitriding salt adhering to the components is oxidized to carbonate in the salt bath ABI, which means that the rinsing water remains free of cyanide. The temperature of the ABI bath must however be at least 330°C.

Figure 8.3 illustrates the neutralization of cyanide and cyanate in relation to the bath temperature and duration of reaction. It is clear from the curve that the destruction of cyanide and cyanate is actually a time reaction, i.e. a combination of hydrolysis and oxidation of bath constituents takes place. With short immersion times, a minimum working

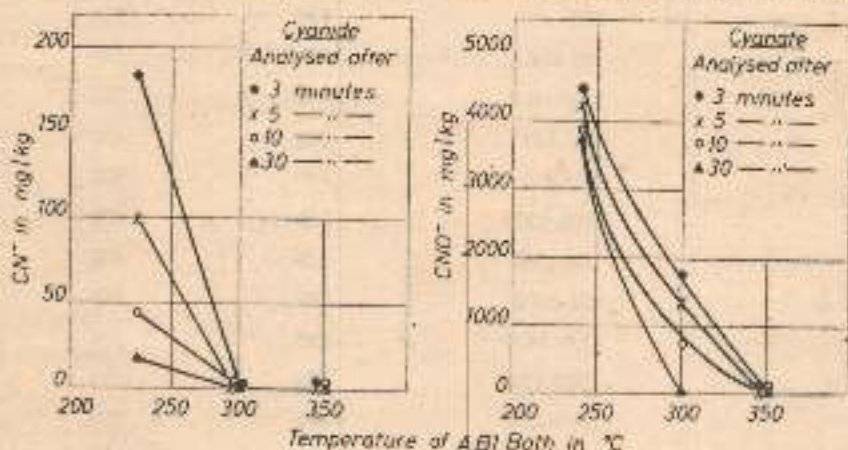


Fig. 8.3 Decomposition of cyanide and cyanate in ABI bath (Courtesy: Degussa, W. Germany).

temperature of 300°C is recommended. The decomposition of cyanide and cyanate leads to the formation of carbonate which is partly dissolved in the bath and which after reaching the limit of solubility, turns to sludge. Components quenched in ABI salt bath possess a cosmetic black finish. Sludge taken out of the tuffride bath can be disposed of quite easily on approved dumps.

8.4 Quality Control

The performance of the tuffrided components depends mainly on the compound layer and the diffusion zone. To get an excellent wear resistance and also to get good sliding and

polishing properties, the compound layer should be free of pores as far as possible. The thickness and porosity of the compound layer may be checked by metallographic or X-ray diffraction, spot test, etc.

Depending on the chemical composition of the steel on the treatment, nitriding results in a considerable increase in hardness. Because of the relatively thin case and the fact that the found hardness is an average value resulting from the higher hardness of the compound layer and the lower hardness of a part of the diffusion zone, this checking can only be carried out with small loads of HV1-HV10 (KP/mm²). Certain requirements such as cleanly ground surface etc., must also be met by tuffiride treated parts. Smaller test loads result in a higher hardness value, since, in that case, only the outer nitrogen-enriched zone is covered. Table 8.1 indicates the hardness attained after tuffirided treatment for different types of steels.

Table 8.1

Material (DIN)	Strength after tempering drawing temperature 600°C; drawing time (KP/mm ²) 90 minutes	Approx. values for surface hardness after 90 minutes tuffiride treatment at 580°C		
		HV 1	HV 10	HV 30
Ck15	600	350	300	200
C45W3	750-850	450	350	250
Ck60	750-900	450	350	250
20MnCr5	800-950	600	450	400
53MnSi4	850-950	450	400	350
90MnV8	1000-1200	550	450	400
42CrMo4	900-1200	650	500	450
X19NiCrMo4	900-1100	600	500	450
55NiCrMoV6	1200-1400	650	550	500
56NiCrMoV7	1300-1500	650	550	500
50NiCr13	1200-1350	600	500	450
X20Cr13	1000-1200	900	600	450
X35CrMo17	1000-1200	900	700	550
X210Cr12	1500-1700	800	600	450
X210CrW12	1500-1800	800	600	500
X165CrMoV12	1400-1900	800	650	500
45CrMoW58	1500-1800	800	700	600
X32CrMoV33	1700-1800	900	850	700
X38CrMoV51	1700-1900	900	850	700
X37CrMoW51	1700-1900	900	800	700
X30WCrV53	1700-1900	900	850	750
X30WCrV93	1500-1800	900	850	800

8.5 Characteristics of Tufftrided Case

The higher hardness, increase in wear resistance and corrosion resistance depend mainly on the tufftrided case. The case consists of an outer layer called the compound layer, underneath which is the diffusion zone, the details of which are as follows.

8.5.1 COMPOUND LAYER

Tufftriding process liberates specific quantities of carbon and nitrogen in the presence of ferrous materials. Most of the nitrogen diffuses into the metal, creating a deep diffusion zone. About 10% of the nitrogen remains at the surface and combines with carbon and iron to form a tough compound zone (Fig. 8.4) 10–20 mm thick, of carbon bearing epsilon iron nitride, which is having good tribological properties (Fig. 8.5).

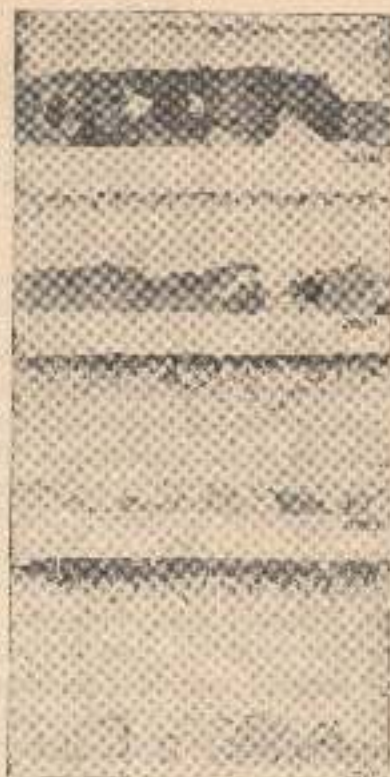


Fig. 8.4 Melonite compound zones, SAE 1015 90'→SW (Courtesy: Degussa, W. Germany)

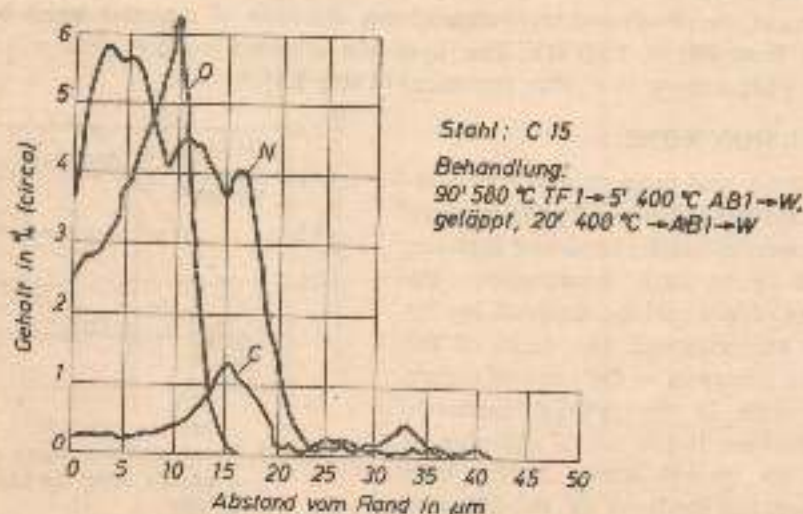


Fig. 8.5 Auger analysis of TFI-AB1 treated specimen

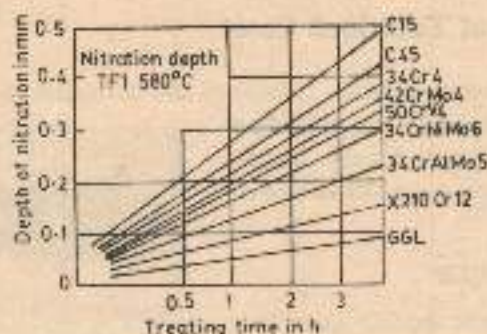


Fig. 8.6 Nitration depth (German Standard DIN 50 190) on various materials after salt-bath nitriding in TF1

The composition, structure and properties of the compound layer are influenced by the material. The presence of carbon and alloy in the material have an influence on the thickness of layer formed. The higher the contents the thinner the layer formed. Figure 8.6 shows data established on parts treated in a tufftride bath containing 36–38% CNO run at 580°C. The condition of a new bath also influences the quality of the compound zone. Therefore the bath must be well maintained and desludged. On cast iron parts the compound layer is slightly more porous than on steel ones. The compound zone more than 0.02 mm is not advisable since it causes very porous layer. This material simply sluffs off to cause handling, dimensional and appearance problems.

The compound zone formed on the surface has good sliding and high antifriction properties. Due to the structure of the compound zone it is not inclined to seize or weld with a metallic surface, as is possible with, for example, case hardened or surface hardened components. This factor is particularly important on tools where a welding of the cold and hot flowing material is to be avoided.

The tufftrided case is not as hard as that which results from conventional nitriding. The hardness of the compound layer depends on the type of material which has a hardness varying from 400 to 1200 HV. The hardness attained in alloy steel will be higher compared to plain carbon steel after treatment (Table 8.1).

8.5.2 DIFFUSION ZONE

Whilst structure and properties of the compound layer are not influenced by the material and these properties, unlike hardened surfaces, are retained up to high temperatures, the hardness and depth of the material are influenced by the material. The depth of the diffusion zone decreases as the level of nitride forming elements in the material increases, due to the decrease in the rate of diffusion of nitrogen in the parent lattice. At the same time, however, the hardness of the diffusion zone increases as the alloy content increases, due to the sub-microscopic precipitation of

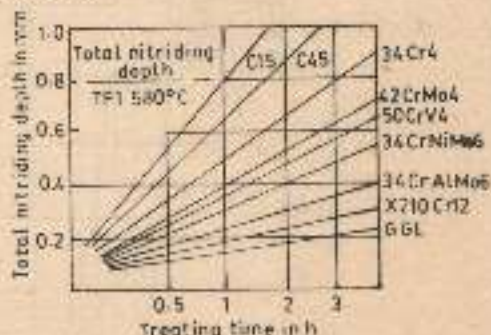


Fig. 8.7 Total nitriding depth on various materials after salt-bath nitriding in TF1

alloy nitrides in a manner identical to conventional gas nitriding. With unalloyed steels, the diffusion layer structure is influenced by the rate of cooling after nitriding. If cooling is done slowly in the case of unalloyed steels some of the nitrogen could precipitate into iron nitride needles in the outer region of the diffusion layer. The nitrogen pickup is approximately twice as deep as the needle depth.

The nitride depths of various materials in relation to the treating time given in Fig. 8.7 are average values at a treating temperature of 580°C (bath containing 34 to 38% CNO).

8.5.3 FATIGUE STRENGTH

Tuffride components yield an improvement in the fatigue strength. During treatment, only nitrogen diffuses inwards from the carbonitride compound layer because the ferrite is in equilibrium concentration with respect to carbon. The nitrogen in deeper diffusion zone is present both as iron and alloy nitride needles and also as interstitial solid solution, which generates favourable surface compressive stresses. As a result of this an increased hardness and higher fatigue resistance are obtained. Figure 8.8 illustrates that an improvement of

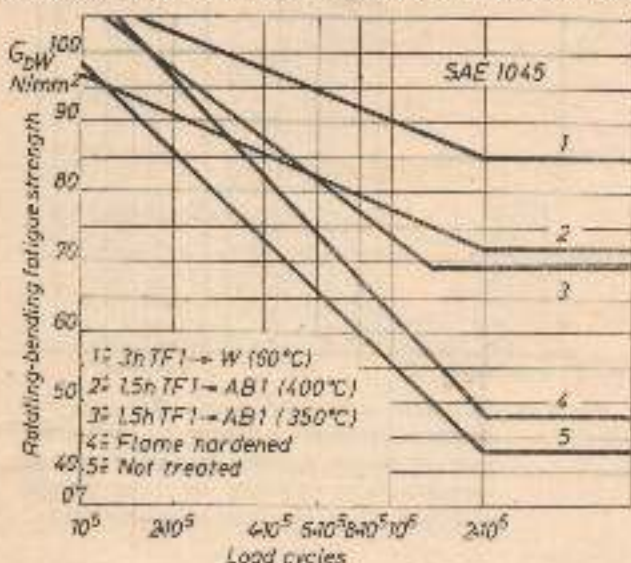


Fig. 8.8 Fatigue strength of crankshafts

55 to 60% can be achieved by quenching in AB1 salt bath and about 90% after quenching in water compared to the untreated crankshaft.

8.5.4 WEAR RESISTANCE

Tuffrided components yield outstanding improvement in wear resistance. This effect is mainly due to the presence of a ductile compound layer of 5 to 20 micron thickness. Figure 8.9 illustrates the higher wear resistance of the tuffrided component compared to the case hardened component.

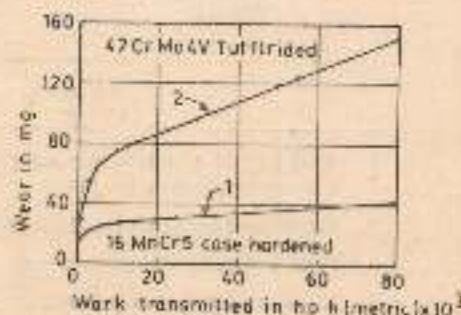


Fig. 8.9 Wear on case-hardened and tuffrided gears

The compound layer formed on the surface of the component possesses superior wear properties compared to the hard chromium plated layer.

8.5.5 CORROSION RESISTANCE

(i) The corrosion resistance of the steels and ferrous casting materials is remarkably increased by the structure of the compound layer formed on the surface of the material. The compound layer should be of adequate depth and as homogeneous as possible.

Components quenched in salt bath (AB1) possess improved corrosion properties compared to the conventional tufftride treatment. Figure 8.10 illustrates a salt spray test on 1015 (AISI) and 4140 (AISI) steel.

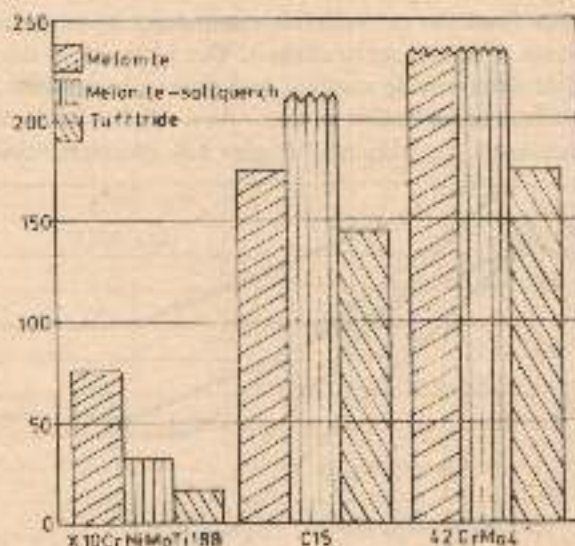


Fig. 8.10 Salt-water spray test shows the improved corrosion resistance achieved by melonizing with salt quench. A jagged line signifies that no corrosion occurred during the entire duration of the test, which was terminated after 220 h.

Table 8.2 Results of Extended Immersion Tests (to DIN 50905 part 4) on a Medium 3% NaCl, 0.1% (present) H_2O_2 , 0.45% C Steel with a Variety of Surface Finishes

Treatment	Weight loss g/m ² /24 h
1. 90 m TF1/10 m AB1/water quench/lap 20 m AB1/water quench (approximately 16 M)	0.3
2. Single hard chrome plate 12 μ m thick	7.1
3. Double chrome plate, 20 μ m soft, 25 μ m hard	7.2
4. Kanigen nickel coating 20 μ m	2.9
5. Triplex plate: 37 μ m copper, 45 μ m nickel, 1.3 μ m chromium	0.4

Table 8.3 Results of Extended Immersion Tests (to DIN 50905 part 4) on a 0.45% C Steel

Treatment	Weight loss g/m ² /24 h
1. 90 m TF1 at 580°C/water quench	12.3
2. 90 m TF1 at 580°C/10 m ABl at 350°C/water quench	0.5
3. 90 m TF1 at 580°C/20 m ABl at 400°C/water quench/lap	8.6
4. 90 m TF1 at 580°C/30 m ABl at 350°C/water quench/lap/20 m ABl at 400°C/water quench	0.3
5. 90 m competitive salt at 565°C/water quench	36.3
6. Untreated	39.3

TUFFTRIDE[®]
SAE 1015

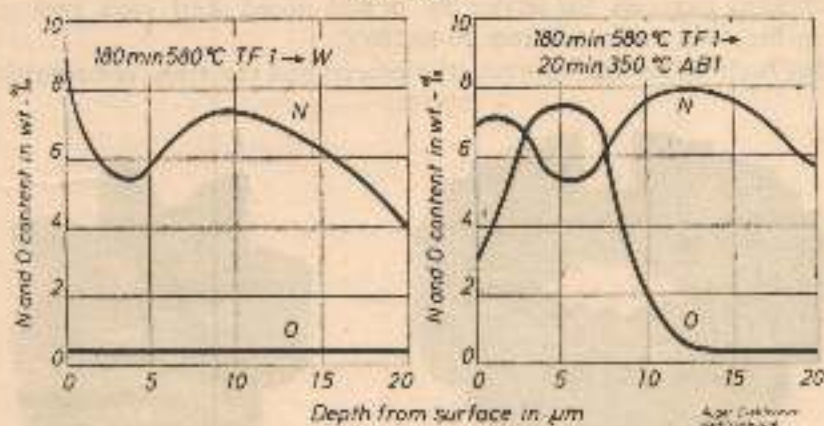


Fig. 8.11 N and O distribution curves in the compound layer

It can be seen from the Tables 8.2 and 8.3 that the components quenched in salt bath (ABl) maintained at 350°C shows the highest corrosion resistance compared to water quenching.

Components also possess higher corrosion resistance compared to hard chrome, nickel, etc. Areas may be examined for the possibility of replacing hard chrome plate by TF1/ABl both.

Superiority in corrosion resistance is due to the oxygen absorption of the compound zone when quenched in a salt bath. Figure 8.11 shows a typical trace for a 0.45% carbon steel given the optimum treatment. The major difference between this sample and a directly water quenched one is the high level of oxygen present in the outermost layers of the compound zone. This is over 6 times greater than that in a water quenched sample and extends well into the compound zone. It is believed that the oxygen dissolved in the lattice of the iron carbonitride and serves to make the layer passive, increasing corrosion resistance.

8.6 Advantages of Tufftriding

1. The case is not as hard as that which results from conventional gas nitriding, therefore drawing, rolling, rivetting etc. may be performed on tufftrided components.
2. Compared to gas nitriding the time required to produce the same case depth is much lesser.
3. Tufftriding yields outstanding improvements in wear and fatigue resistance compared to conventional surface hardening methods.
4. Replacement of plain carbon steel for more expensive alloy steels with consequent further appreciable saving. This together with the simplification of manufacturing procedures made possible by tufftriding due to absence of distortion helps to lower production cost considerably.
5. The process may be employed for unalloyed steels, alloy steels, tool steels, steel castings, grey cast iron, spheroidal cast iron, etc.
6. Tufftrided components make possible a remarkable improvement in corrosion resistance. This is frequently of great importance for precision components and pumps. In many cases plating can be avoided.
7. Tufftriding increases the service life of high speed steel tools, such as reamers, brouches, twist drills, etc. from 50 to 200%.
8. Other basic differences between this process and the more common nitriding and

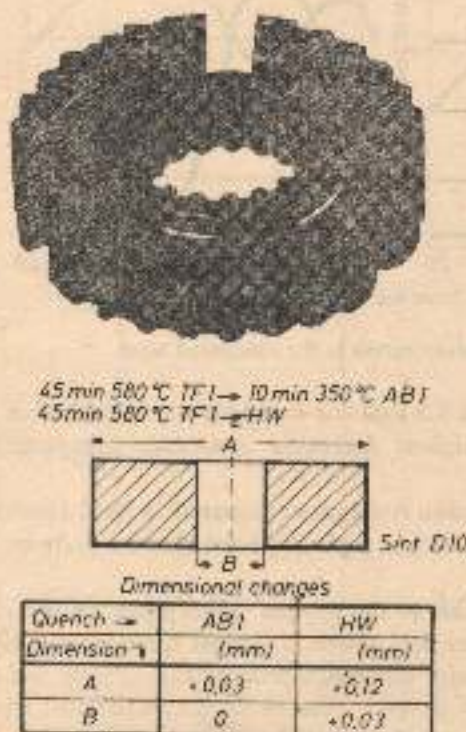


Fig. 8.12 (a) Dimensional changes in sliding sleeves (Courtesy: Degussa, W. Germany)

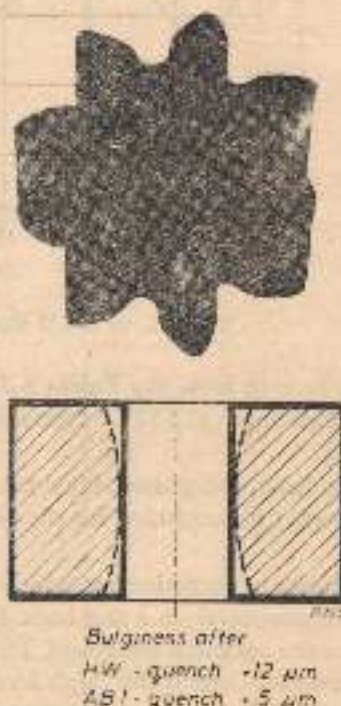


Fig. 8.12 (b) Change in dimensions in oil-pump gear

heat treating processes are the characteristic low temperatures and cycle time involved. This provides greater economy in processing and enables the automation of the process.

9. Dimensional changes caused by this treatment are negligible due to the low operating temperatures. Quenching in AB1 bath further reduces the distortion. Hence components treated by this method are within the tolerance limit and may be directly assembled (Fig. 8.12). This is an added advantage to many applications.
10. Considerable savings are effected because grinding operations are not required after treatment.
11. Avoidance of crack of sensitive components or tools is almost eliminated.
12. Additional surface treatment such as blue annealing etc., is eliminated due to the dark surface produced after quenching in oxidizing bath. This is an added advantage for decorative purposes (Fig. 8.13).



Fig. 8.13 Effect of quenching on colour of component

13. Disposal of cyanide is almost eliminated compared to the conventional salt bath cyaniding or cyanide process, since quenching in the AB1 oxidizing bath destroys the harmful substances and, also, complicated post treatment of the waste water is eliminated.
14. Tufftriding may also be applied to cast irons for the purpose of improving wear properties and in some cases for the purpose of achieving higher fatigue resistance.
15. When two form fitting surfaces move under power transmission fretting corrosion is bound to occur on both dry and lubricated running contact surfaces. This corrosion can have very many impairing effects. The compound layer of tufftride treated components helps prevent this corrosion.

8.7 Examples of Application

The tufftriding process may be employed for a wider range of applications, to reduce the

product cost considerably by introducing less expensive components to eliminate the costly electroplating. Apart from this, the wear resistance, corrosion resistance and fatigue strength may be increased to increase the life of the component. The different types of applications considering the above facts are as follows:

8.7.1 CRANKSHAFTS

Crankshafts for high working stresses are mostly made of chromium or chromium/molybdenum alloyed steels 37Cr4 or 42CrMo4 (SAE 4137 or 5120). In special cases crankshafts are made of chromium/nickel low carbon steel and carburized on the running surfaces, while the radii must be protected because of the need to preserve a certain straightenability of the crankshafts (Fig. 8.14).

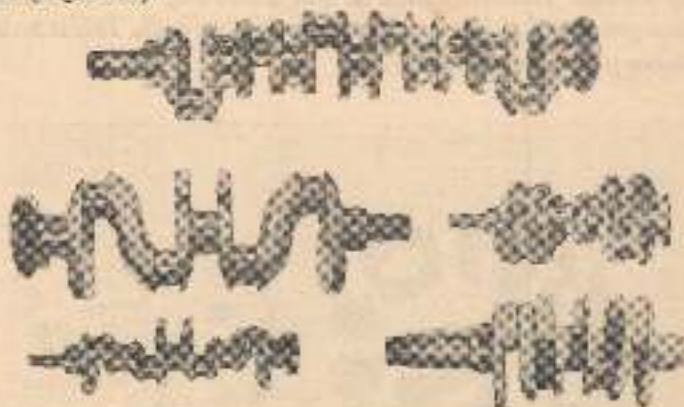


Fig. 8.14 Crankshafts (Courtesy: Degussa, W. Germany)

In a specific instance, a total saving of 4 per cent per crankshaft could be obtained by changing over from a chromium nickel alloy low carbon steel to a chromium alloyed medium carbon steel 37Cr4 (SAE 4137). A further saving of about 50% would be possible by the use of a plain medium carbon steel C45 (SAE 1045).

Finally, another cost reduction could be achieved by employing steel in the normalized condition, sparing the hardening and tempering operation. With a view to the fatigue strength, there would be no objection to such an alteration.

As is well known the essential factor for crankshafts is a substantially increased fatigue strength which enables the motor power to be raised without having to resort to a complete redesign.

8.7.2 CAMSHAFTS

Camshafts are usually carburized and hardened, or induction or flame hardened. Tuffride makes it possible to use a plain carbon steel in the normalized condition for the manufacture of camshafts with savings on the material cost. However, more essential is the feature that camshafts suffer no distortion by a tuffride treatment and, therefore, need not be straightened prior to mounting whereas straightening has always been necessary for induction hardened camshafts.

8.7.3 JOURNALS AND STEERING LEVERS

These components are tuffrided for the purpose of an increased fatigue life. At least ste-

ering levers might be manufactured from a plain material and in fact this is already done in many cases.

8.7.4 CYLINDER LINERS, CYLINDER BLOCKS AND CYLINDER HEADS

Cylinder liners for diesel engines are currently tuffride treated in order to prevent any seizure that may occur on cold starts or during the run-in period of an engine. Improved corrosion resistance is another advantage of tuffriding and particularly valuable for wet cylinder sleeves. Whole cylinder blocks for sport car engines have been tuffride treated resulting in an increase of the motor performance because of possible mounting with closer tolerances. Heavy-stressed cylinder heads of diesel engines are tuffride treated to eliminate the cracking of the bridges. In these instances the tuffride treatment means an additional expense, but this is justified in the light of the resultant technical improvement.

8.7.5 CONNECTING RODS

Tuffride treatment is also beneficial on connecting rods of big engines to prevent fretting corrosion between bearing shell and end holes. Also in this case the application of the tuffride process is not a question of reduced costs but of greater safety.

8.7.6 WATER-PUMP GEARS, LIDS AND SHAFTS

These parts are mainly tuffride treated for improved corrosion resistance. The tuffride treatment is substantially simpler and cheaper than a protective electro-plating and is quite sufficient. The impeller wheels are made of grey cast iron, while the shafts and lids are of plain steel carbon.

8.7.7 DIFFERENTIAL CASES OF HIGH SPEED SPORT CARS

Differential cases usually made of cast iron were subjected to high stresses after comparatively short running times (on test stand after app. 30000 km). The abrasion occurred in the area where the gears were in pressure contact with the case and amounted to 4 mm. Tuffride treatment of the differential cases was an answer to this problem, namely, that the machining grooves were still visible after the same running time.

8.7.8 DIFFERENTIAL CASE COVERS

This part is tuffride treated for better wear resistance.

8.7.9 ROCKER ARMS, ROCKER ARMSHAFTS AND ROCKER ARMLINKS

Tuffriding enabled the production cost of rocker arms to be substantially reduced, while the fatigue strength was greatly increased. In connection therewith, bearing shells usually made of expensive non-ferrous metals are no longer required since tuffride treated rocker arms do not seize on the rocker armshafts. Fatigue fractures which occasionally occurred on the transition area from the bearing to the rocker arm neck are also prevented by tuffriding. The surface of the rocker arm after tuffriding is induction hardened as usual. The tuffride treatment helps to reduce wear and tear on the rocker armshaft. The clearance of the bearings is thereby preserved for a longer time, which means that the bearings take that much longer to wear out. Good running properties in the case of deficient lubrication are ensured by tuffride on rocker arm shafts as well as on rocker arm links.

8.7.10 OIL PUMP AND INJECTION PUMP SPINDLES

These were so far mounted in either untreated or tempered condition. The benefits derived from a tuffride treatment consist in improved wear and running properties as well as in an increased corrosion resistance. If oil pump spindles had been carburized this may be replaced by tuffride treatment at a lower cost.

8.7.11 STARTER RINGS

Starter rings are subjected to a very severe wear and have usually been carburized. Very often subsequent grinding becomes necessary because of the distortion caused by the carburizing operation. The tuffride treatment which is a distortion-free treatment, not only helps lower the production cost, but also improves the wear properties substantially.

8.7.12 CARRIER WHEEL PINS

These pins were mostly hardened and tempered. To a considerable extent they are now tuffride treated for better wear and running properties.

8.7.13 VALVE STEM GUIDES

Here it is for good running properties that the tuffride treatment is used on these parts.

8.7.14 SLIDE VALVES AND TRANSMISSION GEAR SYNCHROMESHES

These parts were usually hardened and tempered, but are now tuffride treated in the normalized condition. Tuffride synchromeshes have a better wear resistance and the hardening and tempering costs are saved at the same time.

8.7.15 UNIVERSAL JOINTS

Universal joints formerly made of case hardening steel are now made of medium carbon steel and are tuffride treated. Good running properties are essential because lubrication is difficult.

8.7.16 DIFFERENTIAL CASE BEARING SHELLS

These parts often failed in service by galling or seizure because of inadequate lubrication. Phosphate coating, chromium plating or any other galvanizing method could not eliminate the seizure problem. Tuffriding, however, proved a quick and efficient remedy.

8.7.17 GEARS

So far only less stressed gears are tuffride treated, such as:

- Crankshaft gears
- Camshaft gears
- Injection gears
- Intermediate gears
- Oil pump gears
- Speedometer drive pinions
- Satellite gears

Up to this day most of these gears have been carburized and hardened. It was customary to use alloy steels because of the possibility of martempering to hold the distortion to a

minimum. The adoption of the tuffride treatment has made it possible to change over to the use of plain medium carbon steels, such as C22 and C35 (SAE 1022 or 1035) (Fig. 8.15). The gears prior to the tuffride treatment are only normalized. No hardening or tempering operation is carried out. As a result, the tuffride treatment has brought about a



Fig. 8.15 Steering gears of a V-8 diesel engine (Courtesy: Degussa, W. Germany)

reduction in the costs of material and also in the heat treatment operation. The distortion, it may be emphasized, is practically nil in all these cases.

So far only the differential satellite gears are tuffride treated in mass production. They are particularly heavystressed gears for trucks and the tuffride treatment is carried out in addition to case hardening. In this specific instance, the tuffride treatment constitutes an additional cost factor, but the increased expenses are justified by the fact that the gears do not seize even when overloaded, since the compound zone possesses good sliding properties and high resistance to wear. Tests have also been carried out on transmission and differential gears; the results have been so good that tuffride treatment has recently been approved for mass production of 3rd speed gears. In this case the savings are considerable, since it has been possible to replace the formerly used chromium/manganese alloy low carbon steel by a plain medium carbon steel C35 (SAE 1035) (normalized). In this case the tuffride treatment also results in a substantially lower treatment cost and an appreciable gain in production time.

Up to what extent it will be possible to apply the tuffride treatment to further the types of gears used in the automotive industry, remains a subject for further investigation.

8.7.18 TREATMENT OF TOOLS

Various types of tool steels can also be tuffrided to increase the service life of tools.

Tools of High Speed Steel One of the oldest fields of application for salt bath nitriding is the treatment of high speed steel machining tools (Fig. 8.17). In order to avoid brittleness of the cutting edge because of the high proportion of nitride-forming alloying elements in these steels, the nitriding times are kept short. These depend on the cutting edge shape

and are generally between 1 and 10 minutes at 570 or 580°C. The tool should be well pre-heated (up to 500°C) so that the holding time in the bath is not longer than the actual nitriding time.

After this treatment, such tools are often subjected to tempering, at temperatures between 350 to 540°C. Such tempering is intended to increase the toughness, particularly at the cutting edge. The tempering is carried out in salt baths or in steam tempering furnaces. Figure 8.17 shows a number of cutting tools after tuffride treatment.



Fig. 8.16 Steering gears



Fig. 8.17 Tuffride-treated HSS cutting tools

In order to achieve a better appearance of such parts, the tools can also be cooled at temperatures between 350 and 420°C in the AB1 bath. Such tools have a brownish to blackish appearance depending on the quality of the material and the surface qualities.

The nitriding effect achieved on such tools is most simply checked by testing the surface hardness with HV1. It was found that, after treatment in the TFI bath, about 100 to 150 HV surface hardnesses are achieved. Therefore the treatment times for such tools can also be reduced.

Treatment of Moulds for Thermoplastic Masses These tools are still case hardened in many instances but in the case of large and complicated moulds, the unavoidable distortion during case hardening is often too great. Injection moulds, either of alloyed case hardening steel (20MnCr5) or of pretempered alloyed steels (34Cr4, 42CrMo4), can be treated successfully with the tuffride process. Should high standards of dimensional stability be necessary, a stress-relief annealing can be carried out at about 620°C before the last machining operation. Such tools are then pre-heated up to 350°C and tuffride treated for 90 to 120 minutes.

Cold Working Tools Tools for the working of metal, such as drawing, bending and rolling, have also given extremely satisfactory service in the tuffride treated condition. Normally

during the stage of formation, the material slides or passes over the surface of the tool, causing wear and welding together. The high abrasion resistance and the good sliding properties of the compound layer not only reduce the wear but also eliminate adhesion to the tool and bonding of the material being drawn. Particularly good results can be obtained when soft materials such as aluminium, brass or austenitic sheets or tubes have to be processed.

Pressure-die Castings, Extrusion and Forging Dies (Fig. 8.18) Due to the great resistance of the compound layer at high temperatures, the lifetime of such tools is considerably improved. Even when, as a result of a long working life, layer has been removed by thermal



Fig. 8.18 Forging dies

decomposition or mechanical wear, the diffusion zone with a hardness of over 900 HV, still shows a noticeably better abrasion resistance than in the non-nitrided condition. Extrusion dies for example are removed after a certain service life, freed from adherent metallic residues, post machined and re-nitrided. Pressing plates can still be used even after ten-fold retreatment. The slight increase in volume caused by the absorption of nitrogen is advantageous during re-nitriding since it compensates for the profile loss due to wear.

The treatment time in the TFI tuffride bath is usually 2 hours for such tools. Here also the cooling in the new cooling bath at a higher temperature (approx. 330–400°C) has proved particularly advantageous.

The following list of applications of tuffride in the automotive industry is far from being complete. Many other parts are actually under test and it may be expected that in the course of time the tuffride treatment will be used for more and more mass produced parts.

Table 8.4

Industrial field	Components
Automobile industry	Crankshafts, universal joints, cylinderliners, camshafts, valves, rocker arms and shafts, spline shafts, cams, stub axles, tappets, distributor pinions, valve guides, oil pump plungers, tappet adapters, tachometer gears, timing gears, passenger seat slides, cylinder heads, change speed forks, connecting rods.
Hydraulic machine components	Valves, sleeves, crankshafts, pistons, pump bodies, bearings, gears and pinions, seals, distributor plates, universal joints, guides and guide rods, gear type pumps.

(Contd.)

Table 8.4 (Contd.)

Industrial field	Components
Machine tool components	Lead screws, bending machines, drilling spindles, lead screw nuts, clutch plates, indexing gears, boring bars, slideways, spline shafts, worm wheels and worms, spindle bearings, cams, racks, operating forks.
High speed steel tools	Drills, milling cutters, extrusion punches, taps, hobs, threading dies, reamers, broaches, cold forming punches, slitting saws.
Diecasting industry	Bolsters, ejector pins, plungers, moving cores, sleeves.
Forging and extrusion industry	Drop hammer slides, forging press slides, extrusion dies for aluminium alloys.
Textile industry	Spinning spindles, loom spindles, stenter clips, winding machine spindles, loom gears.
Domestic appliances	Sewing machine parts, lawn mower parts, typewriter parts, shirt ironer actuating racks, vacuum cleaner parts, cash register parts.
Railways	Hydraulic buffers, brake pins, valve guides for locomotives, dampers, bogie pins, valve spindles.
Miscellaneous	Glass and plastic moulds, stainless steel valve spindles, plastic moulding machine parts, plasticiser rolls for plastic extrusion, ships propeller retaining nuts, marine engine cylinder head nuts, stainless steel nuts and bolts, overhead conveyor rails.

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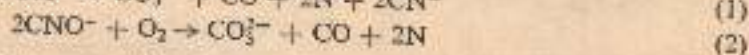
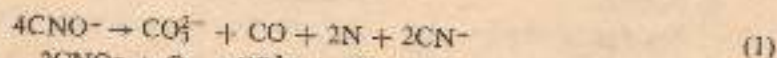
Sursulf

The conventional sulphur-bearing and sulphur-free baths based on cyanide compounds have been used for many years for nitrocarburizing. However, the toxicity of their sludges and effluents and the ever-increasing cost of toxification and disposal has led to the use of cyanide-free salts for nitrocarburizing. Sursulf is one such process which uses cyanide free salts for nitrocarburizing. It is a patent process developed by a French company (hydro-mecanique et Frottement).

Sursulf process is a low polluting nitriding salt bath treatment, accelerated by sulphur additions. It is operated at a temperature of $565 \pm 5^\circ\text{C}$ ($1050 \pm 10^\circ\text{F}$), in which nitrogen and carbon are liberated in the presence of steel surface. The nitrogen thus liberated along with carbon forms a compound layer on the surface of the component and beneath this layer it forms a deep diffusion zone of nitrides. The presence of sulphur in the bath produces sulphur compounds in the surface layers of the treated parts which have known lubricating properties and are especially useful where the environment makes the use of conventional lubricants ineffective or impracticable. The case thus formed provides an effective solution to problems of wear, fatigue, scuffing and corrosion encountered with ferrous components used in the engineering industry.^{1,2}

9.1 Mechanism of Sursulf Bath

The essential ingredients of sursulf bath are cyanates and carbonates of lithium, sodium and potassium along with small amounts of potassium sulphide (K_2S). In order to provide agitation and to stimulate chemical activity, dry air is introduced into the bath. The cyanate is the source for nitrogen and sulphide (K_2S) is the source for sulphur. Cyanate catalytically decomposes at the surface of the steel components being treated, to liberate carbon monoxide and nascent nitrogen. The carbon monoxide dissociates to liberate carbon which in conjunction with the nascent nitrogen diffuses into the material being treated to form the compound layer as follows.



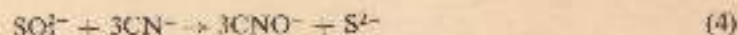
The sulphides in the bath react with the components being treated to form iron sulphide on the extreme outer surface layer of the treated component. The compound layer

thus formed improves the anticracking, seizure resistance and wear resistant properties of the surface of the components. The carbonates produced in the bath, instead of being allowed to build up as a wasteful product, are constantly converted into cyanate by the addition of a regenerator salt, designated as organic compounds belonging to the amides-amines group (designated as CR2).

Cyanide produced in the bath is partly oxidized into cyanate in the presence of atmospheric oxygen according to the following reaction,



The potassium sulphide added to the bath becomes partially oxidized as sulphite, sulphate and thiosulphate,



As a result of the above reaction (4) the cyanides are oxidized into cyanate, thus removing the cyanides in the bath to a very low figure of the order of 0.1% or even only 0.05% by weight.

The inclusion of lithium acts as a catalyst, accelerating the nitrocarburizing reaction. It stabilises the cyanate reducing the natural transformation to carbonate at the operating temperature. It also lowers the melting point of the bath (400–410°C), whilst sodium and potassium are added to maintain the fluidity of the bath.

Table 9.1 indicates the chemical composition of a standard sursulf bath.

Table 9.1 Chemical Composition of a Standard Sursulf Bath

CN^-	$\leq 0.8\%$
CNO_2^-	$36 \pm 2\%$
CO_3^{2-}	$19 \pm 2\%$
K^+	$24.5 \pm 2\%$
Na^+	$20 \pm 2\%$
Li^+	$1.25 \pm 0.2\%$
S^{2-}	2 to 10 PPM

9.2 Equipment for Sursulf Process

- | | |
|-------------------------------|--|
| 1. Degreasing Plant | To clean the components from grease, oil, scale oxides, etc. |
| 2. Preheating furnace | For preheating the components to 300–500°C before placing in the treatment bath. |
| 3. Pot | Pots used are made of mild steel or titanium lines. |
| 4. Furnaces | Heated by gas or electricity. |
| 5. Stainless steel pipe | To pass the compressed air to the bath with a flow meter to measure the air blown into the bath. |
| 6. Cold water tank | For quenching the components after treatment. |
| 7. Hot water tank | For washing the components. |
| 8. Suitable jigs and fixtures | For loading and unloading the components. |

9.3 Prior Treatment

Sursulf bath treatment must always be carried out after all machining operations have been completed. Complicated workpieces which are liable to deform must, under all circumstances, be stress relieved at or above 570°C before final machining operation. Alloyed steels are normally hardened and tempered before the final machining operation. Grey cast iron may be stress relieved after rough machining and before final machining operation.

9.4 Bath Preparation

Sursulf bath is prepared by melting commercially available salt (designated as CR4) alkaline cyanate and carbonate of lithium, sodium and potassium in a clean dry mild steel pot. The heat may be gas or electricity. After the requisite quantity of salt has been melted out, the bath temperature is raised to 570°C. Regenerator salt is then added and the bath is preferably aged for 2 days to allow the cyanates production necessary for the nitriding reaction to proceed. Potassium sulphide is added regularly in order to maintain a constant chemical composition of the bath and to control the metallurgical properties of the treated components. Addition of sulphur depends on the wear and scuffing properties required. For a higher wear resistance the bath should contain between 2 and 5 ppm of S²⁻ which allows a compact compound zone to be obtained. For higher scuffing properties the bath should contain between 20 and 30 ppm of active sulphur, which gives rise to a thicker compound zone. The cyanate maintained in the bath to carry out the process is normally in the range of 25-37%. Table 9.1 indicates the chemical composition of a standard bath for the process.

After the new bath has settled down, the cyanate content is maintained at a predetermined amount by a regular addition of regenerator salts. The composition of the bath is controlled through necessary chemical analysis carried out periodically. The dry compressed air is introduced into the bath at a controlled rate. This serves to maintain the uniformity of chemical composition by agitation, and to produce oxides of sulphur which are able to remove any traces of free cyanide developed in the bath.

9.5 Operating Conditions

Before placing the components in the bath they should be free from moisture, dirt, scales, etc. This is accomplished by vapour degreasing or possibly washing in an alkaline detergent. After this, the components are properly wired or placed in suitable fixtures or baskets so that the working faces of components are not touched. Physical contact of parts results in less efficient treatment and hence this should be avoided.

Before placing in the bath the components are preheated to about 450°C. This accomplishes two things. First, it ensures that the components are dry and therefore prevents a blow-out of molten salt. Secondly, it reduces the amount by which the temperature of the bath falls and when components are introduced reduces the thermal shock. This pre-heating is done in air, in a furnace heated by any convenient means.

After this the components are placed in a treating bath maintained at $570 \pm 5^\circ\text{C}$. Holding

time in the bath may vary between 5 minutes and 2 hours, depending on the type of components being treated and the properties required. Components are withdrawn from the bath after the requisite soaking time. They are then cooled in air, oil or water depending on the type of material (Fig. 9.1).

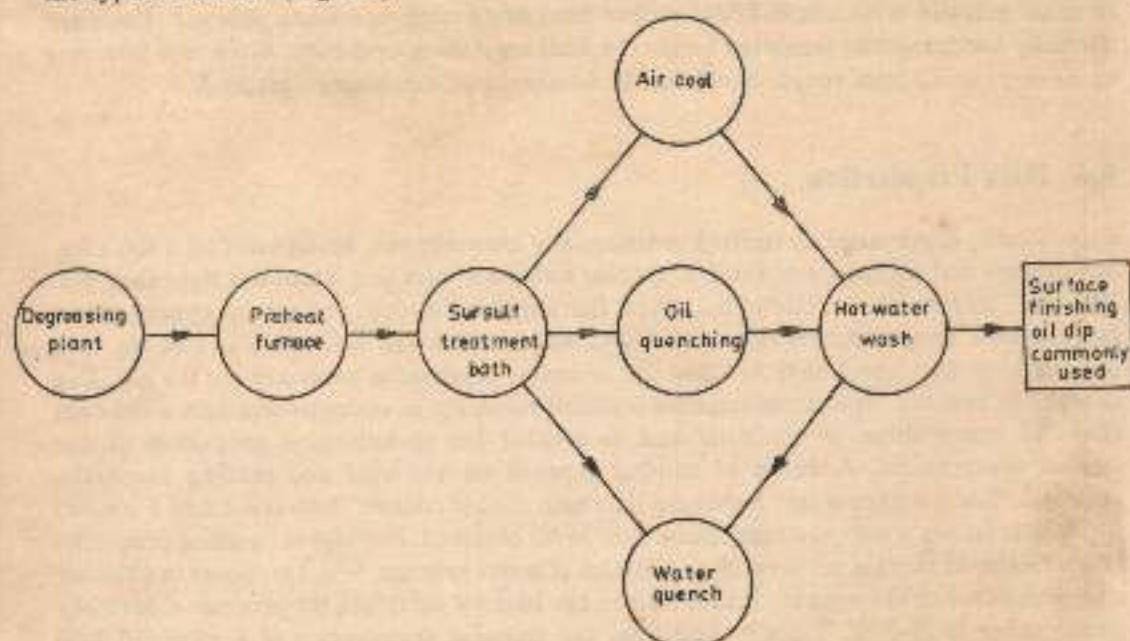


Fig. 9.1 Treatment Sequence—sursulf process

Components made out of unalloyed steels, which are treated only for improvement in fatigue strength, are to be quenched in cold water so that nitrogen is held in the solid solution. To avoid distortion, complicated and thin components may be cooled in air to 400°C and then quenched.

Components made out of alloyed steels and tool steels may be air cooled. Silvery finish is obtained after washing in hot water. Although treated surfaces have a natural resistance to corrosion, further protection during storage is given by dipping in one of the various rust-inhibiting mediums such as water-repellent oil.

9.6 Properties of the Treated Components

The surface of the sursulf treated component consists of two different zones: the compound zone on the surface and the diffusion zone beneath this layer. The monophase compound layer consists of epsilon nitrides only, having a thickness of 10 to 20 microns and possessing good tribological properties. The formation of compound zone depends on the carbon and alloy content of the substrate. The more compact the compound zone, the higher will be the hardness and the less the thickness. Depending on the active sulphur in the bath it is possible to obtain surface layers having different microstructures. This means that baths can be adapted individually to produce good resistance to scuffing and fatigue or to give a good wear resistance as well as a good fatigue resistance.

The presence of active sulphur stabilizes the epsilon (ϵ) phase, this effect being more marked when the substrate contains additional elements such as nickel, molybdenum, chromium, etc. Apart from this a very high concentration of nitrogen in both compound zone and substrate after only short treatment times.

Figure 9.2 illustrates the comparison of the average concentration in the surface layers of 0.38% carbon steel, steel samples treated in sursulf baths with and without sulphur, that the presence of sulphur in the bath accelerates the kinetics of formation of the epsilon phase for a given operating temperature.²

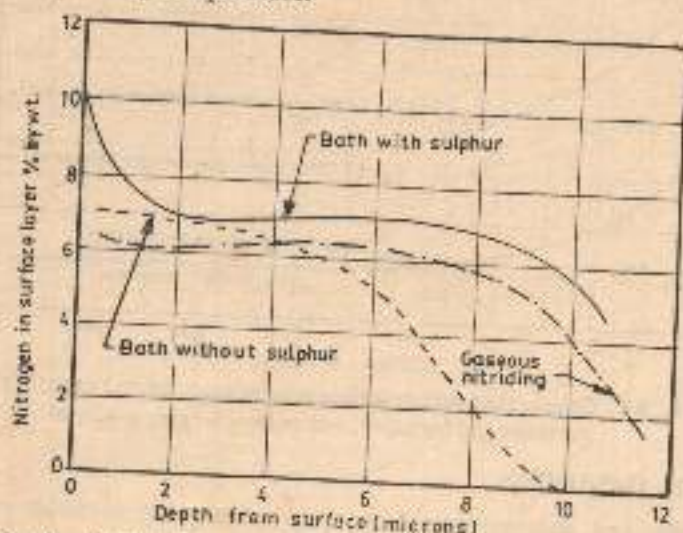


Fig. 9.2 Relation between nitrogen concentration and depth below surface in the compound zone of a 0.38% C steel treated in the bath with and without sulphur

9.6.1 WEAR RESISTANCE

Wear resistance of treated components will be increased when the compound layers obtained are compact, that is, free from porosity. The compound layer consisting of epsilon nitrides only, and having at the extreme surface a very shallow zone containing sulphur compounds confers simultaneously effective resistance to two forms of wear. Thus treated parts resist adhesive wear because the phenomena of scuffing and 'picking up' are suppressed and they also resist abrasive wear better because there is a reduction of the loss of particles from the surface as compared with the amount lost from bi-phased compound layers containing both epsilon (ϵ) and gamma dash (γ') nitrides.

The higher wear resistance can be obtained only when the sulphur content in the bath is maintained at 1 to 5 ppm (S^{2-}).

9.6.2 FATIGUE RESISTANCE

Sursulf treated components possess an improvement in fatigue strength, since the high nitriding potential of the bath ensures a greater depth of diffusion zone compared to cyanide content baths. The depth of the diffusion zone depends on the presence of alloy contents. It reduces as the alloy content increases.¹ The improvement in fatigue strength depends on the depth/hardness gradient of the diffusion zone. The improvement in fatigue

strength are due to nitrogen being held in solid solution, an effect that produces strain on the ferritic lattice structure. This strain increases both the hardness and the fatigue strength of the material.

Figure 9.3 illustrates the improvement in surface fatigue resistance of a one per cent chromium alloy steel and a flake graphite pearlite cast iron.

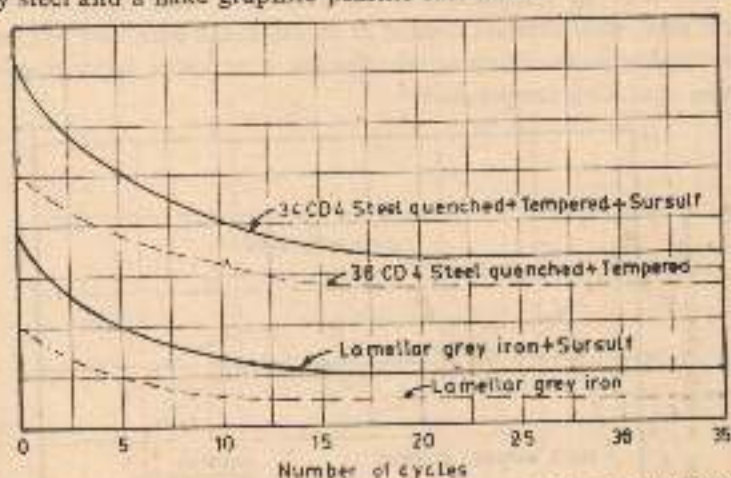


Fig. 9.3 Comparative surface fatigue tests on steel—35CD4 (AISI4137), quenched and tempered, and on lamellar grey cast iron¹

9.6.3 SURFACE HARDNESS

The hardness obtained depends on the presence of alloying elements in the component.

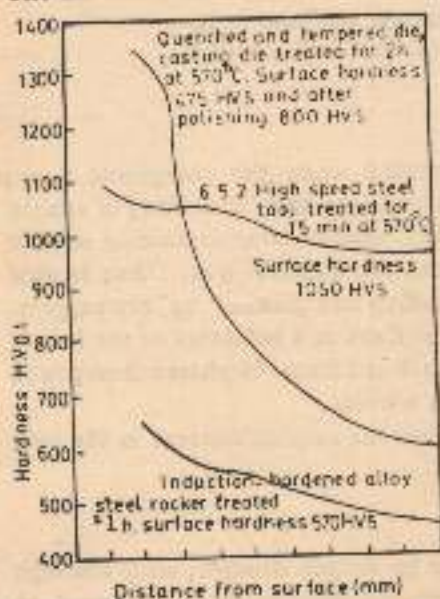


Fig. 9.4 Depth-hardness curves for three sursulf-treated materials¹

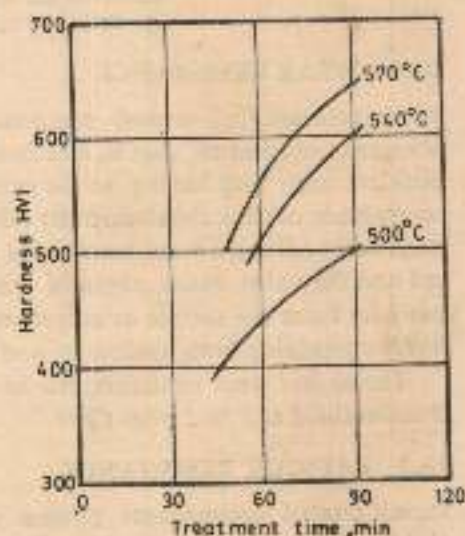


Fig. 9.5 Hardness of sursulf-treated alloy steel just beneath compound layer, as a function of time and temperature¹

The higher the carbon and alloy contents, the higher will be the surface hardness obtained. On the contrary, the total depth of the nitrided zone is reduced as the alloy content is increased (Fig. 9.4). The hardness obtained also depends on the core hardness and the temperature adopted. The best results may be obtained when the temperature is $570 \pm 5^\circ\text{C}$ and it should not be below 550°C , as this will result in lower hardness (Fig. 9.5).

9.6.4 SCUFFING (SEIZURE) RESISTANCE

The presence of a slight amount of porosity at the surface of the compound layer resulting from treatment increases the scoring and seizure resistance properties. It increases the load carrying capacity of the lubricant by raising the limiting load beyond which, during running, there is a change in the lubrication film or even complete breakdown of the oil film.

The sulphur compounds present in the superficial porous zone of the surface layer act as inhibitors of welding, thus facilitating running-in, adhesion of the lubricant to the surface, delaying the limiting conditions beyond which modification of lubricant occurs.

To achieve this the bath should have sulphur in the higher range of about $\text{S}^{2-} = 100$ ppm.

9.6.5 RESISTANCE TO CORROSION

In the case of components treated in a low sulphur bath and subsequently surface finished by micropolishing, it is possible to obtain microlayers having a good compactness which

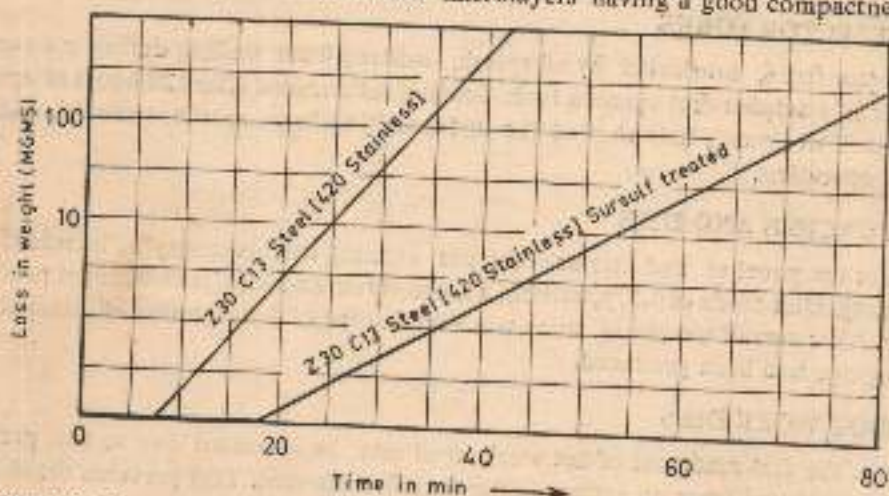


Fig. 9.6 Comparative tests of the resistance to cavitation erosion of a 13% chromium steel before and after sursulf treatment

exhibits excellent corrosion resistance. The compound layer thus formed also contributes towards a considerable improvement in the resistance of certain components to cavitation-erosion (Fig. 9.6).

9.7 Advantages

1. Sursulf treated components possess high wear and fatigue strength resistance. In addition, sursulf simultaneously improves their resistance to scuffing and seizure.

2. Since the process is carried out at a low temperature, the dimensional changes are negligible.
3. The process is non-toxic, therefore there is no disposal problem.
4. Sursulf treated components show greater resistance to corrosion and cavitation-erosion.
5. All types of ferrous materials can be treated.
6. The pots used to contain molten salts need not be titanium; even a mild steel pot can be used. This will bring down the initial investment.

9.8 Examples of Application

9.8.1 GEARS

Since the compound layer has a good wear resistance, it may be applied for gears of various types such as:

- (i) Distributor gears
- (ii) Transmission gears
- (iii) Reduction gears
- (iv) Gear box and engine gears

9.8.2 SELECTOR FORKS

Steel selector forks, lubricated by oil splash, suffered from scuffing during use even after treatment in a sulphur-free cyanide bath. Scuffing commenced after 120 hours of operation. After sursulf treatment, tests showed the surface still to be in excellent condition after 850 hours of operation.

9.8.3 PUNCHES AND DIES

The life of the punches and dies used for hot forming machines may be increased by sursulf treating. Dies made of 0.35% carbon, 1% chromium and 0.3% molybdenum produce 500 forgings. After sursulf treatment, there was no evidence of deterioration of either tool until 2000 forgings had been produced.

9.8.4 HOT WORK DIES

The life of the dies made out of hot work steel may be increased due to the presence of compact compound layer on surface after sursulf treatment. This prevents the sticking or welding of hot material to the surface.

9.8.5 S.G. IRON

Component parts made from pearlitic S.G. iron were subjected, in use, to a load of 12 daN/mm², a sliding speed of 0.04 m/s, and were immersed in oil containing 3% sea water. In the untreated condition, seizure occurred and the parts were worn to a depth of 2 mm after only 3000 operations. After sursulf treatment, the parts withstood 240,000 operations and merely became polished, the wear being limited to about 5 microns.

9.8.6 S.G. IRON WORM

The worm was made from case-hardened steel, its mating wheel from pearlitic S.G.

iron, and lubrication was by Mobil reduction gear oil no. 629. The speed of rotation was 450 r.p.m. and the torque 30 Nm. When using the cast iron worm wheel in the untreated condition, seizure took place after only a few hours of use. After treatment, the combination of case-hardened steel work against treated cast iron wheel functioned satisfactorily for 2000 hours before the treated layer was worn away.

9.8.7 PREVENTION OF SCUFFING OF HYDRAULIC PUMP DISTRIBUTOR PLATES

The plates were of quenched and tempered steel and in use were running against bronze in hydraulic oil. The load varied between 0 and 45 N/mm², the speed of rotation was 1500 r.p.m. and the surface finish of the plates 0.05 microns C.L.A. It was found that when using untreated or even hard chrome-plated plates with a super-finished surface, scuffing occurred after 20 hours working, whereas sursulf treatment of the plates maintained both plates and bronze followers in good condition for 200 hours.

Annexure I

Area of application	Typical examples		
Automobile components	Crankshafts Camshafts Splice shafts Stub axles	Differentials Universal joints Valves Cams	Cylinder liners Rockers Tappets Distributor pinions
Hydraulic components	Valves Needle Valves Pistons Seals Gudgeon Pump bodies Connecting rods	Sleeves Bearings Distributor plates Distributor discs Guides Guide rods Crank shafts	Regulator arms Universal arms Adjusting screws Pinions Gears Operating screws
Machine tool components	Pinions Worm and worm wheels Lead screws Splined shafts Threaded bushes Bearings Spindle bearings	Tool holders Slides Housings Guide rods Guides Racks Operating forks	Sleeves Pivots Bushes Cams Pivot pins Cutters Saw blades
Mining industry components	Guides Slides Adjustment wedges Screw stops Distributor slides Control screws Brake components	Control rods Universal joints Chain links Chain pin bushes Chain pinions Jack screws Pulleys	Pump con-rods Pistons Valves Hydraulic pistons Drill parts Punches Pressure testing bolts

(Contd.)

Annexure 1 (Contd.)

Area of application	Typical examples		
Miscellaneous components	Textile winding	Thrust bearings	Glass and plastic moulds
	machine parts		
	Loom parts	Axles	Injectors and ejectors of plastic moulding machines
	Loom gears	Toothed quadrants	
	Flying shear rockers	Brake parts	
	Turbine shafts	Punches and dies	

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4. *Journal du Frottement Industriel*, 8th July 1980, p. 7.

Sulfinuzing

The sulfinuzing process is employed primarily to introduce sulphur into the surface of a treated component. The components to be treated are held in a specially prepared cyanide bath. Sodium sulphide (Na_2S) is an additional constituent in the bath and the bath is maintained usually at 570°C . The combination of the cyanide bath with sulphides provides not only a means of carrying the sulphur to the surface of the steel but also produces a case rich in carbon and nitrogen. Immersion time in the bath varies from 5 minutes to 3 hours depending on the chemical composition of the steel. This process produces a compound layer about 10 to 15 microns thick in which the iron has been converted into iron nitrides together with some iron carbides and sulphides, the latter being the infilling element in the slightly porous surface.

It is being accepted that these pores, which readily absorb oil, assist the anti-scuffing properties of sulfinuz treated components under lubricated conditions.

The compound layer thus formed has good antiscuffing and wear properties.

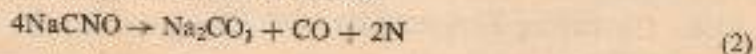
10.1 Mechanism of Sulfinuzing

The sulfinuzing bath consists basically of sodium cyanide, chloride, carbonate and sulphite when first made up. But atmospheric oxidation of the cyanide when melted at 570°C , and reduction of the sulphite by the cyanide, result in a working bath of cyanide consisting of chlorides, cyanate, carbonate and sulphides.¹⁻³

The chemical reactions in the bath are as follows:

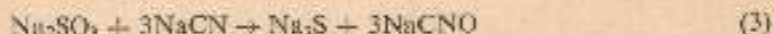


Sodium cyanate thus formed catalytically decomposes at the surface of the component to liberate carbon monoxide and nascent nitrogen as follows:



The carbon monoxide formed subsequently dissociates to liberate active carbon which in conjunction with nascent nitrogen diffuses into the material being treated to form the compound layer.

The sulphur present originally in sodium sulphite reacts with the sodium cyanide to form sodium sulphide and sodium cyanate as follows:



The sodium sulphide then reacts with the iron to form iron sulphide,



10.2 Pre-Treatment

The components after rough machining should be stress relieved before the sulfinox treatment. Especially complicated work pieces which are liable to deform must under all circumstances be stress relieved at or above 570°C.

Components should be free from decarburization, dirt, grease, etc.

Usually the components are preheated to a temperature of 350 to 400°C to avoid damage by heat shock and also to prevent the temperature from dropping unduly in the bath. After the through heating, components are placed in the sulfinox bath. The composition of the bath should be continuously checked.

10.3 Operation of the Bath

The bath is prepared by melting a commercially available salt mixture in a mild steel pot. The heating may be by gas or by electricity. After the requisite quantity of suitable salts have been melted, the bath is maintained at 570°C \pm 10°C for a certain length of time, say more than 12 hours. The bath consists basically of alkali metal cyanide, chloride, carbonate and sulphite when first made up, but atmospheric oxidation of the cyanide when aged at 550 to 600°C, and reduction of the sulphite by the cyanide, result in a working bath of cyanide, chloride, carbonate, cyanate and sulphide. One composition of a sulfinox chemical composition bath may be for instance:

Cyanide as NaCN	9.4%
Cyanate NaCNO	11.7%
Active sulphur (i.e., present as Na ₂ S)	0.18%
Chloride and carbonate	Remainder

It is necessary that the bath should be aerated to ensure uniformity of the composition and hence uniform efficiency of treatment of parts when placed in any position in the bath.

Finally the bath should be covered using the proper material so that excessive oxidation on the surface is prevented and radiation is minimized.

10.4 Operating Temperature and Time

After the sulfinox melt is prepared in a mild steel pot, the operating temperature is maintained between 540 and 600°C depending on the type of steel used. For austenite stainless steels and the nimonic series of alloys the operating temperature is generally about 600°C. For tool steels, alloy steels etc., the operating temperature employed is 540°C \pm 5°C.

High speed cutting tools are normally treated only for about 5 to 15 minutes to avoid

the brittleness. Cast iron and alloy steel are treated for 1 to 3 hours at $570^{\circ} \pm 10^{\circ}\text{C}$.

In general the penetration of sulphur into the surface under optimum conditions is a function of treatment time.

10.5 Quenching and Washing

Components after treatment are quenched in air or oil or water depending on the type of steel and the properties required. For example to increase the fatigue resistance, unalloyed steels should be water quenched, whereas tool steels are air cooled or oil quenched.

After cooling, all parts should be washed in water at 80 to 90°C and subsequently subjected to brief pickling treatment to remove any iron sulphide deposit still remaining on this surface.

10.6 Dimensional Changes

Generally no dimensional changes occur when the sulphur level in the bath is low. A medium level of sulphur results in a dimensional loss in the order of 0.0001 inches and with a high sulphur level in the bath, a noticeable surface loss occurs. Also, dimensional changes may take place if the components are not stress relieved after heavy machining operations. This is because of the release of machining stresses during the treatment.

10.7 Advantages

Sulfinizing, which gives a deep, porous layer without a superficial hardness, is recommended to resist friction, and has the following advantages:

1. Economy in choice of steel and cast iron.
2. Eliminates case hardening or nitriding in certain cases.
3. Less wear on rubbing surfaces.
4. Lower cost.
5. The surface accepts and retains lubricants excellently and resists seizure even when dry.

10.8 Disadvantages

1. Disposal of cyanide waste
2. Toxic nature of the salt
3. Salts should be stored in a separate room.

10.9 Materials Suitable for Sulfinizing

All ferrous materials are suitable for treatment, besides special alloys such as the nimonic

series, and monel metal. Titanium and titanium alloys can also be treated. While considering the suitability of the components for treatment the effect of the temperature of operation on the core hardness of the parts should be borne in mind.

The parts that are regularly sulfinox treated are as follows:

10.9.1 MILD STEEL AND LOW-ALLOY STEELS

Large and small parts, including large retaining nuts for ship's propellers and cylinder head nuts for marine engines, as well as flexible couplings and coupling claws, are treated to prevent scuffing or wear. Clutch plates are found to give better anti-scuffing properties when treated mild steel plates rather than alternate mild steel and bronze plates are used. Stentor pins and clips are used in textile industry.

Tecometer gears, diesel engine pumps, plungers, rotors, etc. are sulfinoxized to prevent scuffing.

10.9.2 CAST IRON PARTS

Treatment of automobile tappets in chilled iron has eliminated the problem of fatigue flitting, and a considerable improvement has been obtained on treated-glass bottle-making machine parts, bitumen pump and shaving machine parts, cylinder liner parts, etc.

The process can also be applied for high speed steel tools as well as out forming punches, bearing rings, etc. Apart from the above type of materials, this process may be applied to hot-work steels, stainless steels and heat resisting steels.

Parts which have previously been ammonia nitrided and ground can, with advantage, be subsequently sulfinox treated and where parts in certain areas require plating after treatment this can be done if the surface is carefully prepared.

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Carburizing

Carburizing is a heat treatment process to increase the surface hardness and wear resistance of components which are required to possess a fairly good impact strength and resistance to wear in service. Carburizing is most widely used as a surface hardening process in general engineering and has been practised for many years. In fact, as early as the ninth century, the Benedictine monk, Theophilus Presbyter, gave a precise method for hardening metallic files. A mixture of three parts of horn meal and one part of salt was used on the surface of a heated file which was subsequently reheated and water quenched.¹

Carburizing increases the surface carbon content of a low carbon steel (0.1–0.2% C) by 0.7–1% in a carbon medium. This medium can be solid (charcoal), molten salt (cyanide), a gaseous or plasma medium. At low temperatures carbon will not diffuse into steel. Both the steel and carburizing material must be heated during carburizing to an elevated temperature. In practice, carburizing is done at temperatures between 900 and 950°C. The components, after carburizing, are usually directly quenched or cooled, reheated, and then quenched in oil or in a warm bath, depending on the alloy content of the steel, to get the martensitic water structure. The hardness obtained after carburizing depends on the type of steel used. The hardness value obtained by carburizing usually ranges from 700–900 VHN.

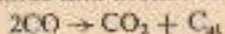
In general, case hardening by carburizing results in a high wear resistant case. However, the best results are obtained when the case consists of a crystalline martensite having small amounts of cementite. In addition to increasing the hardness and wear resistance of steel, carburizing, followed by hardening and tempering increases the resistance to alternating loads. This is due to the appearance of compressive residual stresses in the carburized layer. The residual stresses greatly increase the fatigue strength of case-hardened parts. Typical components that are subjected to this treatment are gears, spindles, shafts, cams, ratchet wheels, levers, steering parts, distribution gears, etc.

Recent developments in carburizing include vacuum carburizing^{2,3} and plasma carburizing.^{4,5} The use of nitrogen as a carrier gas, instead of an endothermic gas, is another notable recent development^{6,7}. It is claimed that the vacuum and plasma carburizing processes impart better mechanical properties and higher hardness to components than conventional carburizing. Another very recent development in carburizing is fluidized bed furnace.^{8,9} This process is claimed to provide a much faster rate of carburizing compared with the conventional carburizing process.

11.1 Theory of Carburizing

Carburizing is usually done at an elevated temperature with a chemical agent such as solid or molten salt, gaseous medium, etc., which can supply an adequate quantity of atomic carbon for absorption and diffusion into the steel. This is achieved by heating both the component and the carburizing medium to a pre-determined temperature, usually in the range of 900–950°C. The diffusion of carbon on to the surface layer of steel takes place in its atomic state.

During carburizing, three important changes take place. First, the atomic carbon is liberated from the carbonaceous medium. This takes place due to the decomposition of carbon monoxide into carbon dioxide and atomic carbon as given below:



Secondly, the carbon atom from the carburizing agent is transferred to the surface of the steel. Thirdly, the carbon so absorbed by the surface of steel is diffused deep into it.

The steel changes its structure from a body-centred cubic lattice (ferrite) to a face-centred cubic lattice (austenite) at about 720°C. Austenite is capable of dissolving carbon. The longer the time or the higher the temperature, the deeper is the carbon diffusion. At a temperature of 720°C the diffusion of carbon in ferrite (Alpha iron) will be 0.02% and in austenite (gamma iron) it is about 0.8%. With a further rise in temperature to 1130°C, the solubility of carbon will be 2%.

In practice, steel is carburized at 900–950°C, and it is held for several hours to diffuse the carbon into steel. The carbon concentration on the surface layer does not exceed 0.8 to 1%. The carburized steel consists of three structural zones: (i) Hypereutectoid zone, (ii) Eutectoid zone, and (iii) Hypoeutectoid zone.

11.2 Carbon Potential

Carbon potential may be defined as that carbon content acquired by a carburized compo-

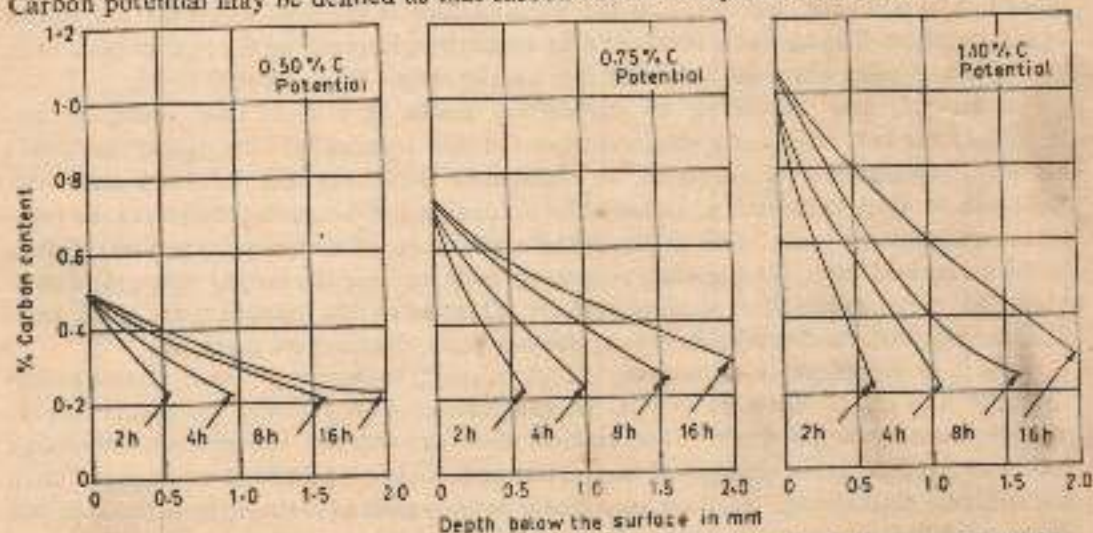


Fig. 11.1 Carbon profile of carburized case (1022 steel) v. carbon potential and duration of carburization of a plain carbon steel carburized at 920°C¹⁰

ment when potential equilibrium conditions have been reached between the steel and the carburizing medium. Thus, for example, if a carburizing agent has a carbon potential of 1% at a given temperature, an unalloyed steel component with less than 1% carbon will be carburized up to 1%, whereas an alloyed steel with a higher carbon content of more than 1% carbon will be decarburized to 1% carbon. The higher the carbon potential, the higher the carbon concentration at the surface of the steel and the deeper is the case when equilibrium has been established.

The desired carbon potential for carburizing is maintained in the range between 0.8 and 1% carbon depending on the type of steel. Typical influence of the carburizing time and carbon potential on the depth of carburizing is shown in Fig. 11.1.¹⁰ It can be seen, therefore, that the percentage of carbon on the case is directly proportional to the carbon potential of the carburizing media.

11.3 Case Depth

The depth of the carburized layer depends on the carburizing temperature, and time. The higher the temperature, the greater is the diffusion rate of carbon atoms in the austenite lattice. The carbon content in the carburized layer decreases gradually from the surface to the core (Fig. 11.2). It is usually higher at the surface (0.8 to 1%), and decreases towards the core. The depth at which the original carbon content of the material (usually less than 0.2% carbon) is reached is called the total case depth. Hence the total case depth is more than the effective case depth. For purposes of definition the effective case depth produced by case hardening is defined as that distance in millimetres from the surface where the hardness specified in Rockwell C is lower by 15% than the hardness specified for the surface.

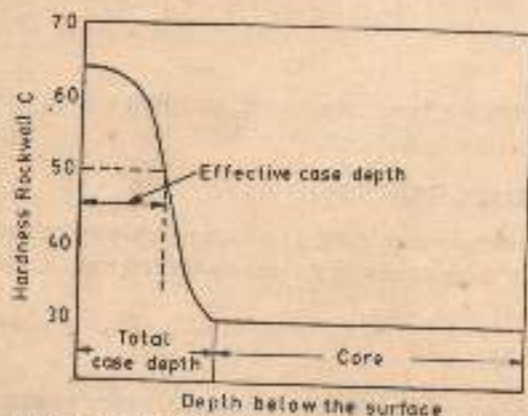


Fig. 11.2 Typical hardness pattern in a carburized part.

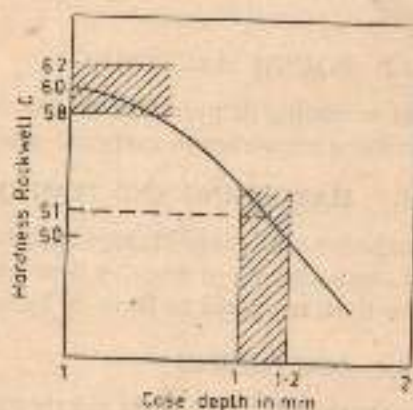


Fig. 11.3 Illustrates how tolerances for surface hardness and case depth are specified in practice.

of the part. For example, if the specified surface hardness is Rockwell C 60 plus or minus 2 and the case depth is 1 to 1.2 mm, then the hardness value should be $60 - 0.15 \times 60 = 51$ HRC at a distance of 1 to 1.2 mm as given by the distribution curve (Fig. 11.3).

The difference between the effective case depth and the total case depth is shown in

Fig. 11.2. Since both these specifications require considerable time and skill to check, more simple methods of estimating the case depth have been developed for shop use. They are: fracturing a notched test bar and measuring the 'Case' as it appears on the low-power microscope. Such methods are suitable for control purposes provided they have been standardised and calibrated by metallographic examination.

11.4 Pre-Process Requirements

The only finishing operation possible after carburizing and hardening is grinding or lapping, since the surface will be too hard to machine. So, all components to be carburized should be machined to the size, leaving sufficient allowance for grinding or lapping.

It is recommended that the following sequence of operations may be adopted for the majority of case-hardening steels.

11.4.1 NORMALISING OR ANNEALING

In the as-rolled or as-forged condition, the structure of steel may vary considerably depending on the finishing temperature and the rate of cooling. If the steel is used in this condition, there will be no consistency either in machinability or in the behaviour of hardening.

In order to get a refined grain structure and a satisfactory condition of machinability, it is necessary that the components are normalized or annealed isothermally, depending upon the type of steel.

Normalizing is done by heating the component to 880-910°C and holding at that temperature for about 1 hour, and subsequently cooling it in air. For highly alloyed steels, it is necessary that they are annealed isothermally. This is done by heating the steel to a temperature of about 850°C and cooling it rapidly to 650°C, and holding it at this temperature until the transformation is complete. Thereafter the components can be air-cooled.

11.4.2 ROUGH MACHINING

After annealing or normalizing the components are rough machined, keeping a sufficient machining allowance to carry out other machining operations.

11.4.3 HARDENING AND TEMPERING (TOUGHENING)

To improve machinability, especially in the case of deep drilling, broaching, key-way milling and tooth-shaving of gears, it is necessary that these components are hardened and, at the same time, tempered to 70 to 80 kg/mm².

11.4.4 MACHINING

The toughened components are then machined after providing sufficient allowance to carry out further operations.

11.4.5 STRESS RELIEVING

If freedom from distortion is of paramount importance, the internal stresses that are produced by machining should be removed before carburizing. This is done by heating the components to 550-600°C, soaking them for 2 to 3 hours in that temperature and subsequently cooling them in air.

11.4.6 MACHINING ALLOWANCE BEFORE CARBURIZING

Before carburizing the component, it should be machined to the nearest final dimension keeping only the necessary grinding allowance, as otherwise the most effective case depth will be ground off after carburizing. A certain amount of additional allowance is also necessary to allow for dimensional changes that occur during the carburizing and hardening process itself. The quantum of this dimensional change depends on the method of machining before carburizing, the quenching method, the amount of case depth, the size of the section and also the grade of steel.

Providing a greater allowance to compensate for distortion due to carburizing is not advisable, as this would require a bigger case depth to be obtained by carburizing, and hence would result in heavy grinding to attain the final size. Grinding of the case should be kept to a minimum because of the high cost of both producing the case and grinding it off. There is also the serious danger of damaging the case by grinding burns or cracks, besides losing the case that has the best resistance to wear. Grinding also reduces the compressive stresses in the case, by the removal of the stressed layer and also by thermal stresses incidental to localized heating.

11.4.7 SELECTIVE CARBURIZING

For various reasons it may be necessary to perform machining operations like broaching, drilling, thread cutting, etc., after case hardening or hardening.

Such areas of the components to be protected from carburizing may be carried out by some of the methods outlined below:

Positive Allowance In this method, an extra material allowance to the extent of 2-3 times the desired case depth is provided. The general practice is to keep an allowance of at least 3 mm at those places where no case hardening is required. After carburizing, the parts are subjected to isothermal annealing below the sub-critical temperature at 650-670°C. Sometimes, cooling the parts in the retort itself, up to 500°C, will lead to annealing. The extra material allowance can now be machined off before the parts are subjected to hardening. The parts can be hardened after machining by any of the hardening methods described.

Partial carburizing can also be accomplished by carburizing and hardening the part completely, then reheating and cooling slowly the areas that are to be soft. Or, the parts can be carburized and slow-cooled from the carburizing temperature, and then reheated and rapidly cooled in areas where hardness is required. In either case, reheating can be done by a flame or an induction coil.

Copper Plating Electrolytic copper plating is employed to protect the surfaces from case-hardening. The plating should be non-porous and the plating thickness should be around 0.04 mm for 1 mm carburizing case depths and 0.07 mm for case depths of more than 1 mm.

It is important that the parts are carefully cleaned before copper plating. An alkaline bath or an acid wetting will give better results.

Pores in the copper deposit may be detected by means of a reagent consisting of 10 parts $K_4Fe(CN)_6$ plus 10 parts NaCl plus 20 parts gelatine dissolved in distilled water. A filter paper is moistened with the solution and placed in the copper deposit. If there are

any pores in the copper deposit blue spots will appear on the paper in 5 minutes.

Protective Paste The surface to be protected from carburizing can also be coated with a protective paste. These are proprietary items. However, protective pastes are not suitable for salt bath carburizing.

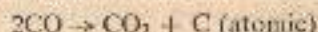
Handling of Components While parts are being transferred from the machine shop to the carburizing furnace, they should be handled carefully to avoid nicks and surface damages that are costly to correct after hardening.

11.5 Methods of Carburizing

By far the most important methods of carburizing fall broadly into three categories: pack carburizing, liquid carburizing, and gas carburizing. The first method uses solid carburizing compounds as the medium for the carbon supply. Liquid carburizing employs molten cyanide for carbon enrichment of the case. The last method, namely gas carburizing, uses hydrocarbon gases as the source of the carburizing medium.

11.5.1 PACK CARBURIZING

As the name implies, this process consists of packing the component in a solid carburizing compound in a suitable box and heating it slowly in a furnace to attain a temperature of about 900 to 950°C. At this temperature, the oxygen in the air reacts with the carbon present in the carburizing compound to produce carbon monoxide. In the presence of iron, the carbon monoxide dissociates as given in the following equation:



The atomic carbon thus formed diffuses into the steel and forms the required case. In order to keep the gas generated by the compound in contact with the steel, it is necessary to pack the parts and the compound in gas-tight containers.

Theory of Pack Carburizing At lower temperatures, the atmospheric oxygen combines with the carbon in the carburizing box and produces carbon dioxide as given below:



As the temperature is increased, the equilibrium of the reaction is displaced to the right, resulting in a progressive enrichment of the carbon monoxide.

Carbon monoxide breaks at the surface of the steel to produce carbon-dioxide and atomic carbon as follows:



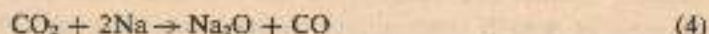
The atomic carbon, thus produced, readily dissolves in the austenitic phase of steel, and diffuses into the body of the steel. The carbon dioxide formed, in addition to the atomic carbon, reacts again with the carburizing compound. This cycle of reaction is repeated.

In a carburizing box, the amount of atmospheric oxygen can vary, and may be insufficient to produce the carburizing gas. Therefore, in practice, barium carbonate, sodium carbonate and calcium carbonate are added as energizers.

The addition of sodium carbonate as a catalyst to the carburizing compound accelerates the rate of carburization as follows.¹¹ When the carburizing compound is heated up and held at the carburizing temperature, sodium carbonate reacts with carbon although the temperature may be below the minimum temperature at which direct dissociation into sodium oxide and carbon dioxide can occur.



The sodium vapour generated by the reaction also exerts an important influence because of the marked affinity for carbon dioxide:

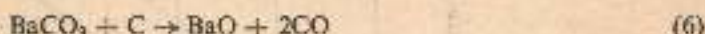


The sodium oxide thus formed will also tend to absorb carbon dioxide because of the low dissociation pressure of sodium carbonate in relation to the equilibrium pressure of carbon dioxide at the gas-steel interface.



Na_2CO_3 , thus formed, is free to react with carbon, and the cycle will be repeated indefinitely.

Addition of barium carbonate will lead to:



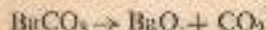
The carbon monoxide thus formed speeds up the carburization for the same reason as mentioned for sodium carbonate.

The carbon-dioxide released during carburization is removed at a faster rate mainly because of the low dissociation pressure of barium carbonate when it reacts with carbon dioxide.



The foregoing cycle can be maintained indefinitely. Again, after the carburization temperature has been maintained for a short period of time, a condition of dynamic balance will be established with the reactions 1, 2, 6 and 7 occurring simultaneously and continuously.

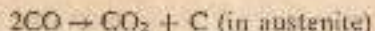
The action of a catalyst such as barium carbonate is due to its dissociation into metallic oxide and carbon dioxide according to the following reaction:



The carbon dioxide, thus released, reacts with the nascent carbon to form carbon monoxide.



The carbon monoxide formed by the foregoing reaction will react with the steel, resulting in the absorption of carbon by austenite, and by forming carbon dioxide as a by-product.



Carburizing Compounds Carburizing compounds used for pack carburizing should be in the form of solids. These compounds are mixtures of materials which, when heated, will generate a gas to give its carbon to the steel. The process of carbon transfer from the

carburizing compound to the steel surface takes place at different speeds depending on the composition and structure of the carburizing compound. The compounds usually consist of a carbon carrier (carburizers), an energizer or activator, and a binding agent. The popular carburizers used are activated charcoal, coal, semicoke and peat coke. Powdered coke may be added to the charcoal to the extent of about 20% of the total volume. The advantages of using a coke-based compound are its higher heat conductivity and low dusting losses as compared to a pure charcoal-based compound. Energizers used in carburizing compounds consist either uniquely of a carbonate or admixtures of various carbonates. Carbonates of barium, sodium and calcium are used in a definite proportion. Barium carbonate, for example, is usually compounded with carbon by mixing the whole mass with a suitable binder, whereas sodium carbonate may be applied to carbon as an aqueous solution followed by drying. Compounds made using tar or molasses as energizers to bind energizers are more effective.¹²

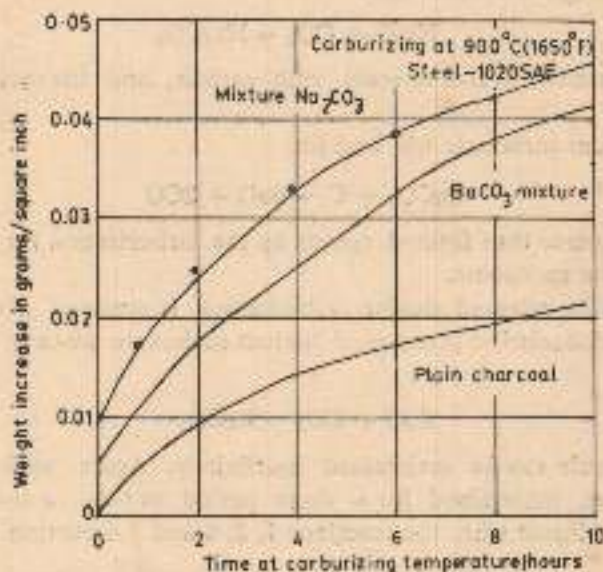


Fig. 11.4 Action of carbonate catalysts in carburization of steel¹¹

Pelletized compounds, made of charcoal powder as energizer and a binder, are more effective than compounds using larger pieces of charcoal. Such pelletized compounds are suitable for direct quenching as the energizers are held intimately in contact with charcoal.

Figure 11.4 illustrates the effect of various energizers (carbonates) on the increase in case depth. It is clear from the figure that the addition of barium carbonate as a catalyst increases the case depth. A still higher case depth can be obtained with the addition of sodium carbonate as a second catalyst, within the same carburizing time.

Various opinions have been expressed as to what proportion of energizers should be used in pack carburizing. A value, of the order of 10%, is about the average concentration but some compounds contain as much as twice this amount. Some claim that as little as 3% is all that is necessary to produce the optimum effect, while others have put the minimum at 7 or 8%. It is certainly necessary to have a little more energizer than the absolute minimum, since a proportion of it seems to combine with carbon ash and get lost in that way. The

effective percentage of energizers is smaller where the compound is re-used. Increase in the percentage of energizer does not, in fact, have any influence on the rate of transfer of carbon, case depth and carbon content. Alloy steels of high chromium, for example 665H17, 835M15, 820M17, etc. suffer from the drawback that with normal carburizing compounds they tend to form an excessive amount of carbides. These carbides built up at grain boundaries cause cracking, both on cooling down to room temperature and in subsequent grinding operations. E. Mitchell¹³ found that this trouble could be eliminated by using some weak carburizing compounds containing only 2.5% of barium carbonate in equal quantity with sodium carbonate.

Sodium carbonate or barium carbonate, when used as catalyst, forms its respective oxide (sodium oxide, barium oxide) during the process. It is found that sodium oxide can attack the carburizing box or even pit the steel parts. For this reason, barium and calcium carbonates are preferred as energizers than sodium carbonate. However, a small quantity of sodium carbonate is sometimes added because it decomposes at a lower temperature than the other carbonates. Table 11.1 shows the compositions of some carburizing compounds that are being used.

Table 11.1 Composition of Some Solid Case Hardening Compounds^{14,15}

Case Hardening	Ingredients	Parts by weight
Compound nos. 1 and 2	Charcoal	90
	Sodium carbonate	10
	Barium carbonate+charcoal	10+90
	(Na_2CO_3 -binder or BaCO_3)	4%
Compound no. 3	Charcoal	50
	Coke	30
	Barium carbonate	12%
	Sodium carbonate	3
	Calcium carbonate	3
	Binder	2

It is also necessary that the size of the compound should provide an adequate support for the components to be carburized. Otherwise the components will separate out from the compound when packing, and will settle at the bottom of the container during handling.

The richness of the compound is maintained with small additions of the fresh compound.

REACTIVATION When an old compound is used, it is necessary to leave the carburizing compound for several hours in air to permit reactivation.

Carburizing Operations

PACKING The components subjected to pack carburizing should be free from rust, grease, etc., before packing into the boxes. Packing is done first by covering the bottom of the box with a 20-30 mm layer of carburizer. This layer keeps the components from coming into

contact with the bottom of the box and avoids deformation during the process.

The components are stacked side by side in this box in a regular fashion, properly supported and surrounded by the carburizing compound in such a way that there is sufficient space above the top surface to pack a 50 mm layer of the carburizing compound before closing the lid. The lid is then closed and made airtight using a clay lining or any other sealing material to prevent air ingress.

The packing operation requires care. It should be ensured that the amount of carburizing compound used is sufficient to provide the required supply of carbon. It is the usual practice to mix the used carburizing compound to the new compound during carburizing. Recommendations on the proportion of the quantities of new and used compound to be employed in pack carburizing can usually be obtained from the supplier, but the proportion rarely exceeds more than one part of new to two parts of the used, and sometimes as little as one to seven parts.

CHARGING In practice, the boxes are first placed in the furnace maintained at 650–700°C and then gradually heated up to a temperature of around 750°C. It is held at this stage until the temperature is uniform throughout the containers so as to have a close control over the process and to allow more uniform depth at the carburizing temperature. After this, the temperature is raised to 900–950°C.

The length of the carburizing time depends upon the required case depth and temperature. After the carburizing time has elapsed the containers are taken out and cooled in air to obtain a faster rate of cooling and to avoid the possibility of a reversed reaction at low temperatures in tightly sealed boxes; this may result in decarburization and prevent the development of a hard surface in the subsequent heat-treatment operation.

In order to control and determine the case depth attained, test pieces of the same material as the carburized parts are inserted in the container. As soon as the specified carburizing time has elapsed one test piece is withdrawn from the container, and it is broken to determine the case depth through necessary tests.

EFFECT OF TEMPERATURE AND CASE DEPTH The penetration of carbon into the component

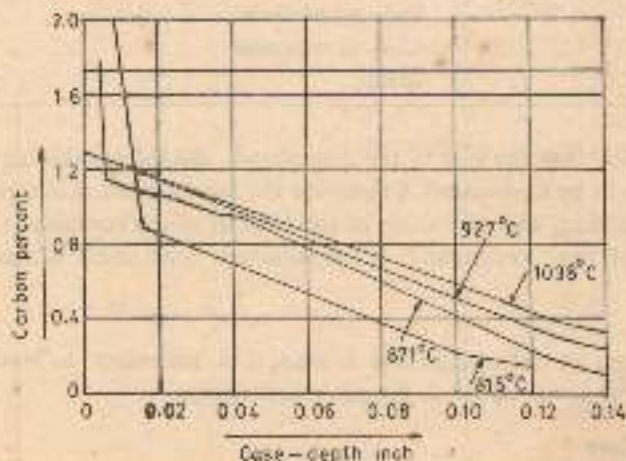


Fig. 11.5 Carbon concentration gradients obtained by carburizing at various temperatures to approximately the same case depth

starts at 750°C when the components are heated to the carburizing temperature. A further rise in temperature, beyond 750°C, increases the rate of carbon penetration. An abrupt transition from case to core occurs in the steel when the carburizing temperature is below 880°C.¹² Figure 11.5 shows some curves which illustrate the carbon distribution in a steel carburized at different temperatures, and the time durations required to produce particular case depths. It is clear from the curves that at the two lower temperatures used, the rate of diffusion of carbon was slow and this enabled the build-up of a high carbon concentration at the extreme edge of the component. With a higher temperature no such extreme concentration of carbon was found. In practice, the best temperature for pack carburizing is 900°C¹³ although temperatures between 880 and 930°C can be used.

A rise in the carburizing temperature to 950°C increases the penetration of carbon, resulting in a higher case depth in a short time. But at this temperature, pronounced carbide networks will form on the case. Hence it is important to maintain the carburizing temperature between 880 and 900°C.¹⁴ The required holding times necessary during carburizing for obtaining various case depths are given in Fig. 11.6.

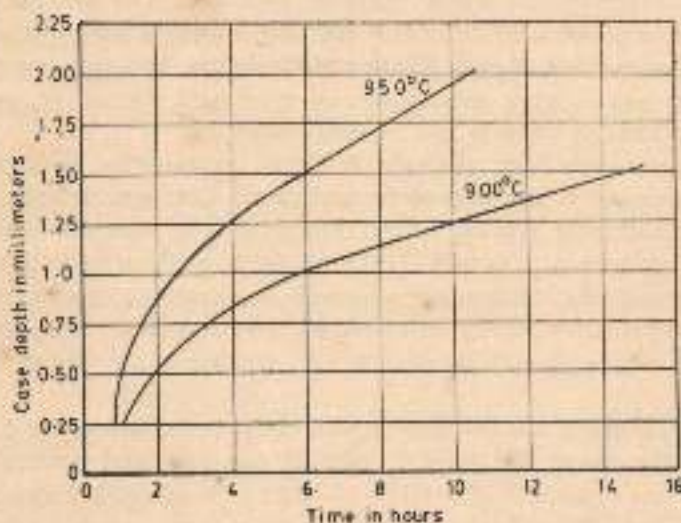


Fig. 11.6 Case depth penetration curve for pack carburizing

If a thick or deep case is required, a longer carburizing period is preferable with the furnace temperature being in excess of 900°C. The reason for this is that, when an excessive temperature is used, the outer layer of metal will absorb carbon at a greater rate than that at which diffusion into the interior occurs. Consequently, upon cooling, the outer areas of the case will consist of free cementite in the network formation.¹⁵ This is known as a supersaturated case, and will almost certainly result in the formation of cracks during quenching or grinding. If the transition is abrupt, from a case containing a high percentage of carbon to a core of the low carbon, the outer areas of the metal become hard and brittle on quenching, whilst the core will remain tough and capable of easy deformation.

The fundamental requirement for obtaining a uniform case depth is a uniform temperature throughout the furnace.

Even with the best of furnaces, it is difficult to obtain a case depth that has a total vari-

ation of less than 0.15 mm from maximum to minimum in any given furnace load. A case depth of less than 0.5 mm should not be specified for pack carburizing.

Carburizing Containers Containers used for pack carburizing are made of heat resistant steel or plain structural carbon or aluminium-coated carbon steels (Fig. 11.7). It is now a



Fig. 11.7 Containers for pack carburizing

general practice to employ such alloys either in the cast form or as welded pressings with suitable ribs. The containers made of heat resisting materials are most economical in the long run for a large number of parts having similar shapes. The containers made of carbon steels will develop scales during carburizing and will have a shorter life, but they are more economical for processing odd lots and unusual shapes.

Carburizing compounds have relatively poor heat conductivity. Hence the use of large carburizing boxes results in unevenly carburized parts. Components packed in the middle of the box are considerably less carburized than those lying near the sides. Therefore, the use of smaller containers is generally preferred for a uniform carburizing effect on the components. Alternatively, the containers should be narrow at least in one dimension to permit the heat to penetrate rapidly and reach all the components at about the same time. Containers should not be placed very close to one another in the furnace as it will impede heat conduction.

The container should preferably have a wall thickness of about 4 to 6 mm for a faster rate of heat transfer. From the point of view of economy and accuracy of treatment, optimum results are obtained if the width of the box is about 150 mm to 250 mm. The boxes should have well-fitting lids to prevent the entry of too much air, but should allow the spent gas to escape. Many containers are equipped with a provision to insert test pieces to check the carburizing results.

Furnaces The furnaces used for pack carburizing can be either batch type furnaces (muffle furnace) or continuous type furnaces. The continuous type furnaces may have a pre-heating, carburizing and a post-carburizing zone. The post-carburizing zone permits the carbon to diffuse in the case and the temperature of the parts to be reduced before final treatment.

The most essential requirement of pack carburizing furnaces is their ability to supply a steady and uniform temperature.

Advantages

1. As compared with salt bath carburizing equipment, pack carburizing boxes are inexpensive. For this reason pack carburizing is justified at present as an economical process, especially for low volume applications.

2. Although gas carburizing is, to a large extent, likely to replace pack carburizing in large heat treatment shops, there will still remain a large number of components which by virtue of their shape or quantities required, will still be carburized most economically by pack carburizing.
3. Pack carburizing can be done in a large variety of furnaces, the principal requirement being uniformity of temperature.
4. As compared to a salt bath, no cyanide disposal is necessary.
5. As compared to both gas carburizing and salt bath, its capital investment is less.
6. There is no necessity of a separate room for storing the carburizing compound; but in the case of liquid carburizing, the salts necessary for the process should be stored under strict supervision.
7. Carburizing compounds give good support to parts, helping to prevent sagging at high temperatures.
8. Special boxes can be made for large, massive parts which are too large for gas or liquid carburizing.
9. It does not require a controlled atmosphere furnace.
10. The same furnace can be used for normalizing, annealing and stress relieving.

Disadvantages

1. The overall carburizing time is excessively long. Apart from heating the components to be carburized, it is also necessary to heat the pots and the carburizing compound which usually weighs more than the components to be carburized.
2. No accurate control of the surface carbon and carbon gradient can be obtained.
3. It is not well suited for direct quenching.
4. It is not suitable for producing light case work with close limits on case depth.
5. Handling of compounds is dirty and dusty.
6. Loading and unloading operations require considerable floor space.

11.5.2 LIQUID CARBURIZING

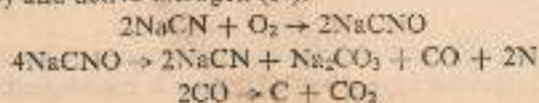
Liquid carburizing is a method of case-hardening the surface of the steel to ensure higher wear resistance. This is done by holding the component in a temperature range of 880–930°C in a molten cyanide bath, so that the atomic carbon diffuses into the surface of the metal along with a small amount of nitrogen.

This molten cyanide bath consists of sodium cyanide and alkaline earth chlorides such as barium chloride, calcium chloride and strontium chloride which function as catalysts to increase the rate of carbon absorption.

What sets the liquid carburizing bath apart from a plain sodium cyanide bath is the mixture of cyanide and chloride which goes towards producing a deep case of high carbon with low nitrogen content.

Chemical Reactions The chemical reaction which takes place during liquid carburizing is explained below:

During carburizing, sodium cyanide in the presence of atmospheric oxygen forms sodium cyanate (NaCNO) which, in turn, decomposes into sodium carbonate (Na_2CO_3), carbon monoxide (CO) and active nitrogen (N):



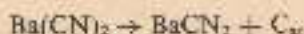
The sodium cyanide thus reformed from the cyanate is available for further reactions, but the sodium carbonate is the end product. The atomic nitrogen combines directly with iron, while carbon monoxide yields atomic carbon when it comes in contact with the steel immersed in the bath. This atomic carbon is absorbed by the steel, entering at the carburizing temperature directly in the gamma iron lattice. As nitrogen interferes with the carbon absorption, plain cyanide baths without any catalyzers are suitable for producing a shallow, high nitrogen-low carbon case.

To produce a deeper case depth and to inhibit the formation of sodium cyanate which may block carbon penetration by the formation of nitrogen, catalysts such as barium chloride, strontium chloride, etc., are added.^{16,17,18} The presence of chlorides hinders the takeup of nitrogen, and favours the absorption of carbon into the steel.

On the other hand, the bath should have a sufficiently high melting point, since carburizing is done at 900 to 950°C. The increased activity of the bath is attributed to the following reaction:



The barium cyanide Ba(CN)_2 formed is unstable and decomposes at high temperatures as follows:



This becomes increasingly prominent with an increase in temperature, thus liberating a larger amount of active carbon with the diminishing amount of active nitrogen. The amount of nitrogen absorbed by the steel at a given temperature is proportional to the cyanate content of the bath.

The presence of nitrogen produced in larger amounts by the liquid carburizing bath to act on the surface of steel is only beneficial as it improves the wear properties of the case.

Salts Used Salts used for the liquid carburizing bath are sodium cyanide as a source of carbon carrier and alkaline earth chlorides as activators. Barium chloride and strontium chloride are mainly used as activators to increase the carbon content of the skin layer on the component and to decrease the melting point and viscosity of the molten bath.^{16,17,18}

Salts for the liquid carburizing bath are available either as a single mixture consisting of all the necessary ingredients (sodium cyanide and alkaline earth catalysts), or separately as sodium cyanide and activators.

The percentage of sodium cyanide to be maintained in the working bath depends on the required case depth and the type of materials to be treated.

To produce a shallow case depth of 0.2 to 0.7 mm, a working bath containing 17 to 20% sodium cyanide is more suitable. This type of bath will give a surface carbon content of 1 to 1.2% carbon. This is unnecessary and sometimes too high for the higher range of alloyed case-hardening steels because it forms a larger amount of retained austenite.

These steels can be satisfactorily carburized to a surface carbon content of about 0.7 to 0.8% carbon by treating them in a 10 to 12% sodium cyanide bath which shows a lower tendency towards the formation of retained austenite at the surface of the carburized and hardened parts.

To produce a deep case depth of 0.5 to 2 mm, a working bath containing 7 to 12% sodium cyanide is used.

Control of carburizing performance depends entirely on whether the required concentration of cyanide within the proper cyanide-catalyst ratio is maintained. Hence, replenishment

may be done not only by adding concentrated cyanide or cyanide-chloride mixture but also by adding a proper mixture of cyanide and catalytic salts. For economical reasons, the cyanide and the activators should be added separately. By suitable additional supply of both salts, it is possible to adjust the carbon-potential level of the bath within the limits of 0.8 to 1.0%.

It is recommended that, as a routine procedure, the cyanide content of the bath be determined each morning and the bath be regenerated with an appropriate amount of cyanide and chlorides. Carburizing baths alter their carbon potential very slowly. However, it is possible to determine the C-value by means of the so-called foil probe, and adjust the carbon potential of the bath. It is most important it is maintained between 0.8 and 1% to avoid the formation of retained austenite and to get a higher hardness.

Table 11.2 Composition of Liquid Carburizing (in percentages)

Salt	Light case (850-930°C)	Deep case (900-950°C)
Sodium cyanide	17 to 23	8 to 12
Barium chloride	15 to 40	45 to 55
Other alkaline earths	0 to 3½	2 to 10
Potassium chloride	—	6 to 20
Sodium chloride	20 to 30	0 to 15
Sodium carbonate	30 max	30 max
Sodium cyanate	1 max	0.30 max

If the carbon potential of the bath is less than 0.6%, hardness obtained will be a little low. A further decrease in carbon potential of the bath will decrease the hardness still further. On the other hand, if the carbon potential of the bath increases to more than 1%, then also the hardness obtained will be a little low due to the presence of retained austenite. Salts are now available in the market that will build up a definite surface carbon concentration, say 0.8%, and a tolerable content of retained austenite.

Free access of air to the bath results in wastage of carbon, since oxygen causes the cyanide to decompose and also generates carbon at a rate in excess of that possible for the steel to absorb. To avoid this, a carbonaceous cover (usually called as Economiser) is usually used to cover the bath. The use of a cover also reduces losses due to radiation.

Operating Temperature For economical reasons, the operating temperature used for liquid carburizing is 880 to 930°C. Below this temperature range, what is produced is a shallow, high nitrogen-low carbon case comparable to that obtained in a plain cyanide bath. As the temperature rises, the concentration of carbon increases, and that of nitrogen decreases. Cases produced with a high temperature bath consist essentially of carbon dissolved in iron. Sufficient nascent nitrogen is available to produce a superficial skin containing nitride which aids in resisting and also in tempering if the part is reheated.

To produce a shallow case depth of 0.1 mm to 0.8 mm, the operating temperature should be around 850 to 900°C and the cyanide percentage maintained should be in the region of 16-20% (Table 11.2). A higher carburizing temperature of around 900-950°C is employed to

produce a case depth of more than 0.5 mm, and the cyanide percentage in the bath is maintained between 8 and 12%. The remaining percentage will be made up of catalysts, usually alkaline earth chlorides. Operating within the range of 900–950°C is more economical to produce a deeper case depth. Operating above 950°C is not economical due to the rapid rise in costs, including the maintenance of equipment required for preheating the work and the critical selection of steel.

The carbon content on the surface of the component may increase as the temperature rises; if the treatment is further continued, it may result in a lower hardness after quenching due to the presence of more retained austenite. Therefore, when components are to be quenched directly from the carburizing bath, a moderate carburizing temperature should be chosen. Typical time-penetration curves for 15Ni4Cr1 (En 39A) steel are shown in Figs. 11.8 and 11.9. The depth of hardness curves pertain to parts carburized for 2, 4 and 6

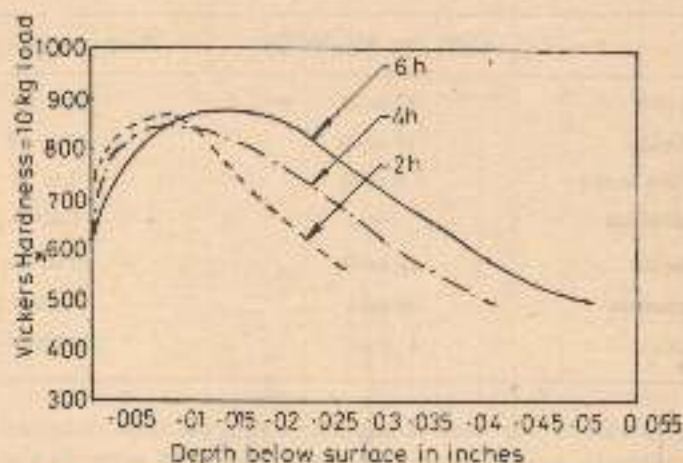


Fig. 11.8 Depth of case hardness after carburizing at 950°C followed by oil-hardening at 770°C

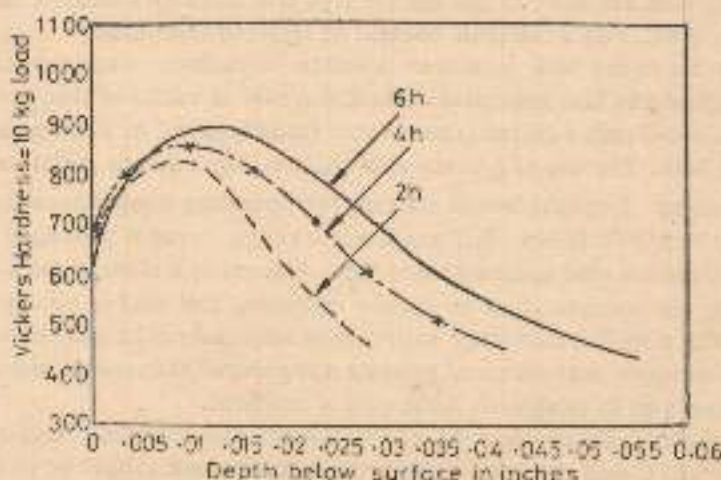


Fig. 11.9 Depth of case hardness after carburizing at 900°C, followed by oil-hardening at 770°C

hours respectively at 900°C and 950°C and subsequently hardened. From these curves, it can be seen how the thickness of the soft zone increases as the treatment time increases due to the retention of austenite. Higher hardness may be obtained by subjecting the steel to the subzero treatment (-80°C) for 15 to 30 minutes¹⁹ which is sufficient to convert the retained austenite to martensite. The increase in case hardness of steel can be seen by comparing Fig. 11.8 with Fig. 11.10, and Fig. 11.9 with Fig. 11.11.

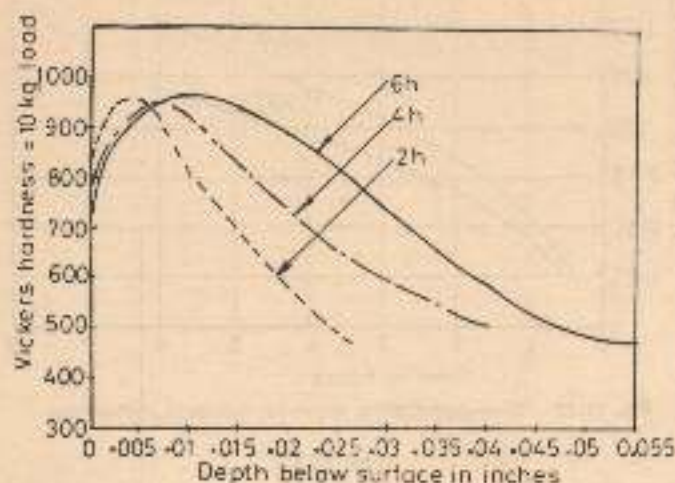


Fig. 11.10 Depth of case hardness after carburizing at 950°C for 2, 4 and 6 h, followed by hardening at 770°C and sub-zero treatment at -80°C

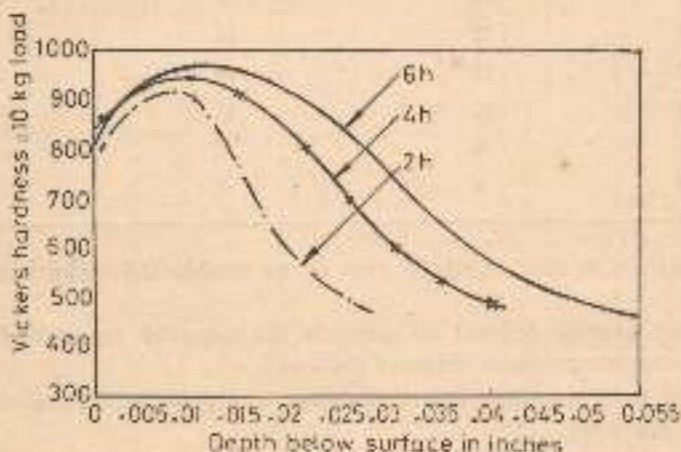


Fig. 11.11 Depth of case hardness after carburizing at 900°C, followed by oil-hardening at 770°C and sub-zero treatment at -80°C

Figure 11.12 illustrates the obtainable total case depths at different temperatures in one of these activated baths. The temperature chosen depends on the alloy steels used, the

case depth required and the permissible amount of distortion. Parts likely to get distorted are carburized at the lower end of the carburizing range.

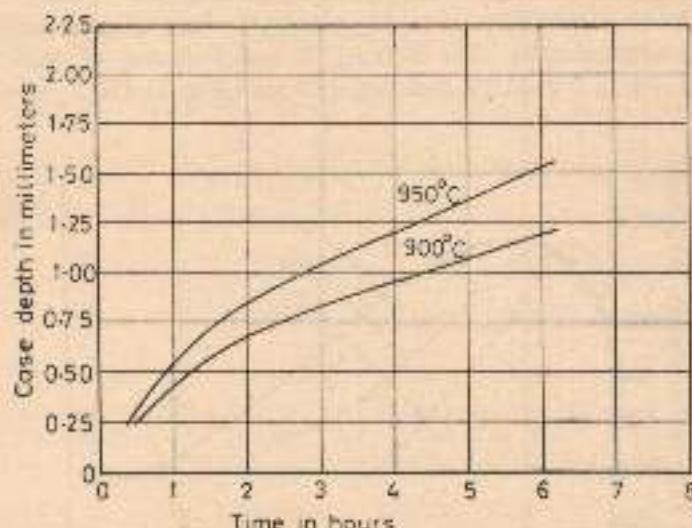


Fig. 11.12 Time-penetration curve for salt-bath carburizing

Table 11.3

Temperature °F (°C)	Minimum	% sodium cyanide preferred	Maximum
1500 (816)	14	18	23
1550 (840)	12	16	20
1600 (870)	11	14	18
1650 (900)	10	12	16
1700 (925)	8	10	14
1750 (950)	6	8	12

Failure to obtain a proper depth of case in an established carburizing cycle can be attributed to:

1. Insufficient cyanide content to generate the required amount of carbon within the time and temperature limits of the cycle.
2. Stratification of the bath due to sludging and presence of sodium carbonate in excessive amounts.
3. Excessive sodium cyanate, either due to improper cyanide-catalyst ratio, or interference with the catalytic action by contamination with silica, metal oxides and other impurities.

Starting a Bath

1. The pots must be perfectly clean and free from other salts, moisture and scale. If they are dirty, they should be cleaned.

2. Melting in an externally heated furnace must be done gradually to prevent local overheating.
3. In an immersed electrode method, the heat input rate is to be controlled by manual setting of the transformer taps, so as not to exceed the rated capacity of transformer.
4. To obtain and follow the advice of furnace and salt manufacturers.

In preparing the bath, it is recommended to fill the pot to half its capacity with the neutral base salt and then heat it gradually to reach the operating temperature. When the salt is completely melted down, then the required quantity of cyanide base salt is introduced gradually to obtain the desired concentration of cyanide. After the melt has been prepared, the bath should be stabilized for several hours at the operating temperature before starting the carburization of components.

Operational Hints

1. Fixture and components used should be completely dry before charging them into the bath.
2. Face masks must always be worn by the operator when charging the work in and out of the furnace, and also while handling molten salts. Asbestos gloves should also be provided to protect the hands.
3. On no account should a wet or damp component be lowered into the cyanide bath. The rapid steam produced will eject the molten salt from the bath which can cause serious burn injuries.
4. Formation of carbonaceous layer is inherent in a liquid carburizing bath. If this layer is insufficient, a higher purity neutral flake or graphite (maximum silica content 1%) or artificial graphite (not over 2% silica) should be used. It also performs the valuable function of reducing radiation losses.
5. Sludge should be removed periodically by scraping the bottom of the pot.
6. The pot should be closed with a lid during cooling and remelting to avoid the risk of spurling.

Furnaces The furnaces used for carburizing may be heated either externally with oil, gas etc., or internally by means of heat resisting or mild steel electrodes. Whatever be the type of furnace used, the pot for holding the molten salt must be made of metal, either of mild steel or a heat resisting nickel-chromium alloy steel. Pots lined with fire bricks are unsuitable.

For deep carburizing, an immersed electrode furnace has been found preferable because of the uniformity of temperature throughout the pot (Fig. 11.13). The volume of salt should be large enough to heat the charge of steel to working range without resulting in too great a drop in the temperature of the salt bath upon immersion. An average of 4 to 5 kg of liquid heat to 1 kg of steel is often used, although proportions depend on the type of furnace and the surface area of work.

In this type of furnace, the molten salt is contained in a welded rectangular or oval shaped pot made of 15 to 25 mm thick mild steel or heat-resisting steel.

The pot is surrounded by an exterior mild steel case for structural support and is separated by a suitable insulating material. The molten salt is heated by passing alternative current through the immersed electrode. As a result of the resistance built up by the passage of current through the salt, heat is generated within the salt itself. The heat is



Fig. 11.13 Electrode-metal pot salt-bath furnace

quickly dissociated by a downward stirring action created by the electrode.

The current is supplied from the secondary circuit of a transformer, having 10 to 15 V output, through necessary taps to adjust the rate of heat input.

Temperature control is accomplished by means of thermocouple pyrometers, which actuate the magnetic switch in the primary circuit of the transformer.

Pyrometers should be checked frequently and regularly. The accuracy of thermocouples can be determined by placing a new calibrated thermocouple alongside the old one in a salt bath at a steady temperature and connecting each in turn to a voltmeter.

Iron constant thermocouples with mild steel sheets or chromel-alumel thermocouples are used in liquid carburizing baths.

Handling of Work Ladles made of mild steel or heat-resistant steel are used for handling very small components. Larger quantities of small parts can be handled in baskets which are lifted by a hoist.

Gears are best suspended one above the other on tackles made of mild steel.

Spindles and shafts are suspended from a specially designed fixture. Delicate parts for case hardening are hung by wires made of mild steel of suitable thickness.

Quenching Quenching may be done in water, oil or salt bath. The choice of the quenching medium depends on (a) material used, (b) hardness required, and (c) allowable degree of distortion.

WATER QUENCHING Mild steel, after liquid carburizing, is usually quenched in water to obtain a higher hardness than that which is possible with oil quenching. Delicate parts must be quenched from a lower range of hardening temperature to avoid distortion and cracks. Alloy case hardening steels should not be quenched in water, as they are likely to result in heavy distortion and cracks.

Sometimes, it may be difficult even with water quenching to harden mild steel which inherently has a fine grain. This is due to the nature of steel, and it is overcome by quenching in a 9% brine solution. Brine solution is made by dissolving sodium chloride (common salt) in a proportion of 1 kg of salt to 30 litres of water. The temperature of water should not exceed 25°C.

OIL OR SALT BATH QUENCHING All types of case hardening steels can be quenched in oil bath. The temperature of oil should, normally, be between 60 and 70°C before quenching. Quenching in salt bath should be done after the part is soaked thoroughly in a neutral bath maintained at 800 to 850°C. Quenching directly in nitrate salt should never be done because of the risk of an explosive reaction between heating and quenching of salts.

The main advantage of quenching in salt bath is that it avoids heavy distortion and cracks.

Testing of Sodium Cyanide

APPARATUS REQUIRED

- Steel rod—1 cm diameter and 1 m long
- Pestle and mortar
- Small balance with 1 gm weight
- Steel spatula
- Beaker—350 ml
- Lead carbonate—100 gm
- Glass filter funnel
- Filter papers—No. 40 Whatman
- Burette—100 ml
- Silver nitrate—1 litre decinormal (17 gms./litre)
- Liquid ammonia—5 cc
- Potassium iodide (10%)—5 drops.

PROCEDURE Open the lid of the bath, and immerse the dry steel rod momentarily in the cyanide bath to be tested. Withdraw the rod immediately and collect the salt adhering to the rod as sample.

Grind the sample in a dry mortar. Dissolve 1 gm of this in 100 ml distilled water in a 250 cc beaker. Add a pinch of lead acetate or lead carbonate to remove the sulphide.

Filter the solution through No. 40 Whatman filter paper followed by three doses of hot water to wash the paper free of all traces of the solution. Collect the filtrate in a 350 cc conical flask. To this filtrate, add 5 cc of liquid ammonia and 10 drops of 10% potassium iodide solution. Titrate this against 0.1 N silver nitrate solution until the solution becomes faint but permanently yellow turbid. (Add the silver nitrate slowly, all the while shaking the flask vigorously.)

CALCULATION Percentage of sodium cyanide = $0.98 \times \text{volume of silver nitrate solution added when titrated.}$

Cleaning the Work Treated in Cyanide When the components are directly quenched in water, most of the adhering salt is removed by water. Components quenched in oil will retain an appreciable amount of salt on the surface, and these should be removed by washing with hot water. Components having blind holes must be washed in boiling water.

Although parts appear to be free from cyanide after quenching in water, they must be washed to remove even microscopic traces of cyanide which, if left, will act as nuclei for rusting.

After washing the parts should be applied with a suitable rust preventive.

Safety Precautions

FOR SODIUM CYANIDE AND SALTS CONTAINING CYANIDE

Sodium cyanide is very poisonous. Poisoning may result from:

1. Swallowing solid cyanide or a solution of cyanide.
2. Inhaling the poisonous hydrogen cyanide gas that emanates when solid cyanide or solution comes in contact with an acid.
3. Burns due to molten cyanide, if not properly treated.
4. Absorption of solid cyanide or solution through the skin, particularly if broken.

Cyanides are hygroscopic, and hydrogen cyanide is given off in small quantities when solid cyanide is exposed to damp air.

Cyanides should be stored in steel drums in a warm, dry room away from acids and foodstuffs. When drums have been opened for removal of salt it is important to close them properly by replacing the lid and seeing that it fits securely so as to avoid any absorption of moisture by the salt. The room in which the salt is stored should be locked and should be in the charge of a responsible person.

Dry gloves should always be worn when handling cyanide. The hands should be thoroughly washed in running water after every handling and at the end of the day's work.

The information given above can be found in the card entitled "Safety Precautions—Sodium Cyanide and Salts containing Cyanide" issued by Imperial Chemical Industries Limited and a copy may be displayed wherever cyanide is stored or used.

FIRST AID

Supplies of the following should be kept ready for immediate use:

1. Cyanide antidote (see below).
2. Saturated solution of sodium bicarbonate and sterile dressings, for the treatment of burns.
3. Capsules of amyl-nitrate for inhalation.
4. Oxygen and face mask for administering oxygen.

The use of these materials is described below and should be explained to workers, who should also be trained in the Holger-Nielson or Schäfer method of artificial respiration.

The following should be available for use by a doctor only:

1. Ampules of nikethamide.
2. Ampules of sodium nitrate, each containing 0.3 gm and ampules of 10 cc sterile distilled water.

3. Ampules of sodium thiosulphate, each containing 25 gm in 50 cc sterile distilled water.
4. 10 cc syringe, two intravenous needles.

CYANIDE ANTIDOTE Keep ready for immediate use the following solutions (obtainable from any pharmacist):

1. 158 gm B.P. ferrous sulphate crystals ($\text{FeSO}_4 \cdot 7\text{H}_2\text{O}$) and 3 gm B.P. citric acid crystals dissolved in a litre of cold distilled water.
2. 60 gm anhydrous sodium carbonate (Na_2CO_3) dissolved in a litre of distilled water.

Dose Mix equal quantities of (1) and (2) to make a tumblerful and swallow the mixture.

The above solutions will keep indefinitely, provided the ferrous sulphate solution is stored away from direct sunlight.

If a worker suspects that he may have had cyanide in his mouth, he must at once swallow a dose of the antidote. At the first sign of poisoning by inhalation of hydrogen cyanide gas, he must leave the dangerous atmosphere. The cyanide antidote must not be used for gas poisoning.

The early symptoms of poisoning by hydrogen cyanide gas are:

1. A sensation of irritation in the throat.
2. Increasing difficulty in breathing, and
3. Watery eyes.

Speed is essential. A doctor must be summoned at once.

1. If the patient has swallowed cyanide and is conscious, give one tumblerful of the antidote.
2. Give nothing by mouth to an unconscious patient.
3. Remove any clothing splashed with molten cyanide or cyanide solution.
4. Keep the patient warm and do not, under any circumstance, allow him to walk about.

If he is breathing, break a capsule of amyl nitrite and allow the patient to inhale the vapour. Administer oxygen through a face mask.

If not breathing, start artificial respiration (Holger-Nielson's or Schäfer's method) at once, and continue until breathing is restored or a doctor has pronounced life extinct. A capsule of amyl nitrite may be crushed and held close to the patient's nose while artificial respiration is being performed.

MEDICAL TREATMENT (FOR THE GUIDANCE OF MEDICAL OFFICERS)

1. Continue inhalations of amyl nitrite for 15 to 30 seconds at a time, at short intervals, over a period of 3 to 5 minutes.
2. Inject intravenously 0.3 gm sodium nitrite in 10 cc sterile water at the rate of 2.5 to 5 cc per minute. *This rate must not be exceeded.*
3. Immediately following this, and through the same needle, inject intravenously sodium thiosulphate 25 gm in 50 cc sterile water at the same rate.
4. An intramuscular or intravenous injection of 1 to 3 cc nikethamide may be given.
5. Keep the patient under observation for 24 to 48 hours.
6. If there is any return of symptoms, the above treatment should be repeated immediately.

TREATMENT OF BURNS FROM SALTS CONTAINING CYANIDE

1. Flood the affected area with a large volume of water or sodium bicarbonate solution.

2. Soak the affected area in sodium bicarbonate solution for a prolonged period.
3. Apply a sterile dressing and report to a doctor or the medical department.
4. If a crust develops or has formed on the burned area before the above treatment can be applied, it should not be removed. Cover with a sterile dressing.
5. If signs of cyanide poisoning supervene, e.g. dizziness, headache or loss of consciousness, give the appropriate first aid and medical treatment.

Advantages of Liquid Bath Carburizing The following are the most important advantages of liquid carburizing:

1. Uniformity in case depth and carbon content, since the circulation of the molten salt provides a constant temperature control and uniform result.
2. High output even from a relatively small furnace due to the rapid rate of heat transfer.
3. Labour costs are reduced, since the operation of the process is simple.
4. The capital cost of equipment is lower than for other competitive methods of handling the same amount of work.
5. Surface decarburizing is eliminated.
6. Time for carburizing is much reduced, when liquid carburizing is substituted for pack carburizing. This is especially true when several hours are necessary to bring the pack carburizing containers to the required temperature depending upon the parts and size of the charge.
7. Distortion is kept to a minimum with liquid carburizing.
8. Adaptable for mechanization and mass production.

Disadvantages The major disadvantages of liquid carburizing are:

1. Great care is required in the disposal of cyanide bearing salts.
2. Difficulty in keeping the installation and its surroundings clean.
3. Necessity of removing the salt from the work by special means, such as hot water spray washing, acid dip, etc.
4. Compressing in hardening is not mechanized.
5. Need for careful handling because of the salts.
6. There is a danger of explosion if moisture is introduced into the salt.
7. Separate storage is required for keeping the salts under lock and key.
8. Preheating is necessary.
9. Exhaust system is a must.
10. Periodic medical check-up of operator is essential.

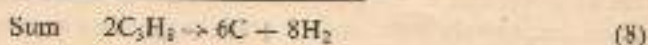
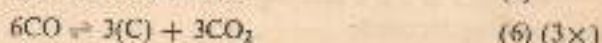
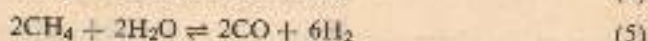
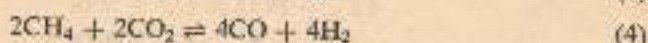
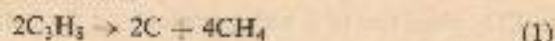
11.5.3 GAS CARBURIZING

Gas carburizing is a process in which the surface of the component is saturated with carbon in a gaseous atmosphere containing carbon. To accomplish this, first the components are heated in a gas-tight furnace in a neutral atmosphere to a predetermined temperature in the range of 900-950°C. Then the furnace is flooded with a suitable gas such as propane, butane, kerosene, benzene, etc. Finally, the components are held at this temperature to allow diffusion of carbon into the case. After the carburizing treatment is over, the components are quenched to get the required hardness, wear resistance and fatigue resistance on the surface, supported by a tougher core.

Carburizing Media The most important requirement of any medium used for gas carbu-

ricing is that it should supply an adequate quantity of nascent carbon for absorption and diffusion into the steel. First, it should contain an adequate proportion of hydrocarbons such as methane or propane to provide the carburizing power. Secondly, oxidizing and decarburizing impurities such as free oxygen, carbon dioxide and water vapour should be held to a minimum. Lastly, the constituents present should be in proper proportions, as otherwise it will not only upset the carburizing reaction, but will also promote the formation of excessive soot. The sources of carbon mainly come from gases, hydrocarbon liquids or artificial liquids. However, for large continuous furnaces, the gas is combined with a neutral diluent or carrier gases.

HYDROCARBON GASES The gases that are used for carburizing are natural gas (methane, propane, butane, etc.) Natural gas and propane are preferable when available with high purity. All these hydrocarbon gases are richer in elementary carbon than is necessary and hence form heavy deposits of soot on the furnace walls and the work. This interferes with the carburizing process, since the austenite does not absorb carbon at the temperature ordinarily employed. For example, the reaction leading to the carbon transfer with propane as the gas medium may be represented as follows.



As shown by equation (1), propane which is the primary carburizing medium dissociates into carbon and methane. The carbon thus produced combines with oxygen and water to form carbon monoxide as given by equations (2) and (3).

Some of the carbon also combines with carbon dioxide and water vapour as shown by equations (3) and (4). The dissociation of propane and the subsequent reactions of methane produce largely carbon. Though carbon is mainly absorbed by the steel, in practice, it is found that the amount of carbon available is more than what is required for absorption. This excessive carbon, on further reaction, precipitates as a heavy soot and deposits on the component as well as on the walls of the furnace. Hence, in gas carburizing, it is necessary that the hydrocarbon gases used are diluted with a carrier gas to avoid the formation of heavy soot. Equation (5) gives the final chemical reaction that occurs in the carburizing process.

A more common commercial practice is to use an endothermic gas or a purified exothermic gas as a carrier gas with the hydrocarbon gases. The ratio of gases used depends on the type of carrier and hydrocarbon gases, the furnace size and condition, amount of circulation and the work surface.

Even though carrier gases may help in avoiding the soot formation apart from better

circulation of gases, it is essential to provide powerful circulating fans to ensure a uniform carbon penetration.

LIQUIDS FOR CARBURIZING Liquids are also extensively used as carburizing media in gas carburizing; these are mixtures based on methyl, ethyl or isopropyl alcohols with additions of benzene or other liquid hydrocarbons such as kerosene, acetone, propane, etc. The organic liquids or their mixtures are introduced into the furnace in the form of drops, and at the carburizing temperature, they are dispersed and vaporized almost instantaneously. The vapours dissociate thermally to provide a carburizing atmosphere containing carbon monoxide (CO), carbon dioxide (CO₂), methane (CH₄) and water vapour (H₂O). For example, when isopropanol is used for gas carburizing, the following dissociation takes place at the carburizing temperature.



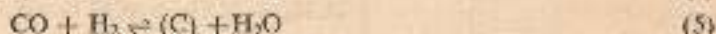
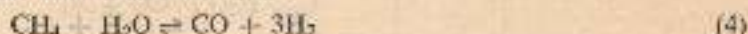
The CO₂ obtained reacts with methane (CH₄)



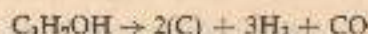
The CO₂ gives rise to a water content via the water equilibrium.



Through this methane can also react with water.



The sum of the above equations (1), (2), (3), (4), and (5) will be given in an idealized carburizing reaction:

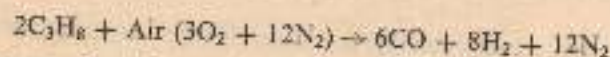


With a correct rate of supply of isopropanol or other carburizing liquids, carburization takes place exclusively over carbon monoxide. The supply of liquid to the carburizing chamber is usually adjusted manually or automatically to obtain the desired carbon potential.

When carburizing liquids are used, forced fan circulation is necessary in the furnace for an even distribution of the carburizing gas within the chamber to ensure uniform carburization and to prevent excessive soot deposition.

Carrier Gases Carrier gas is mainly used as a diluent in a continuous gas carburizing and sealed quench furnace along with hydrocarbons.²⁰⁻²² The carrier gas is generated from town gas, natural gas or propane in an 'endothermic type' atmosphere generator. The products consist of mainly nitrogen, hydrogen, carbon monoxide and controllable proportions of carbon dioxide, water vapour and methane. This type of atmosphere is produced by passing a carefully controlled mixture of hydrocarbons and air, over a heated nickel catalyst in a pressure-tight retort heated externally. The temperature of the catalyst is maintained at 1000 to 1200°C to obtain a completely reacted gas and to obtain consistent results. After the gas passes over the catalyst it is cooled by chilling it to 300°C in a water jacket. This prevents the formation of carbon and carbon dioxide from carbon monoxide as is the case with slow cooling.

For example, if a propane and air mixture (1 part propane and 7.5 parts air) is used, the resultant reaction will be:



The carrier gases produced by propane and natural gas are listed in the following table:

Table 11.4 Carrier Gases Used in Gas Carburizing²¹

Analysis	Endothermic gas from natural gas	Endothermic gas from propane	Nitrogen methane "endo-mix"
% CO	19.8	23.8	15-20
% H ₂	40.4	31.2	35-45
% CO ₂	0.3	0.3	0.4
% CH ₄	0.5	0.1	0.3
Dew point	0°C	0°C	0°C

Gas Carburizing Furnaces. The furnaces used for gas carburizing are generally classified into continuous type and batch type furnaces.^{21, 22}

CONTINUOUS TYPE FURNACES Continuous type furnaces are more suitable for long runs of similar components requiring the same case depth. The different types of continuous furnaces are: 1. Pusher type continuous furnace 2. Shaker hearth furnace 3. Rotary retort furnace.

In a continuous type furnace, the component to be carburized is charged at one end and passed through the preheating, purging, carburizing and diffusion zones. It is then discharged at the other end for cooling or quenching and other subsequent operations.

The furnace should be constructed in such a way that air infiltration and contamination of the carburizing atmosphere by the quenching medium is kept to a minimum.

Rotary retort^{21, 22} and shaker hearth^{21, 22} furnaces are used for lower case depths of 0.2 mm to 0.3 mm for small components. The types of components suitable are pins, washers, bushes, small shafts, gears and similar small components.

Pusher type furnaces^{21, 22} are used most widely for continuous carburizing of heavier loads. With this method the components are placed on robust heat-resisting trays which are pushed through the furnace at pre-determined time intervals. After the completion of the carburizing cycle the components may be quenched or slowly cooled. This type of furnace is normally equipped with a quenching, washing and tempering facility.

Continuous type furnaces are suitable for mass production. The running costs are considerably lower due to the greater efficiency of work flow and the reduced amount of labour required as a result of automation. However, maximum economy in production can be achieved only if the continuous furnace runs continuously. The initial capital investment costs are higher compared to batch type furnaces.

BATCH TYPE FURNACES Batch type furnaces are suitable for small batches of components having varying case depths. There are two types of furnaces mainly used for batch carburizing. They are horizontal or vertical type of furnaces. Horizontal furnaces are sealed quench furnaces; the vertical type is the pit type furnace.

Horizontal furnaces are most suitable for carburizing and quenching. Components treated in this furnace are free from scales.

Pit type furnaces are mainly suitable for long, slender components and also for other types of components. The pit type furnace is cheaper compared to the sealed quench furnace.

In the batch type furnace, the components to be carburized are loaded into the furnace using heat-resisting fixtures or trays. They are first preheated, then carburized at the required temperature, and finally cooled or quenched.

CHARGE CARRIERS In a pit-type furnace, the components should be loaded on a suitable fixture, to ensure minimum distortion and to provide a proper circulating atmosphere. It is important that the components are supported properly on this fixture, avoiding excessive unsupported lengths which may cause serious distortion problems.

The fixtures normally used in pit-type furnaces are shown in Fig. 11.14.

Methods of Gas Carburizing Gas carburizing may be done either by using liquid hydrocarbons or hydrocarbon gases along with a carrier gas.

Liquid carburizing is mainly adopted in pit type of furnaces, whereas carburizing by using hydrocarbon gases and carrier gas may be carried out in continuous type furnaces or batch type of furnaces.

LIQUID METHODS There are two types of liquid methods, the single liquid method and the two-liquid method. Both methods are carried out in a pit type furnace.

Before the furnace is used for carburizing, it is necessary to burn the charge-fixtures, retort and inner-furnace components under a carburizing atmosphere for a sufficient length of time, so that a state of equilibrium is reached between the carburizing atmosphere and the components. During the operation of the furnace it is the normal practice for the furnace to be first heated to around 860 to 900°C after which the charge is loaded, the flow rate of carburizing being adjusted after the charge attains 750°C. It is preferable to remove the charge, upon completion of the carburizing time, only when the temperature of the furnace has been reduced to about 800 to 840°C. This procedure will ensure a longer life of the retort, while at the same time proving safer and easier for the operating personnel.

SINGLE-LIQUID METHOD In this method, gas carburizing is carried out with the help of organic liquids, either in their pure form or in the form of mixtures.

In most of the pit type furnaces,^{23,24} the drip feed method of carburizing is employed. The components to be carburized should be free from rust, oil or grease before loading them on fixtures. The component should be properly placed in the fixture, ensuring free circulation of gases. The fixture is placed in a retort and the lid is closed to make it air-tight. This loaded retort is placed in the furnace.

The furnace is then closed, and power is turned on. After the furnace temperature

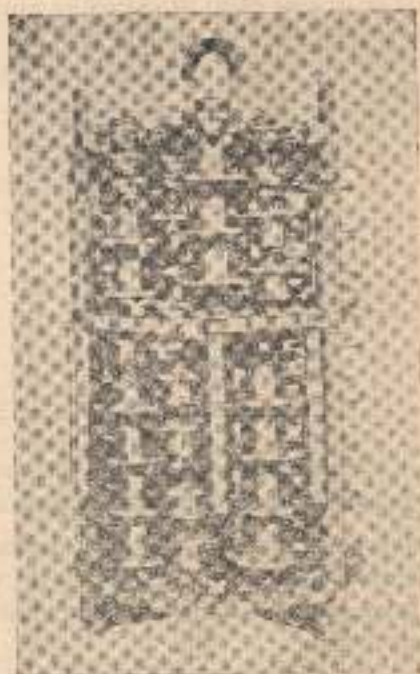


Fig. 11.14 Loaded charging frame for carburizing

reaches about 750°C , the liquid is introduced into the retort. This liquid burns with air and oxygen; all the free oxygen is consumed shortly. Further introduction of liquid during heating produces a controlled atmosphere protecting the components against the formation of scale. The amount of liquid consumed for a considerable carburizing effect to take place depends mainly on the size of the furnace.

When the furnace attains a temperature of 925°C , the charge is uniformly heated,

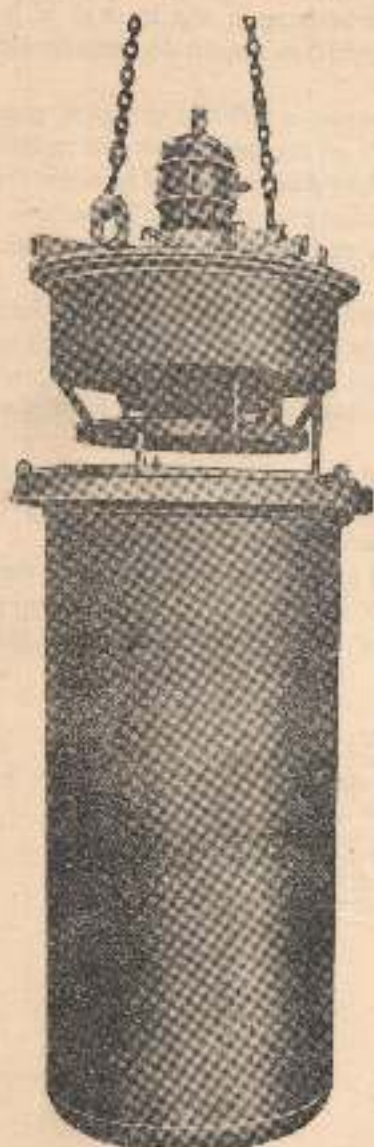


Fig. 11.15 (a) Retort for gas-carburizing furnace

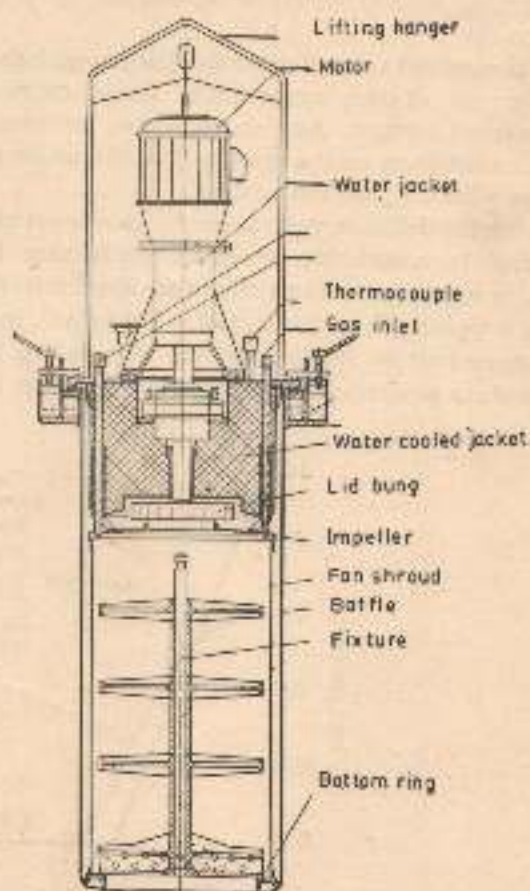


Fig. 11.15 (b) Retort assembly for gas-carburizing furnace (Courtesy: Fabricast Bombay, India).

allowing full flow of the liquid. This temperature is maintained for the required period of time.

During the first period, known as the active carburizing period, the carburizing medium is supplied in excess to keep it sufficient even for large surfaces. This is necessary because the demand for carbon by steel surfaces is the greatest, when work first reaches the carburizing temperature. The excess of dissociated carburizer leaves the furnace in the form of methane (CH_4), i.e. in a gaseous form, but a part of it is precipitated within the furnace as soot and a part of it contributes to overcarburizing in the form of a layer with a high carbon content. To minimize sooting, the liquid flow may be decreased progressively in accordance with the decreased demand.

If the carburizing period is about four hours or longer, a *diffusion* period is usually desirable, in order to control the surface carbon content on the case. With this technique at the end of the active carburizing period, the atmosphere flow is reduced to a low value, or cut off, and the charge is allowed to soak at the carburizing temperature. This allows the high surface carbon content developed during the active carburizing period to decrease to 0.80 to 1.0%.

The required ratio of active to diffusion periods depends on a number of factors, including the type of steel, temperature, the geometrical shape of components and the desired final carbon content. As a rough guide, however, when operating at a temperature of 925°C , a diffusion period equal to half the active carburizing period is found to produce a surface with 0.8% carbon content.

After the diffusion period, the furnace is opened and the retort transferred to a cooling chamber. It is desirable to reduce the furnace temperature to about 100°C below the carburizing temperature to minimise decarburization and oxidation during transfer.

In a typical gas carburizing of a 400 kg net charge to a case depth of 1 mm in an electrically heated retort furnace, having dimensions of 500 mm diam \times 1000 mm, a drip feed atmosphere generation was used. The total cycle time of $7\frac{1}{4}$ hours was made up as follows:

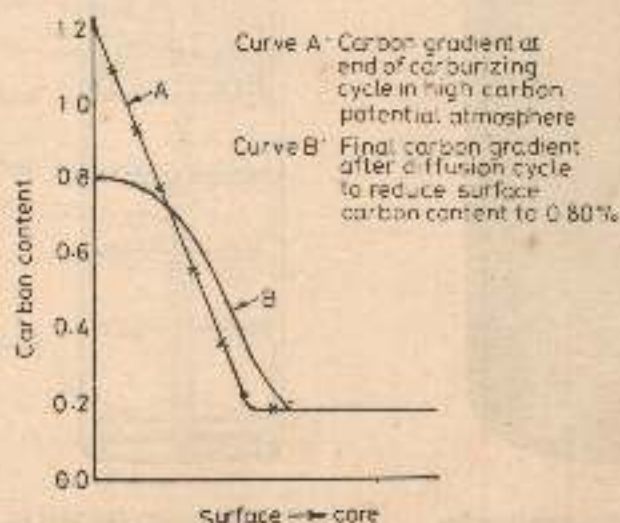


Fig. 11.16 Effect of diffusion treatment on carbon gradient in carburized case

Heating up	2½ h
Carburizing	3½ h
Diffusion	1¼ h
Load and unload	¼ h

Furnace heating: 270 kW and carburizing fluid 6 litres.

Two-Liquid Methods The two-liquid method, also known as the carbomag process, is based on the use of two different organic liquids which are introduced into the furnace simultaneously and separately to carburize the parts.^{24,25}

The first liquid introduced into the furnace generates a carrier gas which only has the function of scavenging the furnace and providing the desired positive pressure during the carburizing process. The liquid is supplied continuously in drops at such a rate that even when the carburizer gas is let in or cut off, a positive pressure will prevail in the furnace.

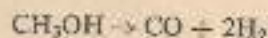
The second liquid cracks to produce the gas necessary for setting the desired carbon potential.

Thus, the carbomag process works like the well-known carrier gas process on the basis of gassification of liquid directly in the carburization furnace.

The advantage of this process is that the carbon potential can be controlled; the need for an endothermic gas generator is eliminated.

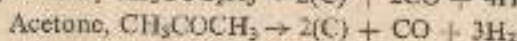
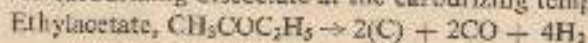
Liquids The liquids used for the carbomag process are mainly methanol as carrier gas and ethyl acetate or acetone as carburizer.

During carburizing, methanol splits at high temperature into carbon monoxide and hydrogen as follows:



The resultant gases formed in the furnace create a positive pressure with a mild carburizing effect.

The liquids used for carburizing dissociate at the carburizing temperature as follows:



Operating Procedure In practice, the operation is similar to the drip feed method.

Methanol is introduced into the furnace after the loaded furnace reaches 750°C to prevent scale formation and to act as a carrier gas by maintaining a positive pressure. After a uniform carburizing temperature is attained (900–930°C), the carburizing liquid is automatically metered into the furnace through a dew point device controlled by a solenoid valve. The operating temperature normally used in the carbomag process is about 930°C. A higher temperature, say 950–1000°C, can also be used depending on the rated capacity of the furnace.

Advantages

1. There is no need for an endothermic gas generator.
2. The carbon potential can be controlled by the dew point device.
3. A higher carbon availability per unit volume promotes a uniform carburizing of blind holes, hard to carburize areas, and carburizing of high density work-loads.
4. Reduced amount of combustible gases.

Disadvantages The disadvantages of this carbomag process are the same as those of the pit type furnace.

CARRIER GAS METHOD OF CARBURIZING Gas carburizing takes place in a gas medium consisting of a carrier gas generated from an endogas generator and a hydrocarbon gas. The standard procedure is to use a low dew point (12 to 6°C) endothermic carrier gas and to enrich the atmosphere with 10-15% natural gas, or 3-8% propane gas, or 1-3% butane. The exact amount of the enriching hydrocarbon gas depends on the surface area to be carburized, case depth and other factors. Usually, a few trials will establish the exact percentage that will produce the correct carburization without sooting.

This method can be carried out in:

1. Sealed quench furnace
2. Continuous type of furnace
3. Shaker hearth furnace
4. Rotary hearth furnace

Sealed Quench Furnace Method The sealed quench furnace is a horizontal type furnace incorporating an integral quench tank and atmosphere lock (Fig. 11.17). The components

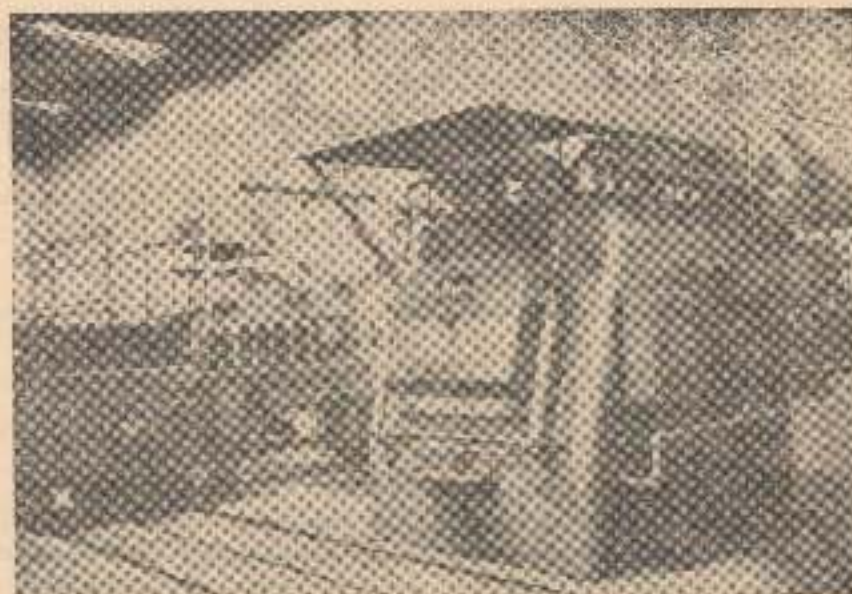


Fig. 11.17 Horizontal sealed-quench furnace (Courtesy: Ipsca Industries International GmbH, W. Germany)

to be treated are loaded onto the furnace in a container, or in a suitable fixture, after the furnace attains the operating temperature. Then the furnace is sealed and the flame curtain is opened to allow the additive to burn out fully and also to avoid ingress of oxygen. The heating is continued with a flow of carrier gas until the operating temperature reaches 925°C. After the carburizing temperature is attained in the furnace and the charge is uniformly heated, the calculated amount of enriching gas is introduced.

The amount of enriching gas introduced into the furnace, in proportion to the carrier gas, should be 10 to 15% of natural gas or 3 to 8% of propane gas, or 1 to 3% of butane gas. The exact amount of enriching gas depends on the surface area to be carburized, case depth and other factors. Usually, the exact percentage that will produce the most rapid

rate of carburization without sooting can be established by trial and error.

In the beginning of the carburizing cycle, the enriching gas flow may be increased, since the demand for carbon by the steel is the greatest when the work first reaches the carburizing temperature.²⁷ Therefore, the operator can set the carbon potential as high as 1.3% carbon, without worrying about whether the surface will reach this carbon content. As time progresses and the case gets deeper, the surface begins to approach a high carbon potential set in the furnace.

At the end of the process, the enriching gas supply to the furnace is stopped and the charge is held in the carrier gas.

If the carburizing time is three hours or longer (case depth of 1 mm or more), a diffusion period is usually desirable,²⁷ in order to control the surface carbon content of the case to 0.8 to 0.9% carbon. After the conclusion of the active carburizing period, the enriching gas is stopped and the charge is allowed to soak at the carburizing temperature in the carrier atmosphere. During this period, the carbon content on the surface is reduced to 0.8 to 0.9% carbon.

As a rough guide, the time required for the diffusion period is equal to half of the active carburizing period to produce a surface of about 0.8% carbon content. After the carburizing or diffusion period, parts are quenched in the integral tank, air cooled for subsequent reheat operations, or individually removed through slot doors for fixture quenching.

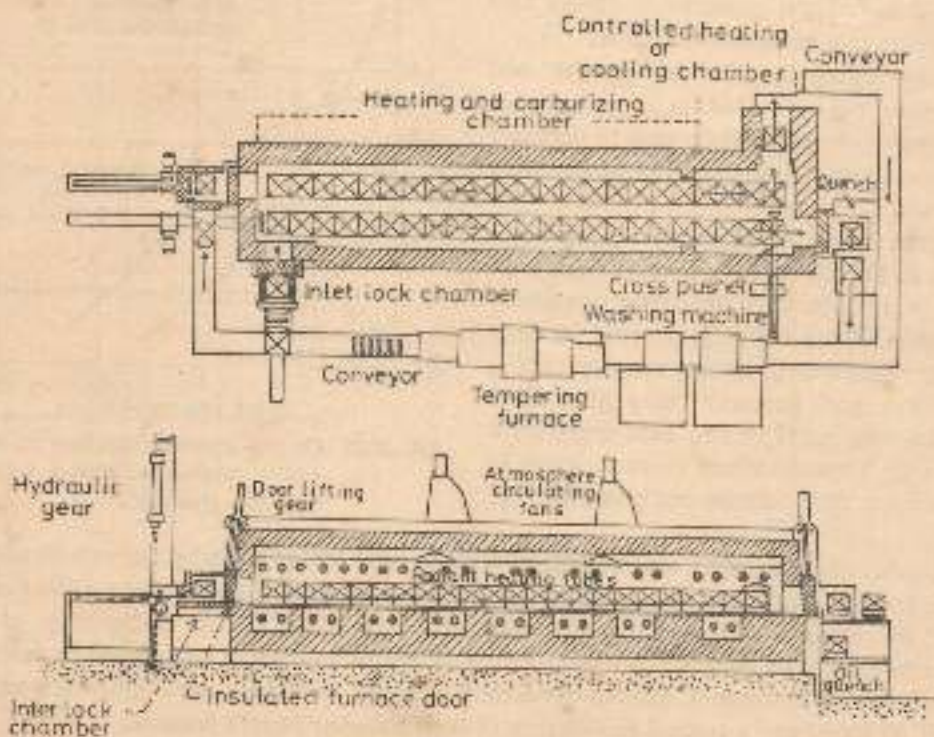


Fig. 11.18 Typical continuous gas-carburizing furnace

Continuous Furnace Method A continuous type furnace, typically a pusher type furnace,^{26, 29} consists of a heating zone, a carburizing zone, a diffusion zone, and a hardening zone along with quenching facilities. Besides a quenching zone, it is also equipped with washing and tempering facilities (Fig. 11.18).

In this method, the components to be carburized are placed in a suitable fixture or tray. They are heated to 900°C in a carrier gas atmosphere supplied from the endothermic generator maintained at a different carbon potential. After the charge is heated, the components are moved to the carburizing zone, and held at a temperature of 925°C. Here, along with the carrier gas an enriching gas is added at a different carbon potential to enrich the surface of the steel with carbon. The holding time in the carburizing zone depends on the required case depth. The components subjected to carburizing in a continuous type furnace contain about 1.2 to 1.3% carbon on the case. The percentage of enriching gas used is about 3 to 10% of the carrier gas.

After the carburizing time has elapsed, the charge is moved to the diffusion zone and held in the same temperature to reduce the carbon in the case to 0.8–0.9% carbon. This occurs in the presence of a carrier gas in the diffusion zone.

After the diffusion cycle the charge is moved to a reducing temperature zone, normally maintained at 840–850°C. After attaining this temperature, the charge is subjected to quenching and subsequent operations.

The cycle can best be duplicated in modern furnaces having definite zone-to-zone separations. The method of separation is a matter of individual preference. Doors and other devices can be equally effective.

Usually, inlets for the carrier gas and active gases are provided at a number of places on the sides of the furnace to obtain a uniform and better distribution of gases inside the furnace.

The real value of furnaces with various zones is in the control of the carbon gradient and in the possibility of obtaining consistent case depths. With a precise control in each zone, the variations in part geometry, mass, surface area, and fixturing have little effect on the carbon gradient and case depth for a given cycle. Typical carbon control levels in a continuous zone furnace are given in Fig. 11.19.²⁰

Shaker hearth and rotary retort furnaces are also used for carburizing. In such furnaces, components are charged at one end and discharged at the other end. They are used only for small components with shallow case depths of 0.1 to 0.17 mm. The carburizing gas is admitted in a metered quantity into the furnace. These furnaces may be completely mechanized with automatic feeders, quench extractors, washing machines, and tempering units. Figure 11.20 illustrates a typical installation of such a shaker hearth furnace.

Control of Furnace Atmosphere

THEORY In furnaces, the carburizing atmosphere is controlled to obtain an equilibrium

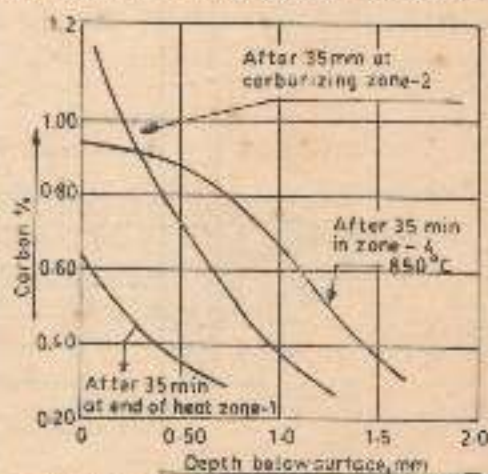


Fig. 11.19 Carbon gradient obtained in a 4-zone continuous furnace with 40-minute push cycle

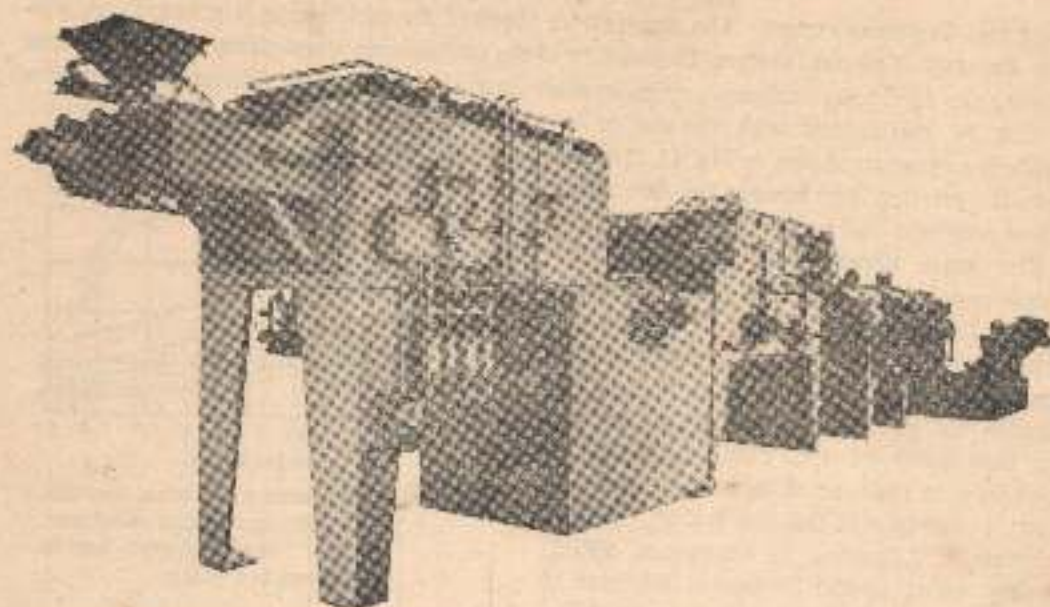
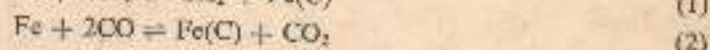


Fig. 11.20 Completely mechanized and automatically controlled hearth furnace (Courtesy: Ipsen Industries International GmbH, W. Germany)

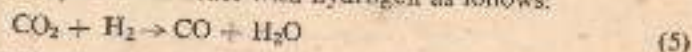
with the desired carbon potential. This may be illustrated by the following reactions that take place in the furnace atmosphere²⁴.



$$\text{Therefore carburizing potential } \frac{(\text{CO})}{\text{CO}_2} \quad (3)$$

$$\text{and } \text{CH}_4/(\text{H}_2)^2 \quad (4)$$

According to equation (1), carbon can be added or subtracted from iron in the austenite state, represented by $\text{Fe}(\text{C})$, by controlling the CH_4/H_2 ratio. For a particular carrier gas the concentration of carbon monoxide and hydrogen is roughly constant for a wide range of carbon potential. In practice, addition of methane (CH_4) or other hydrocarbons, or reducing the carbon dioxide constant, will increase the carbon potential during carburizing. Carbon dioxide in the furnace atmosphere will react with hydrogen as follows:



Thus, the carbon dioxide constant and water constant, or the dew point, are interdependent. A high dew point will promote the formation of carbon dioxide and, therefore, will reduce the carburizing potential. Methane and other hydrocarbons will react with water as follows:



Therefore, hydrocarbons may be added to reduce the dew point and increase the carbon potential.

From this it can be seen that the carbon potential can be determined by the measurement of carbon dioxide or dew point.

PRACTICAL CONSIDERATIONS The atmosphere required for carburizing is primarily an adequate quantity of nascent carbon. Controlling of the carburizing atmosphere is accomplished by using the dew point analyzer or similar such instruments.^{24,26} The desired carbon potential can be maintained with the aid of an equilibrium diagram shown in Fig. 11.21 which shows the relationships between the dew point, carbon potential and temperature.

The gases supplied to the carburizing furnace consist of a carrier gas and an enriching gas. To maintain the neutral atmosphere in the furnace, the carrier gas is supplied with a carbon potential of 0.6% carbon from the endothermic generator which is maintained at a dew point of 4°C. This may be varied depending on the type of furnace. The desired carbon percentage in the case is 0.8% carbon. To attain 0.8% carbon in the case at 930°C, the dew point of the furnace is adjusted to -3°C with the aid of an equilibrium diagram.

To increase the carbon potential to 0.8% carbon in the furnace, an enriching gas is added.

In practice, at the beginning of the cycle, the enriching gas flow is increased to maintain the carbon potential to 1.2 to 1.3%. To attain this carbon potential, the dew point is

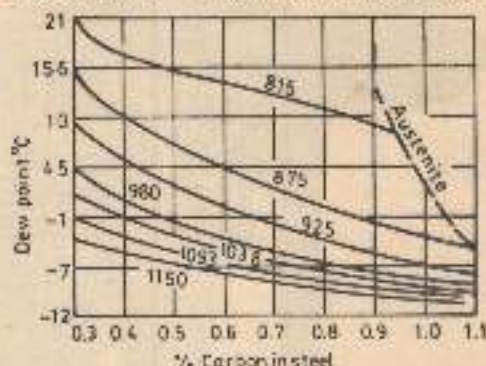


Fig. 11.21 Experimental curves showing equilibrium conditions between steel and endogas having various dew points

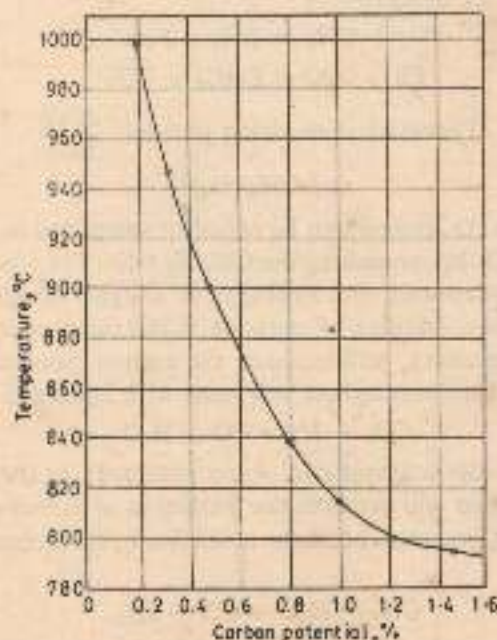


Fig. 11.22 The carbon potential of an endothermic gas of fixed composition, as a function of temperature

adjusted to -8 to -10°C . In the beginning of the carburizing cycle, the diffusion of carbon into steel at this temperature is more. As time progresses and the case gets deeper, the surface begins to approach the high carbon potential, set in the furnace. After the carburizing period is over, the flow of the enriching gas is stopped. The dew point in the furnace is adjusted to -3°C to attain 0.8% carbon in the case. During this period no enriching gas is added, and the furnace is held at the same temperature to start the diffusion period. The high carbon diffuses into the metal, accompanied by an interaction of the surface of the charge with the carrier gas.

As a rough guide, the time required for the diffusion period will be half of the active carburizing period. This diffusion period is essential if the case depth is 1 mm or more. For case depths below 1 mm the diffusion period is not necessary. Although the furnace atmosphere potential may be set to 1 to 1.2% carbon (as would be indicated by a test piece placed in the furnace), the surface carbon of a relatively larger cross section would not exceed the desired 0.8% carbon.

If the charge is to be quenched for hardening, the furnace temperature may be lowered to 850°C and the dew point suitably adjusted, because the carbon potential increases for the same composition of the atmosphere and dew point²⁰ as the temperature decreases²¹ (Fig. 11.22).

The other equipment used for controlling the carburizing potential are: infrared analyzer, carbon resistance method, oxygen probe method and microanalysis method.

Effect of Temperature Since carburization is primarily a diffusion process, the higher the temperature, the greater will be the rate of carbon penetration and case depth. Gas carburizing may be carried out in the temperature range of 880 – 980°C . In practice, the temperature most commonly employed is 920 to 930°C . Below this temperature range, cracking of the hydrocarbon may not be complete and the carbon dioxide content will be high.²⁴ Essentially, this range represents a compromise between the speed of carburizing which increases with temperature, and the furnace life which becomes shorter as the operating temperature is increased. For shallow case carburizing, where the case depth must be within a narrow specified range, lower temperatures are frequently used, since the case depth can be more accurately controlled with a slower rate of carburizing. It is most important that the temperature must be uniform in the furnace for consistent results in carburization. The relationships between the case depth, temperature and time are given in Table 11.5.

Table 11.5 Case Depth in Relation to Temperature and Total Time of Treatment (After Hours)

Time at Temp $^{\circ}\text{C}$	Case depth in mm				
	70 $^{\circ}\text{C}$	900	925	950	980
1	0.45	0.55	0.65	0.75	0.85
2	0.55	0.75	0.9	1.05	1.2
3	0.65	0.95	1.1	1.3	1.5
4	0.75	1.1	1.25	1.5	1.75
5	0.85	1.2	1.4	1.7	1.95
6	1.1	1.3	1.55	1.85	2.15
8	1.25	1.5	1.8	2.1	2.45
10	1.4	1.7	2.0	2.35	2.75

Horn, P.E., "Case depth: An attempt at practical diffusion", *MP*, 1943, pp. 265-272.

Advantages of Gas Carburizing

1. Time-temperature cycles can be determined accurately for close control of the case depth. Composition of the carburizing gas can be varied to provide a close control of the carbon content of the case.
2. The whole charge is heated to a carburizing temperature before carburizing commences. It is hence possible to obtain a uniform degree of case depth that is not obtainable by any other method.
3. Part handling is clean and relatively efficient.
4. The process is readily adaptable for continuous operation, and requires minimum floor space.
5. Less time is required to attain the carburizing temperature, since there is no need to heat the boxes as in pack carburizing.
6. Direct quenching of the charge from the carburizing temperature reduces the heat treatment cost and also results in minimum distortion.

Disadvantages of Gas Carburizing

1. High capital investment for the furnaces.
2. A generator is required to produce the endogas used as carrier for the carburizing mixture.
3. Baskets and fixtures are expensive.
4. It calls for a greater degree of skill on the part of the operator and requires an understanding of at least the fundamental reactions.
5. A partial carburizing cannot be done, as is possible in salt bath carburizing.

11.6 Heat Treatment After Carburizing

Irrespective of the method of carburizing, the carburizing parts should undergo a certain heat treatment for the following reasons:

1. To produce a hard surface to resist wear and possess higher impact strength.
2. As a result of being held for a long time at elevated temperature during carburizing, the internal portion of parts made of plain carbon steel will also acquire a coarse-grained structure, and this has to be refined after carburizing.
3. The carburized case may contain excess cementite as a network, thus inducing brittleness which will result in cracks during grinding.

The subsequent heat treatment of the carburized component will vary according to the type of component and severity of the condition to be encountered in service. To obtain maximum refinement of both core and case, two forms of heat treatment are required. The first involves heating to a specific temperature so as to refine the core, and the second, reheating to a lower temperature suitable for hardening the case. Sometimes a single heat treatment is adopted, either to harden the case or refine the core, or to obtain both at a suitable temperature.

Two fine grain steels may be single-quenched satisfactorily. Sometimes, they are quenched even directly from the hardening temperature.

Quenching media used at different stages in the hardening treatment depend mainly on the composition of the steel and on the size of the component. For steels with high alloy contents, oil quenching or salt bath quenching (150–180°C) is usually sufficient to

produce a hard case and to reduce distortion and cracking. For unalloyed steels, water or brine or polymer quenchants may be adopted.

Details of heat treatment methods adopted after carburizing are given below:

11.6.1 DIRECT HARDENING

In direct hardening method, the components are hardened directly from the carburizing temperature. This method can be employed when the components are carburized by using molten liquid or a gaseous medium. Quenching can be done in water, oil, or in a martempering bath, depending on the type of steel used. For minimum distortion, quenching in a martempering bath may be adopted, followed by air cooling. For this reason direct hardening generally results in the smallest dimensional changes of the components. Figure 11.23 shows the direct hardening method.

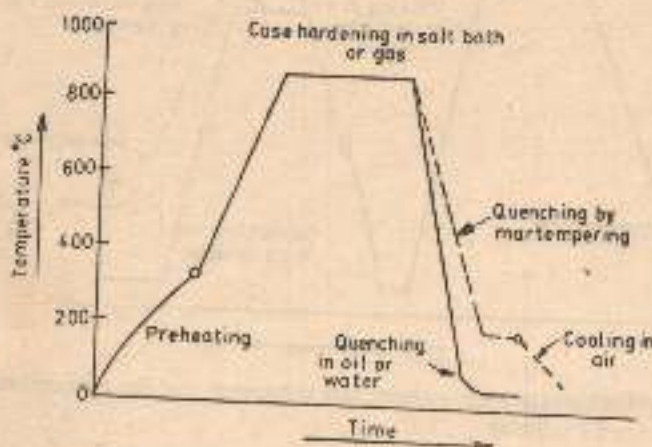


Fig. 11.23 Carburizing cycle for direct case hardening

Quenching directly from the carburizing temperature results in the hardening of both case and core. However, quenching directly from the carburizing temperature may leave retained austenite, when high alloy content steels are treated to minimize the retained austenite. In steels of high alloy content, it is the usual practice to control the carbon of the case to a somewhat lower level than in lower alloy and plain carbon steels.¹²

To reduce the amounts of retained austenite and distortion, the carburized components are quenched from a temperature of about 800°C after a little precooling in open air or in a furnace. The amount of retained austenite may be further reduced by the subzero treatment at -80°C.¹³ Components quenched from a low temperature reveal less distortion.

This method is most suitable for fine-grained steels. It is economical and may be used whenever possible.

11.6.2 SINGLE HARDENING WITHOUT CORE REFINEMENT

Parts which are pack-carburized, are first allowed to cool in the box, and then heated to a temperature necessary for hardening. After heating them just above A_c1 temperature (750–780°C), they are quenched in water, oil or salt bath. In quenching from such a tempe-

perature, the outer zone will be hardened and the core will be partially refined. This avoids overheating of the surface layer and results in reduced distortion. Therefore, this method is more suitable for treatment of intricately shaped parts.

This method can also be adopted for parts that are carburized in a salt bath, whose case depth exceeds 0.5 mm with 0.8 to 1.0% carbon potential. If the parts are quenched directly from the carburizing bath, it may lead to lower surface hardness due to the presence of retained austenite resulting from higher surface carbon. Quenching from a low temperature, after air cooling, results in a higher hardness (Fig. 11.24). The amount of retained austenite may be reduced further by subzero treatment.

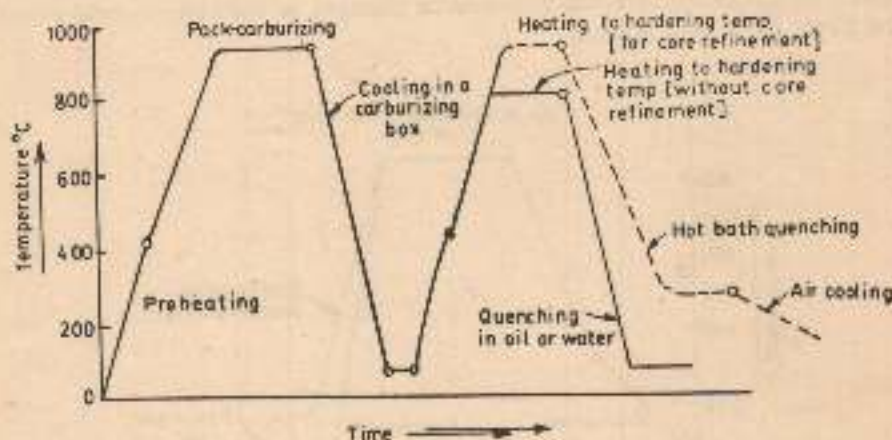


Fig. 11.24 Carburizing cycle without core refinement, and for core refinement and hardening

11.6.3 SINGLE HARDENING WITH CORE REFINEMENT

In this method, after carburizing, the components are cooled slowly to room temperature. They are then reheated to a higher temperature (880–900°C) for core refinement. Parts quenched from this temperature possess a higher impact and tensile strength. This method is widely used for automobile gears, and the resulting product has a case which secures more support from the hardened core, specially required for heavy duty services. A further advantage is the minimized distortion, since only one quenching treatment is used. The treatment is best adopted for fine-grained steels. If used on steels possessing marked hardening tendencies, the high quenching temperature favours the retention of austenite due to the presence of a relatively high proportion of alloying elements. This may result in some reduction in case hardness. Retention of austenite is undesirable, and it can be reduced by a suitable subzero treatment.

Single hardening with core refinement is being increasingly preferred over other methods. It is true that the grain of the surface layer is somewhat coarse, but this is quite often accepted in view of the fact that the mechanical properties of the core are equal to those produced by a double-hardening operation.

11.6.4 SINGLE HARDENING WITH INTERMEDIATE ANNEALING

In this method, after carburizing the parts are annealed at 650 to 670°C. After annealing,

the carburized layer is machined off in areas where further operations like broaching, drilling etc., are to be performed after hardening. The annealed parts are then heated to the required hardening temperature to get the desired hardness on the carburized zone and the required toughness on the core. Now, the operations such as broaching and drilling can be easily performed on the core (Fig. 11.25).

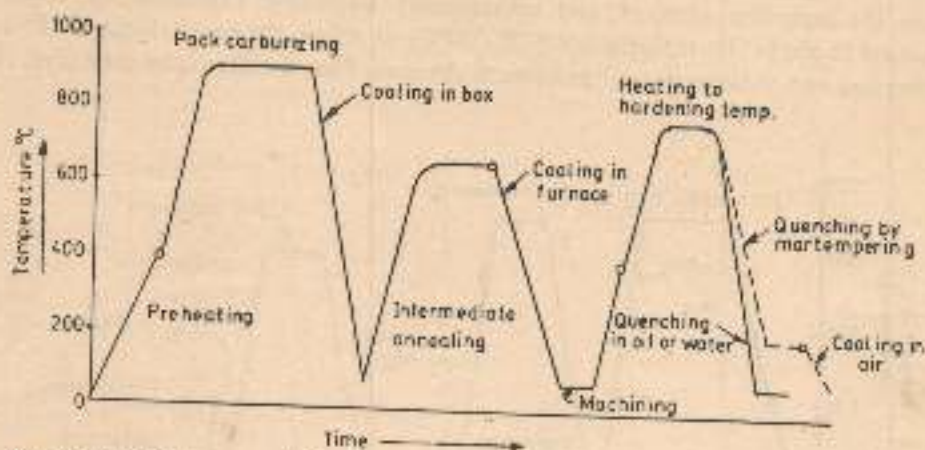


Fig. 11.25 Carburizing cycle for single hardening with intermediate annealing and hardening

11.6.5 SINGLE HARDENING WITH ISOTHERMAL ANNEALING

This method may be applied in salt bath carburizing when the case depth exceeds 0.8 mm. By employing this method, a higher case hardness can be obtained compared to the direct quenching method (Fig. 11.26).

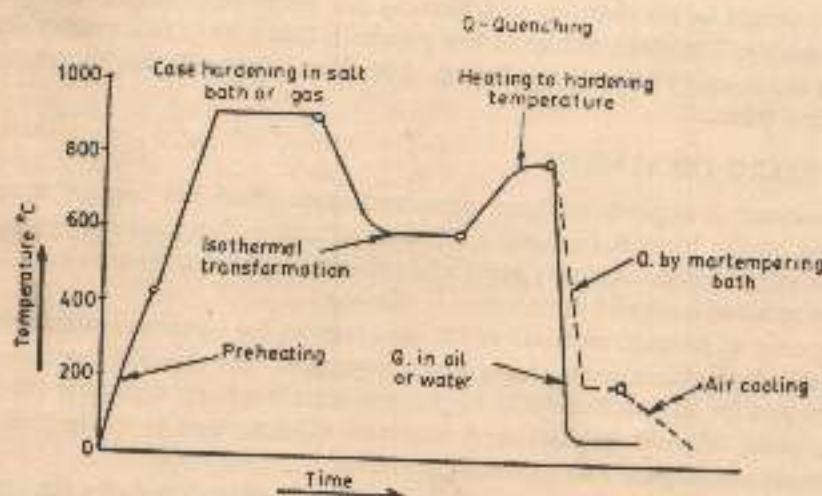


Fig. 11.26 Carburizing cycle with isothermal annealing and hardening

If the parts are to be finish-machined subsequent to carburizing, isothermal annealing should be followed by cooling in air.

11.6.6 DOUBLE HARDENING

Parts requiring high mechanical properties are subjected to double hardening after cooling from the carburizing temperature. In this method, both case and core are refined.

Parts are finished, reheated to above A_{c3} point (880–900°C) to refine the core and to eliminate the cementite network, and subsequently quenched. Thereafter, the articles are again heated to above A_{c1} temperature (750–780°C) to refine the case, eliminate the effects of overheating and to impart high hardness to the case. They are then quenched (Fig. 11.27).

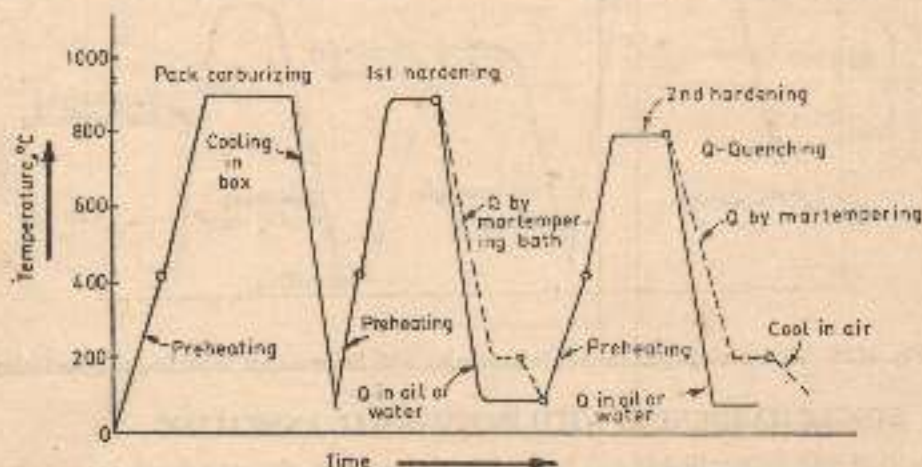


Fig. 11.27 Carburizing cycle for double hardening.

This method should be restricted to such parts as are required to have a fine-grained case of superior quality. The disadvantage of this process is that it leads to a greater dimensional change than in the case of simple hardening. For these reasons double hardening is not of much practical value.

11.6.7 SUBZERO TREATMENT

Subzero treatment is applied to those carburized cases which are susceptible to austenite retention and also to increase hardness and wear-resistance of components.²³

Precision parts, highest accuracy gears and spindles made of alloy case-hardening steels may contain retained austenite during case hardening.

The presence of retained austenite in the case reduces the maximum attainable hardness and gradually effects dimensional changes on the parts, as the retained austenite continues to transform slowly into martensite at room temperature a long time after the hardening process. In order to avoid subsequent dimensional changes and to obtain peak hardness, the components are subjected to a subzero treatment.

Subzero treatment should be carried out immediately after hardening the components. Prolonged holding at room temperature, after hardening, will stabilize the austenite.

Therefore, the following heat treatment procedure should be adopted in the given order (Fig. 11.28):

1. Carburize

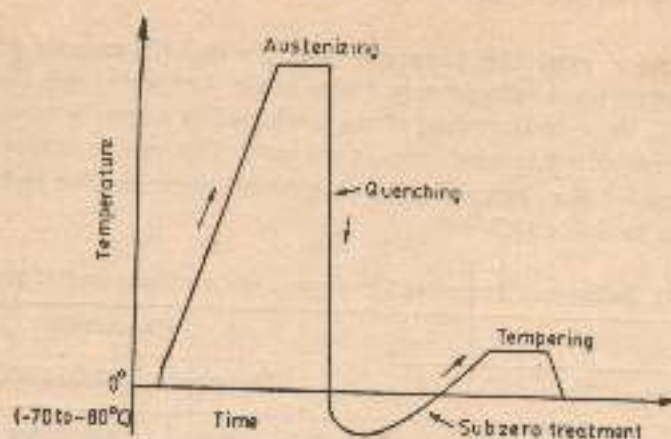


Fig. 11.28 Surface hardness after quenching directly from a carburizing temperature of 930°C

2. Harden
3. Sub-zero treatment (-80 to -100°C)
4. Tempering (150 to 180°C).

Table 11.6 gives results obtained by subzero treatment of various steels.²²

Table 11.6 Effect of Sub-zero Treatment on Case Hardness

Steel		Pack carburized at 900°C case hardness		
Specification	Type	Heat treatment °C	Quenched	After 40 minutes at -80°C
659M15 (En39A)	4½% Ni	OQ 870, OQ 780	876	945
		OQ 780	854	909
		OQ 820	720	900
EN 37	5% Ni	OQ 830, OQ 760	672	722
		OQ 760	766	786
		OQ 700	756	810
665M23 (EN35)	2% Ni-Mo	OQ 870, OQ 780	892	938
		OQ 780	882	911
		OQ 820	732	959

OQ=Oil Quench

11.6.8 TEMPERING

Case-hardened steels should be tempered to relieve the quenching stresses that are induced during hardening. This is particularly so when the hardened surface is to be ground and the brittleness of the martensite formed to be reduced. Resistance to cracking during grinding operations is improved by stress-relieving the hardened parts in the temperature range of 120–180°C. This does not reduce appreciably the hardness and hence the wear resistance of the case. Such stress-relieving treatment, however, does not help to overcome the grinding cracks associated with undissolved carbide in the network form.

The soaking time is preferably about one hour per inch (25 minutes per centimetre) of the section, and the parts are subsequently cooled in air. Tempering will decrease the hardness by 1 to 3 HRC. In some instances, where shock loading occurs in service, it is desirable to promote a somewhat better toughness in the case. This can be achieved by tempering at a higher temperature, for example at 200°C, although some sacrifice in hardness must be accepted, as shown in Table 11.7.²²

Table 11.7 Influence of Tempering Temperature on Case Hardness (Oil quenched)

Specification	Steel Type	Hardness HV			
		Untempered	100°C	150°C	200°C
EN 33	3% Ni	800	800	745	670
EN 35	2% Ni-Mo 665M23	850	850	790	720
EN 36	3% Ni-Cr 655M13	825	825	760	690
EN 37/38	5% Ni & 5/5% Ni-Mo	780	775	710	660
EN 39A	44% Ni-Cr 659M15	800	795	730	690
	44% Ni-Cr-Mo 835M13				

11.7 Flame Hardening after Carburization

Carburized components may also be flame-hardened to attain a hard, wear-resistant case. The depth of the hardened case may vary in relation to the depth of carburization. The flame hardening procedure is applied to heat the carburized case to its full depth for hardening. Parts to be subjected to flame hardening are first carburized and then air cooled slowly to obtain a low hardness. After this treatment, flame hardening is done on a certain portion of the part, or fully, depending on the requirement. The flame hardening temperature will be in the range of 850–880°C. To attain uniform results, the speed of travel of the flame head or the duration of heating should be held constant. Since the cores of low-carbon steels, so treated, do not harden substantially, the method provides a means of accurately controlling the case depth of the hardened case.

The advantage of flame hardening is that selective hardening of some portions of the part is possible. Differential hardness may also be obtained. Since the unhardened portion is soft, machining operations such as drilling, tapping, etc., may be done during assembly. Since the components, after carburizing, are cooled slowly from the carburizing temperature, the distortion will be less.

11.8 Induction Hardening after Carburizing

Components, after carburizing and air cooling or annealing, may be adopted for induction hardening. This process helps develop better dimensional characteristics. In components like gears, it increases the bending fatigue, and in the case of rear axles and power shafts, there is a considerable improvement in torsional properties.

By adopting this hardening method after carburizing, a low cost material can be used

for most of the components. It also reduces the heat treatment cost. Differential and partial hardness can be achieved in shafts and pinion shafts. For example, in the case of a pinion, a hardness of 58 to 60 RC can be obtained at the tooth portion while the remaining portion has a hardness of 40 to 45 RC. This can be achieved by varying the power supply during induction hardening which controls the temperature.

Since dimensional variation and distortion will be less after carburizing and air cooling, components like gears can be subjected to machining operations such as drilling and broaching prior to induction hardening, so that only the teeth are hardened.

11.9 Recent Trends in Carburizing

11.9.1 VACUUM CARBURIZING

Carburizing at higher temperatures (1000–1100°C) is unusual in conventional furnaces, for it may cause an excessive grain growth in the steel. However, in the last decade, high temperature carburizing has been carried out effectively by using vacuum furnaces. This method has shown significant savings both in processing time and the volume of gas, in addition to obtaining improved mechanical properties.^{34,35} The reduced process time results chiefly from the higher, permissible temperature, and the savings in natural gas or methane represent a considerable saving of energy. Information on this process first appeared in the early 1970s when specialists from Hayes Company (USA) achieved vacuum carburizing in modern furnaces.

The components to be carburized are first placed in the heating chamber kept in a tray, and the furnace is then evacuated. The work is thereafter heated in the furnace to the carburizing temperature. The temperature is usually in the range of 1000–1050°C. At this stage, a controlled amount of hydrocarbon gas (methane, butane, propane, etc.) is introduced into the furnace with a supply pressure in the range of 50–200 m bar. The amount used is based on the size of the load, area of the surfaces to be carburized, the depth and concentration. At the carburizing temperature, the maximum carbon potential of the atmosphere makes it possible to achieve a higher concentration of carbon (1.5 to 1.8%) on the surface. At the end of the saturation period, the flow of gas is shut off, and the vacuum pump evacuates the excess gas. After this, the diffusion cycle sets in, during which the desired effective case depth and carbon concentration are achieved. After the carburizing treatment the components are quenched to attain the desired hardness.

11.9.2 PLASMA CARBURIZING

In plasma carburizing, carbon is imparted to the surface of the steel by the impingement of carbon ions escaping from an ionised gas or plasma.⁴³ The workpiece to be treated is heated to a carburizing temperature, i.e., 1040 to 1050°C in vacuum, with a subsequent introduction of a small volume of carbon bearing gas. The workpiece being the cathode, it is placed near the anode of a DC circuit. A high DC voltage impressed between the workpiece in the anode ionises the gas into a glowing plasma. A thin plasma envelops the workpiece completely, reaching all its surfaces. Due to ionization, this thin plasma dissociates the carburizing gas and a high carbon potential is established on the surface of the steel. Since carbon bearing gas in the furnace is dissociated by the plasma principally at the electrode region, a high carbon potential exists only in such areas. In other areas

of the surface, i.e. outside the inter-electrode space, the carbon potential is quite low. Thus, the tendency to form free carbon in areas remote from the work load is diminished.

The total cycle time for plasma carburizing is only half that required to achieve similar results with vacuum carburizing. Compared to the conventional gas carburizing, a total energy usage ratio of 1.0 : 0.08 is claimed in favour of plasma carburizing.

Plasma carburizing is extremely quick. For example, a 2 mm thick effective case depth can be attained in a sample AISI 1018 steel at 1050°C in 52 minutes. This is attributed to a combination of high temperature, higher effective Carbon potential and the increased rate at which carbon enters the surface due to the action of plasma. Such a single stage treatment yields an elongated plateau of over-high carbon in the case. Hence a boost/diffuse procedure is adopted, involving typically 10 minutes carburizing at 1050°C and followed by 30 minutes of diffusion at the same temperature to achieve a normal case depth of 1 mm.

11.9.3 CARBURIZING, USING NITROGEN/METHONAL AS CARRIER GAS

In recent years, considerable interest is being taken to find alternative carrier gases to be used with the endothermic gas for controlled atmosphere carburizing. One such method uses the nitrogen/methonal endomix gas for carburizing.^{6,7,9}

If methonal is fed directly into the furnace, it readily cracks at the carburizing temperature to produce carbon monoxide and hydrogen in the same ratio as obtained in using an endothermic gas. The typical reaction that occurs is:



By adding an appropriate amount of nitrogen, the endothermic gas can be synthesized readily in the furnace as follows:



The atmosphere so produced can be regarded as a synthetic endothermic gas, similar to that produced from a natural gas. The typical composition of an endothermic gas derived from propane and natural gas, and the composition of endomix gas are given in Table 11.8. It is clear from the table that the composition of the atmosphere in the furnace is similar to that when an endothermic gas is used.

Table 11.8 Typical Composition of the Nitrogen/Methonal Atmosphere in the Furnace Compared with Endothermic Gas

Analysis	Nitrogen/Methonal Endomix	Endothermic gas	
		From natural gas	From propane
% CO	15-20	19.8	23.8
% H ₂	35-45	40.4	31.2
% CO ₂	0.4	0.3	0.3
% CH ₄	0.3	0.5	0.1
% N ₂	Balance	Balance	Balance

The components to be carburized are heated to the carburizing temperature of about 925°C in a sealed quench furnace. A base atmosphere of 50% methonal and 50% nitrogen of natural gas were made in order to regulate the carbon potential. The hardness and the case obtained for different time periods is given in Table 11.9.

Table 11.9 Results of Short-cycle Carburizing Trials

Furnace time, hours	Endomix gas effective case depth, mm	Gas surface hardness	Endothermic effective, case depth mm	Gas surface hardness
8	1.19	773	1.17	766
7	1.09	775	1.09	798
5	0.91	775	0.91	780
3	0.61	780	0.61	786

The most important advantages claimed for this process are clearness of the atmosphere, good, soot-free surface appearance of components, and the elimination of an endothermic gas generator. Further, the process does not represent a close monitoring of the gas system and is extremely rapid to start.

11.10 Shop Problems and Remedies

There are a number of shop problems usually encountered in the carburizing process. The nature of the problem encountered will depend upon the practical situation that prevails; nevertheless the most commonly encountered problems are:

1. Low hardness
2. Uneven case depth
3. Insufficient case depth
4. Non-uniform carburizing
5. Sooting
6. Distortion
7. Soft spots
8. Cracking exfoliation
9. Grinding cracks

The shop problems listed above are discussed in greater level in the following pages.

11.10.1 LOW HARDNESS

It is found that the commonly caused problem of low hardness is mainly due to a higher case depth, presence of retained austenites and decarburization.

Higher Case Depth To get more than 0.8 to 1.4 mm case depth by salt bath or pack carburizing, the surface of the steel will be enriched by a higher carbon content (1.22 to 1.44% carbon), since quenching from the carburizing temperature at 925°C results in a lower hardness (Fig. 11.29). This is due to the presence of retained austenite.^{32,33} This problem may be overcome by subjecting the components to a single quench treatment. Thus, after cooling to room temperature (from the carburizing temperature) the components are subjected to heating above the critical temperature (800–830°C), followed by quenching.

It may be seen from Fig. 11.30 that there is an increase in hardness after the single quench treatment. At this low temperature the dissolution of carbon content will be 0.8 to 1.0% into austenite. This reduces the risk of formation of retained austenite after quenching.

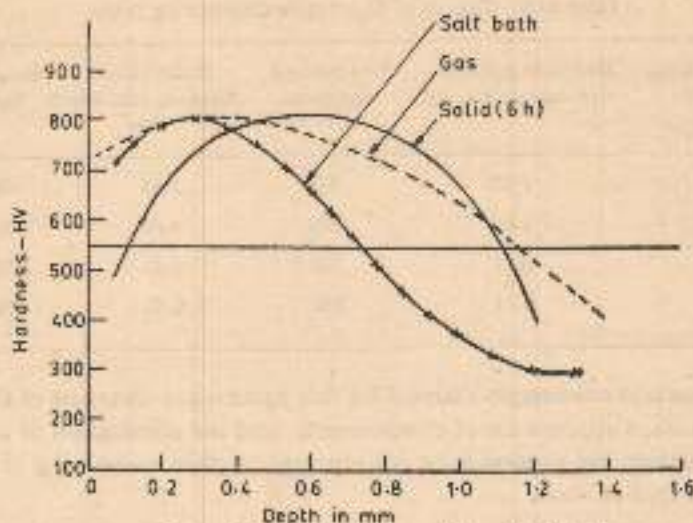


Fig. 11.29 Surface hardness after quenching directly from a carburizing temperature of 930°C

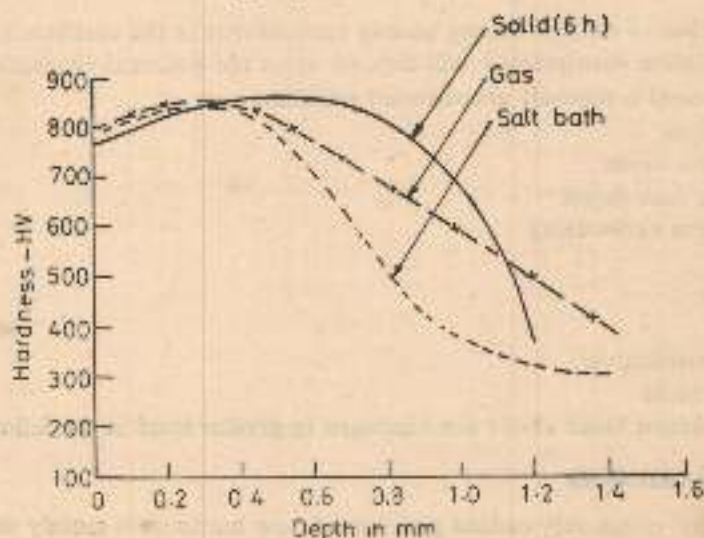


Fig. 11.30 Surface hardening after carburizing and single-quench treatment. Hardening temperature 830°C

Retained Austenite In the hardened condition, a low case hardness is sometimes encountered, even when the case hardenability of the steel is adequate. This is mainly due to retained austenite.^{32,33} Retained austenite occurs mostly in high alloy steels.³⁷ This is due to the presence of carbon in austenite; along with the alloying elements it will tend to stabilize at the carburizing temperature and resist the transformation into martensite on quenching. If this combination is quenched from high carburizing temperature, some of the austenite does not change into martensite during cooling and remains as a part of the structure. This is called the retained austenite. It is soft, and hence contributes towards lowering the overall hardness of the components.

The amount of austenite is increased by a slower cooling rate, a higher hardening temperature, and an increase in the alloying elements.⁴¹ The retained austenite may be transformed into martensite by cooling to about 50 to 100°C, with an increase in hardness of about 15 to 16 rockwell C³⁸ (Table 5.10). The amount of retained austenite can be minimized by hardening the component from a lower range of hardening temperature and a faster rate of quenching.

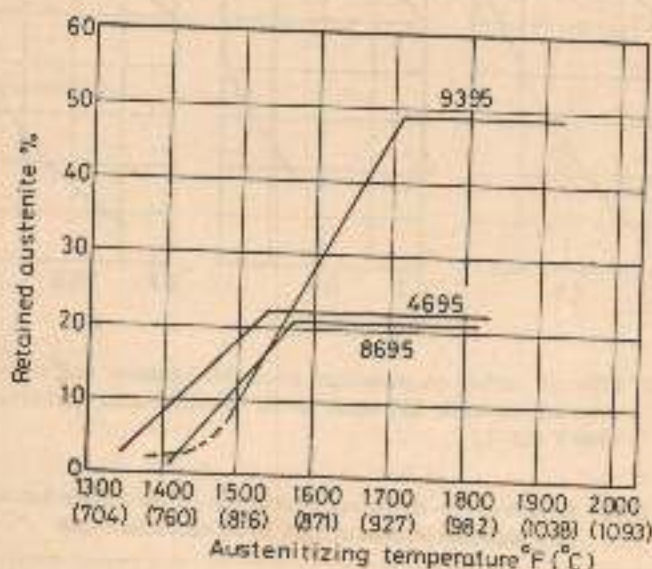


Fig. 11.31 Effect of austenitizing temperature on the amount of austenite retained at room temperature

Figure 11.31 illustrates the effect of hardening temperature on the amount of retained austenite. It is clear that in the case of AISI 9300 steel, at a hardening temperature of 930°C, there is 50% austenite upon quenching.

The presence of retained austenite can be minimized by limiting the absorption of carbon during carburizing.

Figure 11.32 shows the relationship between the carbon content, the hardness as quenched and the amount of retained austenite in the case of three highly alloyed steels, directly quenched after carburizing. A maximum case hardness having 0.6 to 0.7% carbon was obtained with an austenite level below 20 per cent. To attain this range of carbon percentage in the case, it is necessary to hold the carbon potential at 0.6 to 0.7% during gas carburizing or by the diffusion process at the end of the carburizing cycle.

Another method of controlling retention of austenite in high-carbon cases is to adopt a subcritical annealing after the carburizing and quenching processes, to precipitate the excess carbon in the form of fine, spheroidized carbides. Subsequent heating at a lower hardening temperature for a short while may lead to the desired hardness.

Subcritical annealing is done at 600 to 610°C for 8 to 12 hours, followed by austenitizing just above the A_{c1} temperature for a minimum length of time.

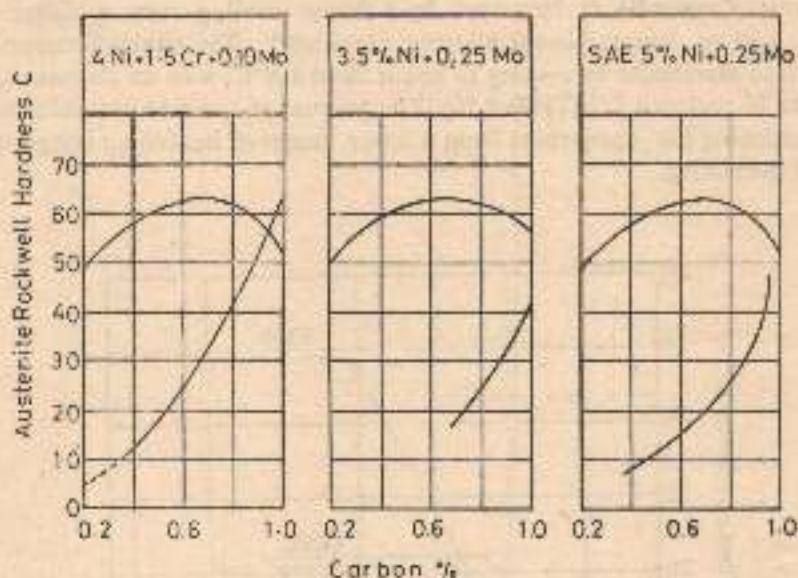


Fig. 11.32 Effect of carbon on maximum attainable hardness and amount of retained austenite in 3 steels direct quenched after carburizing at 1700°F (927°C)

Table 11.10 Results of low-temperature treatment on the surface hardness of a high-carbon case of 3316 nickel-chromium steel

Treatment as quenched	Rockwell 15N hardness	Rockwell C hardness
As quenched	83	45
Quenched and tempered at 150°C	83	45
Quenched and treated at -84°C	91	62
Quenched, treated 3 h at -84°C and tempered at 150°C	91.5	63
Quenched, tempered 3 h at 150°C and treated at -84°C	90	60

Decarburization In pack-carburizing, the phenomenon of decarburization may occur during cooling if the rate of cooling is too slow, since at lower temperatures, the atmosphere in the box may become one of decarburizing rather than carburizing. The decarburized layer of steel will have a low hardness due to the presence of lower carbon.³⁹ To attain the required carbon content on the surface, carburizing should be repeated at a normal temperature for a short time, followed by cooling of the container in air at a faster rate.

11.10.3 UNEVEN CASE DEPTH

The variation in the case depth, which occurs on pack carburizing, may be due to an im-

proper packing or an uneven heating of the container. An excessively fine carburizing compound may also cause soft spots by preventing contact between some portions of the steel surface and the carburizer.

Prevention Thorough mixing of the carburizer; use of a solution of carbonate and molasses as a binder in the manufacture of the carburizer; uniform heat soaking of the container.

In gas carburizing, if the free flow of gas all around the surface is prevented, some parts of the components will not be in contact with the gas long enough to be carburized. This may result in an uneven case depth, and it is necessary to have a uniform distribution of the gas around the charge. This can be achieved by means of a powerful circulating fan together with a suitable baffle system.

11.10.4 INSUFFICIENT CASE DEPTH

Insufficient case depth may be due to the low temperature employed during carburizing. To attain the required case depth, carburizing should be repeated with the usual carburizer at a normal temperature between 900 and 930°C.

Insufficient case depth may be due to a weak solid carburizer or an insufficient gas feed in gas carburizing. Use of a strong carburizer and sufficient feeding of gas may assure the required case depth.

11.10.5 NON-UNIFORM CARBURIZING

This is due to improper cleaning of components before carburizing. If the components are dirty, with a greasy work surface or an oxidized surface, it will lead to non-uniform carburizing. To avoid this, it is most essential that the components are thoroughly cleaned before carburizing, either by degreasing, or sand blasting, or acid cleaning.

11.10.6 SOOTING

Sooting in gas carburizing not only spoils the appearance of the work but also interferes with carburizing. Sooting is due to an excessive amount of gas being fed into the furnace, resulting in a free-carbon deposit on the components and in the furnace.³² This may be minimized, or prevented, by giving proper attention to the gas carburizing atmosphere, so that the rate of carbon supply to the steel surface does not exceed the rate at which it can be absorbed. Various methods can be adopted, but the use of either a diluted hydrocarbon mixture under controlled flow conditions, or a mixture of gases which will mutually react to give an atmosphere in equilibrium, is generally satisfactory.

11.10.7 DISTORTION

A certain amount of dimensional alteration usually takes place due to the alteration in microstructure when a part is quenched. Generally, in case hardened parts this takes place in the form of expansion or contraction in bores of gears, keys in spindles, etc., and it depends somewhat on the composition of the steel and the microstructure. Such alterations are unavoidable but uniform, and can be allowed in machining. Too rapid a rate of heating and a higher case depth will also increase distortion. The distortion may occur during hardening due to the following reasons:

Release of Internal Stresses Stresses can be caused in steel by carrying out rolling, forging

or machining operations before hardening. It is these stresses that will be released during heating to the hardening temperature and cause heavy distortion after hardening. It is best to release stresses due to rolling or forging by annealing or normalizing before machining. When heavy machining has to be done and minimum distortion is essential, it is advisable to give a stress-relieving treatment at 550 to 600°C for 1 to 2 hours, between roughing and finishing operations. After stress-relieving, the finishing operation should be done with light cuts at the lowest allowable speed.

Drastic Quenching Distortion may take place due to drastic quenching; the extent depends on the shape of components. Long, slender parts or parts with abrupt and considerable changes of section will always warp to a certain extent after the steel is quenched from the hardening bath. Distortion will be more if the components are water-quenched, and may be reduced by quenching in oil (60°C). Further, it may be reduced by quenching in a warm bath maintained at 180 to 200°C, and subsequently cooling in air.

High Temperature Hardening Distortion may be reduced by hardening from a low (780°C) or a medium hardening temperature (800–830°C).

However, when case-hardened mild steel parts of fair size, with only a superficial case, are water-quenched from approximately 900°C, there is a decided tendency for warpage and expansion. This may be obviated by conferring a deeper case on the parts, and by oil quenching from a carburizing temperature of 900°C followed by reheating to 730°C and quenching in water.

Rehardening It is important to select an initial suitable hardening temperature, so as to avoid repeated hardening to get the final hardness. Sometimes, repeated hardening will lead to abnormal dimensional changes in the component, leading to rejection of the component itself. Hence, it is also necessary to counter-check the furnace temperature before hardening.

Uneven Heating Uneven heating is a cause of distortion. It is more common in the 'box' carburizing process, where the portion of the component nearest to the wall of the box gets heated well before the central parts get heated. Also, long shafts which have to be laid horizontally, undergo distortion as the carburizing compound underneath them gets consolidated, resulting in unevenness. Such parts can be hung vertically by using a proper fixture. The carburizing treatment of such components should be done either by liquid carburizing or gas carburizing to reduce distortion to a minimum.

Soft Spots The presence of dirt patches or scale on the surface will also hinder, or entirely prevent, the penetration of carbon. This may result in soft spots. Hence it is necessary to clean the components thoroughly before carburizing.

Unevenness of carburizing may be another cause for soft spots. This is more common in pack carburizing, if the compounds are not properly mixed before packing. Soft spots may also result because of the insufficient time allowed for the centre of the pack to attain and remain at the required temperature for a sufficiently long time during carburizing. Even though carburization may have taken place, it may be very thin in some places, and a subsequent grinding may expose the soft core.

Another cause for softness may be the development of an excessively high temperature under the grinding wheel.

Use of an insufficient quenching media, too warm a condition of quenching media, or

improper agitation of the quenchant may also cause soft spots in the case of a heavy charge.

Prevention

1. Proper mixing and packing of compounds.
2. Avoiding repeated use of used compounds.
3. Using proper coolant during grinding.
4. Control of temperature of quenching media (Oil: 60–70°C, Water: 25°C).

11.10.8 GRINDING CRACKS

Normally, case-hardened alloy steels possess good grinding properties. But the supersaturated case has a greater tendency to crack while grinding than a eutectoid case. Even a perfect case can crack if an unsuitable wheel, without proper dressing, is used. The process of grinding heavy cuts or insufficient coolant may also cause cracks.

Prevention

1. Correct choice of the grinding wheel.
2. Proper dressing.
3. Sufficient coolant, especially with high velocity jets.

11.10.9 CRACKING AND EXFOLIATION

If thin sections are deep carburized during the carburizing cycle and the parts are quenched in water or brine, hardening cracks usually occur, or else the cases may become brittle. The remedy is to avoid deep carburizing, or recommend design alterations.

Cracking and exfoliation occur on the carburized components due to the supersaturation of the case with carbon, leading to the formation of a carbide network. This phenomenon takes place because of too-slow heating to the carburizing temperature (mainly in pack carburizing) with a high carbon potential. This condition happens when the loaded charge is large in volume and the carbon potential of the unboosted carrier gas is high at a lower temperature.

In pack carburizing, if the concentration of the carburizing compound is higher, the austenite is supersaturated with carbon, leading to precipitation at the austenite grain boundaries, when the components are subjected to slow cooling from the carburizing temperature. This structure causes brittleness and is responsible for the development of cracking and exfoliation.

Prevention

1. Maintain appropriate carbon potential in the carrier gas during heating.
2. In pack-carburizing, a low activator may be preferred.
3. A faster rate of cooling may be adopted after carburizing.
4. Single or double hardening with case refinement may be adopted during heat treatment.

11.10.10 CASE HARDENING STEELS

Case hardening or carburizing steels are primarily intended for components requiring a surface with high resistance to wear or indentation, and a core having an adequate strength to withstand structural loading, but tough enough to ensure that the component has a good resistance to shock. Apart from this, an enhanced fatigue strength is also of primary importance. The marked improvement of the fatigue limit, simultaneously associated with

the case hardening process, is basically due to the internal strain which counteracts the local high impact strain.

Low carbon steels, containing from 0.1 to 0.2% of carbon, may be subjected to carburizing. Steels with higher carbon, say 0.2 to 0.3%, may be employed for large components, since they possess a higher hardenability. As tempering is not essential for case-hardening steels since the hardness decreases from the surface of the core, the tensile strength of the core can generally be influenced only by the addition of alloying elements such as manganese, chromium, nickel, molybdenum, etc. The presence of alloying elements increases hardenability. The use of alloy steels reduces distortion while quenching, since oil or salt bath may be used instead of water as the quenching medium. This enables complex machine parts to be successfully carburized and subsequently heat treated.

It should be borne in mind that a low carbon alloy steel should be selected for components such as, spindles, shafts and gears, which undergo broaching, drilling, tapping, keyway, etc. A maximum of 0.1 to 0.12% carbon content steels should be selected to make sure that even small cross sections do not attain a high core hardness, say around RC 30. In practice, if it is more than RC 30, broaching, drilling or tapping becomes difficult after hardening.

The hardness of the case varies according to the type of steel and the treatment applied. For example, the hardness of water-quenched carbon steels is about 950 VHN, and in the case of highly alloyed steels, particularly those with nickel as the major alloying element, the hardness may be as low as 700 VHN (HRC 58). A factor contributing to this lower hardness may be that, after quenching, the case of the highly alloyed steel is completely transformed to martensite, and the presence of retained austenite, which is a soft constituent, will influence the final overall hardness. The presence of retained austenite is not advisable for applications where maintenance of extreme accuracy is essential. In the long run, at room temperature, the transformation of the retained austenite could lead to very marked dimensional changes. In such instances, stability can be ensured by applying a subzero treatment (-80°C) after hardening to transform the retained austenite to martensite. The recommended case hardness (after final quenching and tempering) should be RC 54-58 for worm gears, RC 59-64 for steel mill gears; and for other gears RC 57-63 (or RC 58-62, if tighter limits are needed). In cast-face gearing, or other uses where tooth chipping may be a problem, a more ductile surface is needed with a hardness of about RC 53-57.

It is recommended that gears with contact stress values of 180,000 psi, should be hardened to at least RC 55. If stresses reach 225,000 psi the hardness should be RC 59-64. And when the stresses reach 300,000 psi, the gear should be hardened to RC 63—a level difficult to reach in production.

The case depth desired for a component depends to a large extent on the design and service requirements of the components. Where high local loading is involved, such as in pinions with a high tooth curvature, ball and roller rods, tappets, etc., the case should be of such depth that the Hertzian stresses developed at any point below the surface are well below the fatigue limit of the material at that point. A deep case may be desirable for parts subjected to wear and this can be allowed to reach an appreciable depth before the parts become unserviceable. For applications such as worm shafts and journal surfaces on which the local surface pressure is comparatively low but high resistance to frictional wear is essential, a much shallower case may be adequate. Table 11.11 indicates the different types of international steels that are used for case hardening.

11.10.11 RECOMMENDED PROCESSING SEQUENCE FOR CARBURIZED COMPONENTS

Depending on the type of component to be manufactured, the following processing sequences may be adopted;

- I. Small and medium size components
 1. Forge
 2. Normalize
 3. Anneal
 4. Pre-machine
 5. Carburize and harden
 6. Temper
 7. Finish machine
- II. Small and medium size components with machining operations, such as drilling, broaching, tapping, etc., after hardening
 1. Forge
 2. Normalize
 3. Anneal
 4. Pre-machine
 5. Carburize and anneal
 6. Machine
 7. Harden and temper
 8. Finish machine
- III. Big and complicated shape components
 1. Forge
 2. Normalize
 3. Anneal
 4. Rough machine
 5. Stress relieve
 6. Pre-machine
 7. Carburize and harden
 8. Temper
 9. Finish machine
- IV. Big and complicated shape components with machining operations such as drilling, tapping, etc., after hardening
 1. Forge
 2. Normalize
 3. Anneal
 4. Rough machine
 5. Stress relieve
 6. Pre-machine
 7. Carburize and anneal
 8. Machine
 9. Harden
 10. Temper
 11. Finish machine

Table 14.11 Case Hardening Steels

Country Standard	ISO	INDIA	DEU	USA	GDR	FRA	USSR	JPN
	ISO	IS	DIN	AISI	BS 970	NFA350	GOST	JIS
1	Type-1	C10	CK10	1010	045M10	XC10	10	S10C
2	Type-2	C14	CK15	1015	080M15	XC12	15	S15C
3	Type-3	15Cr65	15Cr13	5015	523M15	—	15Ch	—
4	Type-5	17Mn1Cr95	16MnCr5	—	527M20	16MC5	18ChG	5MnCr21H
5	Type-7	20MnCr1	20MnCr5	—	—	20MC5	18ChGT	5MnCr20
6	—	16Ni1Cr80	—	A3130	635M17	20NC6	20ChN	—
7	—	16Ni80Cr60	—	A3115	5M15	20NC2	—	—
8	—	13Ni3Cr80	14NiCr14	E3310	655M13	16NC12	—	SNC22H
9	—	15Ni4Cr1	14NiCr18	—	(EN30A) 659H115	12ND16	—	—
10	—	20Ni2Mo25	—	4620	665M20	—	—	—
11	—	20Ni55Cr50Mo20	21NiCrMo2	8620	805M20	20NC32	—	SNCM21
12	Type-10	15Ni2Cr1Mo15	15CrNi6	4320	815M17	16NC6	12ChN3	ASNC22
13	Type-14	16NiCr2Mo20	17Cr-NiMo6	—	820M17	18NC6	12Ch2N4A	—

Data Sheet 11.2—Type 1 (ISO)

CHARACTERISTICS AND APPLICATIONS

A non-alloy case hardening steel which can be carburized and water-hardened to produce an extremely hard and wear resistant case, with a core strength of the order of 50 kg/mm² and with a very good resistance to shock.

Used for making cam shafts, light duty gears, worms, gudgeon pins, select or forks, pawls, ratchets, chain wheels, tappets, etc. Table 11.12 gives the chemical composition and mechanical properties of International standard steels.

HEAT TREATMENT

Forging commence	1200°C max
Finish	900°C min
Carburizing	900–920°C
Core hardening	900°C (Oil or water)
Case hardening	760–780°C (Water quench)
Tempering	150–180°C (To relieve stresses)

Table 11.12

Steel	Standard Designation	ISO R683, XO-70	IS 4432-67	DIN 17210-69	ASTM 1010	BS 970/1-83	NFA 15-551-83	GOST 1050-74	JIS G4051-79
		Type 1	C10	CK10	1010	045M10	XC10	10	S10C
Chemical composition	C %	0.07–0.13	0.15 max	0.07–0.13	0.88–0.13	0.07–0.13	0.06–0.12	0.07–0.14	0.08–0.13
	Si %	0.15–0.40	0.05–0.35	0.15–0.35	0.10 max	0.10–0.40	0.05–0.30	0.17–0.37	0.15–0.35
	Mn %	0.30–0.60	0.3–0.6	0.3–0.6	0.3–0.06	0.3–0.6	0.3–0.5	0.35–0.65	0.3–0.6
	≤P %	0.035	0.05	0.035	0.04	0.035	0.035	0.035	0.030
	≤S %	0.035	0.035	0.035	0.05	0.035	0.035	0.035	0.035
	Cu %	—	—	—	—	≤0.3	—	≤0.15	—
	Mo %	—	—	—	—	—	—	—	—
	Ni %	—	—	—	—	—	—	—	—
	Others	—	—	—	—	≤0.4	—	≤0.25	—
		—	—	—	—	—	—	—	—
Mechanical properties	Dimensions	11 30	15	11 30	—	19	16	—	—
	0.2% proof stress N/mm ²	295	—	390	—	—	345	—	—
	min	245	—	295	—	—	—	—	—
	Tensile strength N/mm ²	490–840	490	640–790	—	430 min	540–830	—	—
		390–690	—	490–640	—	—	—	—	—
	Elongation % min	13	—	13	—	18	16	—	—
		15	—	16	—	—	—	—	—
	Reduction of area % min	—	—	40	—	—	—	—	—
		—	—	50	—	—	—	—	—

Data Sheet 11.3—Type 2 (ISO)**CHARACTERISTICS AND APPLICATIONS**

A general purpose case hardening steel develops a core strength of the order of 50 kg/mm², used for low stressed parts, such as small gear wheels, hubs, journals, pins, axle drums, pressed and stamped parts, shafts, levers, etc., used in vehicle construction and general engineering work, bolt levers, pawles, ratchets, chain wheels. Table 11.13 gives the chemical composition and mechanical properties of International Standard steels.

HEAT TREATMENT

Forging commence	1200°C max
Forging finish	900°C min
Carburizing	900–920°C
Core hardening	900°C
Case hardening	760–780°C (Water quench)
Tempering	150–180°C (To relieve stresses)

Figure 11.33 illustrates the end-quench hardenability and case hardened gradient.

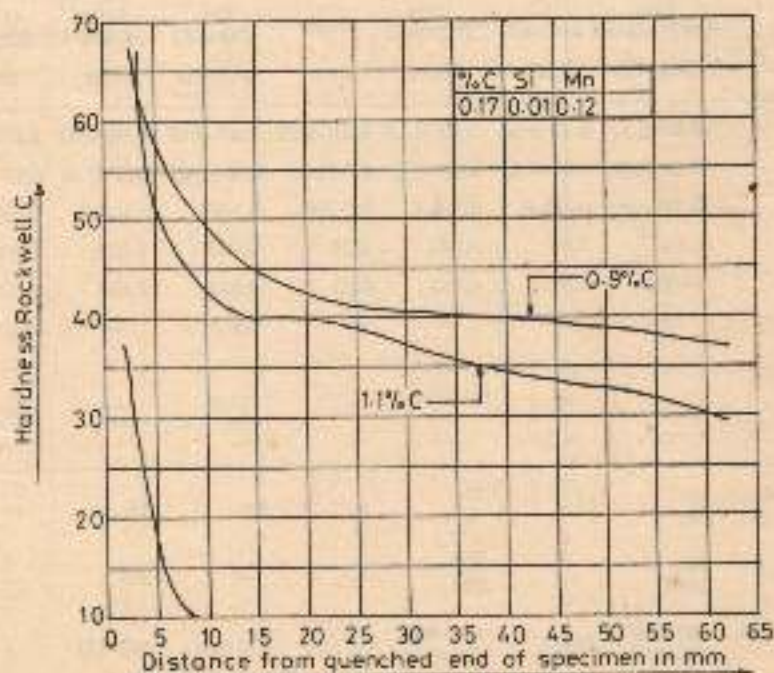


Fig. 11.33 End-quench hardenability curve and case-hardened gradient for steel—C14 (AISI-1018) carburized at 925°C for 9 h and case-hardened at 925°C for 20 min.

Table 11.13

Standard	ISO R683, XI-70	IS 4432-67	DIN 1721-69	AISI ASTM A876-81	BS 970/1-81	NFA 35-551-83	GOST 1050-74	JIS 4051-79
Designation	Type-2	C14	CK15	1015	080M15	XC12	15	S15C
Chemical composition	C %	0.12-0.18	0.10-0.18	0.13-0.18	0.12-0.18	0.10-0.16	0.12-0.19	0.13-0.18
	Si %	0.15-0.40	0.05-0.35	0.15-0.35	0.10-0.40	0.05-0.30	0.17-0.37	0.15-0.35
	Mn %	0.30-0.60	0.40-0.70	0.30-0.60	0.60-1.00	0.20-0.50	0.35-0.65	0.30-0.60
	≤ P %	0.035	0.035	0.04	0.035	0.035	0.040	0.03
	≤ S %	0.035	0.05	0.05	0.035	0.035	0.040	0.035
	Cr %	—	—	—	—	—	0.25	—
	Mo %	—	—	—	—	—	—	—
	Ni %	—	—	—	—	—	—	—
	Others	—	—	—	—	—	—	—
	Dimensions	11 30	15	11 30	19	16 16-40	—	—
Mechanical properties	0.2 % proof stress N/mm ² min	245 265	—	440 355	—	500 380	—	—
	Tensile strength N/mm ²	580-925 445-740	480	740-890 590-790	460 min	690-1080 540-830	—	—
	Elongation % min	12 14	17	12 14	16	11 15	—	—
	Reduction of area % min	—	—	35 45	—	—	—	—

Data Sheet 11.4—Type 3 (ISO)**CHARACTERISTICS AND APPLICATIONS**

Used for small parts with medium core strength (60–85 kg/mm²) and good wear resistance, such as piston pins, bushes, drilling machine spindles, roller bearings and measuring instruments, distribution gear parts, transmission parts, etc. Table 11.14 gives the chemical composition and mechanical properties of International Standard steels.

HEAT TREATMENT

Forging commence	1150°C max
Forging finish	850°C min
Normalizing	870–900°C (Air cool)
Soft annealing	650–700°C (Air cool)
Carburizing	900–930°C
Core hardening	850–880°C (Water quench)
Intermediate annealing	650–680°C
Case-hardening	770–800°C (Oil/salt quench)
Tempering	150–200°C (To relieve stresses and to avoid grinding cracks)

Figure 11.34 illustrates the end-quench hardenability and case hardened gradient.

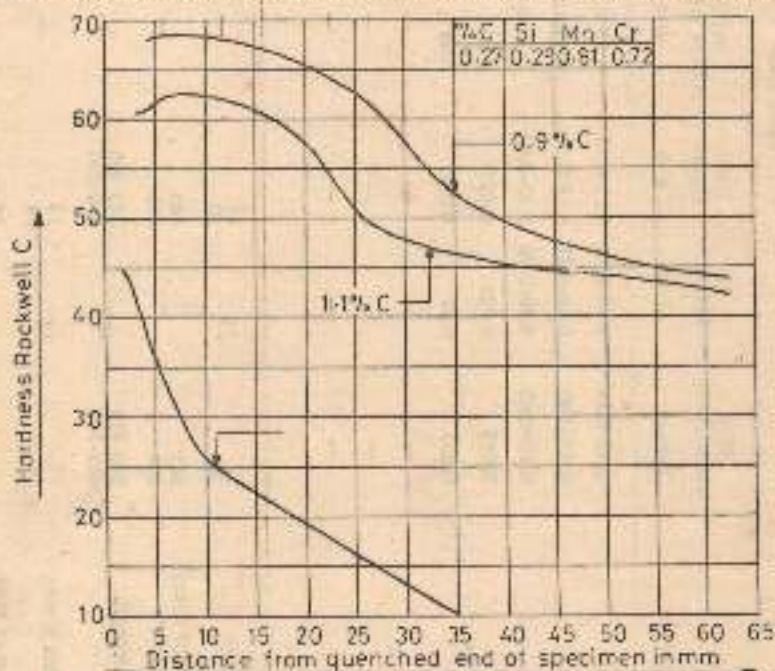


Fig. 11.34 End-quench hardenability curve and case-hardening gradient for Steel—15Cr65 carburized at 925°C for 9 h and case-hardened at 925°C for 20 min

Data Sheet 11.5—Type 5 (ISO)**CHARACTERISTICS AND TYPICAL APPLICATIONS**

Wear resistance parts requiring a core strength of up to 80–110 kg/mm² depending on the section thickness used for gear wheels, shafts, spindles, cam shafts, levers, steering parts, components in motor vehicles and general engineering distribution gears, etc. Table 11.15 gives the chemical composition and mechanical properties of International Standard steels.

HEAT TREATMENT

Forging commence	1100°C max
Forging finish	900°C
Normalizing	840–870°C
Soft annealing	650–700°C (Cool in air)
Carburizing	870–900°C
Core hardening	840–870°C (Oil/salt quench)
Intermediate annealing	650–700°C
Case hardening	810–840°C (Oil/salt quench)
Tempering	150–200°C (To relieve stresses and to avoid grinding cracks)

Figure 11.35 illustrates the end-quench hardenability and case hardness gradient.

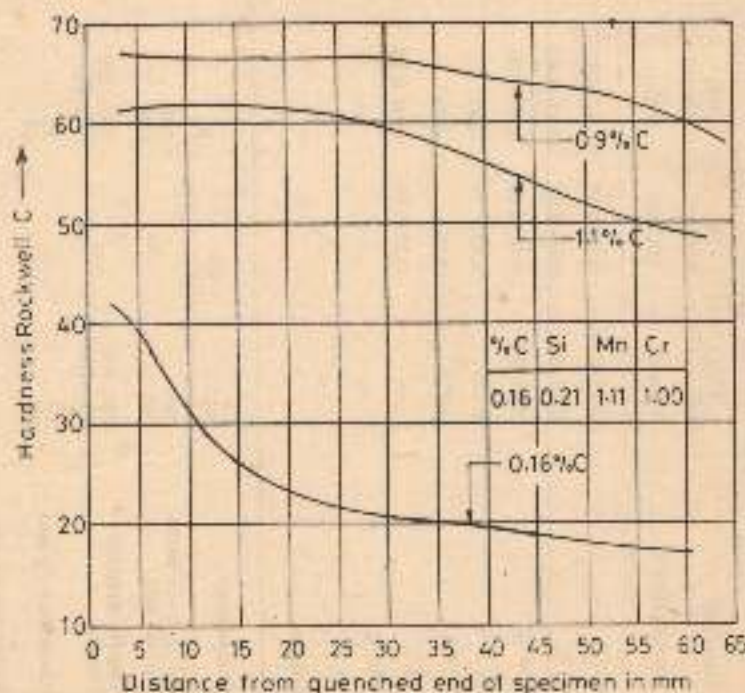


Fig. 11.35 End-quench hardenability curve and case-hardening gradient for steel—17MnCr95 carburized at 925°C for 9 h and case-hardened at 925°C

Table 11.15

Steel	Standard Designation	ISO R683/X1-70 Type-5	IS 4432-67 17Mn1Cr95	DIN 17210-69 16MnCr15	AISI	KS 970/3-71 527M20	NFA 353551-84 16MC15	GOST 4543-71 18ChG	JIS G4106-65 5MnCr21
Chemical composition	C %	0.13-0.19	0.14-0.19	0.14-0.19	—	0.17-0.23	0.14-0.19	0.15-0.21	0.16-0.23
	Si %	0.15-0.40	0.10-0.35	0.15-0.40	—	0.10-0.35	0.10-0.40	0.17-0.37	0.15-0.35
	Mn %	1.00-1.40	1.10-1.30	1.00-1.30	—	0.60-0.90	1.00-1.30	0.90-1.20	1.20-1.50
	≤ P %	0.035	0.035	0.035	—	0.035	0.035	0.035	0.030
	≤ S %	0.035	0.050	0.035	—	0.035	0.035	0.035	0.030
	Cr %	0.80-1.10	0.80-1.10	0.80-1.10	—	0.60-0.90	0.80-1.10	0.50-1.20	0.35-0.70
	Mo %	—	—	—	—	—	—	—	—
	Ni %	—	—	—	—	—	—	—	—
	Others	—	—	—	—	—	—	—	—
	Others	—	—	—	—	—	—	—	—
Mechanical properties	Dimensions	11 30	30	11 30	—	19	16 16-40	15	25
	0.2 % proof stress N/mm ² min	635 490	—	635 590	—	—	700 600	735	—
	Tensile strength N/mm ²	930-1270 780-1080	784	880-1180 780-1080	—	770 min	980-1330 830-1180	880 min	835 min
	Elongation % min	9 10	11	9 10	—	12	9 10	10	13
	Reduction of area % min	—	—	35 40	—	—	—	40	—

Data Sheet 11.6—Type-7 (ISO)**CHARACTERISTICS AND APPLICATIONS**

Due to their favourable composition and higher wear resistance, they rank under the most economical case hardening steels. Their applications include parts subjected to medium stresses but with a high surface hardness with a core strength of up to 100–130 kg/mm² depending on the section thickness such as gear wheels, steering parts, shafts, cam shafts, spindles, etc., for construction of vehicles and for general engineering work. Table 11.16 gives the chemical composition and mechanical properties of International Standard steels.

HEAT TREATMENT

Forging commence	1100°C max
Forging finish	850°C min
Normalizing	850–880°C (Cool in air)
Soft annealing	650–700°C (Cool in air)
Carburizing	900–930°C
Core hardening	840–870°C (Oil/salt quench)
Intermediate annealing	650–700°C
Case-hardening	810–840°C (Quenching in oil/salt)
Tempering	150–200°C (To relieve stresses and to avoid grinding cracks)

Figure 11.36 illustrates the end-quench hardenability curve and case hardness gradient.

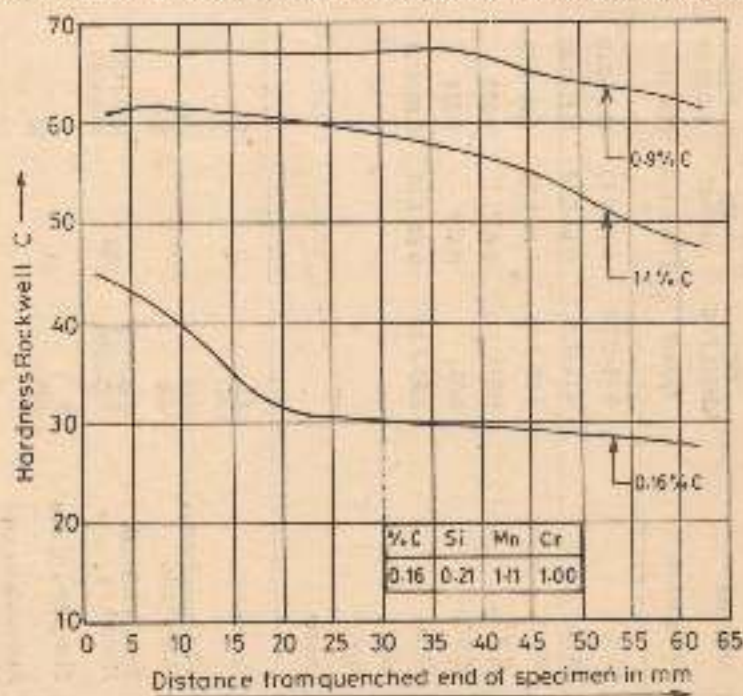


Fig. 11.36 End-quench hardenability curve and case-hardness gradient for steel—20MnCr1 (DIN 20MnCr5) carburized at 925°C for 9 h and case hardened at 925°C for 20 min

Table 11.16

Steel	Standard Designation	ISO R683/X1-79 Type-7	IS 4032-67 20MnCr1	DIN 17210-69 20MnCr5	AISI	BS	NFA 35/551-64 20MnCr5	GOST 18ChGT	JIS G4105-65 5MnCr420
Chemical composition	C %	0.15-0.21	0.17-0.22	0.17-0.22	—	—	0.17-0.22	0.17-0.23	0.17-0.23
	Si %	0.15-0.40	0.10-0.35	0.15-0.40	—	—	0.10-0.40	0.17-0.37	0.10-0.40
	Mn %	0.60-0.90	1.00-1.40	1.10-1.40	—	—	1.10-1.40	0.80-1.10	1.10-1.40
	≤ P %	0.035	0.035	0.035	—	—	0.035	0.035	0.035
	≤ S %	0.035	0.050	0.035	—	—	0.035	0.035	0.035
	Cr %	0.85-1.15	1.00-1.30	1.00-1.30	—	—	1.00-1.30	1.00-1.30	1.00-1.30
	Mo %	0.15-0.25	—	—	—	—	—	—	—
	Ni %	—	—	—	—	—	—	—	—
	Others	—	—	—	—	—	—	—	—
Mechanical properties	Dimensions	11 30	30	11 30	—	—	16-40	10	—
	0.2% proof stress N/mm ² min	685 540	—	725 685	—	—	700 850	835	—
	Tensile strength N/mm ²	1030-1390 830-1130	981	1080-1380 980-1280	—	—	1200-1550 950-1300	980 min	—
	Elongation % min	8 10	8	7 8	—	—	—	9	—
	Reduction of area % min	—	—	30 35	—	—	—	50	—

Data Sheet 11.7—16Ni1Cr80 (IS)**CHARACTERISTICS AND APPLICATIONS**

Used for gear box and transmission components, axles, driver shafts, cam shafts, etc. It develops a core strength of the order of 85 kg/mm² (29 mm) with moderate resistance to shock. Table 11.17 gives the chemical composition and mechanical properties of International Standard steels.

HEAT TREATMENT

Forging commence	1150°C max
Forging finish	900°C
Normalizing	850–880°C (Cool in air)
Soft annealing	650–670°C (Cool in air)
Carburizing	900–930°C
Core hardening	850–880°C (Oil/salt quench)
Intermediate annealing	650°C
Case-hardening	780–820°C (Oil/salt quench)
Tempering	150–200°C (To relieve stresses and to avoid grinding cracks)

Table 11.17

Steel	Standard	ISO R683/X1-70	IS 4432/67	DIN	AISI	BS 970/1-83	NFA 35/551-84	GOST	JIS
	Designation	Type 9	16Ni1Cr80	—	A5130	637M17	20NC6	20ChN	—
Chemical composition	C %	0.12–0.18	0.12–0.20	—	0.17–0.22	0.14–0.20	0.16–0.21	0.17–0.23	—
	Si %	0.15–0.40	0.10–0.35	—	0.20–0.35	0.035	0.1–0.4	0.17–0.37	—
	Mn %	0.60–0.90	0.60–1.00	—	0.60–0.80	0.6–0.9	0.6–0.9	0.4–0.7	—
	≤ P %	0.035	0.035	—	0.04	0.04	0.035	0.035	—
	≤ S %	0.035	0.050	—	0.04	0.05	0.035	0.045	—
	Cr %	0.8–1.1	0.6–1.0	—	0.55–0.75	0.60–1.0	0.90–1.20	0.45–0.75	—
	Mo %	—	—	—	—	—	—	—	—
	Ni %	1.3–1.7	0.8–1.2	—	1.1–1.4	0.85–1.25	1.2–1.5	1.0–1.4	—
	Others								
Mechanical properties	Dimensions	11 30	60 100	—	—	19	16 16.40	—	—
	0.2% proof stress N/mm ² min	630 540	—	—	—	—	850 700	—	—
	Tensile strength N/mm ²	981–1324 834–1128	785 736	—	—	930	1200–1550 950–1300	—	—
	Elongation % min	8 10	—	—	—	—	8 9	—	—
	Reduction of area % min	—	—	—	—	—	—	—	—

Data Sheet 11.8—16Ni80Cr60 (IS)

CHARACTERISTICS AND APPLICATIONS

Widely used in automobile industry for lightly loaded gear box and transmission components, also in the aircraft industry for cams etc. It develops a core strength of the order of 70 kg/mm² (29 mm) with good resistance to shock. Table 11.18 gives the chemical composition and mechanical properties of International Standard steels.

HEAT TREATMENT

Forging commence	1150°C max
Forging finish	900°C min
Normalizing	850–880°C (Cool in air)
Soft annealing	650–680°C (Cool in air)
Carburizing	900–930°C
Core hardening	850–880°C (Oil/salt quench)
Intermediate annealing	650°C
Case-hardening	780–820°C (Oil/salt quench)
Tempering	150–200°C (To relieve stresses and to avoid grinding cracks)

Table 11.18

Steel	Standard Designation	ISO	IS 4432/67 16Ni80Cr60	DIN	AISI	BS 970/1–83 635M15	NFA	GOST	JIS
		—		—	A3115		20NC2	—	—
Chemical composition	C%	—	0.12–0.20	—	0.13–0.18	0.12–0.18	0.8–0.23	—	—
	Si%	—	0.10–0.35	—	0.2–0.35	0.035	0.1–0.4	—	—
	Mn%	—	0.6–1.0	—	0.4–0.6	0.6–0.9	0.4–0.7	—	—
	≤ P%	—	0.035	—	0.04	0.04	0.04	—	—
	≤ S%	—	0.05	—	0.04	0.05	0.035	—	—
	Cr%	—	0.4–0.8	—	0.55–0.75	0.4–0.8	0.5–0.7	—	—
	Mo%	—	—	—	—	—	—	—	—
	Ni%	—	0.6–1.0	—	1.1–1.4	0.7–1.1	0.5–0.7	—	—
Mechanical properties	Others	—	—	—	—	—	—	—	—
	Dimensions	—	90	—	—	—	—	—	—
	0.2% proof stress N/mm ² min	—	—	—	—	—	—	—	—
	Tensile strength N/mm ²	—	687	—	—	—	—	—	—
	Elongation % min	—	15	—	—	—	—	—	—
	Reduction of area % min	—	—	—	—	—	—	—	—

Figures 11.37 (a) and (b) show the effect of tempering temperature on case hardness and the end-quench (Jominy) hardenability band, respectively.

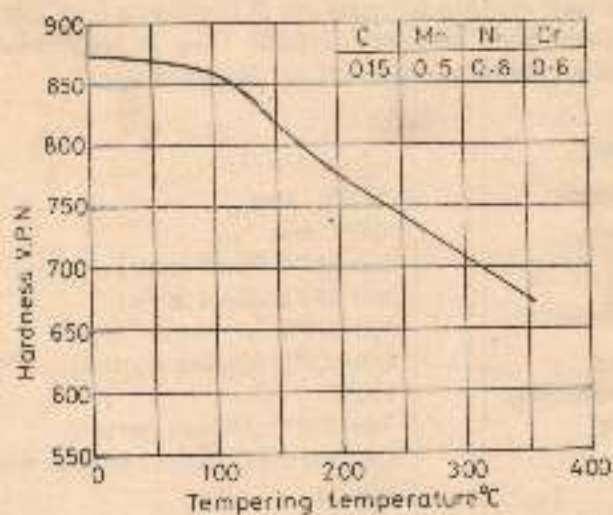


Fig. 11.37 (a) Effect of tempering temperature on case hardness for steel—16Ni80Cr60 (En 351), carburized 900°C, oil-refined 860°C, oil-hardened 800°C

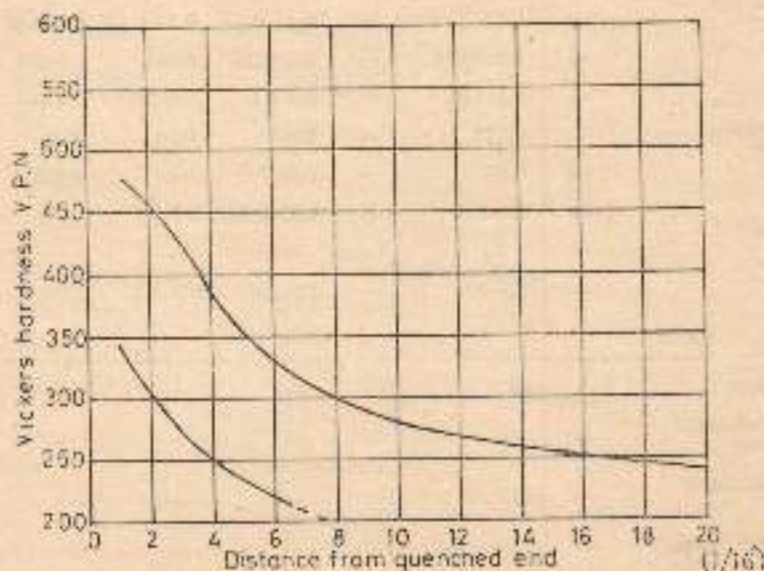


Fig. 11.37 (b) End-quench (Jominy) hardenability band

Data Sheet 11.9—13Ni3Cr80 (IS)

CHARACTERISTICS AND APPLICATIONS

Highly stressed parts of high toughness and a core strength of up to 100 kg/mm² (29 mm) for automotive and transmission appliances, such as bevel gears, pinion, rim gears, shafts, crank shafts, pin, etc. Table 11.19 gives the chemical composition and mechanical properties of International Standard steels.

HEAT TREATMENT

Forging commence	1100°C max
Forging finish	900°C min
Normalizing	830–860°C (Cool in air)
Soft annealing	620–650°C (Cool in air)
Carburizing	900–930°C
Core hardening	830–860°C (Oil/salt quench)
Intermediate annealing	630–650°C
Case hardening	790–810°C (Oil/salt quench)
Tempering	150–200°C (To relieve hardening stresses and to avoid grinding cracks)

Figure 11.38 (a) shows the effect of tempering temperature on case hardness, while Fig. 11.38 (b) demonstrates the end-quench (Jominy) hardenability band.

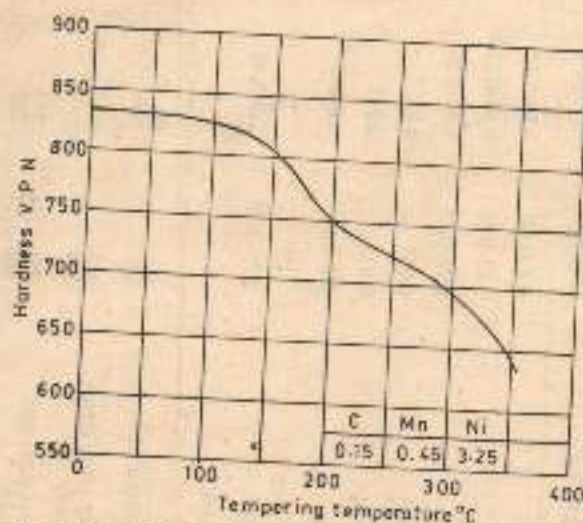


Fig. 11.38 (a) Effect of tempering temperature on case hardness for steel—13Ni3Cr80 (En 36), carburized 900°C, oil-refined 900°C, oil-hardened 760°C

Table 11.19

Steel	Standard Designation	ISO R683/X1-70 Type-11	IS 4432-67 13Ni3Cr80	DIN 17210-69 14NiCr14	AISI 3310H	BS 970/1-83 655M13	NFA 16NC12	GOST	JIS G4102/65 SNC22
Chemical composition	C %	0.1-0.16	0.10-0.15	0.10-0.17	0.07-0.13	0.12-0.16	0.12-0.17	—	0.12-0.18
	Si %	0.15-0.40	0.10-0.35	0.15-0.35	0.20-0.35	0.10-0.35	0.35	—	0.15-0.35
	Mn %	0.35-0.65	0.40-0.70	0.40-0.70	0.45-0.60	0.35-0.60	0.50	—	0.30-0.70
	≤ P %	0.035	0.05	0.035	0.025	0.040	0.030	—	0.030
	≤ S %	0.035	0.025	0.035	0.025	0.050	0.025	—	0.030
	Cr %	0.6-0.9	0.6-1.0	0.55-0.95	1.40-1.75	0.70-1.00	0.50-1.00	—	0.7-1.0
	Mo %	—	—	—	—	—	—	—	—
	Ni %	2.75-3.25	3.0-3.50	3.25-3.75	3.20-3.75	3.00-3.75	3.00-3.50	—	3.00-3.50
	Others	—	—	—	—	—	—	—	—
	Dimensions	11 30	60 100	11 30	—	19	—	—	25
Mechanical properties	0.2% proof stress N/mm ² min	638 589	—	835 785	—	—	—	—	—
	Tensile strength N/mm ²	981-1324 890-1177	833 785	1030-1320 930-1230	—	1000	—	—	981
	Elongation % min	8 9	12	9 30	—	9	—	—	12
	Reduction of area % min	—	—	40 45	—	—	—	—	—

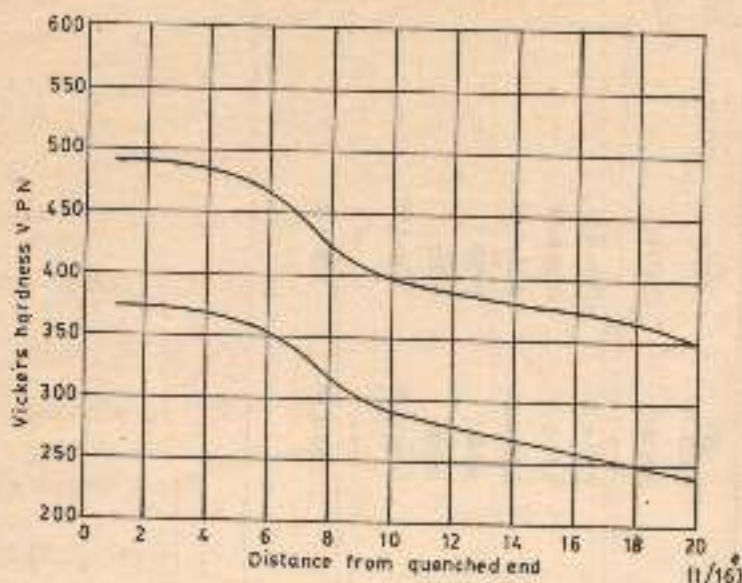


Fig. 11.38 (b) End-quench (Jominy) hardenability band

Data Sheet 11.10—15Ni4Cr1 (IS)

CHARACTERISTICS AND APPLICATIONS

Highly stressed parts with toughness and a core strength of up to 135 kg/mm² (14 mm) with good resistance to shock. Carburizes and hardens to produce a hard wear resistance.

Used mainly for components such as gear wheels, steering parts, crank shafts, pins, counter shafts. Also used for aero-engine gears and super charger gears. Table 11.20 gives the chemical composition and mechanical properties of International Standard steels.

HEAT TREATMENT

Forging commence	1100°C max
Forging finish	900°C min
Normalizing	830–860°C (Air cool)
Soft annealing	650–640°C (Cool in air)
Carburizing	900–930°C
Core hardening	850–880°C (Oil/salt quench)
Intermediate annealing	600–630°C
Case hardening	780–810°C (Oil/salt quench)
Tempering	150–200°C (To relieve stresses and to avoid cracks during grinding)

Table 11.20

Steel	Standard	ISO R	IS 4432:67 15N4Cr1	DIN 14N/Cr18	AISI	BS 920/3-71 659M15	NFA 12ND16	GOST	JIS
Chemical composition	Designation	—	—	—	—	—	—	—	—
	C %	—	0.12-0.18	0.10-0.17	—	0.12-0.18	0.08-0.15	—	—
	Si %	—	0.10-0.35	0.15-0.35	—	0.10-0.35	0.10-0.35	—	—
	Mn %	—	0.40-0.70	0.40-0.70	—	0.25-0.50	0.35-0.60	—	—
	≤ P %	—	0.035	0.035	—	0.040	0.040	—	—
	≤ S %	—	0.035	0.035	—	0.050	0.035	—	—
	Cr %	—	1.00-1.40	0.90-1.30	—	1.00-1.40	0.70-1.20	—	—
	Mo %	—	—	—	—	—	—	—	—
	Ni %	—	3.80-4.30	4.25-4.75	—	3.90-4.30	3.70-4.40	—	—
	Others	—	—	—	—	—	—	—	—
Mechanical Properties	Dimensions	—	30 90	11 50	—	—	—	—	—
	0.2% proof stress N/mm ² min	—	—	930 885	—	—	—	—	—
	Tensile strength N/mm ²	—	1324 1046	1270-1420 1180-1370	—	—	—	—	—
	Elongation % min	—	9	7	—	—	—	—	—
	Reduction of area % min	—	—	35 40	—	—	—	—	—

Data Sheet 11.11—20Ni2Mo25 (IS)

CHARACTERISTICS AND APPLICATIONS

Parts requiring core strength of the order of 85–120 kg/mm² (29 mm) with very good resistance to shock. This is a popular, high grade carburizing steel for important parts where reliability and uniformity are required.

Applications include cam shafts, cams, gears in the automotive industry for differential pinions, differential pinion shafts, knuckle pins, piston pins, spline shafts, differential and transmission gears and bearings. In aircraft engines it is used for cam shafts, bearing and gears. Table 11.21 gives the chemical composition and mechanical properties of International Standard steels.

HEAT TREATMENT

Forging commence	1200°C max
Forging finish	900°C min
Normalizing	850–880°C (Cool in air)
Soft annealing	650–670°C (Cool in air)
Carburizing	880–920°C
Core hardening	850–880°C (Oil/salt quench)
Intermediate annealing	650–670°C
Case hardening	780–820°C (Oil/salt quench)
Tempering	150–200°C (To relieve stresses and avoid grinding cracks)

Figure 11.39 illustrates the end-quench hardenability band and case hardness gradient.

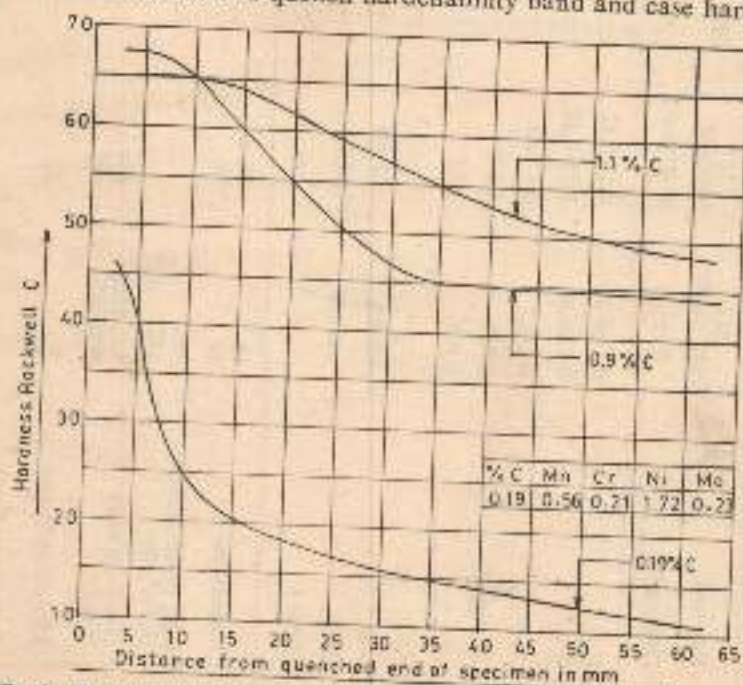


Fig. 11.39 End-quench hardenability band and case-hardness gradient for steel—20Ni2Mo25, carburized at 925°C for 9 h and case hardened at 925°C for 20 min.

Table 11.21

Steel	Standard Designation	ISO R681/XT-70 Type-6	IS 4432-67 20Ni2Mo25	DIN	AISI	BS 970/2-83 665M20	NFA	GOST	JIS
Chemical composition	C %	0.17-0.23	0.17-0.22	—	0.17-0.23	0.17-0.23	—	—	—
	Si %	0.15-0.40	0.15-0.35	—	0.2-0.35	0	—	—	—
	Mn %	0.4-0.7	0.4-0.65	—	0.45-0.65	0.35-0.75	—	—	—
	≤ P %	0.035	0.035	—	0.04	—	—	—	—
	≤ S %	0.035	0.05	—	0.04	—	—	—	—
	Cr %	—	—	—	—	—	—	—	—
	Mo %	0.2-0.3	0.2-0.3	—	0.2-0.3	0.2-0.3	—	—	—
	Ni %	1.6-2.0	1.65-2.0	—	1.65-2.0	1.5-2.0	—	—	—
	Others	—	—	—	—	—	—	—	—
	Dimensions	11 30	30 60	—	—	19	—	—	—
Mechanical properties	0.2% proof stress N/mm ² min	589 442	—	—	—	—	—	—	—
	Tensile strength N/mm ²	885-1226 640-935	834 697	—	—	850	—	—	—
	Elongation % min	9 12	12	—	—	11	—	—	—
	Reduction of area % min	—	—	—	—	—	—	—	—

Data Sheet 11.12—20Ni55Cr50Mo20 (IS)

CHARACTERISTICS AND TYPE OF APPLICATIONS

Parts requiring very high toughness, with a core strength of up to 80–130 kg/mm² (29 mm).
Machinability fairly good.

Used for gears, pinions, shafts, steering mechanisms, automobile gear box and transmission components, differential ring gears, aircraft engines, cam shafts, spline shafts, etc., Table 11.22 indicates the chemical composition and mechanical properties of International Standard steels.

HEAT TREATMENT

Forging commence	1150°C max
Forging finish	900°C min
Normalizing	850–880°C (Cool in air)
Soft annealing	650–700°C (Cool in air)
Carburizing	880–930°C
Core hardening	850–880°C (Oil/salt quench)
Intermediate annealing	630–650°C
Case hardening	800–830°C (Oil/salt quench)
Tempering	150–200°C (To relieve stresses and to avoid grinding cracks)

Figure 11.40 illustrates the end-quench hardenability band and case-hardness gradient.

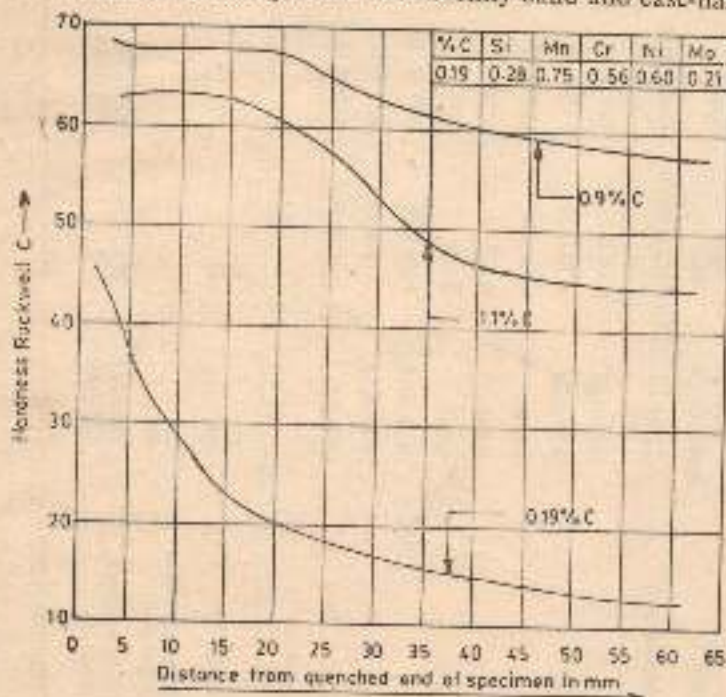


Fig. 11.40 End-quench hardenability band and case-hardness gradient for steel—21NiCrMo2, carburized at 925°C for 9 h and case-hardened at 925°C for 20 min

Table 11.22

Steel	Standard	ISO R683/X1.70 Type 12	IS 4432-67 20Ni5Cr40Mo20	DIN 21NiCrMo2	AISI 8620	BS 970/1-83 805M20	NFA 35/551-84 20NCD2	GOST	JIS G4103-65 8NCM21
Chemical composition	C %	0.17-0.23	0.10-0.23	0.17-0.23	0.18-0.23	0.17-0.23	0.17-0.23	—	0.17-0.23
	Si %	0.15-0.40	0.20-0.35	0.15-0.40	0.15-0.30	0.10-0.35	0.10-0.40	—	0.15-0.35
	Mn %	0.6-0.9	0.70-0.90	0.60-0.90	0.70-0.90	0.60-0.95	0.65-0.95	—	0.60-0.90
	≤ P %	0.035	0.035	0.035	0.035	0.040	0.035	—	0.030
	≤ S %	0.035	0.030	0.035	0.040	0.050	0.035	—	0.030
	Cr %	0.35-0.65	0.40-0.60	0.35-0.65	0.40-0.60	0.35-0.65	0.40-0.65	—	0.40-0.65
	Mo %	0.15-0.24	0.15-0.25	0.15-0.25	0.15-0.25	0.15-0.25	0.15-0.25	—	0.15-0.30
	Ni %	0.4-0.7	0.40-0.70	0.40-0.70	0.40-0.70	0.35-0.75	0.40-0.70	—	0.40-0.70
Mechanical properties	Others								
	Dimensions	11 30	30 90	11 30	—	19	16 17-40	—	25
	0.2% proof stress N/mm ² min	638 490	—	785 590	—	—	750 600	—	—
	Tensile strength N/mm ²	680-1125 735-1030	685 735	980-1270 780-1080	—	850	1050-1450 800-1200	—	835
	Elongation % min	8 11	11	9 10	—	11	8 10	—	17
	Reduction of area % min	—	—	35 40	—	—	—	—	—

Data Sheet 11.13—Type 10 (ISO)

CHARACTERISTICS AND APPLICATIONS

A medium-grade case-hardening steel. It develops a core strength of the order of 95–130 kg/mm² (29 mm) (depending on the cross section) with good resistance to shock, carburized and hardened to produce a hard wear resistance.

Used for heavy-duty gears, heavy-vehicle and automobile transmission components, aircraft engine bearings and gears. Table 11.23 gives the chemical composition and mechanical properties of International Standard steels.

HEAT TREATMENT

Forging commence	1150°C max
Forging finish	900°C min
Normalizing	860–880°C (Cool in air)
Soft annealing	650°C (Cool in air)
Carburizing	875–930°C
Core hardening	830–860°C (Oil/salt quench)
Intermediate annealing	650°C
Case-hardening	780–820°C (Oil/salt quench)
Tempering	150–200°C (To relieve stresses and reduce the danger of grinding cracks)

Figure 11.41 illustrates the effect of tempering temperature on case hardness.

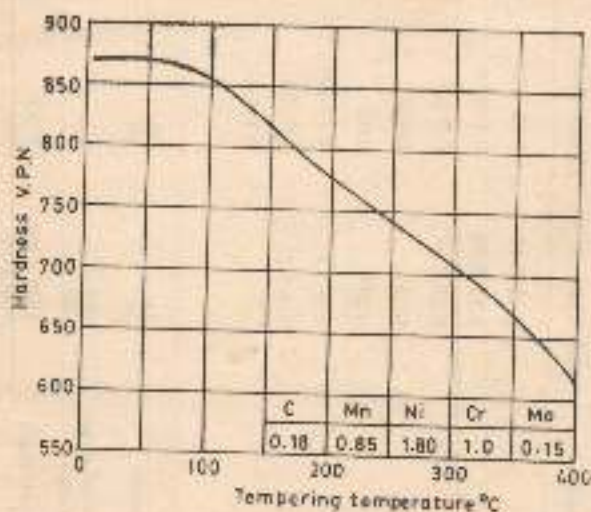


Fig. 11.41(a) Effect of tempering temperature on case-hardness for steel—15Ni2Cr1Mo15 (En 354)

Table 11.23

Steel	Standard	ISO R683/XL-70 Type 10	TS 4432-67 15Ni2CrMo15	DIN 17210-69 15CrNi6	AISI 4320	BS 970/1-83 815M17	NEA 35/551-84 16NC6	GOST 4543-71 12ChN13P	JIS
Chemical composition	C %	0.11-0.17	0.12-0.18	0.12-0.17	0.17-0.22	0.14-0.20	0.12-0.17	0.09-0.16	—
	Si %	0.15-0.40	0.1-0.35	0.15-0.35	0.2-0.35	0.1-0.35	0.1-0.4	0.17-0.37	—
	Mn %	0.35-0.65	0.6-1.0	0.4-0.6	0.45-0.65	0.6-0.9	0.6-0.9	0.3-0.6	—
	≤ P %	0.035	0.035	0.035	0.035	0.035	0.035	0.025	—
	≤ S %	0.035	0.05	0.035	0.040	0.035	0.035	0.025	—
	Cr %	1.4-1.7	0.75-2.0	1.4-1.7	0.4-0.6	0.8-1.2	0.85-1.15	0.6-0.9	—
	Ni %	1.3-1.7	1.5-2.0	1.4-1.7	1.65-2.00	1.2-1.7	1.2-1.6	2.75-3.25	—
Mechanical properties	Mo %	—	0.1-0.2	—	0.2-0.3	0.1-0.2	—	—	—
	Others	—	—	—	—	—	—	—	—
	Dimensions	11 30	30 60	11 30	—	—	16 17-40	15	—
	0.2% proof stress N/mm ² min	685 635	—	685 635	—	—	800 620	685	—
	Tensile strength N/mm ²	1030-1380 930-1230	1080 980	960-1280 880-1180	—	—	1100-1400 850-1150	930 min	—
	Elongation % min	8 9	9	8 9	—	—	9 10	11	—
	Reduction of area % min	—	—	35 40	—	—	—	35	—

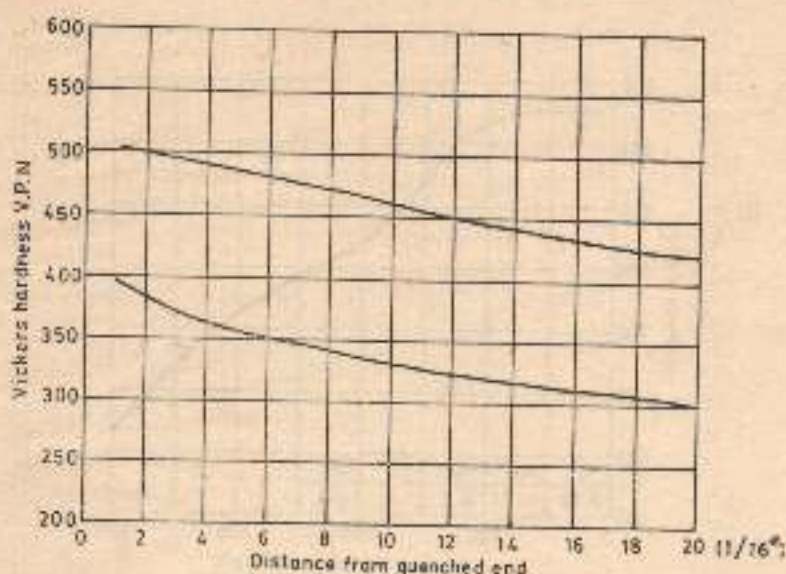


Fig. 11.41 (b) End quench (Jominy) hardenability band

Data Sheet 11.14—Type 14 (ISO)

CHARACTERISTICS AND APPLICATIONS

Suitable for heavy and highly stressed gearing components requiring high toughness, with a core strength of the order of 100–140 kg/mm² (29 mm) (70–85 tsi) and good resistance to shock. It may be carburized and hardened to produce a hard wear-resistance case.

Used for shafts, pinions, differential pinions, heavy duty gears, main spindles, heavy vehicle and transmission components etc. Table 11.24 gives the chemical composition and mechanical properties of International Standard steels.

HEAT TREATMENT

Forging commence	1150°C max
Forging finish	900°C min
Normalizing	850–880°C (Cool in air)
Soft annealing	650–700°C (Cool in air)
Carburizing	880–930°C
Core hardening	830–860°C (Oil quench)
Intermediate annealing	630–650°C
Case-hardening	760–800°C (Quench in oil)
Tempering	150–200°C (Recommended to relieve stresses and to reduce grinding cracks)

Figure 11.42 shows the effect of tempering temperature on case hardness.

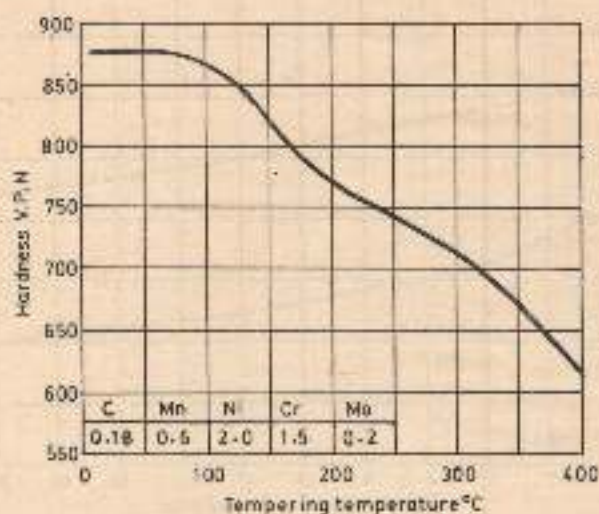


Fig. 11.42 (a) Effect of tempering temperature on case hardness for steel—16NiCr2Mo20 (B9-En 355), carburized 900°C, oil-refined 860°C, oil-hardened 800°C

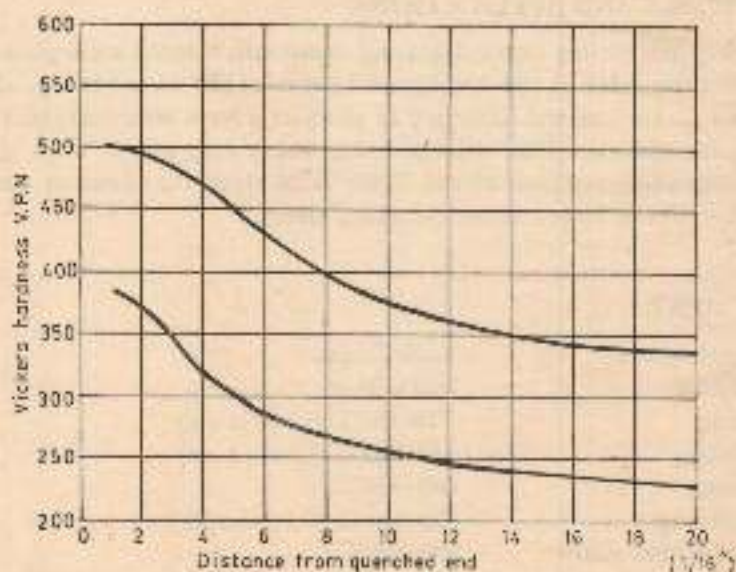


Fig. 11.42 (b) End-quench (Jominy) hardenability band

Table 11.24

Steel	Standard	ISO R683:XL-70	IS 4432-62	DIN 17210-69	AISI	BS 970/1-83	NFA 35/551-84	GOST	JIS
	Designation	Type 14	16NiCr2Mo20	17CrNiMo6	—	820M17	18NCD6	12Ch2N4A	—
Chemical composition	C %	0.11-0.17	0.12-0.20	0.14-0.19	—	0.14-0.20	0.14-0.20	0.09-0.16	—
	Si %	0.15-0.40	0.10-0.35	0.15-0.40	—	0.10-0.35	0.10-0.40	0.17-0.37	—
	Mn %	0.30-0.60	0.40-0.70	0.40-0.60	—	0.60-0.90	0.60-0.90	0.30-0.60	—
	≤ P %	0.035	0.035	0.035	—	0.035	0.035	0.025	—
	≤ S %	0.035	0.050	0.035	—	0.035	0.035	0.025	—
	Cr %	0.80-1.0	1.40-1.70	1.50-1.80	—	0.80-1.20	0.85-1.15	1.25-1.65	—
	Mo %	0.20-0.30	0.15-0.25	0.25-0.35	—	0.10-0.20	0.15-0.25	—	—
	Ni %	1.2-1.6	1.8-2.2	1.40-1.70	—	1.5-2.0	1.20-1.60	3.25-5.65	—
	Others								
Mechanical properties	Dimensions	11 30	30 90	11 30	—	19	16 17-40	15	—
	0.2% proof stress N/mm ² mils	785 735	—	835 785	—	—	850 750	930	—
	Tensile strength N/mm ²	1130-1470 1080-1370	1324 1130	1180-1430 1080-1330	—	1160	1200-1550 1000-1300	1130	—
	Elongation % min	8	9	7 8	—	8	8 9	10	—
	Reduction of area % min	—	—	30 35	—	—	—	30	—

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Cyaniding

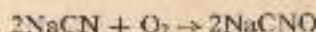
Cyaniding, also called liquid carbonitriding, is used to impart carbon and nitrogen to the surface of components, especially on small parts. This is carried out in a molten salt bath composed of sodium cyanide (20–50%), sodium cyanate and sodium carbonate, with or without sodium chloride as a diluent. Cyaniding time varies approximately between 5 and 90 minutes depending on the depth of the case required. The resulting case contains about 0.6 to 0.8% carbon and 0.3 to 0.5% nitrogen. The presence of nitrogen increases the hardenability of the steel.¹

The main object of cyaniding is to increase the hardness and wear resistance under small specific loads. The carbonitrided layer increases the endurance limit and thus the fatigue strength, particularly in the case of medium and small components. Cyaniding may be applied for carbon and all types of constructional steels. It is normally applied for bolts, screws, nuts, small gears, and other machine parts of low and medium carbon steels.

12.1 Chemical Phenomena Related to Cyaniding

The cyaniding bath consists of a mixture of sodium cyanide (20–50%), and sodium cyanates, carbonates, alkaline chlorides and alkaline earth chlorides. At an operating temperature of about 760 to 950°C the percentage of sodium cyanate does not normally exceed 3%. Sodium carbonate is the end product finally formed when the molten cyanide main chemical reactions occurs during the process.

The sodium cyanide in the bath gets oxidized due to the presence of oxygen in the air as follows:



Sodium cyanate decomposes thermally to give sodium cyanide, sodium carbonate, carbon monoxide and nitrogen as follows:



The cyanide reformed from the cyanate is available for further reaction, the sodium carbonate being the end product.

Carbon monoxide, formed by the decomposition of sodium cyanate (NaCNO), forms atomic carbon when it comes into contact with the iron. This atomic carbon directly enters into the gamma iron lattice at the operating temperature.



At the same time nitrogen produced by the dissociation of the sodium cyanate is also introduced into the gamma iron.

Since sodium carbonate is the end product of the carburizing reaction, it tends to build up in the cyanide bath to as much as 80% of the composition of the bath. The presence of alkali earth chlorates activates the salt bath. The composition of a working cyanide/carbonate bath is usually as follows^{1,2}:

Sodium cyanide	→ 20-50%
Sodium cyanate	→ 0.5-3%
Sodium carbonate	→ Balance

12.2 Cyanide Carbonate Baths

Cyaniding is carried out in a bath containing 20-50% cyanide. To prepare a bath for cyaniding, first neutral salts are melted in a clean dry pot. The required amount of sodium cyanide is then added. The salts should be free from moisture before placing in the pot. Neutral salts, anhydrous sodium carbonate and sodium chloride are added to provide fluidity and to control the melting point of the mixture. After thorough melting the bath temperature is raised to the specified case-hardening temperature. Also, the surface of the bath is covered with a fine grade graphite powder to conserve the bath strength, prevent fume, reduce fuel consumption and to increase the pot life.

It is also necessary to check the bath composition daily to maintain the desired percentage of sodium cyanide after treating the components in the bath. To maintain the bath strength, sodium cyanide (96-98%) alone may be added. It may be necessary to remove some of the melt from the pot to accommodate the fresh cyanide going in and yet maintain the correct level.

The composition of the bath prepared mainly depends on the required case depth and the material used. For a lower case depth of 0.25 mm or less, the percentage of cyanide maintained in the bath should be around 20-25% and for a higher case depth of 0.6 mm or more, the cyanide percentage in the bath should be around 40-50%. In general, a preferred composition for normal applications on different materials is roughly 30% sodium cyanide, 40% sodium carbonate and 30% sodium chloride.

A cyanide bath containing 10-30% sodium cyanide can be used for reheating the carburized components for hardening (after removing the carburized layer). A 2 to 15% sodium cyanide bath can be used for clean hardening or carbon restoration of medium carbon steels.

12.3 Surface Hardening in Cyanide

Cyaniding is carried out in the temperature range of about 800-900°C. The components to be treated should be free from moisture, scale, dirt, oil, etc., and should be immersed in the bath by using some suitable fixture or basket or suspenders depending on the type and size of the component. Before placing them into the bath, components are preheated to

200–500°C, to remove the moisture. Introduction of the charge into the bath results in a fall of the temperature of the bath and hence it is again heated until the required temperature of 850–900°C is reached. The charge is then allowed to soak for about 10 to 60 minutes, depending on the required case depth. Holding for more than one hour may also be adopted, but normally in such cases liquid carburizing is preferred. After the soaking time is over, the components are quenched in water or oil depending on the type of material used, the hardness required and the degree of distortion allowed.

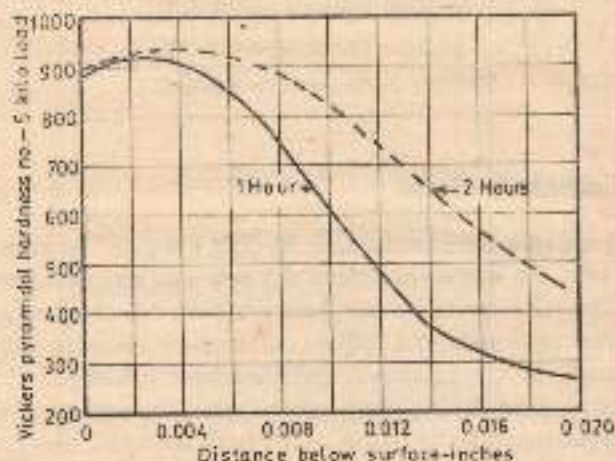


Fig. 12.1 Depth-hardness curves of 9/16 in. diameter MS steel carburized in a 43% NaCN bath at 900°C, for the times stated, oil-quenched and then hardened with a water quench from 780°C. Bars ground in steps.^{1,3}

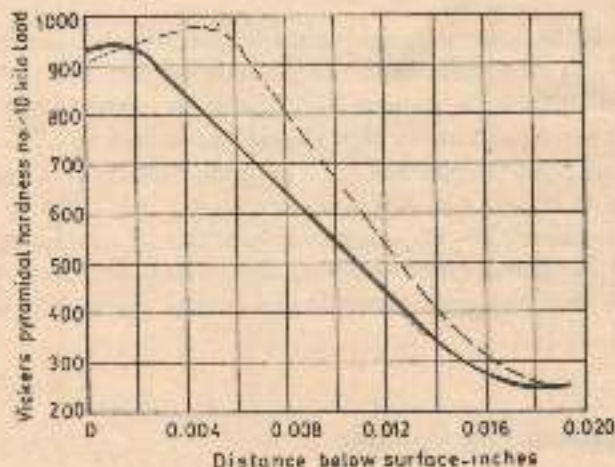


Fig. 12.2 Depth-hardness curves of 9/16 in. diameter MS steels carburized in a 40% NaCN bath at 850°C, for the times stated, oil-quenched and then hardened with a water quench from 780°C. Bars ground in steps.

Components made from mild steels are normally water quenched to achieve a higher hardness. Thin components are sometimes oil quenched. When there is a distortion problem, the components may be first quenched in oil, reheated to 780°C and then quenched in water. Figures 12.1 and 12.2 illustrate higher hardness obtained in the case of components quenched in water. The temperature of water before quenching should be around 25°C.

Oil hardening steels such as alloy steels and high carbon tool steels are quenched in oil. The oil used should be a pure mineral oil and the temperature of the oil should not exceed 60–70°C.

12.4 Equipment for Cyaniding

Pots used for cyaniding are made of plain mild steel or a nickel-chromium heat-resisting alloy.

Furnaces used for the cyaniding process employ either gas, oil or electricity for heating. Electrical heating using immersed electrodes are usually preferred. Generally this equipment used for liquid carburizing can also be used for cyaniding.

Since the immersion time is short, the temperature control system employed in the furnace must be accurate. It is necessary to check the pyrometer and thermocouples daily. The accuracy of the thermocouples can be determined by a new calibrated thermocouple with the old one in the salt bath at a steady temperature, and connecting each in turn to the instrument. If the old thermocouple reads low it should be removed.

Handling of small components may be done by using fixtures. The gears are suspended one above the other using tackles; for delicate parts wires are used for suspension. The material used for fixtures, tackles and baskets is either mild steel or Ni-Cr heat resisting steels.

12.5 Selective Hardening

Selective hardening is employed for hardening an end-portion of the component by immersing it only to the depth required. Both ends of long spindles can be hardened, leaving the centre soft. However the line between the hard and soft areas cannot be precisely controlled. Areas where softness is required can also be obtained by a 0.03 mm thick copper plating around the portion. However, if the cyanide percentage in the bath exceeds 30%, copper plating is not advisable since the copper dissolves and redeposits on to the work piece. Another alternative is to provide some extra allowance before the final machining; after the treatment, the components may be ground.

12.6 Effect of Temperature on Bath Strength and Case

Cyaniding is done in the temperature range of about 800 to 950°C. A lower temperature is preferred when it is aimed to reduce the distortion after quenching; a high temperature may be preferred for robust parts. Increasing the temperature will enable a greater case depth in a given time. At higher temperatures more of carbon goes into the case than

nitrogen. But as the temperature of the bath is lowered the ratio of nitrogen to carbon in the case increases. Figure 12.3 illustrates the effect of temperature on the cyanide case.

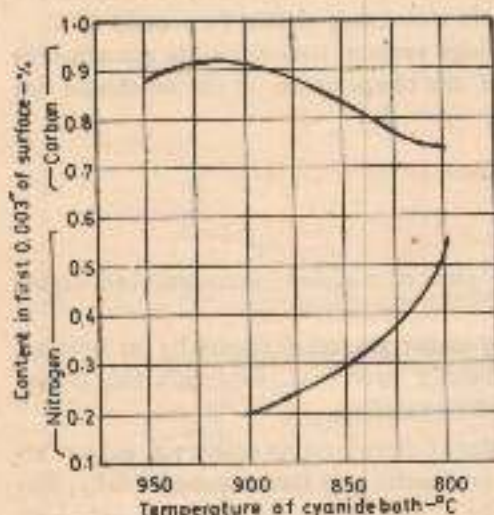


Fig. 12.3 The effect of temperature of carburizing on the composition of a case produced in a cyanide carbonate bath containing 50% NaCN, cyanided for 2½ h at the temperature stated

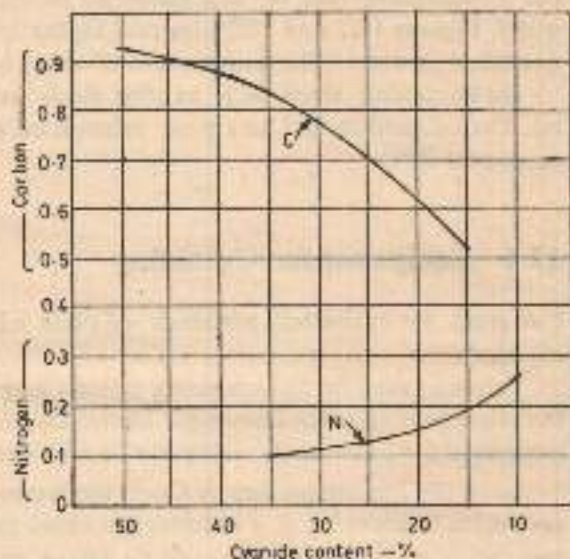


Fig. 12.4 Surface concentrations of carbon and nitrogen as functions of the NaCN content, when carburizing unalloyed case-hardening steel for 2½ h at 950°C in a liquid carburizing bath under a protective cover of graphite. The C and N estimations were carried out on a 0.075 mm thick surface layer on a specimen.

As the temperature is lowered to 800°C, the carbon content diminishes but the nitrogen percentage increases¹.

The amount of carbon and nitrogen picked up by the steel depends mainly on its temperature. Figure 12.4 shows that the carbon concentration increases whereas the nitrogen decreases, as the cyanide content increases from 10 to 50%. Hence it is most important to maintain the correct strength in a cyanide bath in order to obtain the desired case. The effect of the bath strength on the hard zone in a case may be seen from Fig. 12.5 which compares the results obtained on test bars carburized for the same time and temperature in 3 baths of different strengths. The bath containing a higher cyanide leads to a higher harden-

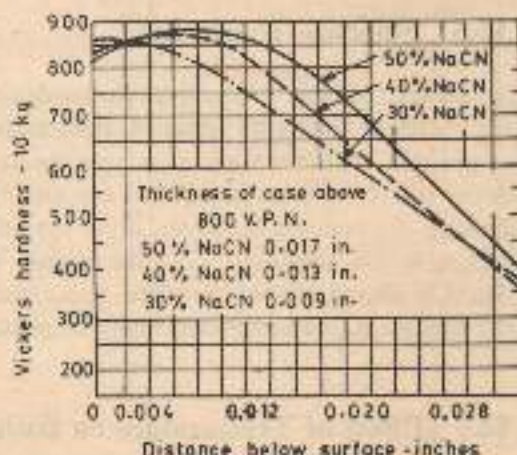


Fig. 12.5 Depth-hardness curves with varying-strength cyanide baths. All bars carburized for 2½ h at 950°C and oil-quenched, reheated to 780°C and water quenched. Bars ground in steps.

ability compared to the lower one. Hence it is necessary to know the correct strength to attain the required case depth on the component by holding it for the required time.

12.7 Properties and Advantages

1. The choice of using either alloyed or unalloyed steel in the process is available, depending upon the desired properties.
2. Even though cyaniding is done above the A_c temperature, the distortion and warping of the component are still less compared to liquid bath carburizing.
3. The presence of nitrogen in the casing increases wear resistance, in addition to improved sliding and friction on the treated surface.

Cyanide cases contain a certain proportion of nitrogen in solution in hard martensite. Hence resistance to softening is increased on heating. For example, a part (or at least its surface portion) on being subjected to heavy rubbing loads tends to get heated due to the friction, and this may result in softening and hence scoring of a normal nitrogen free case. However the case containing nitrogen will not score, owing to the nitrogen rich martensite, which has the ability to resist appreciable softening.

Cyaniding is superior to pack carburizing where hard, shallow cases are required, since a hypereutectoid case can build up in a relatively short time whereas such cases are not so easy to obtain with pack carburizing.

The process is used for surface hardening many articles which cannot be hardened economically by any other process. This applies particularly to small parts which are ideally suited for treatment by this method.

12.8 Disadvantages

1. The disposal of cyanide waste.
2. Salts must be stored in a separate room.
3. The toxic nature of the salt.
4. The difficulty of maintaining a constant bath composition due to dissociation of the cyanide.
5. Deterioration of plant occurs due to corrosion because the salts are hygroscopic and salt fumes which have densed on to the equipment produce thin films which, when cold, rapidly hydrate, causing accelerated rusting. This also applied to other ferrous equipment in the vicinity.

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Carbonitriding

Carbonitriding is one of the case hardening processes in which carbon and nitrogen are diffused into the surface of the component simultaneously at a predetermined temperature followed by quenching.

The process is carried out in a controlled atmosphere so that both carbon and nitrogen are absorbed simultaneously by the heated component. The concentration of hardening elements is more at the outer surface of the steel and decreases progressively towards the core. The carbonitrided components may be subsequently heat treated so as to form a hard wear-resistant case of the type normally obtained by treatment in a cyanide salt bath.

The process is used in the production of shallow cases on carbon and alloy steels.^{1,2} The treatment is usually done at 850–900°C using a carburizing gas with low additions of ammonia.

Ammonia dissociates into hydrogen and nitrogen, the latter reacting with the surface of the steel to form nitrides. In addition, however, a small amount of nitrogen goes into solution increasing the hardenability to some extent. The subsequent quenching ensures the final full skin hardness. Carbonitriding results in a higher hardenability of the surface layer as compared to carburizing and allows steel with a lower content of alloying elements to be used.

The primary object of carbonitriding is to impart a hard case to the steel in order to provide resistance to metallic and abrasive wear. The process competes with liquid cyaniding, carburizing and to a lesser extent with nitriding.

13.1 Carbonitriding Atmosphere

The gaseous atmosphere used for carbonitriding consists of a carrier gas, an enriching gas and the ammonia gas.

13.1.1 CARRIER GAS

Gases such as cooking gas, endothermic gas or exothermic gas can be used as carrier gas to reduce the soot formation and to obtain uniform results. The carrier gas also provides a scavenging effect within the furnace by sweeping the gases from the surface of the reacting elements and thus facilitates the control of the process. The endothermic carrier gas is produced by passing air with natural gas or other hydrocarbon gases in a fixed propor-

tion over a heated catalyst. The composition of a carrier gas varies to some extent but generally a typical composition would be 0.4-0.5% CO_2 ; 20-25% CO ; 35-40% H_2 ; 1.0% H_2O ; 40-45% N_2 and 0.1-0.2% CH_4 .

13.1.2 ENRICHING GAS

A gas supplying the necessary carbon for the process is called the enriching gas. Such gases occur as natural gases, butane and propane. Liquid hydrocarbons which vaporizes at high temperatures are also good sources of enriching gas.

13.1.3 AMMONIA GAS

A gas supplying the necessary nitrogen for the process such as anhydrous ammonia is available commercially in cylinders.

13.2 Process

Carbonitriding may be carried out in a batch type or continuous type furnace. The majority of carbonitriding is done in an oil quench batch type furnace (sealed quench furnace). The components to be treated should be free from dirt, grease and oxide layers before charging them to the furnace. To obtain the maximum net load that can be carbonitrided and quenched uniformly, the method of supporting the work in the furnace i.e. whether to use trays or fixtures, should be worked out carefully. Contact between the components is detrimental to obtaining a uniform case depth on them. Dense loads result in an uneven case depth.

Carbonitriding is done in the temperature range of 800-900°C. Since the active carbonitriding period is relatively short, it is important that the charge is heated uniformly up to the desired temperature, as otherwise it will result in variation of case depth on the charge. First the carrier gas is supplied during the heating cycle; when the desired temperature is reached, the gas is enriched with ammonia and enriching gas (propane 2-3%) for the actual carbonitriding cycle.

Further, since the steel will take up carbon and nitrogen from the atmosphere more rapidly during short treatments, it is important that the appropriate gaseous atmosphere is maintained with a constant composition of gases circulating around the charge. Forced air circulation will improve the degree of gas and temperature uniformity depending upon the closeness with which the charge is stocked. When the charge is closely stocked in baskets forced circulation is essential.

After the carbonitriding time elapses the components are quenched in a sealed quench furnace. If discoloration of the component can be tolerated, the charge may be exposed to air when it is being transferred from furnace to quench tank.

13.3 Carbonitriding Temperature

The choice of the carbonitriding temperature depends on a number of factors, namely, the composition of material, dimensional tolerances, wear resistance, fatigue limit and the desired hardness level. The temperature used for carbonitriding varies from 650 to 950°C.

With increasing temperature the amount of nitrogen absorbed decreases and the process approaches carburizing. The case depth increases as the temperature increases (Fig. 13.1).

At low temperature carbonitrided cases consist largely of a high-nitrogen compound layer. These cases do not have as many desirable characteristics as those found in cases formed at high temperatures and can be used to avoid distortion of the components.

Most carbonitriding is done at 800 to 900°C which is the lowest temperature at which the formation of a nitrogen bearing compound layer can be suppressed. At higher temperature the penetration is rapid and, as illustrated by Fig. 13.1, the case depths produced will be fast and uniform. Figure 13.2 on the other hand illustrates that by increasing the carbonitriding temperature the hardness also increases but the hardenability of the case decreases with the amount of nitrogen content in the case. Figure 13.3 shows the effects of

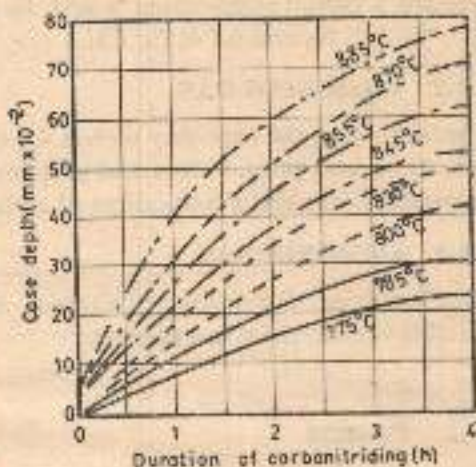


Fig. 13.1 Case depth v. duration of carbonitriding

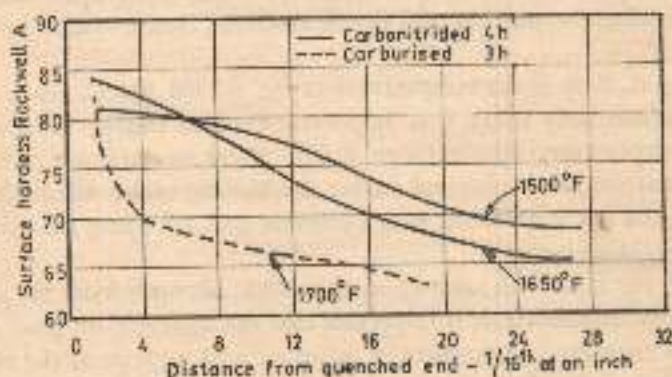


Fig. 13.2 Hardness-distance curves for steel 1020 carbonitrided at 1500 and 1650°F and carburized at 1700°F

treatment temperatures and the amount of ammonia supplied. The nitrogen content increases with an increasing quantity of ammonia and decreases with increasing temperature.

Carbonitriding of mild steels in the temperature range of 900–930°C² produces the most favourable combination of hardness, microstructure, wear and fatigue properties. At this temperature the nitrogen content was held at a lower level (0.2–0.25%) resulting in less retained austenite and increased hardness (Fig. 13.4).

Since carbonitriding can be carried out under a wide variety of operating conditions a close control of the case properties, however, depends on the proper control of temperature, time, gas composition, quenching rate and the type of steel.

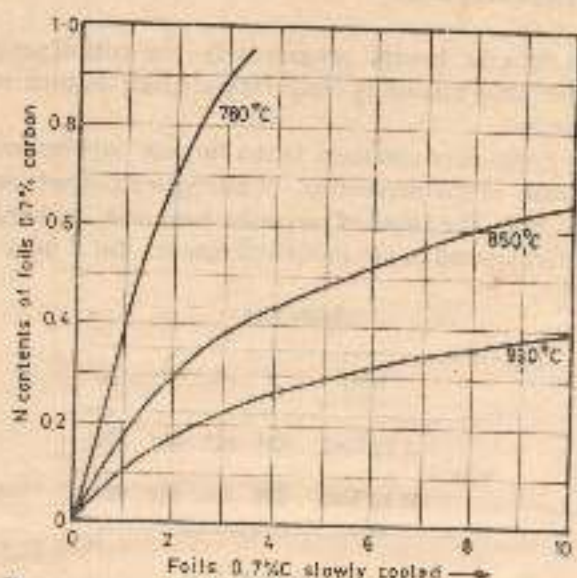


Fig. 13.3 Dependence of nitrogen potential at different temperatures on ammonia addition during carbonitriding

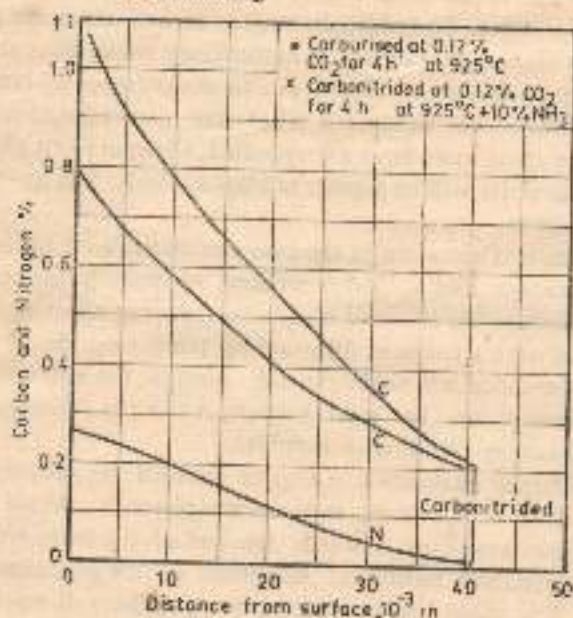


Fig. 13.4 Layer analysis of carburized and carbonitrided mild steel

13.4 Effect of Ammonia Addition

Ammonia additions are made to the process atmosphere according to the type of case required and the particular gas used. The ammonia content is usually kept between 3 and 8%. The normal value of the nitrogen content of the surface layer is about 3 to 4%. The presence

of nitrogen content in the case lowers progressively the critical temperature of the case, thus permitting a lower case-hardening temperature which in turn reduces progressively the critical cooling velocity.

An increase in the addition of ammonia in the furnace atmosphere for a given temperature causes an increase in the percentage of nitrogen absorbed and a decrease in the amount of carbon absorbed. The effect of increased ammonia on hardness is illustrated in Table 13.1, for mild steel treated in an industrial furnace for 1 hour at 860°C, and water quenched from 760°C.

Table 13.1

NH ₃	3	5	7	10
5 kg load	854	927	891	874
V.D.N.				
15 kg load	820	894	820	854

13.5 Heat-Treatment of Carbonitrided Cases

The presence of nitrogen in the austenite lowers the critical temperature and retards the transformation rate of cooling. To reduce distortion, as well as cracking, less severe quenching rates are necessary than those needed for carburizing steels. The relatively soft surface of carbonitrided and quenched steels results due to the presence of retained austenite. This retained austenite is undesirable because it affects the dimensional tolerances of the work piece, especially when close tolerances are specified. Compared to plain carbon steels, the presence of retained austenite will be greater in alloyed steels. The quenching media applied will also affect this amount.

The presence of retained austenite in the case can be reduced by adopting an adequate heat treatment temperature and a corresponding quenching procedure. Tempering of components will also reduce the retained austenite. Another effective method is to subject the components to subzero treatment followed by tempering. Since subzero treatment is expensive it is usually avoided whenever possible. Because the amount of retained austenite is normally at a maximum near the steel surface, it can be removed by machining after treatment (as for instance by grinding or lapping).

The presence of retained austenite can also be reduced by adopting a higher temperature and a minimum level of ammonia in the atmosphere to obtain the desired hardenability. Shutting off the ammonia towards the end of the carbonitriding period greatly reduces the amount of retained austenite. Adoption of this procedure may be attractive in industrial practice. The slight loss in case depth would be well worth the gain in surface hardness.

13.6 Quenching

Carbonitrided parts are quenched in oil or water or cooled in air. The ideal cooling rate is one which will harden the case, result in the desired core structure and keep the distortion due to quenching within tolerable limits.

Use of water quenching is usually restricted to those furnaces on which the work is transferred from the furnace into the air prior to quenching. This avoids the possible contamination of the furnace atmosphere by water vapour.

13.7 Method of Checking the Case

It is recommended that the Vickers or the Rockwell 15 or 30 kg hardness testing method be adopted to check the case hardness. The depth of the hardened case can be determined from the fractured structure of a test piece or from a traversed polished section. Using Rockwell C or B scale for testing may give erroneous results.

13.8 Properties of the Carbonitrided Case

1. Since carbonitriding is done at a temperature lower than that used in carburizing, distortion of the components is reduced.
2. Lower quenching rates are possible, since the presence of nitrogen in the case reduces the critical cooling velocity and permits the use of milder quenching. Therefore distortion and cracks resulting from quenching are reduced.¹
3. Both carbon and alloy steels respond to the process.
4. Carbonitrided cases are more uniform than the carburized cases, because the carbon dioxide and water vapour in the atmosphere are less detrimental in the presence of ammonia.
5. Cases produced by carbonitriding are more resistant to tempering than the carburized case.² This is due to the presence of nitrogen in the carbonitrided case which increases the resistance to tempering. To a large extent the nitrogen content on the case determines the amount of softening that occurs during tempering. Increased

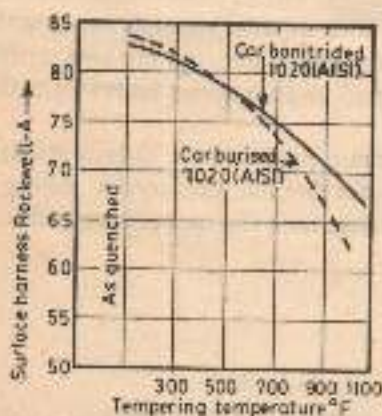


Fig. 13.5 Surface hardness of the case as a function of tempering temperature. Carbonitrided at 845°C (1550°F)

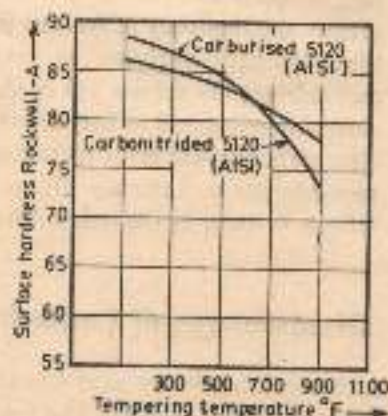


Fig. 13.6 Surface hardness for carbonitrided AISI 5120 as a function of tempering temperature

resistance to tempering may be desirable where the temperatures at service are abnormally high. Figures 13.5 and 13.6 present the surface hardness of a case as a function of the tempering temperature of steels 1020 and 5120 (AISI).

6. While distortion, warping or dimensional changes of the components are more likely in carbonitriding at higher temperatures (above the critical line A_{c1}) than below, they are still less serious than those resulting from the cementation process.
7. Better working conditions are assured as the process is not dangerous to operating personnel (as is the case with cyanide baths). The major advantage of carbonitriding is that the nitrogen absorbed during processing lowers the critical cooling rate of the component. That is, the hardenability of the case is significantly greater when nitrogen is added by carbonitriding than when the same steel is only carburized (Fig. 13.7). This advantage allows a cheaper steel, with a lower content of alloying elements to be used. Plain carbon steels may be substituted for alloy steels.
8. The presence of nitrogen in the transformation range increases the hardness of the component above that obtained by cementation. The case containing nitrogen is extremely wear resistant and superior in quality to those obtained by cementation. The presence of free compound of nitrogen in the case ensures superior wear resisting properties in addition to improved sliding. The presence of nitrogen reduces greatly the tendency of ferrous materials to stick or weld to other metal surfaces.
9. Since the carbonitriding process is done at a lower temperature compared to gas carburizing, the service life of the furnace and its accessories increases with a considerable reduction in fuel consumption.
10. The carbonitrided layer increases the endurance limit and the fatigue strength compared to gas carburizing. Figure 13.7 illustrates that the resistance to rolling contact fatigue is more in the case of the carbonitriding than the carburizing method.

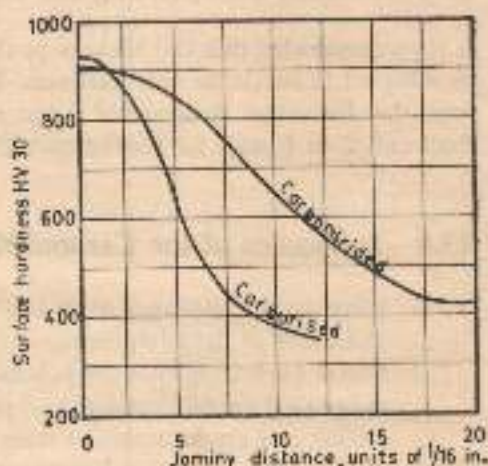


Fig. 13.7 Jominy hardenability curves for mild steel after carburizing and carbonitriding treatments for 4 h at 925°C.

13.9 Disadvantages of Carbonitriding

1. Carbonitriding is not used where a thick case is desired.
2. Carbonitriding requires the use of costly gaseous atmosphere and a slower case hardening rate. However, if the volume is large, carbonitriding gives lower unit costs.
3. Carbonitrided parts possess a relatively poor impact strength compared to carburized components. This limitation normally precludes the application of carbonitriding to parts subjected to heavy impact loading such as gear and ratchet teeth.

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Flame Hardening

Flame hardening consists of hardening the surface of the component by heating it above the transformation temperature using a high temperature flame or high velocity combustion products and then quenching it in water or oil. The depth of the hardened layer ranges from 1 to 7 mm deep.

Flame hardening is similar to induction hardening in terms of the materials processed and their applications. Flame hardening plants tend to be cheaper than induction hardening plants but the operation costs are higher. The process cannot be as readily automated as induction hardening and is more suitable for hardening different types of uneven components. The skill of the operator is of paramount importance in carrying out this process.

In a number of engineering applications stress distribution is not uniform throughout a component's section, the surface being heavily stressed while the interior is stressed to a much smaller extent. In order to prevent failure at the surface it becomes necessary to provide additional strength at the surface. This not only increases the resistance to wear and indentation, but also increases the fatigue strength. Flame and induction hardening are employed to achieve this by altering the structure at the surface by local hardening. While normalized plain carbon steels are used for a number of applications, steels in the hardened and tempered conditions are used when high core strength and good impact properties are required.

14.1 Gases Used

The gases used for heating are a mixture of air or oxygen with natural gas, propane or acetylene. They are mixed in a burner unit which has a shape to suit the component to be hardened. The fuel gases are mixed with air or oxygen to produce a flame of varying temperature. The heating capacity of the oxy-acetylene flame is high (3100°C) compared to the air-fuel gas or an oxygen-acetylene gas flame. Oxy-acetylene flame at 2500°C may be used mainly to heat the surface of large components and flames based on other gases are more useful for heating relatively small cross sections.

14.2 Burners

The design of the burners is an important factor in the process of flame hardening. In

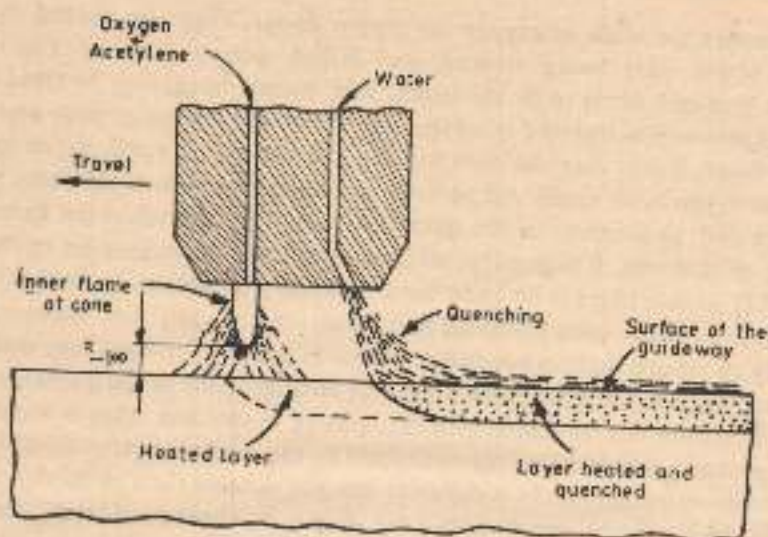


Fig. 14.1 Flame head with integral quenching

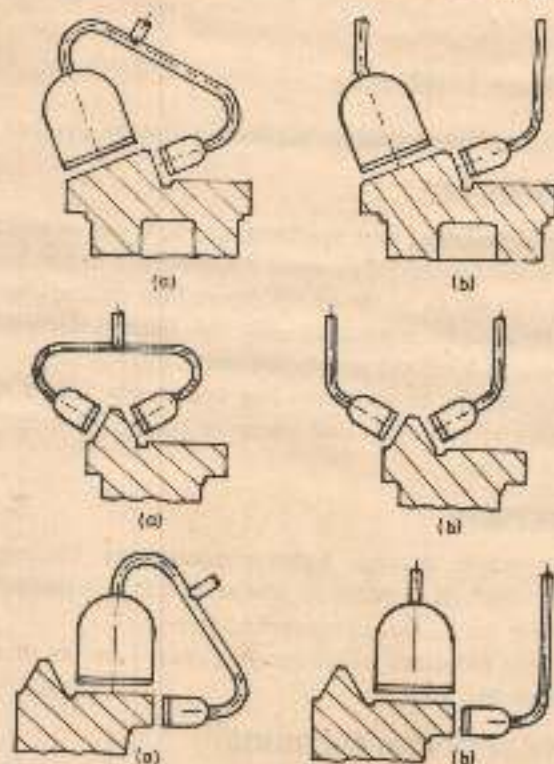


Fig. 14.2 Hardening of different cross-sections of guideways: (a) Burner heads fed from one torch, (b) Each head fed from a different torch

general the burners are made of copper or copper alloys. They are shaped to conform to the curvature of the part being treated, with drilled parts or inserted tips directing the flames on the localized areas to be hardened. The burner heads may be fitted with removable orifices of screw-in or inserted types through which the fuel gases issue and are burned. This type of flame heads may be used for a wider range of applications by opening or plugging parts in the burn heads. All parts in any one burner are of the same diameter.

The design and positioning of the quenching jet may also affect the flame hardening. In a majority of burners, it is possible to incorporate the quenching jet in the heating tip itself (Fig. 14.1) so that there is no need for a separate installation. In certain instances, for example, welder's torch used for flame hardening are generally not water-cooled. Hence it is necessary to ensure that an adequate volume of water is brought into contact with the hot work piece to ensure drastic quenching. The arrangements of the quenching jets should be such that it should not interfere with the heating operation. This is usually controlled through the pressure regulator valves connected to the water pipes.

A wide range of burner heads of different designs suitable for a particular application is available (Fig. 14.1). Some are designed for flame hardening of teeth, the continuous hardening lathe bed guide ways (Fig. 14.2 (a) and (b), shafts, and for internal hardening of cylinders of different kinds.

14.3 Methods of Flame Hardening

The generally accepted techniques of flame hardening may be divided as follows:

14.3.1 SPOT OR STATIONARY

In this method both the component and the flame are held stationary. In general, the work is heated by hand with a welding torch or some other burner to the hardening temperature and then quenched immediately in water or oil depending on the chemical composition of the steel. This method is usually employed only for limited hardening areas and where the amount of work involved does not justify the installation of several jigs and other equipment. This is mainly adopted for components like bolt heads, top of the screw, etc. When hardening a large number of parts it is customary to keep the burner stationary and hold the part by hand or in a fixture.

14.3.2 SPINNING METHOD

In this method the component is spun between stationary heating jets until the whole surface is heated to the desired hardening temperature; it is quenched by immersion or by spraying water directly on to the component.

This method is suitable for gears which are less than 4 inches in diameter, hubs, shafts and similar such components.

14.3.3 PROGRESSIVE SPINNING METHODS

This method is carried out on cylindrical objects. The hardening is achieved by progressively heating along the axis of the object which itself is spinning. The heating is followed closely by a quenching jet. The rate of spinning is of the order of 3 to 12 inches per minute.

The heating and quenching jet are both fixed to a carriage which can be steadily traversed along the work.

This method can be adapted to a broad range of diameters and lengths.

14.3.4 PROGRESSIVE METHOD

This method is used for even surfaces. This method of hardening employs a flame head, usually of the multiple-orifice type, with or without integrated quenching facilities that traverse the surface to be hardened. As the surface is heated progressively, it is followed by a quenching medium (Fig. 14.2). The rate of movement is relatively low (50–200 mm/min) and it depends on the desired case depth.

The equipment used for this method consists of a flame head mounted on a movable carriage running on a channel or track at a regulated speed. This method is more suitable for the hardening of lathe beds and guide ways. This method can also be adopted for curved parts such as cams by the use of the tracer-template method.

14.4 Treatment Prior to Flame Hardening

It is essential that the components after heavy machining should be stress relieved in the temperature range of 550–600°C for 1 to 2 hours followed by air cooling. The stress relieving operation releases stresses that are developed during machining, avoids cracking and reduces the distortion during flame hardening. Small components need not be stress relieved.

Sometimes it is essential to heat treat the part prior to flame hardening in order to develop the optimum properties at the core. This may be achieved by hardening and tempering. Sometimes an annealed structure may be desired. A fine grained metal is preferred to a coarse grained one for flame hardening.

Pre-heating of components prior to flame hardening will increase the depth of hardness and avoid cracking, especially in the case of some alloy steels.

Prior to flame hardening the component should be free from scale, rust, dirt, decarburization, laps, seam folds and fins. Otherwise, it may result in a soft surface skin and cause localized overheating leading to cracking even after proper heating and quenching.

14.5 Quenching Liquids

Quenching media used in flame hardening consist of mainly water or a dilute soluble oil solution. Compressed air, passed through the quench blocks, is used as a quenching medium in some applications. In certain instances it is necessary to quench the parts in caustic or brine solutions, or else in a large variety of oils.

Components heated by the progressive spinning method are usually quenched by a spray integrated into the flame heads. Quenching liquids at a constant pressure and temperature are pumped through a number of small openings in a ring into the heated surface as it revolves. The quench emerges as a circumferential spray and progressively quenches a narrow band of heated surface as the work revolves. As only a small area is being quenched with a constant supply of fresh liquid, uniformity of quench is assured.

The components heated by the progressive method are usually quenched by a spray integrated into the flame head and provide for a full coverage of the heated zone. Uniform heating and spray-quenching of proper volume produces a flame hardened surface free of soft spots.

14.6 Case Depth

The depth of hardness obtained depends mainly on the chemical composition of the steel, the hardening temperature, and the rate of cooling. For instance, the presence, of appreciable quantities of alloying elements such as nickel or chromium promote the depth of hardening. The depth of hardness obtained also depends on the rate of movement of the flame head (Fig. 14.3).

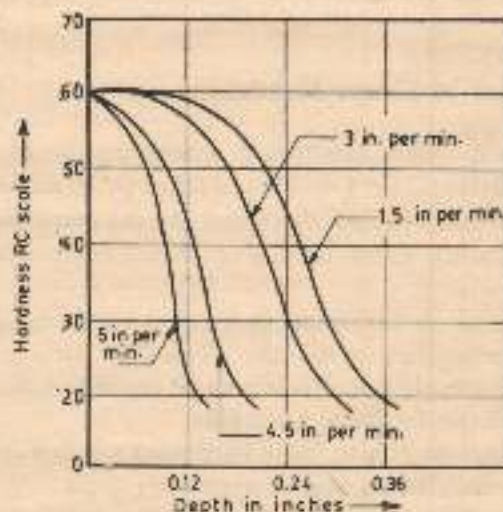


Fig. 14.3 Hardening v. depth curves, for AISI 1050 steel hardness, by flame travelling at indicated speeds¹

Flame hardened components possess the maximum possible surface hardness compared to other hardening processes.

14.7 Steel Suitable for Flame Hardening

Theoretically all steels hardenable by the conventional method can be flame hardened. But in practice however there are certain restrictions to the type of steel that can be treated, since some steels may tend to crack. The carbon steels containing 0.30 to 0.57% are most widely applied. Carbon steel containing 0.35% carbon is mainly used for machine elements requiring high fatigue strength but exposed to little wear. Steels containing 0.45% carbon are extensively used for all kinds of parts requiring flame hardening. In the auto-

mobile and motor vehicle industry small crankshafts, rocker arms, spindles, spline shafts, and other items are made using this steel. In certain applications a 0.6% carbon steel develops cracks but steels containing 0.55% carbon can be used as replacements on such occasions. Here, the carbon content is high enough to reach the desired hardness of 60 RC on lathe spindles and tailstock sleeves and similar components required for heavy duty. Steels containing 0.6% carbon may be used for parts with smooth surfaces uninterrupted by oil holes, bores, taps, etc., without the danger of cracks developing. Where a maximum hardness of 61 RC is required, steels with carbon content higher than 0.7% can also be flame hardened; they require greater skill and care in handling.

Alloy steels are also used for parts subjected to heavy oscillating or impact loads. Even very heavy cross sections can be heat treated for sufficient strength. For this type of application, the more commonly used steels are those with 0.35 to 0.62% carbon along with 0.12 to 0.20% vanadium and 1 to 1.2% chromium. The presence of alloying elements in steels has no effect on the hardness of the steel. Apart from this, steels containing Mo, Ni are also used in special cases.

Parts requiring higher case depths, as for instance straightening rolls for sheet steel and gears with small teeth, are normally spin hardened.

Apart from the above materials, stainless steels, cast steels, grey cast iron, spheroidal cast iron and malleable cast iron can also be flame hardened.

Table 15.5 illustrates the different types of steels used for induction hardening as well as flame hardening.

14.8 Tempering

After flame hardening it is necessary that the components should be tempered. Self-tempering of the component by heat diffused from the heated zone is not desirable for the majority of the components. But on large components, flame hardened to a greater depth about 5 to 7 mm or more, the residual heat present after quenching may be sufficient to relieve hardening stresses. Thus subsequent tempering may be unnecessary.

In the majority of cases the simultaneous hardening and tempering is of great value in treating the larger parts. This treatment may be done in a conventional way, either in an oil bath or forced air circulation or salt bath. The main object of this treatment is the relief of stresses produced by flame hardening, and for this purpose a tempering temperature of 175 to 200°C is sufficient.

14.9 Advantages of Flame Hardening

1. A wide selection of steels may be used.
2. May be applied to parts more or less without restriction on the size and shape.
3. Compared to carburizing and nitriding the flame hardening method is more rapid.
4. Selective surface hardening of area is possible without heating the whole mass.
5. Wide depth of hardness may be obtained with control.
6. May be adopted for large components where conventional furnace heating and quenching is impracticable or uneconomical (e.g. extremely large gears, lathe beds, guide ways, rollers and dies).

7. In certain cases, it is possible to substitute case by plain carbon steels instead of adopting carburizing by using an expensive alloyed steel; thus it works out economical.

14.10 Disadvantages

1. It is difficult to measure the exact temperature on the component during the process. Estimation of this temperature has in many cases to be left to the skill of the operator, and to determine it in the light of flame is not easy.
2. To standardize the process for a particular component, it is necessary to carry out a trial run, in order to be reasonably certain that the temperature to which the steel is being heated is the optimum temperature.
3. The exact case depth control is difficult compared to the induction hardening method.
4. Fuel gases used are explosive, hence utmost care is required while operating the process or during the handling of gas cylinders.

Induction Hardening

When surface hardening is done by means of induction heating, the method is known as induction hardening. This method involves heating the component by an induced current to temperatures at which the rate of formation of austenite is very rapid, and then quenching it to transform the austenite to martensite. The hardness thus formed is somewhat higher than that obtained by conventional methods of hardening; the fatigue strength obtained is also higher.⁴ For the purpose of induction hardening it is usual to employ an alternating current at a frequency ranging from 50 c/s to 1000 kc/s. The advantage of induction hardening over the conventional methods is mainly the rapid heating of the surface of the component without an appreciable rise in the temperature of the core. This condition makes it possible to case harden components in a few seconds with very little distortion and without the formation of an oxide layer or a decarburized zone. The use of steels of inferior quality for the same practical applications is also made possible.⁴ The rapid heating method employed in induction heating enables the heat treatment to be performed directly in the machining production line without interrupting the technological sequences of operations thus reducing the overall cycle time to a minimum. As a result of these and other advantages, applications of induction hardening is mainly used for gears, cam shafts, automobile parts, lathe beds, axles, etc.

15.1 Equipment for Induction Hardening

High frequency motor-generators and valve-generators are used as sources of power supply

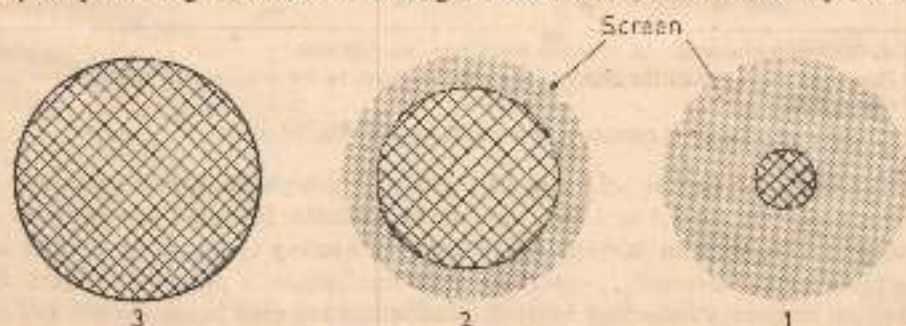


Fig. 15.1 Illustrates the depth of induction-hardened case depending on the frequency (1) 50 cps (2) 2500 cps (3) 250000 cps

for induction hardening. The motor-generator sets are employed in cases where the frequencies required do not exceed 10,000 cps and valve-generators in those cases where still higher frequencies are needed. The depth of heat penetration diminishes, as the frequency increases. Figure 15.1 presents a diagram showing the effect of frequency on heat penetration.

Surface heating by high frequency electric current is determined on the basis of the following main factors, namely, the frequency and the time of heating.^{3,2} The frequency is usually selected to give the optimum range of case depth. Table 15.1 illustrates the frequencies most widely applied in practice to obtain different case depths for various diameters of the component. As shown in this tabulation the lower frequencies are used in cold rolling

Table 15.1 Selection of Frequency for Induction Heating (in the case of steel)

Hardened depth mm	Dimensions mm	Frequency				
		Commercial frequency 50-60 cps	Motor generator			Vacuum tube 200 kc or higher
			1000C	3000C	10,000C	
0.4-1.25	6-25					A
	8-16				B	A
	16-25				A	A
1.25-2.5	25-50			B	A	B
	25-50		B	A	A	
	19-50			A	A	B
2.5-5.0	50-100		A	A	B	
	100		A	B	C	
	3-6					A
Through hardening	6-12				B	A
	12-25			D	A	B
	25-50			A	A	
	55-100		A	A	B	
	100-200	B	A	B		
	200	A	A			

(a) A. Optimum frequency B. Suitable frequency C. Possible.

(b) Hardened depth means the depth of the layer hardened to the minimum of HRC 50 measured from the surface.

(c) Megacycle frequency is necessary for a depth smaller than 0.4 mm.

and are suitable for depths of 7 mm and above. The high frequency induction heating installations are used for 1.5 to 2 mm case depth suitable for small components and for parts subjected to wear in service. Many localized heating applications can be achieved only by radio high frequencies, because accurate localization is obtained at these frequencies. Medium frequency induction heating installations are used in automobile and machine tool industries to attain case depths of 4 to 6 mm and for parts whose surface should be hardened to withstand crushing.

The primary considerations for induction hardening are the depth of heating and the size of the component. As the frequency governs the depth of penetration, the equipment should be selected mainly keeping this in view (Table 15.2).

Table 15.2 Effect of Frequency on Depth of Case Hardness

Power input W/cm ²	Frequency kHz	Depth of hardening
15-19	450	0.5-1.1
8-12	450	1.1-2.3
15-25	10	1.5-2.3
15-23	10	2.3-3.0
15-22	10	3.0-4.0
23-26	3	2.3-3.0
22-25	3	3.0-4.0
15-22	3	4.0-5.0

On the basis of the required depth of hardened part and the size of the component, Table 15.1 indicates the power sources and the frequencies required.

As it is desirable to use the available electrical capacity to the full, it is a good practice, when deciding the plant, to select a frequency which will work satisfactorily taking the minimum time for induction hardening. If a greater depth of hardening is desired, then a lower frequency is selected, and to produce a thin case or layers of hardness the highest possible is used.

15.2 Heating Inductors

[The heating effect attained with the aid of a generator is not only dependent upon the generator output and heating time, but also on the manner in which the component is heated depending on the shape of the inductor and its position with respect to the work piece. The depth and configuration of the heated layer obtained on the surface of a component depends upon the shape of the inductor, the distance between the inductor and the zones to be heated, and also upon the magnitude of the power-input into the inductor and the frequency of the supply current. Hence the design of the inductor or work coil should be such as to direct the eddy currents only into those sectors of the component which require heat treatment. The distance required for a stationary component should be about 2 to 3 mm, for rotating parts it should be 2 to 4 mm and for a progressive shape it will be about 2 to 5 mm depending on the type of component.]

The tighter (gap) the coupling between the component and inductor, the higher is the degree of efficiency. The clearance between the component and the inductor should remain within 2 to 6 mm. Inadequate spacing may cause a contact between the work and the inductor, or puncture the air gap between them, and overheat the external layer particularly when vacuum-tube oscillators are used. Larger clearances may be chosen for deeper

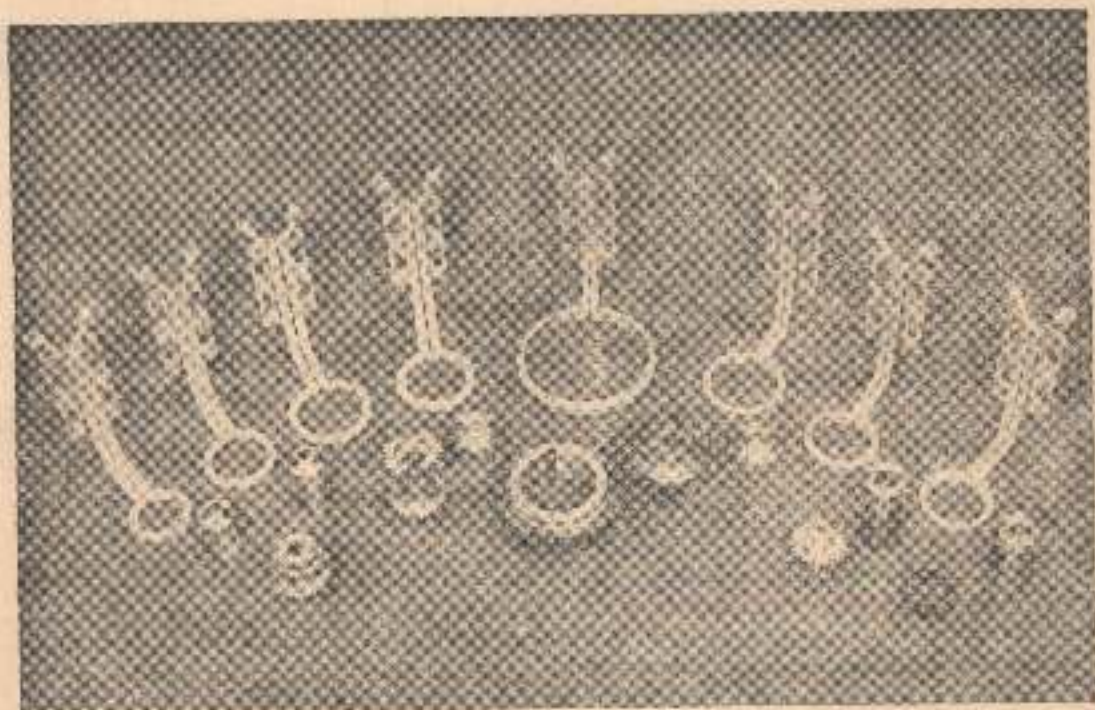


Fig. 15.2 Different types of inductors (Courtesy: HMT Ltd, Machine Tools Division, Bangalore)

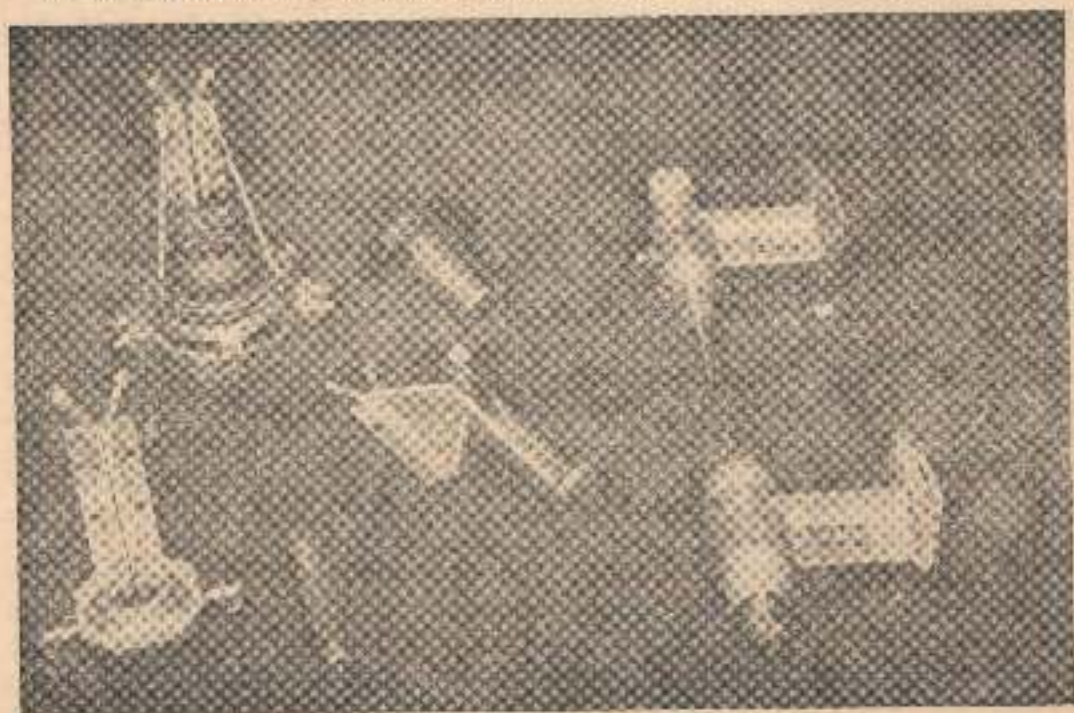


Fig. 15.3 Different types of inductors (Courtesy: HMT Ltd., Machine Tools Division, Bangalore)

hardening. The spacing of turns in a multi-turn inductor should be minimum so as to ensure uniform heating. Normally it will be about 2 to 4 mm and roughly the same spacing is maintained between the coil and the work piece. By varying this distance it is possible to influence the rate of heating to a very large extent.

The different types of inductors that are used for hardening gears, spindles, shafts, etc. are shown in Figs. 15.2 and 15.3.

15.3 Selection of Prior Structure

The steel structure prior to induction hardening is of great importance, particularly in the case of very thin sections requiring very short heating time. The heating up process in induction hardening is very rapid (at the most it does not last more than a few seconds) and therefore there is little time available for the carbide solution necessary for the production of martensite. It is undesirable therefore that, if the structure is not favourably resolved, no proper transformation will take place. To some extent the higher temperatures that are possible with furnace hardening can compensate for the very short heating time without the danger of grain size enlargement.^{4,4} It is however usual to obtain a suitable structure for induction hardening by a preliminary treatment or by normalizing. Where possible 'as cast' or spheroidal structures should be avoided.

The initial microstructure of steel exerts considerable influence on the process of austenite formation. The smaller the size of the pearlite particles, the higher the rate of formation of the austenite nuclei and of the growth of the austenite grain. Therefore in induction hardening of medium carbon steel, a sorbite initial structure is recommended^{2,4} which is characterized by a smaller grain size and a more uniform distribution of the grain of cementite. The diffusion path of carbon in the process of the austenite formation in steel possessing a sorbite structure is shorter than in the normalized steel whose structure consists of free ferrite and pearlite. It may be seen from Fig. 15.4 that a sorbite structure is the ideal structure prior to induction hardening for medium carbon steels, which results in a higher hardness and a greater depth of hardening, whereas the steels normalized and furnace cooled show a lower hardness.

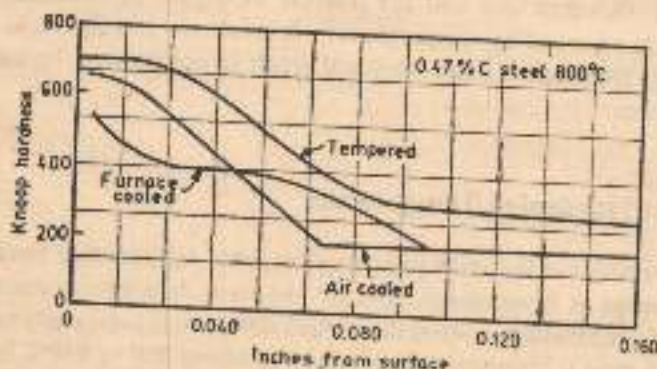


Fig. 15.4 Effect of prior structure on the hardness penetration of steel-0.47% C. All samples were induction heated to 800°C (1470°F).

It is not always feasible to heat treat the components to produce the desired structure. In such cases a double induction hardening treatment will yield satisfactory results.⁴ This is illustrated in Figs. 15.5 (a) and (b) in which two steels are given a double treatment at

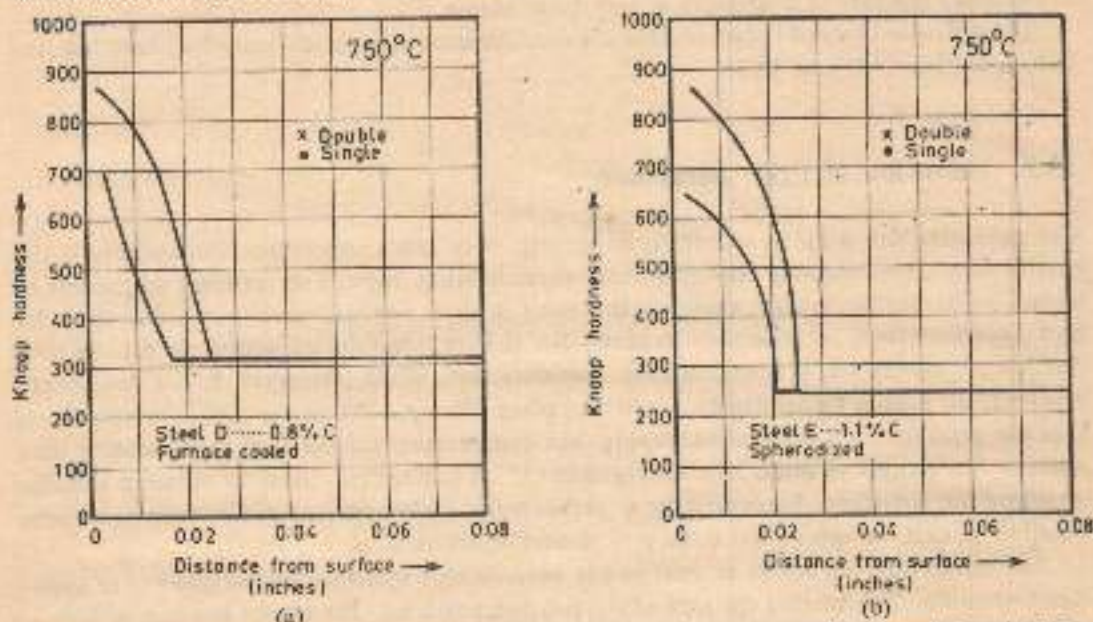


Fig. 15.5 (a), (b) Effect of double-hardening treatment on the hardness penetration of steels D and E. The samples were induction-hardened to 750°C.⁴

750°C. The double treatment could be varied in many ways; for example, the first treatment could involve a high temperature hardening, followed by a second low temperature hardening. The purpose of the first treatment is to obtain a satisfactory carbon distribution generally by heating to a high temperature quenching. The second treatment is to produce the desired hardened layer at the surface.⁴

Steels containing more than 0.5% carbon are frequently spheroidized for improved machinability, but this structure has the poorest response to induction-hardening, and hence requires higher hardening temperatures. It is about 150 to 160°C more than the normal hardening temperature. But this will result in coarsening the austenite grain size and may lead to quenching cracks.

15.4 Induction Hardening Temperature

The heating temperature is the most important variable in induction hardening. To obtain satisfactory properties it is necessary to heat the steel to a temperature higher than the normal hardening temperature, so that the carbon diffusion is sufficiently rapid. For instance with 0.45% carbon steel it requires a temperature of about 900 to 950°C for induction hardening. If the steel is having carbide forming elements it may be necessary to raise the hardening temperature by 70°C to 150°C above the conventional hardening temperature to take full advantage of the alloying elements.⁴ The exact heating temperature depends on

the length of the heating cycle, the alloying elements present, the specific effects desired for the alloying elements and the surface hardness required. These higher temperatures at the surface are used to obtain an adequate solution of the carbon and alloying elements in

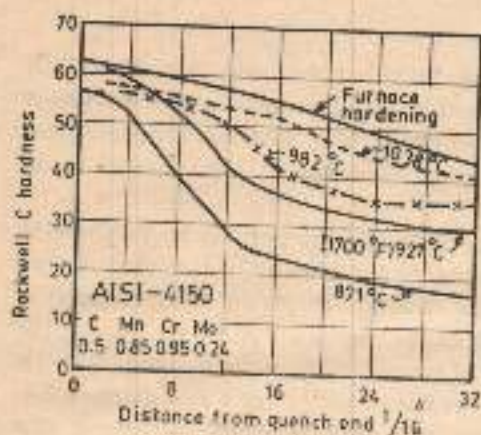


Fig. 15.6 Effect of austenitizing temperature on the degree of carbide solution*

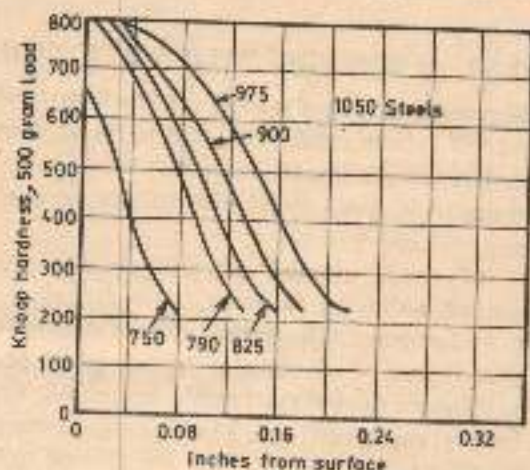


Fig. 15.7 Hardness-penetration curves of specimens induction hardened to the designated temperature (AISI 1050)

the austenite with a very short heating cycle. Figure 15.6 illustrates the effect of austenitizing temperature on the degree of carbide solution. The higher the austenitizing temperature the greater is the case depth obtained (Fig. 15.7).

The temperature required also depends on the rate of heating. As the heating rate is greater, higher hardening temperatures are required to obtain the maximum hardness value. For example, at a rate of 50°C/second the minimum hardening temperature for full quench hardening is 840°C; at a rate of 400°C/second a temperature of 920°C is required; and at a rate of 700°C/second heating up to 960 to 1000°C is required (Fig. 15.8).

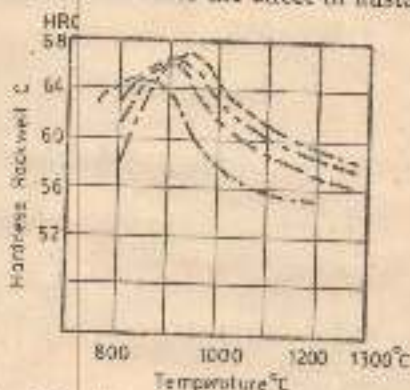


Fig. 15.8 Variation in surface hardness of steel—KhvG as a function of quenching temperature at different heating rates

The heating conditions at which the maximum hardness is obtained are generally called the 'optimum' hardening conditions. This condition can be selected in accordance with the type of steel, the shape of the component, the required thickness of the hardness layer and the frequency of the supply current.

[When heating castings of grey iron for surface hardening it is recommended that temperatures of 1050 to 1150°C be employed, for at these temperatures the graphite dissolves particularly rapidly. For surface hardening of spheroidal graphite cast iron the temperature required is 950 to 1000°C.]

15.5 Methods of Induction Hardening

Induction hardening may be accomplished by various methods.

15.5.1 HARDENING WITH STATIC COIL

This method is used mainly for small parts which can be either manually or mechanically loaded into the coil. The area to be hardened should be small enough so that the power output can achieve the required hardness in a single step. This kind of hardening for example is most useful for hardening the heads of bolts, nuts and similar such small components.

In case of circular components like gears etc., normally the part to be hardened is rotated within the inductor, the width of which is equal to the breadth of the surface area to be hardened. The part is rotated during hardening in order to obtain the greatest possible degree of uniformity in the width and depth of the hardened zone. By turning the work piece during the heating up period, the effect of irregularities in the induced magnetic field is smoothed out. The turning of the job keeps the distortion at a minimum. When the time of heating given for the process has elapsed, the part descends by means of a



Fig. 15.9 Gear hardening with static coil (Courtesy: HMT Ltd, Machine Tools Division, Bangalore)

hydraulic device into the quenching bath to ensure that the whole of the heated portion is immersed in the bath (Fig. 15.9).

An additional sprinkler installed at this point ensures sufficient agitation of the water to avoid the danger of soft spots being formed. In many cases rotating the work piece during quenching helps the formation of soft spots by preventing the generation of steam pockets on the hot surface which leads to the formation of soft spots.

15.5.2 PROGRESSIVE HARDENING

In progressive hardening only a part of the surface to be hardened is exposed to heating at any one moment, while the remainder stays cold. During hardening the component to be hardened performs two movements simultaneously. As it rotates, it also moves along the axis, while the inductor remains stationary (in some methods the reverse is true—the

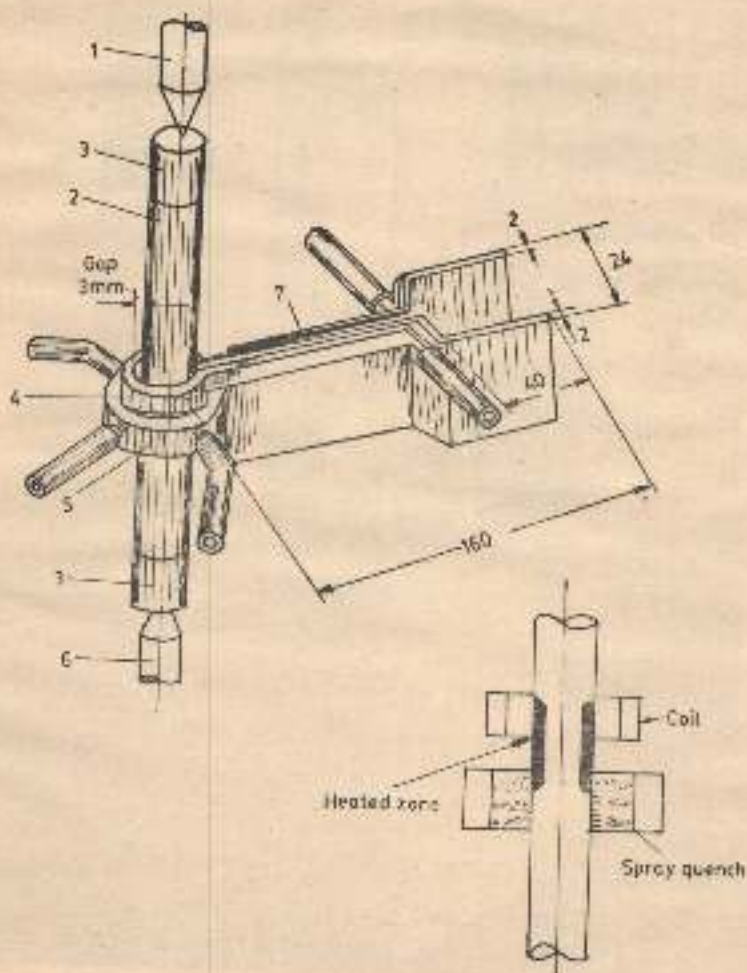


Fig. 15.10 External appearance of a cylindrical inductor with quenching attachment. 6, 1—Rotating centre for hardening machine, 2—Work piece, 3—Extension, 4—Inductor, 5—Quenching attachment

component is stationary and the inductor moves along it). In such cases the heat is applied progressively while cooling is effected by means of a quench being fixed at the outgoing side of the coil. The principle of progressive hardening is shown schematically in Fig. 15.10. The shaft to be hardened is slowly moved through a coil, which rapidly raises the surface layer to the hardening temperature. This hot zone then moves through a quenching ring situated below the coil. The generator power and the speed at which the work passes through the coil determines the surface temperature. Increasing the generator power or

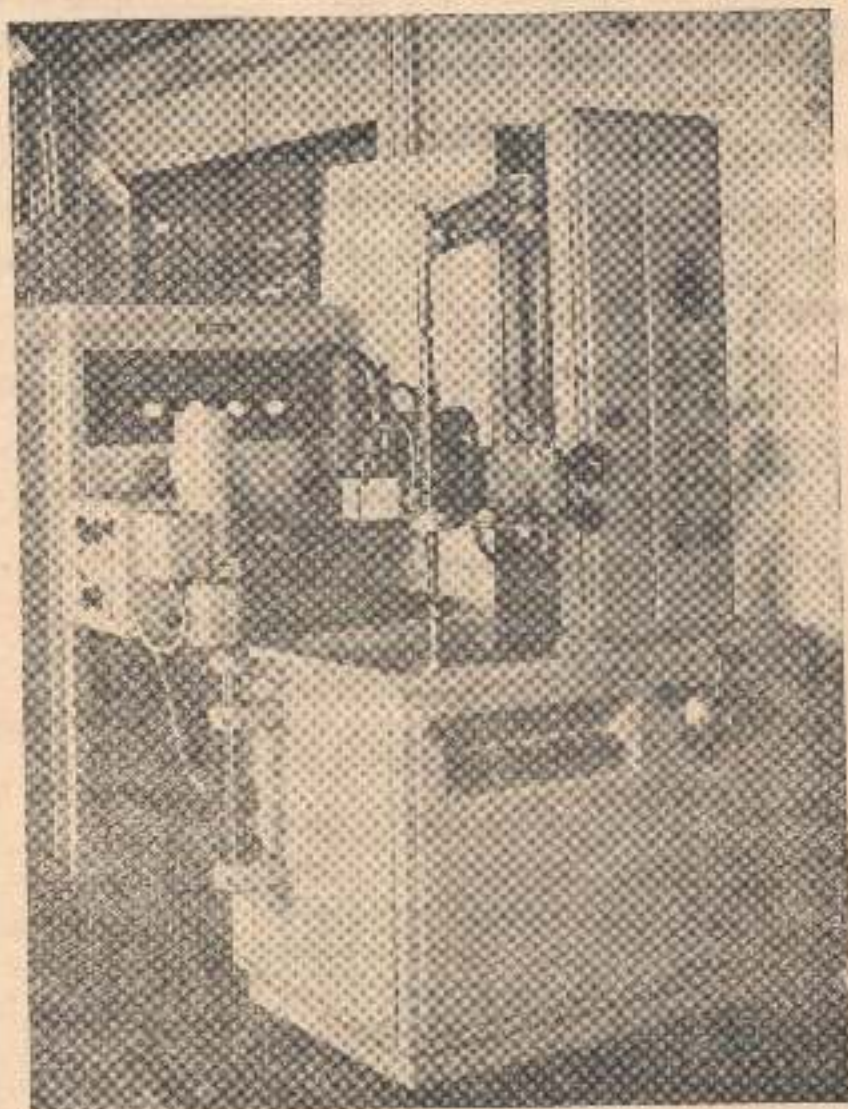


Fig. 15.11 Progressive induction hardening

slowing down the speed of the component both serve to raise the surface temperature and vice versa. If both the generator power and component speed are increased, penetration will be less, whilst conversely the combination of low power and low work speed will produce a deep penetration. Figure 15.11 indicates the progressive induction hardening plant.

In many cases during progressive hardening of a long axle or a shaft it must be rotated during the treatment to obtain a uniform heating and to reduce distortion. Any eccentricity of the axis of the shaft with respect to the coil is thus compensated.

Gears of small diameter are heated in an annular inductor, similar in form to that of a gear. The teeth of large diameter gears (module exceeding 8) are heated individually, i.e. one at a time, by means of a loop-type inductor (Fig. 15.12).

In static and progressive hardening, the depth of the hardened layer may be varied considerably even in similar jobs of the same material heated by currents of the same frequency. The depth of hardness is influenced by the time factor, and with increasing time the heat is transformed according to the thermal conductivity of the material from the outside to the interior resulting in higher depth of case (Fig. 15.13). In static hardening, it is possible, by choosing a low specific density and correspondingly increasing the heating time, to cause the entire cross section to be heated throughout. The depth of hardening therefore depends on the hardenability of the steel. In progressive hardening the heating time is governed by the ratio of the active length of the inductor coil and the travelling speed of the job. In this case also lowering of the specific density, together with reduction in the rate of travel of the work, causes an increase in the depth of hardening.

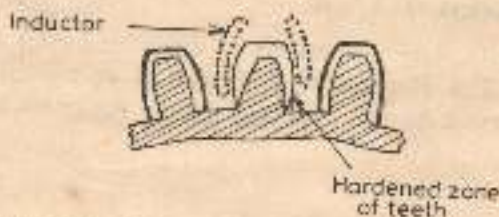
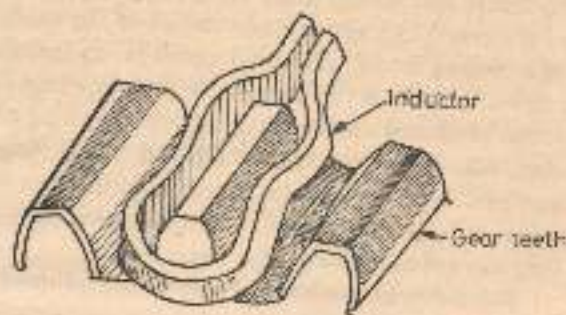


Fig. 15.12 Relative positions of the inductor and the tooth of a spur gear wheel, with successive treatment of individual teeth

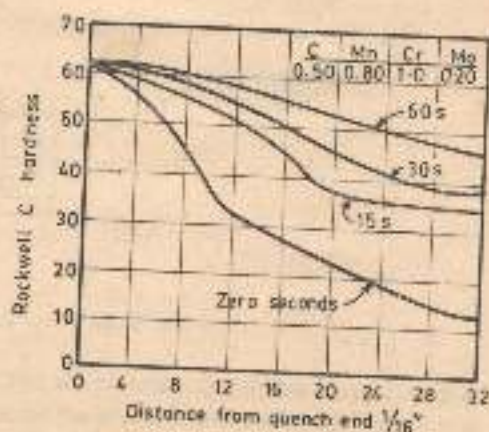


Fig. 15.13 Effect of time and temperature on the degree of carbide solution and the transformation characteristics of steel—AISI 4150*

15.6 Quenching

The process of hardening is critically controlled by the rate of cooling. Natural cooling is not fast enough to attain the martensite structure. Hence the fast rate of cooling is effected by forced quenching using water, oil, water emulsion or forced air depending on the type of material. The appropriate choice of the cooling medium is essential since an application of a wrong liquid will either result in an insufficient hardness or in a hardened layer with material crack. Water is suitable for plain carbon steel, low alloy steels and cast irons. Oil is the preferred choice for materials requiring a very mild quench, whether spray or immersion, and is used for highly alloyed steels, high carbon steels and for parts with abrupt sections. Water emulsion is also used in case where the quench rate must be between the water and oil. Soluble oil in concentration varying from 0.5 to 10% present have been used. Polymer solutions have also been used.

The different methods of quenching adopted are:

1. Agitated quench
2. Progressive quench
3. Static quench.

15.6.1 AGITATED QUENCH

One of the most common methods of quenching after induction heating is the agitated tank quench. The component is heated in an induction coil and indexed manually or automatically into a quench bath (Fig. 15.14). Agitation for the quenchant can be provided

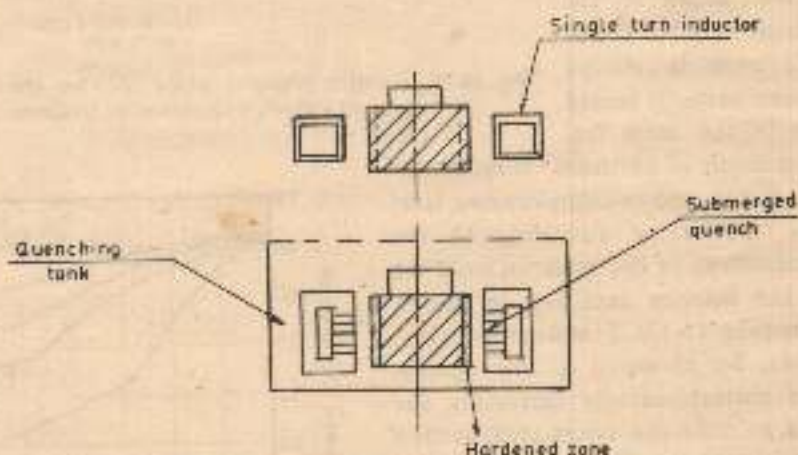


Fig. 15.14 Gear hardening and quenching unit

in a variety of ways, from simple air agitation to a spray quenching using a pump. Great care should be taken to maintain sufficient pressure at all points around the surface of the quench face to ensure an even quenching.

15.6.2 PROGRESSIVE HEAT AND QUENCH

In progressive heating the quenching method adopted is shown in Fig. 15.15 (for flat

surface) and in Fig. 15.16 (for circular shapes). A part is heated by either passing the part continuously into the inductor or by passing the inductor on the part. The angle of incidence is very important and experience has shown that 40 to 50° must be used. This allows

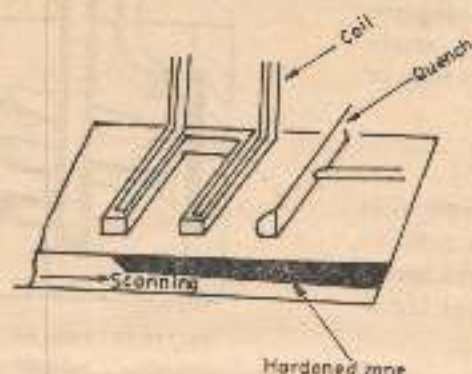


Fig. 15.15 Progressive hardening of rectangular block

sprays to wash the surface with an even film of water or oil, resulting in an even depth of hardness and eliminating the local over hardened spots. It is necessary that not only an adequate flow should be maintained to lower the part temperature sufficiently to ensure complete transformation to martensite but also a suitable pressure of flow should be main-

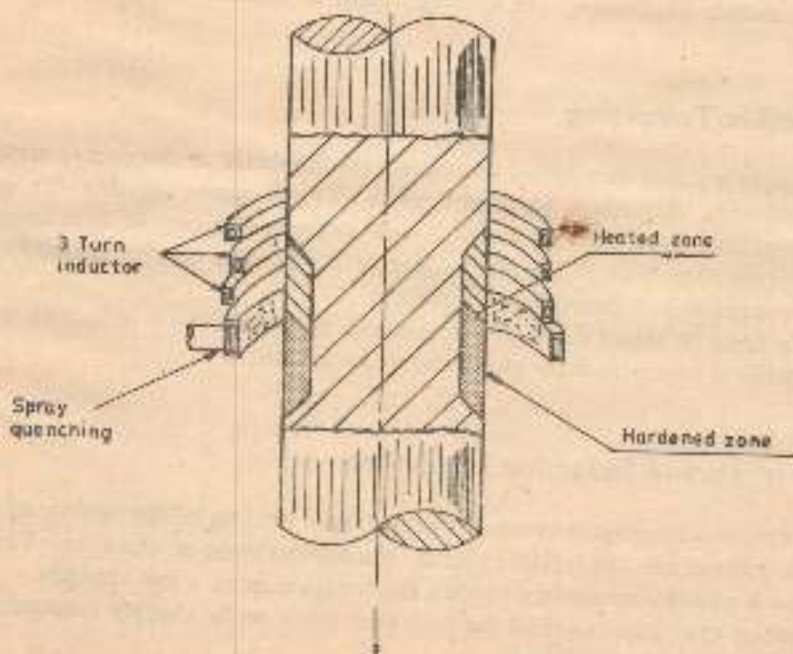


Fig. 15.16 Continuous successive heating and hardening

tained to prevent self-tempering of the section to be hardened. In certain applications, the heat treated parts may not be cooled completely to the room temperature, thus aiding subsequent tempering applications. To attain this, the flow of quenchant may be adjusted.

15.6.3 STATIC QUENCH

In this method the component after being heated in the coil remains there and is quenched by the spraying device located beside the inductor (see Fig. 15.17).

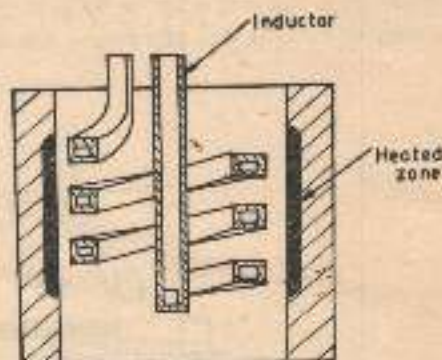


Fig. 15.17 Inductor for internal surface hardening (3-turn cylindrical inductor)

15.7 Tempering

[Tempering of induction-hardened components is not recommended for parts in which the maximum wear resistance or fatigue properties are desired. A low-temperature anneal reduces internal compressive stresses which contribute towards a higher hardness and endurance limit.] The components to be ground after induction hardening should be tempered at 150–160°C to avoid cracks during grinding. A higher tempering temperature may be adopted to reduce hardness to the specified value of HRC.

15.8 Induction Tempering

Induction tempering may be applied to reduce the hardness of the components, in particular on previously induction hardened parts. This is more suitable for symmetrical shaped components (rounds, hexagonals). These components may be heat treated to uniform desired properties. With this method differential hardness may be attained in a component, with a consequent improvement in quality.

Great care must be taken during heating since the objective of induction tempering is to produce uniform hardness throughout the cross section.

15.9 Advantages of Induction Hardening

1. The special advantage accrues due to the rapid heating of the surface of the components without an appreciable rise in the temperature of the core. This condition makes it possible to surface harden the component in a few seconds.
2. It enables the time required for heat treatment to be sharply reduced, thereby increasing labour productivity.
3. It makes it possible to use a steel of inferior quality with the same practical effect as will be obtained with a much higher class of steel.

4. Accurate electrical control of heat transmission and a high rate of temperature increase can be extended to obtain a completely automatic electronic control, which can be fitted directly on to the production line.
5. Deformation due to induction hardening is considerably reduced.
6. It enables the components to be heated without the formation of an oxide layer or surface decarburization so that the allowance for subsequent machining may be reduced.
7. In comparison with ordinary hardened steels, induction hardened steels possess a higher hardness (Fig. 15.18) due to (a) compressive stresses in the martensite zone of the surface hardened samples, and (b) a finer martensite structure with less retained austenite which is usually obtained due to lack of homogenization during heating.
8. Using a cheaper variety of steel, induction hardening can obtain the wear resistance that is normally obtained in the case of carburized steels. Table 15.3 indicates the results of wear testing of carburized and surface hardened steels. The wear resistance of an induction hardened component is almost the same compared to the carburized and hardened steel (Table 15.3).

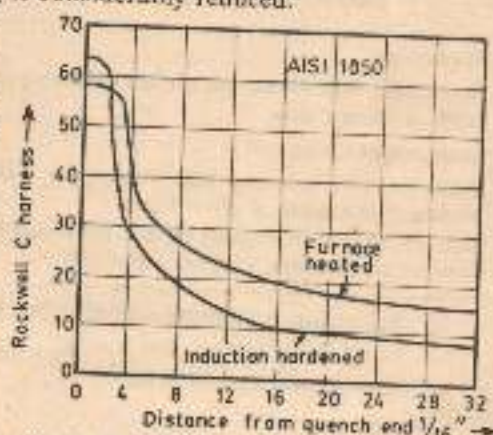


Fig. 15.18 Comparison of transformation characteristics of steel—AISI 1050 as developed by end-quenched specimens which are induction and flame hardened

Table 15.3 Results of Wear Testing Carburized and Surface Hardened

Type of steel	Heat treatment	Vickers surface hardness (load 10 kg)	Wear (mg) steel specimen	Bronze bushing
18KhNVA	Carburizing 1.5 mm, quench hardening 780°C, tempering 180°C	675	0.5	4.5
40KhNMA 18 35Ni1Cr60	Quench hardening 860°C, tempering 550°C, Surface hardening 1 mm, tempering 180°C	748	4.5	4.0
10	Carburizing 1.5 mm, quench hardening 780°C, tempering 170°C	782	4.0	3.0
45	Quench hardening 860°C, tempering 550°C, surface hardening 1 mm, tempering 180°C	748	7.0	3.5

9. Components induction hardened generally possess a higher fatigue and impact strength compared to other hardening methods (Table 15.4).

Table 15.4 Results of Fatigue Testing (in Transverse Bend) Specimens of Steel 50Kh, 18 mm dia. After Surface Hardening and Other Forms of Treatment (15Kh, 0.51% C, 0.18% Si, 0.67% Mn, 0.90% Cr, 55Cr₆)

Heat treatment of specimens	Type of specimen	Fatigue kg/cm ²	Limit %
Normalized	Smooth	35.6	100
Normalized with subsequent surface hardening to a depth of about 1 mm	Same	46.2	130
Quenched and tempered	Same	40.7	114
Quenched and tempered with subsequent surface hardening to a depth of about 1 mm	Same	57.8	162
Normalized with subsequent surface hardening to a depth of about 1 mm, with heating to 450°	Same	48.0	135

10. Induction hardening can also be applied for annealing, normalizing, brazing etc., apart from surface hardening.
11. Energy utilization is less.

15.10 Disadvantages of Induction Hardening

1. The use of this method is limited only by the complexity of the inductors which have to be manufactured.
2. High capital investment necessitates high degree of equipment utilization.
3. It is not suitable for all types of steel.

15.11 Steels for Induction Hardening

The basis of selection of induction hardening steels is similar but not identical to that of choosing steels hardened by other methods. The steels with carbon content of about 0.30% and above are mainly used for induction hardening. Steels having less than 0.3% carbon are not generally induction hardened since the hardness produced will be too low. For instance a 0.2% carbon steel will harden only to Rockwell 40C but a 0.45% steel will result in Rockwell 60C. In practice, surface hardening of a component is seldom done on a steel containing more than 0.5% carbon since the higher the carbon the greater the risk of cracking. The addition of special alloying elements does not greatly influence the degree of hardness (Fig. 15.19). Sometimes in order to obtain a greater depth of hardened zone addition of alloying elements is carried out more with a view of improving the



Fig. 15.19. Comparison of transformation characteristics of steel AISI 4340, as developed by end-quenched specimens that are induction and flame hardened

strength of the steel in terms of tensile, yield, impact and fatigue properties. This improved strength enables the desired hardness to be obtained.^{4,5}

The property of surface heating by induction influences to a great extent the choice of steel. The problem of incomplete transformation below the surface does not occur as only the surface layers have been heated. Also, the fast rate of heating of the surface means that a fast quench can be used without the risk of distortion due to internal stresses. The core of the piece therefore retains its initial strength, as it has not been heated or hardened at all. These two effects mean that a plain carbon steel can often be substituted for a more expensive alloy steel previously hardened by heating methods.¹ Another reason for preferring plain carbon steels for induction hardening is that in general they go into solution faster at a lower temperature than alloy steels. This means that a shorter heating time can be used, with less loss of heat to the centre and with increased production rates. A further reason is that a water quench, which is more economical than an oil quench, can often be used. The only reason for using an alloy steel is to produce a hardened piece with an usually high core strength. Different types of steels that are used for induction and flame hardening are listed in data sheets. If the heat treatment is well controlled, tool steels and stainless steels can also be induction hardened.

The steel, prior to induction hardening, should be in the hardened and tempered or normalized state² and the hardness would be such as is acceptable for the unhardened sections. In the case of full annealed or spheroidized steel similar pre-treatment should always be avoided since the dissolution of the carbides is longer than the normal heating up time. Apart from the above steels, cast iron can also be successfully induction hardened.

Steels that are mainly used are given in Table 15.5. Their chemical compositions and mechanical properties are given in Tables 15.6 to 15.13.

Table 15.5 Induction and Flame Hardening Steels

Country Standard	ISO ISO	India IS	DEU DIN	USA AISI	GBR BS 970	FRA NFA 35	USSR GOST	JPN JIS
1	Type 1	35C8	CF35	1035	06DA35	XC38TS	35	S35C
2	Type 3	45C8	CF45	1045	060A47	XC42TS	45	S45C
3	Type 5	55C6	CF53	1050	060A52	XC48TS	50	S50C
4	Type 7	—	38Cr4	5135	520H36	—	38ChA	SCr3
5	Type 8	40Cr4	42Cr4	5140	580M40	42CHTS	40Cb	SCr4
6	Type 9	40Cr4Mo3	41CrMo4	4140	708M40	42CD4TS	40CLFA	SCM4
7	Type 13	50Cr4V2	50CrV4	6150	735A50	50CV4	50KHGFA	SUP10
8	Type 10	—	—	8640	—	40NCD2TS	—	—

Data Sheet 15.1—Type 1 (ISO)**TYPICAL APPLICATIONS**

This steel is mainly used for machine parts requiring high fatigue strength but exposed to little wear. It is used for highly stressed components of motor vehicles and machines. Table 15.6 gives the mechanical properties and chemical composition of International Standard steels that are mainly used.

HOT WORKING AND HEAT TREATMENT

Hot working	1100–850°C
Normalizing	860–890°C
Hardening	840–880°C (Water quench) 860–880°C (Oil quench)
Tempering	550–650°C

The flame or induction hardening temperature will be 30–50°C higher than hardening temperature followed by water quenching.

Stress relieving	150–180°C min., 1 h
Surface hardness	HRC 51–55

Data Sheet 15.2—Type 3 (ISO)**TYPICAL APPLICATIONS**

This steel is extensively used for all kinds of components used in machine tool as well as automobile industries such as gears, spindles, pinions, guideways, cam shafts, tilting levers, gudgeon pins and similar parts of machinery. Table 15.7 gives the mechanical properties and chemical composition of International Standard steels that are mainly used.

HOT WORKING AND HEAT TREATMENT

Forging	1100–850°C
Normalizing	850–870°C
Hardening	820–850°C (Water quench) 830–860°C (Oil quench)
Tempering	550–650°C

Flame or induction hardening temperature will be 40–50°C higher than hardening followed by water quenching.

Stress relieving	150–180°C min., 1 h
Surface hardness	HRC 55–60

Data Sheet 15.3—Type 5 (ISO)**TYPICAL APPLICATIONS**

This steel is used mainly for lathe spindles, guideways, tailstock sleeves, tie bars and similar components required for heavy duty without the danger of crack formation, even for shapes difficult to harden. It is also used for gear change, gudgeon pins, worm shafts, gear

Table 15.6

Country	ISO	India	DEU	USA	GBR	FRA	USSR	JPN
Standard norm	ISO 683/X11-72	IS	DIN 17212-72	AISI	BS 970:1-83	NFA35-563-83	GOST 1050-74	JIS G4051-79
Designation	Type-1	35C8	C135	1035	080A35	XC38TS	35	S55C
Chemical composition	C	0.33-0.39	0.32-0.4	0.32-0.38	0.33-0.38	0.35-0.4	0.32-0.4	0.32-0.38
	Si	0.15-0.40	0.2-0.4	0.15-0.35	0.1-0.4	0.1-0.4	0.17-0.37	0.15-0.35
	Mn	0.50-0.80	0.6-0.9	0.5-0.8	0.5-0.7	0.5-0.8	0.5-0.8	0.6-0.9
	P	0.035	0.05	0.025	0.035	0.025	0.04	0.030
	S	0.035	0.05	0.035	0.035	0.03	0.04	0.035
	Cr	—	—	—	—	—	—	—
	Mo	—	—	—	—	—	—	—
	Ni	—	—	—	—	—	—	—
Mechanical properties	Dimensions	16-40 41-100	16-40 41-100	—	29	16-40 41-100	—	—
	0.2% proof stress N/mm ² min	360 320	360 320	—	370	400 355	—	—
	Tensile strength N/mm ²	580-730 540-690	580-730 540-690	—	625-755	630-770 590-740	—	—
	Elongation % min	19 20	19 20	—	16	17 18	—	—
	Reduction of area % min	—	—	—	—	—	—	—

Table 15.7

Country	ISO	India	DEU	USA	GBR	FRA	USSR	JPN
Standard norm	ISO 683/XII 72	IS	DIN 17212-72	AISI	BS 970/1-83	NTA35-563-83	GOST 1030-74	JIS G4051-79
Designation	Type 3	45C8	C345	1045	D50A47	XC42TS	45	S45C
Chemical composition	C	0.43-0.49	0.43-0.49	0.43-0.5	0.45-0.5	0.4-0.45	0.42-0.5	0.42-0.48
	Si	0.15-0.40	0.15-0.35	0.15-0.3	0.1-0.4	0.1-0.4	0.17-0.37	0.15-0.25
	Mn	0.5-0.8	0.5-0.8	0.6-0.9	0.5-0.7	0.5-0.8	0.5-0.8	0.6-0.9
	P	0.035	0.025	0.04	0.035	0.025	0.04	0.03
	S	0.035	0.035	0.05	0.035	0.020	0.04	0.035
	Ni	—	—	—	—	—	—0.25	—
Mechanical properties	Dimensions	16-40 41-100	16-40 41-100	—	63	16-40 41-100	—	—
	0.2% proof stress N/mm ² min	410 370	410 370	—	400	430 390	—	—
	Tensile strength N/mm ²	660-800 620-765	660-800 620-760	—	700-880	670-810 620-760	—	—
	Elongation % min	16 17	16 17	—	14	16 17	—	—
	Reduction of area % min	—	—	—	—	—	—	—

shafts, etc. Table 15.8 gives the mechanical properties and chemical composition of International Standard steels.

HOT WORKING AND HEAT TREATMENT

Forging	1050–850°C
Annealing	650–700°C
Annealed BHN 220	
Hardening	805–835°C (Water quench) 815–845°C (Oil quench)
Tempering	550–660°C

Flame or induction hardening is done at 30–50°C above the hardening temperature, followed by water quenching. Proper care should be taken while hardening, since the carbon content is higher, to avoid the formation of cracks.

Stress relieving	150–180°C min., 1 h
Surface hardness	HRC 57–62

Data Sheet 15.4—Type 7 (ISO)

TYPICAL APPLICATIONS

This steel is used mainly for highly stressed components of motor vehicles and machine parts such as gears, engine shafts, pins, etc. It is used for case depth in the range of 4 to 7 mm. Table 15.9 gives the mechanical properties and chemical composition of International Standard steels.

HOT WORKING AND HEAT TREATMENT

Forging	1050–850°C
Annealing	680–710°C
Annealed BHN	210–220
Hardening	830–850°C (Water quench) 830–860°C (Oil quench)
Tempering	560–680°C

Flame or induction hardening temperature will be 40–50°C higher than hardening temperature followed by water quenching. Due care has to be taken while hardening the surface to avoid cracks, since the steel is alloyed.

Stress relieving	150–180°C min., 1 h
Surface hardness	HRC 53–54

Data Sheet 15.5—Type 8 (ISO)

TYPICAL APPLICATIONS

Used for highly stressed parts of motor vehicles, engines, shafts, crankshafts of vehicles, parts for machinery, etc. Mainly used when case depth required is in the range of 4–8 mm. Table 15.10 gives the mechanical properties and chemical composition of International Standard steels.

Table 15.8

Country	ISO	India	DEU	USA	GBR	FRA	USSR	JPN
Standard norm	ISO 683/XII-72	IS 55C6	DIN 17212-72	AISI 1050	BS970/1-83	NFA35-563-83	GOST 1050-74	JIS G4051-79
Designation	Type-5	55C6	C-53	1050	080A52	52M4T5	50	S50C
Chemical composition	C	0.5-0.57	0.5-0.57	0.48-0.55	0.5-0.55	0.49-0.55	0.47-0.55	0.47-0.53
	Si	0.15-0.40	0.2-0.4	0.15-0.30	0.1-0.4	0.10-0.40	0.15-0.30	0.15-0.35
	Mn	0.4-0.7	0.5-0.65	0.4-0.7	0.6-0.9	0.5-0.8	0.6-0.9	0.6-0.9
	P	0.035	0.035	0.025	0.040	0.025	0.04	0.030
	S	0.035	0.035	0.035	0.050	0.03	0.05	0.035
	Ni	—	—	—	—	0.25	—	—
Mechanical properties	Dimensions	16-40 41-100	16-40 41-100	—	63	16-40 41-100	—	—
	0.2% proof stress N/mm ² min	430 410	430 400	—	450	410 390	—	—
	Tensile strength N/mm ²	690-830 640-780	690-830 640-780	—	775-925	710-890 690-860	—	—
	Elongation % min	14 15	14 15	—	14	14 13	—	—
	Reduction of area % min	—	—	—	—	—	—	—

Table 15.9

Country	ISO	India	DEU	USA	GBR	FRA	USSR	JPN
Standard norm	ISO 683/X11-72	IS	DIN 17212-72	AISI	BS970/1.83	NFA35-563-83	GOST 4503-71	JIS 4104-79
Designation	Type 7		38Cr4	5135	530H36	—	38 ChA	SCr3
Chemical composition	C	—	0.34-0.4	0.33-0.38	0.33-0.4	0.33-0.39	0.35-0.42	0.33-0.38
	Si	—	0.15-0.4	0.20-0.35	0.1-0.35	0.1-0.4	0.17-0.37	0.15-0.35
	Mn	—	0.6-0.9	0.6-0.9	0.5-0.9	0.6-0.9	0.5-0.8	0.6-0.85
	P	—	0.025	0.035	0.035	Mo-0.15-0.3	0.025	0.030
	S	—	0.035	0.040	0.035	—	0.025	0.030
	Cr	0.9-1.20	0.9-1.2	0.8-1.05	0.8-1.25	0.85-1.15	0.8-1.1	0.9-1.20
Mechanical properties	Dimensions	16-40 41-100	16-40 41-100	—	63 100	16-40 41-100	—	—
	0.2% proof stress N/mm ² min	630 510	630 510	—	570 510	715 610	—	—
	Tensile strength N/mm ²	830-980 740-880	830-980 740-880	—	775-925 700-850	880-1080 830-980	—	—
	Elongation % min	13 14	13 14	—	15 17	12 14	—	—
	Reduction of area % min	—	—	—	—	—	—	—

Table 15.10

Country	ISO	India	DFU	USA	GBR	FRA	USSR	JPN
Standard norm	ISO 683: XII-72	IS	DIN 17212-72	AISI	BS970: 1-83	NFA35-563-81	GOST 4543-71	JIS 4104-79
Designation	Type-8	40Cr4	42Cr4	5160	580M40	42CHTS	40Ch	SCr4
Chemical composition	C	0.38-0.44	0.38-0.44	0.38-0.43	0.36-0.44	0.38-0.44	0.36-0.44	0.38-0.43
	Si	0.15-0.4	0.15-0.4	0.2-0.35	0.1-0.35	0.1-0.4	0.17-0.17	0.15-0.35
	Mn	0.6-0.9	0.5-0.8	0.7-0.9	0.6-0.9	0.5-0.9	0.5-0.8	0.6-0.85
	P	0.035	0.035	0.035	0.035	0.025	0.035	0.030
	S	0.035	0.035	0.04	0.035	0.030	0.035	0.030
	Ni	0.9-1.2	0.90-1.20	0.7-0.90	0.8-1.25	0.85-1.15	0.8-1.10 Ni-0.30	0.9-1.2
Mechanical properties	Dimensions	16-40 41-100	16-40 41-100	—	—	16-40 41-100	25	—
	0.2% proof stress N/mm ² min	670 560	670 560	—	—	685 560	785	—
	Tensile strength N/mm ²	880-1080 780-930	880-1080 780-930	—	—	880-1080 780-930	980	930 min
	Elongation % min	12 14	12 13	—	—	13	10	13
	Reduction of area % min	—	—	—	—	—	—	—

HOT WORKING AND HEAT TREATMENT

Forging	1050-850°C
Annealing	680-720°C
Hardening	830-850°C (Water quench) 840-860°C (Oil quench)
Tempering	580-670°C

The flame or induction hardening temperature will be 40-50°C higher than the hardening temperature followed by water quenching. Due care has to be taken while surface hardening since it is an alloyed steel.

Stress relieving	150-180°C min., 1 h
Surface hardness	HRC 54-55

Data Sheet 15.6—Type 9 (ISO)**TYPICAL APPLICATIONS**

Used for highly stressed components of vehicles and machines where a high wear resistance of the surface and very good core properties are required. Pinions, crankshafts, gear shafts, etc. Used when the case depth required is in the range of 4-8 mm. Table 15.11 gives the mechanical properties and chemical composition of International Standard steels.

HOT WORKING AND HEAT TREATMENT

Forging	1050-850°C
Annealing	670-720°C
Annealed BHN	210-220
Hardening	820-840°C (Water quench) 840-860°C (Oil quench)
Tempering	670-720°C

The flame or induction hardening temperature will be 40-50°C higher than the hardening temperature followed by water quenching. Due care has to be taken since the steel is alloyed.

Stress relieving	150-180°C min., 1 h
Surface hardness	HRC 53-55

Data Sheet 15.7—Type 13 (ISO)**TYPICAL APPLICATIONS**

Used for parts subjected to heavy loads with oscillating or impact forces acting on them. Even very small cross sections can be heat treated for sufficient strength. Used for vehicles, engines, and machines such as gears, drilling rods for drilling towers, dredger pins, etc. Table 15.12 gives the mechanical properties and chemical composition of International Standard steels.

Table 15.11

Country	ISO	IndIn	DEU	USA	GBR	FRA	USSR	JPN
Standard norm	ISO R 683, XII 72	IS	DIN 17212 72	AISI	BS970/1-83	NFA35- 563-83	GOST 4543-71	JIS C4405-79
Designation	Type-9	40Cr-Mn3	41Cr-Mn4	4140	708M40	42CD4TS	40KhFA	SCM4
Chemical composition	C	0.38-0.44	0.38-0.45	0.38-0.43	0.36-0.44	0.38-0.44	0.37-0.44	0.38-0.43
	Si	0.15-0.4	0.1-0.35	0.15-0.4	0.10-0.35	0.1-0.4	0.17-0.37	0.15-0.35
	Mn	0.5-0.8	0.5-0.8	0.75-1.0	0.7-1.0	0.6-0.9	0.5-0.8	0.65-0.85
	≤P	0.035	0.035	0.035	0.035	0.025	0.025	0.03
	≤S	0.035	0.035	0.040	0.035	0.030	0.025	0.03
	Cr	0.9-1.2	0.9-1.2	0.8-1.10	0.9-1.2	0.85-1.15	0.8-1.2 V-0.1-0.2	0.9-1.2
	Mo	0.15-0.30	0.2-0.35	0.15-0.30	0.5-0.25	0.15-0.3	—	0.15-0.30
Mechanical properties	Diameter mm	16-40 41-100	16-40 41-100	—	16-29 30-100	16-40 41-100	25	25
	0.2% proof stress N/mm ² min	760 640	760 640	—	740 570	815 705	735	—
	Tensile strength N/mm ²	980-1180 880-1080	980-1180 880-1080	—	925-1075 775-925	980-1180 880-1080	880 min	980 min
	Elongation % min	11 12	11 12	—	12 15	11 12	10	12
	Reduction of area % min	—	—	—	—	—	—	—

Table 15.12

Country	ISO	India	DEU	USA	GBR	FRA	USSR	JPN
Standard norm	ISO 683/XIII-73	IS	DIN 17212-72	AISI	BS970/1-83	NFA35-551-83	GOST 4543-71	JIS
Designation	Type-13	40Cr4V2	50CrV4	6150	735A50	50CV4	50KHGFA	SUP10
Chemical composition	C	0.48-0.55	0.46-0.54	0.48-0.53	0.46-0.54	0.47-0.55	0.48-0.55	0.45-0.55
	Si	0.15-0.4	0.1-0.35	0.2-0.35	0.1-0.35	0.1-0.4	0.17-0.37	0.15-0.35
	Mn	0.7-1.00	0.5-0.8	0.7-1.1	0.6-0.9	0.7-1.0	0.8-1.0	0.65-0.95
	P	0.035	0.035	0.035	0.04	0.035	0.03	0.035
	S	0.035	0.035	0.040	0.04	0.035	0.03	0.035
	Cr	0.9-1.2	0.9-1.2	0.8-1.1	0.8-1.1	0.85-1.15	0.75-1.2	0.8-1.1
	V	0.1-0.2	0.15-0.3	0.15V	0.15V	0.1-0.20	0.8-1.10	0.15-0.25
Mechanical properties	Dimensions	10	10	—	10	—	—	—
	0.2 % proof stress N/mm ² min	1180	—	—	1125	—	—	—
	Tensile strength N/mm ²	1370 min	—	—	1320-1570	—	—	—
	Elongation % min	6	—	—	7	—	—	—
	Reduction of area % min	—	—	—	—	—	—	—

Table 15.13

Country	ISO	India	DEU	USA	GBR	FRA	USSR	JPN
Standard norm	ISO 683/X11-72	IS	DIN	AISI	BS 970/1-83	NF A35-563-83	GOST	JIS
Designation	Type-10	—	—	8640	—	40NCD2TS	—	—
Chemical composition	C	—	—	0.38-0.43	—	0.38-0.44	—	—
	Si	—	—	0.15-0.30	—	0.1-0.4	—	—
	Mn	—	—	0.75-1.0	—	0.7-1.0	—	—
	P	—	—	0.035	—	0.04	—	—
	S	—	—	0.04	—	0.035	—	—
	Cr	—	—	0.4-0.6	—	0.4-0.6	—	—
	Mo	—	—	0.15-0.25	—	0.15-0.3	—	—
	Ni	—	—	0.4-0.7	—	0.4-0.7	—	—
Mechanical properties	Dimensions	16-40	—	50	—	—	—	—
	0.2 % proof stress N/mm ² min	41-100	—	100	—	—	—	—
	Tensile strength N/mm ²	360	—	—	—	—	—	—
	Elongation % min	580-730 540-690	—	1035 889	—	—	—	—
	Reduction of area % min	19 20	—	—	—	—	—	—
	—	—	—	—	—	—	—	—

HOT WORKING AND HEAT TREATMENT

Forging	1050-850°C
Annealing	650-680°C
Annealed BHN	220-230°C
Hardening	820-840°C (Water quench) 860-880°C (Oil quench)
Tempering	680-720°C

The flame or induction hardening temperature will be 40-50°C higher than the hardening temperature followed by water quenching. Due care has to be taken since the steel is alloyed.

Stress relieving	150-180°C min., 1 h
Surface hardness	HRC 58-62

Data Sheet 15.8—Type 10 (ISO)**TYPICAL APPLICATIONS**

This steel may be used for very highly stressed components, medium- and large-sized parts requiring a high degree of strength and toughness. Mainly used for automotive and aircraft parts, gear shafts, gears and pinions, etc. Table 15.13 gives the mechanical properties and chemical composition of International Standard steels.

HEAT TREATMENT

Forging	1050-850°C
Annealing	650-700°C
Hardening	830-800°C (Oil quench)
Tempering	540-600°C

The flame or induction hardening temperature will be 40-50°C higher than the hardening temperature followed by water quenching. Due care has to be taken while surface hardening since it is an alloyed steel.

Stress-relieving	150-180°C min., 1 h
Surface hardness	HRC 54-55

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General Engineering Steels (Quenched and Tempered Steels)

Carbon steels are (Carbon 0.25–0.60 per cent and manganese 1.0 per cent max.) extensively used in the form of bars, general engineering forgings and drop forgings after a simple normalizing treatment. The optimum combination of properties for a given material is available only for components not bigger than a certain size which, for carbon steels, is quite small (low limiting ruling sections).

The superior combination of tensile strength, yield strength and ductility, and shock resistance may be obtained from these carbon steels after hardening and tempering. For any one steel there is a minimum speed at which that steel should be cooled to produce effective hardening. Also, the rate at which heat may be absorbed by a quenching medium is affected by ruling sections. While it may be possible to harden satisfactorily small sections of a particular steel by quenching, it may not be possible to harden large sections of the same steel. This effect of mass or size profoundly influences the choice of steel for hardening and tempering. For carbon steels the rate of cooling necessary to give satisfactory hardening is so high that the size of the section in which these steels can be satisfactorily heat-treated is limited. Moreover, the parameters of transformation taking place in the metal are such that uniform properties cannot be imparted to work greater than certain thickness, owing to the difference in the cooling rate between the centre and surface of section thickness. Furthermore, high tensile strength in plain carbon steels is generally associated with a comparatively low yield point and a reduction in ductility and toughness. Hence it is only possible to obtain medium tensile strength levels combined with reasonable ductility and toughness in carbon steels.

Therefore, for larger sizes and for higher tensile strength, it is necessary to use a steel which hardens effectively even when the rate of heat abstraction in quenching is low. These difficulties are overcome by resorting to alloy steels.

By the addition of alloying elements such as manganese, nickel, chromium, molybdenum and vanadium, the minimum rate at which cooling should be carried out to obtain effective hardening is decreased, depending on the amount of element or combination of elements added. Apart from this, it reduces distortion and cracks in the components.

A combination of more than one alloy element is used more often than any single one. This is because the efficiency of any given section is greater where several cooperative elements are present than when an equivalent proportion of just one of them is used. In

addition, some elements possess disadvantages that counterbalance their beneficial action and it is desirable to limit their content in the metal. Combinations can also be found, in which the respective disadvantages of elements are cancelled by their respective advantages, while other advantages of the two act cooperatively. For example, chromium alone can cause grain coarsening whereas nickel can cause graphitization in high carbon steels on prolonged heating. Chromium stabilizes any carbide present, whereas nickel aids grain refinement. Thus, a combination of the two renders a steel safe from both points of view. Moreover, chromium and nickel help in strengthening the metal, improving hardenability and increasing toughness.

By a suitable choice of alloying elements and with appropriate heat treatment, a very wide range of tensile strengths combined with high yield ratios, excellent ductility and toughness, improved wear resistance and many other special properties can be achieved.

The maximum hardness obtainable in any particular steel is a function of the carbon content, but the rate of cooling for hardening necessary to produce this hardness is governed by the alloy content. As the cross-section at the time of quenching increases, the cooling rate in the interior of the mass is necessarily reduced, and it follows, therefore, that the heavier the section the higher the alloy content necessary to produce any given set of properties. Thus, the application of the steel is governed not only by the mechanical properties required in the heat treated part, but also on the ruling section at the time of heat treatment.

The number of alloy steels available makes the choice of steel for any particular application extremely difficult and, in fact, in most cases, there are a number of steels which will perform the same function equally well. Application of steel mainly depends on the relative merits, cost and availability of the various qualities having similar ranges of properties, apart from the hardenability of the steel. Table 16.1 gives the different types of International Standard steels and the Data sheets give the applications.

16.1 Heat Treatment

Steels containing low alloys may be machined in the as-forged condition. In the case of higher alloy steels, it is difficult to machine in the as-forged condition. Hence they may be softened either by annealing or normalizing, followed by tempering.

16.1.1 ANNEALING

Components such as gears, spindles, shafts, spline shafts, etc., are normally made out of alloy steels. To manufacture these components the steel used should be in the soft condition. The alloy steels are usually received from steel mills in the annealed condition. However, if they are subjected to hot or cold forming, often they must be annealed again before subsequent operations, even though it is possible to manufacture in the as-forged condition.

Steel in the as-forged condition will be having a coarse-grained structure due to a long holding time temperature during forging. Components that are manufactured in the as-forged condition may reveal heavy distortion or cracks during the hardening process. Sometimes it is difficult to machine the components in the forged condition. Manufacturing

the components in the forged condition may not be acceptable. To overcome this problem during the manufacture of gears, spindles, wheel spindles etc., it is essential to carry out annealing. Annealing imparts the best condition for working, machining, and offers the most favourable grain-structure for hardening.

Depending on the type of furnace and type of steel either full-annealing or sub-critical annealing may be adopted. Sometimes isothermal annealing may be adopted. Details of the annealing application are mentioned in the data sheets for different types of steels. For purposes of annealing the components are heated slowly and uniformly to the specified annealing temperature, so that the heat penetrates throughout the section. They are held in that temperature for several hours. Subsequently, they are slowly cooled in the furnace up to 500°C. Then they are air-cooled to the room temperature. It is very important that during annealing precautions against decarburization and scaling are taken.

Furnaces used for annealing should be equipped with an accurate temperature control. To protect the surface from decarburization, scaling etc., annealing may be carried out in a controlled atmosphere, using furnace non-oxidizing salt baths or an insert pack material such as spent or pitchcoke.

16.1.2 STRESS RELIEVING

Intricately shaped and slender components should be stress relieved before bringing to the final dimensions in order to avoid the possibility of heavy distortion or cracks that may develop during the hardening process. This treatment is done after rough-machining, or before final machining, in order to relieve the stresses induced in the components during machining or straightening which may give rise to cracks or distortion during hardening.

Stress-relieving consists of heating the components slowly to the temperature of 550–650°C and holding in that temperature for about 1–2 hours. Subsequently, the components are cooled in the furnace up to 400°C to prevent the introduction of new stresses. Thereafter, they are cooled in air. This operation is most commonly performed in air-furnaces or salt baths used for tempering. After stress-relieving, it may be necessary to correct the dimensions before hardening because the relief of stresses causes some dimensional changes.

16.1.3 HARDENING

The components to be hardened are heated slowly to the specified hardening temperature mentioned in the data sheet for the particular type of steel. It is a normal practice to preheat the component to around 600–650°C and hold in that temperature for equalization of temperature throughout the cross-section (30 seconds per mm). Preheating is normally employed for heavy, intricate and slender components as a safeguard against cracking or heavy distortion. For small components preheating is not necessary. After preheating, the components may be heated quickly to the specified hardening temperature and maintained at that temperature for a period depending on the cross-section. The lower limits of the stated temperature range for hardening are selected for the smaller dimensions and intricate shapes, and the upper limit for larger dimensions. After the steel is held for the desired length of time, quenching in water or oil is done, depending on the type of steel (Fig. 16.1).

When the components are in the quenching bath, both components and quenching medium shall be kept in motion to increase the cooling effect and to prevent soft parts. While quenching in water, the temperature of water should be 30–40°C, and for oil, it

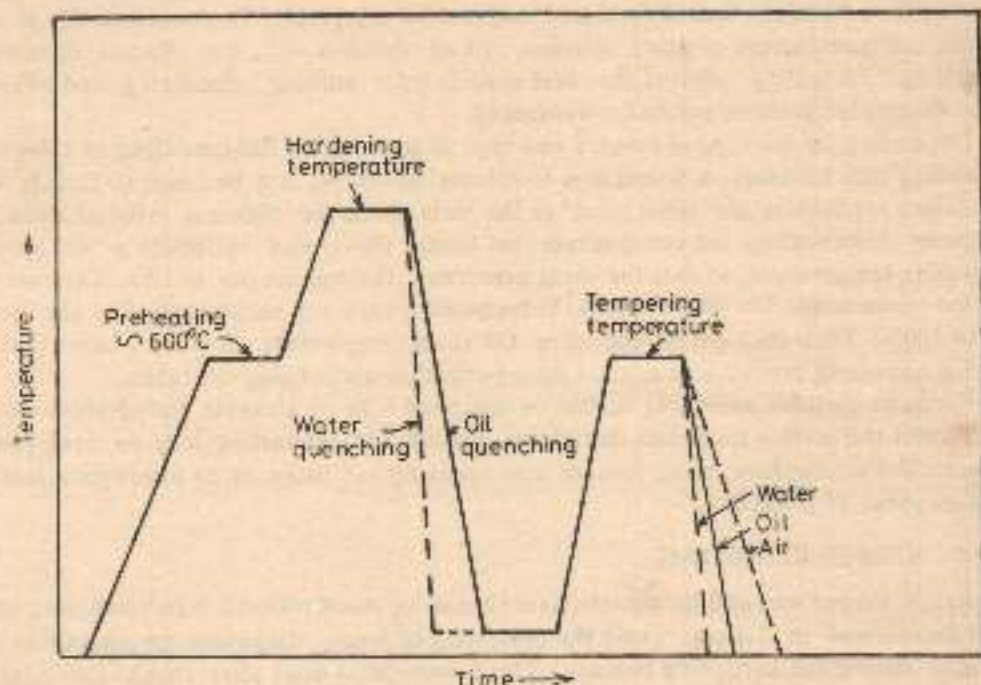


Fig. 16.1 Heat treatment sequence for constructional steel (hardened and tempered)

should be 60–80°C. The oil should be free from water and shall be maintained in a free condition.

After the components are removed from the quenching bath, they should be tempered immediately when they attain the hand-warm temperature. Allowing for too long a time after hardening may lead to cracks forming on the components. Since the components in the fully hardened condition are not only brittle but even highly stressed, it may lead to cracks.

The furnaces employed for hardening shall be designed so as to ensure a uniform temperature throughout the heating space. They should be equipped with a good temperature control system. Both, controlled atmosphere furnace and salt bath have proved satisfactory for service over the entire specified hardening temperature range mentioned in the data sheets. The attainable depth of hardness is illustrated in the data sheets (hardenability bands). It is also advisable to check the success of heat treatment by measuring the hardness obtained. It is also highly important to adopt all possible precautionary methods against surface decarburization in order to avoid a corresponding reduction of fatigue strength and wear resistance.

16.1.4 MARTEMPERING

Martempering is often employed to minimize the distortion without sacrificing the hardness. Martempering consists of quenching the components from the austenitizing bath in oil or salt bath maintained near the M_s temperature of the steel which does not permit the formation of martensite. The holding time in the quenching bath is selected in such a

manner that the temperature equalization occurs without any structural change (see isothermal diagram). Thereafter, the components are cooled in air. In this process, hardening takes place through the entire section of the component during air cooling, thus preventing undue distortion which is liable to occur in the component. The hardness, after martempering, is occasionally somewhat lower than that obtained by the ordinary hardening method. Figure 16.1 illustrates the sequence of hardening.

16.1.5 TEMPERING

After quenching, the hardened components should be immediately tempered in order to relieve the developed stresses by cooling, and to produce a more desirable combination of strength, hardness and toughness.

Tempering may be carried out in salt bath or in a circulating air type furnace. Temperature control by means of a pyrometer is advisable. Tempering consists of heating the components to the desired temperature, depending on the type of steel, and holding at that temperature for a definite period. Subsequent cooling to room temperature should be slow and uniform to prevent the non-uniform relief of hardening stresses that could cause warping. Holding time is normally a minimum of 1 hour. The tempering diagram for different grades of steels, given in the data sheets, will serve as a guide to judge the obtainable hardness. Depending on the holding time and temperature in the tempering bath, there will be a certain variation in the obtainable hardness which may vary within a range of plus or minus of Rockwell C units. With the increasing section thickness of the component, the as-quenched hardness will drop somewhat. This, in conjunction with the longer tempering time customary for the heavier sections, necessitates a slightly lower tempering temperature.

16.1.6 SURFACE TREATMENTS

The surface treatments such as carbonitriding, tufftriding, nitriding, ion-nitriding, flame and induction hardening, etc. may be applied for steels to increase wear resistance and life of the component.

16.1.7 RECOMMENDED PROCESSING SEQUENCE

1. Forge
2. Normalize
3. Anneal
4. Rough machine
5. Stress relieve
6. Pre-final machine
7. Austenitize
8. Quench
9. Temper
10. Finish machine

Table 16.1 General Engineering Steels

Country Standard	ISO ISO	India IS	DEU DIN	USA AISI	GBR BS970	FRA NFA35	USSR GOST	JPN JIS
1	C30 C30e	30C8	C30	1030	080M30	XC32	30	S30C
2	C35 C35e	35C8	C35	1035	080H36	XC638H1	35	S35C
3	C40 C40e	40C8	C40	1040	080M40	XC42H1	40	S40C
4	C45 C45e	45C8	C45	1045	080M46	XC48H1	45	S45C
5	C50 C50e	50C8	C50	1050	080M50	XC48H2	50	S50C
6	C55 C55e	55C8	C55	1055	070M55	XC55H1	55	S55C
7	C60	—	C60	1060	060A62	—	60	—
8	Type-1	27Cr15	28Mn6	1330	150M28	35M5	36G2	SMn1
9	Type-2	37Cr15	36Mn5	1340	150M36	40M6	40G2	SMn2H
10	—	35Mn6Mo3	—	—	605M36	—	—	—
11	Type-1	—	34Cr4	5132	530A32	32C4	35Ch	SCr2
12	Type-3	40Cr4	41Cr4	5140	530M40	42C4	45Cb	SCr4
13	Type-2	—	37Cr4	5135	530A36	38C4	40Ch	SCr3
14	—	55Cr2	—	5155	527A60	—	—	—
15	Type-13	—	50CrV4	6150	—	50CV4	50Ch	SUP10
16	—	40Ni14	31NiCr4	2340	—	38NC12	—	SNC3
17	—	35Ni5Cr2	36NiCr6	3135	640H35	35NC6	—	SNC1
18	Type-5 5a, 5b	30Ni12Cr5	35NiCr18	—	EN30A	40NC17	—	—
19	Type-1	—	25CrMo4	4130	708A25	25CD4	30ChM	SCM2
20	Type-2	—	34CrMo4	4137	708A37	35CD4	35ChM	SCM3
21	Type-3	40CrMo3	40CrMo4	4140	708M40	42CD4	—	SCM4
22	Type-1 1a, 1b	25Cr13Mo6	32CrMo12	—	722M24	30CD12	—	—
23	Type-2 2a, 2b	40Ni6Cr4Mo2	36CrNiMo4	—	816M40	40NCD3	40ChNMA	—
24	Type-3 3a, 3b	40Ni6Cr4Mo3	34CrNiMo6	—	817M40	35NCD6	36Cb2N2MFA	SNCM8
25	Type-4	—	—	4340	—	—	—	—
26	—	40Ni10 Cr3Mo6	40NiMo Cr105	—	826M40	—	—	—
27	Type-5	—	30CrNiMo8	—	823M30	30CND8	30Cb2NVA	SNCM5
28	Type-6	—	—	—	—	35NCD16	—	—

Data Sheet 16.1—C30 (ISO)**HOT WORKING AND HEAT TREATMENT**

Forging	1200°C Max. (Commence) 850°C Min. (Finish)
Normalizing	860–890°C (Cool in air)
Softening	650–700°C
Hardening	860–900°C (Quench in water or brine, oil quench section below 6 mm)
Tempering	550–650°C

CHARACTERISTICS AND TYPICAL APPLICATIONS

This is a water-hardening medium-carbon constructional steel, mainly used for producing forgings and parts machined from hot-rolled and cold-drawn bars. Also available for fabrication processes involving cold heading or cold extrusion. It may be used for machinery parts such as sprockets, gears, steam boiler 'planks', flanges, studs and nuts. Table 16.2 gives the chemical composition and mechanical properties of International Standard steels that are mainly used.

Data Sheet 16.2—C35 (ISO)**HOT WORKING AND HEAT TREATMENT**

Forging	1200°C (Commence) 850°C (Finish)
Normalizing	850–880°C (Air cool)
Annealing	870°C (Furnace cool at a rate of 28°C per hour to 650°C, followed by air cool to room temperature)
Hardening	850–880°C (Quench in oil) 830–850°C (Quench in water)
Tempering	550–670°C

Figure 16.2 illustrates the hardenability band.

CHARACTERISTICS AND TYPICAL APPLICATIONS

General purpose steel, which may be heat treated to produce a tensile strength of the order of 600–750 N/mm² (limiting ruling section 63 mm). This steel is available in bars or billets for forgings. It may be used for cold heading, cold forging, and cold extrusion; it possesses good machinability. It can be flame and induction hardened to attain higher wear resistance.

Used for general engineering purpose such as gear shafts, large crankshafts for combustion and steam engines, crane hooks, railway axles, spindles, etc. Table 16.3 gives the chemical composition and mechanical properties of International Standard steels that are mainly used.

Table 16.2

Country	ISO	India	DEU	USA	GBR	FRA	USSR	IPN
Standard norm	ISO R683/1-68	IS 5517-78	DIN	AISI	BS970/1-72	NFA35- 551-73	GOST	JIS
Designation	C30e C30	30C8	C30	1030	080M30	XC32	30	S30C
Chemical composition	C	0.27-0.34	0.25-0.35	0.27-0.34	0.28-0.34	0.26-0.34	0.27-0.35	0.27-0.35
	Si	0.15-0.40	0.10-0.35	0.40	0.10-0.20	0.10-0.40	0.17-0.37	0.15-0.35
	Mn	0.50-0.80	0.60-0.90	0.5-0.8	0.60-0.90	0.60-1.0	0.50-0.80	0.60-0.90
	≤ P	0.035 (0.05)	0.035	0.035	0.040	0.050	0.035	0.030
	≤ S	0.055 (0.05)	0.035	0.035	0.050	0.050	0.040	0.035
	Cr	—	—	—	—	—	0.25	—
	Ni	—	—	—	—	—	0.25	—
Mechanical properties	Dimensions	16-40 41-100	30	16-40 41-100	13	63 19	16-60 41-100	25
	0.2% proof stress N/mm ² min	335 295	400	350 300	440	340 415	365 335	—
	Tensile strength N/mm ²	540-685 490-640	600-750	550-690 500-650	590-670	550-700 625-775	570-720 540-690	540 min
	Elongation % min	20 21	18	20 21	28	18 16	18 19	23 min
	Reduction of area % min	45 50	—	45 50	65 70	—	—	57 min

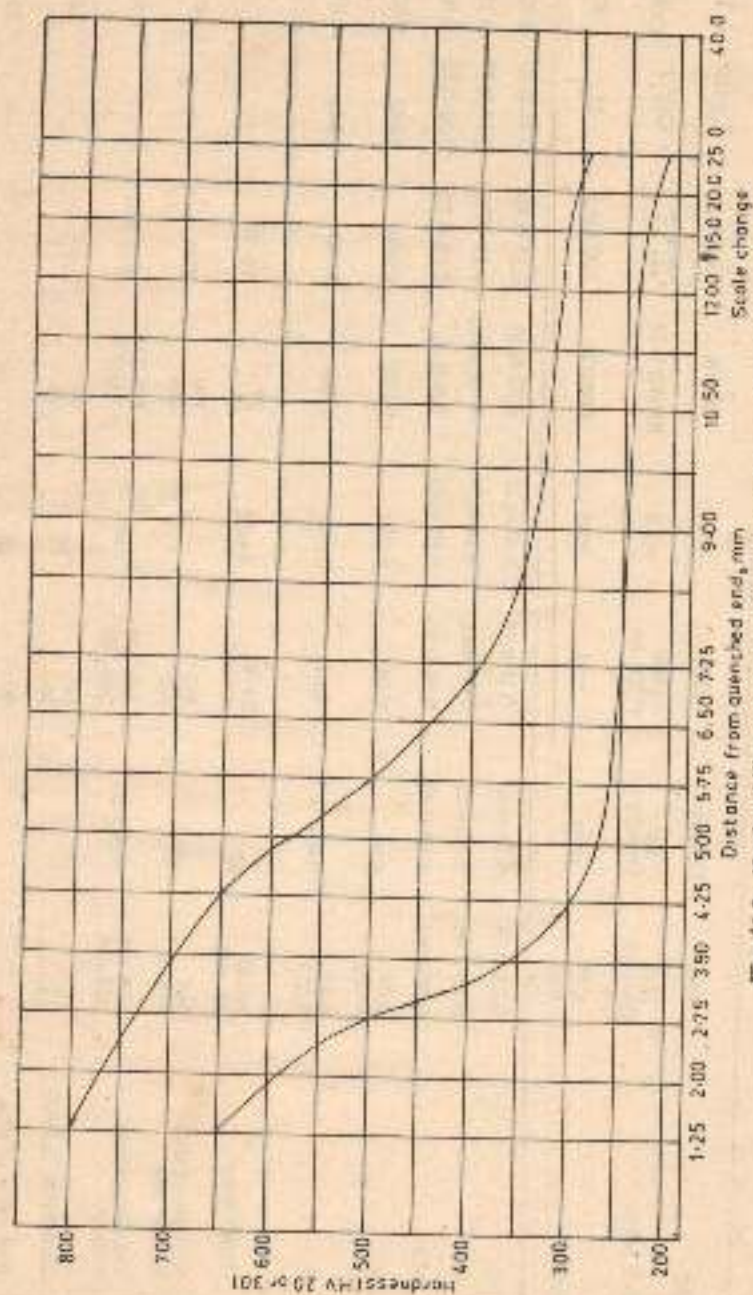


Fig. 16.2 Hardenability curves for thorough hardening steel 080H36

Table 16.3

Country	ISO	INDIA	DEU	USA	GBR	FRA	USSR	JPN
Standard norm	ISO 683:1-68	IS 5517-78	DIN 17230-84	AISI	BS970:1-72	NFA35 551-75	GOST	JIS Cr4051-63
Designation	C35 C35	35C8	C35	1035	080H36	XC38A1	15	S45C
Chemical composition	C	0.32-0.39	0.32-0.39	0.32-0.38	0.32-0.40	0.35-0.40	0.32-0.40	0.32-0.38
	Si	0.15-0.40	0.10-0.35	0.15-0.25	0.40 max.	0.15-0.35	0.17-0.37	0.15-0.35
	Mn	0.50-0.80	0.60-0.90	0.60-0.90	0.6-0.10	0.50-0.80	0.50-0.80	0.60-0.90
	P	0.05 0.035	0.04	0.045	0.050	0.040	0.040	0.030 max.
	S	0.05 0.035	0.04	0.045	0.050	0.040	0.040	0.035 max.
Mechanical properties	Dimensions	16-40 41-100	63	16-40 41-100	29 13	16-50	—	—
	0.2% proof stress N/mm ² min	365 325	400	365 325	570 450	400	—	25
	Tensile strength N/mm ²	580-730 540-690	600-750	580-730 540-700	625-775 700-850	630-770	—	570 min
	Elongation % min	19 20	18	19 20	16 16	17	—	20 min
	Reduction of area % min	—	—	40 45	—	—	—	35 min

Data Sheet 16.3—C40 (ISO)

HOT WORKING AND HEAT TREATMENT

Forging	1200°C (Commence) 850°C (Finish)
Normalizing	830–860°C (Cool in air)
Annealing	845°C (Furnace cool at a rate of 25°C per hour to 650°C subsequently cooled in air)
Hardening	830–860°C (Quench in water or oil)
Tempering	550–660°C

Figure 16.3(a) illustrates the tempering response and Fig. 16.3(b) the hardenability band.

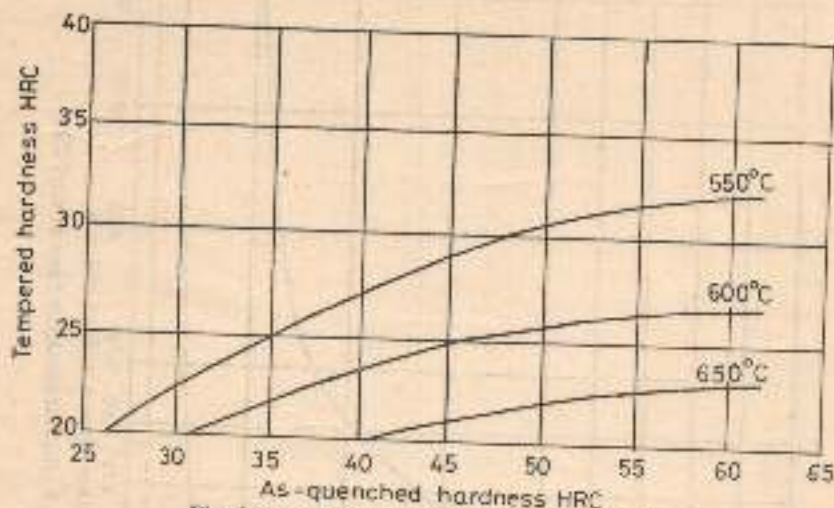


Fig. 16.3 (a) Tempering response of steel C40

CHARACTERISTICS AND TYPICAL APPLICATIONS

This is a medium-carbon steel. It develops a tensile strength of 700–850 N/mm² and is widely used for forgings that will be heat treated. Higher range of manganese provides increased hardenability. Mainly used for motor vehicles, engines and pins, bolts, screws, gears, king pins, etc. Table 16.4 gives the chemical composition and mechanical properties of steels that are mainly used.

Data Sheet 16.4—C45 (ISO) *E_n8*

HOT WORKING AND HEAT TREATMENT

Forging	1150°C Max. (Commence) 850°C Min. (Finish)
Annealing	Heat to 845°C (Cool in furnace at a rate of not exceeding 28°C per hour up to 650°C)
Normalizing	830–860°C (Air cool)
Hardening	830–860°C (Quench in water/oil)
Tempering	530–670°C

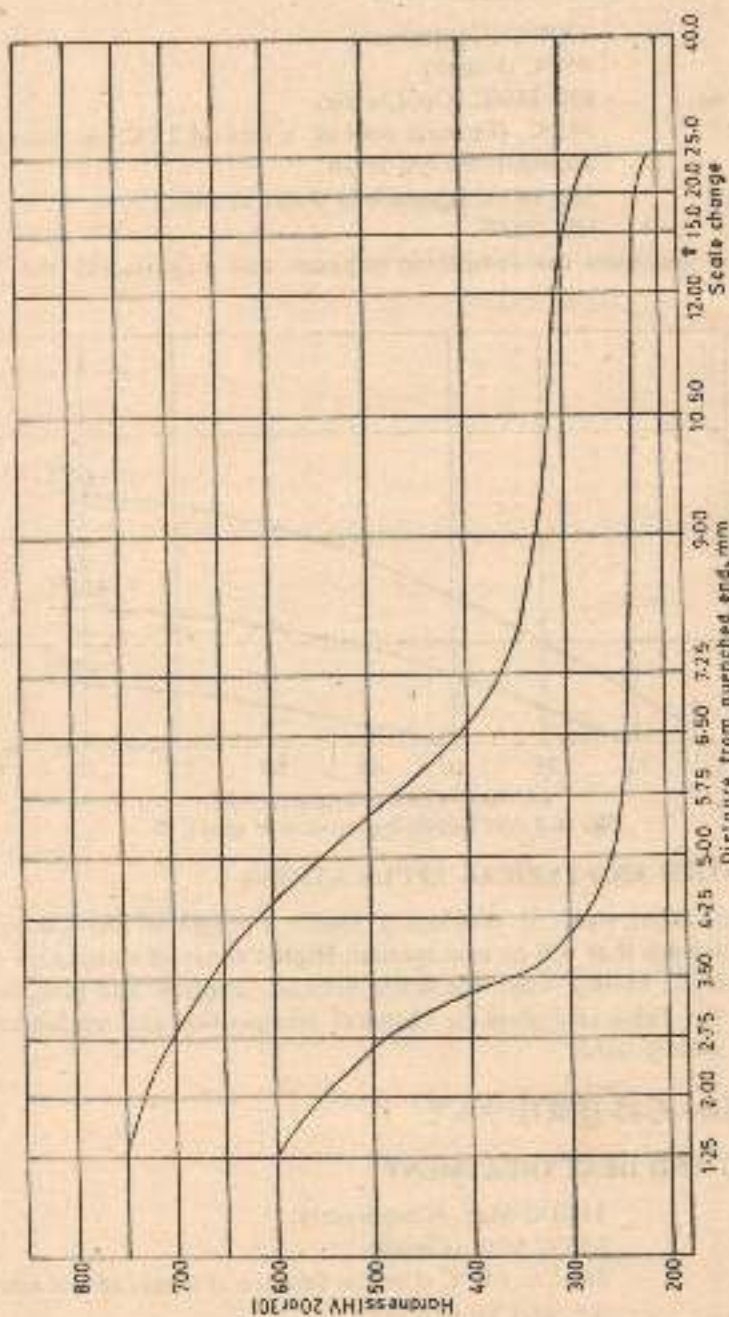


Fig. 16.3 (b) Hardenability band of steel C40

Table 16.4

Country	ISO	India	DEU	USA	GBR	FRA	USSR	JPN
Standard norm	ISO 682/1-68	IS 5517-78	DIN 17200-84	AISI	BS970/1-83	NFA34-552-84	GOST	JIS G4051-79
Designation	C40	40C8	C-40	1040	080M40	XC42	40	S40C
Chemical composition	C	0.37-0.44	0.37-0.44	0.37-0.44	0.36-0.44	0.40-0.45	0.37-0.45	0.37-0.43
	Si	0.15-0.40	0.40	0.15-0.35	0.10-0.40	0.15-0.35	0.17-0.37	0.15-0.35
	Mn	0.5-0.8	0.5-0.80	0.60-0.90	0.60-0.90	0.50-0.80	0.50-0.80	0.60-0.90
	$\leq P$	0.035	0.035	0.040	0.050	0.035	0.035	0.030
	$\leq S$	0.015	0.030	0.050	0.050	0.035	0.040	0.035
Mechanical properties	Dimensions	16-40	16-40	13	63	16	—	25
	0.2% proof stress N/mm ² min	41-100	41-100	100	19	11-40	—	—
	Tensile strength N/mm ²	390	400	—	355	520	—	—
	Elongation % min	345	325	—	450	430	—	—
	Reduction of area % min	620-765	630-780	640-720	625-775	740-880	—	610 min
		580-730	550-700		700-850	670-810		
		18	18	27	16	14		20 min
		19	20	30	16	16		30 min
		—	40	65-0	—	—		
		—	50	61-0	—	—		

Table 16.5

Country	ISO	India	DEU	USA	GBR	FRA	USSR	JPN
Standard norm	ISO 683/1-68	IS 5517-78	DIN 17200-84	AISI	BS190/1-83	NFA33- 552-84	GOST	JIS 4051-79
Designation	C45	45C3	C45	1043	080M46	XC48H1	45	S45C
Chemical composition	C	0.42-0.50	0.42-0.50	0.43-0.50	0.40-0.50	0.40-0.50 0.45-0.51	0.42-0.50	0.42-0.48
	Si	0.15-0.40	0.15-0.25	0.15-0.25	0.10-0.40	0.15-0.35	0.17-0.37	0.15-0.35
	Mn	0.50-0.80	0.50-0.80	0.60-0.90	0.60-1.40	0.50-0.80	0.50-0.80	0.60-0.90
	P	0.035 0.05	—	0.045	0.050	0.030	0.040	0.03
	S	0.035 0.05	—	0.045	0.050	0.035	0.040	0.035
	Cr	—	—	—	—	—	—	—
Mechanical properties	Mo	—	—	—	—	—	—	—
	Ni	—	—	—	—	—	—	—
	Dimensions	16-40 41-100	16-40 41-100	100 30	100 29	16-40 41-100	—	25
Mechanical properties	0.2% proof stress N/mm ² min	410 375	380 450	—	340 415	590 460	—	—
	Tensile strength N/mm ²	660-810 620-770	600-750 700-850	600-750 700-850	625-775 700-850	780-930 710-855	—	685 min
	Elongation % min	16 17	16 17	—	16 16	13 13	—	17 min
	Reduction of area % min	—	25 40	—	—	—	—	45 min

Figure 16.4(a) illustrates the effect of tempering and Fig. 16.4(b) the hardenability band.

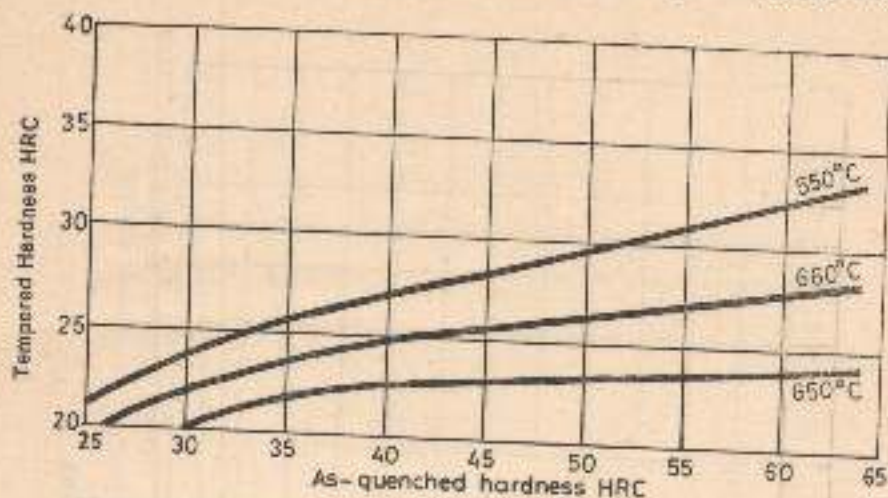


Fig. 16.4 (a) Tempering response of steel C45 (Courtesy: Wolfson Heat Treatment Centre, England).

CHARACTERISTIC AND TYPICAL APPLICATIONS

It develops a tensile strength of the order of 620–720 N/mm² (in a medium size section) and possesses a moderate wear resistance. This steel is mainly used for flame and induction hardening and it can produce surface hardness approximately Rc 55–61 to a depth of 2 mm. Available in a variety of product forms, excellent forgeability, responds readily to heat treatment. Used extensively for pins, crankshafts, gears, spindles, bolts, screws, kind pins, push-rods, punchings, hubs, cam shafts, gear shafts, clutch disks and other components for motor vehicles, railway cars, locomotive axles, and in particular for gears in machine tools to bring down the cost and increase the productivity. Table 16.5 gives the chemical composition and mechanical properties of International Standard steels that are mainly used.

Data Sheet 16.5—C50 (ISO)

HOT WORKING AND HEAT TREATMENT

Forging	1150°C Max. (Commence) 850°C Min. (Finish)
Normalizing	810–840°C (Air cool)
Annealing	830°C (Cool in furnace at a rate not exceeding 25–28°C per hour to 650°C. Subsequently cool in air)
Hardening	810–840°C (Quench in oil)
Tempering	550–660°C

CHARACTERISTICS AND TYPICAL APPLICATIONS

It develops a tensile strength of the order of 800 to 950 N/mm² (medium size section). Mainly used for small and medium forgings. Used for flame and induction hardening to

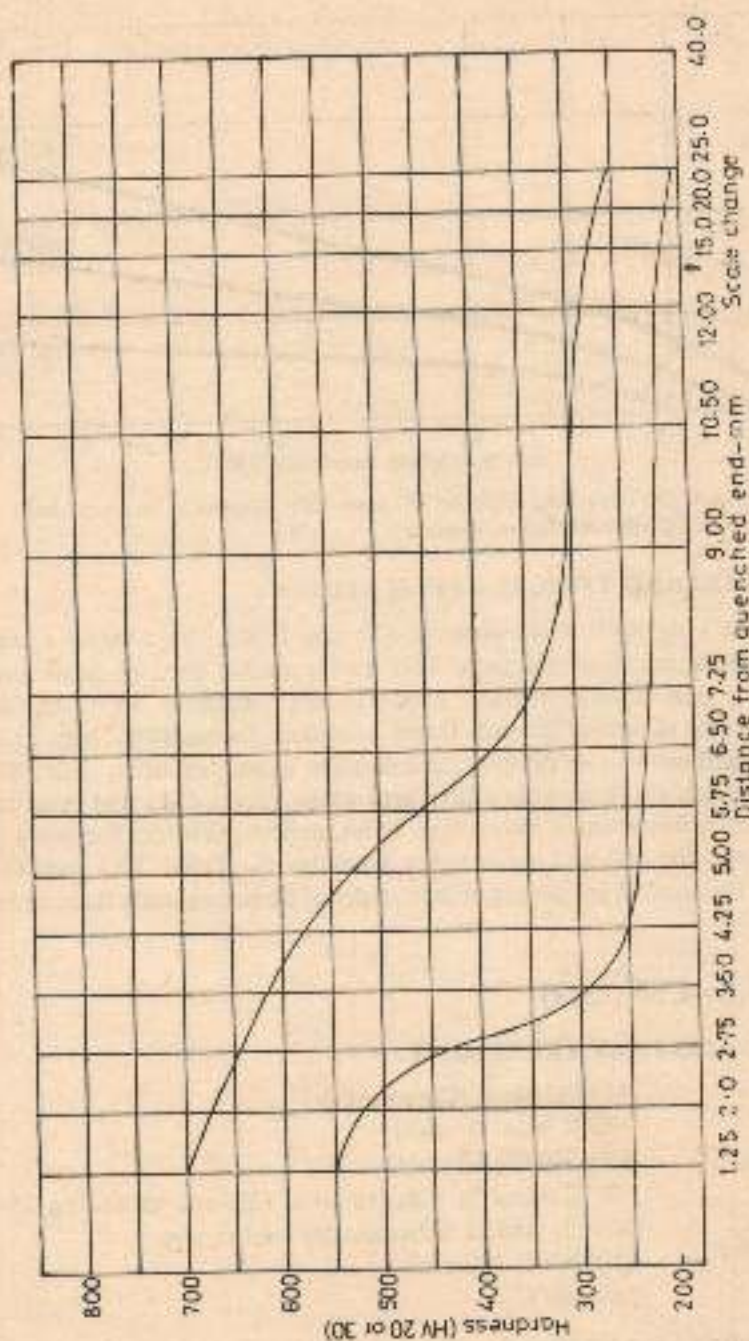


Fig. 16.4 (b) Hardenability band of steel C45

Table 16.6

Country	ISO	India	DEU	USA	GBR	FRA	USSR	JPN
Standard norm	ISO R683:1-68	IS 5517-78	DIN 17200-84	ASTM	BS970:1-83	NFA35 552-84	GOST	JIS G4051-79
Designation	C50e C50	50C8	C50	1050	080M50	XC4SH2	50	S50C
Chemical composition								
C	0.47-0.55	0.45-0.55	0.47-0.55	0.48-0.55	0.45-0.55	0.45-0.51	0.47-0.55	0.47-0.53
Si	0.15-0.40	0.10-0.35	0.4 max	0.20-0.35	0.10-0.40	0.15-0.35	0.17-0.37	0.15-0.35
Mn	0.60-0.90	0.60-0.90	0.6-0.9	0.60-0.90	0.60-1.00	≤1.20	0.50-0.80	0.60-0.90
≤ P	0.035	0.035	0.035	0.040	0.050	0.035	0.055	0.030
≤ S	0.035	0.035	0.03	0.050	0.050	0.035	0.040	0.035
Mechanical properties								
Dimensions	16-40 41-100	63 30	16-40 41-100	13	150 63	17-40	—	25
0.2% proof stress N/mm ² min	460 400	460 540	460 400	—	360 400	460	—	—
Tensile strength N/mm ²	700-845 650-800	700-850 800-950	700-845 650-800	880-740	625-775 700-850	710-850	—	740 min
Elongation % min	15 16	15 13	15 16	23	—	13 15	—	15 min
Reduction of area % min	35 40	—	35 40	53	—	—	—	40 min

attain high surface hardness and wear resistance (58 to 60 HRC). Possess a good machinability. Used for piston pins, boring bars, gear shafts, wheels, transmission parts, etc. Table 16.6 gives the chemical composition and mechanical properties of International Standard steels that are mainly used.

Data Sheet 16.6—C55 (ISO) *Em 9*

HOT WORKING AND HEAT TREATMENT

Forging	1150°C Max. (Commence) 850°C Min. (Finish)
Annealing	830°C (Cool in furnace at a rate of 25°C per hour up to 650°C)
Normalizing	830°C (Air cool)
Hardening	810–840°C (Quench in oil or water depending on the cross section of the component)
Tempering	550–650°C

CHARACTERISTICS AND TYPICAL APPLICATIONS

It develops a tensile strength of the order of 700–850 N/mm² (medium size section) and possesses a moderate wear resistance. It possesses a good characteristic, it is mainly used for flame and induction hardening to attain high surface hardness with superior wear resistance properties. Used for medium stressed shafts or road motor vehicles, motor cylinders, spindles, screws, bolts, heavy machinery parts, wrenches, hammers, pliers, screw driver, knife plates, parts of agricultural components. Table 16.7 gives the chemical composition and mechanical properties of International Standard steels that are mainly used.

Data Sheet 16.7—C60 (ISO)

HOT WORKING AND HEAT TREATMENT

Forging	1050°C Max. (Commence) 850°C Min. (Finish)
Normalizing	820–850°C (Cool in air)
Annealing	650–700°C
Hardening	810–840°C (Quench in oil) 800–830°C (Quench in water)
Tempering	550–660°C (According to the mechanical properties required)

CHARACTERISTICS AND TYPICAL APPLICATIONS

It possesses high tensile strength, ranging from 920 to 925 N/mm² in small sections 740 to 890 N/mm² in medium sized sections, and good wear resistance. It may be flamed and induction hardened to produce a high surface hardness with superior wear resistance.

Used for gears, cylinders, crankshafts, cams, machine parts requiring moderate wear resistance, and general engineering such as axles, shafts, pressed and punched parts, piston rods and gear racks. Table 16.8 gives the chemical composition and mechanical properties of steels that are mainly used.

Table 16.7

Country	ISO	India	DEU	USA	GBR	FRA	USSR	IPN
Standard norm	ISO R 683:1-68	IS 5517-78	DTN 17200-84	AISI	B5970/1-83	NFA35- 551-75	GOST	JIS
Designation	C55 C55	55C8	C55	1055	070M55	XC55H1	55	S55C
Chemical composition	C	0.52-0.60	0.52-0.60	0.50-0.60	0.50-0.60	0.52-0.60	0.52-0.60	0.52-0.58
	Si	0.15-0.40	0.15-0.35	0.15-0.35	0.10-0.40	0.15-0.35	0.17-0.37	0.15-0.35
	Mn	0.60-0.90	0.60-0.90	0.60-0.90	0.50-0.90	0.5-0.8	0.50-0.80	0.6-0.9
	P	0.035 0.050	—	0.045	0.040	0.035	0.040	0.035
	S	0.035 0.050	—	0.045	0.050	0.035	0.040	0.035
Mechanical properties	Dimensions	16-40 41-100	63 30	16-40 41-100	100 63	16-40	—	25
	0.2% proof stress N/mm ² min	460 420	410 540	460 420	385 450	490	—	—
	Tensile strength N/mm ²	740-890 700-850	700-850 800-950	740-890 700-850	700-850 775-930	760-900	—	785 min
	Elongation % min	14 15	13 13	14 15	14	14	—	14 min
	Reduction of area % min	—	—	30 35	—	—	—	35 min

Table 16.8

Country	ISO	India	DEU	USA	GBR	FRA	USSR	JPN
Standard norm	ISO R689/1 68	IS	DIN 17200-84	AISI ASTMA 576 B1	B5970/1-72	NF A35 551-75	GOST 1050-74	JIS
Designation	C60		C60	1060	06DA62		60	
Chemical composition	C%	0.57-0.65	0.57-0.65	0.55-0.65	0.60-0.65	—	0.57-0.65	—
	Si%	0.15-0.40	0.40 max	0.15-0.35	0.40	—	0.17-0.37	—
	Mn	0.60-0.90	0.60-0.90	0.60-0.90	0.70-0.90	—	0.50-0.80	—
	P	0.05	0.045	0.04	0.05	—	0.04	—
	S	0.05	0.045	0.05	0.05	—	0.04	—
Mechanical properties	Dimensions	16-40 41-100	16-40 41-100	25	—	—	—	—
	0.2% proof stress N/mm ² min	490 450	490 450	—	—	—	—	—
	Tensile strength N/mm ²	980-925 740-830	780-930 740-830	885	—	—	—	—
	Elongation % min	13 14	13 14	20	—	—	—	—
	Reduction of area % min	—	25 30	30	—	—	—	—

Data Sheet 16.8—Type 1 (ISO)

HOT WORKING AND HEAT TREATMENT

Forging	1200°C Max. (Commence) 850°C Min. (Finish)
Annealing	Heat to 845°C, furnace cool at a rate of 11°C per hour up to 600°C (Cooled in air)
Softening	650–700°C (Furnace cooling)
Normalizing	850–880°C (Air cooling)
Hardening	820–850°C (Quench in water) 860–900°C (Quench in oil)
Tempering	550–650°C (Tempering temperature adopted according to the required mechanical properties)

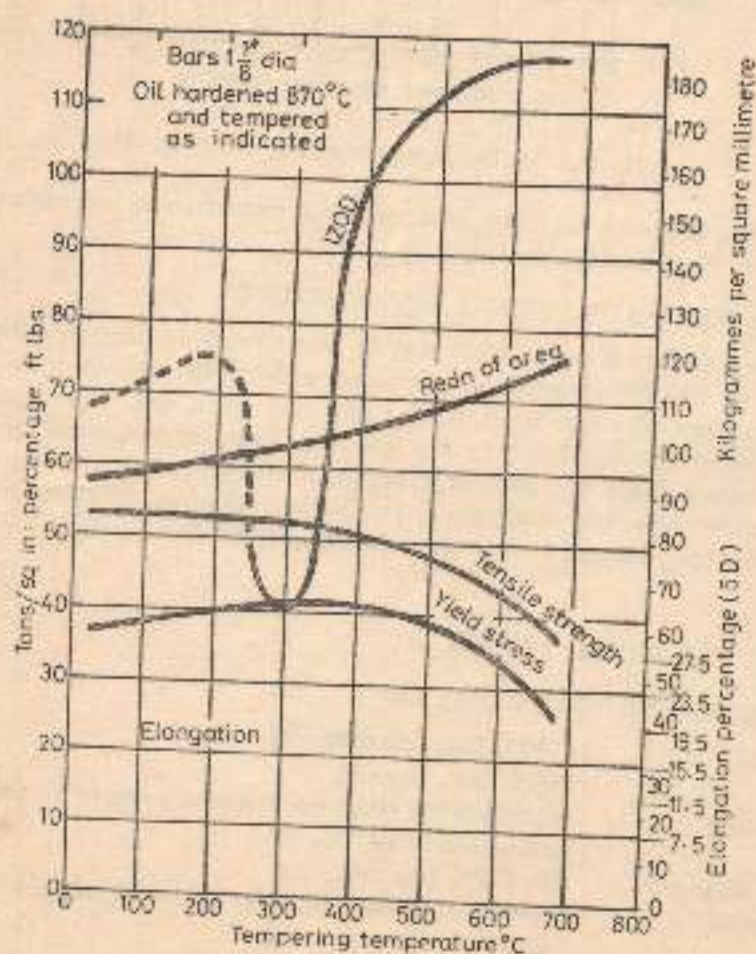


Fig. 16.5 (a) Effect of tempering on mechanical properties of steel 1S 27C15
(Courtesy: Pergamon Press, England)

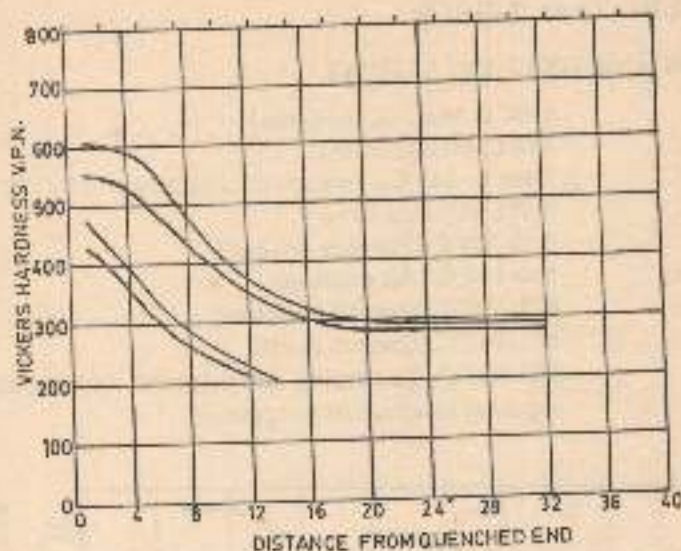


Fig. 16.5 (b) Hardenability bands of steel IS 27C13

Figure 16.5(a) illustrates the effect of tempering temperature on mechanical properties, and Fig. 16.5(b) illustrates the hardenability band.

CHARACTERISTICS AND TYPICAL APPLICATIONS

Manganese heat treatment steel, which may be heat treated to produce a tensile strength of the order of 690–840 in small sections and 640–790 in medium size. This steel is usually oil quenched, although large sections may have to be water quenched to develop maximum hardness. Forgeability is very good. It possesses good ductility and excellent resistance to shock. Used for welded structure, shafting, spindles, various levers, gear parts, coupling bars, screws chain-links, etc. Table 16.9 gives the chemical composition and mechanical properties of International Standard steels that are mainly used.

Data Sheet 16.9—Type 2 (ISO)

HOT WORKING AND HEAT TREATMENT

Forging	1200°C Max. (Commence) 850°C Min. (Finish)
Annealing	Heat to 800°C (Furnace cooled at a rate of 11°C (20°F) to 600°C and cooled in air)
Normalizing	850–880°C (Air cooling)
Hardening	820–850°C (Quench in water for heavy section) 840–870°C (Quench in oil)
Tempering	500–650°C (Water/oil)

Figure 16.6(a) illustrates the effect of tempering on mechanical properties and Fig. 16.6(b) illustrates the hardenability band.

Table 16.9

Country	ISO	India	DEU	USA	GBR	FRA	USSR	JPN
Standard norm	ISO R683/V-70	IS 5517-78	DIN 17210-84	AISI	BS970/1-83	NFA35 552-84	GOST 4543-71	JIS G4106-79
Designation	Type 1	27C15	28Mn6	1330	150M28	35M5	36G2	SMn433
Chemical composition	C	0.25-0.32	0.22-0.32	0.28-0.33	0.24-0.32	0.32-0.38	0.31-0.39	0.30-0.36
	Si	0.15-0.40	0.10-0.35	0.15-0.50	0.10-0.40	0.15-0.35	0.17-0.37	0.15-0.35
	Mn	1.30-1.65	1.30-1.70	1.60-1.90	1.30-1.70	1.10-1.40	1.40-1.80	1.20-1.50
	≤P	0.035	0.035	0.035	0.050	0.035	0.035	0.030
	≤S	0.035	0.035	0.040	0.050	0.035	0.035	0.030
Mechanical Properties	Dimensions	16-40 41-100	16-40 41-100	13	130 63	16-40 41-100	25	—
	0.2% proof stress N/mm ² min	490 440	490 440	—	370 450	500 470	363	—
	Tensile strength N/mm ²	690-840 640-790	690-840 640-790	880-740	625-775 700-850	670-870 620-770	620	—
	Elongation % min	15 16	15 16	18	16	16 17	13	—
	Reduction of area % min	—	45 50	60	—	—	40	—

Table 16.10

Country	ISO	India	DEU	USA	GBR	FRA	USSR	JPN
Standard notation	ISO R 683/V-70	IS 5517-78	DIN 17200-84	AISI	BS 970:1 83	NFA 35- 552 B4	GOST	JIS G 4106 68
Designation	Type 2	37C15	36Mn5	1340	150M36	40M6	40G2	SM 438
Chemical composition	C	0.33-0.40	0.32-0.42	0.34-0.40	0.38-0.43	0.32-0.40	0.37-0.43	0.34-0.41
	Si	0.15-0.40	0.10-0.25	0.15-0.35	0.15-0.35	0.10-0.40	0.15-0.40	0.15-0.35
	Mn	1.30-1.65	1.30-1.70	1.20-1.50	1.60-1.90	1.30-1.70	1.3-1.7	1.35-1.65
	≤ P	0.06	0.035	0.035	0.040	0.050	0.035	0.030
	≤ S	0.15-0.25	0.035	0.035	0.040	0.050	0.035	0.030
Mechanical properties	Dimensions	16-40 41-100	15 100	16-40 41-100	13	150 63	16-40 41-100	25
	0.2% proof stress N/mm ² min	490 460	700 440	590 540	—	370 450	430 410	—
	Tensile strength N/mm ²	740-880 690-830	900-1050 800-750	830-980 740-880	965-800	625-775 700-850	680-830 650-800	—
	Elongation % min	16 17	15 18	10 12	17	18 16	15 16	—
	Reduction of area % min	—	—	40 45	—	—	—	—

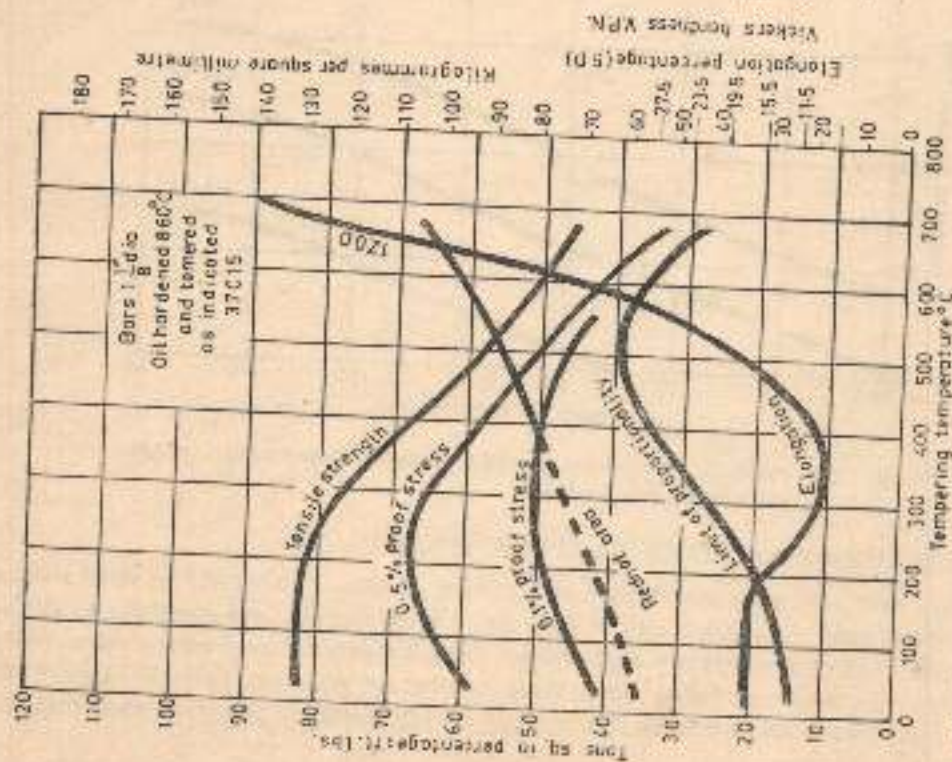


Fig. 16.6 (a) Effect of tempering on mechanical properties of steel IS 37C15 (Courtesy: Pergamon Press, England)

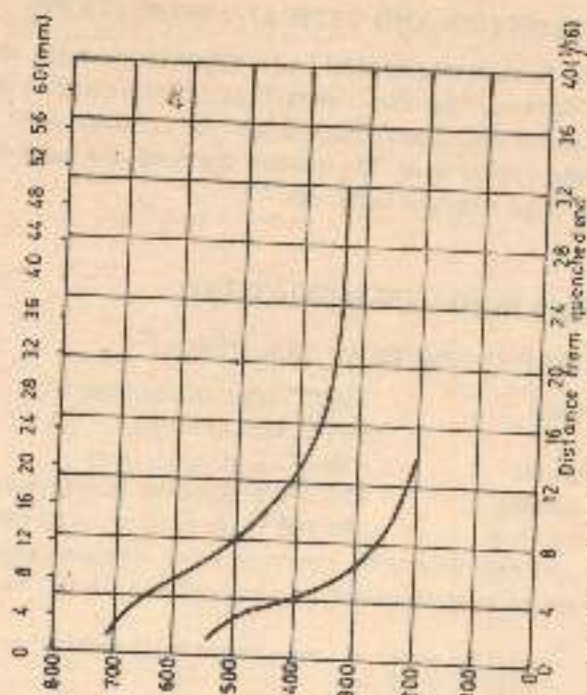


Fig. 16.6 (b) Hardenability bands of steel IS 37 C15

CHARACTERISTICS AND TYPICAL APPLICATIONS

Manganese heat treatable steel with a tensile strength of 590–785 N/mm² in small size and 590–740 N/mm² medium size and combined with good ductility and resistance to shock. Available as hot rolled and finished bar for constructional applications. Also available as cold heading quality wire. These steels are used for axles, shafts, connecting rods, screws, gear parts, high strength bolts, etc.

Data Sheet 16.10—35Mn6Mo3 (IS)**HOT WORKING AND HEAT TREATMENT**

Forging	1200°C Max. (Commence) 900°C Min. (Finish)
Softening	650–670°C (Cool in air)
Hardening	830–860°C (Quench in oil/water)
Tempering	550–600°C (According to mechanical properties required)

Figure 16.7(a) illustrates the tempering response, Fig. 16.7(b) the effect of tempering temperature on mechanical properties, and Fig. 16.7(c) the hardenability band.

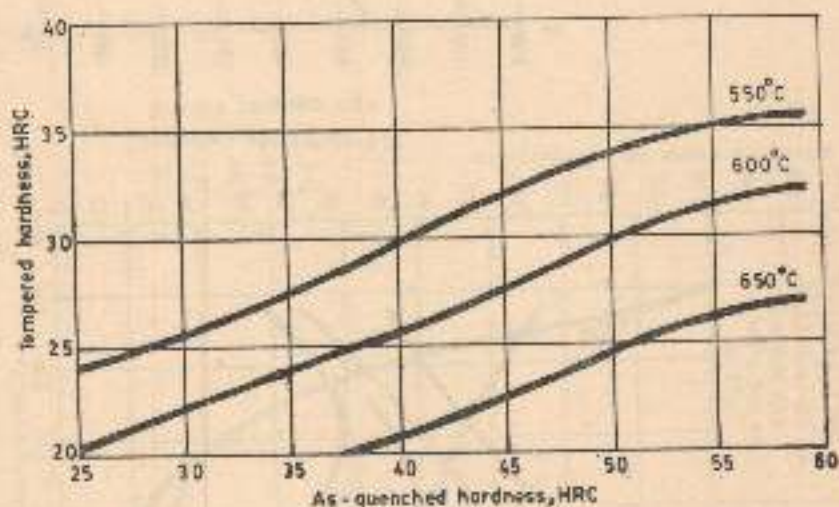


Fig. 16.7 (a) Tempering response of steel IS 35Mn6Mo3 (Courtesy: Wolfson Heat Treatment Centre, England)

CHARACTERISTICS AND TYPICAL APPLICATIONS

A low alloy steel with a tensile strength of the order of 1000–1150 N/mm² in small section and 800–950 N/mm² in medium size. It possesses a good ductility and resistance to shock. It is suitable for low temperature applications. Used for general engineering components such as levers, bolts, crankshafts, wheel studs, connecting rods, etc. Table 16.11 gives the chemical composition and mechanical properties of International Standard steels that are mainly used.

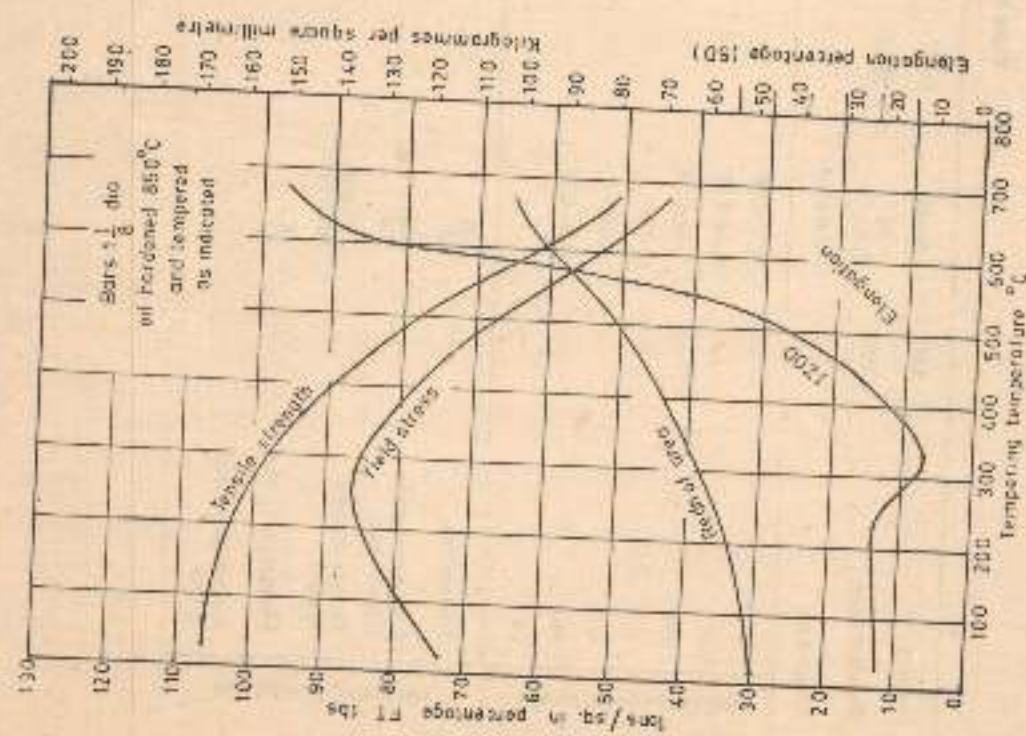


Fig. 16.7 (b) Effect of tempering on mechanical properties of steel IS 35Mn6Mo3

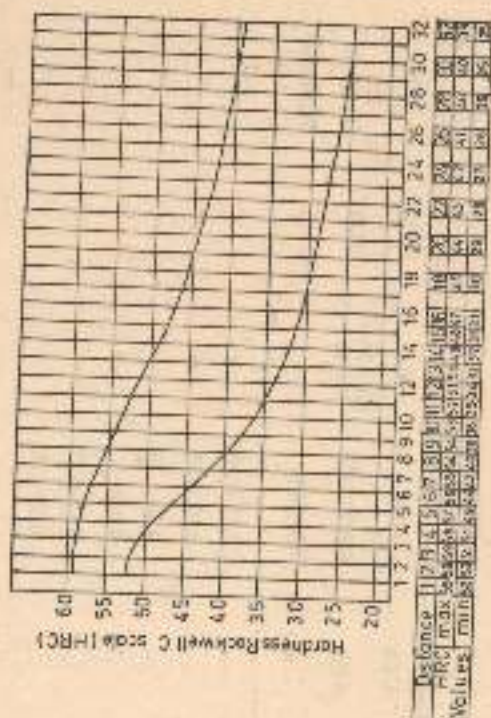


Fig. 16.7 (c) Hardenability bands of steel IS 35Mn6Mo3

Table 16.11

Country	ISO	India	DEU	USA	GBR	FRA	USSR	JPN
Standard norm	ISO	IS 5517-78	DIN	AISI	BS970/1-83	NFAS- 551-75	GOST	JIS G4105-79
Designation	—	35Ni6Mo3	—	—	605M36	—	—	SCM433
Chemical composition	C	0.30-0.40	—	—	0.32-0.40	—	—	—
	Si	0.10-0.35	—	—	0.10-0.35	—	—	—
	Mn	1.30-1.80	—	—	1.30-1.70	—	—	—
	≤ P	0.035	—	—	0.060	—	—	—
	≤ S	0.035	—	—	0.15-0.25	—	—	—
	Mo	0.20-0.35	—	—	0.22-0.52	—	—	—
	Cr	—	—	—	—	—	—	—
Mechanical properties	Dimensions	100 30	—	—	100 19	—	—	—
	0.2% proof stress N/mm ² min	600 800	—	—	510 835	—	—	—
	Tensile strength N/mm ²	800-950 1000-1150	—	—	755-925 1000-1150	—	—	—
	Elongation % min	16 13	—	—	15 12	—	—	—
	Reduction of area % min	—	—	—	—	—	—	—

Data Sheet 16.11—Type 1 (ISO)**HOT WORKING AND HEAT TREATMENT**

Forging	1050°C Max. (Commence) 850°C Min. (Finish)
Normalizing	850–870°C (Cool in air)
Annealing	680–720°C
Hardening	840–870°C (Quench in oil) 830–860°C (Quench in water)
Tempering	540–680°C (According to the mechanical properties required)

CHARACTERISTICS AND TYPICAL APPLICATIONS

This is a chromium content steel, which may be heat-treated in medium-sized sections to produce a tensile strength of the order of 690–835 N/mm² combined with good resistance to shock and good ductility.

Used for components such as front axles, steering knuckles, shafts, highly stressed components of motor vehicles and machines. This steel may be flamed and induction hardened to increase wear resistance. Table 16.12 gives the chemical composition and mechanical properties of International Standard steels that are mainly used.

Data Sheet 16.12—Type 3 (ISO)**HOT WORKING AND HEAT TREATMENT**

Forging	1200°C Max (Commence) 850°C Min (Finish)
Normalizing	850–880°C (Air cool)
Annealing	(1) Heat to 750°C followed by rapid cooling to 690°C, hold for 8 hours. (2) For pearlite structure—Heat to 830°C followed by rapid cooling to 740°C, then cool at a rate not exceeding 11°C per hour up to 670°C.
Hardening	850–880°C (Quench in oil)
Tempering	550–700°C
Stress-relieving	120–200°C

Figure 16.8(a) illustrates the effect of tempering temperature on mechanical properties. Fig. 16.8(b) the hardenability band and Fig. 16.8(c) the guide to tempering response.

CHARACTERISTICS AND TYPICAL APPLICATIONS

Chromium heat treatment steel, may be heat treated to produce a tensile strength of 780 to 930 N/mm² (in medium size) and combined with good ductility. It is suitable for flame and induction hardening to develop wear resistance surface. Used for making gears, gear shafts, wear resistance plates for earth moving and concrete handling equipments, crankshafts, pistons, for highly stressed parts of motor vehicles, piston rods, kind pins, bushes, bolts, crankshafts etc. It develops a hardness of the order of 51 to 58 HRC. Table 16.13 gives the mechanical properties and chemical composition of International Standard steels that are mainly used.

Table 16.12

Country	ISO	India	DEU	USA	GDR	FRA	USSR	JPN
Standard norm	ISO R 683/V11-70	IS	DIN 17200-84	AISI ASTM A322-82	BS 970 1-72	NFA 35 551-75	GOST 4543-71	JIS G 4104-65
Designation	Type 1	—	34Cr4	5132	530A32	32C4	35Ch	SCr430
Chemical composition	C %	—	0.30-0.37	0.30-0.35	0.30-0.35	0.30-0.35	0.31-0.39	0.25-0.33
	Si %	—	0.40 max	0.15-0.30	0.40 max	0.10-0.40	0.17-0.37	0.15-0.25
	Mn	—	0.60-0.90	0.60-0.80	0.60-0.80	0.60-0.90	0.50-0.80	0.60-0.85
	P	—	0.035	0.035	0.04	0.035	0.035	0.03
	S	—	0.03	0.040	0.04	0.035	0.035	0.03
	Cr	—	0.90-1.20	0.75-1.00	0.90-1.20	0.90-1.20	0.80-1.10	0.90-1.20
Mechanical properties	Dimensions	16-40 41-100	16-40 41-100	—	100	16-40 41-100	25	25
	0.2% proof stress N/mm ² min	590 460	590 460	—	510	590 510	—	—
	Tensile strength N/mm ²	785-930 690-835	800-950 700-850	—	700-850	780-930 690-830	930 min	790 min
	Elongation % min	14 15	14 15	—	17	14 15	11	18
	Reduction of area %, min	—	40 45	—	—	—	45	55

Table 16.13

Country	ISO	India	DEU	USA	GBR	FRA	USSR	JPN
Standard norm	ISO R 683/VII-70	IS 4317-78	DIN 17210-84	AISI	BS970/1-83	NFA35- 552-84	GOST 4543-71	JIS GH104-79
Designation	Type 3	40Cr4	41Cr4	5140	530M40	42C4	45Ch	SCr440
Chemical composition								
C	0.38-0.45	0.35-0.45	0.38-0.45	0.38-0.43	0.36-0.44	0.4-0.45	0.41-0.49	0.28-0.43
Si	0.15-0.40	0.10-0.35	0.15-0.40	0.15-0.30	0.10-0.25	0.10-0.40	0.17-0.37	0.15-0.35
Mn	0.60-0.90	0.60-0.90	0.50-0.80	0.70-0.90	0.60-0.90	0.60-0.90	0.50-0.80	0.60-0.85
P	0.035	0.035	0.035	0.035	0.025	0.035	0.035	≤ 0.030
S	0.035	0.035	0.035	0.040	0.025	0.035	0.035	≤ 0.030
Cr	0.90-1.20	0.90-1.20	0.90-1.20	0.70-0.90	0.90-1.20	0.9-1.2	0.80-1.10	0.90-1.20
Mechanical properties								
Dimensions	16-40 41-100	100 30	16-40 41-100	13	63 100	16-40 41-100	25	25
0.2% proof stress N/mm ² min	670 560	540 700	665 560	—	570 510	660 590	835	—
Tensile strength N/mm ²	880-1080 780-930	700-850 900-1050	880-1100 780-940	1000-1200	775-925 700-850	880-1390 780-930	1030	930 min
Elongation % min	12 14	18 15	12 14	17	13 15	12 13	9	13 min
Reduction of area % min	—	—	45 50	—	—	—	45	40 min

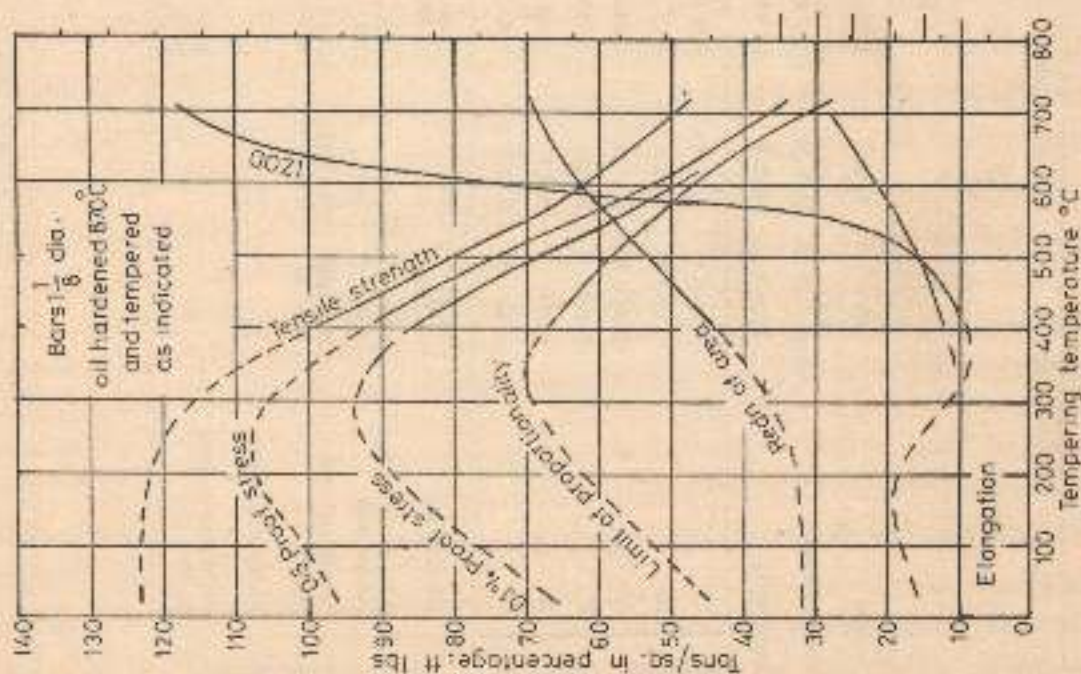


Fig. 16.8 (a) Effect of tempering on mechanical properties of steel IS 40Cr4 (Courtesy: Pergamon Press, England)

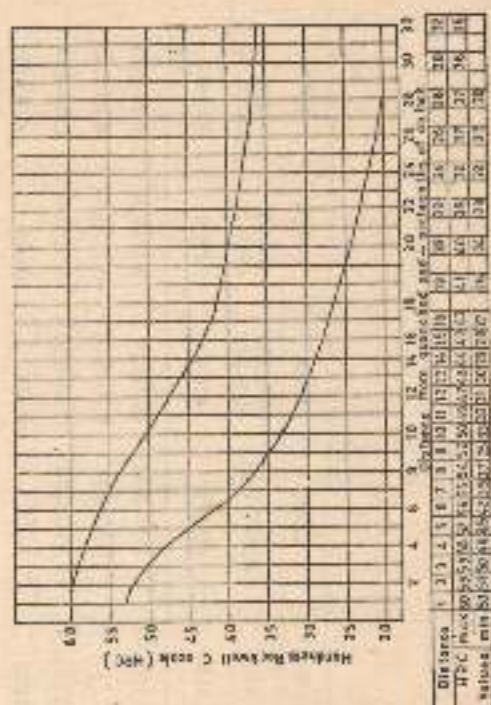


Fig. 16.8 (b) Hardenability bands of steel IS 40Cr4 (Source: BS970)

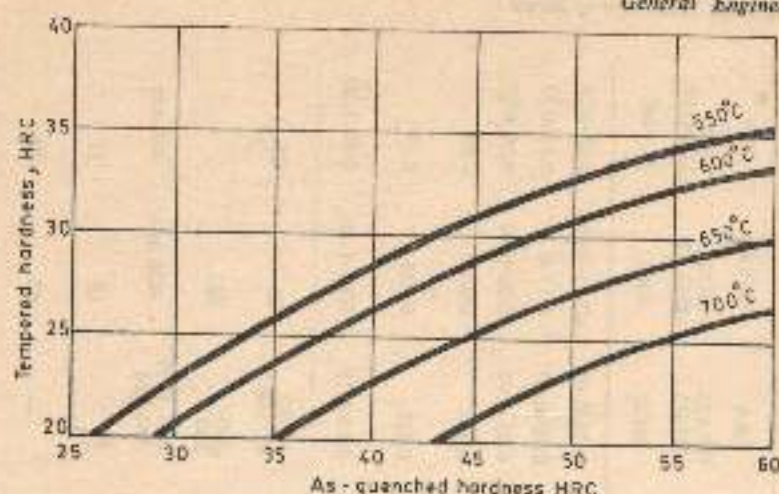


Fig. 16.8 (c) Tempering response of steel 1540Cr4 (Courtesy: Wolfson Heat Treatment Centre, England)

Data Sheet 16.13—Type-2 (ISO)

HOT WORKING AND HEAT TREATMENT

Forging	1050°C Max (Commence) 850°C Min (Finish)
Normalizing	845–885°C (Cool in air)
Annealing	680–720°C
Hardening	835–865°C (Quench in oil) 825–855°C (Quench in water)
Tempering	540–680°C (According to the mechanical properties required)

CHARACTERISTICS AND TYPICAL APPLICATIONS

This steel may be heat treated to produce a tensile strength of the order of 740–890 N/mm² in medium sized specimens. It possesses good ductility and resistance to shock. It may be flamed and induction hardened to produce a surface with high wear resistance.

Used for components such as steering knuckles, shafts, front axles, highly stressed components of motor vehicles and machines. Table 16.14 gives the chemical composition and mechanical properties of International Standard steels that are mainly used.

Data Sheet 16.14—55Cr 3 (IS)

HOT WORKING AND HEAT TREATMENT

Forging	1200°C Max. (Commence) 850°C Min. (Finish)
Annealing	1. Heat to 750°C (Soak for 30 min.) followed by rapid cooling to 700°C, then cool to 650°C at a rate not exceeding 6°C per hour. 2. Heat to 750°C (Soak for 30 min.) followed by rapid cooling to 675°C and held at this temperature for 10 hours.
Hardening	800–850°C (Quench in oil)
Tempering	500–700°C

Table 16.14

Country	ISO	India	DEU	USA	GDR	FRA	USSR	JPN
Standard norm	ISO R683/VII-70	IS	DIN 17200-84	AISI ASTM322-82	RS970/1-72	NFA35 551-75	GOST 4543-71	JIS G4104-79
Designation	Type 2	—	37C4	5135	530A26	38C4	40C2	SCr440
Chemical composition	C %	—	0.34-0.41	0.33-0.38	0.34-0.39	0.35-0.40	0.36-0.44	0.32-0.38
	Si %	—	0.40 max	0.15-0.30	0.40 max	0.10-0.40	0.17-0.37	0.15-0.35
	Mn	—	0.60-0.90	0.60-0.80	0.60-0.80	0.60-0.90	0.50-0.80	0.60-0.85
	P	—	0.035	0.035	0.04	0.035	0.035	0.03
	S	—	0.03	0.04	0.04	0.035	0.035	0.03
C ₂	0.90-1.20	—	0.90-1.20	0.80-1.05	0.90-1.20	0.85-1.15	0.80-1.10	0.90-1.20
Mechanical properties	Dimensions	16-40 41-100	16-40 41-100	—	100	16-40 41-100	25	25
	0.2% proof stress N/mm ² min	630 510	630 510	—	510	620 540	835	—
	Tensile strength N/mm ²	835-980 740-890	850-980 740-850	—	700-850	830-1050 730-880	1030 min	880 min
	Elongation % min	13 14	13 14	—	17	13 14	10	15
	Reduction of area % min	—	40	—	—	—	45	50

Table 16.15

Country	ISO	INDIA	DEU	USA	GBR	FRA	USSR	JPN
Standard norm	ISO	IS	DIN	AISI	BS970/1-83	NFA35	GOST	JIS
Designation		55Cr3		5155	527A60			
Chemical composition	C	0.50-0.60	—	0.51-0.59	0.55-0.65	—	—	—
	Si	0.10-0.35	—	0.15-0.30	0.10-0.35	—	—	—
	Mn	0.60-0.80	—	0.70-0.90	0.70-1.00	—	—	—
	≤ P	0.035	—	0.035	0.040	—	—	—
	≤ S	0.015	—	0.040	0.040	—	—	—
	Cr	0.60-0.80	—	0.70-0.90	0.60-0.90	—	—	—
	Ni	—	—	—	—	—	—	—
Mechanical properties	Dimensions	63 30	—	—	—	—	—	—
	0.2% proof stress N/mm ² min	660 740	—	—	—	—	—	—
	Tensile strength N/mm ²	900-1050 1000-1150	—	—	—	—	—	—
	Elongation % min	—	—	—	—	—	—	—
	Reduction of area % min	—	—	—	—	—	—	—

CHARACTERISTICS AND TYPICAL APPLICATIONS

This steel may be heat treated to produce a tensile strength of the order of 1000–1150 N/mm² (ruling section 63 mm). Hardness attained in the as-quenched condition 57 to 63 HRC. Because of the higher carbon content and high hardenability, this grade does not have a good weldability. Table 16.15 gives the chemical composition and mechanical properties of International Standard steels that are mainly used.

Data Sheet 16.15—Type 13 (ISO)**HOT WORKING AND HEAT TREATMENT**

Forging	1050°C Max. (Commence) 850°C Min. (Finish)
Normalizing	840–880°C (Cool in air)
Softening	680–720°C
Hardening	830–860°C (Quench in oil) 820–850°C (Quench in water)
Tempering	540–650°C (Min 1 h)

CHARACTERISTICS AND TYPICAL APPLICATIONS

Used for parts of medium and large cross-sections requiring high tensile strength and toughness, such as motor vehicles, engines, machines such as gears, shafts, crankshafts, connecting rods, gear shafts, pumps and intermediate gears, etc. It possesses tensile strength of the order of 1100–1300 N/mm² in medium-sized sections and good wear resistance. Table 16.16 gives the chemical composition and mechanical properties of International Standard steels that are mainly used.

Data Sheet 16.16—40Ni4 (IS)**HOT WORKING AND HEAT TREATMENT**

Forging	1200°C Max. (Commence) 850°C Min. (Finish)
Normalizing	830–860°C (Cool in air)
Soft annealing	Heat to 715°C, followed by sudden cooling to 605°C, hold for 10 h cool in air to room temperature.
Hardening	850–860°C (Quench in oil)
Tempering	550–650°C

CHARACTERISTICS AND TYPICAL APPLICATIONS

This steel possesses a toughness of the order of 900–1050 N/mm² in medium size and 800–950 N/mm² bigger section. It may be used for heavy forgings, turbine blades, severely stressed screws, bolts, etc. It is also used for components working at low temperatures (in refrigeration, compressors, locomotives and aircraft). Table 16.17 gives the chemical composition and mechanical properties of International Standard steels that are mainly used.

Table 16.16

Country	ISO	INDIA	DEU	USA	GBR	FRA	USSR	JPN
Standard norm	ISO 683/XIV-73	IS 18	DIN 17200-84	AISI ASTMA322-82	BS970:1-72	NFA35-552-83	GOST 4543-71	JIS G4801-77
Designation	Type 13		50CrV4	6150		50CrV4	50Ch	SUP10
Chemical composition	C %	0.47-0.55	0.47-0.55	0.48-0.53	—	0.47-0.55	0.46-0.54	0.48-0.55
	Si %	0.40 max	0.40 max	0.15-0.35	—	0.10-0.40	0.17-0.37	0.15-0.35
	Mn	0.70-1.10	0.70-1.10	0.70-0.90	—	0.70-1.00	0.50-0.80	0.65-0.95
	P	0.035	0.035	0.035	—	0.035	0.035	0.035
	S	0.035	0.035	0.04	—	0.035	0.035	0.035
	Cr	0.90-1.20	0.90-1.20	0.80-1.10	—	0.90-1.20	0.80-1.10	0.80-1.10
	V	0.10-0.20	0.10-0.20	0.15 max	—	0.10-0.20	—	0.15-0.25
Mechanical properties	Dimensions	—	16-40 41-100	25 100	—	16-40 41-100	25	—
	0.2% proof stress N/mm ² min	—	1050 900	—	—	785 685	885	—
	Tensile strength N/mm ²	—	1250-1450 1100-1300	1200-980 1050-845	—	980-1180 880-1080	1080 min	—
	Elongation % min	—	9 10	—	—	10 12	9	—
	Reduction of area % min	—	40 45	—	—	—	40	—

Table 16.17

Country	ISO	INDIA	DEU	USA	GBR	FRA	USSR	JPN
Standard name	ISO	IS 5517-78	DIN	AISI	BS970/1-72	NFA35-552-84	GOST	JIS G4102-79
Designation		40N14	21NiCr14	2340		30NC12		SNC3
Chemical composition	C	0.35-0.45	0.27-0.35	0.38-0.43	—	0.25-0.33	—	0.32-0.40
	Si	0.10-0.25	0.15-0.35	0.20-0.35	—	0.10-0.40	—	0.15-0.35
	Mn	0.50-0.80	0.40-0.80	0.70-0.90	—	0.35-0.60	—	0.35-0.65
	P	0.035	0.035	0.040	—	0.040	—	0.030
	S	0.035	0.035	0.040	—	0.035	—	0.030
	Cr	0.30 max	0.55-0.94	—	—	0.50-1.00	—	0.60-1.00
	Ni	3.20-3.60	3.25-3.75	3.25-3.75	—	3.00-3.50	—	3.00-3.50
Mechanical properties	Dimensions	63 100	40-100 101-160	—	—	—	—	25
	0.2% proof stress N/mm ² min	700 600	635 590	—	—	—	—	—
	Tensile strength N/mm ²	900-1050 800-950	830-980 780-930	—	—	—	—	930 min
	Elongation % min	15 16	12 13	—	—	—	—	15 min
	Reduction of area % min	—	—	—	—	—	—	45 min

Data Sheet 16.17—35Ni5Cr2 (IS)

HOT WORKING AND HEAT TREATMENT

Forging	1200°C Max. (Commence)
	900°C Min. (Finish)
Softening	620–650°C
Normalizing	850–880°C
Hardening	820–850°C (Quench in oil)
Tempering	500–560°C

Figure 16.9(a) illustrates the effect of tempering temperature on tensile strength, Fig. 16.9(b) the hardenability curve and Fig. 16.9(c) the guide to tempering response.

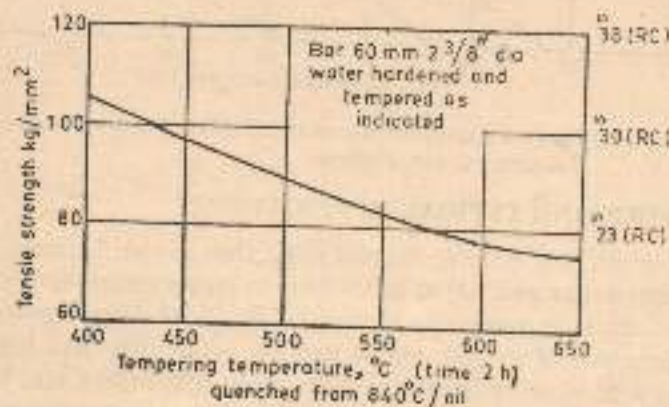


Fig. 16.9 (a) Effect of tempering on tensile strength of steel IS35Ni5Cr2 (Courtesy: Roehling Stahllexport GmbH, W. Germany)

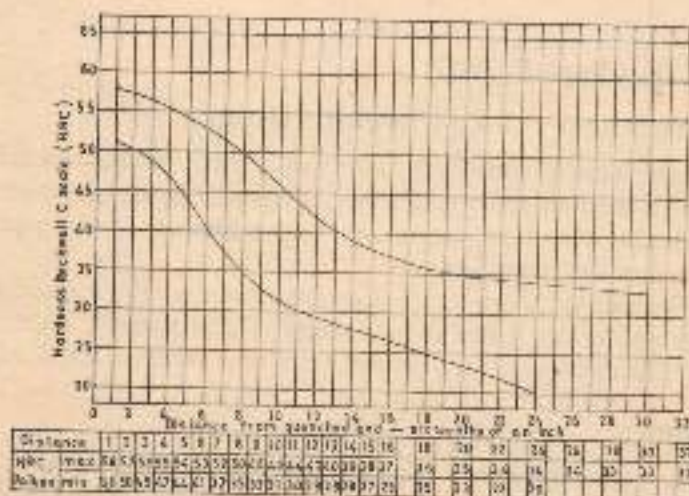


Fig. 16.9 (b) Hardenability bonds of steel IS35Ni5Cr2

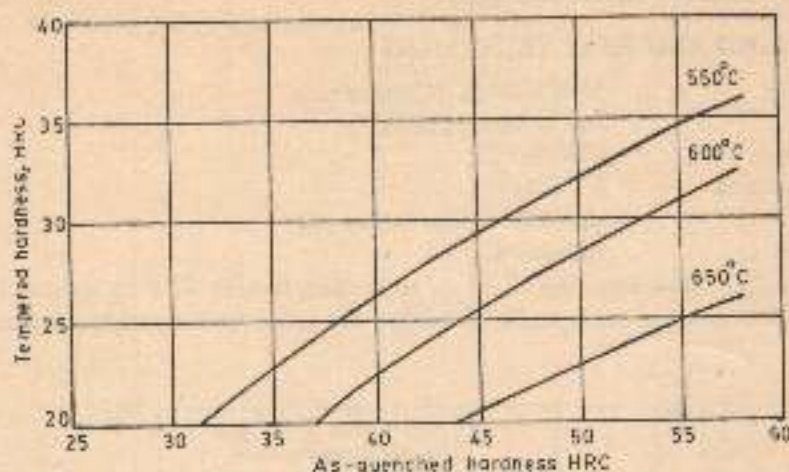


Fig. 16.9 (c) Tempering response of steel IS 35Ni5Cr2 (Courtesy: Wolfson Heat Treatment Centre, England)

CHARACTERISTICS AND TYPICAL APPLICATIONS

NiCr alloy steel, which may be heat treated to produce a tensile strength of the order of 780 to 930 in medium size and 700 to 850 N/mm² in bigger section combines good ductility with resistance to shock. It develops a hardness of 50–55 HRC in the as-quenched condition. Used in the construction of aircraft, highly stressed automobile and engine parts such as bolts, connecting rods, steering knuckles, chain parts, drill collars, etc. Water quenching is adopted in hardening of sections greater than 40 mm in diameter and simpler parts. Table 16.18 gives the chemical composition and mechanical properties of International Standard steels that are mainly used.

Data Sheet 16.18—Type 5 (ISO)

CHARACTERISTICS AND TYPICAL APPLICATIONS

This steel possesses high hardenability and can be heat treated to a tensile strength of 1080–1275 N/mm² in medium-sized specimens. It can also be air hardened. The advantage of air hardening is that distortion can be kept to a minimum so that parts can be almost finish-machined before heat treatment.

This steel can be used for highly stressed gears and components requiring a steel possessing a tensile strength of the order of 160 kg/mm² (1570 N/mm²). Table 16.19 gives the chemical composition and mechanical properties of International Standard steels.

HEAT TREATMENT

- | | |
|-----------|---|
| Annealing | Heat slowly to a temperature of 630–650°C, and hold in that temperature for a required length of time and subsequently cool in air. |
| Hardening | Heat slowly in a neutral atmosphere to a temperature of 810–830°C. |

Table 16.19

Country	ISO	INDIA	DFU	USA	GBR	FRA	USSR	IPN
Standard norm	ISO R683/ VIII 70	IS 5517-78	DFN 17200-84	AISI	BS970/1 72	NFA35- 551-75	GOST	JIS
Designation	Type 5, Sa, 5b	30N513C75	35NiCr18		EN30A	40NC17		
Chemical composition	C %	0.26-0.33	0.29-0.34	—	0.26-0.45	0.37-0.45	—	—
	Si %	0.15-0.40	0.20-0.40	—	0.10-0.35	0.10-0.40	—	—
	Mn	0.30-0.60	0.40-0.70	—	0.40-0.60	0.15-0.55	—	—
	P	0.035	0.035	—	0.05	0.04	—	—
	S	0.035 0.02-0.35 0.03-0.05	0.035	—	0.05	0.035	—	—
	Cr	1.80-2.20	1.10-1.40	—	1.10-1.40	1.50-2.00	—	—
	Mo	0.30-0.50	—	—	—	—	—	—
Mechanical properties	Ni	1.80-2.20	3.90-4.30	—	5.90-4.30	4.00-4.50	—	—
	Ductilities	16-40 41-100	63	40-100 101-161	—	—	—	—
	0.2% proof stress N/mm ² min	1030 890	1200	1030 885	—	—	—	—
	Tensile strength N/mm ²	1225-1420 1080-1275	1550 min	1270-1470 1080-1270	—	—	—	—
	Elongation % min	9 10	8	7 9	—	—	—	—
	Reduction of area % min	—	—	35 40	—	—	—	—

Adopt lower range of temperature for small and light components and higher limit for large and heavy sections. Holding time depends on the section thickness. Subsequently quench in oil or air. Temper immediately and cool to hand warm.

Tempering 620–530°C for the required mechanical properties.

Data Sheet 16.19—Type-1 (ISO)

HOT WORKING AND HEAT TREATMENT

Forging	1100°C max. (Commence) 850°C min. (Finish)
Annealing	680–720°C (Furnace cooling)
Normalizing	860–890°C (Air cooling)
Hardening	820–850°C (Quench in water) 830–860°C (Quench in oil)
Tempering	480–650°C (According to mechanical properties required)

CHARACTERISTICS AND TYPICAL APPLICATIONS

This steel may be heat treated to produce a tensile strength of the order of 800–950 N/mm² in small sections and 700–850 N/mm² in medium sections. It possesses good ductility and resistance to shock. It may be flame and induction hardened to increase wear resistance. It may also be nitrided to increase the life of the component. It is used mainly for gears, axle shafts, pinion shafts, king pins, steering levers, etc. Table 16.20 gives the chemical composition and mechanical properties of International Standard steels.

Data Sheet 16.20—Type-2 (ISO)

CHARACTERISTICS AND TYPICAL APPLICATIONS

A steel of high specific strength under static and dynamic stresses, suitable for pinion shafts, pins, king pins, connecting rods, gears, crankshafts, buck gearing shafts, compensating levers, etc. Table 16.21 gives the chemical composition and mechanical properties for International Standard steels.

HOT WORKING AND HEAT TREATMENT

Forging	Commence 1050°C max. Finish 850°C min.
Annealing	Heat to 840°C followed by rapid cooling to 670°C. Hold for 5–6 hours, followed by furnace cooling (Pearlite structure) Heat to 750°C, cool rapidly to 675°C and hold for 10 hours. Annealed BHN—215–220.
Hardening	830–850°C (Oil quenching)
Tempering	530–670°C (according to mechanical properties required).

Table 16.20

Country	ISO	INDIA	DEU	USA	GBR	FRA	USSR	JPN
Standard norm	ISO R683/41-168	IS	DIN 17200-84	AISI ASTM A322-82	BS970/1-72	NFA25 551-75	GOST 4543-71	JS G4105-65
Designation	Type 1		25CrMo4	4130	708A25	25CD4	30ChM	SCM2 SCM430
Chemical composition	C %	—	0.22-0.29	0.28-0.33	0.23-0.28	0.23-0.28	0.26-0.34	0.28-0.33
	Si %	—	0.15-0.40	0.15-0.30	0.4 max.	0.10-0.40	0.17-0.37	0.15-0.35
	Mn	—	0.30-0.80	0.40-0.60	0.30-0.80	0.60-0.90	0.40-0.70	0.60-0.80
	P	—	0.035	0.035	0.04	0.035	0.035	0.03
	S	—	0.03	0.04	0.04	0.035	0.035	0.03
	Cr	—	0.90-1.20	0.80-1.10	0.90-1.20	0.90-1.20	0.80-1.10	0.90-1.20
Mechanical properties	Mo	—	0.15-0.30	0.15-0.25	0.15-0.25	0.15-0.25	0.15-0.25	0.15-0.30
	Dimensions	10-40 41-100	40-100 101-160	25 100	63	16-40 41-100	25	25
	0.2% proof stress N/mm ² min	390 460	450 410	—	665	600 530	735	—
	Tensile strength N/mm ²	780-930 690-840	690-830 640-780	940-890 800-710	850-1000	780-930 690-840	930 min	840
	Elongation % min	14 15	15 16	20 21	13	14 15	11	18
	Reduction of area % min	—	60 65	61 63	—	—	45	55

Table 16.21

Country	ISO	INDIA	DEU	USA	GBR	FRA	USSR	JPN
Standard norm	ISO R683/II-68	IS	DTN 17200-84	AISI	BS970/1-83	NFA35- 552-84	GOST	JIS G4105-79
Designation	Type 2		34CrMo4	4137	708A37	34CD4	35ChM	SCM3 SCM435
Chemical composition	C	—	0.30-0.37	0.35-0.40	0.35-0.40	0.31-0.37	0.32-0.40	0.33-0.38
	Si	—	≤ 0.40 (max.)	0.20-0.35	0.10-0.35	0.10-0.40	0.17-0.37	0.15-0.35
	Mn	—	0.60-0.90	0.70-0.90	0.70-1.00	0.60-0.90	0.40-0.70	0.60-0.80
	P	—	0.035	0.035	0.040	0.035	0.025	0.030
	S	—	0.035	0.040	0.040	0.035	0.035	0.030
	Cr	—	0.9-1.2	0.80-1.10	0.9-1.2	0.9-1.2	0.8-1.10	0.9-1.20
	Mo	—	0.15-0.30	0.15-0.25	0.15-0.25	0.15-0.25	0.15-0.25	0.15-0.30
Mechanical properties	Ni	—	—	—	0.40	—	0.25	—
	Dimensions	16-40 41-100	16-40 41-100	—	63	16-40 41-100	25	25
	0.2% proof stress N/mm ² min	665 560	665 560	—	665	700 600	835	—
	Tensile strength N/mm ²	880-1080 780-930	900-1080 780-930	—	850-1000	880-1080 780-930	935	930 min
	Elongation % min	12 14	12 14	—	13	12 14	12	15
	Reduction of area % min	—	50	—	—	—	45	50

Data Sheet 16.21—Type-3 (ISO) *En19***HOT WORKING AND HEAT TREATMENT**

Forging	1200°C max. (Commence) 850°C min. (Finish)
Normalizing	850–880°C (Cool in air)
Annealing	Heat to 750°C (soak for 30 min), followed by rapid cooling to 675°C and hold for 9 hours, followed by air cool to room temperature. For predominantly pearlite structure, heat to 845°C, followed by rapid cooling to 750°C, then cool slowly at a rate not exceeding 14°C per hour to 665°C, subsequently cooled in air.
Hardening	850–880°C (Quench in oil)
Tempering	550–720°C.

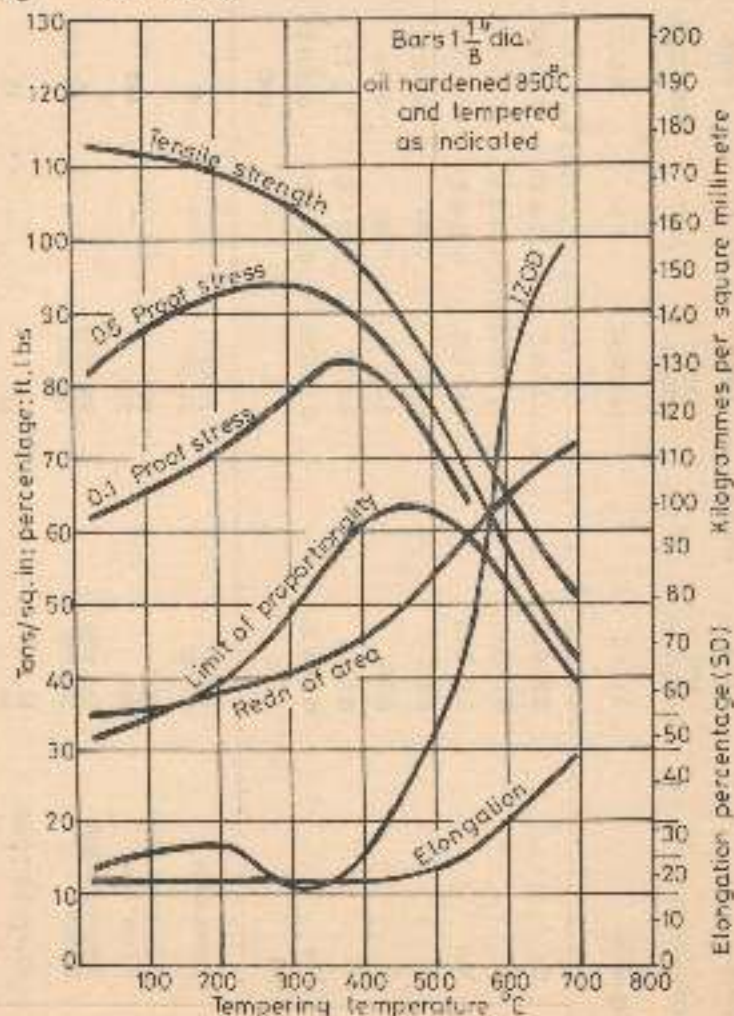


Fig. 16.10 Effect of tempering on mechanical properties of steel BS 40Cr4Mo3 (Courtesy: Pergamon Press, England)

Table 16.22

Country	ISO	INDIA	DEU	USA	GBR	FRA	USSR	JPN
Standard norm	ISO R 683:II-68	IS 5517-78	DIN 17200-84	AISI	BS970:1-83	NFA35 552-84	GOST	JIS G4105-79
Designation	Type 3	40Cr4Mo3	42CrMo4	4140	708M40	42CD4		SCM4
Chemical composition	C	0.38-0.45	0.38-0.45	0.38-0.43	0.36-0.44	0.39-0.46	—	0.38-0.43
	Si	0.15-0.40	0.15-0.40	0.15-0.30	0.10-0.35	0.10-0.40	—	0.15-0.35
	Mn	0.50-1.00	0.50-0.80	0.75-1.00	0.70-1.00	0.60-0.90	—	0.65-0.85
	P	0.035	0.035	0.075	0.040	0.035	—	0.030
	S	0.035	0.035	0.040	0.040	0.035	—	0.030
	Cr	0.90-1.20	0.90-1.20	0.80-1.10	0.90-1.20	0.9-1.2	—	0.90-1.20
	Mo	0.15-0.30	0.15-0.30	0.15-0.25	0.15-0.25	0.15-0.25	—	0.15-0.30
Mechanical properties	Densities	16-40 41-100	16-40 41-100	13-1 100	29 63	16-40 41-100	—	25
	0.2% proof stress N/mm ² min	765 635	765 635	1110 685	755 675	770 700	—	—
	Tensile strength N/mm ²	980-1180 890-1080	980-1180 880-1080	1185 885	920-1080 850-1000	980-1180 880-1080	—	980 min
	Elongation % min	11 12	12 12	15 19	12 15	11 12	—	12 min
	Reduction of area % min	—	45 50	55 60	—	—	—	45 min

Figure 16.10 illustrates the effect of tempering temperature on mechanical properties.

CHARACTERISTICS AND TYPICAL APPLICATIONS

Chromium molybdenum heat treatment steel, which may be heat treated to produce tensile strengths of the order of 980–1180 N/mm² in small sections and 880–1080 N/mm² in medium section, has good ductility and resistance to shock. It develops a hardness of 54–59 HRC in the quenched condition. These steels may be successfully nitrided for maximum wear resistance. When fully hardened, they possess the outstanding property of relatively high impact strength at high hardness and tensile strength. Used for making automobile components, aircraft parts such as steering knuckles, connecting rods and high tensile bolts, and also for trailer axle shafts. Also used in the oil industry for making bits, core drills, reamer bodies, drill collars, piston rods, pump parts, etc. Table 16.22 gives the chemical composition and mechanical properties of International Standard steels.

Data Sheet 16.22—Type-1 (ISO)

CHARACTERISTICS AND TYPICAL APPLICATIONS

This steel possesses excellent hardenability and may be heat treated to develop a wide range of tensile strengths combined with excellent ductility and resistance to shock. It also possesses a good resistance to embrittlement at an elevated temperature. This steel may be used as a mechanical alloy. Nitriding steels are an alternative to nickel-chrome-molybdenum steels.

Components requiring medium to high tensile properties such as crank shafts, gears, cylinder liners for automobile engines and machine parts requiring high surface hardness and wear resistance. Table 16.23 gives the chemical composition and mechanical properties of International Standard steels.

HEAT TREATMENT

Soft annealing	Heat slowly to 700–750°C, hold in that temperature for required length of time and followed by furnace cooling up to 550°C thereafter in air.
Hardening	Heat slowly in a neutral media to 890–910°C, hold in that temperature for a required length of time, depending on the section thickness followed by quench in oil.
Tempering	Up to 750°C according to mechanical properties required.

Data Sheet 16.23—Type-2 (ISO)

CHARACTERISTICS AND TYPICAL APPLICATIONS

These steels possess good ductility and resistance to shock. They may be heat treated to a tensile strength of the order of 880–980 N/mm² in medium section and 800–950 N/mm² in bigger section.

For highly stressed components such as connecting rods, shafts, king pins, steering gear parts, crankshafts. The steel is also suitable for larger components because even parts of

Table 16.23

Country	ISO	INDIA	DEU	USA	GBR	FRA	USSR	JPN
Standard norm	ISO R683/V1	IS 5517-78	DIN 17200-69	AISI	BS970:1-83	NFA15- 552-84	GOST	JIS
Designation	*Type 1, 1n, 1b	25Cr13Mo6	31CrMo12		722M24	30CD12		
Chemical composition	C	0.28-0.35	0.28-0.30	0.28-0.35	—	0.28-0.35	—	—
	Si	0.15-0.40	0.35 max.	0.15-0.40	—	0.10-0.35	—	—
	Mn	0.40-0.70	0.40-0.70	0.40-0.70	—	0.45-0.70	—	—
	P	0.035	0.035	0.035	—	0.025	—	—
	S	0.035 0.02-0.035 0.03-0.05	0.035	0.035	—	0.035	—	—
	Cr	2.80-3.30	2.50-3.40	2.80-3.30	—	2.80-3.30	—	—
	Mo	0.30-0.50	0.45-0.65	0.30-0.50	—	0.30-0.50	—	—
Mechanical properties	Ni	0.30 (max.)	—	(≤ 0.30)	—	—	—	—
	Dimensions	16-40 41-100	150 63	16-40 41-100	152	16-40 41-100	—	—
	0.2% proof stress N/mm ² min	835 785	700 1300	1020 855	—	810 778	—	—
	Tensile strength N/mm ²	1030-1230 980-1180	900-1050 1550 min	1230-1430 1080-1280	920-1080	1030-1230 980-1180	—	—
	Elongation % min	10 11	15 8	9 10	12	10 11	—	—
	Reduction of area % min	—	—	35 40	—	—	—	—

*For all the three, chemical composition is same, except sulphur.

Table 16.24

Country	ISO	INDIA	DEU	USA	GBR	FRA	USSR	JPN
Standard norm	ISO R683/VIII-79	IS	DIN 17200-84	AISI	BS970:2-70	NFA35- 552-75	GOST 4543-71	JIS
Designation	*Type 2, 2h, 2b	40Ni6Cr4Mo2	36CrNiMo4			40NCD3	40ChNMA	
Chemical composition	C	0.38-0.43	0.32-0.40	—	0.36-0.44	0.36-0.43	0.37-0.44	—
	Si	0.15-0.40	0.15-0.40	—	0.10-0.35	0.10-0.40	0.17-0.37	—
	Mn	0.50-0.80	0.10-0.35	—	0.45-0.70	0.50-0.80	0.50-0.80	—
	P	0.035	0.035	—	0.04	0.035	0.025	—
	S	0.035 0.020-0.025 0.03-0.05	0.035	—	0.04	0.035	0.025	—
	Cr	0.60-0.90	0.9-1.3	—	1.00-1.40	0.60-0.90	0.60-0.90	—
	Mo	0.15-0.30	0.10-0.20	—	0.10-0.20	0.15-0.30	0.15-0.25	—
	Ni	0.70-1.00	1.2-1.6	—	1.30-1.70	0.70-1.00	1.25-1.65	—
Mechanical properties	Dimensions	16-40 41-100	30 100	16-40 41-100	29 102	16-70 41-100	25	—
	0.2% proof stress N/mm ² min.	785 685	880 700	785 685	855 675	735 705	835	—
	Tensile strength N/mm ²	980-1175 885-1080	1100-1250 900-1050	980-1180 880-1030	1000-1160 880-1000	930-1130 880-1080	900 max.	—
	Elongation % min.	11 12	11 15	11 12	12 50	11 12	12	—
	Reduction of area % min.	—	—	50 55	—	—	55	—

*For all three, chemical composition is the same, except sulphur.

large cross-sections can be effectively heat-treated and they are very tough. Table 16.24 gives the chemical composition and mechanical properties of International Standard steels.

HOT WORKING AND HEAT TREATMENT

Forging	1050°C max. (Commence) 850°C min. (Finish)
Annealing	Heat to 750°C, followed by rapid cooling to 700°C, then cool at a rate of 3°C per hour. Heat to 750°C. After the desired soaking, cool rapidly to 660°C and hold for 12-13 h, followed by furnace/air cooling.
Hardening	830-850°C (Quench in oil)
Tempering	550-670°C (According to mechanical properties required)

Data Sheet 16.24—Type-3 (ISO)

HOT WORKING AND HEAT TREATMENT

Forging	1200°C max. (Commence) 900°C min. (Finish)
Annealing	1. Heat to 750°C followed by rapid cooling to 650°C and hold for 12-13 h. 2. Heat to 750°C, cool rapidly to 705°C, followed by cooling at a rate of 3-565°C.
Hardening	830-850°C (Oil)
Tempering	150-200°C 550-700°C

Figure 16.11(a) illustrates the effect of tempering on mechanical properties, Fig. 16.11(b) the guide to tempering response and Fig. 16.11(c) the hardenability band.

CHARACTERISTICS AND APPLICATIONS

CrNiMo steel can be heat treated to produce a tensile strength of the order of 980-1180 N/mm² in medium size and 900-1100 N/mm² in bigger section thickness. It also possesses good ductility and resistance to shock. It has good hardenability enabling it to be used for medium tensile strength, in fairly large sections, and possesses good resistance wear. It can also be used for flame and induction hardening, nitriding, used for high tensile strength machine parts, leads, screws, spindles, collets, boring bars, crankshafts, gears, high tensile strength bolts. It may be nitrided to produce high surface hardness and to increase fatigue strength. Table 16.25 gives the chemical composition and mechanical properties of International Standard steels.

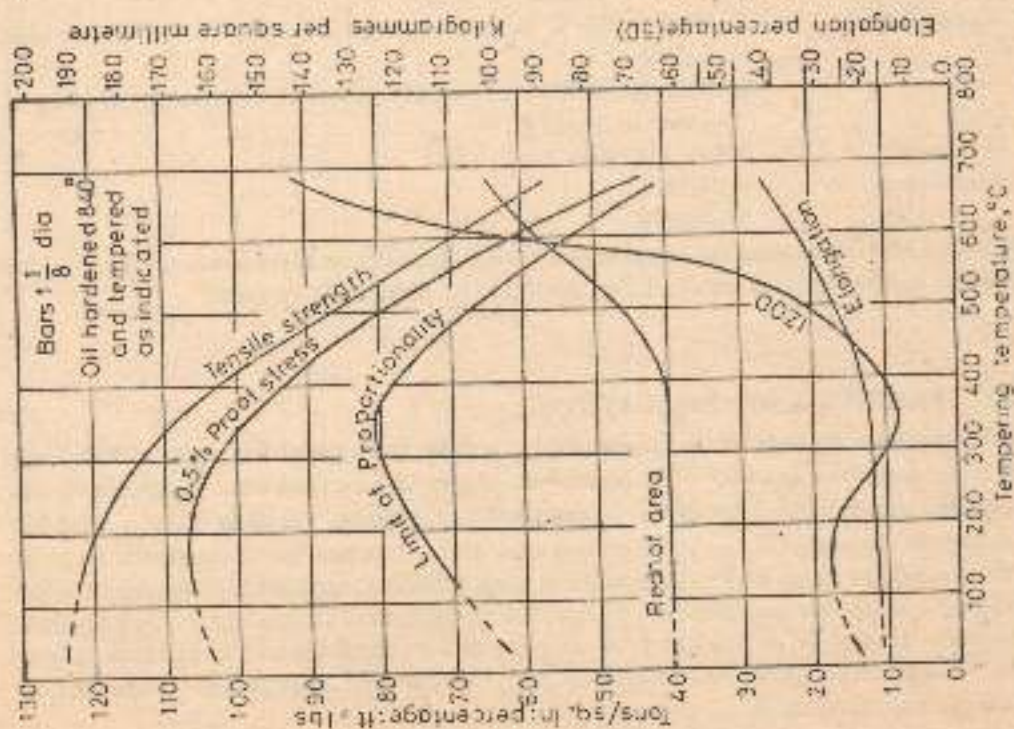


Fig. 16.11 (a) Effect of tempering on mechanical properties of steel 18-40Ni6Cr4Mo3 (Courtesy: Pergamon Press, England)

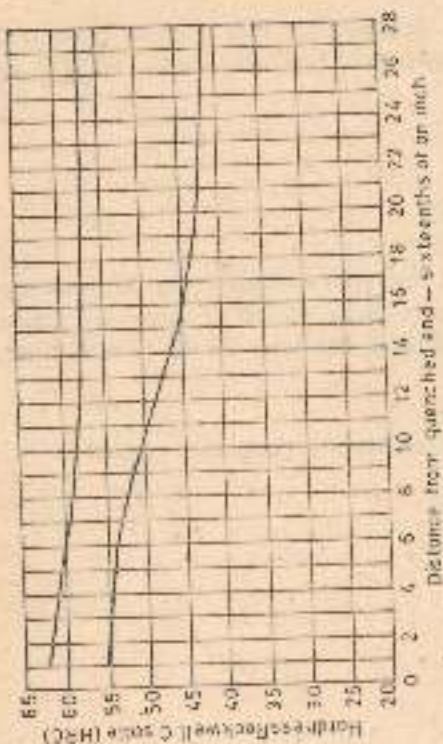


Fig. 16.11 (b) Tempering response of steel 18-40Ni6Cr4Mo3 (Courtesy: Wolfson Heat Treatment Centre, England)

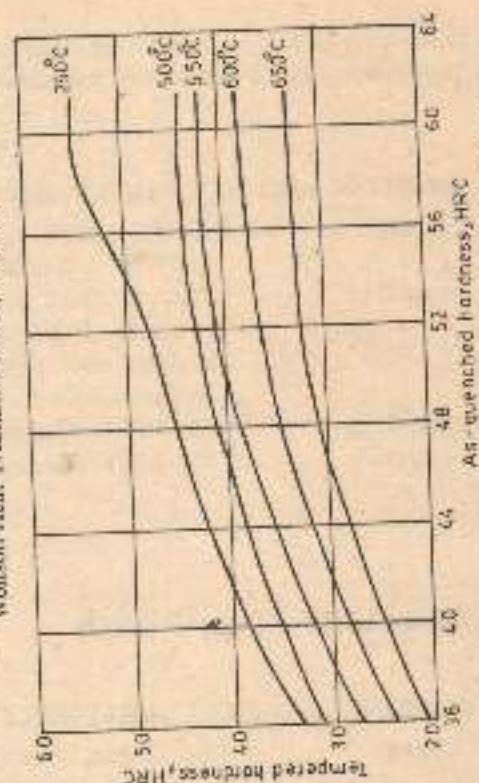


Fig. 16.11 (c) Hardenability band of steel 18-40Ni6Cr4Mo3

Table 16.25

Country	ISO	INDIA	DEU	USA	GBR	FRA	USSR	JPN
Standard norm	ISO R683/VIII-79	IS 5517-78	DIN 17200-84	AISI	BS970/1-83	NFA35- 551-75	GOST 4543-71	JIS G4103-79
Designation	*Type 3, 30, 36	40Ni6Cr4Mo3	34CrNiMo6		817M40	35NCT06	36CH2N2MFA	SNCM8 SNCM439
Chemical composition	C	0.32-0.39	0.30-0.38	—	0.36-0.44	0.30-0.37	0.33-0.40	0.36-0.43
	Si	0.15-0.40	0.15-0.40	—	0.10-0.35	0.10-0.40	0.17-0.37	0.15-0.35
	Mn	0.30-0.80	0.40-0.60	—	0.45-0.70	0.60-0.90	0.25-0.50	0.60-0.90
	P	0.035	0.035	—	0.040	0.035	0.025	0.030
	S	0.035 0.02-0.035 0.03-0.05	0.035	—	0.040	0.035	0.025	0.020
	Cr	1.30-1.70	0.90-1.30	—	1.00-1.40	0.85-1.15	1.30-1.70	0.60-1.00
	Mo	0.15-0.30	0.20-0.35	—	0.20-0.35	0.15-0.30	0.30-0.40	0.15-0.30
Mechanical properties	Ni	1.30-1.70	1.25-1.75	—	1.60-1.70	1.30-1.60	1.30-1.70	1.60-2.00
	Dimensions	16-40 41-100	100 50	41-100 100-160	29 63	16-40 41-100	25	25
	0.2% proof stress N/mm ² min.	885 785	800 1300	785 685	940 855	835 735	1080	—
	Tensile strength N/mm ²	1080-1280 980-1180	1000-1150 1550 min	980-1180 880-1080	1080-1240 1060-1160	1030-1230 930-1130	1175	980 min.
	Elongation % min.	10 11	13 14	11 12	11 12	10 11	12	16 min.
	Reduction of area % min.	—	—	50 55	—	—	50	45 min.

*For all the three, chemical composition is same, except sulphur.

Table 16.26

Country	ISO	INDIA	DEU	USA	GHR	FRA	USSR	JPN
Standard norm	ISO R693/VIII-70	IS	DIN	AISI	BS970/1-72	NTA22- 531-75	GOST	JIS
Designation	Type 4, 4b, 4b			4340				SNC48S
Chemical composition	C, %	0.37-0.44	—	0.38-0.43	—	—	—	0.36-0.43
	Si, %	0.15-0.40	—	0.15-0.35	—	—	—	0.15-0.35
	Mn	0.55-0.85	—	0.60-0.90	—	—	—	0.60-0.90
	P	0.035(4) 0.02-0.035(4b) 0.03-0.05(4b)	—	0.035	—	—	—	0.03
	S	0.035	—	0.04	—	—	—	0.03
	Cr	0.65-0.95	—	0.70-0.90	—	—	—	0.60-1.00
	Mo	0.15-0.30	—	0.20-0.30	—	—	—	0.15-0.30
Mechanical properties	Ni	1.60-2.00	—	1.65-2.00	—	—	—	1.60-2.00
	Dimensions	16-40 41-100	—	25 100	—	—	—	25
	0.2% proof stress N/mm ² min	880 780	—	—	—	—	—	—
	Tensile strength N/mm ²	1080-1280 960-1180	—	1210-1060 1140-860	—	—	—	980 min
	Elongation, % min	30 11	—	—	—	—	—	16 min
	Reduction of area %, min	—	—	—	—	—	—	45 min

Data Sheet 16.25—Type-4 (ISO)

12m24

HOT WORKING AND HEAT TREATMENT

Forging	1200°C max. (Commence) 1050°C min. (Finish)
Annealing	680–720°C
Normalizing	850–880°C (Air cool)
Hardening	820–860°C (Quench in oil)
Tempering	500–650°C (According to the mechanical properties required)

CHARACTERISTICS AND TYPICAL APPLICATIONS

This steel can be heat treated to a tensile strength of the order of 980–1180 N/mm² in medium-sized sections. It has good ductility and resistance to shock. It offers great resistance to fatigue under all conditions of fluctuating stress, simple or complex, and machines excellently.

Used for larger parts in general mechanical, automotive and vehicle engineering, such as axles, shafts, crankshafts, connecting rods, driving shafts, air frames, under-carriages, etc. Table 16.26 gives the chemical composition and mechanical properties of International Standard steels.

Data Sheet 16.26—40Ni10Cr3Mo6 (IS)

HOT WORKING AND HEAT TREATMENT

Forging	1200°C max. (Commence) 850°C min. (Finish)
Softening	650°C (Cool in air)
Hardening	820–850°C (Cool in oil)
Tempering	up to 660°C

Figure 16.12(a) is a guide to tempering response, Fig. 16.12(b) is a typical curve showing the effect of tempering temperature on mechanical properties, and Fig. 16.12(c) illustrates the hardenability band.

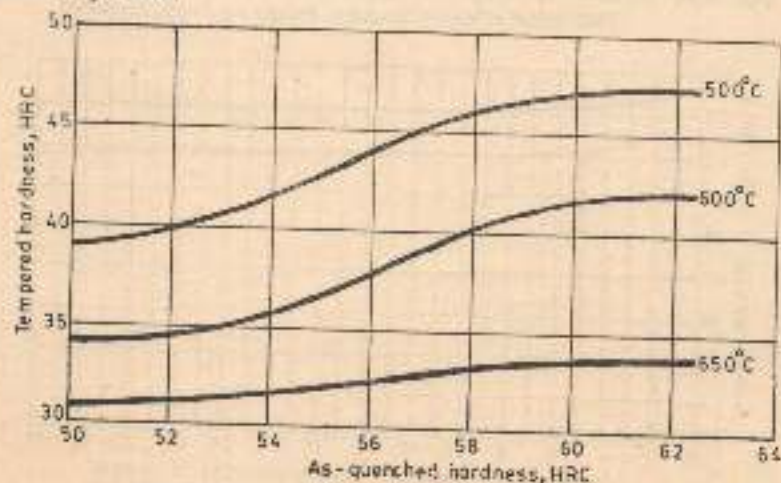


Fig. 16.12 (a) Tempering response of steel 426M40

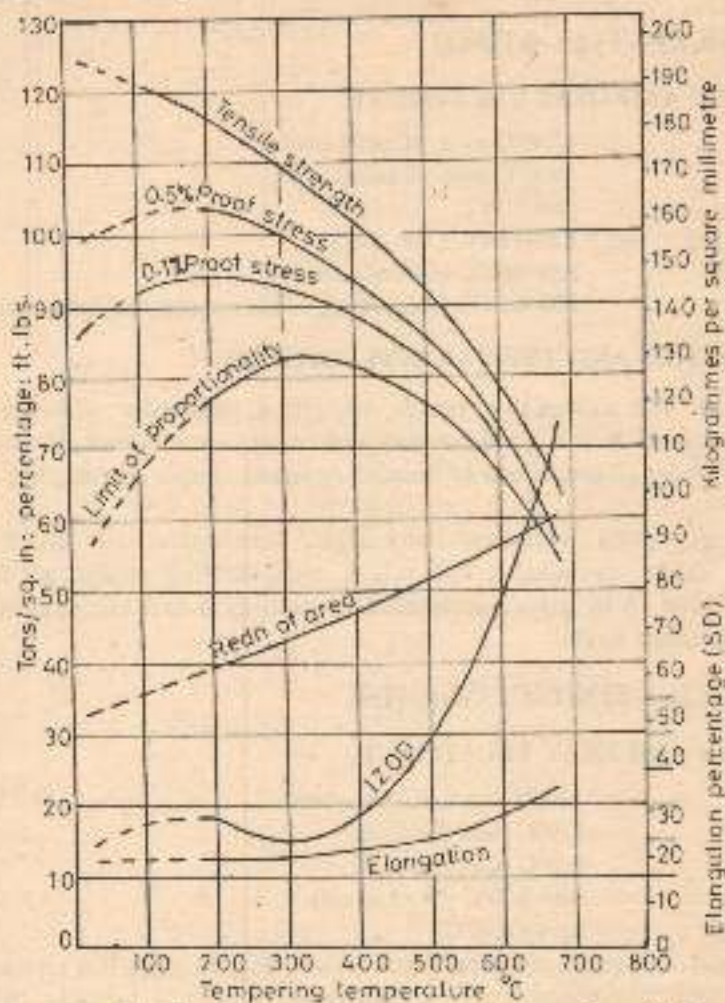


Fig. 16.12 (b) Effect of tempering on mechanical properties of steel S40 Ni10Cr3Mo6 (Courtesy: Pergamon Press, England)

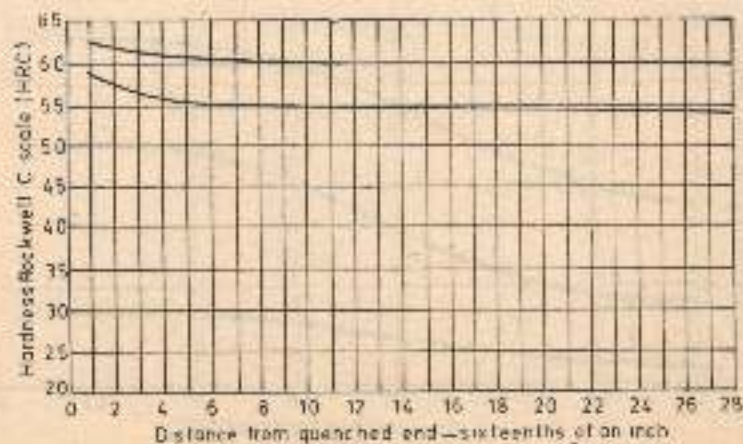


Fig. 16.12 (c) Hardenability band of S25M40

Table 16.27

Country	ISO	INDIA	DEU	USA	GDR	FRA	USSR	JPN
Standard design	ISO	155517-78	DIN	AISI	BS/NI/1-72	NFA35-551.75	GOST	JIS
Designation		4N510Cr3Mo6	40NiMoCr105		82NiMo40			
Chemical composition	C	0.36-0.40	0.37-0.43	—	0.36-0.44	—	—	—
	Si	0.15-0.35	0.15-0.35	—	0.1-0.35	—	—	—
	Mn	0.40-0.70	0.5-0.70	—	0.45-0.70	—	—	—
	P	0.035	0.035	—	0.040	—	—	—
	S	0.035	0.035	—	0.050	—	—	—
	Cr	0.50-0.80	0.60-0.80	—	0.50-0.80	—	—	—
	Mo	0.40-0.70	0.40-0.60	—	0.45-0.65	—	—	—
	Ni	2.25-2.75	2.40-2.70	—	2.30-2.80	—	—	—
Mechanical properties	Dimensions	100 150	—	—	29-100 150-250	—	—	—
	0.2% proof stress N/mm ² min	1300 1000	—	—	1125 725	—	—	—
	Tensile strength N/mm ²	1550 min 1200-1350	—	—	1550 min 925-1075	—	—	—
	Elongation % min	8 10	—	—	7 13	—	—	—
	Reduction of area % min	—	—	—	—	—	—	—

Table 16.28

Country	ISO	INDIA	DEU	USA	GBR	FRA	USSR	JPN
Standard norm	ISO R683/VIII 70	IS	DIN 17200-84	AISI	BS970/2-70	NFA35- 552-84	GOST 4540-71	JIS G4103-65
Designation	Type 5		30CrNiMo8		821M30	30CND8	30C2NVA	SNCM5 (SNCM630)
Category								
Chemical composition	C %	0.26-0.33	0.26-0.34	—	0.26-0.34	0.26-0.33	0.27-0.34	0.25-0.35
	Si %	0.15-0.40	0.40 max.	—	0.10-0.35	0.10-0.40	0.17-0.37	0.13-0.35
	Mn	0.30-0.60	0.30-0.60	—	0.15-0.60	0.30-0.60	0.30-0.60	0.35-0.60
	P	0.035	0.035	—	0.025	0.03	0.025	0.03
	S	0.035	0.03	—	0.025	0.025	0.025	0.03
	Cr	1.80-2.20	1.80-2.20	—	1.80-2.20	1.80-2.20	1.60-2.00	2.50-3.50
	Mo	0.30-0.50	0.30-0.50	—	0.30-0.50	0.30-0.50	(W-1.20-1.60)	0.50-0.70
Mechanical properties	Ni	1.80-2.20	1.80-2.20	—	1.80-2.20	1.80-2.20	1.40-1.80	2.50-3.50
	Dimensions	16-40 41-100	16-40 41-100	—	63 102	16-40 41-100	25	25
	0.2% proof stress N/mm ² min.	1030 885	1030 885	—	1020 940	850 800	980	—
	Tensile strength N/mm ²	1225-1420 1080-1275	1220-1420 1080-1270	—	1160-1320 1080-1240	1030-1225 980-1180	1180 min	1080 min
	Elongation % min.	9 10	9 10	—	10 11	12 12	10	15
	Reduction of area % min.	—	40 45	—	—	—	45	45

Table 16.29

Country	ISO	INDIA	DEU	USA	GBR	FRA	USSR	JPN
Standard norm	ISO: R683, VTH-70	IS	DIN	AISI	B5970/2-70	NF-A35- 5594-75	GOST	JIS
Designation	Type 6, 6a, 6b				835M30	35NCD16		
Chemical composition	C %	0.30-0.37	—	—	0.26-0.34	0.32-0.39	—	—
	Si %	0.15-0.40	—	—	0.1-0.35	0.30-0.60	—	—
	Mn	0.30-0.60	—	—	.45-.75	0.10-0.20	—	—
	P	0.035	—	—	0.04	0.03	—	—
	S	0.035 0.02-0.035 0.03-0.05	—	—	0.04	0.025	—	—
	Cr	1.60-2.00	—	—	1.1-1.4	1.60-2.00	—	—
	Mo	0.25-0.45	—	—	.2-.35	0.25-0.45	—	—
	Ni	3.70-4.20	—	—	3.9-4.3	3.60-4.10	—	—
	Dimensions	16-40 41-100	—	—	—	16-40 41-100	—	—
	0.2% proof stress N/mm ² , min	1030 930	—	—	—	880 880	—	—
Mechanical properties	Tensile strength N/mm ²	1225-1420 1130-1350	—	—	—	1080-1280 1080-1280	—	—
	Elongation % min	9 10	—	—	—	10 10	—	—
	Reduction of area % min	—	—	—	—	—	—	—

CHARACTERISTICS AND TYPICAL APPLICATIONS

CrNiMo is a high-strength alloy steel which can be heat treated to produce a tensile strength of 1000–1150 N/mm² in the ruling section of 150 mm. Due to its high molybdenum content, this steel is free from temper brittleness and is used to make high stressed bolts and studs, shafts, crankshafts, connecting rods, gears, axles, components for all types of aircraft, power units, air frames, undercarriages, etc. Table 16.27 gives the chemical composition and mechanical properties of International Standard steels that are mainly used.

Data Sheet 16.27—Type-5 (ISO)**HOT WORKING AND HEAT TREATMENT**

Forging	1050°C max. (Commence) 850°C min. (Finish)
Normalizing	850–880°C (Cool in air)
Annealing	650–700°C
Hardening	830–860°C (Quench in oil)
Tempering	540–680°C (According to the mechanical properties required)

CHARACTERISTICS AND TYPICAL APPLICATIONS

This is a high-strength alloy steel of high hardenability which may be treated even in fairly large sections to produce tensile strengths ranging from 1080–1275 N/mm². It has good ductility and resistance to shock, and due to its high molybdenum content it is free from temper-brittleness. It offers great resistance to fatigue under all conditions of fluctuating stress.

Used for highly stressed components of large cross-section of aircraft, automotive and general-engineering applications such as propeller shafts, gear shafts, crankshafts, highly stressed gears, die blocks, mandrel bars, etc. Table 16.28 gives the chemical composition and mechanical properties of International Standard steels that are mainly used.

Data Sheet 16.28—Type-6 (ISO)**HOT WORKING AND HEAT TREATMENT**

Forging	1200°C max. (Commence) 850°C min. (Finish)
Annealing	630–°C (Cool in air)
Hardening	810–830°C (Cool in air or quench in oil)
Tempering	250°C max.

For ruling sections over 65 mm, quenching in oil is recommended.

CHARACTERISTICS AND TYPICAL APPLICATIONS

This is an air hardening steel for diameters up to 65 mm and attains tensile strengths of the order of 1130–1220 N/mm², in fairly large sections. It has good ductility and resistance to

wear and shock. The advantage of this steel is that distortion can be minimized so that parts can be machined to, or nearer to, finished size before heat-treatment. The presence of higher molybdenum results in higher impact values.

This steel can be used for highly stressed gears and other components requiring a steel processing a tensile strength of the above-mentioned range. Table 16.29 gives the chemical composition and mechanical properties of International Standard steels that are mainly used.

REFERENCES

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Free Cutting Steels

It has long been recognised that these steels, by virtue of their inherent free machining properties, not only increase productivity significantly but also permit the production of irregular and highly intricate components with a good surface finish and dimensional accuracy.

Although cold drawing of low-carbon steel improves its surface finish on machining by reducing the tendency to drag and tear, the addition of sulphur and lead, sometimes individually and in combination, improves its machinability markedly, and makes the steel free-cutting. Apart from these additions, further improvement in machinability of the steel can be achieved by the addition of selenium, tellurium and bismuth in small quantities. Addition of sulphur to steels results in some sacrifice of cold forming properties, weldability and forging characteristics. Applications of these steels are similar to those of carbon steels with carbon manganese contents, and low alloy contents, but they are specially intended where easy machining is the primary requirement. These steels are successfully used in all industries, particularly in automobiles, auto-ancillaries, textiles, etc.

Sulphur is added to steel with the main objective of reducing the cost of manufacture. It may be noted that the presence of sulphur is more effective in reducing friction during machining. Sulphur combines mostly with manganese in the steel to form manganese sulphide, and precipitates as sulphur inclusions. The inclusion may remain globular or become stretched out in the direction of rolling. These inclusions are responsible for the low co-efficient of friction in the steel. These inclusions have a low melting point compared to that of steel; at temperatures prevailing at the chip-tool interface during cutting they should be fairly soft and should tend to "smear" over the tool face. This action would provide a "sandwich filling" of low shear strength material between the chip and tool face. This results in increasing the machinability of steel because of the tight curling of chips produced mainly due to a low coefficient of friction.

The amount of sulphur in resulphurized steels varies from 0.08 to 0.4%. The increase in sulphur content in steel leads to a good breaking of chips in actual practice. The reduced coefficient of friction of high-sulphur steels is the main reason for improved machinability of such steels, as characterised by the lower tool forces, lower power consumption and

reduced tool wear.

Sulphur is more effective in reducing the friction when added to plain carbon steels than when added to low alloy steels and stainless steels.

The presence of sulphide inclusions in steel affects the mechanical properties. Ductility, impact, fatigue and transverse properties of sulphurized steels are, in fact, considerably inferior to those of the corresponding untreated steels. Improvement in the machining behaviour on the addition of sulphur is generally restricted to producing components subjected to low stresses.

Lead is also added to the steel to improve the machinability of plain carbon steels. The main benefit again is the large reduction in the co-efficient of friction. The reason for reduced friction is due to the smearing of the insoluble lead inclusions over the face of the tool, allowing free sliding of the chip. This results in improved machinability without impairing the mechanical properties as sulphur does. Lead may be added to the sulphurized steels to further enhance the machinability. Percentage of lead added to steel varies between 0.15 and 0.35%.

In general, the reduced cost of machining with the use of free cutting steels can be attributed to the following reasons:

1. Long tool life due to low friction,
2. High cutting speeds,
3. Low power requirement,
4. Accuracy of machined parts,
5. Smooth surface finish of components avoids additional operation, and
6. Minimum dressing of tool due to very low wear.

17.1 Availability of Free Cutting Steels

Free cutting steels are available either in cold-drawn or hot-rolled condition. Cold-drawn steels give a better finish and eliminate the need for overall machining. Cold-drawn steel bars are also available in close tolerances and are suitable for use in automatic machines. Hot rolled steels may be normalized to obtain uniform properties.

Normalized or cold drawn steel may also be used for parts which are finally required in the case-hardened or hardened and tempered condition. Steels 10C8 S10, 11C10 S25, 14C14 S14 may be case-hardened. Table 17.1 indicates the machinability ratings for various steels in the cold-drawn condition. These ratings are based on a value of 100 per cent for steel 11C10 S25 in the cold-drawn condition. This value involves turning at a cutting speed of 54.9 surface meters (or 180 surface feet) per minute for feeds up to 0.1778 mm (or 0.007 inch) per revolution, and depths of cut of up to 6.35 mm (or 0.250 inch) using appropriate cutting fluids with high speed steel tools (18-4-1) (DIN).

Table 17.1 Machinability Ratings for Various Steels in the Cold Drawn Condition

Sl. No.	IS Steel	Type of processing	BHN	Average machinability rating (Cold drawn 11C10 S25, 100 %)
1.	10C8 S10 (DIN 10S20)	Hot rolled	101	—
		Cold rolled	121	80
2.	14C14 S14 (1118 AISI)	Hot rolled	121	—
		Cold rolled	137	90
3.	40C10 S18 (212M36BS-970)	Hot rolled	179	—
			197	70
4.	11C10 S25 (8S 970 230 M07)	Hot rolled	121	—
		Cold rolled	137	100
5.	40C15 S12 (1141 AISI)	Hot rolled	287	—
		Cold rolled	212	70

17.2 Heat Treatment

1. **Stress Relieving** This treatment is carried out in the temperature range of 550–600°C. The components are heated slowly and held at this temperature for 1 to 2 hours and cooled slowly in the furnace. There will not be any significant modification of other properties of the component after treatment.

2. **Normalizing** Heat slowly and thoroughly until the entire cross section of the part is at the normalizing temperature of 860–900°C, depending on the chemical composition. These are subsequently cooled in air.

3. **Annealing** Parts are annealed to impart spheroidal cementite for better machinability. The parts to be annealed should be heated slowly to a temperature of 650–700°C and held at this temperature for one hour or more depending on the size of the part and cooled slowly, preferably in a furnace.

4. **Case Hardening** Free-cutting steels of case-hardening grades can be carburized by any conventional method (solid or liquid or gas carburizing). Parts are carburized in the temperature range of 880–900°C and subsequently lowered to 800 to 820°C temperature for case-hardening, and quenched from this temperature in water, oil or warm bath. If necessary, tempering may be done at 150 to 180°C.

5. **Hardening** The parts to be hardened are heated slowly to the austenitizing temperature and held for a definite length of time at this temperature depending on the cross section.

The austenitizing temperature depends on the chemical composition, and it varies between 820–880°C. After austenitizing the parts may be quenched in water or oil, depending on the geometry and size of the part.

Tempering is to be done immediately after quenching. The tempering temperature and duration are governed by the desired mechanical properties. The temperature varies from 540–680°C.

17.3 Applications

The different types of free machining steels that are mainly used are given in Table 17.1. Applications, mechanical properties and chemical compositions are given in detail in the data sheets.

Table 17.2 Free Cutting Steel

Country	ISO	INDIA	DEU	USA	GBR	FRA	USSR	JPN
Standard	ISO	IS	DIN	AISI	BS970	NFA35-	GOST	JIS
1	Type 1	13S25	9520	1212	220Mn7	—	—	SUM 21
2	Type 2	—	25Mn28	1213	230Mn7	S250 (250)	—	SUM 22
3	Type 2Pb	—	95MnPb28	12L13	—	S250Pb	A514	SUM 22L
4	Type 3	—	95Mn36	1215	240Mn7	S300	—	SUM 23
5	Type 3Pb	—	95MnPb36	12L14	—	S300Pb	—	SUM 24L
6	Type 4	—	10S20	1108	210M15	10F1	A11	SUM 12
7	Type 4Pb	—	10SPb20	11208	—	CC10Pb	—	SUM 23L
8	Type 6	—	—	1116	210A15	—	—	SUM 32
9	Type 7	—	35S20	1139	212M36	—	—	—
10	Type 8	—	—	1138	216M36	—	A35	—
11	Type 9	40Mn2S12	—	1137	—	35MPb	—	SUM 41
12	Type 10	—	45S20	1146	216M44	45MP4	—	SUM 42

Data Sheet 17.1—Type-1 (ISO)**CHARACTERISTICS AND TYPICAL APPLICATIONS**

This is an easy machining steel suitable for case hardening. When used in automatic machine tools, lathes or turret lathes, etc., high cutting speeds and a mirror finish can be assured. This excellent finish gives a case that requires a minimum of dressing. Because of excellent machining qualities, this grade may be used even when case hardening is required. The mechanical properties appear satisfactory in the supplied condition. Table 17.3 shows the chemical composition and mechanical properties of International Standard Steels that are mainly used.

HEAT TREATMENT

Normalizing	900–930°C
Annealing	650–700°C
Carburizing	900–930°C
Hardening	820°C (Oil or water quench)
Tempering	150–175°C

Table 17.3

Steel	Standard	ISO R683:IX-70	IS 4431-67	DIN 1651-70	ASTM 1212	BS970 1-83	NFA 35-551-75	GOST	JIS G4804-71
	Designation	Type 1	13S25	9S20	1212	220Mn7	—	—	SUM 21
Chemical composition	C %	0.13 max.	0.08–0.18	0.13 max.	0.13 max.	0.15 max.	—	—	0.13
	Si %	0.05	0.10	0.05	0.08	—	—	—	0.08
	Mn %	0.6–1.2	0.8–1.2	0.6–1.2	0.7–1.0	0.9–1.5	—	—	0.7–1.0
	≤ P %	0.11	0.06	0.10	0.07–0.12	0.07	—	—	0.07–0.12
	≤ S %	0.18–0.25	0.2–0.3	0.18–0.25	0.16–0.23	0.2–0.3	—	—	0.16–0.23
	Cr %	—	—	—	—	—	—	—	—
	Mo %	—	—	—	—	—	—	—	—
	Ni %	—	—	—	—	—	—	—	—
	Others	—	—	—	—	—	—	—	—
	Dimensions	16–40	20	16–40	—	16–40	—	—	—
Mechanical properties	0.2% proof stress N/mm ² min	355	—	355	—	200	—	—	—
	Tensile strength N/mm ²	440–740	490	480–710	—	430 min	—	—	—
	Elongation % min	9	8	9	—	8	—	—	—
	Reduction of area % min	—	—	—	—	—	—	—	—
		—	—	—	—	—	—	—	—

Data Sheet 17.2—Type-2 (ISO)

TYPICAL APPLICATIONS AND CHARACTERISTICS

Free cutting steels are suited for case hardening and where machinability is more important than mechanical properties. Used for light-duty unstressed parts in general engineering. Most suitable for rapid production of fine-finished components and automatic machines. *Example:* light duty studs, nuts, cycle components and parts for textile and printing machinery, scooter parts or fuel injection equipment parts such as threaded banjo bolt, reducing nipple, part of hand priming pump, etc.

HEAT TREATMENT

Normalizing	850–880°C (Cool in air)
Hardening	840–870°C (Quench in water/oil)
Carburizing	900–930°C (Water/oil)

Note In general, the steel is delivered ready for use from steel manufacturers. For case hardening, the above process may be adopted.

Table 17.4

Steel	Standard Designation	ISO R683/LX-70 Type 2	IS 95Mn28	DIN 1651-70	AISI 1213	BS 970/1-83 230Mo7	NFA 35-561-85 S230	GOST	JIS G4804-71 SUM 22
Chemical composition	C %	0.14 max.	—	0.14 max.	0.13 max.	0.15 max.	0.14 max.	—	0.13 max.
	Si %	0.05	—	0.05	0.08	0.06	0.08	—	—
	Mn %	0.9–1.3	—	0.9–1.3	0.70–1.0	0.9–1.3	0.9–1.4	—	0.7–1.0
	P %	0.11	—	0.10	0.12	0.07	0.11	—	0.12
	S %	0.24–0.32	—	0.24–0.32	0.24–0.33	0.25–0.32	0.25–0.32	—	0.24–0.33
	Cr %	—	—	—	—	—	—	—	—
	Mo %	—	—	—	—	—	—	—	—
	Ni %	—	—	—	—	—	—	—	—
	Others	—	—	—	—	—	—	—	—
Mechanical properties	Dimensions	16–40	—	16–40	—	40–63	50	—	—
	0.2% proof stress N/mm ² min	380	—	380	—	240	—	—	—
	Tensile strength N/mm ²	455–760	—	460–710	—	390 min	380 min	—	—
	Elongation % min	8	—	8	—	9	24	—	—
	Reduction of area % min	—	—	—	—	—	—	—	—

Data Sheet 17.3—Type-2Pb (ISO)**CHARACTERISTICS AND APPLICATIONS**

This is a lead-content-free machining-grade steel. The presence of lead serves as an internal lubricant and reduces the built-up heat between the cutting edges of the tool. This steel is most commonly used when a lot of machining is necessary to produce the finished parts. These grades are supplied ready for machining and assembly and no further heat-treatment is required. Table 17.5 gives the chemical composition and mechanical properties of International Standard steels.

Table 17.5

Steel	Standard	ISO R683/IX-70	IS	DIN 1651-73	ASTI	BS 970/1-83	NFA 35-561-85	GOST	JIS G4804-71
	Designation	Type 2Pb		95MnPt38	12L13	—	S230Pb	AS14	SUM22L
Chemical composition	C %	0.14 max.	—	0.14 max.	0.13 max.	—	0.14 max.	0.1-0.17 max.	0.13 max.
	Si %	0.05	—	0.05	0.08	—	0.05	0.10	—
	Mn %	0.9-1.3	—	0.9-1.3	0.70-1.0	—	0.9-1.5	1.0-1.3	0.7-1.0
	≤ P %	0.11	—	0.10	0.07-0.12	—	0.1	0.1	0.07-0.12
	≤ S %	0.24-0.32	—	0.24-0.32	0.24-0.33	—	0.25-0.32	0.15-0.3	0.24-0.33
	Pb	0.15-0.35	—	0.15-0.30	0.15-0.35	—	0.20-0.30	0.15-0.30	0.10-0.35
Mechanical properties	Others								
	Dimensions	16-40	—	16-40	—	—	50	—	—
	0.2% proof stress N/mm ² min	375	—	375	—	—	—	—	—
	Tensile strength N/mm ²	460-760	—	460-705	—	—	380 min	—	—
	Elongation % min	8	—	8	—	—	8	—	—

Data Sheet 17.4—Type-3 (ISO)

CHARACTERISTICS AND TYPICAL APPLICATIONS

This free-cutting steel possesses an optimum machinability that ensures maximum economy in the mass production of turned parts. In general, the steel is delivered ready for use from the manufacturers. Table 17.6 gives the chemical composition and mechanical properties of International Standard steels.

HEAT TREATMENT

Normalizing	880-910°C (Air cool)
Carburizing	910-930°C
Hardening	820-860°C (Quench in oil)
Tempering	150-200°C

Table 17.6

Steel	Standard	ISO R683/IX-70	IS	DIN 1651-70	AISI	BS 970/1-83	NFA 35-561-85	GOST	JIS G4804-71
	Designation	Type 3		9SMn36	1215	240Mo7	S300		SUM 23
Chemical composition	C %	0.15	—	0.15	0.09	0.15	0.15	—	0.09
	Si %	0.05	—	0.05	—	—	0.06	—	—
	Mn %	1.0-1.5	—	1.0-1.5	0.75-1.05	1.10-1.50	1.0-1.5	—	0.75-1.05
	≤ P %	0.11	—	0.10	0.04-0.09	0.07	0.10	—	0.04-0.09
	≤ S %	0.30-0.40	—	0.32-0.40	0.26-0.35	0.3-0.6	0.3-0.4	—	0.26-0.35
	Cr %	—	—	—	—	—	—	—	—
	Mo %	—	—	—	—	—	—	—	—
	Ni %	—	—	—	—	—	—	—	—
	Others	—	—	—	—	—	—	—	—
Mechanical properties	Dimensions	15-40	—	16-40	—	16-40	30	—	—
	0.2% proof stress N/mm ² min	390	—	390	—	—	—	—	—
	Tensile strength N/mm ²	490-790	—	460-710	—	400 min	400 min	—	—
	Elongation % min	8	—	8	—	8	23	—	—
	Reduction of area % min	—	—	—	—	—	—	—	—

Data Sheet 17.5—Type-3Pb (ISO)

This is a lead-content-free machining steel. It is most commonly used when a lot of machining is necessary to produce the finish parts. In general, the steel is delivered ready for use from the manufacturers. Table 17.7 gives the chemical composition and mechanical properties of International Standard steels.

Table 17.7

Steel	Standard	ISO R683/LX-70	IS	DIN 1661-70	AISI	BS	NFA 35/561-85	GOST	JIS G4804-71
	Designation	Type 3Pb		98.MnPb36	12L14		S300Pb		SU/M 24L
Chemical composition	C %	0.15	—	0.15	0.15	—	0.14	—	0.15
	Si %	0.05	—	0.05	—	—	0.05	—	—
	Mn %	1.0-1.5	—	1.0-1.5	0.85-1.15	—	1.0-1.5	—	0.85-1.15
	≤ P %	0.11	—	0.11	0.04-0.09	—	0.10	—	0.04-0.09
	≤ S %	0.3-0.4	—	0.32-0.40	0.26-0.35	—	0.32-0.40	—	0.26-0.35
	Pb %	0.15-0.35	—	0.15-0.30	0.15-0.35	—	0.2-0.3	—	0.10-0.35
	Mo %	—	—	—	—	—	—	—	—
	Ni %	—	—	—	—	—	—	—	—
	Others	—	—	—	—	—	—	—	—
Mechanical properties	Dimensions	16-40	—	16-40	19-32	—	50	—	—
	0.2% proof stress N/mm ² min	350	—	390	415	—	—	—	—
	Tensile strength N/mm ²	490-750	—	490-740	540 min	—	400 min	—	—
	Elongation % min	8	—	8	10	—	23	—	—
	Reduction of area % min	—	—	—	—	—	—	—	—

Data Sheet 17.6—Type-4 (ISO)

TYPICAL APPLICATIONS AND CHARACTERISTICS

A general-purpose case hardening, carbonitriding steel with a modest level of sulphur to give easy machining. Components may be water or oil quenched to obtain higher hardness after case hardening. The tough core is more resistant to shock and the steel can be employed for all lightly stressed components which require a good wear-resistant surface. Used for cam shafts, gudgeon pins, light-duty gears, bushes, etc., where fairly good machinability and surface finish are desired. Table 17.8 gives the chemical composition and mechanical properties of International Standard steels.

HEAT TREATMENT

Forging	900–1200°C
Normalizing	850–880°C (Cool in air)
Hardening	840–870°C (Quench in oil)
Carburizing	900–930°C
Rehardening	760–780°C (Oil/water)

Table 17.8

Steel	Standard	ISO R683/IX-70	IS	DIN 1661-70	AISI	BS 970/1-72	NFA 35/562-81	GOST	JIS G4804-71
	Designation	Type 4		10S20	1108	210M15	10F1	A11	SUM 12
Chemical composition	C %	0.07–0.13	—	0.07–0.13	0.08–0.13	0.12–0.18	0.07–0.13	0.07–0.15	0.08–0.13
	Si %	0.15–0.40	—	0.10–0.40	—	0.10–0.40	0.10–0.40	0.10	—
	Mn %	0.50–0.90	—	0.50–0.90	0.50–0.80	0.90–1.30	0.60–0.90	0.80–1.12	0.60–0.90
	≤ P %	0.06	—	0.060	0.04	0.05	0.04	0.10	0.04
	≤ S %	0.15–0.25	—	0.15–0.25	0.08–0.13	0.10–0.18	0.09–0.13	0.15–0.25	0.08–0.13
	Cr %	—	—	—	—	—	—	—	—
	Mo %	—	—	—	—	—	—	—	—
	Ni %	—	—	—	—	—	—	—	—
	Others	—	—	—	—	—	—	—	—
	Dimensions	16–40	—	16–40	19–32	19	16	—	—
Mechanical properties	0.2% proof stress N/mm ² min	355	—	355	320	215	225	—	—
	Tensile strength N/mm ²	440–740	—	460–710	390 min	400	340–440	—	—
	Elongation % min	9	—	9	20	16	28	—	—
	Reduction of area % min	—	—	—	—	—	—	—	—

Data Sheet 17.7—Type-4Pb (ISO)**CHARACTERISTICS AND APPLICATIONS**

The presence of lead in this free-machining steel improves the production rate by 20 to 25% as it lubricates the cutting edge of the tool and permits an increase in cutting speed and feed. No further heat treatment is necessary, since this grade is supplied ready for machining and assembly. Mainly used for mass production of machined shapes and components of all kinds, on high-speed automatic lathes. Table 17.9 gives the chemical composition and mechanical properties of International Standard steels.

Table 17.9

Steel	Standard	ISO R683/IX-70	IS	DIN 1651-70	AISI	BS	NFA 35/551-75	GOST	JIS
	Designation	Type 4Pb	—	10SPb20	11L08	—	CC10Pb	—	—
Chemical composition	C %	0.07-0.13	—	0.07-0.13	0.08-0.13	—	0.05-0.15	—	—
	Si %	0.15-0.40	—	0.10-0.40	—	—	0.30	—	—
	Mn %	0.50-0.90	—	0.60-0.90	0.60-0.80	—	0.3-0.5	—	—
	≤ P %	0.06	—	0.05	0.04	—	0.04	—	—
	≤ S %	0.15-0.25	—	0.15-0.25	0.08-0.13	—	0.04	—	—
	Cr %	0.15-0.35	—	0.15-0.30	0.15-0.25	—	0.15-0.25	—	—
	Mo %	—	—	—	—	—	—	—	—
	Ni %	—	—	—	—	—	—	—	—
	Others	—	—	—	—	—	—	—	—
Mechanical properties	Dimensions	16-40	—	16-40	19-52	—	16	—	—
	0.2% proof stress N/mm ² min	355	—	355	320	—	225	—	—
	Tensile strength N/mm ²	440-740	—	460-710	390 min	—	340-440	—	—
	Elongation % min	9	—	9	20	—	30	—	—
	Reduction of area % min	—	—	—	—	—	—	—	—

Data Sheet 17.8—Type-6 (ISO)

CHARACTERISTICS AND TYPICAL APPLICATIONS

A semi free-cutting carbo-manganese steel designed for case hardening. Used for parts where fairly good machinability and finish are necessary, with tensile strength higher than 10C8S10. Presence of relatively lower sulphur range serves as a compromise between machining and mechanical properties. The parts may be case hardened. Typical components produced from this grade are screw, slotted plug, locking screw, etc. The durability and impact strength of this steel are as good as any results obtainable. Table 17.10 gives the chemical composition and mechanical properties of International Standard steels.

HEAT TREATMENT

Normalizing	880-930°C (Cool in air)
Hardening	880-930°C
Carburizing	900-930°C (Quench in oil/water)

Table 17.10

Steel	Standard	ISO R683/IX-70	IS	DIN	AISI	BS 970/1-83	NTA	GOST	JIS
	Designation	Type 6			1116	210A15			SUM 32
Chemical composition	C %	0.14-0.20	—	—	0.14-0.20	0.13-0.18	—	—	0.12-0.20
	Si %	0.15-0.40	—	—	—	0.10-0.40	—	—	—
	Mn %	0.50-0.90	—	—	1.10-1.40	0.50-1.20	—	—	0.60-1.10
	≤ P %	0.06	—	—	0.04	0.05	—	—	0.04
	≤ S %	0.15-0.25	—	—	0.16-0.23	0.10-0.18	—	—	0.10-0.20
	Cr %	—	—	—	—	—	—	—	—
	Mo %	—	—	—	—	—	—	—	—
	Ni %	—	—	—	—	—	—	—	—
	Others	—	—	—	—	—	—	—	—
Mechanical properties	Dimensions	16-40	—	—	—	19	—	—	—
	0.2% proof stress N/mm ² min	375	—	—	—	—	—	—	—
	Tensile strength N/mm ²	440-735	—	—	530	650	—	—	—
	Elongation % min	9	—	—	17	—	—	—	—
	Reduction of area % min	—	—	—	—	—	—	—	—

Data Sheet 17.9—Type-7 (ISO)**CHARACTERISTICS AND TYPICAL APPLICATIONS**

Widely used grade of free-cutting steel of high strength. It is also heat treatable. Suitable for parts in machine tools, motor cars, motors and general engineering that require a large amount of machining in their manufacture. Table 17.11 gives the chemical composition and mechanical properties of International Standard steels.

HEAT TREATMENT

Normalizing	860–880°C (Air cool)
Hardening	840–860°C (Water or oil quench)
Tempering	540–680°C

Table 17.11

Steel	Standard	ISO R683/IX-70	IS	DIN 1631-70	AISI	BS	NFA 35-562-81	GOST	JIS
	Designation	Type 7		35S20	1139	212M36	35MF6		
Chemical composition	C %	0.32–0.39	—	0.32–0.39	0.35–0.43	0.32–0.40	0.32–0.39	—	—
	Si %	0.15–0.40	—	0.10–0.40	—	0.25	0.1–0.4	—	—
	Mn %	0.50–0.90	—	0.50–0.90	1.35–1.65	1.00–1.40	1.3–1.7	—	—
	≤ P %	0.06	—	0.06	0.04	0.06	0.04	—	—
	≤ S %	0.15–0.25	—	0.15–0.25	0.13–0.20	0.12–0.20	0.09–0.13	—	—
	Cr %	—	—	—	—	—	—	—	—
	Mo %	—	—	—	—	—	—	—	—
	Ni %	—	—	—	—	—	—	—	—
	Others	—	—	—	—	—	—	—	—
Mechanical properties	Dimensions	16–40	—	16–40	—	63	16	—	—
	0.2% proof stress N/mm ² min	315	—	360	—	370	735	—	—
	Tensile strength N/mm ²	540–740	—	580–725	—	625–775	880–1080	—	—
	Elongation % min	16	—	16	—	18	9	—	—
	Reduction of area % min	—	—	—	—	—	—	—	—

Data Sheet 17.12—Type-10 (ISO)

CHARACTERISTICS AND TYPICAL APPLICATIONS

This steel is preferred to the plain carbon varieties where a lot of machining is necessary. It is suited to higher stressed parts. Mainly used in general engineering and motor manufacture in constructional and turned parts requiring high strength characteristics such as axes, shafts, small crank-shafts, etc. Table 17.14 gives the chemical composition and mechanical properties of International Standard steels.

HEAT TREATMENT

Normalizing	840–870°C (Cool in air)
Hardening	840–870°C (Quench in oil or water)
Tempering	540–680°C

Table 17.14

Steel	Standard	ISO R683/IX-70	IS	DIN 1651-70	AISI	BS 970/1-83	NFA 35/562-81	GOST	JIS G4804-71
	Designation	Type 10		45S20	1146	216M44	45MF4		SUM 42
Chemical composition	C %	0.42–0.50	—	0.42–0.50	0.42–0.49	0.40–0.48	0.42–0.49	—	0.37–0.45
	Si %	0.15–0.40	—	0.10–0.40	—	0.25	0.10–0.40	—	—
	Mn %	0.50–0.90	—	0.50–0.90	0.70–1.00	1.20–1.50	0.80–1.10	—	1.35–1.65
	≤P %	0.06	—	0.06	0.04	0.06	0.04	—	0.04
	≤S %	0.15–0.25	—	0.15–0.25	0.08–0.13	0.12–0.20	0.09–0.13	—	0.08–0.13
	Cr %	—	—	—	—	—	—	—	—
	Mo %	—	—	—	—	—	—	—	—
	Ni %	—	—	—	—	—	—	—	—
	Others	—	—	—	—	—	—	—	—
Mechanical properties	Dimensions	16–40	—	16–40	19–22	100	16	—	—
	0.2% proof stress N/mm ² min	380	—	410	—	415	785	—	—
	Tensile strength N/mm ²	610–810	—	660–810	650 min	700–950	930–1130	—	—
	Elongation % min	13	—	12	12	15	8	—	—
	Reduction of area % min	—	—	—	—	—	—	—	—

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5. BS 970, Part 1, 1985, *General Inspection and Testing Procedures and Specific Requirements for Carbon, Carbon-Manganese Alloy and Stainless Steels*.
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7. NFA 35—562, *Heat-treated Free Cutting Special Steel—Bars and Wire Rods Drawing Types*.
8. JISG 4804—1971, *Resulphurized Carbon Steels*.

Spring Steels

Depending on the type of application, springs are made of carbon steels, silicon and manganese containing steels, silicon-manganese steels, alloyed steels, stainless steels. Springs must be capable of storing and releasing the energy. After repeated application of load, they must retain their original shape and dimension. This property may be attained by the use of a highly elastic material and by proper design because the allowable stress values determine the choice of material and design.

Major requirements of spring steels are:

- (i) Should have a high yield strength (of the order of 21000 kg/mm^2) or more accurately, a high proportional limit, so that it will not show any appreciable permanent set;
- (ii) A high fatigue strength under alternating and fluctuating stresses with a reserve for occasional or more frequent overloads (e.g. vehicle springs when stressed in their resonance range);
- (iii) Should have an adequate plastic range for the forming (winding) of the springs.

These desirable properties of springs can be achieved firstly by a higher carbon content or with suitable alloying elements, and secondly by heat treatment. The actual springiness of steel is determined by its modulus of elasticity which is about 21000 kg/mm^2 , the modulus of rigidity being about 8000 kg/mm^2 . It is possible to influence the moduli of elasticity and shear by severe cold working treatments. Spring failure is almost invariably from fatigue, with some stress raisers as nucleus.

Steel springs are used in hard, high strength condition. To attain these properties springs are hardened and tempered. In the hardened condition, the steel should have 100% martensite to attain the maximum yield strength to avoid excessive set in service. The presence of retained austenite in the hardened condition lowers the yield strength and produces excessive set.

Use of carbon steel for smaller sections results in martensite as against larger sections in which hardness will be less when carbon steel is used. However, hardenability of the steel may be increased by the addition of alloying elements. To get high yield strength on tempering martensite needs to be high in carbon. The combination of high carbon along with alloying elements will possess the desired hardenability in different sections. Hence the desired properties of springs can be achieved firstly by higher carbon content or by addition of suitable alloying elements and, secondly, by a suitable heat treatment. Fatigue failure may occur if the hardening temperature is too high or too low.

For many applications, where the working stresses are low, carbon spring steels are quite satisfactory for smaller cross-sections. But, for higher cross-sections or high duty springs, steels of higher hardenability are used. Hence, in addition to carbon spring steel, mainly alloy steels having principal alloying elements such as manganese-silicon, chromium, vanadium, molybdenum, etc., are used for the production of springs. Spring steels that are commercially available are carbon spring steel, silico-manganese steel, manganese alloyed steel, silicon alloyed steel, chrome-vanadium steel, etc.

Springs of small dimensions are also usually made from patented drawn spring wires coiled in the cold state. They possess a very high tensile strength and elastic properties compared to the normally drawn wire. They also possess good ductility and toughness. Springs made out of patented wire do not require hardening. They are only subjected to tempering at 200 to 250°C.

Drawn spring steels used for high-duty valve springs in the automotive and aircraft industries are coiled in the annealed condition, and finally hardened and oil-tempered, as this treatment imparts to them an improved fatigue strength.

For springs subjected to elevated temperatures special alloy steels with high resistance to temperature are used. These steels are normally alloyed with molybdenum, nickel, tungsten or vanadium, and they are used for valve springs of engines, packing springs and bypass valve springs in locomotives and springs for super-heated steam slide valves in locomotives.

18.1 Heat Treatment

It is most important that the spring should be heat treated with the utmost care, since this determines the quality of the springs. The temperature is checked by suitable measuring instruments during the heat treatment process. It is also advisable to check the success of heat treatment by means of a suitable fracture test and by testing the Vicker hardness of the product after hardening and tempering. It is important to adopt all possible precautionary measures against surface decarburization during heat treatment in order to avoid unnecessary reduction of the fatigue strength of the product. Usually applied heat treatment processes are soft annealing, normalizing, hardening and tempering.

18.1.1 HOT SHAPING OF STEEL PARTS TO SPRINGS

The parts are thoroughly heated in a neutral atmosphere to the maximum temperature limit of hot working operations (900–920°C), depending on the chemical composition of the steel, followed by cambering or coiling. The temperature limit for hot working ranges between 920 and 830°C depending on the chemical composition.

18.1.2 SOFT ANNEALING

Soft annealing may be necessary in the case of difficult shaping operations, which involve cold working of the steel such as cold coiling, cutting and stamping by milling or turning, etc. The treatment is carried out in the temperature range of 640–680°C in a neutral atmosphere to protect against decarburization. Steels alloyed with silicon are particularly sensitive to surface decarburization, and they should, therefore, be annealed for a short time only at the lower limit of the temperature range. Holding time at this temperature range

extends to several hours, depending on the cross section. It is then cooled slowly down to the room temperature in the furnace.

18.1.3 NORMALIZING

Normalizing may be necessary if the spring is exposed to high stresses and in such cases where they cause difficulties when shaped. The adopted temperature range is between 830 and 860°C. Normalizing is not necessary if the correct temperature is maintained during hot shaping.

18.1.4 HARDENING

The springs are uniformly and thoroughly heated to the hardening temperature. Special care has to be taken to prevent them from changing their dimension and shape. To achieve this the springs should be first of all heated in a horizontal position, for a spring being placed vertically for heating may deflect under the action of its own weight in the hot condition. To prevent springs from becoming distorted the bottom of the furnace on which the springs are placed must be smooth and even. To prevent long springs from warping during heating they may be fitted on suitable mandrels made of a thin-wall section. Very small springs may be heated after placing them in a pan.

Holding at the hardening temperature depends on the cross section which can be calculated on the basis of one minute for each one millimetre wire diameter. The lower limits of the hardening temperature range are selected for smaller dimensions, and the upper limits for longer dimensions.

If the hardening temperature is too low, the desired hardness will not be obtained; if excessive hardening temperatures are used, grain coarsening, brittleness and excessive decarburization will occur. Fatigue failure may occur if the hardening temperature is too low or too high.

Steels alloyed with silicon are particularly sensitive to surface decarburization; hence holding time at the hardening temperature should be as short as possible to avoid decarburization.

In the manufacture of heavy coil springs, it is a common practice to quench directly on the mandrel, as the optimum temperature of steel is too low after coiling. This means that a directly quenched spring has inevitably been hardened from an excessive temperature when making springs from alloy steel, unless a low coiling temperature can be used. All springs should be allowed to cool after coiling, and re-heated to the optimum temperature for final hardening. High hardenability steels, after coiling, are allowed to cool to about 100°C and immediately taken up for hardening. Cooling highly alloyed steels to the room temperature, after coiling, may develop surface cracks. It is most important that the furnace atmosphere should be neutral to avoid decarburization. Fatigue life of the spring steel may be increased by carburizing and nitriding.

18.1.5 QUENCHING

After holding for the desired length of time in the hardening temperature, springs are taken out for cooling in oil or water, depending on the chemical composition of the steel. The temperature of the quenching water must be between 30°C and 40°C, and it should never be below 20°C. The water in the bath should be kept in motion by a suitable delivery of water in order to remove steam bubbles forming in the water.

The temperature of the quenching oil should be around 60°C. The oil should have a good fluidity. It must, therefore, have a sufficiently low grade viscosity. The oil as well as the parts quenched should be kept in motion during cooling. The oil should be free from water.

Steels of high hardenability should be withdrawn from the oil at a temperature between 100 and 200°C, and charged immediately into a tempering furnace to avoid the risk of cracking.

18.1.6 TEMPERING

The springs are tempered in the temperature range of 470–540°C. The temperature adopted depends on the desired properties. Tempering should be carried out directly after the hardening treatment in order to avoid cracking on hardening. The practice of tempering springs for a very short time at a somewhat higher temperature than the normal level is not recommended for alloy steels. A soaking time for alloy steels should be at least one and half minutes for each millimetre of the wire diameter, but not less than half an hour in any case.

18.1.7 PATENTING

This process consists of heating the steel above the A_{c3} point to 1000–1050°C. At this temperature the austenite is coarsened. It is then cooled either in air blast, die block, oil or lead alloy depending on the application. After austenitizing the parts are quenched in a bath of molten lead held at a desired temperature, not far below the critical temperature in order to facilitate the formation of a sorbitic structure. Since this structure is stronger than a coarse one, the final product has a better strength for working than the cold-worked wire.

In practice, the process consists of heating the wire to a temperature above A_{c1} by passing continuously through a long tube furnace and then cooled by drawing into a bath maintained at a temperature of around 450°C, i.e., the wire is subjected to an isothermal hardening. As a result of patenting, the structure of the wire is transformed into sorbite, representing a step in the transformation from austenite to pearlite in which the grains are very small and the iron carbide is distributed in a very finely divided form in the ferrite. The patented wire is then subjected to cold working.

18.2 Hardening and Tempering Equipment

Hardening furnaces employed for this purpose are to be constructed so as to ensure uniform temperature control. In order to avoid surface decarburization, salt-bath hardening furnaces may be employed which give very good results. They also prevent oxidation of the material being hardened. Controlled atmosphere furnaces may also be employed. The furnaces should be equipped with an accurate temperature control system.

The tempering may be carried out in a salt or lead bath and also forced air circulation furnace may be used.

18.3 Decarburization

Springs must be free from surface decarburization in order to avoid early failure of springs in service. The endurance of a spring with a decarburized rough surface is so reduced that its life is far below what it should normally be.

The surface of the rolled bar is always decarburized to some extent due to the heating done for rolling. Springs made after hardening will not attain full hardness on the extreme surface. This results in a lack of strength, particularly under fatigue conditions. Further, the rolled bar is liable to contain minor surface defects. They act as stress raisers in helical springs or torsion bars, where the material is subjected to torsional stress, and may lead to early failure. Decarburization may also take place during coiling, or due to the furnace atmosphere, and due to the temperature employed. Hence proper attention may be given to the use of a correct atmosphere. It is necessary to employ the shortest possible heating time to reach the coiling temperature. Decarburization may take place during austenitizing, especially in silicon-manganese steels which are prone to deep decarburization. Hence, during hardening, the shortest time may be employed. The presence of a decarburized layer from the rolled condition further enhances the decarburization during hardening. This may be avoided by lightly shot-blasting between coiling and hardening.

The effect of very slight decarburization can be removed by shot-peening the springs after heat-treatment.

18.4 Application

The different types of spring steels that are mainly used are given in Table 18.1. Application, mechanical properties and chemical composition are given in data sheets.

Table 18.1

Country Standard	ISO ISO	INDIA IS	DEU DIN	USA AISI	GBR BS970	FRA NFA35	USSR GOST	JPN JIS
1	—	C70	CK67	1063	080A67	XC68	—	—
2	Type 1	C75	CK75	1074	Eu42C	XC75	75	—
3	Type 2	C85	CK85	1084	—	—	—	—
4	Type 3	—	46Si7	—	—	45S7	—	—
5	Type 4	—	51Si7	9255	250A53	51S7	50S2	—
6	Type 5	55Si2Mn90	55Si7	9255	250A53	55S7	60SGA	SUP6
7	Type 6	—	—	9260	250A58	—	—	SUP7
8	Type 7	—	60SiCr7	9260	250A61	61SC7	60S2	SUP7
9	Type 8	—	55Cr4	5155	527A60	55C3	50KHGA	SUP9
10	Type 9	—	—	5160	527A60	—	—	—
11	Type 11	—	—	—	—	45CD6	—	—
12	Type 13	50Cr1V2J	50CrV4	6150	735A50	50CV4	50KHGFA	SUP10
13	Type 14	—	51CrMoV4	—	—	51CDV4	—	—

Data Sheet 18.1—C70 (IS)**CHARACTERISTICS AND APPLICATIONS**

This is an oil quenching steel, used for parts requiring high wear resistance making baffle springs, shock absorbers, spring for seat cushions for road vehicles. It is also used for making rail tyres, unhardened gears and worms, clips, etc. Table 18.2 gives the mechanical properties and chemical composition of International Standard steels.

HEAT TREATMENT

Soft annealing	600–650°C
Hardening	800–830°C (Oil quench)
Tempering	420–500°C
Hardened and tempered to HRC 36–47.	

Table 18.2

Country	ISO	INDIA	DEU	USA	GBR	FRA	USSR	JPN	
Standard norm	ISO	IS	DIN 17222-79	AISI	BS 970/5-72	NFA35	GOST	JIS	
Designation		C70	CK67	1065	080A67	XC68	65GA		
Chemical composition	C	—	0.65-0.75	0.65-0.72	0.60-0.70	0.65-0.70	0.65-0.73	0.65-0.70	—
	Si	—	0.10-0.35	0.15-0.35	0.35 max.	0.10-0.35	0.15-0.35	0.15-0.30	—
	Mn	—	0.50-0.80	0.60-0.90	0.60-0.90	0.70-0.90	0.40-0.70	0.70-1.00	—
	P	—	0.035	0.035	0.040	0.050	0.035	0.025	—
	S	—	0.035	0.035	0.050	0.050	0.035	0.025	—
Mechanical properties	Dimensions	—	—	2.5 min.	—	—	—	—	—
	0.2% proof stress N/mm ² min.	—	—	1275	—	—	—	—	—
	Tensile strength N/mm ²	—	1175-1580	1230-1770	—	—	—	—	—
	Elongation % min.	—	—	—	—	—	—	—	—
	Reduction of area % min.	—	—	—	—	—	—	—	—

Data Sheet 18.2—Type-1 (ISO)**CHARACTERISTICS AND APPLICATIONS**

This is a steel for making light, flat springs from annealed stock. Because of good wear

Table 18.3

Country	ISO	INDIA	DEU	USA	GBR	FRA	USSR	JPN
Standard norm	ISO R 683/XIV-73	IS	DIN 17222-79	AISI	BS970/B-72	NFA35	GOST	JIS
Designation	Type 1	C75	CK75	1074	En42C	XC75	75	
Chemical composition	C	0.72-0.85	0.70-0.80	0.70-0.80	0.70-0.80	0.70-0.80	0.72-0.80	
	Si	0.15-0.40	0.15-0.15	0.035	0.035 max.	0.15-0.30	0.17-0.37	
	Mn	0.5-0.8	0.60-0.80	0.50-0.80	0.55-0.80	0.40-0.70	0.50-0.80	
	P	0.050	0.035	0.040	0.050	0.035	0.035	
	S	0.050	0.035	0.050	0.050	0.035	0.040	
Mechanical properties	Dimensions	10	2.5 min					
	0.2% proof stress N/mm ² min	880	1275					
	Tensile strength N/mm ²	1180	1320-1875					
	Elongation % min	—	—					
	Reduction of area % min	6	6					

Table 18.4

Country	ISO	INDIA	DEU	USA	GBR	FRA	USSR	JPN
Standard norm	ISO R 683: XIV 73	IS	DIN 1722 79	AISI	BS 970: 573	—	GOST	JIS G 4401-77
Designation	Type 2	C 35	Ck 35	1084	080A81	—	85	SCrP3
Chemical composition	C	0.72-0.85	0.80-0.90	0.80-0.93	0.78-0.85	—	0.82-0.90	0.75-0.90
	Si	0.15-0.4	0.10-0.35	0.35	0.1-0.4	—	0.17-0.37	0.15-0.35
	Mn	0.5-0.8	0.50-0.80	0.45-0.65	0.5-0.7	—	0.50-0.80	0.3-0.6
	≤ P	0.035	0.035	0.040	0.05	—	0.035	0.035
	S	0.035	0.035	0.050	≤ 0.05	—	0.035	0.035
Mechanical properties	Dimensions	10	—	2.5 min.	—	—	—	13
	0.2% proof stress N/mm ² min.	880	—	1270	—	—	—	875 min.
	Tensile strength N/mm ²	1180	—	1400-1950	—	—	—	1080 min.
	Elongation % min.	6	—	6	—	—	—	8
	Reduction of area % min.	—	—	—	—	—	—	—

properties when properly heat treated, it is used to make plough-shares, rake teeth, scrapers and shovels. Table 18.3 gives the mechanical properties and chemical composition of International Standard steels.

HEAT TREATMENT

Soft annealing	600-650°C
Hardening	780-810°C (Oil quench)
Tempering	420-500°C
Hardened and tempered to HRC 36-47.	

Data Sheet 18.3—Type-2 (ISO)

CHARACTERISTICS AND APPLICATIONS

These steels are used for making flat and coil springs for automobiles and railway vehicles. Valve springs, wires and musical wires are special applications of this steel. After suitable heat treatment, these steels are also used to make scraper blades, disc and spring tooth harrows. Table 18.4 gives the mechanical properties and chemical composition of International Standard steels.

HEAT TREATMENT

Soft annealing	600-650°C
Hardening	780-810°C (Oil quenching)
Tempering	600-650°C

Data Sheet 18.4—Type-3 (ISO)

CHARACTERISTICS AND APPLICATIONS

This is a water hardening spring steel used for lock washers and spring plates for screw locking device, and springs for cultivators. Also used for spiral springs, railway, car springs and springs for agricultural machines. Flat sizes up to 14 mm thickness may be used for applications. Table 18.5 gives the mechanical properties and chemical composition of International Standard steels.

HEAT TREATMENT

Normalizing	530-870°C
Soft annealing	640-680°C
Hardening	830-860°C (Water quenching)
Tempering	470-540°C
Cambering or coiling	900-850°C

Table 18.5

Country		ISO	INDIA	DEU	USA	GBR	FRA	USSR	JPN
Standard norm		ISO R683/XIV-73	IS	DIN 17221-55	AISI	BS970/ 1-72	NFA35- 552-84	GOST	JIS
Designation		Type 3	—	46Si7	—	—	46S7	—	—
Chemical composition	C %	0.43-0.50	—	0.42-0.5	—	—	0.42-0.50	—	—
	Si %	1.5-2.0	—	1.5-1.8	—	—	1.60-2.00	—	—
	Mn	0.50-0.80	—	0.50-0.80	—	—	0.50-0.80	—	—
	P	0.040	—	0.05	—	—	0.035	—	—
	S	0.040	—	0.05	—	—	0.035	—	—
Mechanical properties	—	—	—	—	—	—	0.30	—	—
	Dimensions	10	—	14	—	—	10	—	—
	0.2% proof stress N/mm ² min.	1080	—	1080	—	—	1300	—	—
	Tensile strength N/mm ²	1270 min.	—	1270-1475	—	—	1450-1700	—	—
	Elongation % min.	6	—	6	—	—	—	—	—
	Reduction of area % min.	—	—	—	—	—	—	—	—

Data Sheet 18.5—Type-4 (ISO)**CHARACTERISTICS AND TYPICAL APPLICATIONS**

This steel is used for laminated springs for rail vehicles, bumper springs and conical and cup springs for use in mechanical engineering and vehicle construction. It possesses tensile strengths of 1300-1570 N/MM² (10 mm thick). Flat sizes up to 18 mm thickness and round sizes up to 25 mm diameter may be used for applications. Table 18.6 gives the mechanical properties and chemical composition of International Standard steels.

HOT WORKING AND HEAT TREATMENT

Forging	Commence 1050°C—max., 850°C—min.
Hot forming	900-820°C
Annealing	640-680°C (Furnace cool)
Hardening	820-850°C (Followed by water quenching)
Tempering	470-540°C

Data Sheet 18.6—Type-5 (ISO)**CHARACTERISTICS AND APPLICATIONS**

This is a manganese-silicon spring steel capable of taking up a good hardness and an in-

Table 18.6

Country	ISO	INDIA	DEU	USA	GBR	FRA	USSR	JPN
Standard norm	ISO R683/XIV-73	IS	DIN 17221-72	ASTM A322-76	BS970/ 1-72	NFA35- 571-84	GOST 2052-53	JIS
Designation	Type 4		51Si7	9255	250A53	51S7	50S2	
Chemical composition	C %	0.47-0.55	—	0.47-0.55	0.51-0.59	0.50-0.57	0.48-0.54	0.47-0.55
	Si %	1.50-2.00	—	1.50-1.80	1.80-2.20	1.70-2.10	1.60-2.00	1.50-2.00
	Mn	0.50-0.80	—	0.50-0.80	0.70-0.95	0.70-1.00	0.50-0.80	0.60-0.90
	P	0.04	—	0.045	0.035	0.05	0.035	0.04
	S	0.04	—	0.045	0.04	0.05	0.035	0.04
Mechanical properties	Dimensions	10	—	10	—	—	10	—
	0.2% proof stress N/mm ² min	1130	—	1130	—	—	1350	—
	Tensile strength N/mm ²	1320	—	1320-1575	—	—	1500-1750	—
	Elongation % min	6	—	6	—	—	6.5	—
	Reduction of area % min	—	—	—	—	—	—	—

creased stability in tempering. It is suitable for application of 14 mm thickness for flat size and 20 mm diameter for round sizes. It is suitable for leaf springs. Helical, conical and cup springs in general mechanical engineering and vehicle construction are some other typical applications. Table 18.7 gives the mechanical properties and chemical composition of International Standard steels.

HEAT TREATMENT

Cambering or coiling	900-850°C
Normalizing	850-880°C
Soft annealing	640-680°C
Hardening	820-850°C (Water) 840-870°C (Oil)
Tempering	470-340°C

Data Sheet 18.7—Type-6

CHARACTERISTICS AND TYPICAL APPLICATIONS

This is an oil hardening spring steel used for leaf springs for automotive and general engineering, helical, conical springs for use in general mechanical engineering and vehicle

Table 18.7

Country	ISO	India	DEU	USA	GBR	FRA	USSR	JPN
Standard norm	ISO R683/XIV 73	IS	DIN 17222-79	AISI	BS970/1-72	NFA 552-84	GOST	JIS G4301-77
Designation	Type 5	55Si2Mn20	55Si7	9255	250A53	55S7	60SGA	SUP6
Chemical composition	C	0.52-0.60	0.52-0.60	0.51-0.59	0.50-0.57	0.51-0.60	0.56-0.64	0.55-0.65
	Si	1.50-2.00	1.50-1.80	1.80-2.20	1.70-2.00	1.60-2.00	1.30-1.80	1.50-1.80
	Mn	0.6-0.9	0.70-1.00	0.70-0.95	0.70-1.00	0.70-1.00	0.80-1.00	0.70-1.00
	P	0.04	0.035	0.035	0.040	0.035	0.025	0.035
	S	0.04	0.035	0.040	0.050	0.035	0.025	0.035
Mechanical properties	Dimension	10	18	—	—	—	—	13
	0.2% proof stress N/mm ² min.	1180	1080	—	—	—	—	1079 min
	Tensile strength N/mm ²	1420	1430-1675	—	—	—	—	1225 min
	Elongation % min.	6	6	—	—	—	—	—
	Reduction of area % min.	—	—	—	—	—	—	—

industries. This steel may be used up to 20 mm thickness for flat sizes and 28 mm diameter for round sizes. Table 18.8 gives the mechanical properties and chemical composition of International Standard steels.

HOT WORKING AND HEAT TREATMENT

Forging	1050°C max. (Commence) 850°C min. (Finish)
Hot forming	900–820°C
Subcritical annealing	640–700°C
Annealed hardness	255 HB
Normalizing	850–880°C
Hardening	830–860°C (Quench in oil)
Tempering	400–550°C

Table 18.8

Country		ISO	INDIA	DEU	USA	GBR	FRA	USSR	JPN
Standard norm		ISO R683/X1V-73	IS	DIN	AISI	BS970/ 1-72	NFA35- 331-75	GOST	JIS G4801-77
Designation		Type 6			9260	250A58			SUP7
Chemical composition	C %	0.57–0.64	—	—	0.55–0.65	0.55–0.62	—	—	0.55–0.63
	Si %	1.70–2.20	—	—	1.80–2.20	1.70–2.10	—	—	1.80–2.00
	Mn	0.70–1.00	—	—	0.70–1.00	0.70–1.00	—	—	0.70–1.00
	P	0.040	—	—	0.04	0.05	—	—	0.035
	S	0.040	—	—	0.04	0.05	—	—	0.035
Mechanical properties	Dimensions	10	—	—	13.5	—	—	—	13
	0.2% proof stress N/mm ² min.	1180	—	—	—	—	—	—	1080
	Tensile strength N/mm ²	1370	—	—	1400	—	—	—	1230 min.
	Elongation % min.	5	—	—	—	—	—	—	9
	Reduction of area % min.	—	—	—	—	—	—	—	—

Data Sheet 18.8—Type-7 (ISO)

CHARACTERISTICS AND TYPICAL APPLICATIONS

This is an oil hardening steel used for torsion bar springs, stabilizers and spring washers for road vehicles, valve springs and springs subjected to high impact stresses. This steel

may be used up to 25 mm thickness for flat sizes and 35 mm diameter for round sizes. Table 18.9 gives the mechanical properties and chemical composition of International Standard steels.

HOT WORKING AND HEAT TREATMENT

Forging	1050°C max. (Commence) 850°C min. (Finish)
Hot forming	900–820°C
Sub-critical annealing	640–700°C
Annealed hardness	255 HB
Normalizing	850–880°C
Hardening	830–860°C (Quench in oil)
Tempering	400–550°C (Depending on the mechanical properties required)

Data Sheet 18.9—Type-8 (ISO)

CHARACTERISTICS AND TYPICAL APPLICATIONS

This is an oil-hardening steel used for high-duty leaf springs, torsion bar springs and stabilizers for road vehicles, helical and cup springs for general mechanical engineering and vehicle construction. Dimensions up to 18 mm for flat sizes and 28 mm diameter for round sizes may be applied. Table 18.10 gives the mechanical properties and chemical composition of International Standard steels.

HOT WORKING AND HEAT TREATMENT

Forging	1100°C max. (Commence) 850°C min. (Finish)
Hot forming	900–820°C
Sub-critical annealing	640–700°C
Annealed hardness	255 HB
Normalizing	850–880°C
Hardening	830–860°C (Quench in oil)
Tempering	400–550°C

Data Sheet 18.10—Type-9 (ISO)

CHARACTERISTICS AND TYPICAL APPLICATIONS

This is an oil-hardening alloy spring steel of good hardenability, suitable for the manufacture of any type of spring where working conditions are severe. Used for highly stressed automotive, locomotive and tank-car springs. Table 18.11 gives the mechanical properties and chemical composition of International Standard steels.

Table 18.9

Country	ISO	INDIA	DEU	USA	GBR	FRA	USSR	JPN
Standard norm	ISO R683/XIV-73	IS	DIN 17221-72	AISI A 322-82	BS970/1-72	NFA35- 551-75	GOST 2025-53	JIS G4801-77
Designation	Type 7	—	60SiCr7	9260	250A61	61SC7	60S2	SUP 7
Chemical composition	C %	—	0.55-0.65	0.56-0.61	0.58-0.63	0.57-0.64	0.57-0.65	0.55-0.65
	Si %	—	1.50-1.80	1.80-2.20	1.70-2.20	1.60-2.00	1.50-2.00	1.80-2.20
	Mn	—	0.70-1.00	0.75-1.00	0.70-1.00	0.60-0.90	0.60-0.90	0.70-1.00
	P	—	0.045	0.035	0.050	0.035	0.04	0.035
	S	—	0.045	0.040	0.050	0.035	0.04	0.035
	Cr	—	0.20-0.40	—	—	0.20-0.45	0.3	—
Mechanical properties	Dimensions	10	10	—	—	10	—	13
	0.2% proof stress N/mm ² min	1180	1130	—	—	1430	—	1079
	Tensile strength N/mm ²	1370 min	1320-1570	—	—	1380-1680	—	1225 min
	Elongation % min	5	6	—	—	5-5	—	9
	Reduction of area % min	—	—	—	—	—	—	—

Table JS.10

Country	ISO	INDIA	DEU	USA	GBR	FRA	USSR	JPN
Standard norm	ISO R683/XIV-73	IS	DIN 17221-72	AISI A322-82	BS570/1-72	NFA35- 571-84	GOST 2052-53	JIS G4801-77
Designation	Type 8		55Cr1	5155	527A60	55C3	50KHGA	SUP9
Chemical composition	C %	0.52-0.59	—	0.51-0.59	0.55-0.65	0.52-0.59	0.45-0.54	0.5-0.6
	Si %	0.15-0.40	—	0.15-0.30	0.10-0.35	0.10-0.40	0.17-0.37	0.15-0.35
	Mn	0.70-1.00	—	0.70-0.90	0.70-1.00	0.70-1.00	0.80-1.00	0.65-0.95
	P	0.035	—	0.035	0.04	0.035	0.03	0.035
	S	0.035	—	0.04	0.04	0.035	0.03	0.035
Chemical composition	0.60-0.90	—	0.60-0.90	0.70-0.90	0.60-0.90	0.60-0.90	0.45-1.20	0.65-0.95
Mechanical properties	Dimensions	10	10	—	—	10	—	13
	0.2% proof stress N/mm ² min	1180	—	—	—	1180	—	1079
	Tensile strength N/mm ²	1370 min	—	—	—	1370-1625	—	1220 min
	Elongation % min	6	—	—	—	6	—	9
	Reduction of area % min	—	—	—	—	—	—	—

HOT WORKING AND HEAT TREATMENT

Forging	1100°C max. (Commence) 850°C min. (Finish)
Hot forming	900-800°C
Annealing	640-680°C
Annealed hardness	255 HB
Normalizing	850-880°C
Hardening	845-860°C (Quench in oil)
Tempering	350-550°C (According to the hardness level required)

Table 18.11

Country	ISO	INDIA	DEU	USA	GBR	FRA	USSR	JPN
Standard norm	ISO R683/XIV-73	IS	DIN	AISI	BS970/1-72	NFA35- 551-75	GOST	JIS
Designation	Type 9	—	—	5160	527A60	—	—	—
Chemical composition	C %	0.56-0.64	—	0.55-0.65	0.55-0.65	—	—	—
	Si %	0.15-0.40	—	0.20-0.35	0.10-0.35	—	—	—
	Mn	0.70-1.00	—	0.75-1.00	0.70-1.00	—	—	—
	P	0.035	—	0.04	0.04	—	—	—
	S	0.035	—	0.04	0.05	—	—	—
	Cr	0.60-0.90	—	0.70-0.90	0.60-0.90	—	—	—
Mechanical properties	Dimensions	10	—	—	—	—	—	—
	0.2% proof stress N/mm ² min	1180	—	—	—	—	—	—
	Tensile strength N/mm ²	1370	—	—	—	—	—	—
	Elongation % min	5	—	—	—	—	—	—
	Reduction of area % min	—	—	—	—	—	—	—

Data Sheet 18.11—Type-11 (ISO)

CHARACTERISTICS AND TYPICAL APPLICATIONS

An oil-hardening alloy spring steel of higher hardenability due to the addition of Cr and Mo may be used for the manufacture of springs of large sections. Used for very high stressed automotive springs. Table 18.12 gives the mechanical properties and chemical composition of International Standard steels.

HOT WORKING AND HEAT TREATMENT

Forging	1100°C max. (Commence) 850°C min. (Finish)
Hot forming	920-830°C
Sub-critical annealing	640-700°C
Annealed hardness	255 HB
Normalizing	850-880°C
Hardening	830-860°C (Quench in oil)
Tempering	450-550°C

Table 18.12

Country		ISO	INDIA	DEU	USA	GBR	FRA	USSR	JPN
Standard norm		ISO R683/XIV-73	IS	DIN	AISI	BS970/1-72	NFA35- 571-84	GOST	JIS
Designation		Type 11					45SCD6		
Chemical composition	C %	0.42-0.50	—	—	—	—	0.42-0.50	—	—
	Si %	1.30-1.70	—	—	—	—	1.30-1.70	—	—
	Mn	0.50-0.60	—	—	—	—	0.50-0.80	—	—
	P	0.035	—	—	—	—	0.035	—	—
	S	0.035	—	—	—	—	0.035	—	—
	Cr	0.50-0.75	—	—	—	—	0.50-0.75	—	—
	Ni	0.15-0.30	—	—	—	—	0.15-0.30	—	—
Mechanical properties	Dimensions	10	—	—	—	—	—	—	—
	0.2% proof stress N/mm ² min	1180	—	—	—	—	—	—	—
	Tensile strength N/mm ²	1370	—	—	—	—	—	—	—
	Elongation % min	6	—	—	—	—	—	—	—
	Reduction of area % min	—	—	—	—	—	—	—	—

Data Sheet 18.12—Type-13 (ISO)**CHARACTERISTICS AND TYPICAL APPLICATIONS**

This steel is used for the most highly stressed springs. It possesses tensile strength of 1370-1670 N/mm² (10 mm thick). Used for leaf, helical and torsion bar springs, stabilizers for rolled vehicles, springs for use in general mechanical engineering, cup springs, spring washers and laminated springs. Dimensions up to 30 mm thickness for flat sizes and 40 mm diameter for round sizes may be applied. Table 18.13 gives the mechanical properties and chemical composition of International Standard steels.

Table 18.13

Country	ISO	INDIA	DEU	USA	GBR	FRA	USSR	JPN
Standard norm	ISO R683/XIV-73	IS 50C21V23	DIN 17222-70	ASTM A322-82	BS970:5-72	NEA35- 571-84	GOST 2062-63	JIS 4801-77
Designation	Type 13		50CrV4	6130	735A30	50CV4	50KHGFA	SUP10
Chemical composition	C	0.48-0.55	0.45-0.55	0.47-0.55	0.48-0.53	0.47-0.55	0.48-0.55	0.45-0.55
	Si	0.15-0.40	0.10-0.35	0.15-0.4	0.15-0.30	0.10-0.40	0.17-0.37	0.15-0.35
	Mn	0.70-1.00	0.50-0.80	0.70-1.10	0.7-0.9	0.7-1.0	0.8-1.00	0.65-0.95
	P	0.035	0.035	0.035	0.035	0.035	0.03	0.035
	S	0.035	0.035	0.035	0.04	0.035	0.03	0.035
	Cr	0.90-1.20	0.9-1.20	0.9-1.20	0.80-1.10	0.85-1.15	0.75-1.20	0.8-1.10
	V	0.1-0.20	0.15-0.30	0.1-0.2	0.15	0.1-0.20	0.15-0.25	0.15-0.25
	Ni						0.4	
Mechanical properties	Dimensions	10	—	10	—	10	—	13
	0.2% proof stress N/mm ² min.	1180	—	1180	—	1125	—	1079
	Tensile strength N/mm ²	1370 min.	—	1370-1675	—	1320-1570	—	1226 min.
	Elongation % min.	6	—	6	—	7	—	10
	Reduction of area % min.	—	—	—	—	—	—	—

HOT WORKING AND HEAT TREATMENT

Forging	1050°C max. (Commence) 850°C min. (Finish)
Hot forming to springs	920–830°C
Annealing	640–680°C (Furnace cool)
Hardening	Heat slowly to 830–860°C in a neutral atmosphere followed by oil quenching
Tempering	420–500°C

Data Sheet 18.13—Type-14 (ISO)**CHARACTERISTICS AND TYPICAL APPLICATIONS**

This steel possesses a higher hardenability due to the addition of Cr, Mo and V. It is recommended for the manufacture of springs of large section. It may be used for large-diameter helical and torsional bar spring stabilizers for road vehicles. Table 18.14 gives the mechanical properties and chemical composition of International Standard steels.

Table 18.14

Country		ISO	INDIA	DEU	USA	GBR	FRA	USSR	JPN
Standard norm		ISO R683/XIV-73	IS	DIN 17221-72	AISI	BS970/ 1-72	NFA35- 571-84	GOST	JIS
Designation		Type 14		51CrMoV4			51CDV4		
Chemical composition	C %	0.48–0.56	—	0.48–0.56	—	—	0.48–0.56	—	—
	Si %	0.15–0.40	—	0.15–0.40	—	—	0.15–0.40	—	—
	Mn	0.70–1.00	—	0.70–1.00	—	—	0.70–1.10	—	—
	P	0.035	—	0.035	—	—	0.025	—	—
	S	0.035	—	0.035	—	—	0.020	—	—
	Cr	0.90–1.20	—	0.90–1.20	—	—	0.90–1.20	—	—
	Mo	0.15–0.25	—	0.15–0.25	—	—	0.15–0.25	—	—
	V	0.07–0.12	—	0.07–0.12	—	—	0.07–0.12	—	—
Mechanical properties	Dimensions	10	—	10	—	—	10	—	—
	0.2% proof stress N/mm ² min.	1180	—	1180	—	—	1300	—	—
	Tensile strength N/mm ²	1370 min.	—	1370–1675	—	—	1450–1780	—	—
	Elongation % min.	6	—	6	—	—	8	—	—
	Reduction of area % min.	—	—	—	—	—	—	—	—

HOT WORKING AND HEAT TREATMENT

Forging	1100°C max. (Commence) 850°C min. (Finish)
Hot forming	920-830°C
Sub-critical annealing	640-700°C
Annealed hardness	255 HB
Normalizing	850-880°C
Hardening	850-880°C (Quench in oil)
Tempering	400-550°C

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Carbon Tool Steels

In spite of the ever increasing demand for alloy tool steels, carbon tool steels find a wide range of applications because of their property of resistance to dynamic stresses and wear resistance.

Carbon tool steels possess a carbon content of about 0.35 to 1.5%. The properties of these steels are manipulated by the addition of carbon alone, and the manganese content is maintained below 0.35%. In the 0.85 to 1.4% carbon range, an increase in carbon increases the wear resistance at the expense of toughness. This increase of wear resistance is due to the presence of undissolved hard carbides in the hardened matrix. Where toughness is required, the lower carbon grades are chosen. An increase in the hardening temperature, within the range recommended for each grade, produces a higher carbon martensite with corresponding increase in hardness and wear resistance.

These steels possess poor hardenability; hence it is necessary to quench them in water to get the desired properties. This in itself is an advantage since the quenched tool will have a hard skin backed by a tough core. Low cost and simplified heat treatment are the additional advantages offered by these steels.

The broad range of applications for plain carbon steels is restricted to such cases where no excessive demands are placed on tempering, strength, hot strength and red hardness; that is where tools are not overly heated, or when the wear resistance need not be excessively high. Moreover, consideration must be given to the required hardening depth or to the question whether through-hardening of tools is required. If through-hardening is necessary, the cross section of the tool is limited by the hardening depth of the steel. In other cases the obtainable hardening depth may be sufficient to impart the desired properties of the tool in question.

Table 19.1 Carbon Tool Steels

Data sheet	ISO	IS	DIN	AISI	BS-970	NFA 35-551	GOST	JIS
19.1	—	50T8	C45W	—	—	Y ₄₈	—	—
19.2	—	60T6	C60W	—	—	Y ₆₅	—	—
19.3	TC70	70T6	C67W	—	—	Y70	U7A	SK7
19.4	TC80	80T3	C80W1	W108	—	Y ₈₀	U8A	SK6
19.5	TC105	105T3	C105W1	W10	BW1B	Y105	U10A	SK3
19.6	TC120	155T3	C125W	W112	BW1C	Y ₁₂₀	U13A	SK2

Sometimes the usability of tool steels may be restricted also by a tendency towards distortion and dimensional change.

Steels containing low carbon may be used for maximum toughness. Steels with higher carbon contents will possess good wear resistance and edge-holding properties. Tools subjected to impact and shock must be made from low carbon steels where toughness and hardness are just sufficiently counter-balanced.

Table 19.1 gives the International Standard steels. Data Sheets 19.1 to 19.6 gives the chemical composition, application and heat treatment details.

HEAT TREATMENT OF CARBON TOOLS

Normalizing If hot working is completed at a temperature appreciably higher than the lower working temperature limit, grain coarsening occurs. This is refined by using the normalizing process. This is effected by heating slowly to 870°C and holding for 1–2 hours, followed by cooling in air. If the overheating has been excessive, particularly with high carbon steels, oil quenching followed by annealing is advisable.

Annealing Carbon tool steels are normally obtained in the annealed condition. The best condition for working and machining, and also the most favourable grain structure preparatory to hardening, is achieved by annealing. Annealing is carried out in a neutral atmosphere in order to avoid scaling and decarburization. The steel is packed in tightly closed annealing boxes filled with cast iron. It is heated slowly to $680\text{--}720^{\circ}\text{C}$ and held at this temperature for the desired length of time, for about 4–8 hours. It is cooled slowly in the furnace. This results in an average Brinell hardness of about 190.

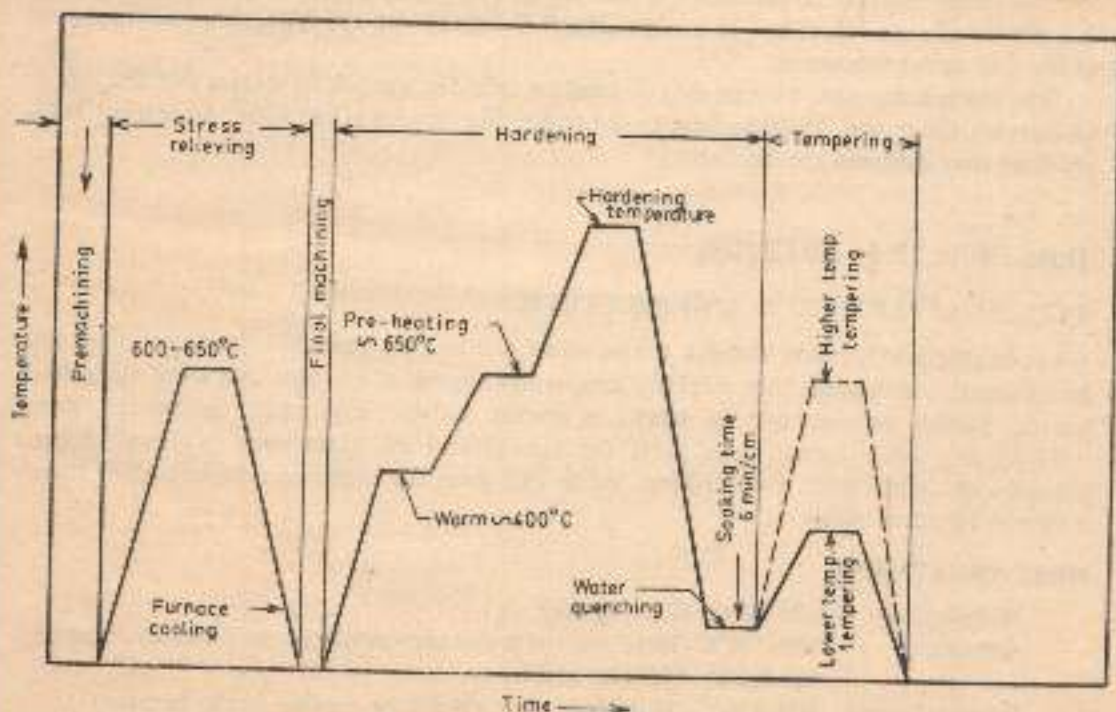


Fig. 19.1 Heat treatment sequence for carbon tool steel

Stress Relieving This is carried out in the temperature range of 600–650°C for 1–2 hrs, followed by slow furnace cooling. This is done to remove the induced internal stresses which are aggravated by hardening and may lead to the risk of cracking or distortion in intricate shaped tools or severely hot worked parts. Stress-relieving should be done prior to finish machining.

Hardening Hardening may be carried out in a muffle furnace with a controlled atmosphere or in a neutral salt bath. The austenitizing temperature for carbon tool steels varies from 760 to 840°C (Fig. 19.1).

The tools should be uniformly and thoroughly pre-heated up to about 400°C, then at 650°C and then heated more quickly up to the specified temperature and soaked for 15 minutes to 5 minutes depending on the cross section.

Quenching Quenching may be done in water or brine or oil depending on the geometry of component. In order to attain a high hardness, quenching may be done in a 5 to 10% brine down to about 90°C and then tempered immediately. Fresh water should be used for flush quenching, and oil quench if the section is small and the maximum hardness is not desired.

Tempering In order to lessen hardening stresses, the tools should be tempered immediately after hardening. It is important that the tool should be removed from the quenching bath whilst still the tool is hand warm. They should be tempered immediately before they reach the room temperature. Tempering may be carried out in oil bath or salt bath or forced air circulation furnace.

The tempering is done between 150 and 300°C. The choice of the tempering temperature is a matter of experience; and to a large extent it depends on the type, shape and purpose of the tool under treatment.

The lower temperature range may be used for relieving quenching strains and the higher to increase toughness. Holding time in the tempering furnace is one hour. Additional holding time may decrease the hardness.

Data Sheet 19.1—50T8 (IS)

TYPICAL APPLICATIONS AND PROPERTIES

All sorts of gimlets, round and flat tongs, screw drivers, nut wrenches, hammers, axes and jack planes, smith tools, hot working dies, wood augers of all types and hand vices, beet knives, blades for meat mining machines, pocket knives, covers and tin opener, stone working and brick laying tools, parts for agricultural machines such as plough shares, ploughs, etc. Chisels for deep drilling. Table 19.2 gives the chemical composition of International Standard steels.

HEAT TREATMENT

Normalizing	820–840°C (Cool in air)
Annealing	680–710°C (Hold for 4–6 h and cool slowly in the furnace) Annealed hardness—170–180 BHN.
Stress relieving	600–650°C (Hold for 1–2 h, then slow cooling in the furnace)
Hardening	Heat slowly to 790–840°C, choose limit of temperature for small and

high sections and upper for large and heavier loads. Holding time 10-50 min. depending on the section thickness followed by water quenching. Temper immediately when cooled to hand warm. Sections less than 5 min. quench in oil.

Obtainable hardness—58-60 RC.

Tempering 100-300°C (According to the hardness required).

Data Sheet 19.2—60T6 (IS)

TYPICAL APPLICATIONS

Bending dies, cold shrinking dies, stone mason's tools, plough shares, porcelain moulding tools, blacksmiths tools, long wearing machinery parts. Table 19.3 gives the chemical composition of International Standard steels.

HEAT TREATMENT

Annealing	680-710°C (Holding time 4-8 h depending on the cross section and charges. Followed by furnace cooling) Annealed hardness—180-200 BHN
Stress relieving	600-650°C (Soak for 1-2 h at the recommended temperature and cool slowly in the furnace)
Hardening	Heat slowly to 790-840°C. Adopt lower limit of temperature for light sections and upper limit of thicker sections. Holding time 10-50 min. depending on the section thickness, followed by water quenching. Temper immediately when cooled to hand warm. Obtainable hardness—58-62 HRC
Tempering	100-300°C (According to the required hardness—Fig. 19.2).

Table 19.2

Country	ISO	INDIA	DEU	USA	GBR	FRA	USSR	JPN
Standard norm	ISO	IS 3749-78	DIN 17350-80	AISI	BS970/1-72	NFA 35- 590-78	GOST	JIS
Designation		50T8	C45W			Y ₄₈		
Chemical composition	C	—	0.45-0.55	0.42-0.50	—	—	0.45-0.51	—
	Si	—	0.10-0.35	0.15-0.40	—	—	0.10-0.40	—
	Mn	—	0.60-0.90	0.60-0.80	—	—	0.50-0.80	—
	P	—	0.035	0.035	—	—	0.035	—
	S	—	0.035	0.035	—	—	0.035	—

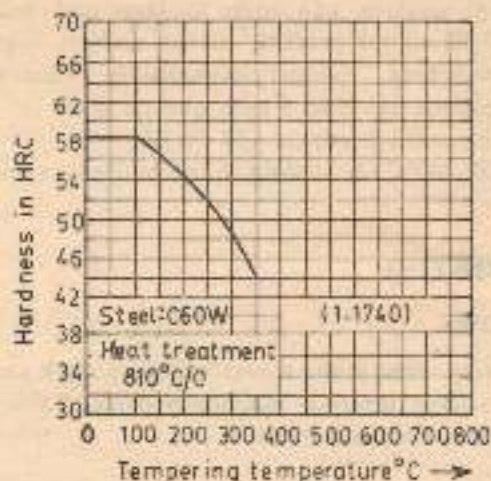


Fig. 19.2 Tempering curve of steel—IS 60T6

Table 19.3

Country	ISO	INDIA	DEU	USA	GBR	FRA	USSR	JPN
Standard norm	ISO	IS 3749-78	DIN 17350-71	AISI	BS970/1-72	NFA-35 590-78	GOST	JIS
Designation		60T6	C60W			Y465		
Chemical composition	C	—	0.55-0.65	0.55-0.65	—	—	0.60-0.69	—
	Si	—	0.19-0.35	0.15-0.40	—	—	0.10-0.40	—
	Mn	—	0.50-0.80	0.60-0.80	—	—	0.50-0.80	—
	P	—	0.035	0.035	—	—	0.035	—
	S	—	0.035	0.035	—	—	0.035	—

Data Sheet 19.3—TC70 (ISO)**TYPICAL APPLICATIONS**

Blacksmith dies and tools for hot working, trimming tools, cold and hot dressing chisels, punches and shear blades for soft sheet metal, choppers, tongs and spades, hammers and mallets for stone working, chuff cutter knives and punches, unhardened dies with accessories for extrusion, casting of lead, zinc and tin, spindles for spinning machines, vice jaws and gripping jaws. Table 19.4 gives the chemical composition of International Standard steels.

HEAT TREATMENT

Annealing 680-710°C (Hold for 4-8 h and cool slowly in the furnace)
 Annealed hardness—200-205 BHN

- Stress relieving 600–650°C (Hold for 1–2 h followed by furnace cooling up to 560°C, thereafter in air)
- Hardening 750–840°C (Holding time 10–50 min. depending on the section thickness followed by quenching in water)
 Approx. 750–780°C, thin work pieces.
 Approx. 770–800°C, thicker work pieces
 Approx. 800–840°C, thinner work pieces quench in oil.
 Obtainable hardness—60–63 (Water)
 56–58 (Oil)
- Tempering 100–300°C (According to the hardness required—Fig. 19.3).

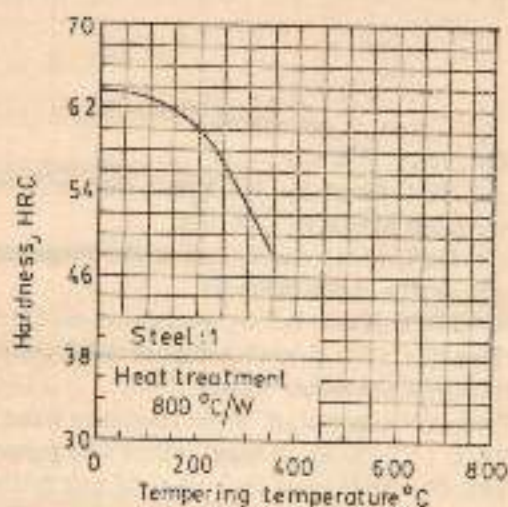


Fig. 19.3 Tempering curve of steel—ISO TC70

Table 19.4

Country	ISO	INDIA	DEU	USA	GBR	FRA	USSR	JPN 4401-72	
Standard norm	ISO 4957-80	IS 3749-78	DIN 17350-80	AISI	BS970/1-72	NFA35- 590-78	GOST	JIS	
Designation	TC70	70T6	C67W			Y1.70	U7A	SK7	
Chemical composition	C	0.65-0.74	0.65-0.75	0.65-0.74	—	—	0.66-0.74	0.65-0.74	0.6-0.7
	Si	0.035	0.10-0.35	0.15-0.30	—	—	0.10-0.25	0.15-0.35	0.035
	Mn	0.035	0.50-0.80	0.1-0.35	—	—	0.10-0.30	0.15-0.30	0.05
	≤ P	0.030	0.035	0.03	—	—	0.02	0.03	0.03
	≤ S	0.030	0.035	0.030	—	—	0.02	0.02	0.03

Data Sheet 19.4—TC80 (ISO)**CHARACTERISTICS**

This steel possesses greater toughness than high carbon steel. It has a deep hardened case with good cutting conditions.

TYPICAL APPLICATIONS

Power moves knives, frame saws, straw slitters, cement scrapers, wood cutting circular saws, coarse files, trimmers, tool bodies for compound tools, large simple blanking dies, dies for soft material, hammer faces and anvil faces for smith tools, large hot forging dies for shear, tongs, etc., vice jaws, mandrels and milling arbours, tailor's scissors, paper scissors, etc. Table 19.5 gives the chemical composition of International Standard steels.

HEAT TREATMENT

Forging	1000°C max. (Commence) 800°C min. (Finish)
Annealing	680–710°C (Soak for 4–8 h then slow cool in furnace) Annealed hardness—200 HB.
Stress relieving	600–650°C (Soak for 1–2 h at the recommended temperature and cool slowly in the furnace)
Hardening	800–830°C (Followed by quenching oil for thinner pieces) 770–810°C (For thicker component followed by water quench) Hardness obtained—62–63 HRC.
Tempering	Temper immediately when cooled to hand warm (Fig. 19.4). 100–300°C (According to type, shape and purpose of tools. Tempering time 1 h. Additional soaking time will further lower hardness.

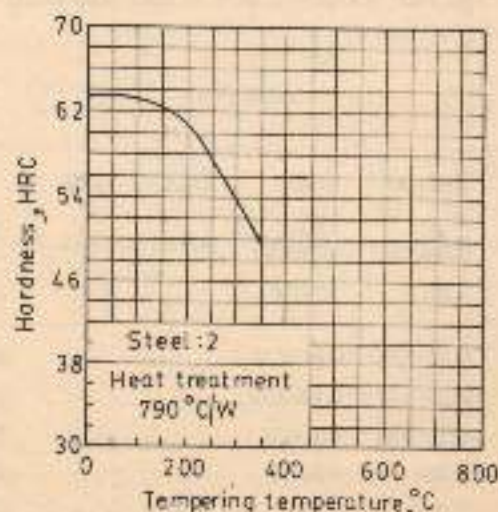


Fig. 19.4 Tempering curve of steel—ISO TC80

Table 19.5

Country	ISO	INDIA	DEU	USA	GBR	FRA	USSR	JPN
Standard norm	ISO 4957-80	IS 3749-78	DIN 17350-80	AISI	BS970/ 1-72	NFA35- 590-78	GOST	JIS 4401-72
Designation	TC80	90T3	C80W ₁	W108		Y.80	U8A	SK6
Chemical composition	C	0.75-0.84	0.75-0.85	0.75-0.85	0.70-0.85	—	0.75-0.84	0.75-0.84 0.7-0.8
	Si	0.35	0.10-0.30	0.10-0.25	0.10-0.40	—	0.10-0.25	0.15-0.35 0.035
	Mn	0.35	0.40 Max	0.1-0.25	0.10-0.40	—	0.10-0.30	0.15-0.30 0.5
	P	0.03	0.035	0.02	0.025	—	0.02	0.03 0.03
	S	0.03	0.035	0.02	0.025	—	0.02	0.02 0.03

Data Sheet 19.5—TC105 (ISO)

CHARACTERISTICS

This is a general-purpose tool steel with an excellent combination of hardness and toughness. It will retain its cutting edges for a long time. The steel also has a higher wear resistance.

TYPICAL APPLICATIONS

Blanking dies and punches, twist drills, reamers, broaches, etc. small shear blades, knives of all kinds, wood shapers, hobs, spinning tools, bending and marking tools, rock working tools for medium hard rock, embossing dies, pneumatic and stone chisels, gauges and wedges, cold forging, drawing, needle, and paper dies, hand and pneumatic chisels, anger bits, axes and plane irons. Table 19.6 gives the chemical composition of International Standard steels.

HEAT TREATMENT

Forging	1000°C max. (Commence) 800°C min. (Finish)
Annealing	680-710°C (Soak for 4-8 h followed by slow cooling in furnace)
Hardening	740-760°C (Thinner pieces in oil)
	750-780°C (Thicker pieces in water)
	770-800°C (Work pieces thinner than 3 mm in oil)
	Hardness attained—64-66 HRC.
Tempering	150-300°C (Depending on the type of component, shape and purpose of tool—tempering time 1 h, additional soaking time may further lower the hardness Fig. 19.5).

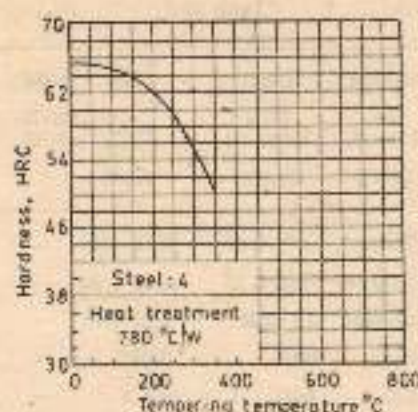


Fig. 19.5 Tempering curve of steel—ISO TC105

Table 19.6

Country	ISO	INDIA	DEU	USA	GBR	FRA	USSR	JPN
Standard norm	ISO 4957-80	IS 3749-78	DIN 17350-80	AISI	BS4659-71	NFA35-390-78	GOST	JIS 4401-72
Designation	TC105	103T3	C105W1	W10	BW18	Y105	U10A	SK3
Chemical composition	C	0.95-1.09	0.95-1.10	1.0-1.10	0.95-1.10	0.95-1.10	0.95-1.04	1.0-1.1
	Si	0.35	0.10-0.30	0.10-0.25	—	≤ 0.03	0.10-0.25	0.15-0.35
	Mn	0.35	0.40 Max	0.10-0.25	—	≤ 0.035	0.10-0.30	0.50
	P	0.03	0.035	0.02	—	0.03	0.02	0.03
	S	0.03	0.035	0.02	—	0.03	0.02	0.03
	V					0.05-0.15		

Data Sheet 19.6—TC120 (ISO)

CHARACTERISTICS

This steel possesses a very high abrasion resistance, compared to other carbon tool steels, and has a higher wear resistance.

TYPICAL APPLICATIONS AND PROPERTIES

Knives for plastics, engraving tools, watch makers tools, chasing tools, drawing dies and punches, hand saw, hack saw, rock working tools, precision cutting surgical instruments, metal chaser's tools, file cutting chisels, porcelain moulding tools, knife sharpeners, small boring and milling tools, natural hard press plates for the manufacture of artificial stone, mandrels and bars for cold drawing tubes of non-ferrous metals. Table 19.7 gives the chemical composition of International Standard steels.

HEAT TREATMENT

Forging	1100°C max. (Commence) 800°C min. (Finish)
Annealing	680–710°C (Soak for 4–8 h then slow cool in furnace) Annealed hardness—200 HB.
Stress relieving	600–650°C (Soak for 1–2 h with slow furnace cooling)
Hardening	760–790°C (Quench in water) 790–820°C (Quench in oil) Obtainable hardness—64–65 HRC.
Tempering	150–250°C (Depending on type of component, shape and purpose of tools. Temper 1 h, additional soaking time may further lower hardness—Fig. 19.6).

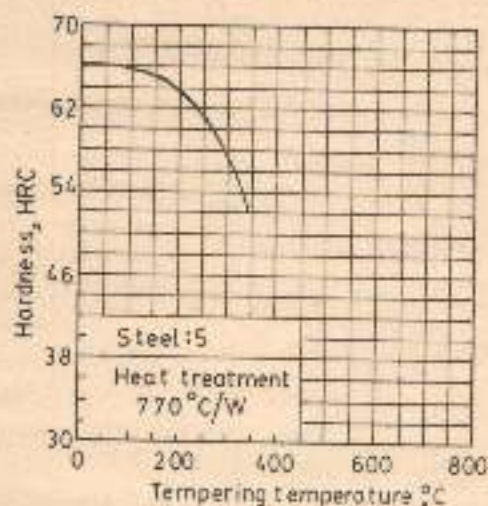


Fig. 19.6 Tempering curve of steel—ISO TC120

Table 19.7

Country	ISO	INDIA	DEU	USA	GBR	FRA	USSR	JPN
Standard norm	ISO 4657-80	IS 3749-78	DIN 17350-80	AISI	BS4650-71	NF A35-590-78	GOST	JIS 4401-72
Designation	TC120	155T3	C125W	W112	BW1-C	Y ₂ 120	U13A	SK2
Chemical composition	C	1.10–1.29	1.25–1.40	1.20–1.30	1.10–1.30	1.10–1.29	1.25–1.35	1.10–1.30
	Si	0.035	0.10–0.30	0.10–0.30	0.30	≤ 0.03	0.10–0.30	0.15–0.35
	Mn	0.035	0.40 Max	0.10–0.35	0.35	0.035	0.10–0.40	0.15–0.30
	P	0.030	0.03	0.03	0.03	—	0.025	0.03
	S	0.030	0.30	0.03	0.03	—	0.025	0.02

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8. JIS—G4401—1972, *Carbon Tool Steels*.

Cold Work Alloy Tool Steels

Cold work steels find a wide range of applications. To meet the large demand varying compositions are essential. They are alloyed with chromium, vanadium, chrome-tungsten, chrome-vanadium, etc.

This group of steels forms the most important type of alloy steels for all cold work applications where resistance to abrasive wear is of prime importance. Cold work steels are employed for the manufacture of tools for applications involving surface temperatures of not more than 200°C. In this temperature range, they must possess the following properties in order to guarantee the resistance to the high stresses arising from the numerous machining and shaping procedures. They should possess higher hardness, higher wear resistance and toughness, higher resistance to pressure and impact, they should also possess high dimensional stability during hardening and tempering.

These steels may be grouped into three distinct types:

1. Low alloy tool steels
2. High carbon-high chromium die steels
3. Special wear resistant cold work steel

Low Alloy Steels are capable of attaining a high degree of hardness, high degree of resistance to wear and dimensional stability compared to carbon tool steels. Compared to high carbon-high chromium die steels they possess improved machinability and toughness at the expense of resistance to abrasion. Hence these steels may be recommended for many applications where the higher carbon quantities have proved to be too brittle. These steels are suitable where fair abrasion resistance must be combined with exceptional toughness. They are also extremely useful for intricate dies that must maintain their shape after hardening and tempering. Thus they are widely used for wood working tools, farming and blanking dies, punches, drawing dies, etc. cutting and punching tools. They resist oxidation at high temperatures to a much greater degree than carbon or other low alloy steels.

High Carbon-High Chromium Cold Work Steels The wear resistance of these steels are higher compared to low alloy hardening steels. The wear resistance of all the high carbon-high chromium types is approximately eight times that of plain carbon steels when vanadium or other special carbides are not present. Difference in wear resistance may be found among the high carbon-high chromium steels. However, that largely results from a change of the carbon content. The presence of high range of chromium results in high hardenability and high hardness even in larger sections. These steels possess the best dimensional stability.

Special Wear Resistant Cold Work Steels These steels possess high wear resistance compared to high carbon-high chromium steels due to the presence of higher range of vanadium in steels. The presence of vanadium carbide is the main reason for dimensional stability but the machinability is poor.

These steels may be used when utmost wear resistance is necessary and manufacturing consideration is of secondary importance. They are specifically recommended for drawing and forming dies employed in fabricating stainless steels.

The different types of International Standard steels that are used are given in Table 20.1. The applications, properties, chemical composition and heat treatment procedure for particular types of steels are given in Data Sheets 20.1 to 20.22.

HEAT TREATMENT

Annealing Cold work steels are usually supplied in annealed condition. However they require further annealing if they are subjected to forging or for reconditioning the hardened component. Annealing may be carried out, where possible, under a protective atmosphere or salt bath. Annealing gives the steels the best machinability and most favourable grain structure prior to hardening. They should be held at the specified temperature for several hours (4-6 hours) after careful and thorough heating. The cooling should be done very slowly, at about 10°C per hour down to 500°C , and finally cooled off in still air.

Stress Relieving After machining, intricate tools should be stress relieved, in order to remove residual stresses caused by heavy working, straightening etc., just before the tools

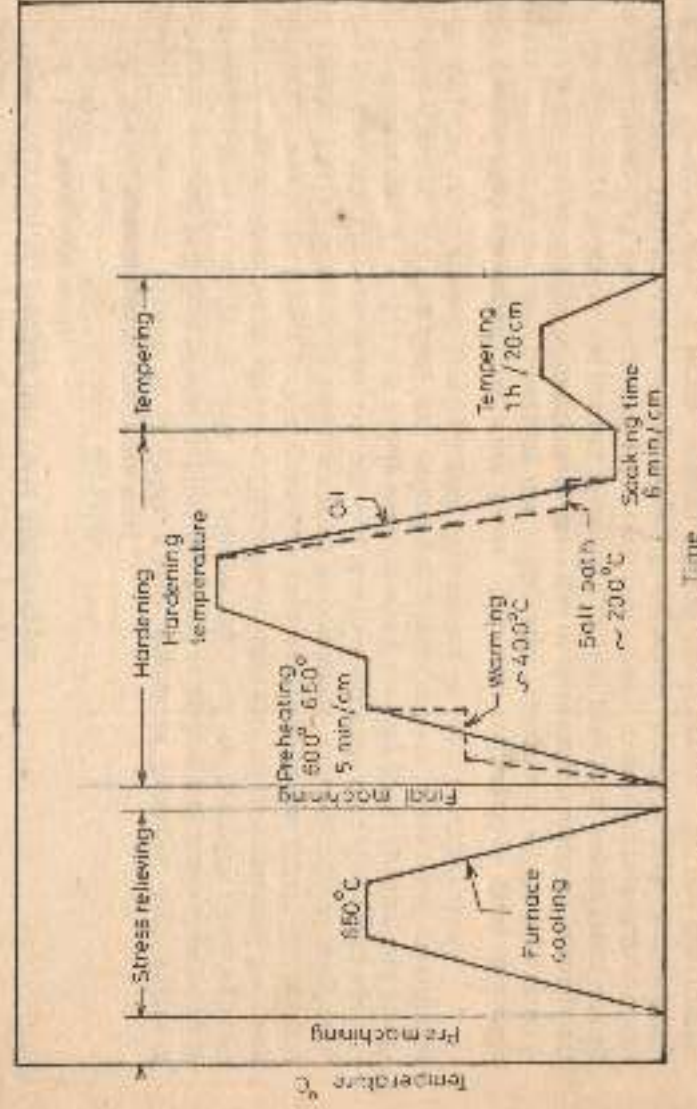


Fig. 20.1(a) Heat treatment sequence of cold work tool steels

are finish machined. This will avoid distortion and in certain cases cracking. This is accomplished by heating the tools to 650–700°C and soaking for 1 to 2 hours followed by slow cooling in the furnace. After this, final machining is done.

Hardening Before hardening, the tools should be finished with a smooth surface. Sharp corners, edges and tool marks should be reduced to a minimum so as to avoid the risk of cracking.

To obtain the benefits of low dimensional changes inherent in these steels, it is essential that parts are slowly and uniformly heated to the hardening temperature. Improved results can be obtained by having two furnaces for hardening, one of these being at a much lower temperature than the other. The tools are first preheated slowly to 650°C in a low temperature furnace; if necessary second preheating may be adopted at 900°C. Then it is transferred to the furnace, maintained at the hardening temperature (Fig. 20.1(a) and 20.1(b)). Soak-

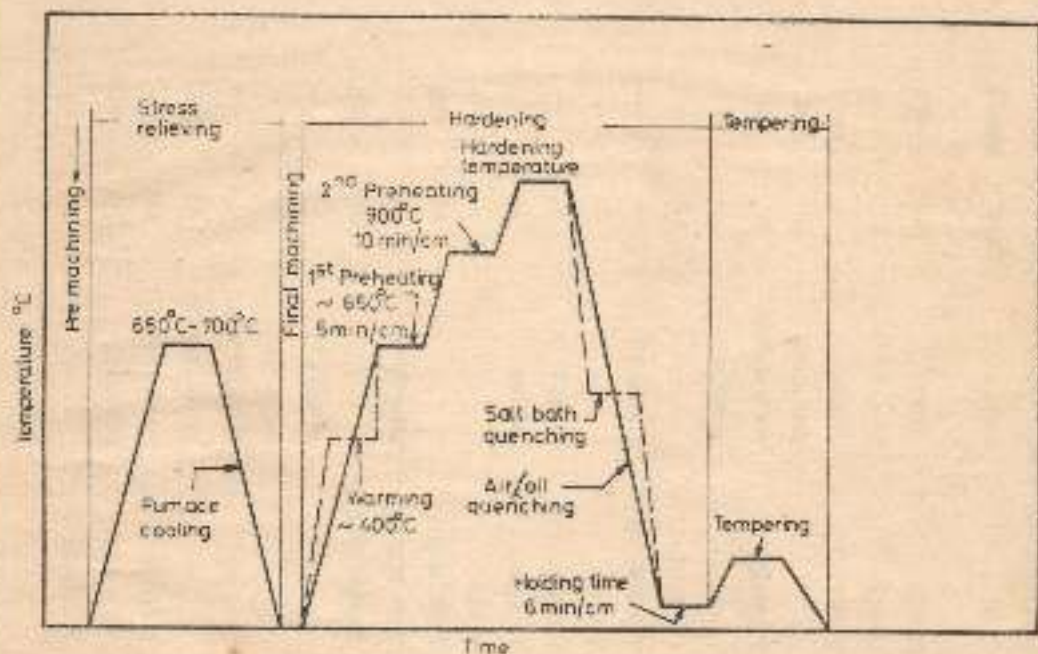


Fig. 20.1(b) Heat treatment sequence for high alloy cold working tool steels

ing times at hardening temperatures depends on the section thickness. Soaking time should commence from the moment the exterior of the tool is judged to have attained specified hardening temperature. Steels in the high carbon high chromium groups require longer period to obtain the desired carbide dissolution, if the steel has to attain the maximum hardness, whereas in other steels 20 minutes per inch of ruling section will suffice. For small parts or intricate shapes, the lower hardening temperature should be selected. Too high an austenitizing temperature results in a drop of hardness. After the desired soaking period, tools are quenched in oil, or salt bath and sometimes air cooled depending on the type of steels.

Table 20.1

Data sheets	ISO	IS	DIN	AISI	BS-970	NFA-35-557	GOST	JIS
20.1	T0V105	T90V2	100V1	W2	BW2	Y 105V	—	SKS43
20.2	—	118Cr2	115CrV3	L2	—	—	11ChF	—
20.3	100Cr2	T105Cr5	100Cr6	—	—	Y100Cr6	Ch	SUJ2
20.4	90MnV2	—	90MnCrV8	02	B02	90MV8	—	—
20.5	95MoCrW1	T90Mn6WCr2	100MnCrW4	01	B01	—	9CrW6	—
20.6	105WCr1	T110WCr4	105WCr6	—	—	105WC66	ChWG	SKS31
20.7	—	T140W15Cr2	—	T2	—	—	—	—
20.8	—	T105W6CrV2	110WCrV5	—	—	—	W2F	SKS2
20.9	31CrMoV1	T35Cr3	—	—	—	—	—	—
20.10	—	T50Cr4V2	51CrV4	—	—	—	—	SKT2
20.11	60SiMn2	T55Cr3V2	59CrV4	—	—	—	—	SKT2
20.12	—	T55Si7Mo3	—	S5	BS5	—	—	SUP6
20.13	45WCrV2	T40W8Cr5V2	45WCrV7	—	—	—	4ChW25	—
20.14	50WCrV2	T50W8Cr5V2	—	Si	BS1	—	—	—
20.15	60WCrV2	—	60WCrV7	—	—	55WC20	—	—
20.16	—	—	50NiCr13	—	—	—	—	—
20.17	—	—	X45NiCrMo4	—	—	40NCD16	—	—
20.18	100CrMoV5	—	X100CrMoV51	A2	DA2	Z100CDV5	—	SKD12
20.19	160CrMoV12	XT160CrMo112	S155CrVMo121	D2	BD2	Z160CDV12	—	—
20.20	210Cr12	XT210Cr12	X210Cr12	D3	BD3	Z210Cr12	Ch12	SKD12
20.21	—	XT215Cr12	—	D4	—	—	—	—
20.22	210CrW12	—	X210CrW12	—	—	—	—	—

The quenching in salt bath reduces the risk of cracking and distortion and is recommended for tools of intricate design. The salt bath temperature is maintained at around 300°C, and the tool is held at this temperature to equalize the temperature. Afterwards it is allowed to cool freely in air and then transferred to the tempering furnace.

Furnaces for Hardening Hardening may be carried out in salt bath, controlled atmosphere furnace, vacuum furnace or muffle furnace. The best result may be obtained by treating in vacuum furnace. Components treated by this method will be absolutely free from decarburization. Heat treating the tools in salt bath and under a controlled atmosphere gives good results.

Muffle furnace may used where the above said furnaces are not available. It takes a longer time, and to protect the tools against decarburization, tools should be packed in a medium which emits gas when heated, such as charcoal, coke grit or cast iron chips, etc.

Tempering Irrespective of the method of quenching used, tempering should take place before the steel has cooled around 50°C to remove the hardening stresses. If the steel is allowed to cool to room temperature before it is tempered, hardening cracks may develop. This treatment may be carried out in an oil bath, forced air circulation furnace or salt bath.

Tools treated in a salt bath should be cleaned thoroughly before tempering in forced air circulation furnace, in order to avoid corrosion. The choice of the tempering temperature is largely a matter of experience, and is dependent on the type of tool and its use. Heating to tempering temperature should be slow and uniform to prevent non-uniform hardening stresses which could cause cracking or working. Soaking should be calculated at one hour per inch of section with a minimum of 2 hours. After tempering the tools should be cooled slowly in air.

Stress Relieving Induced by Work Removal of stresses induced by work is advisable from time to time for tools in use. This occasional stress relieving is effected at about 50°C below the original tempering temperatures by prolonged heating in a water or oil bath.

Data Sheet 20.1—TCV105 (ISO)

CHARACTERISTICS

This is a water hardening steel which develops a fine-grained structure with greater ability to retain sharp edges than plain carbon steels. It is a low-cost tool steel with fair-to-good wear resistance as carbon content increases. Table 20.2 gives the chemical composition of International Standard steels.

TYPICAL APPLICATIONS

Dies for cold heading, dies for embossing and engraving, wood working and circular shear knives, cold blanking dies, stamping, drawing and forming dies, small press tools, blanking punches, shear blades, dies for cold pressing of screws and rivets, chick and vice jaws, lathe centre, straw slitting cutters.

HEAT TREATMENT

Forging	1000°C max. (Commence)
	800°C min. (Finish)

- Annealing** Heat slowly to 750–780°C, adopt lower limit for small sections and higher limit for larger sections. Holding time varies from 30 minutes to 2½ hours depending on the section thickness and size of the furnace. Subsequently cooled at a rate of 25°C per hour. After cooling to 550°C, cool in air.
Annealed hardness BHN—200–215
- Stress relieving** 600–650°C (Holding time 1 h per 25 mm of section thickness, followed by furnace cooling up to 500°C, further cooled in air).
- Hardening** Heat slowly to 750 to 850°C, lower limit of temperature for small sections and higher limit of temperature for large sections. Holding time at the hardening temperature 10 to 35 minutes depending on the cross section. Subsequently cooled in agitated water or brine. Temper immediately when cooled to hand warm.
Obtainable hardness—64–67 HRC.
- Tempering** 150–300°C (Depending on the type of component. Temper 1 h additional holding time may lower the hardness—Fig. 20.2).

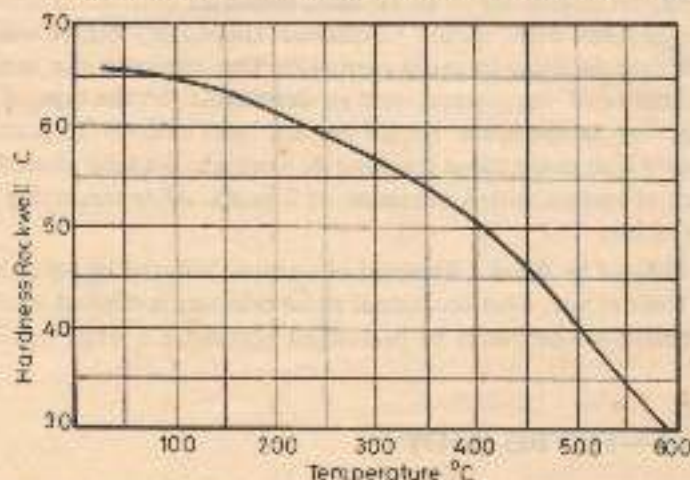


Fig. 20.2 Tempering curve of steel—ISO TCV105 (Courtesy: Roehling Stahlexport GmbH, W. Germany)

Table 20.2

Country	ISO	INDIA	DEU	USA	GBR	FRA	USSR	JPN
Standard norm	ISO 4957-80	IS 3749-78	DIN 17350-80	ASTM	BS4639-71	NFA35-590-78	GOST	JIS 4404-72
Designation	TCV105	T90V2	100V1	W2	BW2	Y.105V		SKS43
Chemical composition	C %	0.95–1.10	0.85–0.95	0.95–1.05	0.95–1.10	0.95–1.10	—	1.00–1.10
	Si %	≤ 0.35	0.10–0.30	0.15–0.25	—	≤ 0.3	0.1–0.25	≤ 0.025
	Mn	≤ 0.35	0.4 max	0.15–0.30	—	≤ 0.35	0.1–0.3	≤ 0.30
	≤ P	0.030	0.035	0.025	—	—	0.02	0.03
	≤ S	0.030	0.035	0.025	—	—	0.02	0.03
	V	0.10–0.30	0.15–0.30	0.12–0.15	0.15–0.35	0.15–0.35	0.05–0.15	0.10–0.25

Data Sheet 20.2—T118Cr2 (IS)

CHARACTERISTICS

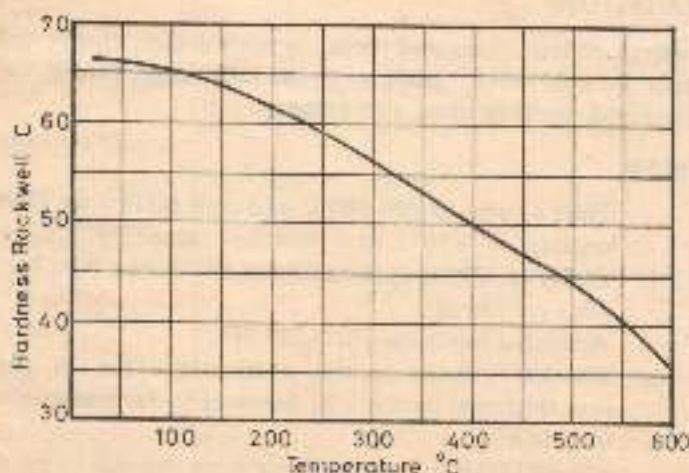
This steel will retain its cutting edge for a long time. It is very tough and easily machinable. Table 20.3 gives the chemical composition of International Standard steels.

TYPICAL APPLICATIONS

Twist drills, counter sinks, threading tools, centre drills and drifts, driving chisels, drawing mandrels, cupping tools, punches in nut manufacture, ejector in nut and bolt presses etc.

HEAT TREATMENT

Annealing	760–790°C (Soak well at this temperature for 1–1½ h depending on the section thickness, then furnace cool at a rate of 25°C per h up to 550°C and then in air) Annealed hardness—170–210°C HB.
Hardening	780–810°C (After adequate soaking time at this temperature, quench in water for 10–30 min, depending on the section thickness. Simple shapes). 800–830°C (Quench in oil. Temper immediately when cooled to hand warm. Hardness attained—RC63–65).
Tempering	100–300°C (According to the hardness required hold for 1 h per 25 mm of section thickness—Fig. 20.3).



20.3 Tempering curve of steel—IS T118Cr2 (Courtesy: Roehling Stahlexport GmbH, W. Germany)

Table 20.3

Country	ISO	INDIA	DEU	USA	GBR	FRA	USSR	JPN
Standard norm	ISO	IS 3749-78	DIN 17350-80	AISI	BS970/ 1-72	NFA35/ 551-75	GOST	JIS
Designation		T118Cr2	115CrV3	L2			11ChF	
Chemical composition	C %	—	1.10-1.25	1.10-1.25	0.50-1.10	—	—	1.05-1.15
	Si %	—	0.10-0.30	0.15-0.30	0.20-0.40	—	—	1.15-0.35
	Mn	—	0.40 max.	0.20-0.40	0.20-0.40	—	—	0.4-0.7
	P	—	—	—	—	—	—	—
	S	—	—	—	—	—	—	—
	Cr	—	0.30-0.60	0.50-0.80	1.0	—	—	0.40-0.70
	V	—	0.30 max.	0.07-0.12	0.2	—	—	0.15-0.30

Data Sheet 20.3—100Cr2 (ISO)

CHARACTERISTICS

This steel possesses high hardness and greater resistance to abrasion than equivalent plain carbon steels. This steel may be used for applications where freedom from distortion in treatment is not the primary consideration. Table 20.4 gives the chemical composition of International Standard steels.

TYPICAL APPLICATIONS

Gauges, taps, reamers, rollers, balls and races, screwing dies, ejector pins, shear blades, dies and press tools for cold work, guide ways for lathe beds, thread cutting tools, press and bending tools, wood working tools, slip gauges.

HEAT TREATMENT

Annealing Heat slowly to 790-800°C and cool rapidly to 750°C, then continue cooling to 675°C at a rate not exceeding 6°C per hour or heat slowly to 790°C cool rapidly to 690°C and hold for 16 hours, thereafter cool in air.

Annealed hardness—210-225 HB.

Stress relieving 600-650°C (Soak in this temperature for 1 h per 25 mm of section thickness (min 1 h) followed by furnace cool up to 500°C and then in air)

Hardening 820-850°C (Held at this temperature depending on the section thickness, followed by quenching in oil)

If the section thickness is greater than 25 mm, should be hardened by quenching in water or brine from 800-820°C. Hardening in water should be applied only if the tools are of simple design. Temper immediately when the tools cool to hand warm.

Tempering

Obtainable hardness—62–64 HRC.

Temper between 150 and 200°C (Holding time 1 h per 25 mm of section thickness—min 1 h (Fig. 20.4)).

Tempered hardness—62–58 HRC.

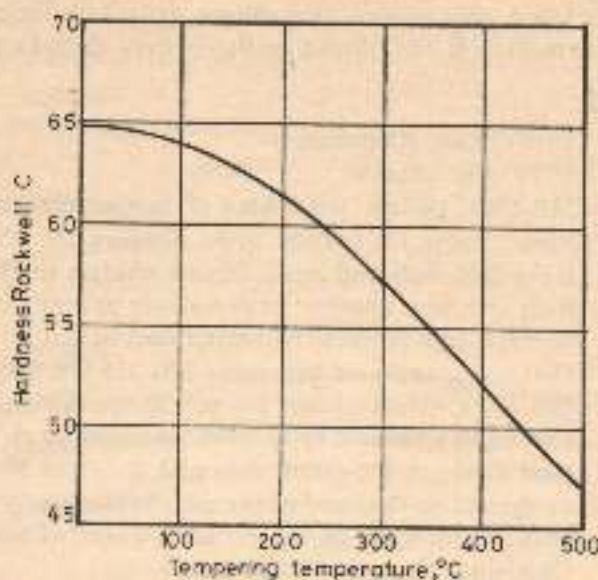


Fig. 20.4 Tempering curve of steel—ISO 100Cr2 (Courtesy: VEW, Austria)

Table 20.4

Country	ISO	INDIA	DEU	USA	GBR	FRA	USSR	JPN	
Standard norm	ISO 4957-80	IS 3749-78	DIN 17330-80	AISI	BS970/ 1-72	NFA35- 590-78	GOST	JIS G4805	
Designation	100Cr2	T105Cr5	100Cr6			Y100C6		SUJ2	
Chemical composition	C %	0.95-1.10	0.90-1.20	0.95-1.10	—	—	0.95-1.10	—	0.95-1.10
	Si %	0.10-0.40	0.10-0.35	0.15-0.35	—	—	0.15-0.35	—	0.15-0.35
	Mn	0.15-0.45	0.20-0.40	0.25-0.50	—	—	0.20-0.40	—	≤ 0.5
	P	—	—	—	—	—	—	—	—
	S	—	—	—	—	—	—	—	—
	Cr	1.35-1.65	1.10-1.60	1.35-1.65	—	—	1.35-1.60	—	1.30-1.60

Data Sheet 20.4—90MnV2 (ISO)

CHARACTERISTICS AND APPLICATIONS

This is a carbon-manganese alloyed grade oil hardening steel having good retention of cutting edges together with high dimensional stability. Excellent dimensional stability during

hardening and high resistance to wear. Table 20.5 gives the chemical composition of International Standard steels.

TYPICAL APPLICATIONS

Punches, dies, coining tools, die sinkers, hand reamers, moulds for plastics, taps, threading dies, milling cutter for wood, plug gauges, ring gauges, gauges blades, angle blocks, marking tools for mint, dies medallion dies, thread milling cutters, thread chasers.

HEAT TREATMENT

Forging	1050°C max. (Commence) 850°C min. (Finish)
Annealing	745–770°C (Adopt lower limit of temperature for smaller tools and higher range for heavier tools. Holding time varies from about 1½ h for light tools and small furnace charges to about 4 h for heavy tools and large charges cooled slowly at a rate of 20°C per hour up to 500°C in a furnace. Thereafter cool in air) Obtainable annealed hardness—190–215 HB (Fig. 20.5(a)).
Stress relieving	600–650°C (Holding time 1 h per 20 mm thickness followed by slow cooling in a furnace up to 500°C and then in air).
Hardening	Heat slowly to 770–800°C then soak for 10 to 30 minutes depending on the section thickness of the tool. Subsequently cool in oil. Temper immediately when cooled to "hand warm" (Fig. 20.5(b)) Obtainable hardness—63–65 HRC.
Tempering	100–300°C (Holding time 1 h per 20 mm thickness). Approximate tempered hardness—62–58 HRC (Fig. 20.5 (c) and (d))



annealed

× 500

Fig. 20.5(a) Annealed steel—ISO 90MnV2. The structure consists of spheroidal carbides in a matrix of ferrite



hardened

× 500

Fig. 20.5(b) Hardened steel—ISO 90MnV2. The structure consists of spheroidal carbide (white dots) in a matrix of untempered martensite



hardened and tempered

× 500

Fig. 20.5(c) Hardened and tempered steel—ISO 90MnV2. The structure consists of spheroidal carbide (white dots) in a matrix of tempered martensite

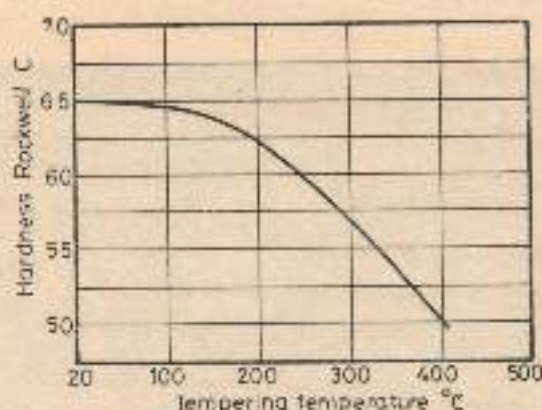


Fig. 20.5(d) Tempering curve of steel—ISO 90MnV2
(Courtesy: VEW, Austria)

Table 20.5

Country		ISO	INDIA	DEU	USA	GBR	FRA	USSR	JPN
Standard norm.		ISO 4957-80	IS	DIN 17150-80	AISI	BS4659-71	NFA35-590-78	GOST	JIS
Designation		90MnV2		90MnCrV8	02	B02	90MV8		
Chemical composition	C%	0.85-0.95	—	0.85-0.95	0.85-0.95	0.85-0.95	0.80-0.95	—	—
	Si%	0.1-0.4	—	0.10-0.40	0.20-0.40	≤ 0.40	0.10-0.40	—	—
	Mn	1.7-2.2	—	1.90-2.10	1.40-1.80	1.50-1.80	1.80-2.20	—	—
	Cr	—	—	0.20-0.50	0.35	—	—	—	—
	S	—	—	—	—	—	—	—	—
	V	0.1-0.30	—	0.05-0.15	—	≤ 0.25	0.05-0.20	—	—
	Mo	—	—	—	0.30	—	—	—	—

Data Sheet 20.5—95MnCrW1 (ISO)

CHARACTERISTICS

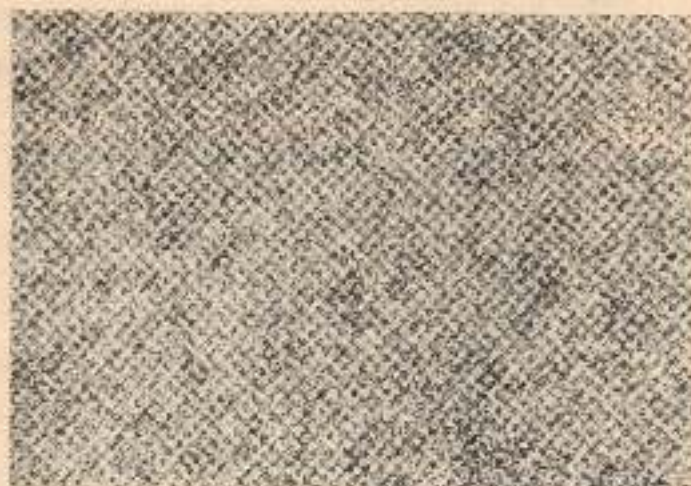
This is an oil-hardening steel with high dimensional stability during heat treatment. Possesses good toughness and wear resistance.

TYPICAL APPLICATIONS

Gauges and precision tools, taps, milling cutters, reamers and form tools, die plates and punches, shear blades, press blanking tools, cold stamping tools, engraving tool, forming dies, small moulds and inserts for plastics, beading, engraving and forming rolls, deep drawing dies, marking tools, blanking dies. Table 20.6 gives the chemical composition of International Standard steels.

HEAT TREATMENT

- Forging 1050°C max. (Commence)
850°C min. (Finish)
- Annealing Heat slowly to 760–780°C in a neutral atmosphere. Apply lower limit for smaller sections and higher limit of temperature for heavier sections. Holding time 1 hour for smaller sections and large charges about 4 hours. Cool slowly in the furnace at a rate of 20°C per hour up to 550°C, afterwards cool in air (Fig. 20.6(a)).



annealed x 500
Fig. 20.6(a) Annealed steel—ISO 95MnCrW1. The structure consists of a dispersion of spheroidal particles of carbide in a matrix of ferrite



hardened x 500
Fig. 20.6(b) Hardened steel—ISO 95MnCrW1. The structure consists of spheroidal carbide particles in a matrix of untempered martensite

- Annealed hardness—190–215 HB.
- Stress relieving** (Optional) 600–650 °C (Holding time 1 hour per 20 mm section thickness, followed by slow cooling in furnace up to 500 °C and then in air).
- Hardening** Heat slowly 780–820 °C. Adopt lower range of hardening temperature for smaller section and higher limit for heavier sections. Holding time 10 to 30 minutes; depends on the section thickness, followed by quenching in oil. Temper immediately when cooled to hand warm (Fig. 20.6(b)).
- Hardness obtained—63–65 HRC.
- Tempering** 150–300 °C (Soaking time 1 hour per 25 mm section thickness—Fig. 20.6 (c) and (d)).



hardened and tempered x 500
 Fig. 20.6(c) Hardened and tempered steel—ISO 95MnCrW1. The structure consists of spheroidal particles of carbide (white dots) in a matrix of tempered martensite.

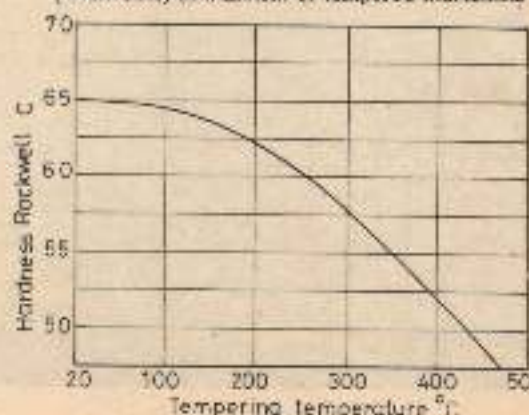


Fig. 20.6(d) Tempering diagram of steel—ISO 95MnCrW1. Time 1 h, section of specimen 20 mm (Courtesy: VEW, Austria).

Table 20.6

Country	ISO	INDIA	DEU	USA	GBR	FRA	USSR	JPN
Standard norm	ISO 4957-80	IS 3749-78	DIN 17350-80	AISI	BS4659-71	NFA35- 551-75	GOST	JIS 4404-72
Designation	95MnCrW1	T90Mn 6WCr2	100Mn CrW4	01	B01		9ChW6	SKS21
Chemical composition	C %	0.90-1.00	0.85-0.95	0.90-1.05	0.85-0.95	0.85-1.00	—	0.85-0.95 1.0-1.1
	Si %	0.10-0.40	0.10-0.35	0.15-0.35	0.20-0.40	≤ 0.40	—	0.15-0.35 ≤ 0.35
	Mn	1.05-1.35	1.25-1.75	1.0-1.20	1.0-1.30	1.10-1.35	—	0.9-1.2 ≤ 0.5
	P	—	—	—	—	—	—	—
	S	—	—	—	—	—	—	—
	Cr	0.35-0.65	0.30-0.60	0.50-0.70	0.40-0.60	0.40-0.60	—	0.5-0.8 0.2-0.5
	V	0.05-0.25	0.25 max.	0.05-0.15	≤ 0.20	≤ 0.25	—	— 0.10-0.25
	W	0.40-0.70	0.40-0.60	0.50-0.70	0.40-0.60	0.40-0.60	—	0.5-0.8 0.5-1.0

Data Sheet 20.6—105WCr1 (ISO)

CHARACTERISTICS

This is an oil hardening heavy-duty steel with a good retention of cutting edges. It is dimensionally stable during hardening and has a good wear resistance together with good toughness. Table 20.7 gives the chemical composition of International Standard steels.

TYPICAL APPLICATIONS

Blanking tools, cutting dies and punches, roller dies and polishing dies, precision end gauges, reference plug gauges, thread calliper gauges, check plugs, gauge blades, angle blocks, milling cutters, reamers, precision shaping knives, good working tools, high production threading dies and taps, small plastic moulding dies.

HEAT TREATMENT

Forging	1050°C max. (Commence) 850°C min. (Finish)
Annealing	790-810°C (Adopt lower range of temperature for small tools and upper range for large tools Holding time 1½ h for small tools and small furnaces charges to about 4 h for heavy charges of large tools. Furnace cool at a rate of 20°C per hour up to about 550°C. Thereafter air cool). Typical annealed hardness—195-215 HB.
Stress relieving	(Optional) Heat to 600-650°C, hold 1 h per 20 mm of cross section (min 1 h) cool in air.
Hardening	Heat slowly to 780-820°C, and hold for 10 to 30 min. depending on

the cross section. Followed by quench in oil or salt bath 150–180°C. Temper immediately when cooled to hand warm. Obtainable hardness—63–66 HRC.

Tempering

100–300°C (Holding time 1 h per 25 mm thickness (minimum soaking time 1 h) Temper hardness 63–58 HRC. (Fig. 20.7 illustrates the tempering graph.)

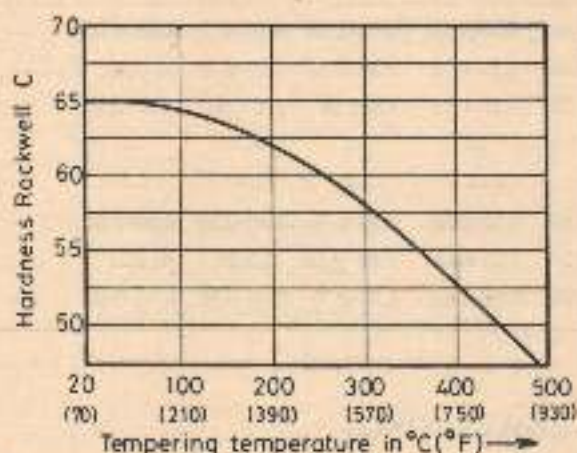


Fig. 20.7 Tempering curve of steel—ISO 105WCr1. Section of specimen 20 mm, time $\frac{1}{2}$ h (Courtesy: VEW, Austria)

Table 20.7

Country	ISO	INDIA	DEU	USA	GBR	FRA	USSR	JPN	
Standard norm	ISO 4957-80	IS 3749-78	DIN 17350-80	AISI	BS970/ 1 72	NFA35 590-78	GOST	JIS 4404-72	
Designation	105WCr1	T110WCr4	105WCr6			105WC13	ChWG	SKS31	
Chemical composition	C %	1.00-1.15	1.0-1.2	1.0-1.30	—	—	1.0-1.15	0.9-1.05	0.95-1.05
	Si %	0.10-0.40	0.10-0.35	0.10-0.40	—	—	0.10-0.40	0.15-0.35	≤ 0.35
	Mn	0.70-1.00	0.25-0.50	0.80-1.10	—	—	0.70-1.00	0.80-1.10	0.90-1.20
	P	—	—	—	—	—	—	—	—
	S	—	—	—	—	—	—	—	—
	Cr	0.80-1.10	0.90-1.30	0.90-1.10	—	—	0.80-1.10	0.9-1.2	0.8-1.20
	W	1.0-1.60	1.25-1.75	1.0-1.30	—	—	1.0-1.60	1.2-1.6	1.0-1.5

Data Sheet 20.7—T140W15Cr2 (IS)

CHARACTERISTICS

This steel may be quenched in water. It possesses high hardness and wear resistance with

high toughness. It will keep its cutting edge for a long time, and an excellent choice for tools working on hard material with low cutting speeds. Table 20.8 gives the chemical composition of International Standard steels.

APPLICATIONS

Precision tools for engineering industry, cold heading tools, punches and dies, scraping tools, shaper tools and form cutters, relieving tools for lathes.

HEAT TREATMENT

Annealing	Heat to 810–840°C. Use lower limit for small sections, upper limit for large sections. Holding time 2–4 h depending on the cross section. Followed by slow cooling at a rate of 20°C per h. Typical annealed hardness 200–280 HB.
Stress relieving	Heat to 600–650°C and hold for 1 h per 20 mm section thickness followed by furnace cooling up to 500°C, thereafter in air.
Hardening	Heat slowly to 800–820°C, hold for 10–50 min, depending on the section thickness. Followed by quenching in water. Temper immediately when cooled to “hand warm”. Obtainable hardness 65–67 HRC.
Tempering	100–200°C, depending on the hardness required. Holding time 1 h per 20 mm section thickness.

Table 20.8

Country	ISO	INDIA	DEU	USA	GBR	FRA	USSR	IPN
Standard norm	ISO	IS 3479-78	DIN	AISI	BS970/ 1-72	NFA35- 551-75	GOST	JIS
Designation		T140W15Cr2		F2				
Chemical composition	C %	1.30–1.50	—	1.20–1.40	—	—	—	—
	Si %	0.10–0.35	—	≤ 0.50	—	—	—	—
	Mn	0.25–0.50	—	≤ 0.50	—	—	—	—
	P	—	—	—	—	—	—	—
	S	—	—	—	—	—	—	—
	Cr	0.20–0.70	—	0.20–0.40	—	—	—	—
	W	3.50–4.20	—	3.0–4.50	—	—	—	—

Data Sheet 20.8—T105W6CrV2 (IS)

CHARACTERISTICS

This steel possesses very good retention of cutting edges and high resistance to wear. Table 20.9 gives the chemical composition of International Standard steels.

TYPICAL APPLICATIONS

Blades and knives for cutting paper, circular and shear blades, wood working tools such

as planing, wood milling cutters turning and milling. Files, profile cutters and forming tools for brass, plastic, etc.

HEAT TREATMENT

Annealing	700–740°C, soak for 4–8 h at the recommended temperature, then cool slowly in the furnace. Annealed hardness—250 BHN max.
Stress relieving	650–670°C. Soak for 1 h per 25 mm of cross section, followed by furnace cooling up to 500°C, thereafter in air.
Hardening	Heat slowly to 800–840°C, hold at that temperature for 10 to 50 min., depending on the cross section. Followed by quenching in oil or 780–800°C, followed by quenching in water. Temper immediately when cooled to hand warm. Obtainable hardness—63–65 HRC.
Tempering	150–250°C (Depending on the hardness).

Table 20.9

Country	ISO	INDIA	DEU	USA	GBR	FRA	USSR	JPN
Standard norm	ISO	IS 3749-78	DIN 17350-80	ASTM	BS970/ 1-72	NFA35- 551-75	GOST	JIS 4404-72
Designation		T105W6CrV2	110WCrV5					SKS2
Chemical composition	C%	— 0.90–1.20	1.05–1.15	—	—	—	—	1.0–1.10
	Si%	— 0.10–0.35	0.15–0.30	—	—	—	—	≤ 0.35
	Mn	— 0.40 max.	0.20–0.40	—	—	—	—	≤ 0.8
	P	—	—	—	—	—	—	—
	S	—	—	—	—	—	—	—
	Cr	— 0.40–0.80	1.10–1.30	—	—	—	—	0.50–1.00
	W	— 1.25–1.75	1.20–1.40	—	—	—	—	1.0–1.50
	V	— 0.20–0.30	0.15–0.25	—	—	—	—	≤ 0.20

Data Sheet 20.9—51CrMnV1 (ISO)

CHARACTERISTICS AND TYPICAL APPLICATIONS

This is tough wear resistant steel, may be used for the manufacture of plastic moulds, injection moulds, collets, springs, jaws, etc. This is also used for the manufacturing of carbide tipped monoblock rock drills as well as drill rods for use of removable carbide tipped bits. Table 20.10 gives the chemical composition of International Standard steels.

HEAT TREATMENT

1. Annealing Heat slowly to 760°C followed by rapid cooling to 650°C and hold for 10 h.

2. Heat slowly to 760°C followed by slow cooling to 675°C at a rate of 5–6°C per h. Thereafter cool in air. Annealed BHN 190–210.
- Stress relieving** 600–650°C, hold at that temperature 1 h per 25 mm of section thickness followed by air cooling.
- Hardening** Heat slowly to 850–870°C. Hold at that temperature for 10 to 30 min. followed by quenching in oil. Temper immediately when cooled to hand warm.
- Obtainable hardness—59–62 HRC
- Tempering** 400–600°C depending on the hardness required. Holding time 1 h per 25 mm of section thickness (Fig. 20.8).

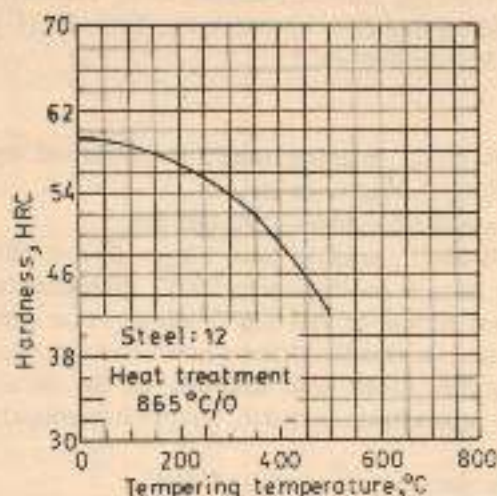


Fig. 20.8 Tempering curve of steel—ISO 51CrMnV1

Table 20.10

Country	ISO	INDIA	DEU	USA	GBR	FRA	USSR	IPN
Standard norm	ISO 4057-80	IS 3749-78	DIN 17350-80	AISI	BS970/ 1-72	NFA35 551-75	GOST	JIS 4404-72
Designation	51CrMnV1	T50Cr4V2	51CrV4					SKT 2
Chemical composition	C %	0.48-0.55	0.45-0.55	—	—	—	—	0.5-0.6
	Si %	0.1-0.4	0.4	0.15-0.35	—	—	—	0.35
	Mn	0.7-1.0	0.5-0.8	0.8-1.10	—	—	—	0.8-1.20
	≤ P	0.03	0.03	0.03	—	—	—	0.03
	≤ S	0.03	0.03	0.03	—	—	—	0.03
	Cr	0.9-1.2	0.9-1.2	0.9-1.2	—	—	—	0.8-1.2
	V	0.05-0.25	0.15-0.30	0.07-0.12	—	—	—	≤ 0.2

Data Sheet 20.10—T55Cr3V2 (IS)**CHARACTERISTICS**

Special high grade vanadium alloy steel possesses a greater depth of hardening than that of ordinary carbon tool steels for water hardening.

TYPICAL APPLICATIONS

Deep drawing tools, pneumatic pistons, measuring instruments (gauges, callipers, etc.) chisels and other wood working tools, cutting tools such as large milling cutters, thread cutters, embossing tools, small shearing blades, blanking tools, numbering stamps and lettering stamps, drift punches, cold forging dies, upsetters, etc. Table 20.11 gives the chemical composition of International Standard steels.

HEAT TREATMENT

Annealing	700–720°C, holding time 3–5 h followed by furnace cooling up to 550°C, thereafter in air. Annealed hardness—190–200 HB.
Stress relieving	600–650°C, holding time 1 h per 20 mm of cross section. Followed by furnace cooling up to 550°C, thereafter in air.
Hardening	Heat slowly to 780–820°C, adopt lower range of hardening temperature for smaller sections and higher limit for heavier sections. Holding time 10–40 min, depends on the section thickness. Followed by quenching in water, temper immediately when cooled to hand warm. Hardness attained—64–65 HRC.
Tempering	150–300°C, soaking time 1 h per 25 mm of cross section.

Table 20.11

Country	ISO	INDIA	DEU	USA	GBR	FRA	USSR	JPN
Standard norm	ISO	IS 3749-78	DIN STAL-86	ASTM	BS970/ 1-72	NFA35- 551-75	GOST	JIS 4404-72
Designation		T55Cr3V2	59CrV4					SKT 2
Chemical composition	C %	—	0.5–0.6	0.55–0.62	—	—	—	0.5–0.6
	Si %	—	—	0.15–0.35	—	—	—	≤ 0.035
	Mn	—	0.6–0.8	0.8–1.10	—	—	—	0.8–1.20
	≤ P	—	0.03	0.035	—	—	—	0.03
	≤ S	—	0.035	0.035	—	—	—	0.03
	Cr	—	0.6–0.8	0.9–1.20	—	—	—	0.8–1.20
	V	—	0.1–0.2	0.07–0.12	—	—	—	≤ 0.2

Data Sheet 20.11—60SiMn2 (ISO)

CHARACTERISTICS

Silicon-Manganese steel used for all types of ancillary tools. Hollow boring bars for high speed pneumatic and high efficient air or scoving hammer tools for coal mines and stone working. Table 20.12 gives the chemical composition of International Standard steels.

TYPICAL APPLICATIONS

Spring collets, clamping jaws, screw drivers, pressure plates, mounting supports, shrink liners, etc.

HEAT TREATMENT

Normalizing	840–860°C, air cooled.
Annealing	Heat slowly 700–730°C, in a neutral atmosphere. Hold in that temperature for at least 4 h and slow furnace cooling. Annealed hardness—220 BHN
Stress relieving	650–670°C, furnace cooled up to 500°C, thereafter in air.
Hardening	Heat slowly to 840–880°C. Soaking time 10–45 min. at this temperature depending on the section thickness, followed by quenching in oil. Temper immediately as soon as tools attain hand warmth. Hardness attained—56–57 HRC
Tempering	150–350°C, holding time 1 h per 20 mm of cross section (Fig. 20.9).

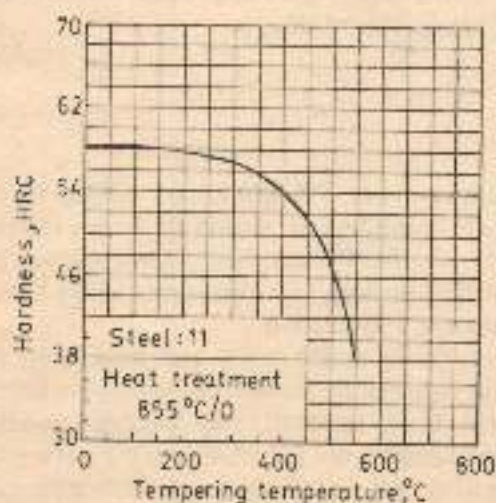


Fig. 20.9 Tempering curve of steel—ISO 60SiMn2

Table 20.12

Country	ISO	INDIA	DEU	USA	GBR	FRA	USSR	JPN
Standard norm	ISO 4957-80	IS 1749-78	DIN	AISI	BS970/ 1-72	NFA35- 551-75	GOST	JIS 4801-67
Designation	60SiMn2	T55Si7						SUP 6
Chemical composition	C %	0.52-0.60	0.5-0.6	—	—	—	—	0.55-0.65
	Si %	1.5-2.0	1.5-2.0	—	—	—	—	1.5-1.8
	Mn	0.6-0.9	0.8-1.0	—	—	—	—	0.7-1.0
	P	0.03	0.03	—	—	—	—	0.035
	S	0.03	0.03	—	—	—	—	0.035

Data Sheet 20.12—T55Si7Mo3 (IS)

CHARACTERISTICS

This is a water hardening shock resistant steel with a wide hardening temperature range. It possesses extreme toughness combined with high hardness and wear resistance. Table 20.13 gives the chemical composition of International Standard steels.

TYPICAL APPLICATIONS

Air hammer tools, caulking tools, chisels for hand and pneumatic, heavy duty punches, air hammer tools, piercing dies, swaging dies and tools, shear blades, slitting cutters, rivet shaps, boiler makers and blacksmith's tools.

HEAT TREATMENT

Annealing	Heat slowly at 790-820°C and hold in that temperature for 1 to 4 hours depending on section thickness, followed by slow cooling at a rate of 10-14°C per hour. Choose lower range of temperature for smaller sections and higher for heavy sections. Typical annealed hardness 190-225 HB.
Stress relieving	Heat slowly to 600-650°C and hold in for 1 hour per 20 mm thickness followed by furnace cooling up to 500°C, thereafter in air.
Hardening	Heat slowly to 650°C, then increase rapidly to 840-900°C. Hold in that temperature for 15 min. to 50 minutes depending on the cross-section, then quench in water. Distortion may be reduced in small sections by oil quenching from 900-920°C. When cooled to hand warmth temper immediately. Asquenched hardness—60-63 HRC.
Tempering	150-230°C, where maximum toughness is required temper within the range 300-480°C (Fig. 20.10).

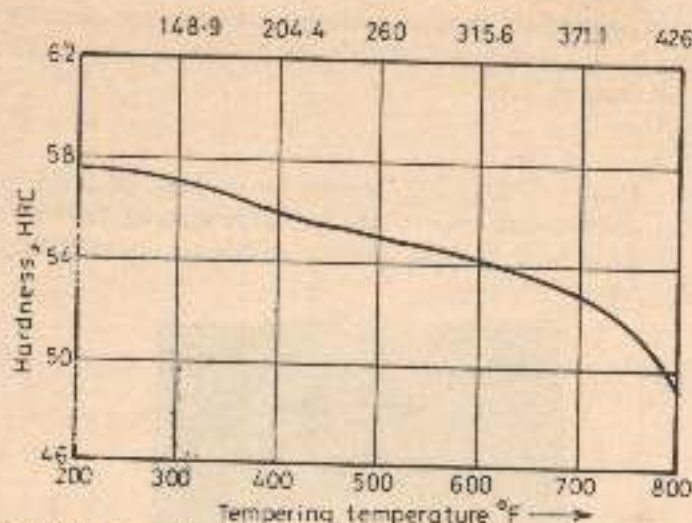


Fig. 20.10 Tempering curve of steel—IS T55Si7Mo3 quenched from 900°C/oil

Table 20.13

Country		ISO	INDIA	DEU	USA	GBR	FR	USSR	JPN
Standard norm		ISO	IS 3749-78	DIN	AISI	BS4659-71	NFA35-551-75	GOST	JIS
Designation			T55Si7Mo3		S5	BS5			
Chemical composition	C%	—	0.50-0.60	—	0.50-0.60	0.50-0.60	—	—	—
	Si%	—	1.50-2.00	—	1.80-2.20	1.60-2.10	—	—	—
	Mn	—	0.80-1.00	—	0.60-0.80	0.50-0.80	—	—	—
	P	—	—	—	—	—	—	—	—
	S	—	—	—	—	—	—	—	—
	Mo	—	0.25-0.40	—	0.30-0.50	0.30-0.60	—	—	—
	V	—	0.12-0.20 (OPT)	—	0.25	0.10-0.30	—	—	—

Data Sheet 20.13—45WCrV2 (ISO)

CHARACTERISTICS

This is a Cr-W-Si water hardening shock-resisting steel. This is a tough and hard steel of high compressive strength and wear resistance. This steel is suitable for continuous loading and for work at high temperatures. Table 20.14 gives the chemical composition of International Standard steels.

TYPICAL APPLICATIONS

Cold shear for large and heavy sections under heavy cutting loads, pneumatic tools such as

chisels, rivet heads, driving chisels, bending tools, piercing dies and piercing punches, cold and hot dressing chisels, wood choppers, etc. Figure 20.11(a) illustrates the application of steel 45WCrV2 for blanking die, etc.

HEAT TREATMENT

Annealing

Heat to 720–760°C. Apply lower limit of temperature for small sections and upper limit for large sections. Soaking time at least 4 h followed by slow cooling in furnace up to 600°C, air cooling to follow.

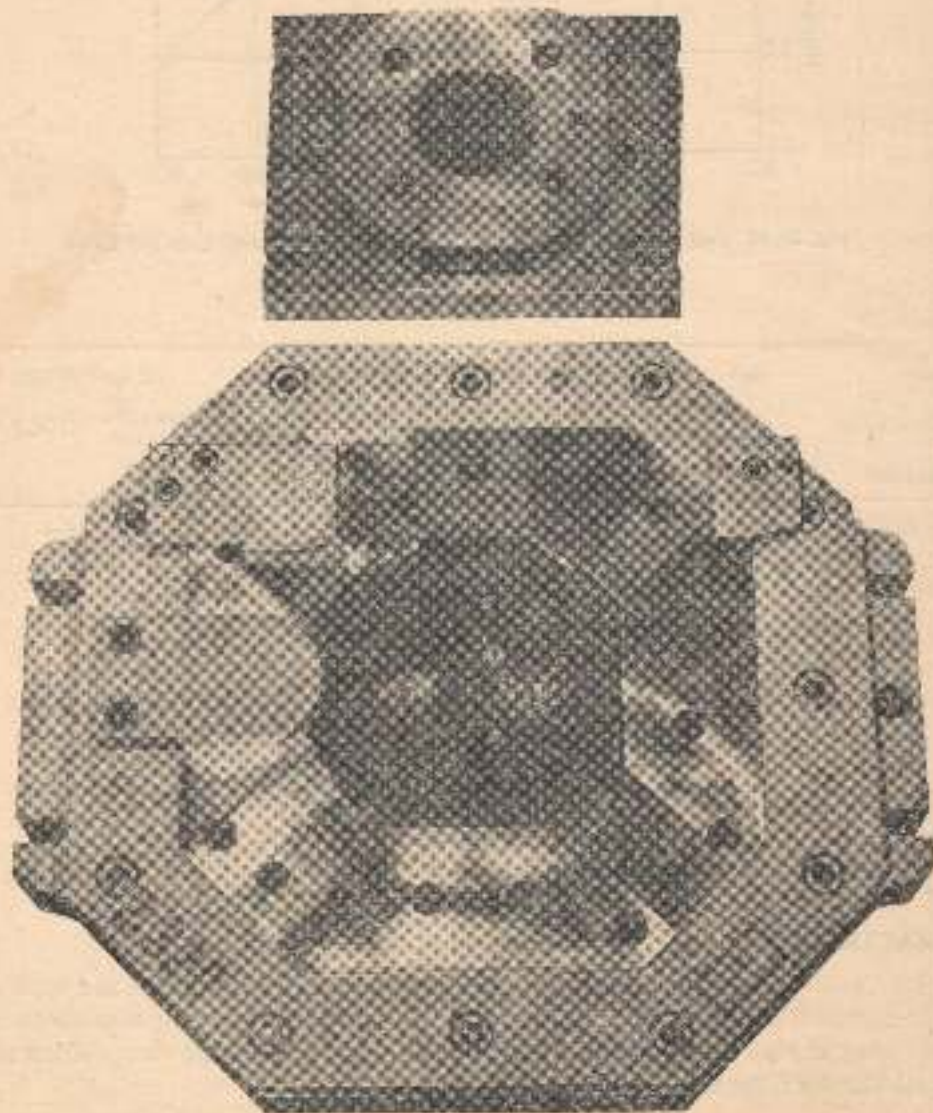


Fig. 20.11(a) Blanking die for dished tractor wheel blanks made of steel—ISO 45WCrV2
(Courtesy: VEW, Austria)

- Stress relieving Annealed hardness—190–220 HB.
Heat slowly to 600–650°C and hold 1 h per 20 mm thickness, followed by furnace cooling up to 500°C, thereafter in air.
- Hardening Heat slowly to 880–920°C. Holding time depends on the section thickness (5–50 min.) followed by quenching in water, when cooled to hand warmth temper immediately.
Asquenched hardness—52–53 HRC.
- Tempering 150–400°C. Holding time 1 h per 20 mm thickness (Fig. 20.11(b)).

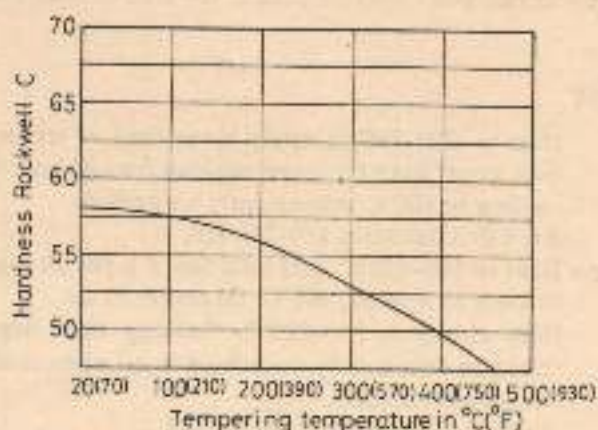


Fig. 20.11(b) Tempering curve of steel—ISO 45WCrV2

Table 20.14

Country	ISO	INDIA	DEU	USA	GBR	USSR	JPN
Standard norm	ISO 4957-80	IS 3749-78	DIN 17350-80	AISI	BS4659-71	GOST	JIS
Designation	45WCrV2	T40W8Cr5V2	45WCrV7		B81	4ChW25	
Chemical composition	C %	0.40–0.50	0.35–0.45	0.40–0.50	—	0.45–0.55	0.35–0.45
	Si %	0.80–1.10	0.50–1.00	0.80–1.10	—	0.7–1.0	0.6–0.9
	Mn	0.15–0.45	0.20–0.40	0.20–0.40	—	0.3–0.7	0.15–0.40
	Cr	0.90–1.20	1.0–1.5	0.90–1.20	—	1.2–1.7	1.0–1.3
	V	0.10–0.30	0.10–0.25	0.15–0.20	—	0.1–0.3	—
	W	1.70–2.30	1.75–2.25	1.80–2.10	—	2.0–2.5	2.0–2.25

Data Sheet 20.14—50WCrV2 (ISO)

CHARACTERISTICS

This is a shock resisting steel. It possesses high fatigue strength and a good abrasion resistance with a high degree of safety in hardening. Table 20.15 gives the chemical composition of International Standard steels.

APPLICATIONS

Pneumatic hammers, all kinds of chisels and caulking tools, rivet snaps, and flanging tools, heavy punches and tough blanking dies, high performance of shear blades, wood work knives, such as barking blades, cutters, and other tools for wood and leather working where toughness is essential.

Hot work tools which must have resistance to repeated temperature changes, tools such as hot piercing mandrels, hot blanking dies, upsetting tools, trimming tools, shear blades, water cooled mandrels in rod and extrusion presses for zinc or lead alloys.

HEAT TREATMENT

Annealing	Heat to 720–760°C. Apply lower limit of temperature for small section, upper limit for large; soaking time at least 4 h followed by slow cooling to 600°C subsequently air cooled. Annealed hardness 190–230 HB.
Stress relieving	Heat to 600–650°C and hold for 1 h per 20 mm thickness. Cool in furnace to approx. 500°C, thereafter in air.
Hardening	Heat slowly to 890–920°C. Soaking time, depends on the section thickness followed by quenching in oil when cooled to hand warmth, temper immediately. Hardness obtainable—55–59 HRC.
Tempering	150–400°C, depending on the required hardness, soaking time 1 h per 20 mm thickness. Temper twice. Figure 20.12 illustrates the tempering graph.

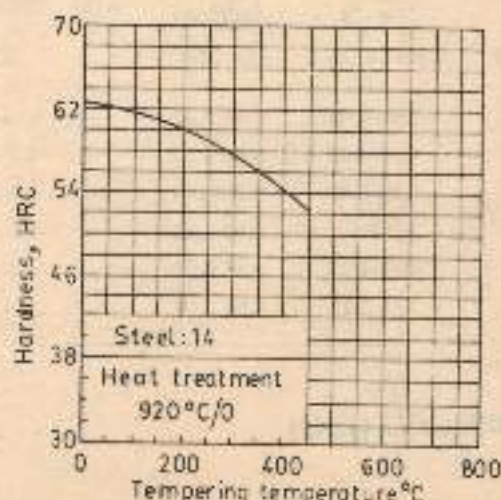


Fig. 20.12 Tempering curve of steel—ISO 50WCrV2

Table 20.15

Country	ISO	INDIA	DEU	USA	GBR	FRA	USSR	JPN
Standard norm	ISO 4957-80	IS 3749-78	DIN	AISI	BS4639-71	NFAS-551-75	GOST	JIS
Designation	50WCrV2	T50W8Cr5V2	S1	BS1				
Chemical composition								
C%	0.45-0.55	0.45-0.55	—	0.45-0.55	0.45-0.55	—	—	—
Si%	0.8-1.0	0.5-1.0	—	0.2-0.4	0.7-1.0	—	—	—
Mn	0.35-0.65	0.2-0.4	—	0.2-0.4	0.3-0.7	—	—	—
P	0.03	—	—	0.03	0.03	—	—	—
S	0.03	—	—	0.03	0.03	—	—	—
Cr	1.3-1.6	1.0-1.5	—	1.25-1.75	1.2-1.7	—	—	—
V	0.1-0.3	0.1-0.25	—	0.15-0.30	0.1-0.3	—	—	—
W	1.7-2.3	1.75-2.25	—	1.00-3.00	1.00-2.50	—	—	—

Data Sheet 20.15—60WCrV2 (ISO)

CHARACTERISTICS AND TYPICAL APPLICATIONS

This is an oil hardening tool steel with high toughness and wear resistance. Table 20.16 gives the chemical composition of International Standard steels.

Cutting tools for plates, punches for cold piercing rails and plates, rivet hammers, hand chisels, tools for pneumatics hammers, drift punches, wood working tools such as chipper knives, wood peeling knives moulding, rebaring, tonguing and grooving irons, high duty moulding cutters such as bevelled milling cutters, button cutters and gullet cutters, slot cutters, teeth for chain saws, etc. Figure 20.13(a) illustrates the applications of 60WCrV2 for blanking tools for fork manufacture.

HOT WORKING AND HEAT TREATMENT

Forging	1050°C max. (Commence) 850°C min. (Finish)
Annealing	720-750°C, 4 h. of soaking followed by furnace cooling. Annealed hardness—230 BHN.
Stress relieving	650°C, soaking time minimum 2 h., followed by furnace cooling.
Hardening	Heat slowly to 880-910°C followed quenching in oil. Temper immediately when cooled to hand warm. Obtainable hardness—59-60 HRC.
Tempering	150-300°C, holding time 1 h per 25 mm thickness (Fig. 20.13(b)).

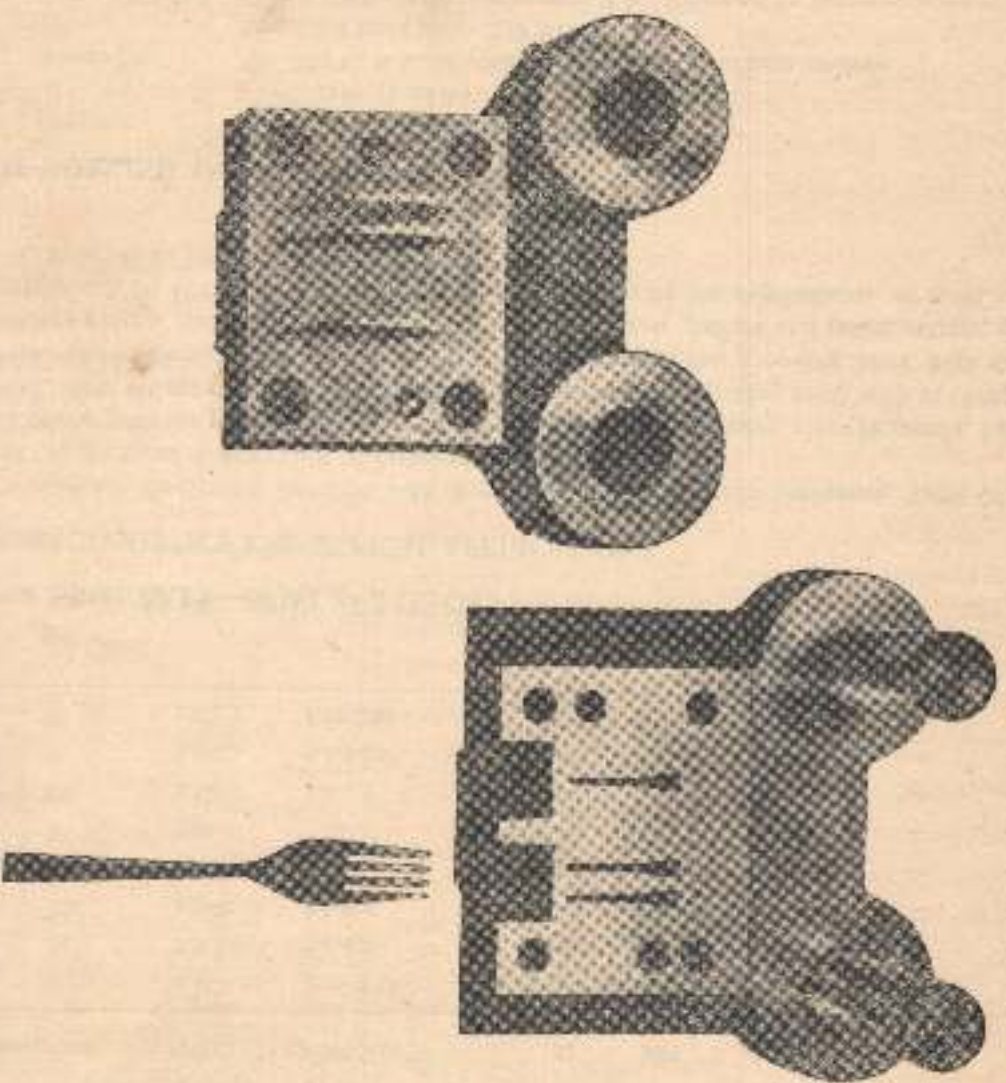


Fig. 20.13(a) Blanking tool for fork manufacture made of steel—ISO 60WCrV2 (Courtesy: VEW, Austria)

shear blades. Dies for the manufacture of spoons and forks, master hubs, Figure 20.14(a), illustrates the application of 50NiCr13 for coin stamping tool.

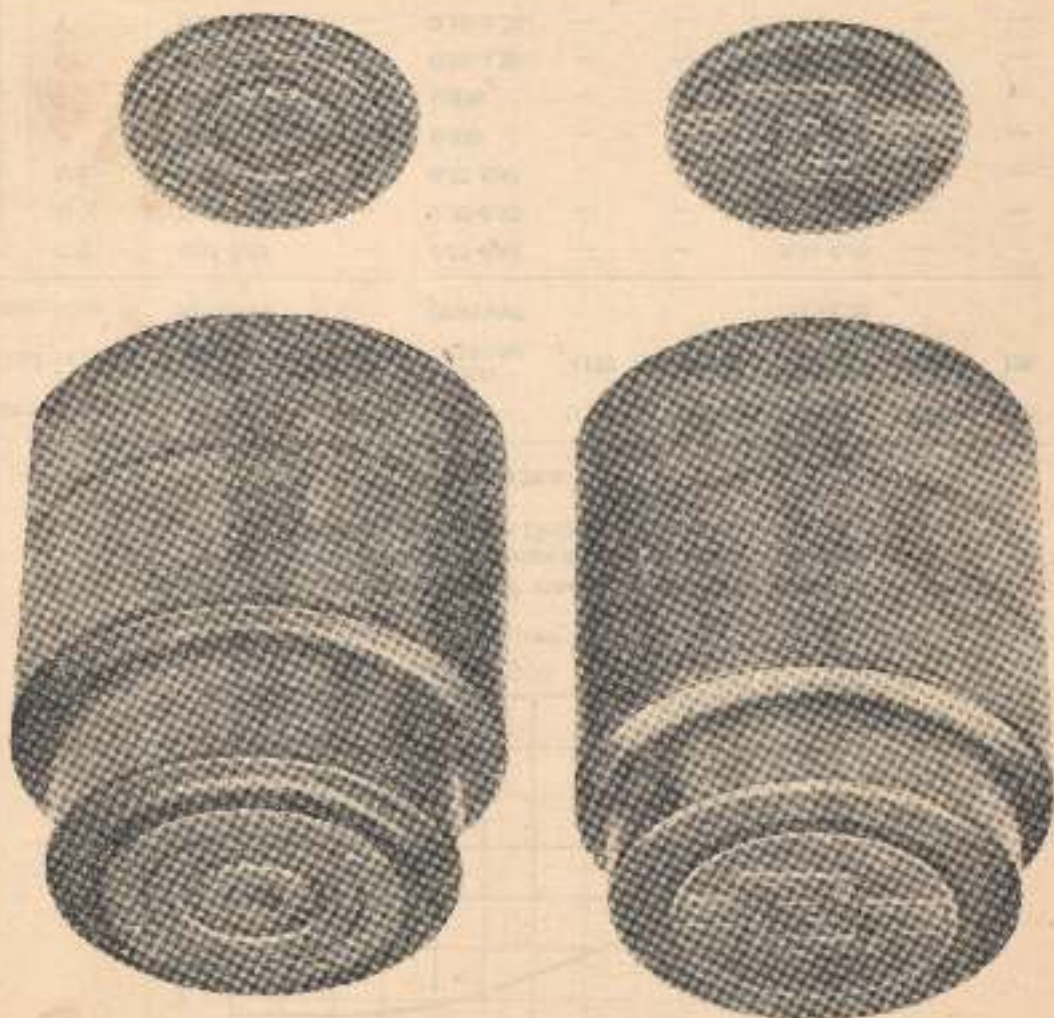


Fig. 20.14(a) Coin-stamping tool made from steel—DIN 50NiCr13 (Courtesy: VEW, Austria)

HEAT TREATMENT

Forging

1050°C max. (Start)
850°C min. (Finish)

Annealing

670–690°C (4–5 h) furnace cooling.
Annealed hardness—210 BHN

Stress relieving

650°C, cool in the furnace up to 500°C, thereafter in air.

Hardening

Heat slowly to 840–870°C and hold for sufficient time, subsequently quenched in oil, salt bath or air depending on the type of tool. When cooled to hand warmth temper immediately.

Obtainable hardness—56–59, RC.

Tempering

Temper between 180 and 240°C, holding time 1 h per 25 mm thickness (Fig. 20.14(b)).

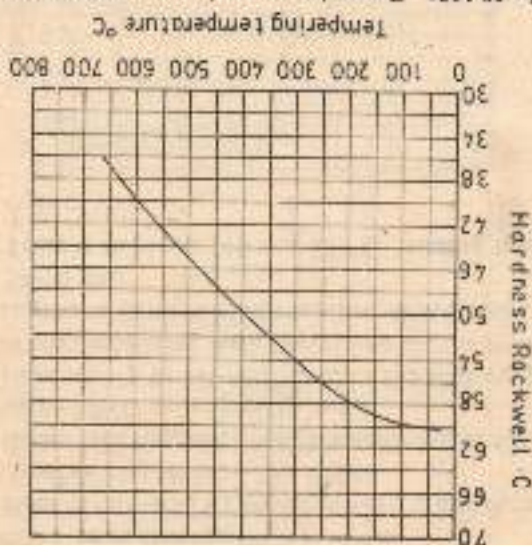


Fig. 20.14(b) Tempering curve of steel-DIN 50NiCr13
(time: 1 h air-cooled) quenched from
850°C/oil. Specimen diameter = 1 × 2 in.

Table 20.17

Country	ISO	INDIA	DEU	USA	GBR	FRA	USSR	JPN
Standard norm	ISO	IS	STAL-86	DIN	BS970	NFA35-551-75	GOST	JIS
Designation			50NiCr13					
Chemical composition								
C%	—	—	—	0.45-0.55	—	—	—	—
Si%	—	—	—	0.15-0.35	—	—	—	—
Mn	—	—	—	0.40-0.60	—	—	—	—
P	—	—	—	0.035	—	—	—	—
S	—	—	—	0.035	—	—	—	—
Cr	—	—	—	0.50-1.20	—	—	—	—
Ni	—	—	—	3.0-3.50	—	—	—	—

Data Sheet 20.17—X45NiCrMo4 (DIN)

CHARACTERISTICS AND TYPICAL APPLICATIONS

Air hardening steel with a high degree of toughness and resistance to shock. Table 20.18 gives the chemical composition of International Standard steels.
Dies for blanking cutlery, coining, stamping and embossing tools for high stress. Bend-
ing tools for high stress shear blades for very large cross section, etc.

HEAT TREATMENT

- Forging** 1050°C max. (Commence)
850°C min. (Finish)
Heat to 610–650°C, soak for 8–10 h and furnace cooled.
Annealed hardness—260 BHN.
Stress relieving after rough machining at 650°C. Cool in the furnace up to 550°C subsequently in air.
Heat slowly to 840–870°C, after the soaking period, cooled in oil, air or martempering bath depending on the type of components. When cooled to hand warmth temper immediately. Obtainable hardness—54–56 RC.
- Hardening** Temper between 180 and 250°C holding time 1 h/25 mm thickness (Fig. 20.15).
- Tempering**

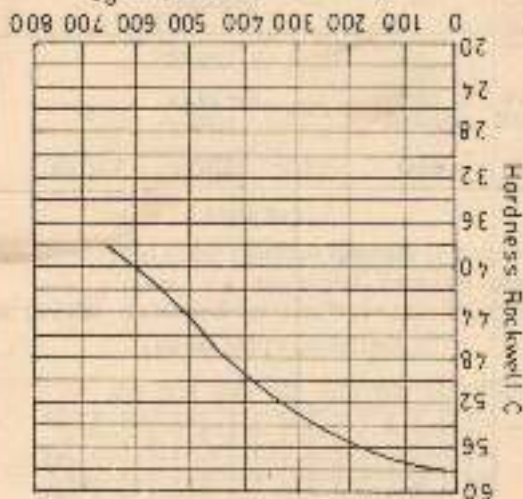


Fig. 20.15 Tempering curve of steel—DIN X45NiCrMo4
(time: 1 h, air-cooled) quenched from 850°C/
oil. Specimen diameter = 1 × 2 in.

Table 20.18

Country	ISO	INDIA	DEU	USA	GBR	FRA	USSR	JPN
Standard norm	ISO	IS	DIN	AISI	BS970	NFA35	GOST	JIS
Designation			X45NiCrMo4		1-72	40NCD16		
C%	—	—	0.40-0.50	—	—	0.35-0.43	—	—
Si%	—	—	0.1-0.40	—	—	0.1-0.4	—	—
Mn	—	—	0.13-0.45	—	—	0.30-0.60	—	—
P	—	—	0.03	—	—	0.025	—	—
S	—	—	0.02	—	—	0.025	—	—
Cr	—	—	1.20-1.50	—	—	1.6-2.0	—	—
Mo	—	—	0.15-0.35	—	—	0.3-0.5	—	—
Ni	—	—	3.8-4.3	—	—	3.7-4.2	—	—

CHARACTERISTICS

This is an air hardening heavy duty steel having high resistance to wear, and maximum dimensional stability during heat treatment. The higher hardness results in very little distortion to give a combination of good resistance to abrasions and relatively high toughness. Its high abrasion resistance after hardening results in generation of excessive heat during grinding unless special precautions are taken. Table 20.19 gives the chemical composition of International Standard steels.

TYPICAL APPLICATIONS

Brick mould liners, cold forging dies, extrusion plungers (cold), forming tools (cold press-sing), shear blades (cold light shock), cold forming dies, wire drawing grips, small moulds, drawing punches, paper and rubber cutting knives, knurling tools, engraving tool, thread rolling dies, guide pins, circular shear blades, cold heading dies, coining dies.

HEAT TREATMENT

Forging

1000°C max. (Commence)

850°C min. (Finish)

Annealing

Heat slowly to 840–870°C. After reaching the temperature throughout cross-section, cool slowly at a rate of 20°C per hour until 550°C and subsequently cooled in air.

Annealed hardness 200–225 HB.

Stress relieving

650–670°C, hold at that temperature for 1 h per 20 mm thickness followed by furnace cooling to 500°C, thereafter in air.

Hardening

Heat slowly to 925–980°C in a neutral atmosphere. Hold in that temperature for 20 min. for small tool and 50 min. for large tools.

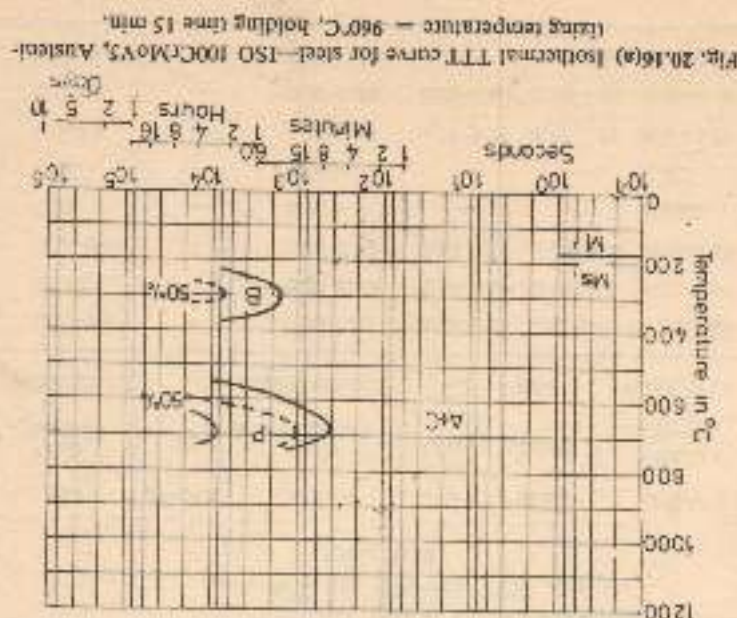


Fig. 20.16(a) Isothermal TTT curve for steel—ISO 100CrMoV5, Austenitizing temperature = 960°C, holding time 15 min.

Adopt lower limit temperature for small tools and higher limit for larger sections. Subsequently cooled in air or oil or salt bath (350-400°C). Temper immediately when cooled to hand warmth. Obtainable hardness 63-65 HRC. Figure 20.16 (a) illustrates the isothermal time-temperature-transformation curve.

Tempering 180-250°C, hold in that temperature for at least 1 h and allow 1 h for every 20 mm thickness (Fig. 20.16(b)).

PROCESSING SEQUENCE

X100CrMoV51(A2) → Rough machine → Stress relieve → Final machining
650-670°C
Grinding → Tempering → Quenching → Austenitizing → Final preheating → Preheating
180-250°C 500-520°C 920-980°C 850-870°C 400-650°C

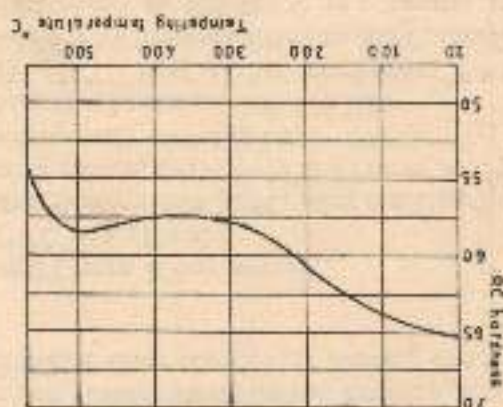


Fig. 20.16(b) Tempering curve for steel—180 100CrMoV5. Hardening temperature = 970°C/oil, time = 1 h. Specimen size = 20 mm (Courtesy: VEW, Austria)

Table 20.19

Country	ISO	INDIA	DEU	USA	GBR	FRA	USSR	JPN
Standard norm	ISO 4957-80	IS	DIN Stahlschussel-86	ASTM A54659-71	NFA35-590-78	GOST G4402-72		
Designation	100CrMoV5	X100CrMoV51	A2	BA2	Z100CrV5	SKD12		
Chemical composition								
C	0.95-1.05	—	0.90-1.05	0.95-1.05	0.90-1.05	—	0.95-1.05	—
Si	0.1-0.4	—	0.20-0.40	0.20-0.40	0.40	—	0.10-0.40	—
Mn	0.35-0.65	—	0.40-0.70	0.45-0.75	0.30-0.70	—	0.50-0.80	—
P	0.03	—	0.035	—	—	—	0.025	—
S	0.03	—	0.035	—	—	—	0.025	—
Cr	4.5-5.5	—	4.80-5.50	4.75-5.55	4.80-5.50	—	4.50-5.50	—
Mo	0.9-1.4	—	0.90-1.40	0.90-1.40	0.90-1.40	—	0.80-1.20	—
V	0.25-0.45	—	0.15-0.30	0.40	0.15-0.40	—	0.20-0.50	—

Data Sheet 20.19—160CrMoV12 (ISO)

CHARACTERISTICS

This is a high chrome alloy steel with or without vanadium and molybdenum. This steel has maximum dimensional stability during heat treatment, possesses high hardness, and great wear resistance. This steel is hardenable to a greater depth than D3(AISI). Compared to D3 this steel has a greater toughness and shock resistance at the expense of a small loss

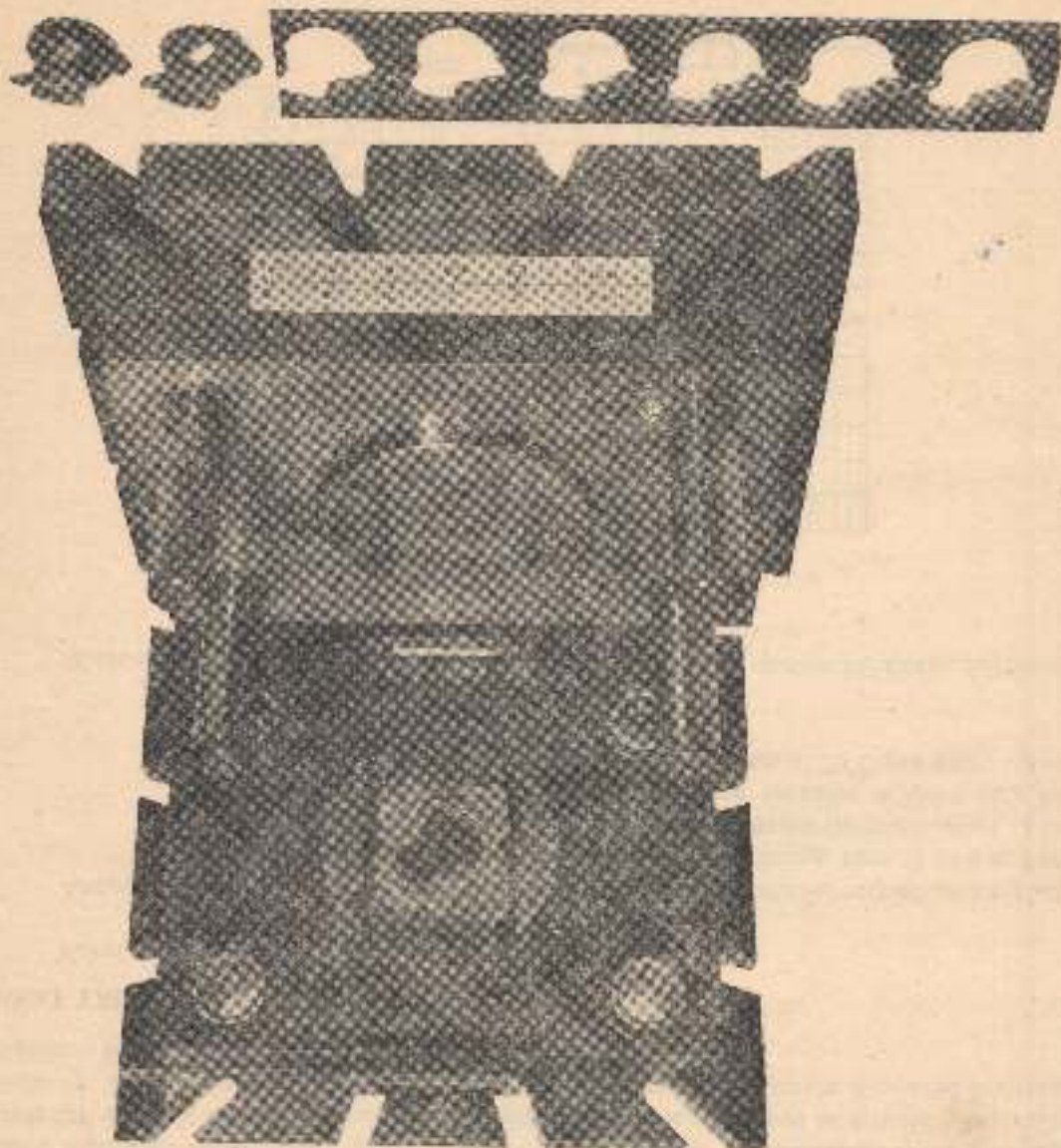


Fig. 20.17(a) A press tool that produces line blanked parts for automobile leeks. The punch and die are made from Uddeholm SFRKER 2 high carbon, high-chromium tool steel at 50-60 HRC (Courtesy: Uddeholm Steel, Sweden)

in hardness. Tools made from D2 will also take a finer edge than those made from D3, hence its use for flying shear blades, fullitine blades, etc. Compared to steel D3 it possesses a lower wear resistance. Table 20.20 gives the chemical composition of International Standard steels.

TYPICAL APPLICATIONS (D3)

Fine pressed tools, master tools, high duty cutting tools, high speed wood working tools, shear blades for cutting light gauge material. Drawing and cold extrusion tools, pressing tools for ceramic and pharmaceutical industries, small moulds and inserts for the plastic industry. Thread rolling dies, slitting cutters, hobbing and lamination dies, cold drawing punches. Figure 20.17(a) illustrates the application of D2 steel.

HEAT TREATMENT

Forging

1100°C max. (Commence)
900°C min. (Finish)

Annealing

Heat to 870–900°C, adopt lower limit for smaller section and higher range of temperature for heavier jobs. Holding time $\frac{1}{2}$ to 6 h. For higher sections and small charges and smaller furnaces adopt $\frac{1}{2}$ to 4 h and for heavier sections and large furnaces 6 hours may be adopted. Cool slowly in the furnace at a rate of 20°C per hour, up to 550°C, afterwards cool in air.

Annealed hardness 215–250 HB.

Stress relieving 650–700°C, holding time 1 h per 25 mm section thickness, followed by slow cooling up to 500°C, thereafter in air.

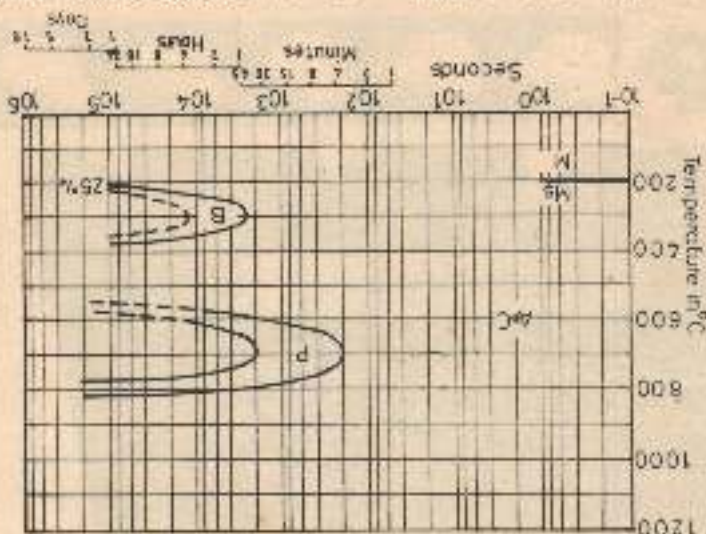


Fig. 20.17(b) Isothermal TTT curve for steel ISO 160CrMoV12. Austenitizing temperature = 1020°C, holding time = 30 min. (Courtesy: VEW, Austria)

Hardening

Heat slowly to 1020–1040°C and hold in that temperature for 15–45 min. depending on the section thickness and the charge. Adopt lower range of hardening temperature for small components. Subsequently quench in air or oil or salt bath. Temper immediately when cooled to hand warm.

Attainable hardness 63–65 HRC. Figure 20.17(b) illustrates the isothermal TTT curve.

Tempering

Tempering is done in the temperature range of 200–250°C to obtain maximum hardness. Higher toughness can be obtained if the steel is tempered in the temperature range of 350–400°C. The tempering time depends on the type of work, steel and the required final properties. Holding time 1 h per 20 mm section thickness (Fig. 20.17(c)).

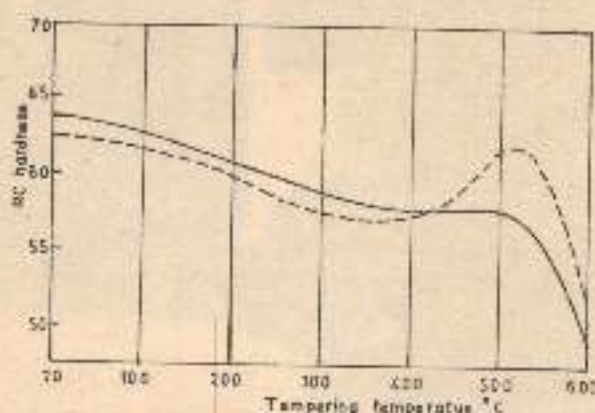


Fig. 20.17(c) Tempering curve. Hardening temperature = 1030°C, time = 1 h, specimen size = 20 mm

Table 20.20

Country	ISO	INDIA	DEU	USA	GBR	FRA	USSR	JPN
Standard norm	ISO 4957-80	IS 3479-78	DIN 17350-80	AISI	BS4639-71	NFA35- 590-78	GOST	JIS
Designation	160CrMoV12	ST160Cr112	X155CrVMo121	D2	BD2	Z160CDV12		
Chemical composition	C	1.45–1.75	1.5–1.7	1.5–1.6	1.4–1.6	1.4–1.6	1.45–1.70	—
	Si	0.1–0.4	—	0.1–0.4	0.3–0.5	0.6	0.1–0.4	—
	Mn	0.15–0.45	—	0.1–0.4	0.3–0.5	0.6	0.15–0.45	—
	Cr	11.0–13.0	11–13	11.5–12.5	11–13	11.5–12.5	11–13	—
	Mo	0.7–1.0	0.8 (Opt)	0.6–0.8	0.7–1.2	0.7–1.2	0.7–1.1	—
	V	0.5–0.8	0.8 (Opt)	0.9–1.1	0.8 (Opt)	0.25–1.00	0.7–1.1	—
	Co	—	—	—	0.6 (Opt)	—	—	—

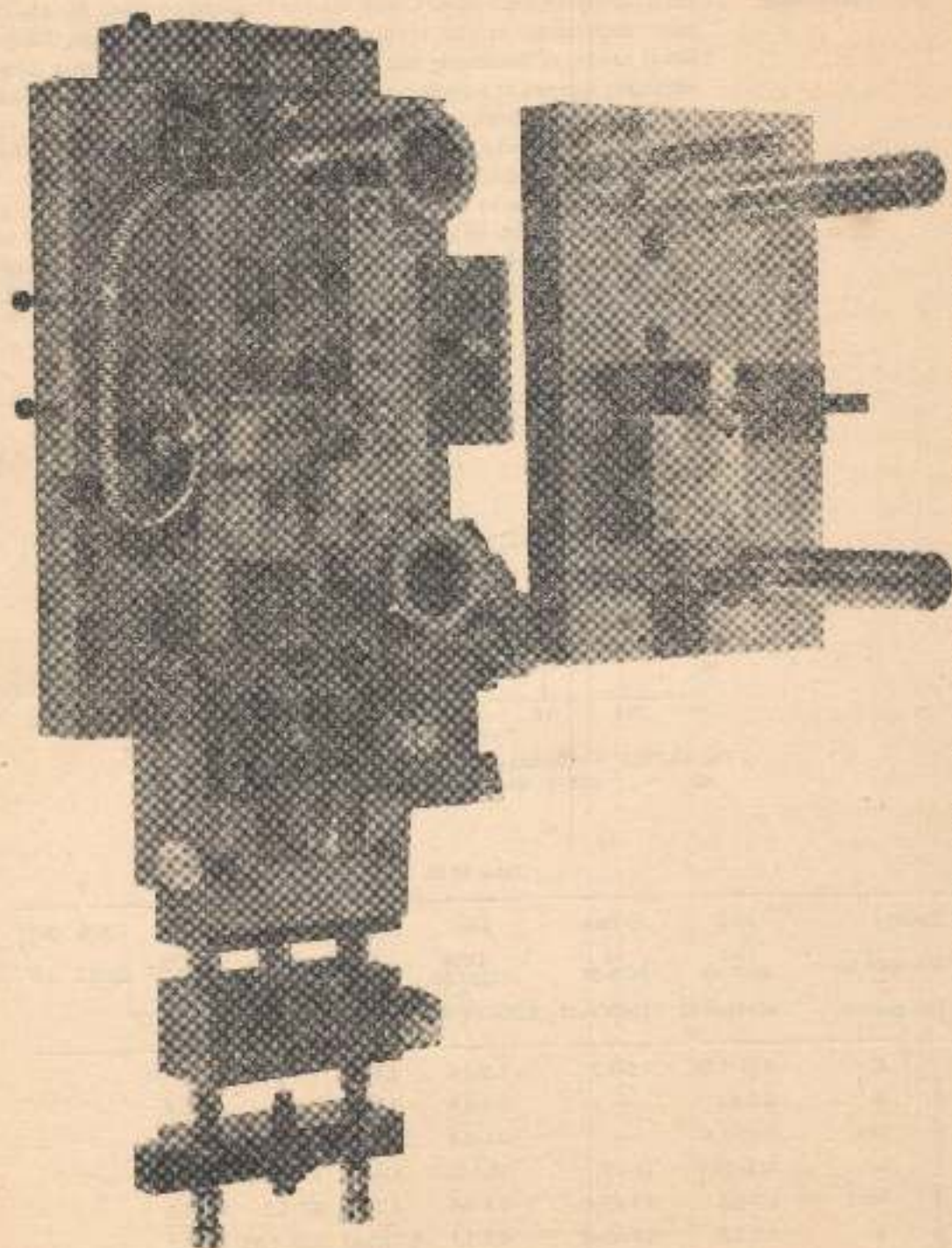


Fig. 20.18(a) Blanking tool for cutlery manufacture, steel—ISO 210Cr12 (Courtesy: VEW, Austria)

Data Sheet 20.20—210Cr12 (ISO)**CHARACTERISTICS**

This is a tool steel of high dimensional stability during heat treatment. It possesses high hardness and extreme wear resistance, particularly under conditions of metallic abrasion. Its high abrasion resistance after hardening causes generation of excessive heat during grinding unless special precautions are taken. Table 20.21 gives the chemical composition of International Standard steels.

Compared to steel D2 it possesses highest wear resistance but has a lower toughness.

TYPICAL APPLICATIONS

Heavy duty cutting and stamping tools, heavy duty and complicated punches, progressive and integral cutting dies, thread rolling dies, punches and dies for cold nut manufacture, dies for moulding abrasive powder, brick press liners, hobbing dies, small moulds and inserts for plastic, deep drawing and wire drawing dies, Burnishing tools and rolls, rolls for cold forming, saw teeth cutting dies, watch casing dies, scrapping and timing tools. Figure 20.18(a) illustrates the application of D3 steel.

HEAT TREATMENT

- | | |
|-----------|---|
| Forging | 1050°C max. (Commence)
850°C min. (Finish) |
| Annealing | 870–900°C. Adopt lower range of temperature for smaller components and higher range for heavy components. Holding time 1½–6 h, for small charges and small furnaces 1½–4 h and for heavier charges and large furnaces 6 h. Followed by slow cooling in the furnace at a rate of 210°C per hour up to 540°C, thereafter in air.
Annealed hardness 220–250 HB. (Figure 20.18(b) illustrates the annealed structure.) |



annealed × 500
 Fig. 20.18(b) The structure consists of small and medium sized spheroidal carbides in a matrix of pearlite and cementite

- Stress relieving 650–700°C, holding time 1 h per 20 mm thickness followed by furnace cooling up to 500°C, thereafter cool in air.
- Hardening 930–980°C, adopt lower limit for smaller components and higher limit of temperature for heavy components. Holding time 15–50 minutes depending on the section thickness. Followed by quenching in oil or salt bath maintained at 450–500°C. Quenching in salt bath reduces distortion compared to oil quenching. When cooled to hand warm temper immediately.



hardened

× 500

Fig. 20.18(c) The structure consists of massive alloy carbides and small alloy spheroidal carbides in a matrix of untempered martensite



hardened and tempered

× 500

Fig. 20.18(d) The structure consists of chromium carbide particles (white) in a matrix of tempered martensite

Tempering

Obtainable hardness 63–65 HRC. Figure 20.18(c) illustrates the hardened structure and Fig. 20.18(e) the isothermal TTT curve. Tempering is done in the temperature range of 200–250°C to obtain maximum hardness. Higher toughness can be obtained if the steel is tempered in the temp. range of 350–400°C. The tempering time depends on the type of work steel and the required final properties. Holding time for tempering 1 h per 20 mm thickness. Figure 20.18(d) illustrates the tempered structure and Fig. 20.18(f) the tempering curve.

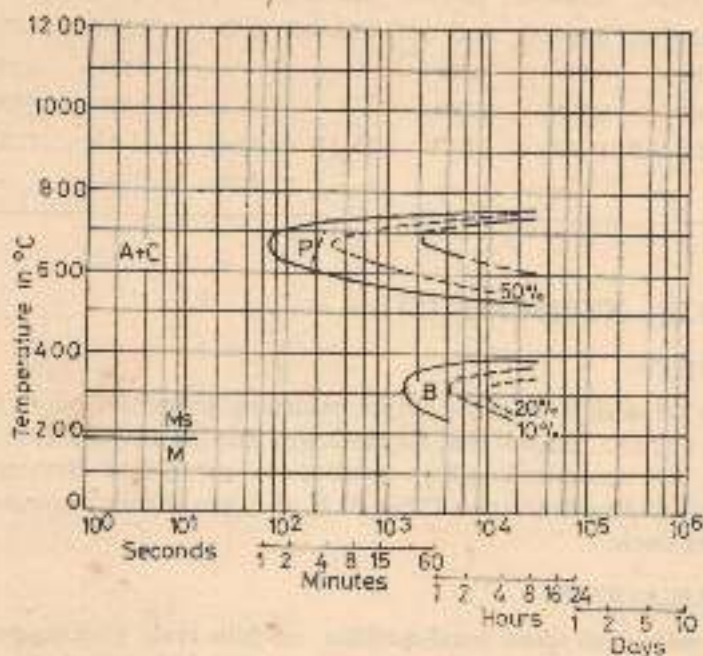


Fig. 20.18(e) Isothermal TTT curve (Courtesy: VEW, Austria)

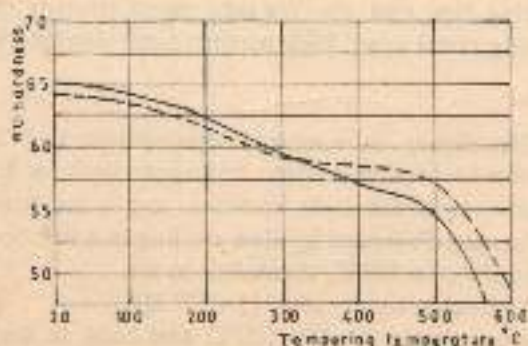


Fig. 20.18(f) Tempering curve. Hardening temperature = 950°C, time 1 = ½ h, specimen size = 20 mm

Table 20.21

Country	ISO	INDIA	DEU	USA	GBR	FRA	USSR	IPN
Standard norm	ISO 4957-80	IS 3479-78	DIN 17350-80	AISI	BS4659-71	NFA35- 590-78	GOST	JIS G4404-72
Designation	210Cr12	XT215Cr12	X210Cr12	D3	BD3	Z200Cr12	Ch12	SKD1
Chemical composition	C	1.9-2.2	2.00-2.30	1.90-2.20	2.00-2.35	1.90-2.30	1.90-2.20	1.80-2.40
	Si	0.1-0.4	0.10-0.40	0.10-0.40	0.25-0.45	0.60	0.10-0.40	0.15-0.35
	Mn	0.15-0.45	0.15-0.45	0.15-0.45	0.24-0.45	0.60	0.15-0.45	0.15-0.40
	P	0.03	0.030	0.030	—	—	0.025	0.030
	S	0.03	0.030	0.030	—	—	0.025	0.030
	Cr	11.0-13.0	11-13	11-12	11-13	12-13	11-13	11.5-13.0
	V	—	—	—	—	0.50	—	—

Data Sheet 20.21—XT215Cr12 (IS)

CHARACTERISTICS

This is similar to D3 steel. It possesses deeper hardening properties due to the presence of 1% molybdenum and as a result of this, air hardening may be adopted. Distortion is almost negligible during heat treatment and high resistance to softening at elevated temperatures. Medium resistance to decarburization Table 20.22 gives the chemical composition of International Standard steels.

TYPICAL APPLICATIONS

Deep drawing tools, high speed wood-working machine tools, piercing punches, dies for nut manufacture, reducing dies for several making, blanking tools for frame and circular saws, sheet and roll shearing blades, high performance thread-rolling dies and heavily loaded punches, die casting dies, and dies for tube manufacturing, mandrels for tube and bar drawing, air hardening metal saws, high performance blanking tools for the sheet.

HEAT TREATMENT

- Annealing** Heat slowly in a neutral atmosphere to 870-900°C. Adopt lower limit for smaller sections and upper limit for larger sections. Holding time $1\frac{1}{2}$ h for light sections to 6 h for heavy sections and large charges. Followed by slow cooling in a furnace at a rate of 20°C per hour up to 550°C, thereafter in air.
Attainable hardness—215-250° HB.
- Stress relieving** Heat slowly to 650-700°C and hold in that temperature 1 h per 20 mm of section thickness. Followed by furnace cooling up to 500°C, thereafter air cool.

- Hardening** Heat slowly to 970–1010°C. Hold at temperature 15 min. for small tools and up to 45 min. for large tools. Followed by quenching in a salt bath 620–640°C, subsequently air cooled. Temper immediately when cooled to hand warmth (60°C).
Hardness attained—64–66 HRC.
- Tempering** 200–500°C, depending on the mechanical properties. Holding time 1 h per 20 mm cross-section. Double temper, cool to room temperature before first tempering.

Table 20.22

Country	ISO	INDIA	DEU	USA	GBR	FRA	USSR	JPN
Standard norm	ISO	IS 3479-78	DIN	AISI	BS970/ 1-72	NFA35- 551-75	GOST	JIS
Designation		XT215Cr12		D4				
Chemical composition	C	—	2.00–2.30	—	2.25	—	—	—
	Si	—	0.10–0.35	—	0.20–0.40	—	—	—
	Mn	—	0.25–0.50	—	0.20–0.40	—	—	—
	Cr	—	11–13	—	12	—	—	—
	Mo	—	0.80 max.	—	1	—	—	—
	V	—	0.80 max.	—	—	—	—	—

Data Sheet 20.22—210CrW12

CHARACTERISTICS AND APPLICATIONS

This is a high carbon and high chromium tool steel with addition of tungsten, possessing superior wear resistance and retention of cutting edges. The additional alloy of tungsten gives superior performance and enhanced resistance to wear and distortion, compared to steel 210Cr12 (ISO).

This steel is mainly used for tools with drastic differences in cross section, as well as intricately shaped tools which tend to distort and crack on water hardening.

Blanking Tools Heavy duty blanking dies, canned food industry, watch industry, cutters for saw teeth, severely stretched punches for bending dies, rolling and forming dies, trimming tools and cutters for wire main manufacture.

Tools for Machining Reamers, heavily stressed wood working tools, cutters for steel wool manufacture. Various types of gauge manufacture.

Wear-resistant tools and parts, such as press tools for highly abrasive ceramic materials, cone pulleys for drawing wires, dies, drawing machines, sand blasting nozzles, etc.

Used for hot work tools such as drawing rings for hot works, highly stressed hammer cores for the manufacture of scythes and sickles, as well as rapid-action hammers for forging hard or high alloy steels.

Used for tools for non-cutting shaping, such as master hobs for plastic moulds, knurling tools, wire drawing dies, thread rolling dies, flanging and beading dies, etc. Table 20.23 gives the chemical composition of International Standard steels.

HOT WORKING AND HEAT TREATMENT

Forging	1050°C max. (Commence) 850°C min. (Finish)
Annealing	870–900°C
Annealed hardness	210–230 BHN.
Stress relieving	Heat pieces slowly to 650–700°C and hold at that temperature for 1 h per 2.5 mm cross-section, followed by furnace cooling. Relieves stresses due to machining and straightening operations.
Hardening	Heat slowly to 930–980°C in a neutral atmosphere and hold at that temperature for 15–50 min. depending on the section thickness. Adopt lower limit for smaller parts and higher limit of temperature for heavy parts. Followed by quenching in oil or salt bath maintained at 400–450°C. Quenching in salt bath reduces distortion compared to oil quenching. When cooled to hand warmth 50–60°C, temper immediately.
Tempering	Obtainable hardness—63–65 HRC Tempering is done in the temperature range of 230–250°C, to obtain maximum hardness. Higher toughness can be obtained by tempering at 350–400°C. Holding time for tempering is 1 h per 20 mm thickness.

Table 20.23

Country	ISO	INDIA	DEU	USA	GBR	FRA	USSR	JPN
Standard norm	ISO 4957-80	IS	DIN 17350-80	ASTM	BS970- 1-72	NFA35- 551-75	GOST	JIS
Designation	210CrW12		X210CrW12					
Chemical composition	C	2.0–2.30	2.0–2.50	—	—	—	—	—
	Si	0.10–0.40	0.10–0.40	—	—	—	—	—
	Mn	0.15–0.45	0.15–0.45	—	—	—	—	—
	Cr	11.0–13.0	11.0–12.0	—	—	—	—	—
	W	0.80–1.10	0.60–0.80	—	—	—	—	—

REFERENCES

- ISO 4957—1980, Table 4, *Chemical Composition Annealed Hardness, Temperature for Hardening and Hardness in the Hardened and Tempered Condition for Alloyed Cold-Work Tool Steels*.
- IS 1570, Part 6, *Tool Steels*.
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- BS 4659—1971, *Tool Steels*, *Stahlschlüssel*—86.
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- JIS, G4401, 1972, *Alloy Tool Steels*, Table 2, 1, 4 and 5.
- JIS G4404, 1972, *Alloy Tool Steels*.
- Stahlschlüssel*—1980.
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Hot Work Tool Steels

Hot work steels form a special group of steels intended mainly for industrial applications used in high temperature metal forming operations. The term hot work is intended to cover all applications except cutting tools where the operating temperature is above 200°C . The steel should possess a high degree of hardness, red hardness hot wear resistance and toughness at elevated temperatures besides having a good thermal conductivity. Only tools made from such steels permit economical forming of ferrous and non-ferrous metals at high temperatures. Dies made of hot work tool steels are mainly used for diecasting and extrusion of aluminium and copper alloys. They are also used for tools for hot pressing of copper alloys and steel forging. The working tool is thus exposed to both severe thermal and mechanical stresses which require several special properties of the tool material. From practical experience it has been found that the hot work steels are exposed to temperature ranging from room temperature to around 800°C , since in hot work operations tools are not maintained at a constant temperature but are exposed to considerable thermal fluctuations. This may give rise to what are known as heat checks.

Heat checks appear on the tool surface owing to the repeated contact with the hot metal and the resulting temperature fluctuations inflicted to the tool. The tool face or surface which comes into contact with the hot metal being processed is subject to thermal shock. As a result, the volume of the heated layer increases. The varying dilatations of the hot surface and the less heated layer below create compressive strains which are inverted by subsequent cooling. Thus a cycle of constantly alternating stresses is produced. As soon as the permissible tension is exceeded, this cyclic stress brings about plastic deformations and even rupture of the material. Thermal cracks which appear in hot work tools are defined as heat checks usually in a network "alligator" pattern, which is the most common formation of thermal cracks, hence it is essential that the hot work steel should possess good heat checking resistance in order to delay the formation of chill cracks appearing on the surface as a consequence of frequent temperature changes in the surface region. To avoid cracks that may develop in edges, and in deep cavities, it should have a good hot strength. Tools subjected to high impact, or tensile stresses at elevated temperature, should possess a high hot strength and high red hardness. Apart from the above demands, it should also possess low tendency to adhere to parts being processed, high resistance to erosion, high temperature corrosion and oxidation, dimensional stability, etc.

A proper hot work tool steel should therefore be characterised by hot yield strength,

high temperature resistance and good ductility and toughness. The above properties are achieved by the addition of alloying elements such as tungsten, molybdenum, chromium, cobalt, vanadium, etc., and to maintain the desired toughness, the carbon content in these grades of steel is maintained around 0.3–0.4%. Since these steels are highly alloyed they possess adequate hardenability and the selection of the quenching medium depends on the size of the tool.

The steels containing high tungsten possess high red hardness, combined with excellent resistance to heat checking and high resistance to abrasive wear. Hence they are recommended for tools demanding maximum life at high operating temperatures, such as extrusion dies, hot forging dies, die casting dies, etc., where the tools are in constant contact with the hot metal. They are, however, least resistant to thermal and mechanical shock and are not recommended for tools subject to intermittent water cooling during forming or where severe impact shock is encountered. For such conditions the choice would lie between the molybdenum and chromium steel or a lower tungsten steel. Hot work steels containing molybdenum possess higher toughness and thermal fatigue resistance.

The steels containing 5% chromium are readily air hardened and possess excellent resistance to heat checking and have a high degree of toughness. They are recommended for all types of tools where the operating temperatures are not excessively high or where water cooling or the working surfaces is desirable. These steels may be air hardened from lower temperature than that required for the 10% tungsten and molybdenum steels, consequently distortion and risk of cracking, resulting from heat treatment, are held at a minimum. Table 21.1 gives the International Standard steels and Data Sheets 21.1 to 21.9 gives the chemical composition, application and heat treatment for different types of International Standard steels.

21.1 Operations Before Hardening

These steels are normally received in annealed condition with hardness of 220 BHN. These steels are machined almost to the final size of the dimensions of the tools. The stresses that are induced due to the heavy machining operation must be reduced to avoid distortion and cracking during subsequent heat treatment. With this in view, they should be so far machined that they may be completed by a finishing cut only after stress relieving. After stress relieving, tools are finished to the final dimensions or with little allowance. The only machining operation possible after hardening is grinding.

21.1.1 STRESS RELIEVING

This is an important aspect of heat treatment of dies which is often overlooked. This operation is to be carried out after rough machining, i.e., after heavy stock removal. During heavy stock removal, especially in case of dies of intricate shape with abrupt changes in cross-section, residual stresses are developed after machining. These stresses have to be relieved before the die is taken up for hardening. If stress-relieving operation is not carried out, the residual stresses will add to the thermal stresses during hardening and may cause the die either to distort or crack. Stress-relieving is not intended to modify the structure in any way. Its purpose is only to relieve the stresses.

The stress-relieving operation is normally carried out in a temperature range of 650 to 700°C. This operation is carried out either in forced air circulation furnace or in muffle furnace. Dies are slowly heated to the desired temperature and held at that temperature for about one hour per 20 mm thickness. After soaking time is over the dies are cooled in the furnace itself at a very slow rate so as to ensure that no additional stresses are introduced by non-uniform temperature gradient due to variations in cross sections. After the stress relieving operation the dies are taken up for pre-final machining.

21.1.2 HARDENING

Preparation of Dies for Hardening In some cases, the heating of dies for hardening should be preceded by a certain preparatory operations. Foreign matters present on the surface of the dies, such as impurities, scale, etc., may drastically decrease the hardening effect, particularly in those cases where high surface hardness have to be obtained. In such cases, it is necessary to clean the surface before heating.

Holes of small diameter in massive portions of the die being treated must be stopped by wet asbestos in order to prevent the entrapment of the salts. Proper fixtures are to be used for the handling of dies during hardening.

Since comparatively high temperatures in the range of 1000-1100°C, are used during the hardening of dies, it is very essential that great care has to be exercised to avoid accidental carburization or decarburization. Either will increase the tendency to heat checking, and apart from this, variation of carbon percentage on the surface of the die after hardening will give misleading surface hardness leading to selection of wrong tempering temperatures. If the depth of the oxidized layer is greater than the allowance provided for finish machining, such as grinding, tapping or polishing, then the die will be considered as irrevocably damaged. The changes in carbon content of the surface layers of dies can also cause cracks during hardening. The measures which must be taken up to protect the surface of the die depends upon the type of furnace used.

Selection of Furnace Depending upon the availability, any of the following furnaces may be used for hardening of dies.

1. Vacuum furnace
2. Controlled atmosphere furnace
3. Muffle furnace
4. Salt bath.

VACUUM FURNACE A recent development in the control of surface analysis is the use of vacuum heat treatment furnaces. Here, the furnace is evacuated during heating and provisions are made for quenching the tools without contact with air. Vacuum treating produces tools without surface scale or decarburization (or carburization) and should be used wherever possible. Another advantage of vacuum heat treating is the uniformity of heating and cooling which insure uniformity of the structure. Mechanical properties attained are superior to other methods of hardening.

The high cost of vacuum heat treating has tended to limit its use but it is becoming more and more popular.

CONTROLLED ATMOSPHERE FURNACE The most common method is the control of furnace atmosphere by introducing gases that are inert to the steel at the quenching temperature. Here the endothermic atmosphere shall be used to prevent decarburizing or carburizing

within normal treatment times by effective techniques that measure either dew point, CO_2 or O_2 potential.

MUFFLE FURNACE In electric muffle furnaces, in the absence of protective atmosphere, the steel should be protected from air by packing in a box filled with some media which should be as neutral as possible.

The cast iron chips can also be used, at about 1000°C but should not exceed 1050°C to avoid the risk of sintering of the chips. If the tool is first wrapped in a thin layer of packing in the cast iron chips, the surface will be protected from mechanical damage. Cast iron chips have a slight carburizing effect. Whenever dies are pack hardened in a container, a thermocouple should be inserted in the pack, for proper controlling of heating time. Pack hardening method may not be so reliable as the other methods described above as they depend very much on the craftsmanship of the operation.

SALT BATH Salt baths are generally used for heat treatment of dies, because they offer a better method of heat treatment which gives a scale-free finish, minimum distortion, and accurate temperature control coupled with low operating costs and higher output provided the baths are carefully operated by maintaining the neutrality of the baths as laid down by the salt manufacturers. The heat treatment cycle for dies using salt bath is discussed.

When manufacturing dies the heat treatment cycle is of vital importance if the dies are to perform well in service. The heat treatment cycle for hardening of dies can be divided into the following steps (Fig. 21.1).

- (a) Preheating
- (b) Final heating
- (c) Soaking
- (d) Quenching
- (e) Tempering

PREHEATING

If dies are heated directly to the hardening temperature in one step, the temperature gradient that sets itself between the surface and the core will give rise to internal stresses due to uneven expansion. If these internal stresses exceed the yield point of the die, it is distorted and if the internal stresses exceed the tensile strength of the metal, then the cracks will be inevitably developed in the die. This can be avoided by preheating the die in two or three steps, kept there until the temperature is even throughout the die before continuing the heating to the hardening temperature. The other advantage of preheating is that the die is exposed to the very high hardening temperature to a lesser time, consequently, decarburization and grain growth brought to the minimum.

Dies that are of simple shape and small sizes can be directly heated to hardening temperature, however, a pre-heat at about 200 to 300°C is normally preferred to drive away the moisture on the die. Die steel have a poor thermal conductivity and as a result, the dies of massive size, intricate shapes and dies with abrupt changes in cross section are to be preheated in two or three stages. The first preheating is done ordinarily in a forced air circulation furnace maintained at 250 to 400°C . After the die has been properly heated, it is transformed to a bath maintained at 600 to 650°C . This step in preheating is very important as the internal stresses developed are gradually relieved as a relieved of plastic deformation, caused by them in this temperature range. Therefore a proper soaking time is given

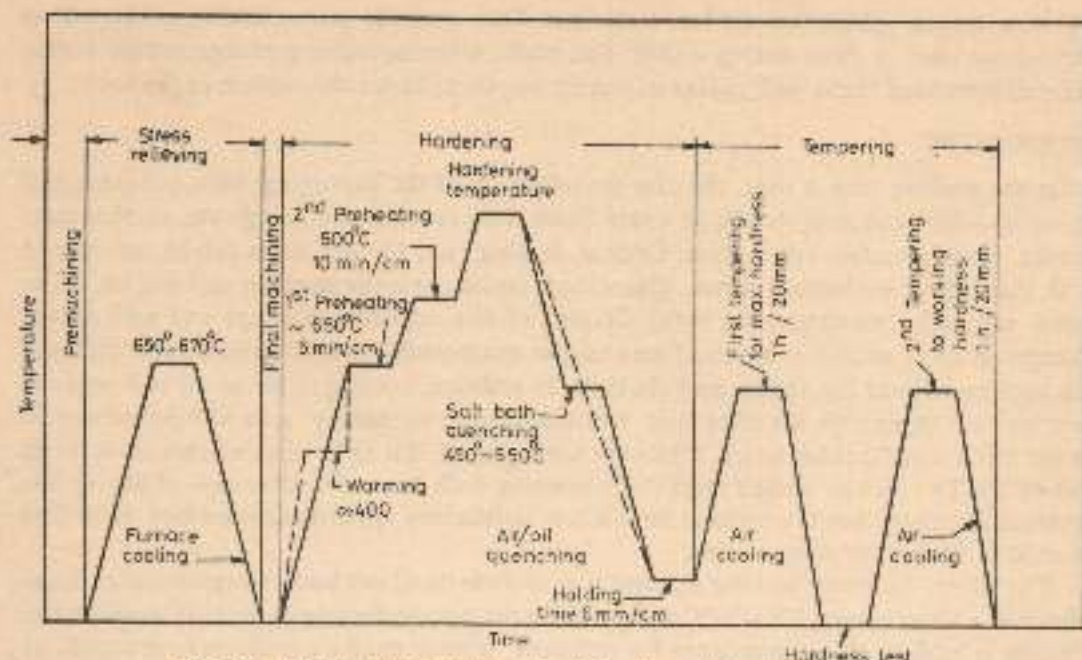


Fig. 21.1 Heat treatment sequence for high alloy cold-working tool steels

so as to ensure that the die is uniformly heated to the bath temperature throughout the cross section. A third step preheating can be done if required around 900°C. From this bath the die is transformed to the high temperature hardening bath maintained at required hardening temperature of the die (Fig. 21.1).

FINAL HEATING AND SOAKING

The choice of hardening temperature, within the limits applicable to the steel in question, should be carefully made, so that overheating and consequent loss of toughness is avoided. The selections of hardening temperature and soaking time are best determined by heat treaters by their experience. After the die has reached the hardening temperature throughout the cross-sections it is soaked at this temperature for a sufficient time to allow enough of the carbides to be dissolved to ensure the desired hardness. Too short a holding time (soaking) will give lower hardness due to insufficient carbide dissolution. Too long a holding time will give insufficient hardness, as the matrix has become too enriched by excessive carbides solution and fails to transform to martensite after quenching. The untransformed matrix i.e., retained austenite will cause lower hardness. Another disadvantage is that excessive grain growth lowers the toughness of the die. The time to be kept at the hardening temperature will depend on the size of the die and the hardening temperature used. It is always advisable to use the middle of the hardening temperature range.

Since the salt baths tend to be slightly oxidizing at a higher temperature the baths should be made neutral by adding a regenerator. For this purpose of regeneration (deoxidization) a small amount of finally crushed ferrosilicon or magnesium fluoride (1-1.5% by weight to the total amount of salt in the bath) is added intensively to the heated bath. Then the bath is agitated. After the agitation is over the bath is allowed to settle for half

an hour before taking the die for treatment. This periodic deoxidization of the bath is carried out once or twice during a shift. Salt baths, when operated and regenerated within the recommended limits will neither carburize nor decarburize the surface of the tools.

QUENCHING

After the soaking time is over, the dies are taken out of the hardening bath and quenched in media which can cool the die at a rate faster than the critical cooling rate, so that martensite transformation takes place. Critical cooling rates for die steels can be determined with the help of isothermal curves. Quenching media normally used for dies are air, oil or fused salt bath (martempering bath). Cooling of dies of intricate shape and with abrupt changes in cross section in air or oil may lead to unacceptable distortion because of differential cooling rates of the surface and the core. In addition, cooling in air or oil will pose the problem of cleaning the die after heat treatment, since hardening salts will get entrapped in the blind and threaded holes. While quenching in oil, it is to be ensured that oil is warm (50–60°C). The dies air cooled from the hardening bath have the advantage of having less retained austenite, but the surfaces have a less satisfactory appearance since they have time to oxidize during the slow cooling.

Therefore, the better cooling method is to use the fused salt bath (martempering) maintained at a temperature, 450–550°C that is above the martensite transformation temperature. The die is held at this temperature for sufficient time to enable a uniform temperature to be reached throughout the cross section but not long enough to cause austenite decomposition. After this the die is cooled in air so that austenite is transformed to martensite. Since the die is held just above the martensite range, the thermal stresses produced as a result of cooling will be neutralized by plastic deformation because of the very high plasticity of the austenite. Thus, at the time the martensite transformation starts the die treated will be almost completely freed from internal stresses and strains. It is true that in the course of the martensitic transformation itself internal stresses will develop but their magnitude will be fairly moderate because the martensite transformation will proceed simultaneously in both the outer layers and centre portion of the piece being hardened. As a result of this there will be less distortion and less danger of quenching cracks appearing in the die.

However, the quantity of retained austenite is greater with martempering operation than with air or oil cooling due to the stabilization of austenite in the steel. To avoid further stabilization of austenite, the dies are washed in boiling water after the die cools down to 50–60°C and taken up for tempering immediately. If tempering cannot be taken up immediately after the die is cooled to 50–60°C it may be kept in a holding furnace maintained at 200–250°C.

HARDNESS TESTING

Hardness testing immediately after quenching is not absolutely necessary. With highly alloyed steels, hardness testing after quenching often gives no indication as to whether the hardening has been properly carried through as in some cases the desired hardness is first found after tempering.

TEMPERING

The hardened die steel contains martensite, retained austenite and carbides. In this condition the die is hard, highly stressed, brittle and dimensionally unstable. It is the function of

the tempering to render the die useful by eliminating internal stresses, brittleness and to increase the desired toughness.

The tempering temperature is chosen to give the proper hardness for the metal to be cast. Considering the varying sensitivity to heat checking at different operating temperatures, the hardness normally used for die casting aluminium and magnesium is in the range 40-48 RC and for copper alloys 37-45 RC. It is recommended to temper the dies twice or more if necessary.

If the die is allowed to cool to room temperature after hardening i.e., before tempering, hardening cracks may develop. To avoid this, the dies are taken up for tempering immediately after the die cools to 50-60°C. This first tempering is done normally at 500-540°C and it is carried out in a martempering bath or in an air circulation furnace. The dies are preheated to 200-250°C before loading for tempering to avoid cracking due to rapid heating (intricate shape dies are particularly liable to crack from this cause). After the preheating the die is charged to tempering bath or furnace maintained at the desired tempering temperature. After the die attains the tempering temperature, it is soaked for 2 to 3 hours depending on the section thickness. After the soaking time is over, the die is allowed to cool to room temperature so that the retained austenite is transformed to martensite and the precipitation of carbides from the martensite is effected. After first tempering the hardness is checked and recorded. Before hardness checking the die is polished to remove any scale that may be present on the die.

If the first tempering gives the satisfactory hardness, the Second tempering temperature is chosen from the graph, to give the required hardness to the die considering the varying sensitivity of heat checking at different operating temperatures. After the second tempering at the required temperature (preheating to be done before loading to the tempering), the die is allowed to cool down to room temperature. The hardness is now checked and recorded. If necessary a third tempering may be carried out.

It may be noted that the tempering of die steels in the temperature range of 600-650°C often causes trouble in hardening shops. Such tools are usually tempered several times. However, repeated tempering treatment above 500°C lowers the degree of hardness so that even a small increase in temperature during the second tempering, can considerably affect the desired hardness.

SPECIAL SURFACE TREATMENT

Tools in the as hardened and tempered condition possess sufficient hardness to perform the task for which they were designed. In order to enhance the tool life further surface treatments are done. Adopting the surface treatment increases the wear resistance and reduces the heat checking.

The oxide layer formed on the surface in the as hardened and tempered condition provides protection against the thermal shock produced by the molten metal at the moment of injection. If this layer is scratched or partially removed, heat cracks are more likely to develop than if the oxide layer is intact. To further improve the surface properties, the following treatments of the diffusion type have been tried with good results.

Nitriding This method is carried out after hardening and tempering in the usual manner. Nitriding is carried out in the temperature range of 520-540°C for 10 hours and above in an atmosphere of ammonia gas. At this temperature nitrogen diffuses into the surface resulting

in the increase of surface hardness and improves considerably the tensile properties at high temperature. Nitriding also offers the advantage of preventing the castings from sticking to the die cavity, and improves the resistance to scaling and erosion.

It is important to note that with increase in the penetration of nitriding there is a reduction in resistance to thermal shock and an increase in embrittlement. Since the nitriding is the last operation, proper precautions may be taken to accommodate the growth of surface (0.02–0.25 mm) before finishing operations.

Nitriding is recommended for die casting of zinc, tin and lead with low melting points and a narrow range of operating temperature. The risk of heat checking in this case is non-existent. When casting aluminium and magnesium alloys nitriding may be helpful if the cavity has thin sections which are rapidly attacked due to their high working temperature.

Dies of copper alloys should not be nitrided because, in this case, nitriding favours heat checking.

Tufftriding (TFI) A new process called tufftriding TFI introduces both carbon and nitrogen in the surface to give a tough, wear resistant case. The treatment consists of holding the die for 1 to 2 hours in a bath of controlled proportions of operating at a temperature of 540–560°C.

Tufftriding improves the resistance to thermal fatigue as well as soldering, erosion and pitting apart from hard wear resistant layer, the life of the tool may be doubled.

Oxidation This process is carried out in the temperature range of 520–540°C in an atmosphere of steam, in a sealed furnace. The process imparts a blue oxide finish of good appearance. The oxide coating enhances the resistance to scoring of moving parts, hence it increases wear resistance. A slight oxidation of the surface is generally beneficial for delaying heat checks. Since iron oxide has a lower thermal conductivity than steel, a thin layer of scale retards heat transfer to the die surface, thus lowering the minimum temperature attained by the die. This decrease in temperature reduces thermal stresses and thereby improves thermal fatigue resistance. This oxide layer prevents contact between the molten metal and the steel and therefore reduces heat checks. This treatment is applied by tempering the dies in a steam atmosphere. The effect of steam tempering is to form a tough, hard porous film of oxide (Fe_3O_4) of about 0.0025 in thickness.

Sarsulf Process This is a relatively new diffusion process which enriches the surface layer with sulphur and nitrogen from a cyanide free special salt bath. It is said to have been used to advantage up to about 700°C. It improves the hot hardness and reduces the tendency of the material to stick to the cavity. This treatment may be carried out in the range of 550–570°C for a period of 1 to 2 hours.

Data Sheet 21.1—30CrMoV3 (ISO)

PROPERTIES

This is a hot work steel with high hardness, hardness retention and abrasion resistance at elevated temperatures combined with sufficient toughness at service temperatures. It also exhibits good thermal conductivity due to its low total content of alloying element and, therefore, an excellent resistance to heat checking. Table 21.2 gives the chemical composition of International Standard steels.

Table 21.1

Country Standard	ISO ISO	INDIA IS	DEU DIN	USA AISI	GBR BS970	FRA NFA25	USSR GOST	JPN JIS
1	30CrMoV3	—	X32CrMoV33	H10	BH10	320CV28	3ChJ3M3F	SKD7
2	35CrMoV5	X135Cr5Mo1V30	X38CrMoV51	H11	BH11	Z38CDV5	4Ch5MF5	SKD6
3	—	XT35Cr5MoW1V30	X37CrMoW51	H12	BH12	Z35CWDV5	—	SKD12
4	40CrMoV5	XT35CrMoV1	X40CrMoV51	H13	BH13	Z40CDV5	4Ch3MF15	SKD61
5	30WCrV9	XT33W3Cr3V38	X30WCrV93	H21	BH21	Z30WCV9	3Ch2W8F	SKD5
6	—	—	—	B10A	—	—	—	—
7	30WCrV5	—	X30WCrV53	—	—	Z32WCV5 33KV	—	SKD4
8	—	—	55NiCrMoV6	—	—	55NC1DV7	5ChWM	SKT4
9	55NiCrMoV2	—	56NiCrMoV7	L6	—	—	—	—

APPLICATIONS

Mainly used for tools for the hot manufacture of screws, rivets, nuts and bolts, dies, heading dies, snaps, hammers, piercing mandrels, etc.

It is also used for tube and rod extrusion presses, especially water-cooled piercing mandrels, and die casting tools for heavy alloys with high melting points.

Tools for the production of hollow bodies, e.g. piercer heads, ejectors, etc. pressing dies for heavy alloys, etc. Tools and dies made of this steel may be subjected to nitriding and nitrocarburizing to enhance their lives. Figure 21.2 illustrates the application.

HOT WORKING AND HEAT TREATMENT

Forging 1100–850°C

Annealing 740–780°C

Annealed hardness 210–235 BHN

Stress relieving After rough-machining, heat the tool to 650–670°C and soak for 1 h per 25 mm thickness followed by furnace cooling up to 450°C and thereafter in air.

Hardening Heat the tools slowly to 1000–1050°C in a neutral atmosphere. Hold at that temperature for 15–45 min. Shorter holding time for small cross-sections and longer time for larger cross-sections may be adopted. Followed by quenching in oil or compressed air or salt bath maintained at 500–550°C. Tools quenched in oil should be taken out when they are around 500°C, and air cooled. Tools quenched in salt baths should be taken out when they attain the bath temperature and air cooled. Distortion is much less in tools quenched in salt bath as compared to oil baths.

Temper immediately when the tool attains a temperature of 50–60°C.



Fig. 21.2 Hollow stems made from steel (ISO)30C1MoV1 hot-work steel for aluminium extrusion press (Courtesy: VEW, Austria)

Tempering Temper between 600 and 700°C, depending on the required hardness. Soaking time 1 h per 20 mm cross-section.

First tempering is done at 600°C. After the holding time elapses, the tools are cooled to room temperature and the hardness checked.

Obtainable hardness—HRC 50–54.

The second tempering is done to attain the working hardness. The temperature adopted depends on the desired working hardness. The tools are cooled in air after the desired soaking time.

The third tempering is done at 30–50°C below the second tempering temperature, to relieve stresses further and to enhance the life of the tools.

PROCESSING SEQUENCE

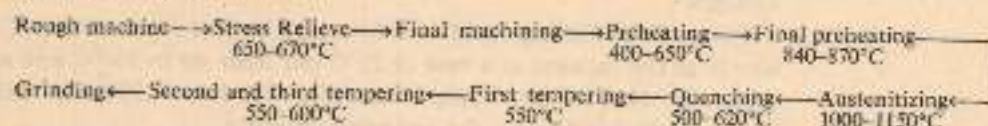


Table 21.2

Country	ISO	INDIA	DEU	USA	GBR	FRA	USSR	JPN	
Standard norm	ISO 4951-80	IS	DIN	AISI	BS4659-71	NFA35-590-78	GOST	JIS	
Designation	30CrMoV3	—	X32CrMoV33	H10	BH10	32DCV28	3Ch3M3F	SKD7	
Chemical composition	C%	0.25-0.35	—	0.28-0.35	0.40	0.30-0.40	0.28-0.35	0.27-0.34	0.28-0.38
	Si%	0.1-0.4	—	0.10-0.40	0.20-0.40	1.10	0.10-0.40	0.20-0.40	0.50
	Mn	0.15-0.45	—	0.15-0.45	0.20-0.40	0.40	0.20-0.50	0.30-0.50	0.60
	Cr	2.50-3.50	—	2.70-3.20	3.25	2.80-3.20	2.60-3.30	2.80-3.50	2.50-3.50
	Mo	2.50-3.00	—	2.60-3.00	2.50	2.65-2.95	2.50-3.00	2.50-3.00	2.50-3.00
	V	0.40-0.70	—	0.40-0.70	0.40	0.50-0.50	0.40-0.70	0.40-0.60	0.40-0.70

Data Sheet 21.2—35CrMoV5 (ISO)

CHARACTERISTICS

This is a chrome–vanadium–molybdenum steel with good resistance to repeated changes in temperature. Resists softening when used at temperatures up to 550°C and has considerable resistance to heat checking. Compared to other chrome–molybdenum hot work steels (H12 and H13) it possesses higher toughness. However it has a low hot wear resistance. This steel may be nitrided to increase the wear resistance and life of the tool. Table 21.3 gives the chemical composition of International Standard steels.

TYPICAL APPLICATIONS

Stamping and bending dies for steel and copper alloys, where excessive surface temperatures are not reached. Extrusion dies, mandrels, liners and die holders for aluminium alloys.

Cores and ejector pins for pressure of casting of tin, lead and zinc base alloys. Gravity die casting dies, injection runs for pressure die casting machines, hot blanking dies, small moulds and inserts for plastic moulding.

HOT WORKING AND HEAT TREATMENT

Forging	1000°C max. (Commence) 900°C min. (Finish)
Annealing	Heat the steel to 845–900°C in a neutral atmosphere, lower range of temperature for smaller section and higher range for heavier section. Hold in that temperature for about one hour for light sections and small furnace charges to about 4 h for heavy sections and large charges.

For pack annealing, hold one hour per inch of cross-section. Cool slowly in the furnace at a rate of 25°C per hour up to 550°C and subsequently cool in air. Typical annealed hardness—200–225 BHN. Figure 21.3(a) illustrates the annealed structure.



annealed × 500
Fig. 21.3(a) The structure consists of a fine dispersion of small spheroidal carbide particles in a matrix of ferrite (white) 35CrMoV5 steel

Stress relieving	After rough machining, heat the tool to 650–670°C and soak for 1 h per 25 mm section thickness and cool slowly in the furnace up to 500°C; further cool in air.
Hardening	Heat slowly to 1000–1040°C in a neutral atmosphere and hold at that temperature for 15–40 min, depending on the cross-section. Adopt shorter times for heavier sections, followed by quenching in air, oil or salt bath. When quenched in oil, the tool should be removed from the oil when it attains around 500°C, followed by air cooling. Quenching in salt bath maintained at 500–620°C is more ideal. Remove the tool when it attains the bath temperature and subsequently cool in

air. Temper immediately when the steel cools to hand warmth $\sim 60^{\circ}\text{C}$. Figure 21.3(b) illustrates the hardened structure and Fig. 21.3(d) the isothermal TTT curve.



hardened

$\times 500$

Fig. 21.3(b) The structure is mainly untempered martensite with very small spheroidal particles of carbide and some retained austenite

Tempering

Temper between 550 and 650°C depending on the hardness required. Holding time 1 h per 20 mm cross-section. First tempering at 550°C should be done to attain the maximum hardness. After the tempering time is over the tool is cooled in air to room temperature.



hardened and tempered

$\times 500$

Fig. 21.3(c) The structure is coarse, tempered martensite with a few spheroidal particles of alloy carbides.

Second tempering is done to attain the working hardness. Choose the tempering temperature from the tempering graph Fig. 21.3(e). After the desired tempering time, cool in air to room temperature obtainable hardness 52–54 HRC.

Third tempering is done in the range of 30–50°C below the second tempering temperature. This is beneficial for increasing the service life and relieve the stresses further. Figure 21.3(c) illustrates the tempered structure, and Fig. 21.3(e) the tempering curve.

PROCESSING SEQUENCE

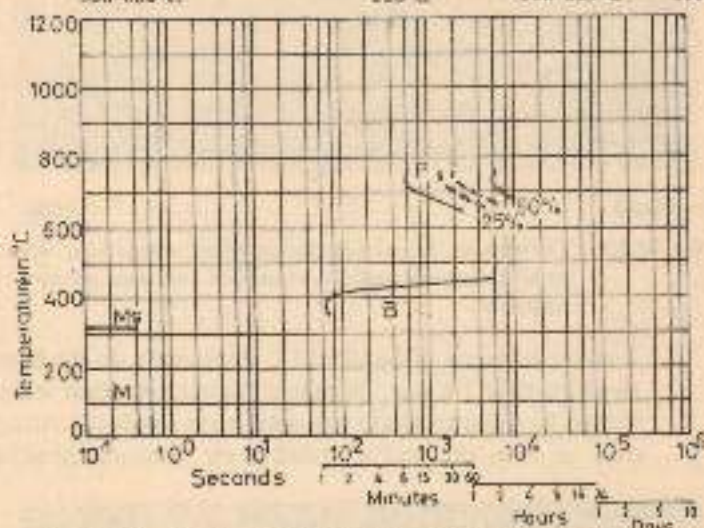
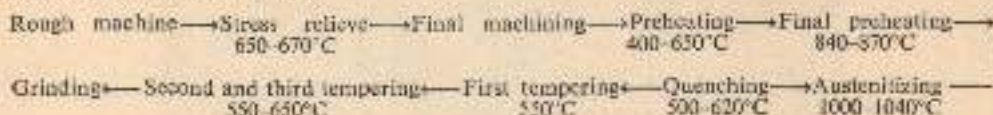


Fig. 21.3(d) Isothermal TTT curves of steel—(ISO) 35CrMoV5. Austenitizing temperature—1030°C, time—15 min. (Courtesy: VEW, Austria)

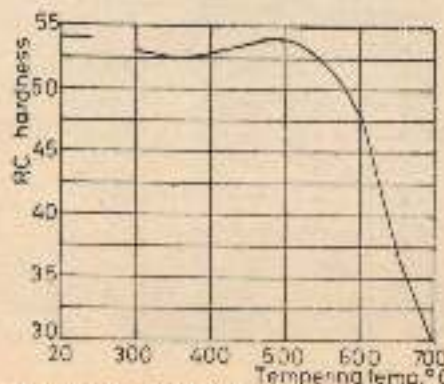


Fig. 21.3(e) Tempering curve. Hardening temperature—1020°C, time—2h, specimen size—50 mm

Table 21.3

Country	ISO	INDIA	DEU	USA	GBR	FRA	USSR	JPN	
Standard norm	ISO 4951-80	IS 3479-78	DIN 17350-80	AISI	BS4659-71	NFA35- 590-78	GOST	JIS	
Designation	35CrMoV5	T35Cr5 Mo1V30	X38Cr MoV51	H11	RH11	Z38CDV5	4Ch5MFS	SKD 6 G4404-72	
Chemical composition	C	0.32-0.42	0.30-0.40	0.36-0.42	0.3-0.4	0.32-0.42	0.34-0.42	0.32-0.40	0.32-0.42
	Si	0.90-1.20	0.80-1.20	0.9-1.2	0.8-1.2	0.85-1.15	0.80-1.20	0.80-1.20	0.80-1.20
	Mn	0.25-0.55	0.20-0.50	0.3-0.5	0.2-0.4	0.4	0.20-0.50	0.15-0.40	≤ 0.50
	P	0.030	0.03	0.03	—	—	0.025	0.030	≤ 0.03
	S	0.030	0.03	0.03	—	—	0.025	0.030	≤ 0.03
	Cr	4.5-5.5	4.8-5.5	4.8-5.5	4.75-5.50	4.75-5.25	4.8-5.5	4.50-5.50	4.50-5.50
	Mo	1.2-1.7	1.1-1.4	1.1-1.4	1.25-1.75	1.25-1.75	1.2-1.5	1.2-1.5	1.0-1.5
	V	0.3-0.5	0.25-0.50	0.25-0.50	0.30-0.50	0.30-0.50	0.3-0.5	0.30-0.50	0.30-0.50

Data Sheet 21.3—T35CrMoW1V30 (IS)

CHARACTERISTICS

This is a tungsten-chrome-molybdenum hot work steel usually air or oil hardened. It has a combination of toughness, red hardness resistance to heat checking and can withstand intermittent water cooling in service. Resists softening when used at temperatures up to 570°C.

Compared to other chrome-molybdenum hot work steels, this steel possesses a higher hot hardness and resistant to softening on heating to elevated temperatures. Hence, it is generally selected for extrusion and hot working operations as opposed to die casting applications. To increase the wear resistance and life of the tool it may be surface treated, such as gas nitriding, sursulf, tufftride, ion nitrided, etc. Table 21.4 gives the chemical composition of International Standard steels.

TYPICAL APPLICATIONS

Extrusion dies, hot working punches, shell piercing tools and forging mandrels, hot plating, stamping and forging dies and inserts for copper stud, gripper and hot forming dies, ejector pins and nozzles for pressure die casting of tin, lead, or zinc base alloys, dies for gravity die-casting of copper base, dies for aluminium and manganese alloys. Figure 21.4(a) illustrates the application.

HOT WORKING AND HEAT TREATMENT

Forging 1100°C max. (Commence)
900°C min. (Finish)

Annealing Heat to 820-870°C (use lower temperature range for smaller sections and higher range for larger sections) and hold at this temperature for 1 h for light section and small furnace charges. For pack anneal-

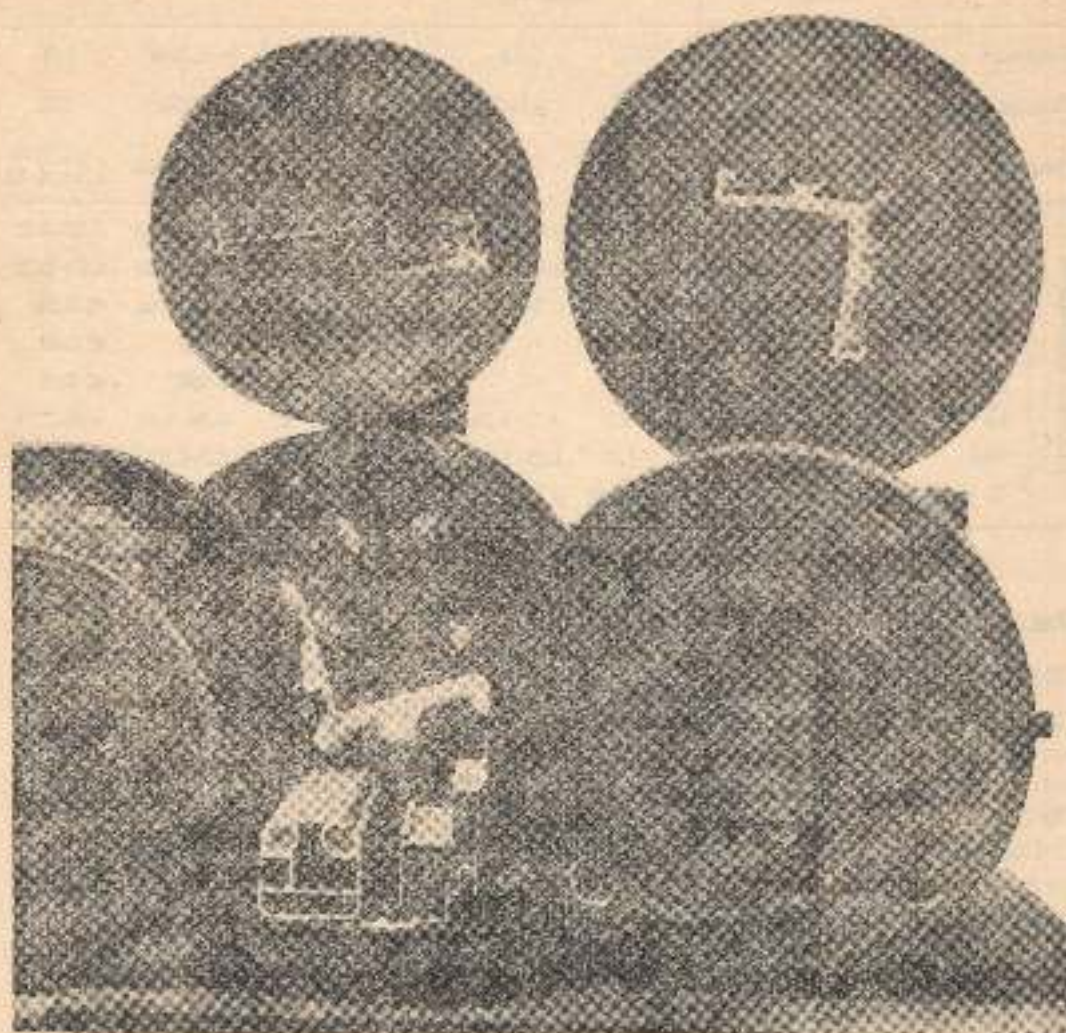


Fig. 21.4(a) Aluminum extrusion dies made from steel (IS)T35CrMoW1V30 hotwork tool steel
(Courtesy: VEW, Austria)

Stress relieving

Hardening

ing 1 h per inch cross-section. Cool slowly in a furnace, not exceeding 28°C per hour until temperature 550°C is reached. Further it may be cooled in air. Typical annealed hardness—210–230 HB.

Heat to 650–670°C and hold in the furnace 1 hour per inch of cross-section, then cool slowly in the furnace.

Heat slowly to 1000–1040°C in a neutral atmosphere and hold in that temperature for 15 to 40 min. Adopt shorter time for smaller sections and longer time for larger sections. Subsequently quench in air or oil or salt bath. When quenched in oil, the tool should be taken out when it attains 500°C and air cooled. Compared to salt bath it

Tempering

results in more distortion. Salt quenching at 500–620°C is more ideal. It will lessen the distortion. After the tool attains the bath temperature, it should be subsequently cooled in air. Temper immediately when the tool cools to 60°C Figure 21.4(b) illustrates the isothermal TTT curve.

Temper between 500 and 650°C depending on the required hardness. Soaking time 1 hour per 20 mm cross-section.

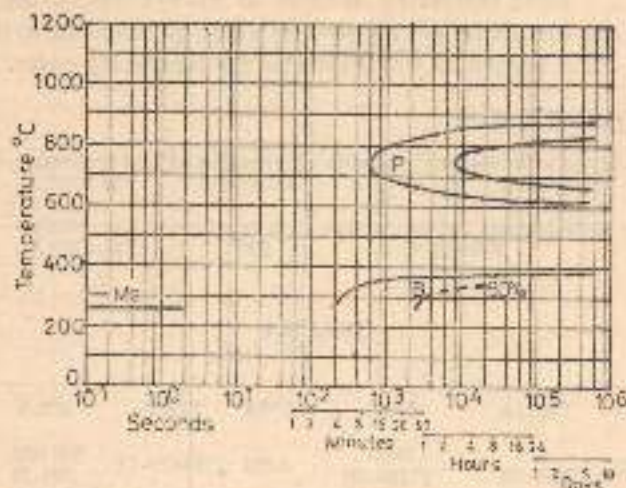


Fig. 21.4(b) Isothermal TTT curve. Austenitizing curve = 1030°C, time = 15 min. (Courtesy: Rochling Stahlexport, W. Germany)

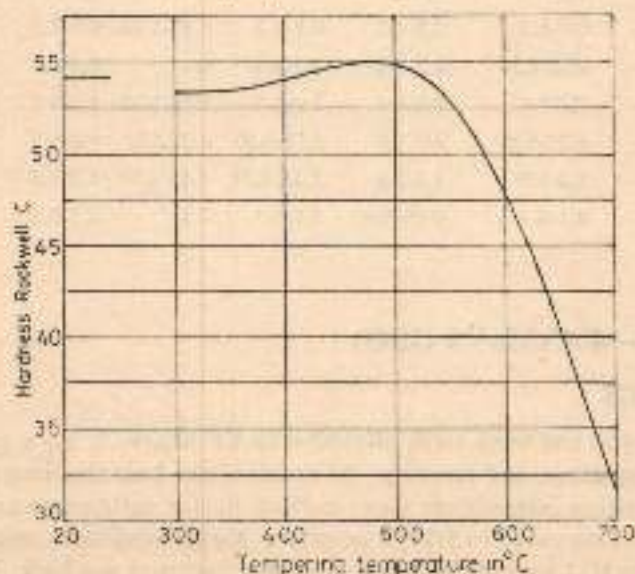


Fig. 21.4(c) Tempering curve. Quenched from 1020°C (oil), diameter of specimen = 1 x 2 inch (Courtesy: Rochling Stahlexport, W. Germany)

First tempering at 500°C should be carried out immediately after the tool attains hand warm 50–60°C. After the tempering time elapsed, it is cooled to room temperature.

Obtainable hardness—52-54 HRC

Second tempering is done to attain the working hardness. Temperature is chosen from the tempering graph, (Fig. 21.4(b)), when the tempering time over, the tools are cooled in the air.

Third tempering is done at 30–50°C below the second tempering to further relieve the stresses and it is beneficial to increase the service life. Figure 21.4(c) illustrates the tempering curve.

PROCESSING SEQUENCE (H12)

Rough machine → Stress relieve → Final machine → Preheating → Final preheating → Austenitize →

Finish grinding to size ← 2nd and 3rd tempering ← First tempering ← Quenching ←

500–650°C 800°C 500–620°C

Table 21.4

Country		ISO	INDIA	DEU	USA	GBR	FRA	USSR	JPN
Standard norm		ISO	IS 3479-78	DIN 17350-80	AISI	BS4659-71	NFA35- 590-78	GOST	JIS G4404-72
Designation			T35CrMo W1V30	X37CrMoW51	H12	BH12	Z35CWDV5		SKD 62
Chemical composition	C	—	0.3-0.4	0.32-0.40	0.3-0.4	0.3-0.4	0.3-0.4	—	0.32-0.42
	Si	—	0.8-1.2	0.9-1.2	0.8-1.2	0.85-1.15	0.8-1.2	—	0.8-1.2
	Mn	—	0.25-0.50	0.3-0.6	0.2-0.4	0.4	0.2-0.5	—	0.05
	W	—	1.2-1.6	1.2-1.4	1.0-1.7	1.25-1.75	1.1-1.6	—	1.0-1.5
	Cr	—	4.75-5.25	5.0-5.6	4.75-5.50	4.75-5.25	4.8-5.5	—	4.5-5.5
	Mo	—	1.2-1.6	1.3-1.6	1.25-1.75	1.25-1.75	1.2-1.5	—	1.0-1.5
	V	—	0.2-0.4	0.15-0.40	0.1-0.5	0.5	0.3-0.5	—	0.2-0.6

Data Sheet 21.4—40CrMoV5 (ISO)

CHARACTERISTICS

This is a highly alloyed hot work steel, alloyed with Cr-Mo-V. It has a good combination of toughness, red hardness, and tenacity. Its resistance to heat checking makes it suitable for applications requiring intermittent water cooling. Resists softening when used at temperatures up to 550°C. Compared to H21, it possesses higher toughness and better machinability. Compared to H11 its wear resistance and hot hardness are high. This steel may be gas nitrided or tufftrided or ion nitrided to increase the wear resistance and life of the tool. Table 21.5 gives the chemical composition of International Standard steels.

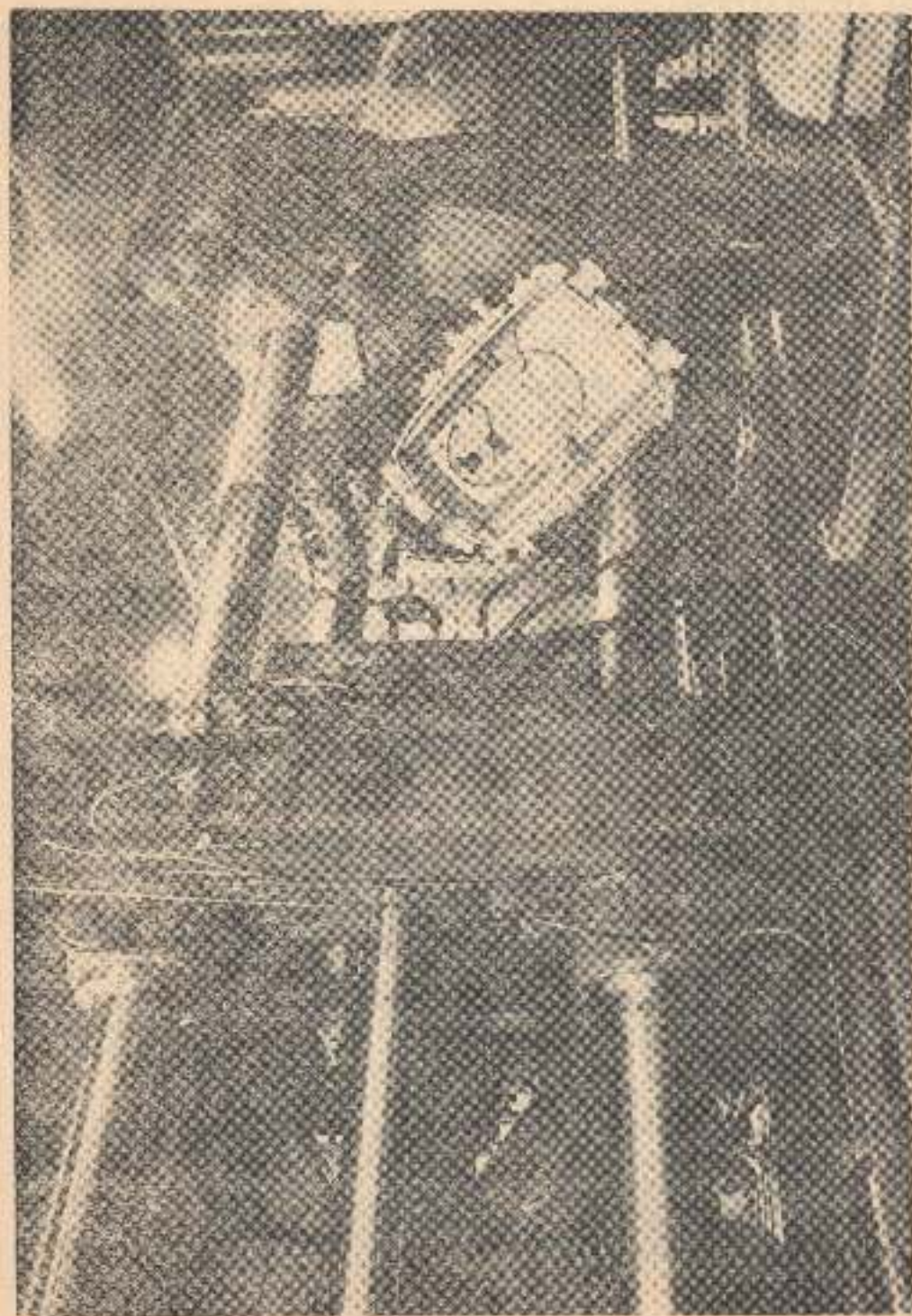


Fig. 21.5(a) Aluminium pressure die casting produced from a die made from Uddeholm ORUAR MSUPRENE hot die steel at 46-48 HRC
(Courtesy: Uddeholm Steels, Sweden)

TYPICAL APPLICATIONS

Extrusion dies, mandrels, ejector dies, hot working punches, shell piercing tools, forging mandrels, ejector pins, shot sleeves, dies for aluminium alloys, die holders, etc. Figure 21.5(a) illustrates the application for aluminium die.

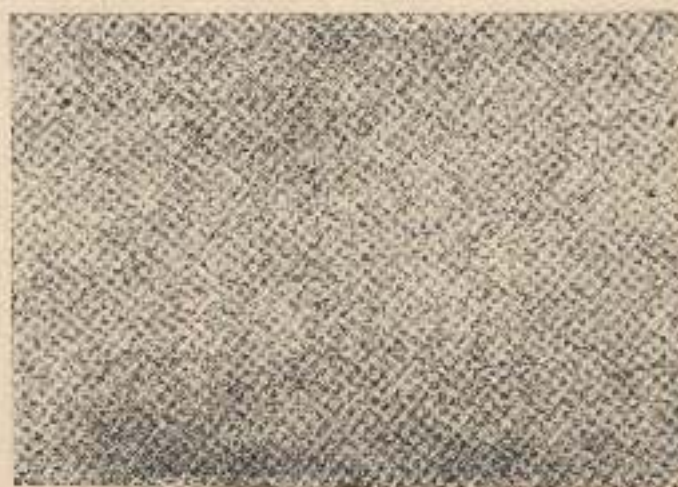
Table 21.5

Country	ISO	INDIA	DEU	USA	GBR	FRA	USSR	JPN
Standard norm	ISO 4957-80	IS 3479-78	DIN 17350-80	AISI	BS4659-71	NFA35- 390-78	GOST	JIS 4404-72
Designation	40CrMoV5	T35Cr MoV1	X40Cr MoV51	H15	BH13	Z40CDV5	40X5MF18	SKD61
Chemical composition	C	0.35-0.45	0.3-0.4	0.37-0.43	0.30-0.40	0.22-0.42	0.36-0.44	0.33-0.42
	Si	0.90-1.20	0.8-1.2	0.9-1.2	0.80-1.20	0.85-1.15	0.8-1.2	0.80-1.20
	Mn	0.25-0.55	0.25-0.50	0.3-0.5	0.20-0.40	0.4	0.2-1.5	0.30
	P	0.030	0.03	0.030	0.03	0.03	0.025	0.03
	S	0.030	0.03	0.03	0.03	0.03	0.025	0.03
	Cr	4.5-5.5	4.75-5.25	5.0-5.50	4.70-5.50	4.75-5.25	4.8-5.5	4.50-5.50
	Mo	1.2-1.7	1.2-1.6	1.2-1.5	1.25-1.75	1.25-1.75	1.2-1.5	1.00-1.50
	V	0.85-1.15	1.0-1.2	0.9-1.1	0.80-1.20	0.9-1.1	0.85-1.15	0.80-1.10

HOT WORKING AND HEAT TREATMENT

Forging 1100°C max. (Commence)
900°C min. (Finish)

Annealing Heat slowly to 840-860°C (use lower temperature range for small sections, and higher range for large sections) and hold at this temperature for about 1 hour for light sections and small furnace charges.



annealed

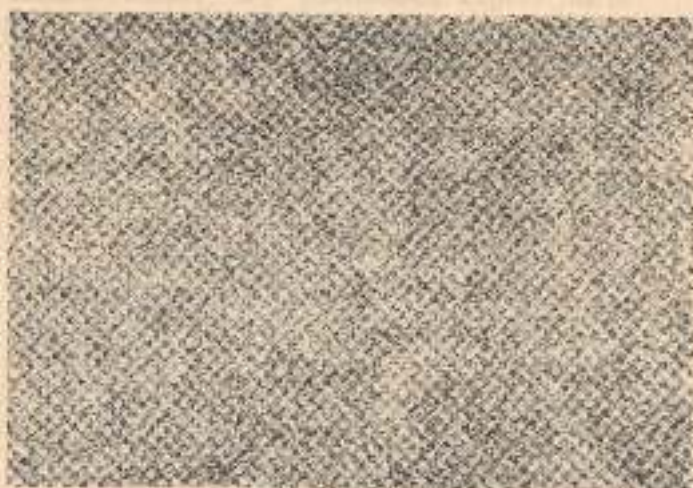
× 500

Fig. 21.5(b) The structure consists of fine spheroidal particles of carbide in a matrix of ferrite

to about 4 h for heavy sections and large charges. For pack annealing, hold 1 h per 25 mm of cross-section. Cool slowly in the furnace at a rate 28°C per hour until 540°C is reached, further it may be cooled fast. Typical annealed hardness 200–230 BHN. Figure 21.5(b) illustrates the annealed structure.

Stress relieving

Heat to 650–675°C and hold for 1 hour per inch of cross-section then cool slowly in the furnace.



hardened

× 500

Fig. 21.5(c) The structure consists of fine spheroidal alloy carbide particles (principally chromium carbide) in a matrix of untempered martensite



hardened and tempered

× 500

Fig. 21.5(d) The structure consists of a matrix of tempered martensite with a few spheroidal particles of alloy carbide

Hardening

Heat slowly to 1020–1060°C. Holding time in the temperature depends on the section thickness. It may vary between 20 and 45 minutes. Use shorter time for small sections and longer time for large sections followed by quenching in air (dry) or oil or salt bath. Oil quench may produce more distortion. The procedure best carried out by quenching into a salt bath held at 500–620°C, and soaking in the quench until the article reaches the temperature of the bath, subsequently cooled in air. Temper immediately when cooled to hand warm 50–60°C. Figure 21.5(c) illustrates the hardened structure, and Fig. 21.5(e) the isothermal TTT curve.

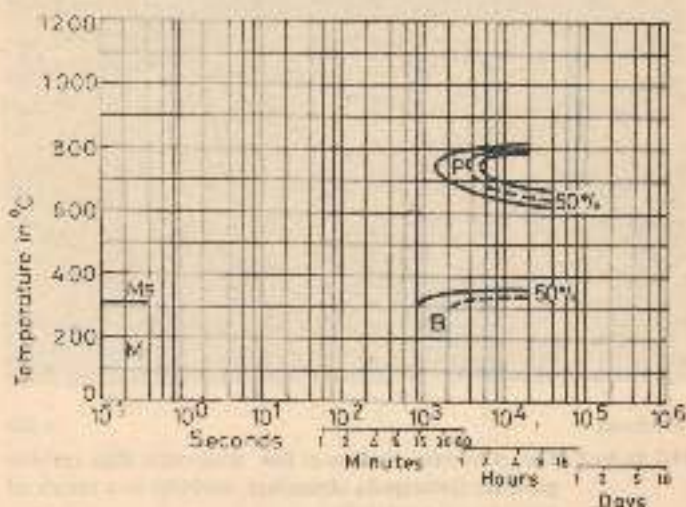


Fig. 21.5(e) Isothermal TTT curves of steel—(ISO) 40CrMoV5. Austenitizing temperature—1020°C, holding time = 15 min.

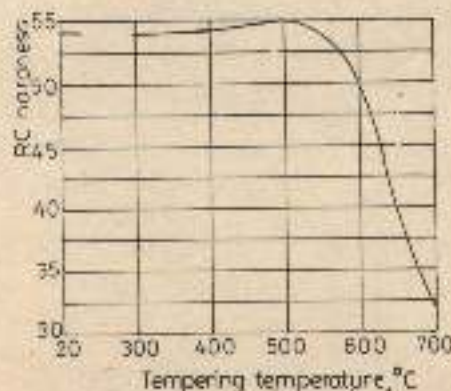


Fig. 21.5(f) Tempering curve of steel—(ISO) 40CrMoV5. Hardening temperature = 1050°C, time = 2 h, specimen size = 50 mm

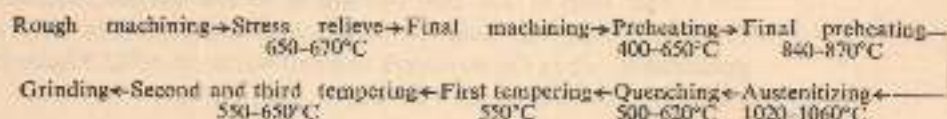
Tempering

Temper between 550 and 650°C depending on the hardness required. Soaking time 1 h per 20 mm cross section.

First tempering done at 550°C to attain the maximum hardness. After holding for the desired length of time, parts are cooled to room temperature.

Obtainable hardness—52–54 HRC second tempering is done to attain the working hardness. Depending on the desired hardness, the temperature is chosen from the tempering curve (Fig. 21.5(f)). Parts are cooled, after holding at the desired tempering temperature, to ambient temperature.

Third tempering at 50–60°C below the second tempering temperature may be adopted for further relieving the stresses and to increase the lives of the parts. Figure 21.5(d) illustrates the tempered structure and Fig. 21.5(f) the tempering curve.

PROCESSING SEQUENCE (H13)**Data Sheet 21.5—30WCrV9 (ISO)****CHARACTERISTICS**

This steel possesses high red hardness with toughness. Their resistance to softening and abrasion makes it suitable for applications where tools are in prolonged contact with hot metal, besides possessing an excellent resistance to deformation and surface heat cracking at high operating temperature. Compared to chrome-molybdenum hot work steel, this has a higher red hardness and higher wear resistance. But toughness of this steel is low.

This steel is not suitable for applications requiring intermittent water cooling, since resistance to thermal shock is only moderate. Thus, the tungsten die steel is employed where maximum hot strength and resistance to softening at elevated temperatures are the principal requirement. Table 21.6 gives the chemical composition of International Standard steels.

TYPICAL APPLICATIONS

Hot forging and blanking dies for making bolts, nuts, rivets, etc., where tools reach a high temperature, pegs and inserts for forging and stamping dies for steel, hot forging dies for copper alloys, extrusion dies, mandrels, Backer blocks, die holders, ejector discs for extrusion of copper and aluminium alloys, cores, ejector pins and nozzles for pressure die casting of copper base alloys, nozzles for pressure die casting of non-ferrous metals and alloys, dies for gravity die casting of copper base alloys.

HOT WORKING AND HEAT TREATMENT

Forging 1065°C max. (Commence)
 900°C min. (Finish)

- Annealing** 870–900°C. Adopt lower range for smaller sections and higher range for longer sections. Atmosphere in the furnace should be neutral. Holding time may vary from 1 h for light sections and small furnace charges to about 4 hours for heavy sections and large charges. Followed by cooling at a rate not exceeding 25°C per h up to 600°C and subsequently cooled in air. Typical annealed hardness 210–248 BHN max.
- Stress relieving** After rough machining the tool should be heated to 650–670°C, hold for one hour per 25 mm cross-section, cool slowly in air up to 400 BHN and then freely in air.
- Hardening** Heat slowly to 1100–1150°C in a neutral atmosphere and hold for 20 to 50 minutes depending on the section thickness, the shorter time should be used for small sections and the longer time for large sections. Quenching may be done in air, gas, oil or salt bath. When quenched in oil remove the tool when the temperature attains around 500°C and cool in air. Best method is to salt quench maintained at 550–640°C after attaining the bath temperature cool in air. Temper immediately when the tool cools to hand warm 50–60°C. Figure 21.6(a) illustrates the isothermal TTT curve.

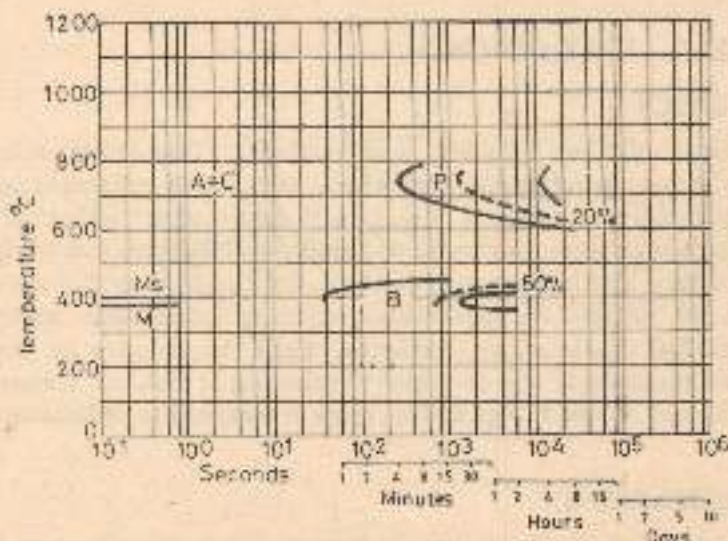


Fig. 21.6(a) Isothermal TTT curves of Steel—(18CrWV9. Austenitizing temperature = 1120°C (Courtesy: Röchling Stablexport, W. Germany)

- Tempering** Tempering between 600 and 700°C, to get the desired hardness. Holding time 1 hour per 20 mm cross-section.
- First tempering at 600°C should be carried out to attain maximum hardness and cool to room temperature in air after the tempering time lapsed. Obtainable hardness 52–54 HRC.

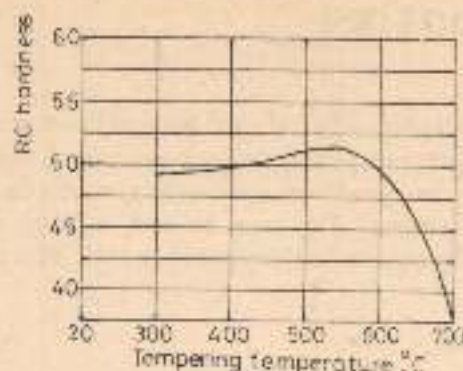


Fig. 21.6 (b) Tempering curve. Hardening temperature = 1110°C, time = 2 h, specimen size = 50 mm (Courtesy: Roehling Stahlexport, W. Germany)

Second tempering is done to attain the working hardness. Choose the tempering temperature from the tempering graph (Fig. 21.6(b)). After the desired holding time cool to room temperature in air.

The third tempering may be done at 30–50°C below the second tempering to relieve the stresses further and to increase the life of the tool.

PROCESSING SEQUENCE (H21)

Rough machine → Stress relieve → Final machining → Preheating → Final preheating
 650–670°C 400–650°C 840–870°C

Grinding → Second and third tempering → First tempering → Quenching → Austenitizing →
 600–700°C 600°C 500–620°C 1100–1150°C

Table 21.6

Country	ISO	INDIA	DEU	USA	GBR	FRA	USSR	JPN	
Standard norm	ISO	IS	DIN	AISI	BS970/ 1-72	NFA35- 551-75	GOST	JIS	
Designation	30WCrV9	XT33W9 C25V38	X30WCrV93	H21	8H21	Z30WCrV9	3Ch2W8F	SKD 5	
Chemical composition	C	0.25-0.35	0.25-0.40	0.25-0.35	0.3-0.4	0.25-0.35	0.25-0.32	0.3-0.4	0.25-0.35
	Si	0.1-0.4	0.10-0.35	0.15-0.30	0.15-0.30	0.4	0.10-0.40	0.15-0.40	0.4
	Mn	0.15-0.45	0.2-0.4	0.2-0.4	0.2-0.4	0.4	0.15-0.45	0.15-0.40	0.6
	P	0.030	—	0.035	—	—	0.025	0.03	—
	S	0.030	—	0.035	—	—	0.025	0.03	—
	Cr	2.5-3.5	2.8-3.3	2.5-2.8	3.0-3.75	2.25-3.25	2.5-3.5	2.2-2.7	2.0-3.0
	V	0.3-0.5	0.25-0.50	0.3-0.4	0.3-0.5	0.6	0.3-0.5	0.2-0.5	0.3-0.5
	W	8.5-9.5	8.0-10.0	8.0-9.0	8.75-10.0	8.5-10.0	8.5-9.5	7.5-8.5	9.0-10.0

Data Sheet 21.6—BH10A (BS)**CHARACTERISTICS**

This is a chromium-molybdenum-cobalt alloyed hot work tool steel. It has a high degree of toughness, very good strength and wear resistance at elevated temperature apart from fine heat checking resistance. It has good heat conductivity, stands up well against temperature shocks and admits water cooling. This may be used in place of H21 steel (AISI). Hot strength and hot wear resistance are low compared to H21. This also has a better hot wear resistance than H13 steel.

TYPICAL APPLICATIONS

Dies for hot pressing and forging of steel dies, dies for making bolts and nuts, hot shearing blades, moulds for die-casting and hot pressing brass, mandrels and dies for extrusion of brass and steel, tools and dies for the manufacture of hollow bodies.

HEAT TREATMENT

Stress relieving Heat to 650–670°C, after rough machining, hold 1 hour per 20 mm thickness and cool in the furnace up to 500°C, followed by air cooling.

Hardening Heat slowly to 1000–1050°C and hold in that temperature for 5–45 min. depending on the cross-section. For lighter sections adopt smaller time and longer time for heavier sections followed by quenching in oil or salt bath. Quenching in salt bath maintained at 500–620°C lessens the distortion, compared to oil quenching. In the process of oil quenching, the tool should be removed when it attains a temperature on the surface of around 500°C, followed by air cooling. Figure 21.7(a) illustrates the isothermal curve.

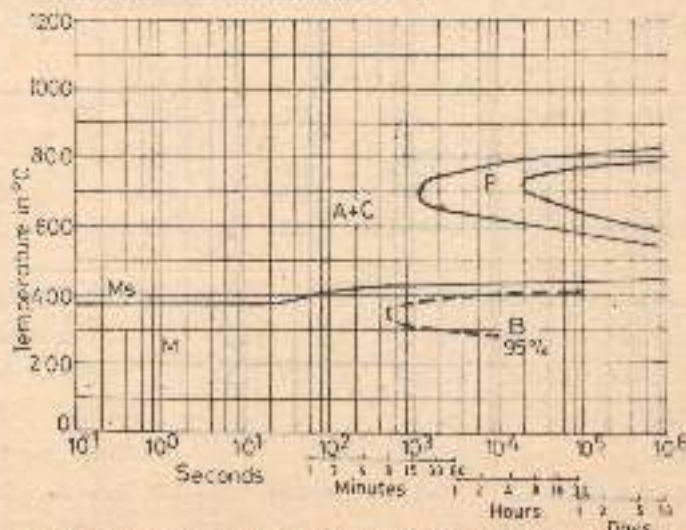


Fig. 21.7(a) Isothermal T-T curves of steel—(BS)BH10A. Austenitizing temperature = 1040°C, holding time = 20 min. (Courtesy: VEW, Austria)

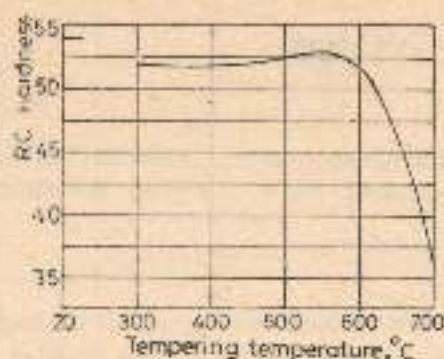


Fig. 21.7(b) Tempering curve. Hardening temperature = 1050°C, time = 2 h, specimen size = 20 mm (Courtesy: VEW, Austria)

Tempering

Temper between 550 and 600°C to get the desired hardness. Holding time 1 hour per 20 mm thickness.

First tempering at 550°C should be done immediately when the tool cools to 50 to 60°C. After holding time over, cool to room temperature in air.

Second tempering is done to attain the working hardness. Choose the tempering temperature from the tempering graph.

Third tempering is done at 30 to 50°C below the second tempering to relieve the stresses further and it is beneficial to increase the life of the tool. Figure 21.7 (b) illustrates the tempering curve.

PROCESSING SEQUENCE (BH10A)

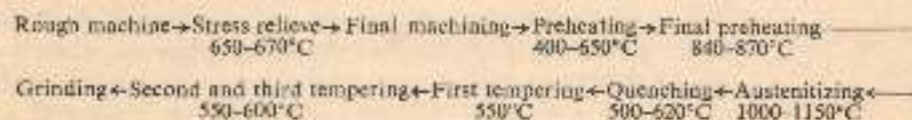


Table 21.7

Country	ISO	INDIA	DEU	USA	GBR	FRA	USSR	JPN
Standard norm	ISO	IS	DIN	AISI	BS4659-71	NFA35-331-75	GOST	JIS
Designation	BH10A							
Chemical composition	C	—	—	—	0.3-0.4	—	—	—
	Si	—	—	—	1.10	—	—	—
	Mn	—	—	—	0.4	—	—	—
	Co	—	—	—	2.8-3.2	—	—	—
	Mo	—	—	—	2.65-2.95	—	—	—
	V	—	—	—	0.3-1.1	—	—	—
	Cr	—	—	—	2.8-3.2	—	—	—

Data Sheet 21.7—30WCrV5 (ISO)**PROPERTIES**

This steel possesses high red hardness and heat retention, good thermal conductivity and excellent resistance to heat checking. Table 21.8 gives the chemical composition of International Standard steels.

APPLICATIONS

This steel is mainly used for setting tools that are subject to shock, such as dies for screws, nuts and rivets, heading dies, jaws and dies for forging machine, etc.

It is also suitable for pressure pads for oil and air cooling, die holders for metal tube and rod extrusion presses, mandrels and dies for lead cable presses, rolling mandrels, die casting tools, etc.

Tools and dies made from this steel may be subjected to nitriding and nitrocarburizing to enhance their lives.

HOT WORKING AND HEAT TREATMENT

Forging	900–1100°C
Annealing	740–780°C
Annealed hardness	210–235 BHN
Stress relieving	After rough machining, the tools are heated to 650–670°C, soaked for 1 h per 25 mm thickness and cooled slowly in the furnace up to 400°C. They are further cooled in air.
Hardening	Heat the parts slowly to 1060–1100°C in a neutral atmosphere and hold at that temperature for 15–40 min. Adopt shorter times for parts with small sections and higher times for larger section thicknesses. This is followed by quenching in oil, compressed air, or a salt bath. When quenched in oil, the tool should be taken out when it attains around 500°C and cooled in air. Compared to salt baths, distortion is more in oil quenching. Salt bath quenching at 500–600°C is more ideal. After attaining the bath temperature, the tool should be air cooled. Temper immediately after the tool attains hand warmth, i.e., 60°C.
Tempering	Temper between 600 and 680°C, depending on the hardness required. Soaking time is 1 h per 20 mm cross-section. First tempering is done at 600°C to attain the maximum hardness. After the soaking time, the tool is cooled to room temperature and the hardness checked. Obtainable hardness—50–54 HRC. Second tempering is done to attain the working hardness. The temperature adopted depends on the working hardness. After the tempering time has elapsed, the tool is cooled to room temperature. The third tempering may be done at 30–50°C below the second tempering, to relieve stresses further and to increase the life of the tool.

Table 21.8

Country	ISO	INDIA	DEU	USA	GBR	FRA	USSR	JPN
Standard norm	ISO 4957-80	IS	DIN	AISI	BS970/ 1-72	NFA35- 590-78	GOST	JIS G4404-72
Designation	30WCrV5	—	X30WCrV53	—	—	Z32WCrV5	—	SKD 4
Chemical composition	C %	0.25-0.35	—	0.25-0.35	—	0.28-0.35	—	0.25-0.35
	Si %	0.10-0.40	—	0.15-0.30	—	0.10-0.40	—	0.40
	Mn	0.15-0.45	—	0.20-0.40	—	0.15-0.45	—	0.60
	Cr	2.0-3.0	—	2.20-2.50	—	2.00-3.00	—	2.00-3.00
	W	4.50-5.10	—	4.00-4.50	—	4.50-5.10	—	5.00-6.00
	V	0.40-0.70	—	0.50-0.70	—	0.40-0.70	—	0.30-0.50

Data Sheet 21.8—55NiCrMoV6 (DIN)

CHARACTERISTICS AND TYPICAL APPLICATIONS

This is an oil hardening steel with great depth of hardening and extreme resistance to wear at elevated temperatures, for high surface pressure and resistance to heat checking. Table 21.9 gives the chemical composition of International Standard steels.

Preferred for all sizes and impressions, for the forging of hard steel as well as for jaws in forging machines, hammers and press anvils, jaw dies and rams for the manufacture of screws, nuts, rivets and bush. Hot hobbing rams and hot shear blades, pressing and tube extrusion stems for the processing of light and heavy metals, die holders, etc.

HOT WORKING AND HEAT TREATMENT

Forging 1050°C max. (Commence)
850°C min. (Finish)

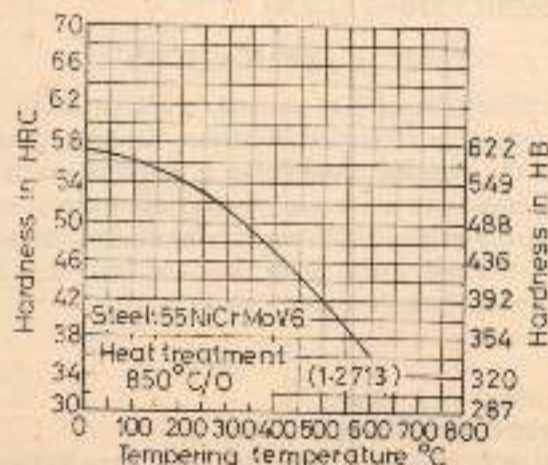


Fig. 21.8 Tempering curve of steel—(DIN) 55NiCrMoV6

Annealing	710–680°C soaking time 4–6 hours, followed furnace cool. Annealed BHN—230.
Stress relieving	Heat slowly to 650°C, soaking time 1 hour per 20 mm thickness followed by furnace cool.
Hardening	Heat slowly to 830–850°C, followed by oil quenching; when cooled to hand warmth temper immediately. Hardness—54–58 RC.
Tempering	Depending on the hardness required, choose the temperature from the tempering curve. Soaking time is 1 h per 20 mm thickness. Figure 21.8 illustrates the tempering curve.

Table 21.9

Country	ISO	INDIA	DEU	USA	GBR	FRA	USSR	JPN
Standard norm	ISO	IS	DIN 17350-80	AISI	B8970/ 1-72	NFA35- 590-78	GOST	JIS 64404-72
Designation			55NiCrMoV6			55NCDV7	5C6NM	SKT 4
Chemical composition	C	—	0.5-0.6	—	—	0.5-0.6	0.5-0.6	0.5-0.6
	Si	—	0.1-0.4	—	—	0.1-0.4	0.15-0.35	0.35
	Mn	—	0.65-0.95	—	—	0.5-0.8	0.5-0.8	0.6-1.0
	P/S	—	0.03/0.03	—	—	0.03/0.03	0.03/0.03	0.03/0.03
	Cr	—	0.6-0.8	—	—	0.7-1.0	0.5-0.8	0.7-1.0
	Mo	—	0.25-0.35	—	—	0.3-0.5	0.15-0.30	0.2-0.5
	Ni	—	1.5-1.8	—	—	1.5-2.0	1.4-1.8	1.3-2.0
	V	—	0.07-0.12	—	—	0.05-0.15	0.05	≤ 0.20

Data Sheet 21.9—56NiCrMoV7 (DIN)

CHARACTERISTICS AND TYPICAL APPLICATIONS

This steel is an oil hardening die steel. It possesses a greater depth of hardening, extreme wear resistance at elevated temperatures, extraordinary hot strength and thermal shock resistance. Table 21.10 gives the chemical composition of International Standard steels.

This steel is recommended for maximum production irrespective of die block size and type of impression or cavity preferred for the forging of hard steels as well as for jaws in forging machines, hammer and press anvils, jaw dies and rams for the manufacture of screws, bending and coining tools, die holders, carriers, etc.

HEAT TREATMENT

Forging	1050°C max. (Start) 850°C min. (Finish)
Annealing	Heat to 680–700°C, hold for 5–6 h; then furnace cooling. Annealed hardness—230–250 BHN. Figure 21.9 (a) illustrates the annealed structure.

- Stress relieving** After rough machining heat slowly to 650°C, hold for 2-3 h followed by furnace cooling up to 500°C, thereafter in air.
- Hardening** Heat slowly to 840-870°C, followed by oil quenching. Temper immediately when cooled to hand warmth. Obtainable hardness—60-61 RC. Figure 21.9(b) illustrates the hardened structure.
- Tempering** According to the hardness desired, temper between 450 and 600°C. Figure 21.9(c) illustrates the tempered structure, and Fig. 21.9(d) the tempering curve.



annealed

× 500

Fig. 21.9 (a) Structure consists of spheroidal cementite particles in a matrix of ferrite

Table 21.10

Country	ISO	INDIA	DEU	USA	GBR	FRA	USSR	JPN
Standard norm	ISO 4957-80	IS	DIN 17350-80	AISI	BS970/ 1-72	NFA35-551-75	GOST	JIS
Designation	55NiCrMoV2		56NiCrMoV7	L6				
Chemical composition	C %	0.5-0.6	—	0.5-0.6	0.65-0.75	—	—	—
	Si %	0.1-0.4	—	0.1-0.4	0.2-0.4	—	—	—
	Mn	0.65-0.95	—	0.65-0.95	0.55-0.85	—	—	—
	P	0.03	—	0.03	—	—	—	—
	S	0.03	—	0.03	—	—	—	—
	Cr	0.95-1.25	—	1.0-1.20	0.65-0.85	—	—	—
	Mo	0.3-0.5	—	0.45-0.55	0.025	—	—	—
	Ni	1.50-2.00	—	1.50-1.80	1.25-1.75	—	—	—
	V	0.05-0.25	—	0.07-0.12	0.025	—	—	—



hardened

× 500

Fig. 21.9 (b) Structure is mainly fine untempered martensite with a few spheroids of cementite



hardened and tempered

× 500

Fig. 21.9 (c) Structure is tempered martensite with a few spheroids of cementite

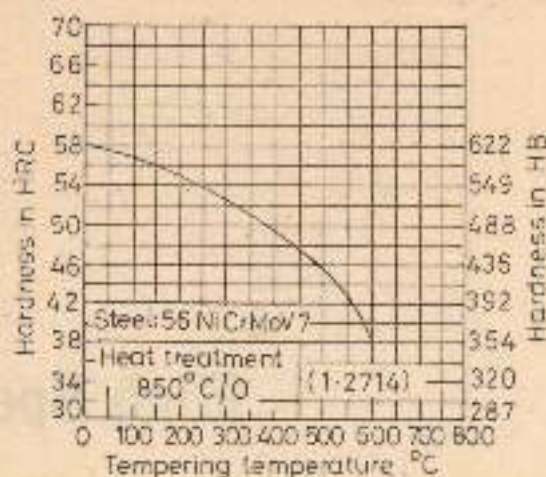


Fig. 21.9 (d) Tempering curve of steel—(ISO) 55NiCrMoV2

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6. NFA 35-590, 1978, *Hot Work Tool Steels*, *Stahlschlüssel-85*.
7. GOST, USSR, *Hot Work Tool Steels*, *Stahlschlüssel-1981*.
8. JIS, G4404, 1972, Table 5, *Alloy Tool Steels*.

High Speed Steels

High speed steel is a highly alloyed tool steel. High speed steels owe their name to the fact that they were originally developed for high speed metal cutting. The properties of high resistance to wear and heat, high initial hardness of about 60 to 65 RC at service temperatures of 600 to 650°C and the economical price of high speed steels have made them a logical choice of many cutting industries.

There are many different types of high speed steels. Originally the principal alloying elements in high speed steel were tungsten, chromium and vanadium in an approximate proportion of 18-4-1. To obtain special features and still higher cutting capacity steels alloyed with cobalt were brought out in 1912 by Mr. Becker. Later in 1927, high speed steels were brought out with an increased content of carbon and vanadium. However very few fundamental changes took place in the composition of high speed steels until 1937. In the mean time, between the first and second world wars, experimentation was started at several sources on the use of molybdenum to replace tungsten entirely or to some extent. Several "Moly" high speed steels were in successful use in production tools before the war started, so that when war actually did break out the switch to molybdenum-bearing high speed steels was quite rapid due to the shortage of tungsten and its higher cost.

In the mean time, carbide tools also came into wide use and in some cases exhibited great merits. Nevertheless, the trend seems to be that the importance of high speed steel will not diminish. It is likely that the use of high speed steel will increase once the properties and usefulness of the modern varieties become generally known by industries. There are many applications for which high speed steel is not only more economical but actually more suitable than tungsten carbides. Today a wide variety of high speed steels are available.

For example, when brittleness is to be avoided, vibration is present, and the cutting edge is subjected to shock, high speed steels are the obvious choice over the other cutting tool materials. High speed steels are now available in a wide variety to cover a large range of machining applications.

22.1 Influence of Alloying Elements on the Properties of High Speed Steel

The desired high hardness, hot strength, red hardness, toughness and wear resistance of the tools depends mainly on the presence of alloying elements present in the high speed steel. The effects of these alloying elements are given below.

TUNGSTEN AND MOLYBDENUM

Molybdenum and tungsten form M_4C carbides in high speed steels, where M represents the metal atom and C the carbon atom. These carbides increase the wear resistance and red hardness of the tools. The M_4C carbides have a hardness of about 73–77 RC.^{1,2} These carbides partially dissolve at higher temperatures (1150–1300°C)^{2,3,4} during hardening and result in maximum secondary hardness after tempering.

High speed steels containing large amounts of molybdenum are usually more sensitive with regard to grain growth during hardening and thus require more precise temperature control. Moreover, they must be hardened from a lower temperature than tungsten high speed steel. Molybdenum high speed steels have a decarburization tendency at the austenitizing temperature.

COBALT

The main effect of cobalt in high speed steels is to increase the hot hardness, which can permit higher cutting speeds. The cobalt does not form carbides, but dissolves in the matrix. Cobalt increases the thermal conductivity and the coercive force while the red hardness remains unchanged. The durability of cobalt content high speed steel is 2 to 3 times more due to higher secondary hardness, wear resistance and thermal conductivity. Cobalt steels are therefore used for planing hard materials and for turning chrome nickel steels and other materials of high hardness, austenite stainless steel including castings and highly alloyed steels. Cobalt content steels give exceptionally good results in high cutting speeds particularly on automatic machines.

The melting point of HSS is raised by the presence of cobalt. As a rule this enables a higher hardening temperature to be used without the risk of grain growth. Higher hardening temperatures permit more of the alloying elements to go into solution, thus improving the hot hardness.

CHROMIUM

A chromium content of about 4% is used in all high speed steels mainly to promote the depth of hardenability. The chromium forms $M_{23}C_6$ carbides, which are fully dissolved (950–1000°C)^{2,3,4} during hardening and have become the primary source of martensite. In tempering $M_{23}C_6$ carbide forms at higher temperature 400–500°C and plays an important role with regard to secondary hardness. $M_{23}C_6$ carbide have a hardness of approximately 1000–1100 HV.^{1,2}

VANADIUM

Vanadium in high speed steels largely forms MC carbide of high hardness (RC 84–85). Due to this the wear resistance increases. MC carbides start dissolve at higher temperature 1100–1150°C^{2,4,5} during hardening. Precipitation of MC carbides takes place during temper-

ing at about 500–600°C resulting in higher secondary hardness. When the vanadium content is at higher level, the grindability will be poor.

22.2 Soft Annealing

After forging and rolling, the steel is subjected to annealing treatment in order to soften it and increase its machinability. It also imparts to the steel a suitable structure for hardening. This treatment is normally done at the manufacturer's works.

The annealing temperature for high speed steel will be in the range of 880–890°C for soft annealing. During annealing the steel must be slowly heated to the annealing temperature. The annealing time depends on the size of the tool and the quantity of steel in the furnace at one time and usually ranges from 4 to 6 hours. Annealing for a longer period



Fig. 22.1 (AISI) M2 steel, annealed. The microstructure consists of a matrix of ferrite containing small to extremely small spheroidal particles (white dots) of alloy carbides.

may lead to coagulation of the carbides which influence hardenability unfavourably. Cooling from the annealing temperature should proceed at a very slow rate (15–20°C/hour) to reach about 650°C in the furnace. The material may then be cooled to room temperature in air. As high speed steel tends to decarburize during heat treatment, special attention should be given to this soft annealing. Decarburization can be avoided by box annealing, e.g., by packing in burnt coke grits, or using controlled atmosphere or vacuum.

The hardness of properly annealed steel for better machinability will be in the range 240–300 HB. An average structure of properly annealed steel is shown in Fig. 22.1.

22.3 Stress Relieving

In the manufacture of stable, accurate tools, it is desirable to stress relieve the tools before hardening them. This is particularly appropriate for complicated tools that have been highly stressed by rough machining. If these residual stresses from such operations are not removed, they get added to the thermal stresses during hardening, and may even cause the tool to distort or crack.

Stress relieving is carried out after enough machining allowance is removed by rough machining, keeping the finish machining allowance for removal after heat treatment. Stress relieving is not intended to modify the structure and it is only to relieve the induced stresses. This is carried out in a temperature range of 650–700°C, either in a forced air circulation furnace or in a muffle furnace. In the stress relieving operation the tools are heated slowly to the desired temperature and held at that temperature for 1 hour per 20 mm thickness. After the soaking time is over, the tools are cooled slowly at a uniform rate, usually in a furnace.

After stress relieving, it is important that the tools be remeasured and any variation in dimensions due to stress relieving be corrected before hardening. If dimensional changes caused by stress relief are not important, the cooling operation may be omitted; and heating can be continued to the quenching temperature (hardening temperature) because stress relieving is considered as a preheating operation.

22.4 Special Heat Treatment for Better Surface Finish

When high surface finish is required, for example in tools like gear hobbing cutters, milling cutters, etc., they should have a smooth surface finish after machining but steels in the normally annealed condition do not give a fine surface finish. It is, therefore, a common practice for the rough machining tools to be prehardened to produce a smooth surface finish on machining.

Prehardening is carried out at 880 to 930°C (1620 to 1710°F) with oil quenching and subsequent tempering at 630 to 650°C (1170 to 1200°F) for one hour to get a hardness of 35 to 40 HRC. This treatment not only improves the surface finish but also acts as a stress relieving treatment after rough machining, thus reducing distortion, lowering size growth and improving the consistency of cutting properties in final hardening by a factor of two or three.^{4,7}

Hardening steel from this relatively low temperature avoids intercrystalline fracture, and reduces the holding time during final hardening to the quenching temperature.

22.5 Mechanism of Hardening (Theory of Hardening)

The structure of high speed steel in the annealed condition consists of 3 main types of carbides $M_{23}C_6$, M_6C and MC carbides in a matrix of ferrite (where M represents a metal atom and C a carbon atom). For the most part, $M_{23}C_6$ is a chromium carbide, M_6C a molybdenum/tungsten carbide and MC a vanadium carbide. The three different carbides go into solution at different temperatures during hardening. These carbides play an important role in the hardened and tempered structure. If we examine a section of annealed high speed steels under the microscope, we find that it has a structure similar to Fig. 22.1. Here the round white particles are principally tungsten/molybdenum carbides and these are imbedded in a soft matrix or background of iron containing certain other elements in solution.

During heating to hardening temperature no change takes place in this structure until the critical temperature is reached at about 800°C . Certain important changes take place at this stage. First, the structure changes from ferrite to austenite and becomes non-magnetic. Secondly, the carbides begin to go into solution. Upon heating further the $M_{23}C_6$ carbides clearly dissolve in the austenite as the temperature is raised. The amount present decreases rapidly as the temperature reaches above 900°C and by the time, 1100°C is reached, this

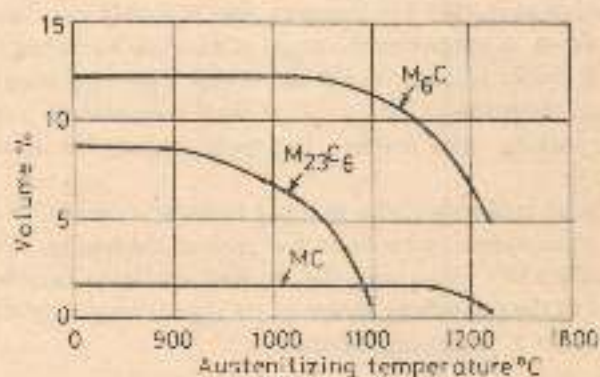


Fig. 22.2 Effect of austenitizing temperature on the amounts of individual carbides in 6-5-4-2 steel ($M_{23}C_6$, M_6C , MC)²

phase is almost entirely in the solution^{3,4,5,8} (Fig. 22.2). The dissolution of $M_{23}C_6$ carbides causes the saturation of austenite with chromium, and thus increases the hardness. At this lower temperature range the M_6C carbide dissolves only to a limited extent; the MC carbide does not dissolve at all. Upon further heating to higher temperatures, the M_6C carbide dissolves more gradually although the rate increases somewhat above 1150°C ,^{4,5,8} while the vanadium rich carbide MC hardly dissolves at all below 1200°C . The continued increase in tungsten, molybdenum, vanadium and chromium content in austenite seems to confirm the presence in M_6C . The dissolution of MC carbide takes place above 1200°C . On heating to a still higher temperature, the dissolution of carbides in the austenite is further enhanced.

The desired hardening temperature is one at which the maximum amount of carbide

is taken into solution with the minimum amount of grain growth. At this point we have a matrix of austenite holding in solution a large quantity of carbides, and also imbedded in a matrix a considerable quantity of undissolved carbides. Hardening temperature employed for molybdenum series will be about 1170 to 1240°C, and for tungsten series will be about 1250 to 1300°C. During commercial hardening M_6C and MC carbides get dissolved partially. Since all of the chromium rich $M_{23}C_6$ carbide is dissolved at the commercial hardening temperature, the excess phase consists of the tungsten or molybdenum rich carbide M_6C and the vanadium rich carbide MC . It may be seen from Fig. 22.2 that the quantities of each carbide phase dissolved during commercial hardening will be in the range of 7 to 10% M_6C , 9 to 11% $M_{23}C_6$, and 1 to 3% MC carbide and all types of high speed steels retain 7 to 12% volume undissolved carbides.

After holding at hardening temperature for the requisite length of time, the steel is then cooled at a rate sufficient to ensure transformation of martensite. Normal practice is to quench them in oil (60 to 100°C) or in warm bath maintained at 580 to 600°C. At a lower temperature the austenite is very stable, particularly between 600 and 400°C. On further cooling no appreciable change takes place until it reaches about 220°C. At this point the austenite matrix begins to change or transform rapidly into martensite with a hard needle-

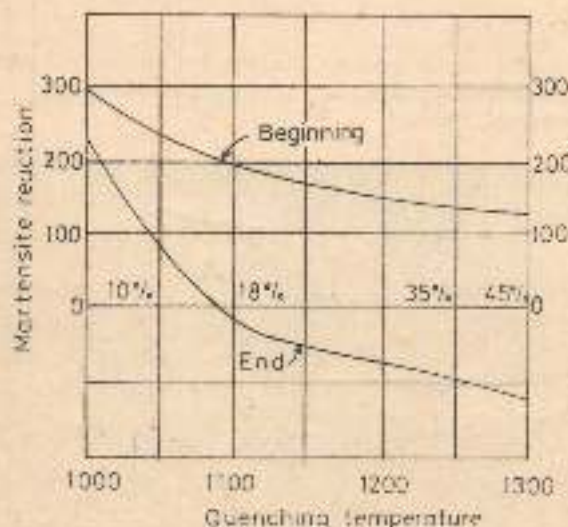
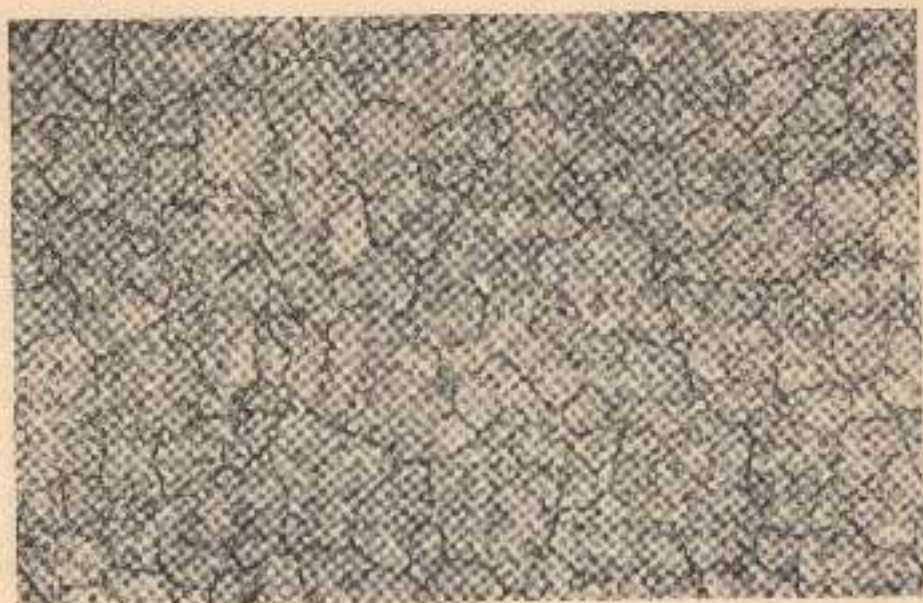


Fig. 22.3 Effect of austenitizing temperature of beginning and end of martensite formation on continuous cooling of 18-4-1 steel (the percentage of austenite retained at room temperature and at 120°C)

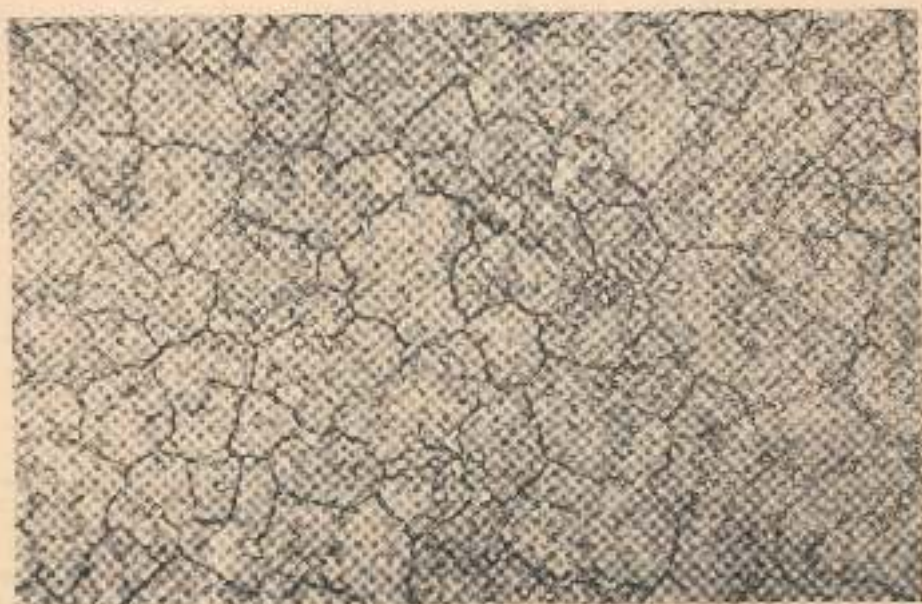
like constituent. The transformation continues as the temperature falls and is accompanied by an expansion of the steel. When the steel reaches room temperature, about 70 to 80% of the austenite is transformed to martensite, so that if cooling is stopped at that point, as it usually is, there will still be present about 20 to 30% of retained austenite depending on the austenitizing temperature (Fig. 22.3). The resulting hardness will be about RC 65 and the structure will be similar to Figs 22.4 (a and b).



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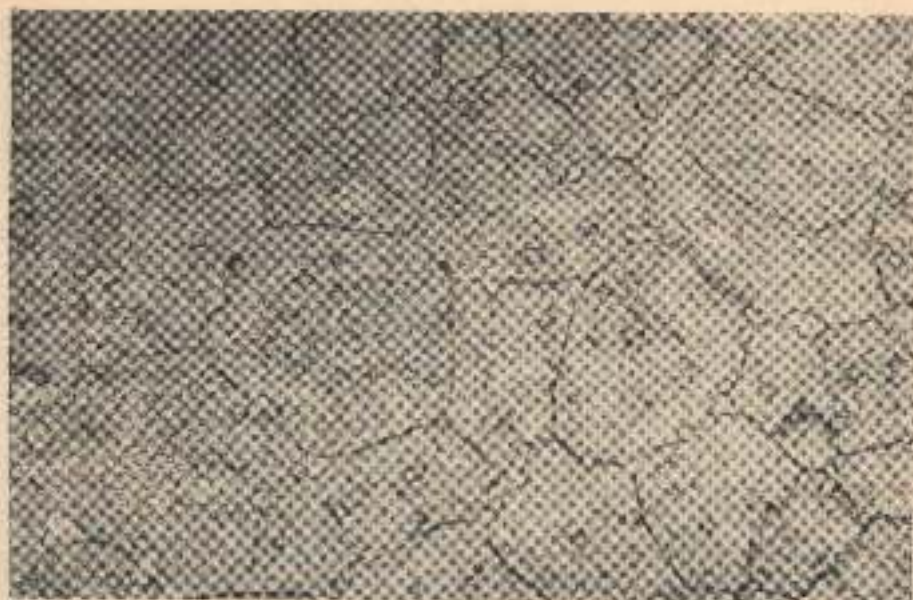
Fig. 22.4 (a) Spheroidal carbide particles in a matrix of untempered martensite. Austenitizing temperature 1220°C, not tempered, grain size = 12.1 intercept (Courtesy: Speed Steel, Sweden.)



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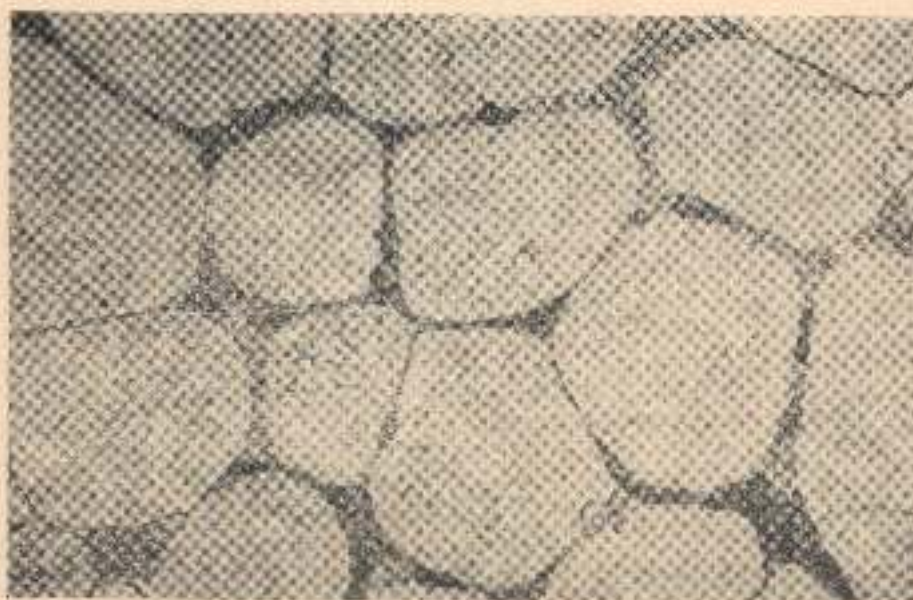
Fig. 22.4 (b) Spheroidal carbide particles in a matrix of untempered martensite with higher hardening temperature 1240°C, not tempered, grain size = 11 intercept (Courtesy: Speed Steel, Sweden.)



177269

× 1000

Fig. 22.4(c) Overheated structure showing precipitated carbide eutectic and grain boundary carbide in a matrix of coarse martensite. Austenitizing temperature 1260°C, not tempered, grain size = 5.8 intercept (Courtesy: Speed Steel, Sweden)



177268

× 1000

Fig. 22.4(d) Overheated structure shows more precipitated carbide eutectic. Austenitizing temperature 1280°C, not tempered, grain size = 5.4 intercept (Courtesy: Speed Steel, Sweden)



177311

×1000

Fig. 22.4(e) Hardened microstructure in a M2 bar (13 mm square). Austenitizing temperature 1140°C, not tempered, grain size = 16 intercept (Courtesy: Speed Steel, Sweden)



177308

1000X

Fig. 22.4(f) Spheroidal carbide particles in a matrix of untempered martensite. Austenitizing temperature 1180°C, grain size = 17.3 intercept (Courtesy: Speed Steel, Sweden)

Heating to very high austenitizing temperature, a reaction occurs between the complex carbides and the adjacent austenite to form certain amounts of liquid. The liquid when cooled to room temperature will again solidify as a eutectic exactly similar to that found in the cast high speed steel. This structure as shown in Figs 22.4(c) and 22.4(d) is characteristic of high speed steels that have been overheated and is generally associated with a very large grain size. For this reason molybdenum content high speed steel should not be heated to above 1250 to 1260°C, and the tungsten content steel above 1310 to 1325°C. The overheated steel is very brittle. Heating the steel below the derived hardening temperature will lead to a lower hardness after tempering or hardening. This is due to insufficient carbide dissolution in the austenite. Figures 22.4 (e) and 22.4 (f) illustrate the structure of under-heated steels,

22.6 Transformation During Cooling

When high speed steel consisting of highly alloyed austenite and undissolved carbides is cooled from the hardening temperature, there is an immediate tendency towards the precipitation of carbides from austenite, since the solubility of Mo, W, Cr, V and C decreases with decreasing temperature. Carbide precipitation from austenite takes place if there is a delay in cooling to the temperature of 650°C. It can be seen from the TTT (Fig. 22.5) diagram that between 760 and 650°C the transformation of austenite is relatively fast being

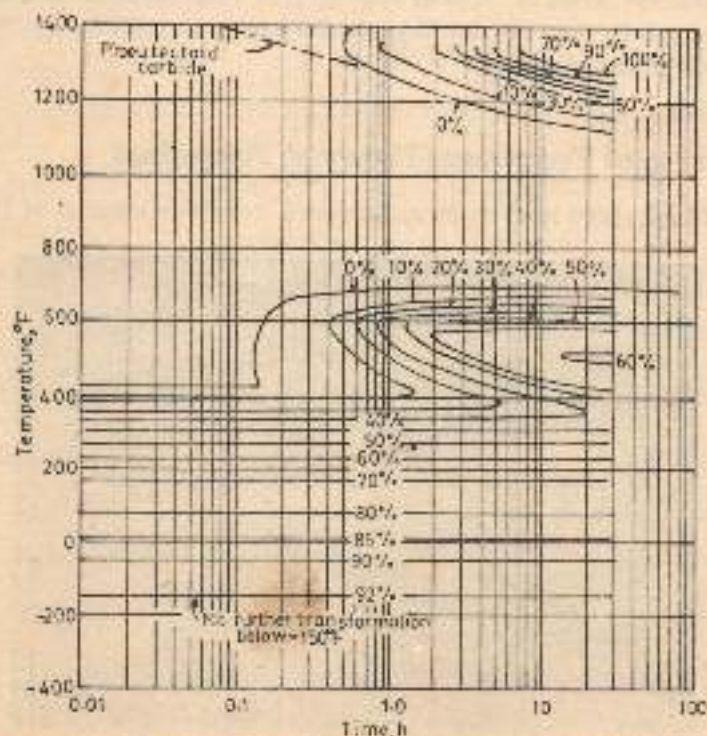


Fig. 22.5 Transformation (TTT) curves for type A1S1,T1 high-speed steel. Austenitizing temperature 2350°F (1288°C) (Gordon, Cohea and Rose)

more rapid at 750°C. (1382°F) The decomposition at this temperature leads to the formation of very fine spheroidite, accompanied by a precipitation of carbide. The precipitated carbides concentrate mainly at grain boundaries and thus lower the strength of steel. For this reason, air hardening cannot be recommended for high speed steels. The grain boundary precipitation will be minimised below 650°C.

At a lower temperature austenite is very stable, particularly between 620 and 400°C, and even holding for a long time can cause no noticeable transformation. This is made use of in salt bath quenching between 500 and 600°C.

As the temperature is lowered, bainite transformation takes place in the temperature range of 400–200°C¹⁰. The maximum amount of bainite that can be formed isothermally is 55 to 60% after holding for more than 6 hours and the remaining 35 to 40% retained austenite is very stable and no further decomposition takes place on subsequent cooling to the room temperature.

A longer holding time in the bainite region results in a lower hardness with a higher strength. Subsequent tempering gives the hardness and structure obtained by the other quenching methods.

The temperature at the beginning and end of the martensite transformation depend on the hardening temperature chosen and cooling conditions. In the majority of high speed steels the martensite transformation begins at 200 to 150°C and does not come to the end even at room temperature. On cooling further, the transformation restarts and proceeds intensively on cooling down to –70 to –80°C (158°F to 176°F) and even then 5 to 6% retained austenite will be there. By cooling still further to –110°C, only 1% of additional austenite undergoes transformation.

22.7 Mechanism of Tempering (Theory of Tempering)

The structure of high speed steel in the as hardened condition consists of 70 to 80% tetra-



22.6(a) Spheroidal carbide particles in a matrix of untempered martensite with higher hardening temperature. The ASTM grain size increases from 14 to 9. (Courtesy: VEW, Austria)



22.6(b) The same steel at higher magnification (Courtesy: VEW, Austria)

gonal martensite, 15 to 30% highly alloyed untransformed austenite and undissolved M_6C and MC carbide (9–12%) (Fig. 22.6 (a) and (b)). If we now re-heat this hardness structure the following changes will take place according to Cohen and Kho and documented by many others as follows.^{12-13,14}

During heating we find a slight drop in hardness as the temperature reaches about 320°C, this is due to the tempering of martensite (Fig. 22.7). Martensite loses its tetragonal form in this stage and gets decomposed to cubic martensite with the rejection of carbon as epsilon carbide. The epsilon carbide subsequently disappears with the appearance of cementite Fe_3C on tempering at somewhat higher temperatures up to about 400°C.

Upon further heating between 400 and 560°C there is a partial resolution of the cementite and precipitation of the alloyed carbides of tungsten carbide W_2C or molybdenum carbide Mo_2C in addition vanadium carbide V_4C_3 may be formed. Accompanied by a pronounced hardening when the secondary carbides precipitate (Table 22.1).

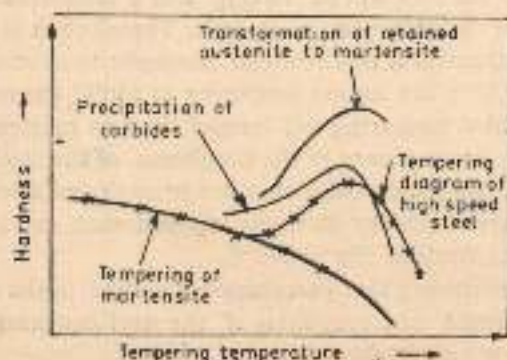


Fig. 22.7 Typical curves illustrate the effect of tempering of high-speed steel

When the secondary carbides precipitate the retained austenite is deprived of its alloying elements and its alloying content drops (carbon and alloying elements partially separate from the austenite during heating at 500 to 600°C). When the high speed steel cools after tempering, the retained austenite which now has a lower alloy content, is less resistant to transformation and can be partially transformed into martensite, a process earlier inhibited during quenching by a higher alloy content. Martensite does not form until the steel cools below about 200°C from the tempering temperature. In order to transform the retained austenite to martensite it is necessary to cool back to room temperature. Because of the new transformation of martensite from the retained austenite the proportion of martensite increases while that of retained austenite diminishes. This in turn makes a contribution to the hardness of the material; indeed the most significant contribution. After first tempering at 550°C the structure will look like Fig. 22.8.



Fig. 22.8 Spheroidal carbide particles in a matrix of tempered martensite. Some small areas of retained austenite are evident. S6-5-2 steel (Courtesy: VEW, Austria).

After first tempering, the tool will be having still a considerable quantity of retained austenite and with some untempered martensite. Therefore it is necessary to repeat the tempering operation to transform this retained austenite to martensite and to temper the newly borne martensite. After the second tempering at 550°C the structure of the steel will be as in Fig. 22.9. The third tempering will temper the new martensite.

There will be further improvement in the toughness of the steels after the fourth tempering.¹⁶ Table 22.1 indicates the carbides that are precipitated after tempering.

To attain the maximum secondary hardness molybdenum steels should be tempered at 540 to 560°C and tungsten steels at 560 to 570°C.

During subsequent tempering the percentage of carbon in the martensite decreases as a result of which the strength and toughness of the steel increases somewhat. Moreover, the thermal conductivity is also improved.

With a tempering temperature between about 620°C and 650°C, resolution of M_2C , and

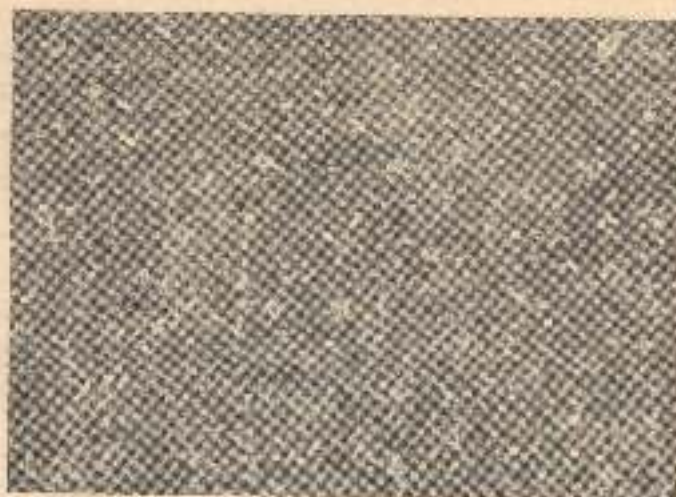


Fig. 22.9 Large and small alloy carbide (white) in tempered martensite (Courtesy: VFW Austria).

Table 22.1

Steel grade	Hardening temp tempering temp 580°C	Total carbide volume %		
		Annealed	Hardened	Tempered
18-4-1-5 0.8%C	1270	26.64	15.42	17.36
18-4-1-5 1.02%C	1190	30.6	19.01	20.09
12-4-2-5 1.01%C	1220	22.65	9.35	11.51

final disappearance of Fe_3C are observed in addition to precipitation of M_{23}C_6 and M_6C . Hardness falls rapidly, and apart from this toughness will reduce.

22.8 Hardening Procedure

Hardening of high speed steel tools is an exacting procedure by means of which the high working temperature and longer tool life can be obtained. The important properties of high red hardness, high wear resistance and higher toughness are actually built into high speed steel by a correct choice of heat treatment parameters. Hardening of high speed steel tools consists of heating, holding, quenching and tempering (Fig. 22.10).

22.8.1 HEATING

Since high speed steel has a low thermal conductivity, the tools made out of H.S.S. should

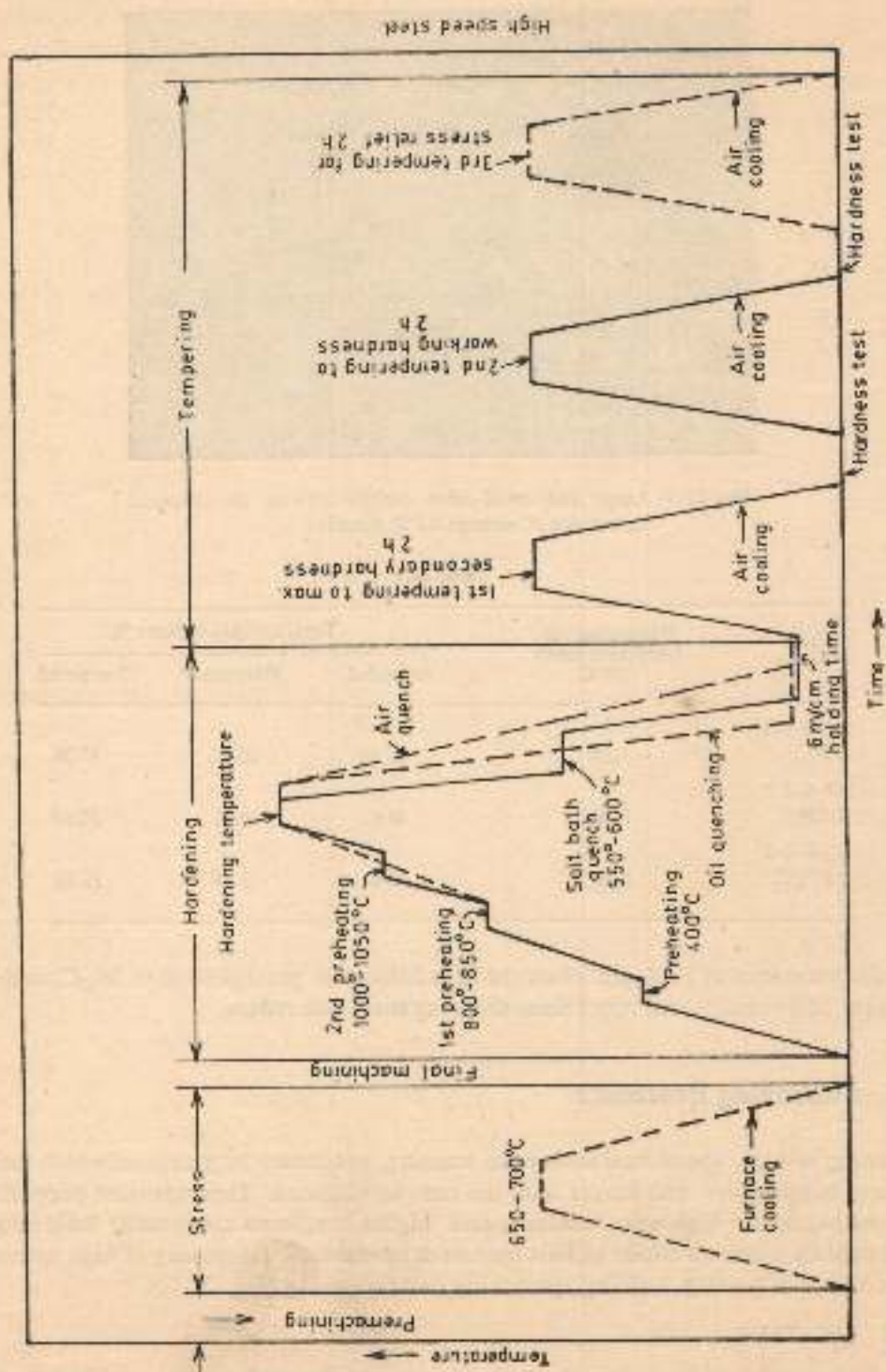


Fig. 22.10 Heat treatment sequence for high-speed steels.

be hardened by heating in stages. If large and complicated tools are heated directly to the hardening temperature in one step, the great difference in temperature between the surface and the core will cause such an uneven expansion that the tool may distort heavily or even crack. Therefore, tools made out of high speed steel should be preheated in stages as follows.

FIRST PREHEATING Normally, the tools are first preheated in an air circulation furnace to 300 to 400°C and held there until the tool temperature is even throughout the tool.

SECOND PREHEATING It is then further heated in a salt bath maintained at 840 to 860°C. The holding time at this temperature is 8 to 9 minutes per centimeter (Fig. 22.10).

THIRD PREHEATING This is done if necessary. The third preheating at 1050 to 1100°C may be found advantageous because it reduces the time of treatment at hardening temperature which, in turn, improves the toughness and cracking resistance of the finished tools. If the third preheating is adopted, the holding time at this temperature is equal to that of final heating.

After the tools are preheated, they are subjected to the final heating in a salt bath as outlined below.

22.8.2 HOLDING TIME

Holding time at hardening temperature will depend upon steel composition, size of the tool, purpose of tools and the hardening temperature employed (Figs. 22.11 (a) and (b)).

The hardening temperature for molybdenum steels lies between 1170°C and 1250°C and for tungsten steels between 1250 and 1300°C.

After the tools attain a uniform hardening temperature, they should be held at this

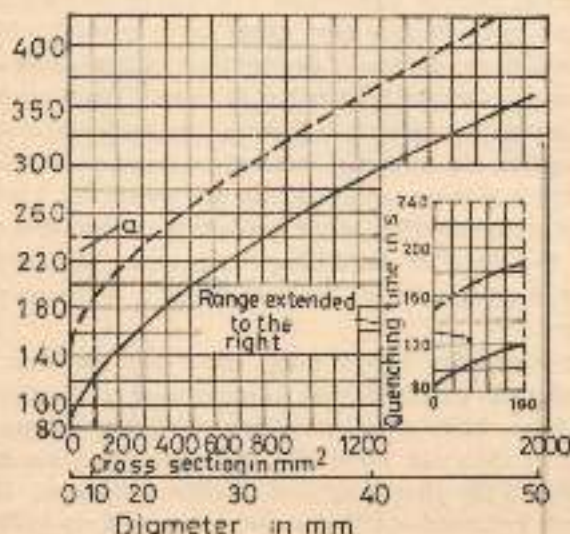


Fig. 22.11(a) Soaking-time curves for hardening of HSS tools with round or nearly round cross-sections (derived from draft DIN 17350)

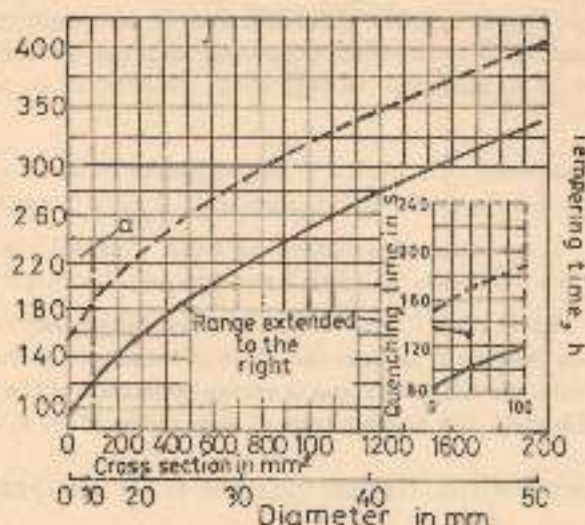


Fig. 22.11(b) Soaking-time curves for hardening of HSS tools with round or nearly round cross-sections (derived from draft DIN 17350)

temperature to allow enough of the carbides to dissolve for ensuring the desired hardness. Too short a holding time will result in insufficient hardness due to low alloy in the austenite. Too long a holding time will give an insufficient hardness to the matrix, which becomes too enriched by excessive carbide dissolution and fails to get transformed into martensite at the normal temperature. It may also cause grain growth with consequent loss of toughness and there is also the danger of development of hardening cracks.

The hardening temperature for S 18-0-1 high speed steel ranges between 1250 and 1280°C. The exact temperature greatly influences the hardness, toughness, red hardness and grain size. In practice, the correctly selected temperature is the one which gives the most favourable condition of these properties for any particular tool. Because of this fact, it is quite necessary to study the effect of the hardening temperature on various properties.

Table 22.2 shows the effects of hardening temperature (quenching condition) on the properties of different high speed steels at the high side of the recommended range and also at low temperature.

By increasing the hardening temperature, more and more carbides dissolve in the material that surround it. So dissolved, they communicate to the steel their own hardness, resistance to wear and the ability to withstand the machining temperature without softening. At the same time, as shown in Table 22.3, the size of the grain increases. Figs 22.4 (e), (f), (g), (h), (i), (j), (k), (l) shown the photographs of structures taken at 1000 magnification of S6-5-2 high speed steels hardened at different temperatures from 1140-1220°C. An increase in time is associated with a decrease in toughness (Table 22.2).

Increased hardening temperature therefore lead to:

- Increase in tool hardness after tempering (Table 22.2).
- Increase in permissible tempering temperature.

Table 22.2

Steel	Quenching temperature	Condition holding time s/mm	HRC after tempering 56°C	Red hardness at 620°C	Bend 4 h/kg/mm ²	kg m/cm ²
R-18	1220	45	62.5-63	58.5-59.0	352-380	4.2-4.5
(S18-0-1)	1260	8	62-63	60-60.5	360-370	3.5-4.3
	1280	8	63.5-64	60.5-61	220-295	1.6-2.5
R6M3	1200	60	62-63.5	51.5-58.7	433-501	4.8-5.5
(S6-5-3)	1220	8	62.5-63.5	58.5-59	306-450	4.0-4.6
	1240	8	63.5-64.5	59.5-60.5	274-341	1.8-3.1
R8M3K6S	1160	90	65.5-66.5	62-62.5	300-317	1.7-1.9
	1200	8	66-66.5	62.5-63	260-316	1.0-1.6
	1220	8	66.5-67.5	63-63.5	210-252	0.6-0.9

R8M3K6S tempered 4 times at 560°C, R-18 and R6M3 tempered 3 times at 560°C.

Table 22.3

Steel	Temperature °C	Time s/mm	Retained austenite	Grain Size
R18	1200	60	16	12
(S18-0-1)	1220	45	15	11-12
	1240	30	17	11
	1260	8	20	10-11
	1280	8	25	10
R8M3K6S	1160	90	40	11-12
	1160	30	38	12
	1180	75	42	11-12
	1200	8	48	10-11
	1220	8	52	10-9

R8M3K6S 1.13 % C, 8.7 % W, 4.35 % Cr, 1.33 % V, 3.7 % Mo, 6.1 % Co, 1.16 % Si

(c) Increase in red-hardness or resistance to heat generated in cutting (Table 22.2).

(d) Increase in wear.

Table 22.4 shows that hardening from 1240°C increases the wear resistance of the tool. But any appreciable grain growth will decrease its toughness, and decrease the resistance of the tool to crumbling of the cutting edge.

Thus, for multipoint tools, when toughness and keenness of the cutting edge are essential, the temperature which will preserve fine grained structure is desirable.

If maximum toughness and fine grain size are the main considerations, the lower limit

of the hardening temperature may be used. It may be seen from Table 22.3 that by using the lower temperature range i.e., 20–40°C below the lower range of hardening temperature, and with longer holding times, it is possible to increase the strength and toughness of the material. But lowering the hardening temperature will decrease the red-hardness by 1–2 HRC and the hardness by 2–3 HRC.

Simple shaped tools and milling cutters should be hardened from higher temperature to attain higher hardness for maximum abrasion resistance.

Tools of thin edges or those subjected to high dynamic loads with interrupted machining conditions have a low resistance to chipping of the cutting edges which is explained by inadequate strength and ductility. Such tools should be hardened from a lower range of hardening temperature, 20–40°C below the minimum with a longer holding time (see Table 22.4) to increase the strength and especially the toughness.

Table 22.4 (After Adaskin et al.)

Drill number S6-5-2	Drilling life at hardening temperature °C			
	1200	1220	1240	1250
1.	137	452	321	234
2.	246	351	527	223
3.	241	378	551	273
4.	283	251	386	—
5.	136	—	588	—
Quenching temperature °C	1200	1220	1240	1250
Grain size, Points	12	10–11	9–10	8–9
Hardness, HRC	64.5	65	65	66
Red hardness, HRC	58	59.5	60.2	61.5
Bending strength, kgf/mm ²	330	320	270	220
Torsional impact strength, kgf/mm	4750	4600	5000	2800

Intricate shaped tools and very large tools of diameter more than 75 to 80 mm should be hardened from the lower limit of the hardening temperature. Tools with fine cutting edges should be taken out several times from the hardening bath to protect the teeth or the fine cutting edges. After the desired length of holding time, the tools are quenched in quenching media.

22.9 Quenching

After the tool is held at the hardening temperature for a correct time, it is taken out and quenched at a rate sufficient to ensure the transformation of austenite to martensite. Quenching of H.S.S. can be done in three different ways:

1. Air cooling
2. Oil quenching
3. Salt bath quenching or martempering.

22.9.1 AIR COOLING

Cooling of tools in air may be recommended for thin sections of uniform size, and more than 20 mm thickness it is not advisable to air cool, as it results in inadequate hardness due to very slow cooling. Air cooled tools show less distortion, but the surface of the tools have a less satisfactory appearance, since they have time to oxidize during slow cooling.

22.9.2 OIL QUENCHING

Small and simple shaped tools are directly quenched in oil. The temperature of the oil should be maintained at 60°C or more to prevent any possible breaking of tools. Intricately shaped tools are precooled from 1000 to 900°C before quenching in oil to avoid quenching cracks that may develop due to the fast rate of cooling. Tools quenched in oil are taken out after they attain 150°C (at this temperature oil is slightly fuming at the tool surface) and further cooled in air.

In larger tools with junctions of heavy and thin sections, quenching cracks may sometimes develop even when hardened with interrupted quenching. In such a case, it may be advisable to quench the tools in hot oil maintained at a temperature between 160 and 180°C and cooled further in the bath itself at a rate of 20–40°C to a temperature 50–60°C.

22.9.3 INTERRUPTED HARDENING

Intricately shaped tools, such as milling cutters with sharp corner junctions of heavy and thin sections and very large tools susceptible to cracking and distortion in other oil quenching methods, are quenched in oil maintained at 90°C, at which temperature austenite is partially transformed to martensite.

After the tools attain the temperature of the bath over the whole cross-section, they are transformed directly to the tempering furnace without allowing them to cool further in air. The tools that are subjected to this treatment should be tempered 3 to 4 times for complete transformation of austenite to martensite, since the amount of retained austenite at this stage of tempering treatment will be 50% to 60% instead of 20–25%.

22.9.4 SALT BATH QUENCHING

Incomplete Isothermal Hardening This is done by quenching the tools at a temperature of 300°C to 250°C (slightly above M_s) and holding at this temperature for 10 to 20 minutes before cooling in air.¹⁹ It can be seen from Fig. 22.12 that by holding the tools at this temperature the structure of steel will have more retained austenite.

The presence of more retained austenite gives lower stress, higher strength, lower value of volume changes and deformation and susceptibility to cracking, compared to step quenching (450–550°C) or oil quenching. Subsequent tempering transforms the retained austenite into martensite at a higher rate. According to Geller and Brimond the tools that are subjected to this treatment show reduced elongation of the order of 20–25% (see Fig. 22.13) and much less distortion compared to those step quenched at 500 to 550°C.

This method of hardening can be recommended, particularly for large tools, to prevent

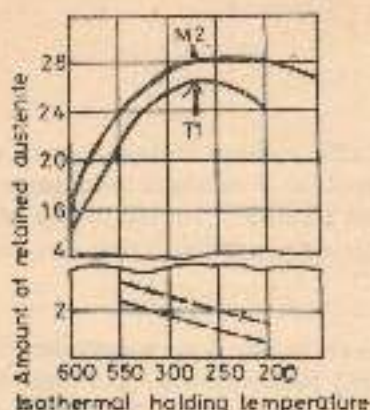


Fig. 22.12 Effect of isothermal holding temperature in steel T1 and M2 and its resistance to tempering at 560°C, after quenching and tempering¹⁹

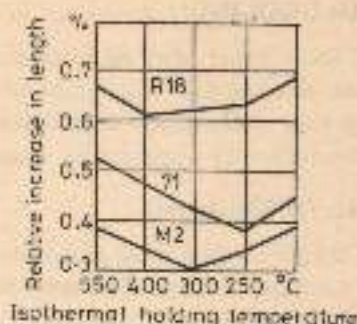


Fig. 22.13 Effect of isothermal holding temperature, during quenching on relative increase in length¹⁹

cracking. Tools having large length to diameter ratio such as drills and reamers are quenched in salt bath to diminish their deformation. Besides, this method can improve to a certain extent the thermal stability and strength of large tools.

High Temperature Martempering Martempering consists of quenching the tools in a salt bath maintained at 630 to 650°C. After the tool attains the bath temperature, it is further

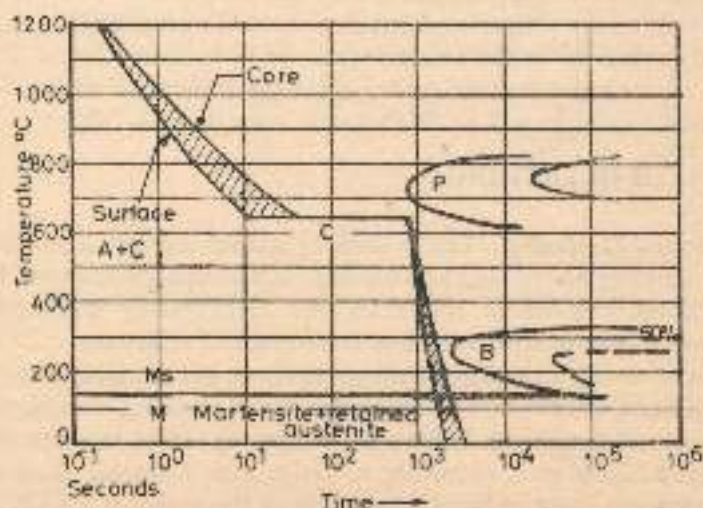


Fig. 22.14 TTT diagram showing a quenched specimen subjected to high-temperature martempering

cooled in air to effect the martensite reaction (Fig. 22.14). The amount of retained austenite in the tools is 25 to 29% (see Figs. 22.15, 22.16). When the same tool is quenched in a salt bath at 600–650°C for 30 minutes 25–26% of retained austenite will remain. If the same tools are quenched in an oil or salt bath (460–550°C), the presence of retained austenite will be 25–26% in an oil bath and 26–29% in a salt bath. Hence structure of the tool does not differ from that quenched in oil or step quenching.^{20,21}

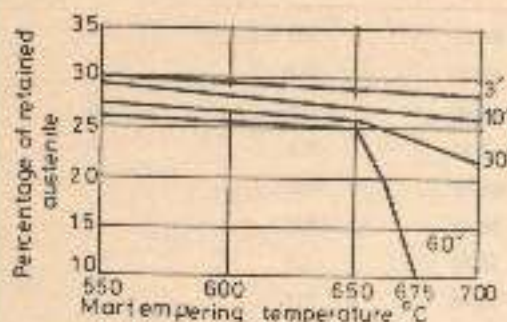


Fig. 22.15 Effect of high-temperature quenching on the properties of HSS 18-0-1²⁰

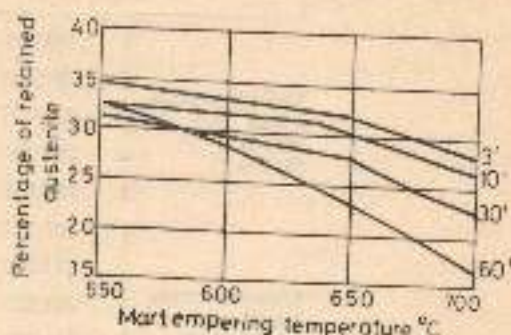


Fig. 22.16 Effect of high-temperature quenching on the properties of HSS (S6-5-3)²⁰

The above method can be recommended for all types of tools and, in particular, for gear cutting tools like worm cutters and shavers.

But it is relevant to mention here that the following are the advantages by quenching the tool at high temperature (630 to 650°C) compared to the other types of quenching.^{20,21}

1. Increase the toughness
2. Retains precise dimensions
3. Lessens distortion (see Table 22.5)

Table 22.5²⁰

Steel tool	Size of tool length mm	Diameter mm	Average
R6M5	120	8	0.16/0.08
S6-5-2 reamer	130	12	0.25/0.09 0.12/0.03 0.12/0.01 0.25/ —
R6M5 Endmill cutter	130	12	0.15/ —
S6-5-2			0.1/ —

Note: Numerators refer to the tool quenched in oil. Denominators refer to tools quenched in salt bath (630–650°C).

4. Increases wear resistance and tool life by 20-30% (see Table 22.6)
5. Increases secondary hardness and red hardness.

Table 22.6²²

Tool	Cutter	H.R.	No of shafts machined	Cutting speed m/min
Endmill cutters 5 mm dia of steel R18 (S18-0-1)	1	169/201	49/53	9.5
	2	207/196	43/58	9.0
	3	214/207	40/40	9.6
	4	207/201	48/55	9.8
	5	179/196	44/58	9.0
Endmill cutters 5 mm dia of steel R6M5 (S6-5-2)	1	207/217	30/32	5.6
	2	217/201	36/50	5.6
	3	229/217	32/46	9.5
	4	211/207	30/40	5.6
	5	189/207	60/60	9.6
	6	189/229	58/60	9.6

Note: Numerators refers to cutters quenched in oil before tempering. Denominators refer to cutters quenched in salt at 630-650°C.

Step Quenching The general practice is to step quench because it avoids hardening stresses and cracks, and effectively minimises distortion. At step quenching temperatures long

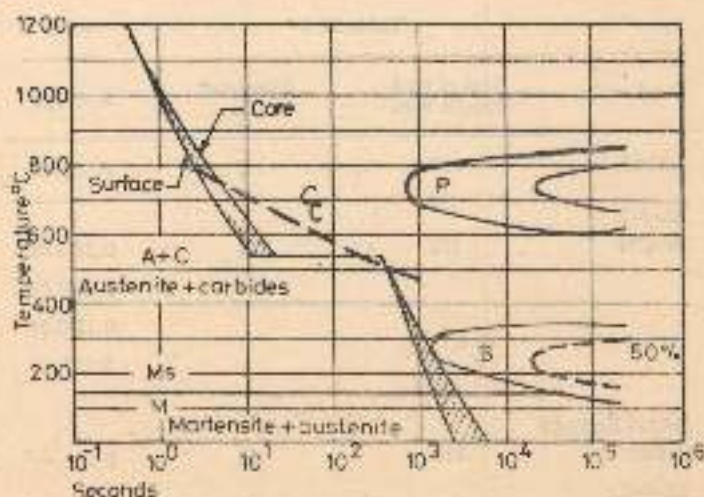


Fig. 22.17 TTT diagram showing a quenched specimen subjected to step quenching

tools can also be straightened. Step quenching is performed by transferring the tools from the hardening bath into a salt bath of about $450\text{--}550^{\circ}\text{C}$ for a time sufficient to equalise the temperature (Fig. 22.17). The tool is subsequently cooled in air. At this temperature even by holding for a long time no noticeable change takes place in the austenite. The structure of the tool quenched in a salt bath at this temperature in no way differs from that obtained by quenching in oil.

22.9.5 SUB-ZERO TREATMENT

By this treatment a large part of the retained austenite can be transformed to martensite. This happens immediately after quenching the H.S.S. from the hardening temperature. The tools are cooled to -70°C (-158°F) for complete transformation of the retained austenite. If the holding time at room temperature is long, the sub-zero treatment has to be done up to -155°C (-311°F) for austenite transformation (Fig. 22.18). In some instances, however, a different procedure has to be adopted; that is, the hardening is followed by tempering after which the sub-zero treatment is done. Finally, a secondary tempering operation is done. Such procedures have to be applied for intricately shaped tools that are vulnerable to high internal quenching stresses. If such tools are sub-zero-treated immediately after hardening, the quenching cracks may develop.

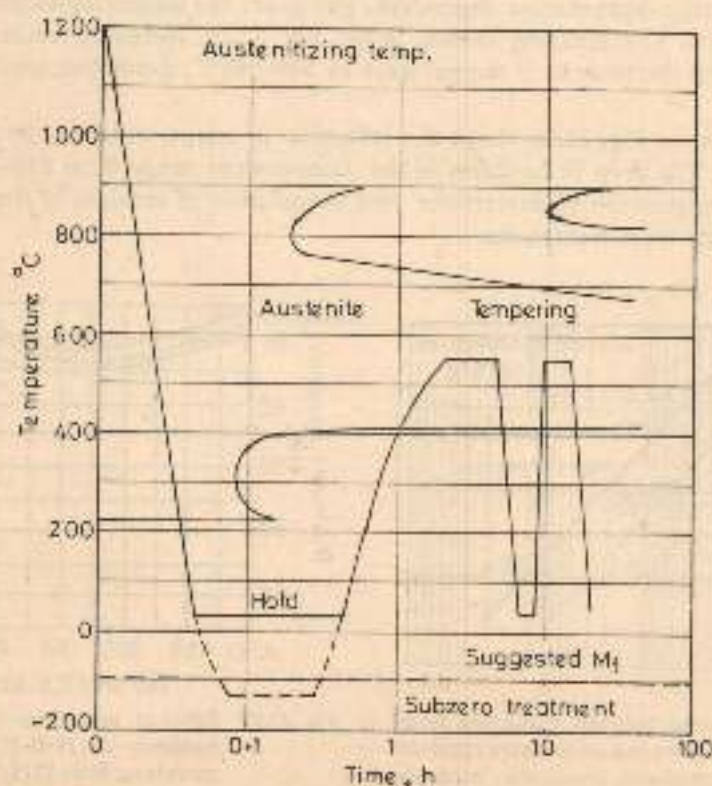


Fig. 22.18 Schematic representation of conventional hardening and tempering treatment and sub-zero treatment superimposed on the isothermal transformation diagram for an M2-type HSS

The above mentioned treatment is convenient to employ in any instance for correction of overheating, since the residual austenite is more (10–20%) in overheated steel, which in practice cannot be avoided in production conditions. The sub-zero treatment is also adopted for the stabilization of size.

22.10 High Speed Steel Tempering

Tempering is an essential and most critical operation of the hardening treatment. The final hardness, strength, toughness and stability of the tools treated depends on the quality of tempering.

Since the structure of the as quenched high speed steel consists of undissolved carbide (6–12%), untransformed austenite (15–30%)^{9,21} and untempered martensite (60–80%), it is inherently brittle and dimensionally unstable.²⁴ The tempering operation renders the steel useful by elevating the internal stresses and by reducing the brittleness and instability without impairing the hardness.

In order to bring about the complete transformation of all the austenite during the first tempering cycle, a definite minimum holding time is required at particular temperatures depending on the type of steel and the temperature used. Therefore all the initial tempering treatments are time-temperature dependent. The lower the tempering temperature longer is the time required. This is clearly shown in the Fig. 22.19. Normally tempering is accomplished by heating the tools to a temperature of 540–580°C, depending on the composition of the steel.

The curve in the Fig. 22.20 shows the influence of temperature on the hardness of the quenched steel. The drop in hardness in the temperature range from 150–400°C is mainly due to the decomposition of martensite and coagulation of carbides of the cementite type which precipitate from martensite.

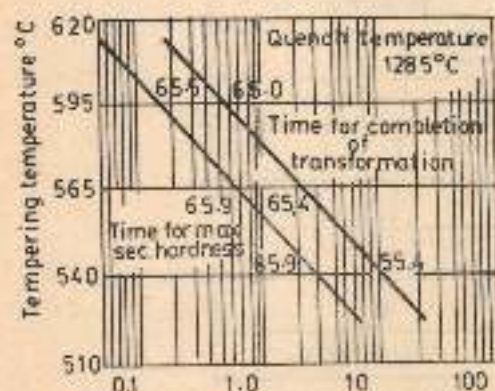


Fig. 22.19 Relation between tempering time and tempering temperature required to produce maximum hardness and to complete the transformation of retained austenite on cooling from tempering temperature²⁴

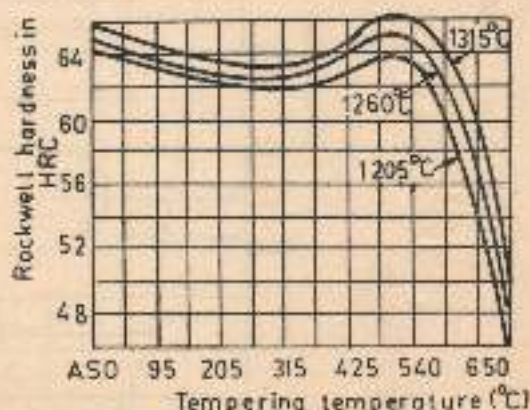


Fig. 22.20 Effect of tempering temperature on the hardness of 18-0-1 HSS steel after quenching from 1315–1260–1205°C

The increase in hardness at higher tempering temperature (known as the secondary hardness) is due to the transformation of the retained austenite into martensite and to the precipitation of carbides from martensite (precipitation hardening of martensite). The high hardness obtained by tempering in the range of 550–580°C is retained when the steel is subsequently heated to 600 to 620°C. This constitutes the high red hardness of the high speed steel tools.

Figure 22.20 shows the effect of tempering on the hardness of high speed steel quenched from different hardening temperatures. It will be noted that the initial hardness develops on quenching. The higher initial hardness obtained by quenching from 1260°C (2300°F) over that obtained by quenching from 1205°C (2201°F) appears to persist at all tempering temperatures. The general feature of these tempering curves, which are similar for all type of high speed steels include an initial drop in the hardness on tempering to approximately 320°C. Above this temperature, the hardness gradually increases to a maximum at a temperature between 510 and 565°C.

The first tempering cycle consists of heating to a preselected temperature and holding for a definite time which will temper and stress relieve the original martensite and condition the retained austenite so most of it will transform.

The tempering and stress relieving of this original martensite is accomplished while heating and holding at the tempering temperature.

Holding at the tempering temperature conditions the retained austenite, so that most

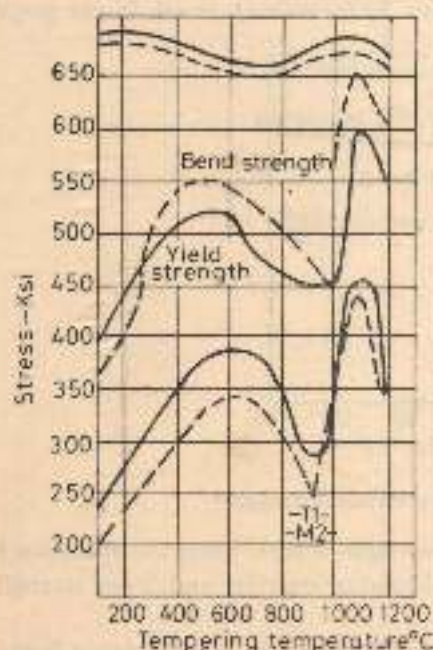


Fig. 22.21 Effect of tempering temperature on yield strength, bend strength and hardness of T1 and M2; Tempering time = 1 h, austenitized at 1285°C—T1, 1050°C—M2²⁸

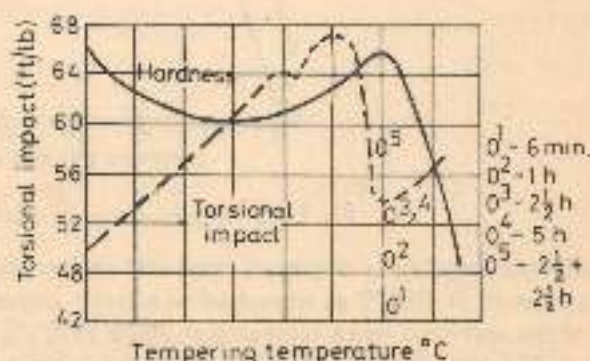


Fig. 22.22 Hardness-torsional impact v. tempering temperature on AISI T1 steel²⁹

of it will transform to new martensite on continuous cooling to room temperature. The formation of new martensite is accomplished by a volume change and new internal stresses are set up which should be relieved by a second tempering.

The effects of temperature after one hour tempering treatment on the bending strength and yield strength are shown in Fig. 22.21. In the quenched condition, both the properties are relatively low, and start increasing in the temperature range of 260–320°C, and above this temperature range between 510 and 540°C the drop in bending and yield strength takes place due to the secondary hardening. At 550°C both the yield strength and bending strength are maximum. The curve shows an improvement in the strength after one hour of tempering, but the steel will still have untempered martensite and a small percentage of retained austenite to martensite and relieves the stresses formed during the first tempering. A third tempering removes completely the stresses that are formed during second tempering.

For this reason an increase in strength and toughness are mainly found in tools after a second and third tempering.

Figure 22.22 illustrates that short tempering times yield low impact values, which can resume to a maximum after about two and half hours. Further rise in impact strength may be observed after double tempering. Repeated tempering will not result in low hardness of the tool.

Figure 22.23 gives the stress-strain curves determined from static torsion tests on M2 (6–5–2) high speed steel hardened from 2200°F followed by quenching in oil. In the graph

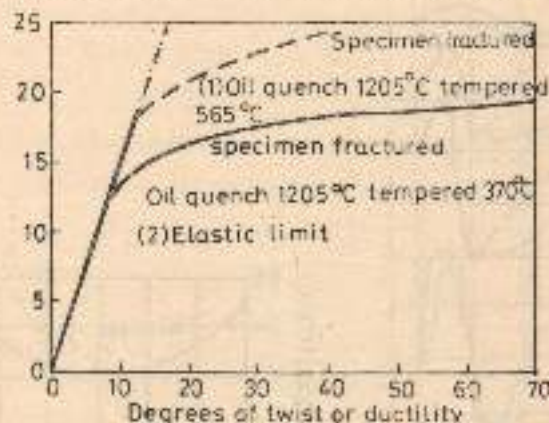


Fig. 22.23 Degree of twist or ductility v. torsional strength.¹⁸

a lower ductility or degree of twist and an increased strength is seen when the specimen is tempered at 1050°F as compared to a large degree of twist or ductility and lower strength of the specimen when tempered at 700°F (370°C).

The rate of cooling from the tempering temperature is important for the reason that it is only while heating to the tempering temperature the austenite transforms to martensite, the actual change itself occurs during cooling. Consequently rapid cooling from the tempering temperature should be avoided since it tends not only to prevent some of the transformation, but helps to set up stresses as well. While the air cooling is not too fast, furnace cooling is preferred. Tools should never be quenched from the tempering temperature.

Tempering time is taken into account after the tool attains the furnace temperature throughout the section of the tool. Time is an important factor in controlling the changes as discussed earlier and for safety a tempering time of at least two hours is always recommended. Large tools are sometimes tempered for about four hours.

22.10.1 HEATING AND COOLING CONDITIONS FOR TEMPERING

High speed steel should be tempered immediately after quenching, preferably in a forced air circulating furnace or salt bath. If an air circulation furnace is used, all traces of salt must be first removed from tools, otherwise severe pitting-type corrosion will occur at the tempering temperature.

It must be stressed that rapid heating of tools to the tempering temperature often leads to failure. In general, the work should be placed in a chamber at a temperature not over 200–250°C, and should be heated slowly in the chamber. If salt baths are used, the tools should be preheated to 200–250°C before placing in the chamber.

After every tempering operation, the tools are cooled to the room temperature to ensure the maximum martensite transformation of the residual austenite. The rate of cooling has almost no effect on the transformation of austenite, but a fast rate of cooling can cause cracking. For this reason water cooling and washing of the still hot tools is not allowed. They should be cooled by compressed air.

22.10.2 METHODS OF TEMPERING

Low Temperature Tempering After the steels are cooled to the room temperature or if necessary cooled to 40–60°C to avoid cracks for complicated tools, they are tempered. The first tempering is done at 350–360°C for 1 hour, instead of tempering of 560–570°C.²⁹ At this temperature, the transformation is associated with the precipitation of carbides of cementite. The cementite carbide precipitated in the first tempering promotes a more uniform distribution of carbides over the grain boundaries during the subsequent tempering operation at 560 to 570°C.

The tools are then cooled to room temperature. Subsequent tempering is carried out in a regular tempering temperature of 550–570°C for 1–2 h. Between each tempering the tools are cooled to the room temperature.

Table 22.7²⁹

Steel	Beyond kg/mm ²	HRC	HRC after tempering at 640°C
R6M5 (S6-5-2)	337	63	59
	356	64–65	59.5–60
R12P3 (S12-1-27)	317	64	62
	354	65	63
R18 (S18-0-1)	210	64	59
	215	65	60–61

Note: Data in numerator refers to samples triple tempered at 560°C/h; denominator tempered at 350°C/h and double tempered at 560°C/h.

The advantage of the first tempering at 350°C is that it improves the secondary hardness, heat resistance and toughness (see Table 22.7). It also increases the durability of tools by 40% (see Table 22.8) compared to the triple tempering at 550–570°C.

It should be noted that the first tempering at 350°C favours the stabilization of austenite, because of which the number of tempering stages at 550 to 570°C is increased to three for W–Mo steels, and to four for W steels with high carbon, including cobalt content.

Table 22.8 (After Yu. A. Geller)

Steel	Tempering temperature °C			Time (min)	HRC	Breaking torque	No of holes drilled	% durability
	1st temp.	2nd temp.	3rd temp.					
R18 (S18-0-1)	350	560	560	60	63.8	2.83	327	142
	560	560	—	60	63.8	2.75	230	100
	580	580	—	10	64.2	2.43	162	70
	530	600	600	61	64.8	3.10	324	143

Double Tempering^{20,21} The first tempering is carried out by raising the temperature after austenite is fairly transformed (Fig. 22.24). This is due to the lower stability of

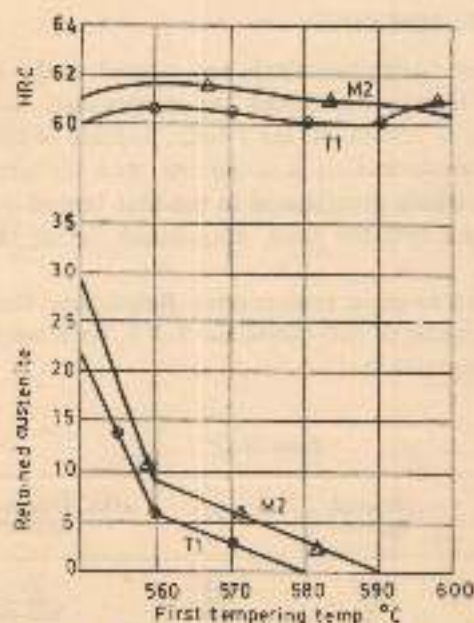


Fig. 22.24 Effect of first tempering on the hardness and amount of retained austenite of HSS²⁹

the retained austenite, resulting from more intensive precipitation of carbon and alloying elements from it during tempering. The second and the third stages (for tungsten steels and of elevated thermal stabilizing) the tempering is done at 550–560°C depending on the type of the steel.

This method of tempering assures a more complete transformation of the residual austenite, and may be recommended for large tools which have retained a big amount of austenite in the core on hardening and also for tungsten-molybdenum steels with an increased content of carbon, which avoids the fourth stage of tempering. The tempering should be for 1-3 h, depending on the size of the tool and the batch.

This method of tempering increases the strength (Table 22.9) and durability of steels without changing the red hardness.

Table 22.9 (after Zablotski)

Steel	Quenching tempering	Tempering condn.	HRC	Hard kg/mm ²	kg m/cm ²	Red hardness
R 18	1280°C	Triple-560-560°C	64.5	264-301	2.0-2.8	62.8
(S18-0-1)		Double, 580 & 560°C	64.5	284-359	2.5-3.8	62.7
R6M3	1240°C	Triple-560°C	63.1	295-330	2.8-3.2	62.3
(S6-5-3)		Double, 580 & 560°C	63.1	353-375	3.3-3.7	62.0
R9	1240°C	Triple-560°C	65.0	375-394	2.0-2.7	63.0
(S9-1-2)		Double, 580°C	64.8	375-417	3.4-3.5	63.0

Table 22.10

Quenching bath temperature	Per cent undissolved carbide	Per cent austenite from fig	Per cent martensite	Per cent undissolved carbide	Per cent tempered martensite	Per cent austenite	Per cent tempered martensite
80	7	23	70	7	70	1	22
125	7	31	62	7	62	3	28
175	7	41	52	7	52	5	36
225	7	53	40	7	40	10	43
275	7	65	28	7	28	16	49
375	7	89	4	7	4	21	68
500	7	93	0	7	0	22	71

Note: The structure of high speed steel, after quenching to the indicated temperature and after tempering directly for 2-2½ hours at 1050°F (565°C) percentage on volume basis.

Tempering at Equal Temperature Tools are tempered with equal temperature at each stage 550-560°C for tungsten-molybdenum steels, including those containing cobalt, and at 560 to 570°C for tungsten and tungsten-cobalt steels. After hardening or step quenching, double tempering is employed for W-Mo steels and molybdenum steels. Triple tempering is done for tungsten steels and most cobalt steels, and quadruple tempering for all steels after incomplete isothermal hardening.

A third, or sometimes fourth, tempering is mainly needed for better stress relieving and for additional improvement of mechanical properties.³²

The time for tempering may either be long or short depending on the tool size and the

number of tools in the process (1½ to 2 hours). The tools are cooled to room temperature between tempering operations.

Tempering After Arrested Quenching If the tools are cooled to room temperature after hardening, the amount of retained austenite in the tools will be 20 to 25%. To avoid distortion and cracks of complicated tools, the tools are not allowed to cool to the room temperature. If the tools are cooled to only 121°C before taking for tempering, then the tools will have 50 to 60% retained austenite (see Table 22.10 and Fig. 22.25).

If the tools are cooled to the room temperature before tempering, the 20–25% austenite at the beginning of tempering virtually undergoes complete transformation.

It may be seen from Fig. 22.26 that tools tempered for more than 10 hours and cooled to 105°C still contain 8 to 10% retained austenite.

Raising the tempering temperature, on the other hand, rapidly decreases the amount

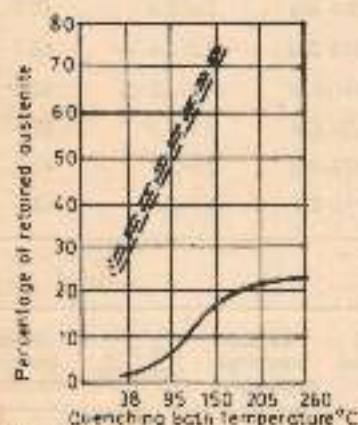


Fig. 22.25 Percentage of austenite in 6-5-2 (M2) HSS after quenching from 1215°C to indicated temperature and single tempering directly from 120°C²⁴

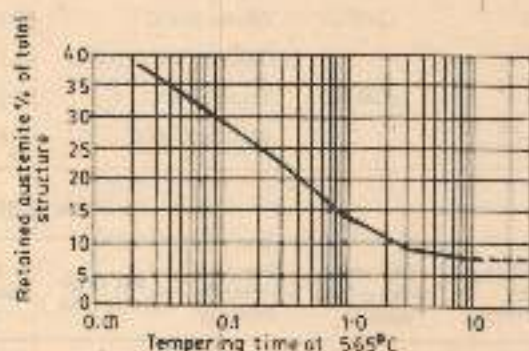


Fig. 22.26 Effect of tempering time on percentage of retained austenite in 6-5-2 HSS, quenched from 1215 to 105°C and tempered directly at 565°C²⁴

of austenite, but it is accompanied by a large drop in hardness (Fig. 22.27). It also reduces the toughness instead of increasing it, and to a lower extent it reduces the strength.

To overcome this condition in instances of arrested cooling during tempering, double tempering is needed to accomplish complete decomposition of the retained austenite. A third tempering results in further improvement of strength properties.

Hence, whenever arrested cooling is adopted, or if the tools are not allowed to cool to the room temperature, it is of utmost importance that the tools are tempered thrice.

22.10.3 TEMPERING AFTER GRINDING

Grinding produces tensile surface stresses on hardened tool steels. The mechanism involved is known as hot upsetting. Heat from grinding generated on the surface causes expansion of the steel; expansion in the plane of the grinding is restrained by cold metal. So it takes place unopposed in a direction perpendicular to the surface by plastic flow. When cooling occurs, the metal tries to shrink back to its original location, but it cannot, because it is no longer plastic. Shrinkage of an area whose perimeter is rigid sets up tensile stresses in

the area. The heat generated during grinding and sharpening is sufficient to produce changes in the surface structure.³⁵ Hence the tools after grinding should be tempered at 400–450°C for 30–60 min, to reduce the grinding stresses and to transform retained austenite that was developed during grinding to martensite.

For high precision tools and instruments should be tempered at 150–180°C for 2–3 h.³⁶ According to Nikonorova and Buzina, the wear resistance of the tool increases 50% after tempering at 400–450°C.

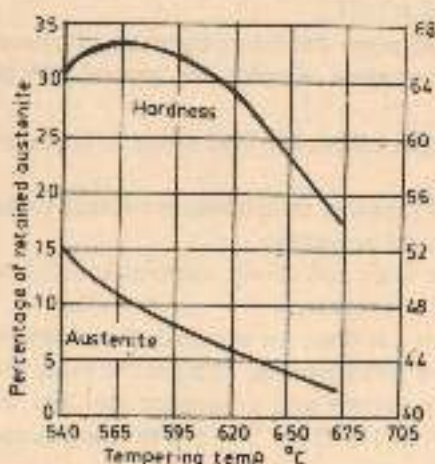


Fig. 22.27 Percentage of austenite and hardness after quenching 6-5-2 type HSS from 1215 to 105°C and tempering directly at indicated temperatures for 2½ h³⁷

The above treatment should be employed as and when the tools are subjected to regrinding and resharping. Dimensional changes after this treatment are negligible.

22.11 Important Guidelines

1. Thick sections and complicated tools are preheated before heating them to the hardening temperature since they possess low thermal conductivity.
2. Hardening temperature should be selected with regard to the suitable austenite grain size and carbide solution. Low hardening temperatures provide fine grained material having good toughness but less satisfactory hot hardness. High hardening temperature results in coarse grained material having poorer toughness but better hot hardness.
3. Complex shaped tool and extremely heavy sections should be hardened at the lower hardening temperature.
4. Tools with fine cutting edges should be taken out several times from hardening bath to protect the teeth or the cutting edges from superheating.
5. With high temperature, there is a greater risk of decarburization.

6. A prolonged holding time at the hardening temperature results in an excessive grain growth and may cause hardening cracks.
7. Quenching of high speed steel at 630 to 650°C gives higher secondary hardness, red hardness and effectively reduces distortion compared to the other methods of normal quenching.
8. Quenching of high speed steel can be done at 250 to 300°C for higher toughness, higher hardness and to reduce distortion.
9. Thick and complicated tools should not be cooled to room temperature. Quenching should be stopped at 80°C.
10. Hardened tools are never put into a tempering furnace that is at full temperature. The furnace temperature should not exceed 250 to 300°C before placing the tools.
11. The material must be allowed to cool down to room temperature between tempering operations.
12. Molybdenum and tungsten molybdenum content tools should be tempered thrice for better mechanical properties.
13. Tungsten content tools and cobalt content tools should be tempered 4 times for better mechanical properties.
14. One extra tempering is done for arrested quenching tools.
15. After grinding and resharpening, temper the tools for one hour at 400 to 450°C to relieve grinding stresses and to increase tool life. For precision tools, tempering is done at 150 to 160°C for 2 to 5 h to increase tool life.

22.12 Shop Problems and Remedies

22.12.1 LOW HARDNESS DUE TO OVERHEATING

The value of hardness for a properly hardened tool will be usually in the range of 62–64 RC. If the tool possesses a hardness value below 60 RC after hardening, it is an indication that the tool is overheated. The overheating produces a more highly alloyed austenite, which is very stable due to the dissolution of larger amount of carbides at higher temperatures in the austenite. The presence of a more highly alloyed austenite in the hardened condition lowers the hardness since this highly alloyed austenite does not transform to martensite. Therefore, overheated tool has a decreased hardness. When overheating is not drastic, such tools will possess the desired hardness after repeated tempering or by subjecting the tools to sub-zero treatment followed by tempering.

If the overheating is very drastic, a reaction occurs between the carbide and the adjacent austenite to form certain amounts of liquid. This liquid when cooled to room temperature will solidify as an eutectic. This structure, shown in Fig. 22.2 (c), (d) is characteristic of high speed steels that have been overheated and is generally associated with a large grain size. In addition, the steel becomes very brittle.³⁷ The carbides which remain undissolved are orientated largely along the grain boundaries.

A high speed steel tool which has acquired this structure due to overheating cannot have its normal properties restored by heat treatment. Tools made of high speed steels which have been damaged by overheating will easily develop grinding cracks and it fails in service very fast due to brittleness.

22.12.2 LOW HARDNESS DUE TO UNDERHEATING

Value of hardness in the proper hardened tool will be in the range of 62-64 RC. If the tools attain a value more than this after hardening, it is an indication that the tools are underheated and such tools will result in lower hardness after tempering.³⁶ This is due to too low a hardening temperature employed or a too little holding time at the hardening temperature.



Underheated structure

× 500



Underheated structure

× 1000

Fig. 22.28 (a), (b) M2 high-speed steel. The structure consists of carbide particles in a matrix of tempered martensite. The excess of small particles is caused by underheating.

The degree of dissolution of carbides in the austenite will be lower in the underheated tool, compared to the properly hardened tool at a higher temperature. This fact explains that there is somewhat an increase in the hardness of tools which have been underheated since less alloyed austenite will result in less retained austenite with a correspondingly greater amount of martensite after hardening. The martensite obtained from the less alloyed austenite is also less alloyed and its resistance against tempering is decreased. This is the underlying cause for the decreased hardness of a tool after tempering which has been underheated. The structure, shown in Fig. 22.28 (a), (b) is characteristic of high speed steels that have been underheated.

The tools that have been underheated in hardening can be rehardened again after annealing. A complete soft annealing must be carried out before rehardening either in a muffle furnace or in a salt bath.

22.12.3 REHARDENING

If the hardening of high speed steel has failed for some reason, the material can be rehardened with good results provided it was not overheated at the first attempt. A complete soft annealing must be carried out before rehardening either in a muffle furnace or in a salt bath.

This is done by heating the tools in a salt bath maintained at 750°C for 15–20 min and further heating to the same bath at 800–820°C for about 45 minutes to reach the temperature and holding that temperature for 15–20 min. The tools are then transferred to a bath maintained at a temperature of about 600–620°C, held for 30 min and subsequently cooled. This will result in a hardness value of 35–37 RC on components which can be easily machined.

In a muffle furnace, the tools are annealed by packing in a box. As a safety measure against decarburization which produces a soft skin after hardening, the steel should be packed in sheet metal containers using cast iron chips. Charcoal cannot be used for packing as it would produce a more highly carburized skin.

The tools are heated slowly until the temperature of about 850°C is reached (maximum heating rate 25°C per h) and soaked in that temperature for about 2–3 h and subsequently cooled. The cooling should be done slowly in the furnace not more than 15°C per hour down to 600°C. It can thereafter be allowed to cool freely while still packed in cast iron chips.

If this precaution is not observed or if the tools are merely tempered at a high temperature the re-hardening will lead to what is known as "fish scale", i.e. a structure having occasional very large grains.

22.12.4 LOW HARDNESS DUE TO FAULTY GRINDING

During grinding the surface temperature of the tools may rise above the tempering temperature either due to insufficient cooling or due to a heavy cut in one pass.^{39,40} This will lead to the lowering of the surface hardness of the tool (Fig. 22.29). Sometimes the extreme outer layer of the tool may even rise to the hardening temperature and cause rehardening. This is the cause for varying results obtained from grinding. To avoid this proper grinding procedures should be adopted using a suitable grinding wheel.

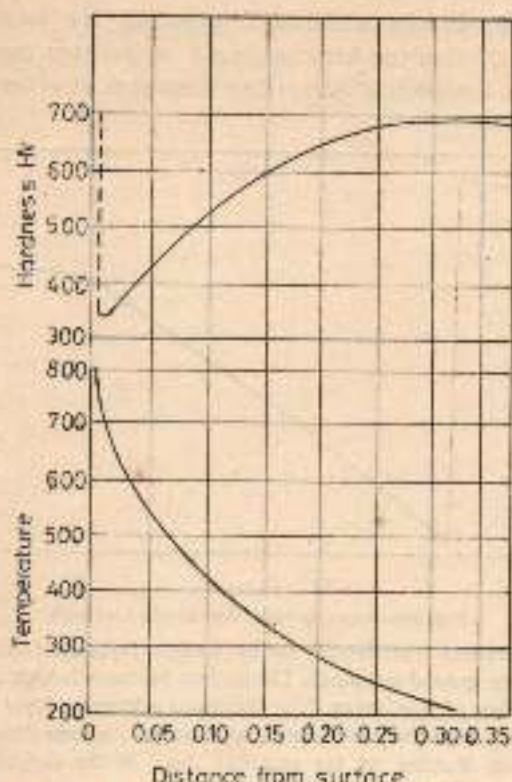


Fig. 22.29 Hardness distribution in a ground surface layer and temperature distribution in different depths when grinding"

22.12.5 COMMON CAUSES FOR CRACKING OF TOOLS

Cracks may develop in high speed steels for the following reasons:

1. **Rapid Heating** Rapid heating of moderate and intricate shaped tools to the hardened temperature without preheating or insufficient preheating will lead to cracks. Due to the low thermal conductivity at high speeds this will lead to a difference in temperature between the surface and the core which may cause uneven expansion leading to development of cracks. Hence preheating of high speed steel tools is a must to avoid cracking.
2. **Due to Overheating** If the high speed steel tools are overheated during hardening, the matrix becomes coarse-grained and a large amount of carbide goes into solution. In addition, the steel becomes very brittle and it may crack during treatment. If they survive the treatment operations, they will easily develop grinding cracks. Hence it is essential that the correct quenching temperature be used.
3. **Tool Rapid Quenching** Quenching of tools after austenitizing in the region of martensite transformation, in particular cooling of large and intricate shaped tools in oil at 20–25°C will result in cracks.

This may be avoided by salt bath quenching at 550–600°C or quenching in oil maintained at 180–200°C.

4. Cracks Due to Grinding Cracks produced in grinding are usually due to the use of unsuitable grinding wheels, either too hard or glazed or perhaps due to too deep a cut in grinding or else due to the omission of tempering treatment after hardening.

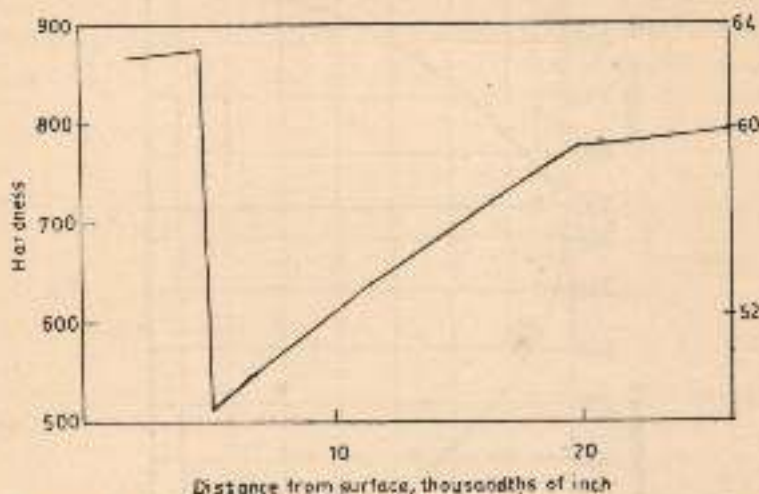


Fig. 22.30 Hardness distribution in the surface layer of a tool that has been ground too much. The surface hardness is high due to the effect of hardening. The hardness is low in a layer under the surface as the temperature approaches the annealing temperature. Further in the material there is the varying effect of tempering³⁹

Grinding cracks may also appear with a deep cut during grinding in one pass.^{39,40,41} If the surface temperature during grinding exceeds the hardening temperature, re-hardening occurs in the surface layer (Fig. 22.30), which will then comprise a mixture of tempered and untempered martensite together with some retained austenite. As a result heavy stresses are encountered which may result in grinding cracks. Sometimes fragments of steel may flake off. In such a case the grinding cracks are usually much deeper than those encountered if the tempering was limited to the surface layer. Grinding stresses can be reduced by tempering at a low temperature of about 400°C for 1–2 h.

5. Cracks Due to Faulty Heat Treatment^{39,40} Improper tempering procedures will leave either untempered martensite or excessive amount of retained austenite which may transform during grinding. If the tools are ground in this condition grinding cracks may develop especially if heavy stock is removed in one pass. Also the heat generated during grinding on the surface of the tool, may induce heavy stresses resulting in grinding cracks. Grinding cracks are usually shallow ranging from 0.01 mm to 0.1 mm. Hence they can be salvaged by tempering at low temperature followed by a very careful grinding to remove only a small amount of metal.

6. Cracks Due to Stress Raisers¹⁷ Deep indentations made with markers and abrupt surface configurations will always lead to stress concentration during hardening and can cause cracks. Typical examples are sharp edges in tooth roots, key ways, etc. Hence the sharp corners on components should be avoided.

7. Cracks Due to Decarburization^{37,39,40} A certain amount of decarburization takes place in high speed steel after heat treatment. Hardening entails an increase in volume. After hardening the decarburized surface layer of the tool will not harden at all or it will be hardened only partially to a very small extent. This will result in a very small increase in the volume whereas the rest of the tool will expand fully due to the formation of martensite. This causes severe stresses in the surface layer resulting in surface cracks which may even affect the underlying material.

This trouble can be avoided by protecting it from decarburization during the heat treatment.

8. Distortion^{37,43} High speed steel tools are not entirely free from distortion during hardening. There are many factors that affect the distortion of the tools during heat treatment. During hardening the change in volume that takes place due to the structural changes and distortion are result of the difference in coefficient of the thermal expansion between the carbides and the matrix. The amount of distortion may increase due to overheating, poor quenching practice, shape and size of the tool or due to improper handling. This is more common in long drills, reamers, thin flat tools etc. This distortion aspect must be considered as early as at the heating stage.

Long tools should preferably be suspended vertically or positioned horizontally in baskets and holders. Because of the sharp reduction in strength at high temperatures they will have a tendency to bend.

Simple shaped thin and flat components can be pressed together in a holder to prevent their warpage. After quenching in salt bath at about 600°C these can be cooled under the press.

Straightening of long tools can be done in a press after hardening. Before tempering the material has to be cooled to room temperature, but this should be done before complete martensite transformation has occurred.

Round components such as drills can often be rolled between two flat surfaces as they cool.

Regardless of how straightening is carried out during hardening, stresses will be induced in the material which can be relieved by tempering. Again the component may bend during tempering.

Straightening of hardened and tempered components can be done when they are cold, although this is a difficult operation requiring a special technique with a sharp straightening tool usually made of sintered carbide tips.

Careful heating by flame below the tempering temperatures can also facilitate straightening of components.

22.13 Furnaces

The type of furnaces used for heat treating of high speed steels are mainly salt bath furnaces, controlled atmosphere furnaces or vacuum furnaces. At present the majority of HSS are being heat treated in salt bath furnaces. The remainder are being heat treated in controlled atmosphere furnaces and vacuum furnaces.

22.13.1 SALT BATH FURNACES

Electrically heated immersion electrode type salt bath furnaces have been found most suitable for heat treating of high speed steel, due to the precise control of temperature time, control and protection of surface from any scaling or decarburization. They function better under continuous operation and may be used where there is a steady flow of high-speed steel tools being hardened.

The normal procedure is to use three different baths and air circulation furnace for heat treatment of high speed steels.

The tools are first preheated, in an air circulation furnace, up to 500–650°C, then transferred to the first salt bath maintained at 800–850°C for further preheating. After thorough soaking, the tools are transferred to the second bath (hardening bath) maintained at the desired austenitizing temperature (hardening temperature) in the range 1200–1280°C. After this the tools are held for the desired length of time, followed by quenching in the third salt bath maintained at 500–630°C. In cases where the production rate is higher, it is advantageous to employ two preheating salt baths as it considerably reduces the required cycle time.

The salt used in this bath is 95% barium chloride and the rest rectifiers. It is important that this bath should be kept neutral, that is inert to the surface of the tools.

In this bath, decarburization takes place due to the formation of oxide after about 6 to 8 h. Oxide formation takes place due to the interaction between the salts and metal, and with the electrodes and the atmosphere, oxide formation will increase when the time increase. Decarburization may be avoided by the periodic addition of rectifier such as borax (0.6–8%) and ferrosilicon (0.35–0.5%) twice during shift and 0.6–0.8% magnesium fluoride once during the shift.⁴²

22.13.2 VACUUM FURNACE

Vacuum furnaces (Fig. 22.31) are also found to be most suitable for hardening of high speed steels. Tools treated in vacuum furnaces possess improved toughness, ductility and fatigue limit. It also avoids post-treatment finishing operation.^{43,44}

First the tools are loaded into the heating chamber of the furnace and the door is closed. The automatic sequence is then energized and the furnace begins to pump down. When a vacuum of 500 microns is created, the furnace heating elements are switched on. The complete heating sequence is then controlled by a pre-programmed microprocessor-based temperature and sequence controller. The vacuum pump continues to work throughout the cycle, but the vacuum can be controlled when it attains a preset level.

When the furnace temperature reaches 900°C (1650°F) the addition heat is controlled to maintain it at this temperature for the duration of the intermediate soak period. At the end of the soaking period, the furnace temperature is raised to the desired hardening temperature. After the final soak period, the furnace is back filled with dry nitrogen to a vacuum of 500 torr. The work moves out of the hot zone and it is partially cooled below 1040°C (1900°F) under a nitrogen atmosphere. After a specific time has elapsed the work is oil quenched. If the quench delay is zero and quenched directly after quenching, the furnace is cooled to a preset temperature.

Alternatively, the work can also be gas quenched. Instead of being lowered into the oil quench, it is retracted into the cooling chamber and the furnace back filled with nitrogen.

The advantages of vacuum hardening are:

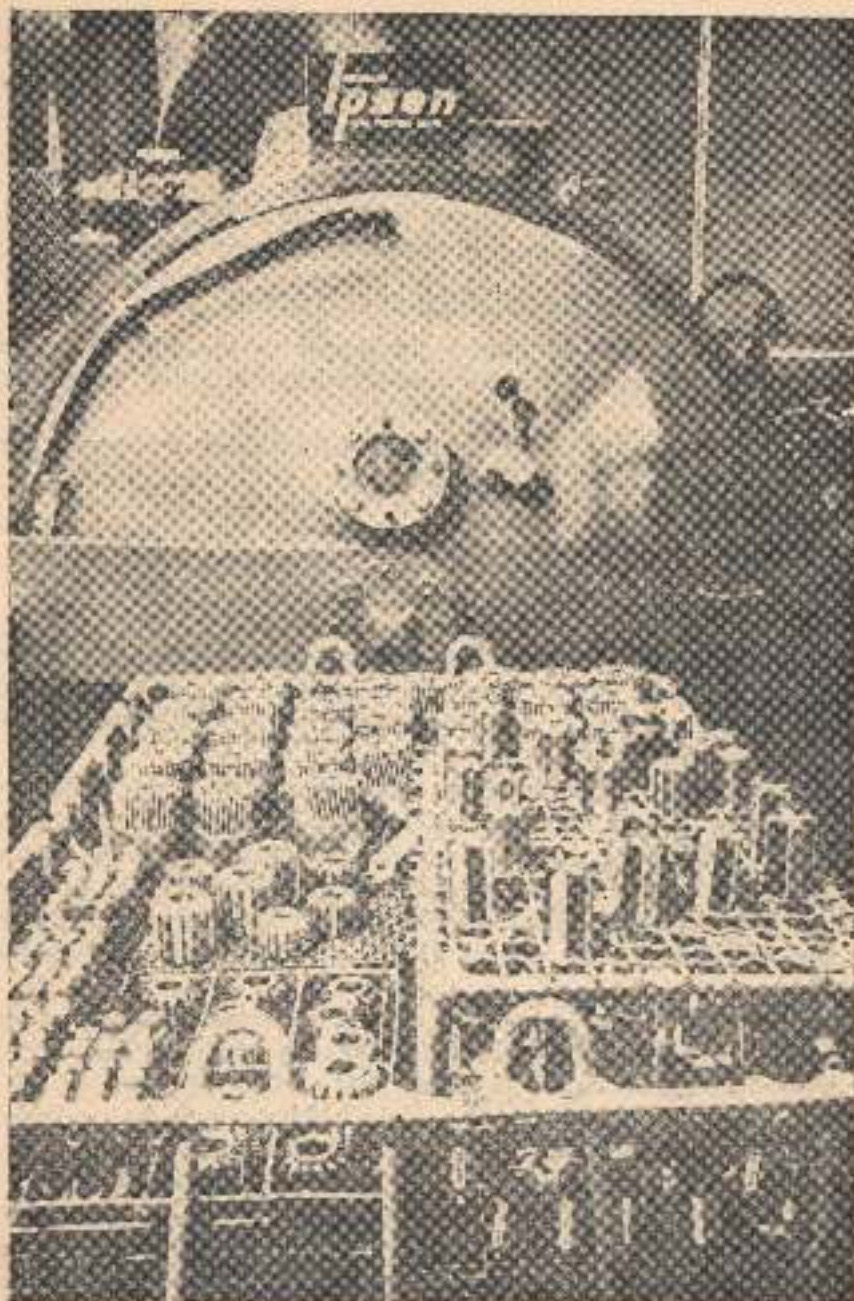


Fig. 22.31 Typical load HSS-tools for IPSEN vacuum furnace with high pressure gas quench

1. Perfect surface protection and minimum tendency for distortion.
2. Eliminates or greatly reduces the costs and risks of subsequent finishing operations.
3. There is no hazardous atmosphere or salts to prepare and control.
4. Due to simple and accurate control of the critical factors, this provides reproducible properties with predictable life of tools and eliminates expensive unexpected failures.
5. It is not dependent upon the operator's skill.
6. Power consumption is very little.

The main disadvantage, compared to salt bath hardening, is the longer time required for heating and the large holding time under vacuum hardening.

22.13.3 SURFACE TREATMENT OF HIGH-SPEED STEEL

The service life of HSS tools is of utmost significance in the present day machining requirements. It is assuming more importance especially when high speed machining is involved.

The service life of tools can be improved by suitable surface treatment. The various methods that are usually adopted are as follows:

1. Nitriding
2. Tufftriding
3. Sulfinizing
4. Steam tempering.

Nitriding⁴⁵ Nitriding consists of saturating the surface layer of the finish hardened tools with nitrogen, which diffuses into the material, forming hard nitrides. This results in higher wear resistance, a low coefficient of friction and scoring resistance thus improving the efficiency of certain types of tools.

Nitriding is performed in a nitrogenous atmosphere or in a bath of liquid cyanides. Salt baths are mainly used for high speed steels and it is performed in a molten bath containing sodium cyanide NaCN , and potassium cyanide at about 580°C . The sodium cyanide reacts with atmospheric oxygen and forms sodium cyanate NaCNO , which diffuses deeper into the bath. The subsequent dissociation of NaCNO liberates atomic nitrogen which penetrates into the metal forming nitrides. This creates a hard zone on the surface of the steel.

The depth of the layer depends upon the amount of nitrogen, the temperature and the time of exposure. The depth of the nitrified layer for tools should not exceed 0.1 mm. The hardness obtained after nitriding will be in the range of 1000–1100 HV.

Nitriding increases the surface hardness of the tool but reduces its toughness. To prevent the tool edges from crumbling, only a short nitriding duration should be used. To improve toughness after nitriding the tool should be tempered at $300\text{--}350^\circ\text{C}$.

Nitriding is recommended in such cases where either the true rake or back rake of the tool has to be reground, but not both rakes, as for example, machine relieved tools of all types. It yields best results on drills, reamers, broaches, countersinks, milling cutters, etc. In certain cases the life of the tool has doubled or even more. It is, of course, impossible to make a general statement as to how much the cutting performance can be improved; many factors are involved such as the type of steel, the shape of the tool and the type of machining. Experiments are being carried out to determine suitable nitriding times for different

types of tool and machining operations. Nitriding may also be applied for high speed steel dies.

Nitriding by the ammonia gas process is not recommended for cutting tools. They should be treated by a liquid bath method to avoid brittleness from too heavy concentration of nitrogen. The gas nitriding may be satisfactory for mandrels and drawing dies used for cold drawing or cold pressing of brass and aluminium. The nitrided case depth for dies should not be in the range 0.01–0.3 mm but lower range always should be preferred for case depth.

Tufftriding⁴⁵ In this process the surface of the hardened and tempered tools are saturated with carbon and nitrogen. Tufftriding is carried out in a molten salt bath containing potassium cyanide (KCN) and potassium cyanate (KCNO). The temperature is normally 570°C. When the tools are immersed in the salt bath, there occurs the diffusion of carbon and nitrogen. Carbon and nitrogen are derived from the decomposition of the cyanate, which in turn is obtained by the oxidation of the cyanide salt. Nitriding time varies widely for different types and size of tools. The time required for heating thick tools to full nitriding temperature is considerably longer than is needed for thin tools and thin cutting edges. Normally it varies between 5 minutes and 60 minutes for example it is about 5 to 15 minutes for cutting tools and 30 to 60 minutes in the case of dies.

Tufftrided tools possess high wear resistance with reduced susceptibility to sticking. It also results in lower coefficient of friction, scoring resistance, improved fatigue resistance and heat resistance.

Sulfinizing⁴⁶⁻⁴⁷ In this process the surface of the hardened and tempered tools are saturated with nitrogen, carbon and sulphur. Sulfinizing is carried out in a molten salt bath containing cyanide and sulphur compounds. The temperature is normally 570°C. The holding time depends on the chemical composition and the case depth required. Sulfinizing improves the hot hardness, wear resistance, resistance to scuffing and reduces tendency to sticking. The hardness will be same as that obtained by nitriding.

22.13.4 STEAM TEMPERING (OXIDATION)⁴⁸

This method involves an additional treatment of conventionally hardened and tempered or nitrided tools. The hardened and the nitrided tools are placed in a hermetically sealed furnace when the temperature is raised to 300–350°C, steam is supplied under a pressure of 0.1–0.3 atm for about 20 to 30 minutes in order to displace the air. The temperature is then raised further to 500–550°C. Upon holding for $\frac{1}{2}$ to 1 hour, the tools are cooled in the steam atmosphere down to 300 to 350°C. Then they are either cooled in air or in the furnace itself. Tools are oiled immediately. This results in a very bluish oxide (Fe_3O_4) skin of high hardness and wear resistance and is found to be very receptive to coolants.

This property reduces slightly the sticking of metal and lowers the coefficient of friction. Since the tools are heated to 500 to 550°C, it is also found to relieve the grinding stresses and promote the transformation of austenite formed during grinding. This may be one of the methods to increase the durability of the tools.

Steam tempering imparts an attractive grey-blue finish to tools due to the oxide film, although its chief advantage is improved corrosion resistance.

22.13.5 OTHER TYPES OF SURFACE TREATMENT

Recent development for the surface treatment of high speed steels are tuffriding,^{49,50} sursulf^{51,52} and nitemper.⁵³ They are rapidly becoming popular since they are almost free from cyanides (for details see the concerned chapters).

22.13.6 GENERAL HINTS FOR GRINDING

1. The use of glazed grinding wheels should be avoided.
2. Avoid excessive pressure when grinding by hand.
3. For machine grinding high feed is recommended.
4. Apply coolant in the correct manner.

Recommendations of makers of grinding wheels with respect to the composition of grinding wheels used for grinding tools made from high speed steel should be correctly observed during the various grinding phases (pre-grinding, sharpening, etc.).

After grinding, the cutting edges should be resharpened by means of an oil stone which will enhance the service life. In the case of turning chisels it is important that the points are properly rounded off.

22.13.7 SELECTION OF HIGH SPEED STEELS

The number of available high speed steel compositions has increased considerably during recent years largely due to widespread efforts to keep pace with demands for increased cutting performance in the use of high output complex alloys. They must meet the increased demands of cutting properties for long periods without decrease of cutting quality.

These properties are based on their ability to retain hardness at elevated temperature, on the red hardness of the matrix in the hardened conditions and on the presence of extremely hard carbides as they are formed by a chemical composition of chromium, molybdenum and tungsten with carbon. The carbides increase the tool life and edge wear resistance. High speed steels are therefore characterised by two prominent properties of red hardness and high wear resistance at elevated temperature along with high toughness.

Red hardness of the high speed steel increases with the additions of cobalt and the wear resistance of the tool increases by a higher vanadium content with an approximately balanced carbon content, as vanadium carbides are much harder than other types of carbides. High speed steels of this composition will give best results for work in automatic machines and for finishing.

Figure 22.32 illustrates the comparative properties of different high speed steels. The high speed steels that are mainly used are given in Table 22.11. Applications and chemical compositions are given in Data Sheets 22.1-22.11.

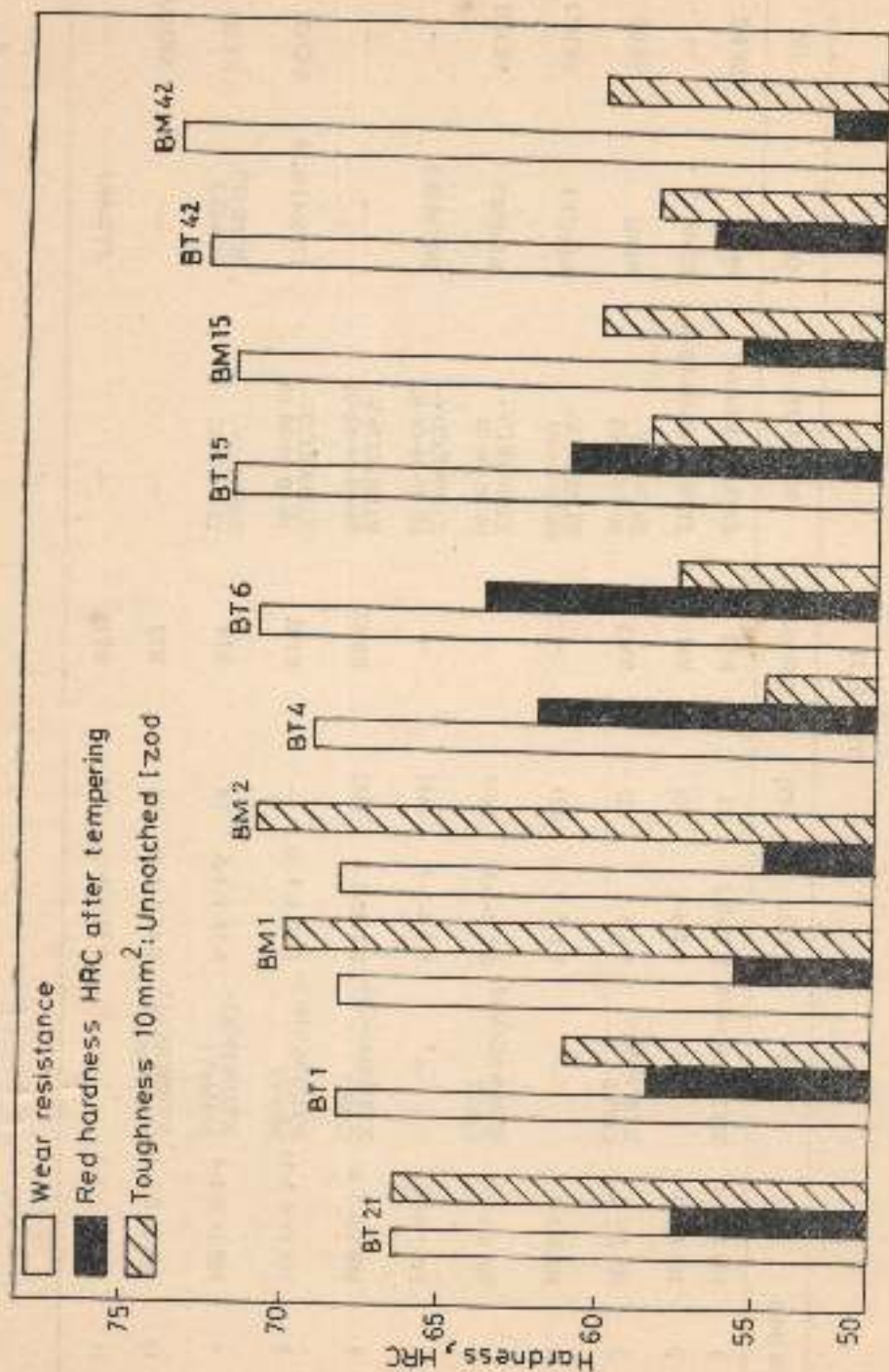


Fig. 22.32 Comparison of properties of selected British high-speed steels (after normal heat treatment)

Table 22.11

Data sheet	ISO	IS	DIN	AISI	BS970/1-72	NFA35-551-75	GOST	JIS
1	HS 18-0-1	XT72W18Cr4V1	S 18-0-1	T1	BT1	Z80WCV18-04-01	P18	SKH2
2	HS 1-8-1	—	S 2-9-1	M1	BM1	Z85WCV-08-04-02-01	P2M8	—
3	HS 6-5-2	XT87W6Mo5-Cr4V2	S 6-5-2	M2	BM2	Z90WDCV-06-05-04-02	R6M5	SKH9
4	HS 6-5-3	—	S 6-5-3	M3	—	Z120WDCV-06-05-04-03	R6M5F3	SKH53
5	HS 6-5-2-5	XT90W6CoMo5-Cr4V2	S 6-5-2-5	M35	—	Z85WDCV-06-05-04-02	R6M5K5	SKH55
6	HS 7-4-2-5	—	S 7-4-2-5	M41	—	Z110WKCVDV-07-05-04-04-02	10P7M4K5	—
7	HS 2-9-1-8	XT110Mo10Co8-Cr4W2	S 2-10-1-8	M42	BM42	Z110DKCWV-09-08-04-02-01	—	—
8	HS 10-4-3-10	XT125WCo10Cr-Mo4V3	S 10-4-3-10	—	BT42	Z130WKCVDV-10-10-04-04-03	12P1043K10	SKH57
9	HS 18-1-1-5	XT75W18Co5-CrMoV1	S 18-1-2-5	T4	BT4	Z80WKCVDV-18-05-04-01	(R18K5F2) P1842K5	SKH3
10	HS 18-0-1-10	XT80W20Co12-Cr4V2Mo1	S 18-1-2-10	T5	BT5	—	—	SKH4A
11	HS 12-1-5-5	—	S 12-1-4-5	T15	BT15	—	P124K5	—

Data Sheet 22.1—HS 18-0-1 (ISO)

PROPERTIES AND APPLICATIONS

This steel is a conventional steel for general use. It possesses a higher red hardness compared to HS 6-5-2, low susceptibility to over heating in hardening and good grindability. It is an all round steel that can be used for a large range of applications, as, for example, *hot work drawing*, shearing, piercing, pressing tools for mild steel or non-ferrous metals. *Cold work*, lathe and planing tools, threading tools, twist drills and reamers, also for cutting knives in nail manufacturing. Table 22.12 gives the chemical composition of International Standard steels.

Table 22.12

Country	ISO	INDIA	DEU	USA	GBR	FRA	USSR	JPN	
Standard norm	ISO 4957-80	IS	DIN 17350-80	AISI	BS4659-71	NFA35 590-78	GOST	JIS 4403-68	
Designation	HS18-0-1	X172W18 Cr4V1	S-18-0-1	T1	BT1	Z80WCV 18-04-01	R18	SKH2	
Chemical composition	C	0.73-0.83	0.65-0.80	0.70-0.78	0.63-0.75	0.70-0.80	0.75-0.83	0.70-0.80	0.7-0.85
	Co	—	—	—	—	≤ 0.60	1.00	—	—
	Cr	3.5-4.5	3.75-4.50	3.80-4.50	3.75-4.50	3.75-4.50	3.5-4.5	3.8-4.4	3.8-4.5
	Mo	—	—	—	—	≤ 0.70	≤ 1.00	≤ 1.00	—
	V	0.9-1.2	1.00-1.25	1.00-1.20	0.89-1.30	1.00-1.25	1.00-1.30	1.00-1.40	0.80-1.20
	W	17.2-18.7	17.5-18.5	17.50-18.50	17.25-18.75	17.50-18.50	17.20-18.70	17.0-18.5	17.0-19.0

HEAT TREATMENT

Stress relieving 650-700°C, soak for 1 hr per 20 mm thickness with slow furnace cooling.

Hardening 1250-1290°C, soaking time depends on the cross-section (Figs 22.11 (a), (b) subsequently quenched in hot oil bath or molten salt bath (530-630°C) when the tool is cooled to 60-80°C temperature, temper immediately. Fig. 22.33 (a) illustrates the isothermal TTT curve.

For tools requiring a high toughness, great care should be taken towards minimum distortion and when red hardness is not much important, harden from 1200-1250°C.

Tempering 550-570°C, temper twice to obtain best results with thorough cooling to room temperature between tempering operation. Soaking time 1½-2 h.

Figure 22.33 (b) illustrates the tempering curve.

Obtainable hardness 63-65 HRC.

S18-0-1 (ATSI T1) → Rough machine → Stress relieving → Final machine →
 630–700°C

Quenching → Hardening temp → Second preheating → First preheating →
 550–630°C 1250–1290°C 840–870°C 400–600°C

→ Temper twice 350–570°C → Finish grinding → Tempering 200–250°C
 (2 hr + 2 hr) or 400–450°C

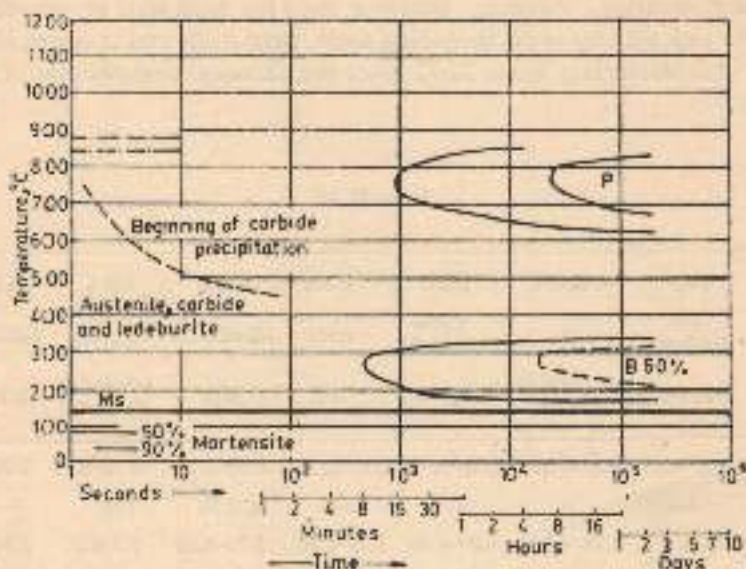


Fig. 22.33(a) Isothermal TTT curve of (ISO) HS 18-0-1 steel. Austenitizing temperature—1270°C

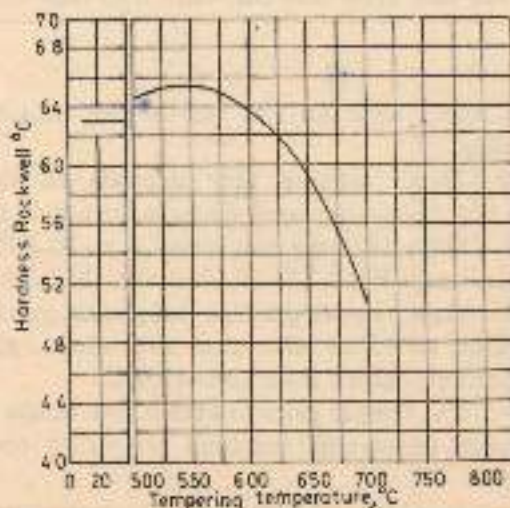


Fig. 22.33(b) Tempering curve. Quenched from 1270°C/oil, size of specimen = $1\frac{1}{16}$ sq. inch (Courtesy: Sarastahl Export GmbH, W. Germany)

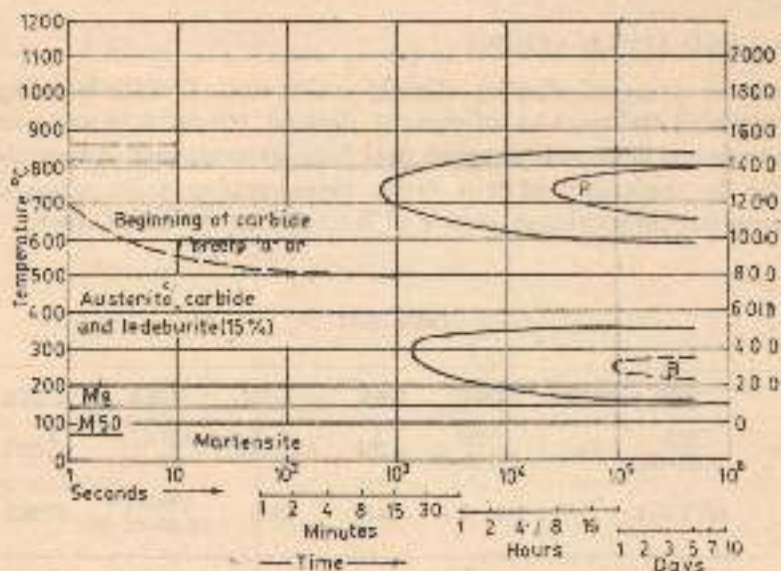


Fig. 22.34(a) Isothermal TTT curve of (ISO) HS 1-8-1 steel. Austenitizing temperature — 1230°C

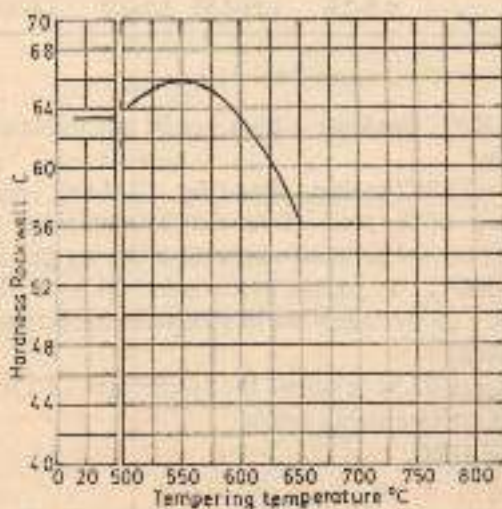


Fig. 22.34(b) Tempering curve. Quenched from 1200°C/oil, size of test specimen = $1\frac{1}{8}$ sq. inch (Courtesy: Sarstahl Export GmbH, West Germany)

Data Sheet 22.3—HS 6-5-2 (ISO)

PROPERTIES AND APPLICATIONS

This is a molybdenum base high speed steel. It possesses a high cutting performance with high toughness. Compared to all other high speed steels it possesses high toughness. This steel is mainly preferred for tools used for applications in which high resistance to shock and impact strength are of particular importance as well as for high rotating stresses. The thermal stability of this steel is lower than that of S 18-0-1 steel. It is susceptible to decarburization during austenitizing.

Increase of carbon content of this steel from 0.85% to 0.95-1.05% increases the thermal stability slightly and improves wear resistance. Because of this, durability of cutting speeds increases by a factor of 1.5-1.8. Table 22.14 gives the chemical composition of International Standard steels.

Table 22.14

Country	ISO	INDIA	DEU	USA	GBR	FRA	USSR	JPN
Standard	ISO 4957-80	IS	DIN 17350-80	AISI	BS4659-71	NFA35- 390-78	GOST	JIS 4403-68
Designation	HS6-5-2	KT87W6- Mo5Cr4V2	86-5-2	M2	BM2	Z85WDCV 06-05-04-02	R6M5	SKH9
Chemical composition	C	0.82-0.92	0.82-0.92	0.86-0.94	0.78-0.88	0.8-0.9	0.8-0.87	0.8-0.9
	Co	—	—	—	≤ 0.6	≤ 1.0	—	—
	Cr	3.5-4.5	3.75-4.50	3.8-4.5	3.75-4.5	3.5-4.5	3.8-4.4	3.8-4.5
	Mo	4.6-5.3	4.75-5.50	4.7-5.2	4.5-5.5	4.75-5.5	4.6-5.3	5.0-5.5
	V	1.7-2.2	1.75-2.05	1.7-2.0	1.6-2.2	1.75-2.05	1.7-2.2	1.2-2.10
	W	5.7-6.7	5.75-6.75	6.0-6.7	5.5-6.75	6.0-6.75	5.7-6.7	5.5-6.7

HEAT TREATMENT

- Stress relieving** 650-700°C, soak for 1 hr per 20 mm thickness, followed by furnace cooling.
- Hardening** 1190-1230°C, soaking time depends on the cross-section of the tools, followed by quenching in hot oil or hot bath (500-600°C). When cooled to hand warm 60-80°C, temper immediately. Where high speed steel is used for cold working, wear resistance and toughness are important properties and hot hardness is of less significance. Hardening may be done from 1170-1180°C. Figure 22.35 (a) illustrates the isothermal TTT curve.
- Tempering** 540-570°C. To obtain best results the tool should be tempered 2 times with thorough cooling to room temperature between tempering. Soaking time is 2 hr Figure 22.35 (b) illustrates the tempering curve.
- Hardness** 64-66 HRC.

S6-5-2 (AISI-M2) → Rough machine → Stress relieving → Final machine →
 650-700°C

Quenching → Hardening temp → Second preheating → First preheating →
 530-620°C 1190-1230°C 840-870°C 400-600°C

→ Tempering 540-570°C Twice → Finish grinding → Tempering 200-250°C
 or 400-430°C
 tempe (2 hrs + 2 hrs)

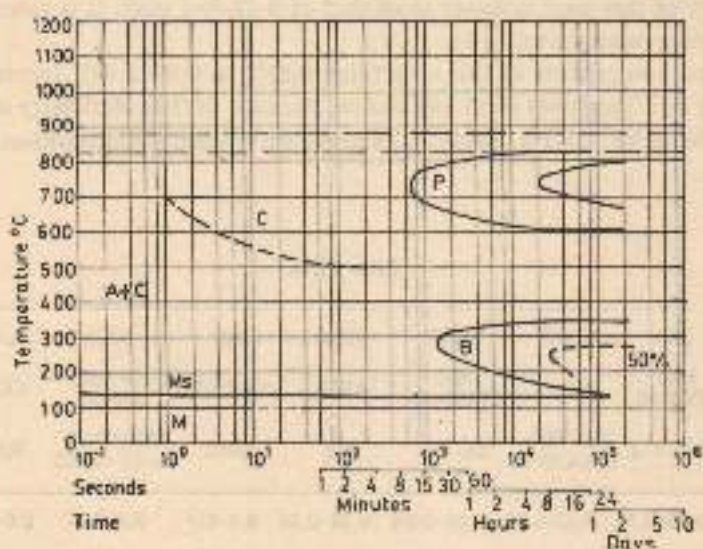


Fig. 22.35(a) Isothermal TTT curve of (ISO) 6-5-2 steel. Austenitizing temperature—1230°C (Courtesy: VEW, Austria)

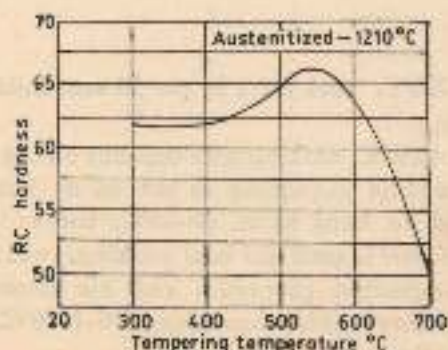


Fig. 22.35(b) Tempering curve, Quenched from 1200°C/oil, size of specimen — 20 sq. inch (Courtesy: VEW, Austria)

Data Sheet 22.4—HS 6-5-3 (ISO)

CHARACTERISTICS AND TYPICAL APPLICATIONS

Compare to M2 high speed steel, the presence of carbon and vanadium is more. This enhances the effect of precipitation hardening in tempering, resulting in higher secondary hardness and higher thermal stability. It possesses a higher hardness compared to M2 steel but toughness will be correspondingly lower. Mainly recommended for heavy duty cutters and reamers as well as for cutting and scraping wheels. Table 22.15 gives the chemical composition of International Standard Steels.

Table 22.15

Country	ISO	INDIA	DEU	USA	FRA	USSR	IPN
Standard norm	ISO 4957-80	IS	DIN 17350-80	AISI	NFA35- 590-78	GOST	JIS 4403-68
Designation	HS6-5-3		S6-5-3	M3(Class 2)	Z120WDCV 06-05-04-03	R6M5F3	SKH53
Chemical composition	C	1.15-1.30	—	1.17-1.27	1.2	1.15-1.25	0.9-1.05 1.10-1.25
	Co	—	—	—	≤ 1.0	—	—
	Cr	3.5-4.5	—	3.8-4.5	4.0	3.5-4.5	3.8-4.5
	Mo	4.6-5.3	—	4.7-5.2	5.0	4.6-5.3	5.5-6.5 4.6-6.2
	V	2.7-3.2	—	2.7-3.2	3.0	2.7-3.2	2.2-2.7 2.8-3.3
	W	5.7-6.7	—	6.0-6.7	6.0	5.7-6.7	5.7-6.7 5.5-6.7

HEAT TREATMENT

Stress relieving	650-700°C, holding time 1 hr per 20 mm of cross-section. Cool slowly in the furnace up to 500°C, thereafter in air.
Hardening	Heat slowly to 1200 to 1240°C. Adopting lower range of hardening temperature results in greater toughness—whereas higher range results in higher hardness and higher hot hardness results in higher wear resistance. Holding time depends on the section thickness, (Fig. 22.11 (a), (b); subsequently quenched in (preferably) salt bath maintained at 550-630°C; thereafter cool in air. Temper immediately when cooled to hand warm (60-80°C).
Tempering	Temper at 540-570°C for at least 2 hr. Temper 3 times to obtain best results with thorough cooling to room temperature between tempering.
Hardness	64-66 HRC.

Data Sheet 22.5—HS 6-5-2-5 (ISO)**PROPERTIES AND APPLICATIONS**

Molybdenum-tungsten base cobalt high speed steel of high cutting power, high resistance to tempering and good toughness. This can be used as a substitute for S18-1-2-5 steel. Its wear resistance is lower compared to S12-1-4-5 but the mechanical properties of this steel are 20 to 30% higher.

Used for turning, planing and slotted tools for roughing work at high cutting speeds and coarse feed also for high duty twist drills and taps, moulding knives, etc. Especially well suited for heavy duty milling cutters and profile tools of any shape, and for twist drills that must meet highest requirements. Table 22.16 gives the chemical composition of International Standard steels.

Table 22.16

Country	ISO	INDIA	DEU	USA	GBR	FRA	USSR	JPN
Standard norm	ISO 4957-80	IS	DIN 17350-80	AISI	BS	NFA35- 590-78	GOST	JIS 4403-68
Designation	HS6-5-2-5	X190W6Co- Mo5Cr4V2	S6-5-2-5	M35		Z8SWDKCV 06-03-05-04 02	R6M5K5	SKH35
Chemical composition	C	0.85-0.95	0.85-0.95	0.88-0.96	0.8	—	0.82-0.90	0.8-0.9
	Co	4.7-5.2	4.75-5.25	4.5-5.0	8.0	—	4.8-5.3	4.5-5.5
	Cr	3.5-4.5	3.75-4.50	3.8-4.5	4.0	—	3.5-4.5	3.8-4.5
	Mo	4.6-5.3	4.75-5.50	4.7-5.2	5.0	—	4.8-5.3	4.8-6.2
	V	1.7-2.2	1.7-2.2	1.7-2.0	2.0	—	1.7-2.2	1.7-2.3
	W	5.7-6.7	5.75-6.75	6.0-6.7	6.0	—	5.7-6.7	5.5-6.7

HEAT TREATMENT

- Stress relieving** 650-700°C, Soaking time 1 hr per 20 mm thickness followed by cooling in furnace.
- Hardening** 1190-1230°C holding time depends on the tool section thickness (Fig. 22.11 (a) (b)). Subsequently cool in hot oil or warm bath 550-630°C. When the steel cools to 60-80°C temper immediately. Figure 22.36 (a) illustrates the isothermal TTT curve.
- Tempering** 550-570°C. To obtain best results, the tools should be tempered three times with thorough cooling between each operation. Holding time is 2 hours. Figure 22.36 (b) illustrates the tempering curve.
- Hardness** 63-64 HRC.

S6-5-2-5 (AISI M35) → Rough machine → Stress relieving → Final machine
 650-700°C
 → Quenching → Hardening temp → Second preheating → First preheating →
 550-630°C 1190-1230°C 840-870°C 400-600°C
 → Tempering 550-570°C, Triple → Finish grinding → Tempering 200-250°C
 (temp 2 hr + 2 hr + 2 hr) or 400-450°C

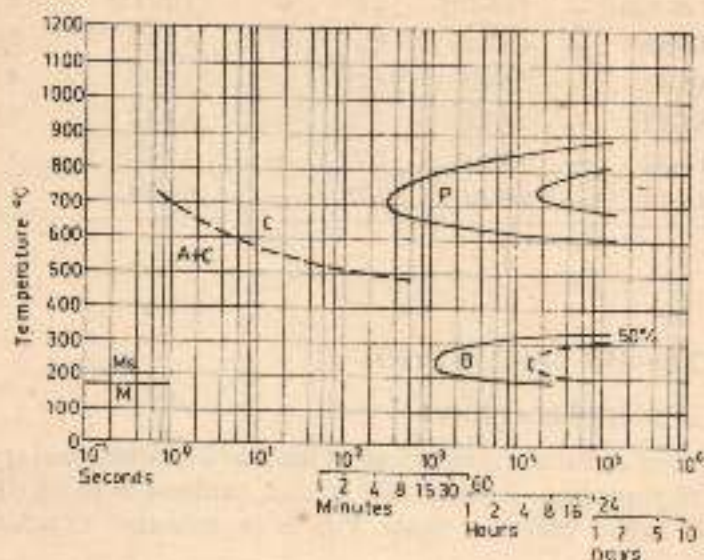


Fig. 22.36(a) Isothermal TTT curve of (ISO) HS 6-5-2-5 steel, austenitized at 1200°C (Courtesy: VEW, Austria).

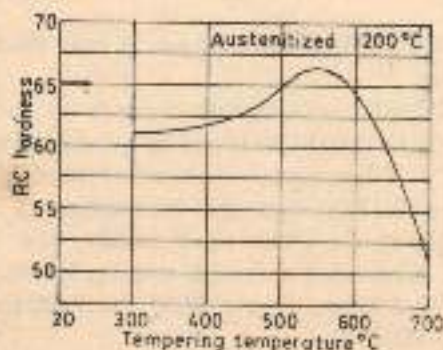


Fig. 22.36(b) Tempering curve. Specimen size = 20 mm (Courtesy: VEW, Austria)

Table 22.17

Country	ISO	INDIA	DEU	USA	GBR	FRA	USSR	JPN	
Standard norm	ISO 4957-80	IS	DIN 17350-80	AISI	BS970: 1-72	NFA35- 590-78	GOST	JIS	
Designation	HS7-4-2-5		57-4-2-5	M41		Z110WKCDV- 07-05-04-04-02	10P7M4K5		
Chemical composition	C	1.05-1.20	—	1.05-1.15	1.1	—	1.05-1.15	1.10	—
	Co	4.7-5.2	—	4.8-5.2	5.0	—	4.7-5.2	5.0	—
	Cr	3.5-4.5	—	3.8-4.5	4.25	—	3.5-4.5	4.1	—
	Mo	3.5-4.2	—	3.6-4.0	3.75	—	3.5-4.2	3.8	—
	V	1.7-2.2	—	1.7-1.9	2.0	—	1.7-2.2	1.8	—
	W	6.4-7.4	—	6.6-7.1	6.75	—	6.4-7.4	6.8	—

Data Sheet 22.6—HS 7-4-2-5 (ISO)

PROPERTIES AND APPLICATIONS

This is a high carbon and cobalt alloyed steel of the modern carbide tool type, and imparts super-high speed properties. It possesses a greater hardness of 66-68 HRC. Along with other high speed cobalt grades, it ranks highest in resistance to softening at elevated temperature.

Mainly used for chip-forming tools, principally multi-edge tools such as milling cutters and similar types of tools. Table 22.17 gives the chemical composition of International Standard steels.

HEAT TREATMENT

Stress relieving	650-700°C, soak for 1 hr per 20 mm thickness, followed by furnace cooling.
Hardening	1190-1230°C, soaking time depends on the cross-section of the tools, (Fig. 22.11 (a), (b)) followed by quenching in hot oil or hot bath (500-630°C). When cooled to hand warm 60-80°C, temper immediately. Figure 22.37 (a) illustrates the isothermal TTT curves.
Tempering	560-580°C. To obtain best results, the tools should be tempered three times with thorough cooling between each tempering soaking time 1½-2 hours. Figure 22.37 (b) illustrates the tempering curve.
Hardness	65-67 HRC.

PROCESSING SEQUENCE

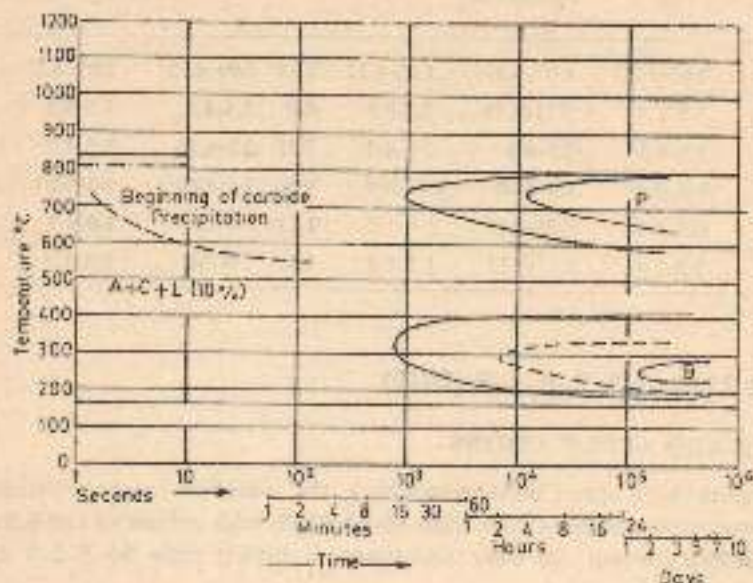
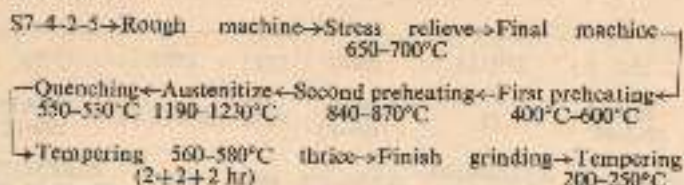


Fig. 22.37(a) Isothermal TTT curve of (ISO) HS 7-4-2-5 steel (Courtesy: Sarsstahl Export GmbH, W. Germany)

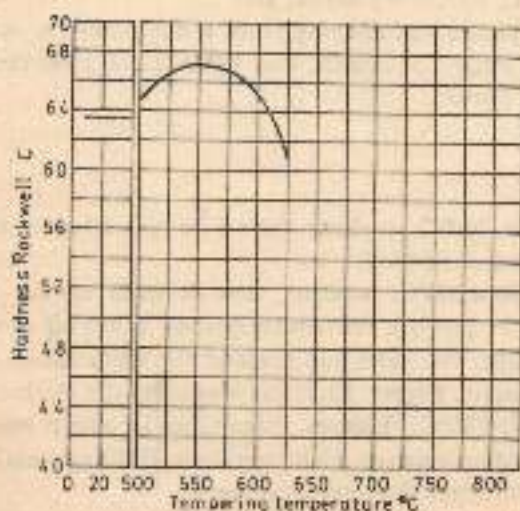


Fig. 22.37(b) Tempering curve. Quenched from 1200°C/oil, size of specimen = 30 × 30 mm

Table 22.18

Country	ISO	INDIA	DEU	USA	GBR	FRA	USSR	JPN
Standard norm	ISO 4957-80	IS	DIN 17350-80	ASTM	B54659-71	NFA35 590-78		JIS
Designation	HS2-9-1-8	XT110Mo10- Co8Cr4W2	S2-10-1-8	M42	BM42	Z110DKCWV 09-08-04-02-01		
Chemical composition	C	1.05-1.20	1.05-1.15	1.05-1.12	1.10	1.00-1.10	1.05-1.15	—
	Co	7.5-8.5	7.75-8.75	7.5-8.5	8.0	7.5-8.5	7.5-8.5	—
	Cr	3.5-4.5	3.5-4.5	3.6-4.4	3.75	3.5-4.25	3.5-4.5	—
	Mo	9.0-10.0	9.0-10.0	9.0-10.0	9.5	9.0-10.0	9.0-10.0	—
	V	0.9-1.4	0.95-1.35	1.0-1.3	1.15	1.0-1.3	1.0-1.3	—
	W	1.3-1.9	1.15-1.85	1.2-1.8	1.5	1.0-2.0	1.3-1.9	—

Data Sheet 22.7—HS 2-9-1-8 (ISO)

PROPERTIES AND APPLICATIONS

A special purpose high speed steel combining the excellent wear resistance properties compared to conventional Mo-W-V high speed steels with enhanced red hardness induced by the high cobalt content. Its wear resistance is higher than S6-5-2-5 and S12-1-4-5 with a better toughness.

Recommended for machining of materials of high tensile strength, manganese steels, heat resistant steels, work hardening alloys, etc.

Suitable for lathes, planer and shaping tools, milling cutters, tool bits, drills, reamers, broaches and inserted blades for cutters, etc. Table 22.18 gives the chemical composition of International Standard steels.

HEAT TREATMENT

Stress relieving	650-700°C; soaking time 1 hr per 20 mm thickness, followed by furnace cooling.
Hardening	1170-1200°C; soaking time depends on the section thickness (Fig. 22.11 (a) (b)); subsequently cool in hot oil or warm bath, 550-630°C; when the steel has reached the temperature 60-80°C temper immediately. Figure 22.38 (a) illustrates the isothermal TTT curve.
Tempering	530-560°C. Temper three times to obtain best results with thorough cooling between each operation. Holding time is 2 hr. Figure 22.38 (b) illustrates the tempering curve.
Hardness	64-68 HRC.

S2-9-1-8 (AISI M42) → Rough machine → Stress relieving → Final machine →
 650-700°C
 Quenching ← Hardening temp ← Second preheating ← First preheating ←
 550-630°C 1170-1210°C 840-870°C 400-600°C
 → Temper thrice 530-560°C → Finish grinding → Tempering 200-250°C or
 (2 hr + 2 hr + 2 hr) 400-450°C

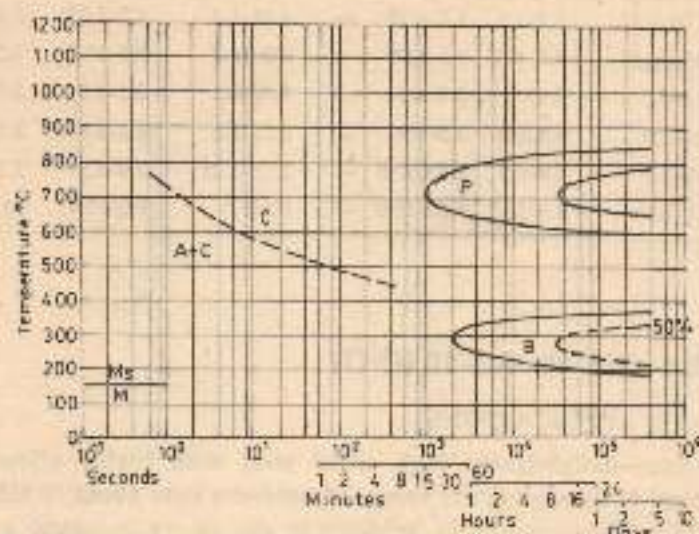


Fig. 22.38(a) Isothermal TTT curve of (ISO) HS 2-9-1-8 steel austenitized at 1190°C (Courtesy: VEW, Austria)

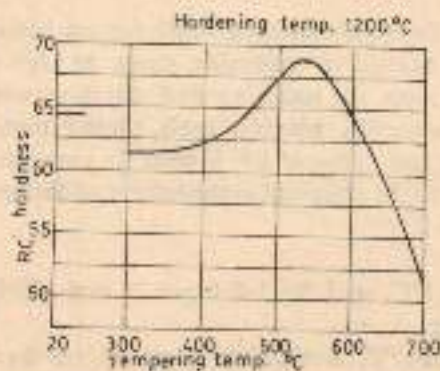


Fig. 22.38(b) Tempering curve. Hardening temperature = 1200°C, specimen size = 20 mm (Courtesy: VEW, Austria)

Table 22.19

Country	ISO	INDIA	DEU	USA	GDR	FRA	USSR	JPN
Standard norm	ISO 4957-80	IS	DIN 17350-80	AISI	B54659-71	NFA35 590-78	*GOST	JIS 4403-68
Designation	HS10-4-3-10	XT125WCo- 10CrMo4V3	S10-4- 3-10		BT42	Z130WKC13V 10-10-04-04-03	12P104 φ5K10	SKH37
Chemical composition	C	1.20-1.35	1.2-1.3	1.2-1.35	—	1.25-1.4	1.2-1.25	1.15-1.3
	Co	9.5-10.5	8.8-10.7	9.5-1.05	—	9.0-10.0	9.5-10.5	9.0-11.0
	Cr	3.5-4.5	3.75-4.50	3.8-4.5	—	3.75-4.5	3.5-4.5	3.75-4.25
	Mo	3.2-3.9	3.0-4.0	3.2-3.9	—	2.75-3.5	3.2-3.9	3.7-4.7
	V	3.0-3.3	2.8-3.5	3.00-3.50	—	2.75-3.25	3.0-3.5	3.25-3.75
	W	9.0-10.1	8.8-10.7	9.00-10.0	—	8.5-9.5	9.0-10.0	10.0-11.0

*Stahlsjussel

Data Sheet 22.8—HS 10-4-3-10 (ISO)

PROPERTIES AND APPLICATIONS

High grade tungsten-molybdenum high speed steel with highly alloyed cobalt and vanadium. This steel possesses highest values of hardness upto about 70 HRC and thermal stability (630-650°C). The increase in hardness is due to an increased concentration of carbon in the martensite, apart from higher thermal stability. The presence of cobalt improves the heat conductivity and highest effect in increasing the tools durability. Compared to all other high speed steels e.g. S2-10-1-8, S18-1-2-10, its wear resistance and thermal stability is more.

This steel may be used for highly stressed tools for machining of materials possessing a high tensile strength. In particular austenitic steels at high cutting speeds, as well as turning tools and forming tools for roughing and finishing work in automatic machines and turret lathes, gear cutting tools, planing tools, thread cutting tools, etc. This steel has shown excellent results and longest life if used in automatic machines and in mass production. Table 22.19 gives the chemical composition of International Standard steels.

HEAT TREATMENT

- Stress relieving** 650-700°C, soak for 1-2 h per 20 mm thickness, followed by furnace cooling.
- Hardening** 1200-1240°C. Soak time depends on the cross section of the tool (Fig. 22.11(a) (b)). Subsequently it is cooled in hot oil or hot bath (550-630°C). When the tool cools to 60-80°C, temper immediately. When this steel is used for cold working, wear resistance and toughness are important properties and hot hardness is of less significance, hardening may be done from 1170-1180°C. Figure 22.39a illustrates the isothermal TTT curve and Fig. 22.39(c) the hardened structure.

Tempering

550–570°C. Temper 3 times to obtain best result with thorough cooling to room temperature between tempering. Holding time is 2 hour. Figure 22.39 (b) illustrates the tempering curve, Fig. 22.39 (d) the structure after the first tempering, Fig. 22.39 (e) the structure after the second tempering, and Fig. 22.39 (f) after the third tempering.

Hardness

65–68 HRC.

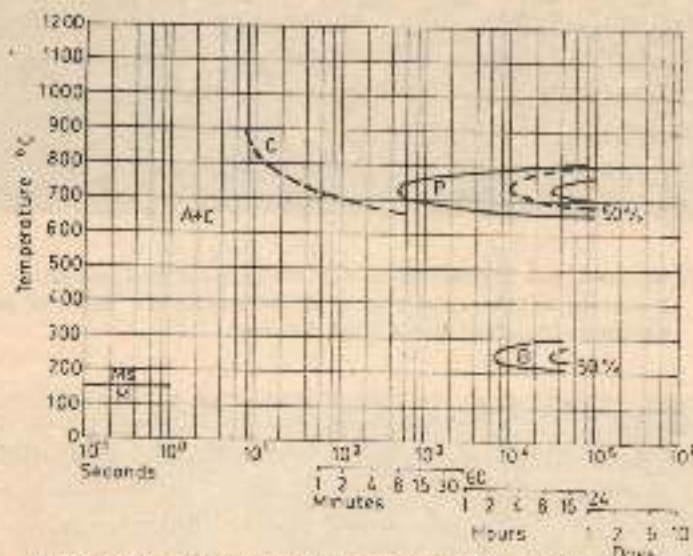
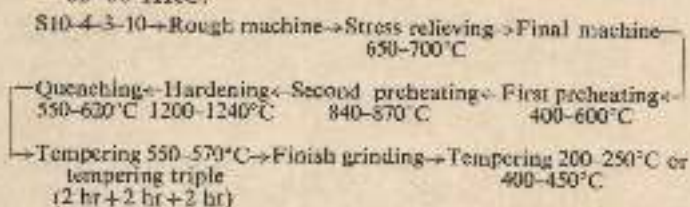


Fig. 22.39(a) Isothermal TTT curve of (ISO) HS10-4-3-10 steel austenitized at 1210°C, holding time 150 s (Courtesy: VEW, Austria)

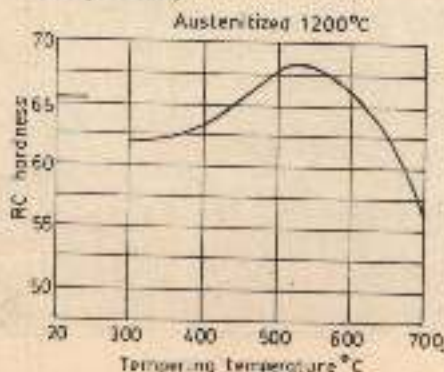


Fig. 22.39(b) Tempering curve: Austenitized at 1200°C, specimen size = 20 mm



Fig. 22.39(c) Microstructure of (ISO) HS 10-4-3-10 high-speed steel austenitized at 1230°C. It consists of spheroidal angular alloy carbides in a matrix of untempered martensite (*Courtesy: Speed Steel, Sweden*)

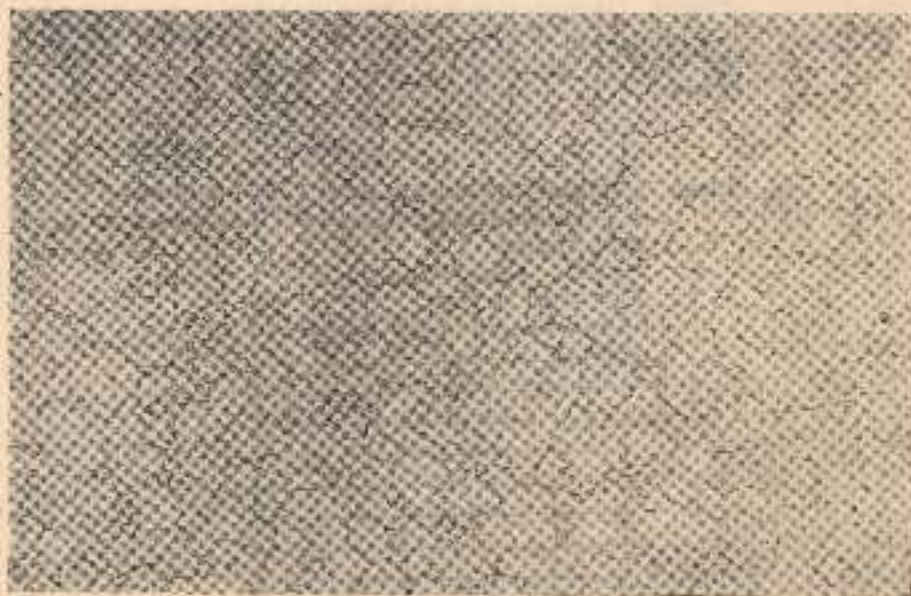


Fig. 22.39(d) Same steel tempered at 550°C for 1 h. Structure consists of long and small alloy carbide particles (white) in a matrix of tempered martensite. Small amount of retained austenite still evident (*Courtesy: Speed Steel, Sweden*)



Fig. 22.39(e) Same steel tempered again at 550°C for 1 h. The structure consists of large and small alloy carbide particles in a matrix of tempered martensite. Very small amount of retained austenite still evident (Courtesy: Speed Steel, Sweden)



Fig. 22.39(f) Same steel tempered again at 550°C for 1 h. The structure consists of large and small alloy carbide particles in a matrix of tempered martensite (Courtesy: Speed Steel, Sweden)

Table 29.20

Country	ISO	INDIA	DEU	USA	GBR	FRA	USSR	JPN	
Standard norm	ISO 4957-80	IS	DIN 17350-80	AISI	BS4659-71	NFA35- 390-78	*GOST	JIS 4403-68	
Designation	HS18-1-1-5	XT75W18Co- 5Cr4MoV1	S18- 1-2-5	T4	BT4	Z80WKCV 18-05-04-01	(R18K5F2) P1842K5	SK H3	
Chemical composition	C	0.75-0.85	0.7-0.8	0.75-0.83	0.7-0.8	0.7-0.8	0.77-0.85	0.85-0.95	0.7-0.85
	Co	4.7-5.2	4.5-5.5	4.5-5.0	4.25-5.75	4.5-5.5	4.5-5.2	5.0-6.0	4.5-5.5
	Cr	3.5-4.5	3.75-4.50	3.8-4.5	3.75-4.5	3.75-4.5	3.5-4.5	3.8-4.4	3.8-4.5
	Mo	0.7-1.0	0.4-1.0	0.5-0.8	0.7-1.0	1.0	0.7-1.0	1.0	—
	V	1.1-1.6	1.0-1.25	1.14-1.17	0.8-1.2	1.0-1.25	1.1-1.6	1.8-2.4	0.8-1.3
	W	17.2-18.7	17.5-19.0	17.5-18.5	17.25-18.75	17.5-18.5	17.2-18.7	17.0-18.5	17.0-19.0

*Stahlsuessel

Data Sheet 22.9—HS 18-1-1-5 (ISO)**PROPERTIES AND APPLICATIONS**

Cobalt alloyed high speed steel with great ability to withstand over stressing, with high red hardness and satisfactory toughness. It is far more efficient than high speed steels which are free from cobalt. Safe to be heat treated. This steel may be used for heavy roughing work, for dry cutting when heavy cuts are required as well as for intermittent cuts. Preferred for the machining of hard and austenitic steels and grey iron castings. This steel is recommended for the manufacture of turning, slotting and planing tools, tool-bits for automatic lathes, milling cutters and drills, gear planing tools, threading dies, screwing dies. Various machining tools for machining hard cast steel, grey cast iron etc. Can also make use of this steel. Table 22.20 gives the chemical composition of International Standard steels.

HEAT TREATMENT

Stress relieving 650-700°C, soak for 1 h per 20 mm thickness at the recommended temperature and cool slowly in the furnace.

Hardening 1250-1300°C, soaking time depends on the cross-section of the tools, (Fig. 22.11(a) (b)), followed by quenching in hot oil or molten salt (550-620°C). When the tool attains 60-80°C, temper immediately.

Milling cutters, twist drills and tools with fine cutting edge should be hardened 1250-1280°C. Figure 22.40 (a) illustrates the isothermal TTT curves.

Tempering 560-580°C, to obtain best results, tools should be tempered three times with thorough cooling between each tempering soaking time 1½-2 hours. Figure 22.40 (b) illustrates the tempering curves.

Hardness 64-66 HRC.

S18-1-1-5 (AISI T4) → Rough machine → Stress relieve → Final machine →
 650–700°C
 → Quenching → Hardening → Second preheating → First preheating →
 550–610°C 1250–1300°C 840–870°C 400–600°C
 → Tempering 550–580°C → Finish grinding → Tempering 200–250°C or
 triple temper 400–450°C
 (2 h + 2 h + 2 h)

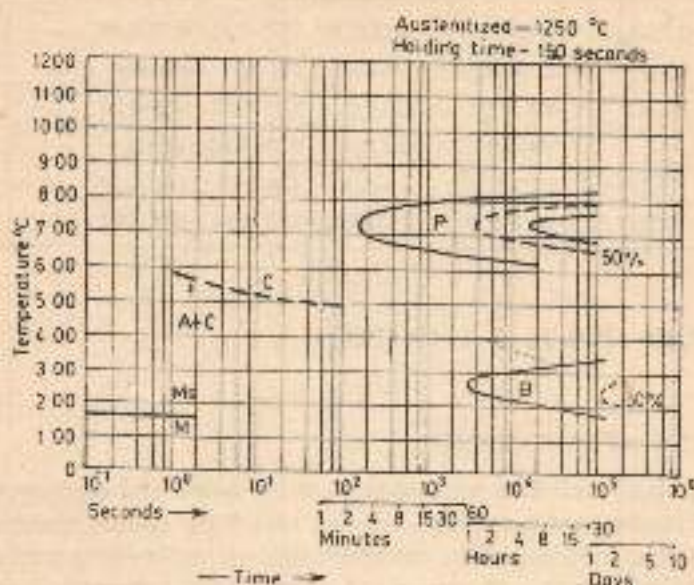


Fig. 22.40(a) Isothermal TTT curve of (ISO) HS 18-1-1-5 steel austenitized at 1250°C. Holding time = 150 s (Courtesy: VEW, Austria)

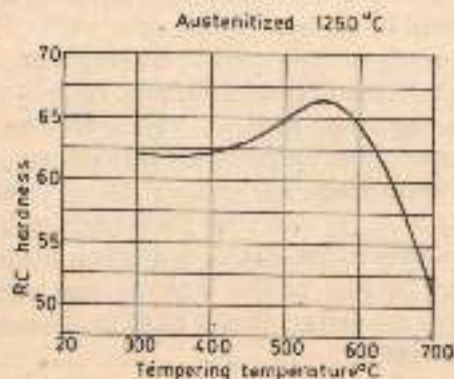


Fig. 22.40(h) Tempering curve. Austenitized at 1250°C, specimen size = 20 mm (Courtesy: VEW, Austria)

Table 22.21

Country	ISO	INDIA	DEU	USA	GBR	FRA	USSR	JPN
Standard norm	ISO 4957-80	IS	DIN 17350-80	AISI	BS4639-71	NFA35- 490-78	GOST	JIS 4403-68
Designation	HS18-0-1-10	XT80W20Co- 11Cr4V2Mo1	S18-1-2-10	T5	BT5			SKH4A
Chemical composition	C	0.75-0.85	0.75-0.85	0.72-0.80	0.75-0.85	0.75-0.85	—	0.7-0.85
	Co	9.5-10.5	11.0-12.5	9.0-10.0	7.0-9.0	9.0-10.0	—	9.0-11.0
	Cr	3.5-4.5	4.0-4.75	3.8-4.5	3.75-4.50	3.75-4.50	—	3.8-4.5
	Mo	—	0.4-1.0	0.5-0.8	0.70-1.00	≤ 1.0	—	—
	V	1.3-1.8	1.25-1.75	1.4-1.7	1.8-2.4	1.75-2.05	—	0.8-1.2
	W	17.2-18.7	19.5-21.0	17.5-18.5	17.5-19.0	18.5-19.5	—	17.0-19.0

Data Sheet 22.10—HS 18-0-1-10 (ISO)

PROPERTIES AND APPLICATIONS

High alloy cobalt high speed steel with highest cutting power and excellent toughness. This steel can be used for heaviest roughing work and with high cutting speeds. Mainly it can be used for machining hard materials, austenitic steels as well as grey iron castings.

Suitable for the manufacture of turning and planing tools subjected to extreme machining conditions. Table 22.21 gives the chemical composition of International Standard steels.

HEAT TREATMENT

- Stress relieving** Heat to 650-670°C, holding time 1 h per 20 mm of cross-section. Followed by furnace cooling upto 500°C. Thereafter in air.
- Hardening** Heat slowly to 1260-1300°C, holding time depends on the cross-section of the tool (Fig. 22.11(a) (b)). Tools hardened from lower range of hardening temperature will have greater toughness compared to those hardened from upper range of hardening temperature. Hardened from upper range will possess higher hardness and hot strength. Figure 22.41 (a) illustrates the isothermal TTT curve.
- Tempering** Heat slowly to 560-580°C. Minimum holding time 2 hours. Temper 3 times for best results with thorough cooling to room temperature between tempering. Figure 22.41 (b) illustrates the tempering curve.
- Hardness** 64-66 HRC.

S18-0-1-10 (AISI T5) → Rough machine → Stress relieving → Final machine →
 650–700°C
 — Quenching → Hardening temp → Second preheating → First preheating →
 550–630°C 1250–1300°C 840–870°C 400–600°C
 → Triple temper 560–570°C → Finish Grinding → Tempering 200–250°C or
 (2 hr + 2 hr + 2 hr) 400–450°C

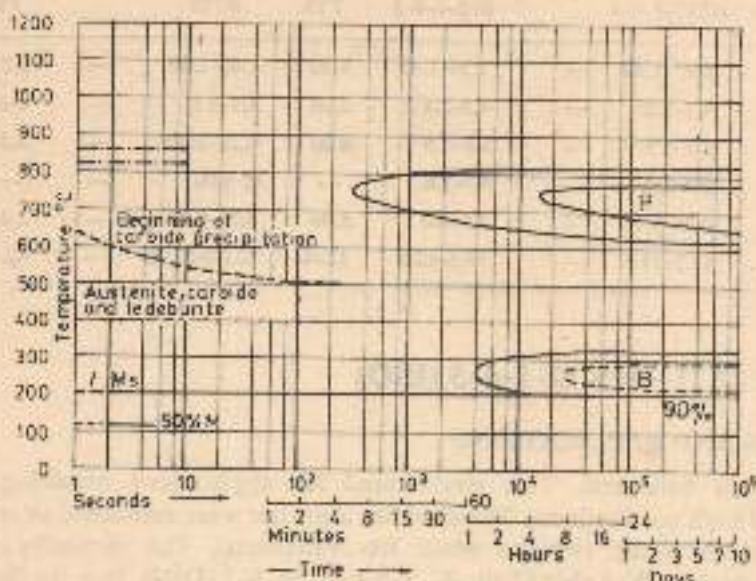


Fig. 22.41(a) Isothermal TTT curve of (ISO) HS 18-0-1-10 steel austenitized at 1280°C (Courtesy: Saestahl Export GmbH, W. Germany)

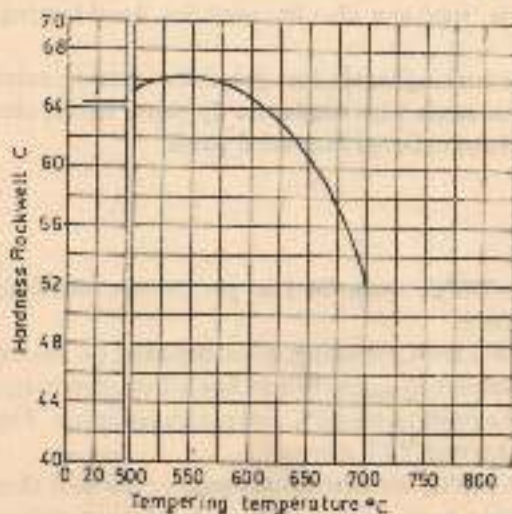


Fig. 22.41(b) Tempering curve. Quenched from 1280°C/oil, specimen size = 1₁₆ sq. inch (Courtesy: Saestahl Export GmbH, W. Germany)

Table 22.22

Country	ISO	INDIA	DEU	USA	GBR	FRA	USSR	IPN
Standard norm	ISO 4957-80	IS	DIN 17350-80	AISI	BS4659-71	NFA35- 551-75	GOST	JIS
Designation	HS12-1-5-5		S12-1-4-5	T15	BT15		P1264K5	
Chemical composition	C	1.45-1.60	—	1.50-1.45	1.50	1.40-1.60	—	1.25-1.40
	Co	4.7-5.2	—	4.5-5.5	5.00	4.5-5.5	—	5-6
	Cr	3.5-4.5	—	3.8-4.5	4.00	4.25-5.00	—	3.5-4.00
	Mo	0.7-1.0	—	0.7-1.0	—	≤ 1.00	—	—
	V	4.75-5.55	—	3.5-4.0	5.00	4.75-5.25	—	3.2-3.8
	W	11.5-13.5	—	11.5-12.5	12.00	12.00-13.00	—	12.5-14.00

Data Sheet 22.11—HS 12-1-5-5 (ISO)

PROPERTIES AND APPLICATIONS

Vanadium-cobalt base steel. This steel is used for applications requiring highest wear resistance and high red hardness. The steel has a greater wear resistance as compared with other steels of the group (which contain less vanadium). The durability of this steel is 3.5-4.0 times higher than that of steels, S18-0-1, S6-5-2 (DIN). Due to the presence of higher vanadium carbides (MC) hardness of this steel is more compared to S6-5-2-5, S2-10-1-8. It is intended for finishing work when a long tool life is required and for heavy rough turning. This steel can also be used for hard cutting as well as fine cutting purposes.

This steel is used for turning tools for precision cutting automatic lathes, tool bits, heat resistant and stainless steels with moderate dynamic loads, etc. Table 22.22 gives the chemical composition of International Standard steels.

HEAT TREATMENT

- Stress relieving 650-700°C, soak for 1 h per 20 mm thickness, followed by furnace cooling.
- Hardening 1210-1250°C, soaking time depends on the cross-section of the tools subsequently quenched in hot oil or hot bath (550-630°C). After the tool cooled to 60-80°C temper immediately. Figure 22.42 (a) illustrates isothermal TTT curve.
- Tempering 550-560°C, for best results temper the tool three times with thorough cooling to room temperature between tempering, soaking time 1½ to 2 hour. Figure 22.42 (b) illustrates the tempering curve.
- Obtainable hardness 65-67 HRC.

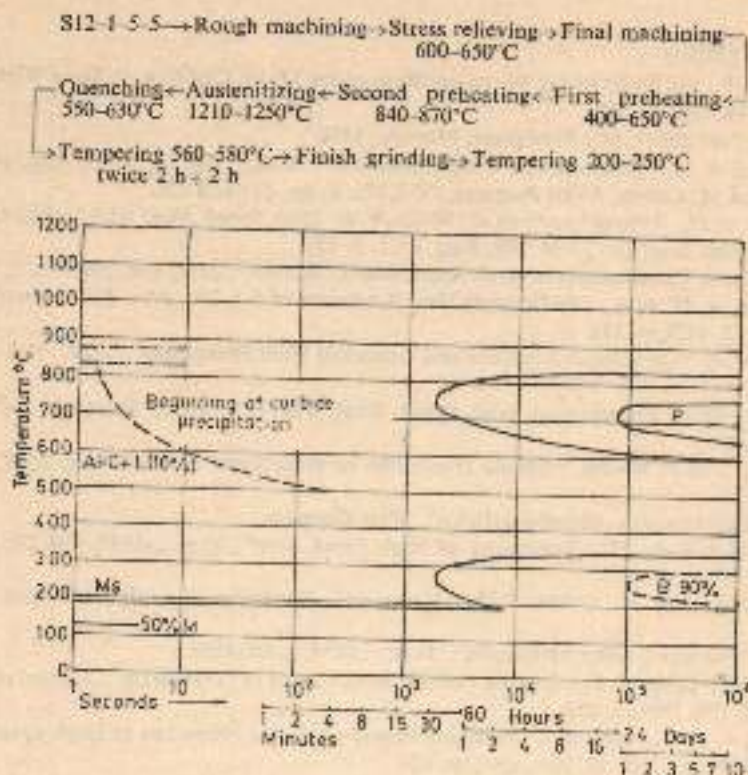


Fig. 22.42(a) Isothermal TTT curve of (ISO) HS 12-1-5-5 steel austenitized at 1230°C (Courtesy: Sarstahl Export GmbH, W. Germany)

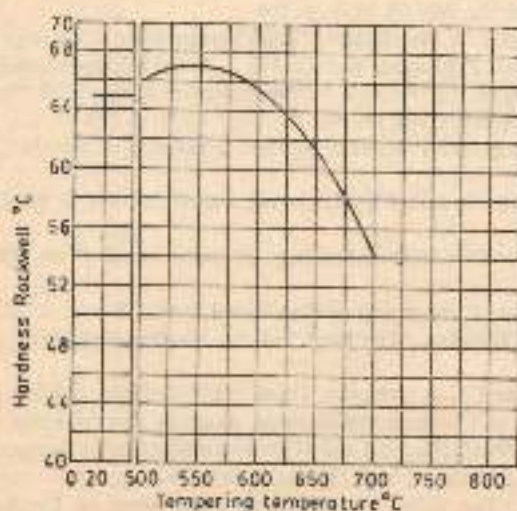


Fig. 22.42(b) Tempering curve. Quenched from 1230°C/oil, specimen size = 30 × 50 mm (Courtesy: Sarstahl Export GmbH, W. Germany)

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Stainless Steels

Stainless steels is the range of alloy steels that resists corrosion (rust). These steels contain more than 12% chromium, with or without alloying elements. As the name suggests, stainless steels are more resistant to rusting than carbon and low alloy steels. This superior corrosion resistance is attributed to the effect of chromium as an alloying element in iron, which results in the formation of a thin oxide film (Cr_2O_3) on the surface of the steel. It also increases the resistance to oxidation at elevated temperature, generally in proportion to the amount used in the alloy. They show remarkable strength and ductility. Generally one or more of the following elements are added to the steels, molybdenum, nickel, titanium, columbium, aluminium, phosphorous, sulphur and selenium. Such elements modify stainless steel so it can be used for a specific purpose. According to the chemical composition and response to heat treatment these steels may be grouped as follows: 1. Martensitic stainless steel. 2. Ferritic stainless steel. 3. Austenitic stainless steel.

23.1 Martensitic Stainless Steels

The chief characteristics of martensitic stainless steels is that they are hardenable. They develop a high hardness and strength, but are not generally suitable for welding. Their corrosion is lowest when compared to other stainless steels.

The hardness obtained depends on the carbon content. It may vary between 0.1% to a maximum of 0.8% carbon. An increase in the carbon content in the steel results in a lowering of corrosion resistance. This is due to the formation of carbides associated with the depletion of chromium from solid solution.

Where formability, softness etc. are required in fabrication and the part is not highly stressed in service, steels having 0.12% maximum carbon is often used. Further increases in carbon content, together with hardening and tempering results in a tensile strength in the range of 60-90 kgf/mm² combined with reasonable toughness and ductility. In this condition, steels find many useful general applications where mild corrosion resistance is required. Also, with higher carbon range in the hardened and lightly tempered condition, tensile strength of about 160 kgf/mm² may be obtained with lower ductility.

When superior machining or free cutting properties are required, steels containing high sulphur in conjunction with zirconium or molybdenum are availed of. These steels may be hardened and tempered. Twelve to fourteen per cent chromium steels may be used where corrosion conditions are not too severe, for example in hydraulic, steam and oil pumps, valves and other engineering components.

These steels are not suitable for welding because of their air hardening tendency and for shafts and parts working in contact with non-ferrous metals (brass, bronze or gunmetal bearing) and with graphite packings. Tempering these steels in the temperature range of 400–500°C is not advisable since they suffer loss of impact strength and there is a marked reduction in general corrosion resistance.

23.2 Ferritic Stainless Steels

These steels contain 17–20% chromium and are somewhat more corrosion resistant than the martensitic steels. Generally these steels are not available for hardening by heat treatment. However in the softened condition they possess good corrosion resistance and good ductility. They are mainly used as cold rolled sheet and strip for subsequent press or roll forming. They may be cold or hot worked and are ferromagnetic. They can be welded, but in some of them, the weld zone becomes brittle. These steels have lower strength at elevated temperatures than martensitic steels. However resistance to scaling and corrosion at elevated temperatures are usually better.

The ferritic stainless steels are not suitable for operations at subzero temperatures since they are susceptible to brittle failure under such conditions.

23.3 Austenite Stainless Steels

As their name implies, these steels have an austenitic microstructure (F.C.C.) at room temperature and cannot be hardened to any great extent by heat treatment, although they can be appreciably strengthened by cold-work. They can be softened by rapid cooling from about 1000°C. They are wholly or largely non-magnetic and in addition to possessing outstanding properties of resistance to corrosion and scaling have good mechanical properties at elevated temperatures. They also possess good weldability especially low carbon variants.

There are many variations in chemical composition but the general purpose steel contains about 18% chromium and 8% nickel with a carbon content as low as possible. Such steel may be readily cold worked so that the hardness and tensile strength are markedly increased.

Owing to the high ductility the steel lends itself readily to manipulation and fabrication, and is extensively used for the production of pressings.

These steels are readily weldable, and they develop a corrosive attack in an area adjacent to the weld, although the weld itself and the body of the part are immune to attack. This may be avoided by heating to about 1100°C followed by rapid cooling. If this method is not possible, steels of stabilized type with niobium titanium may be used.

All the chromium nickel steels exhibit excellent resistance to oxidation in oxidising atmospheres up to 800°C. In addition the steels retain greater strength at higher temperatures than martensitic and ferritic steels. For applications involving thermal cycling to temperatures above 450°C, together with corrosive conditions, the stabilized or very low carbon steel should be used.

When maximum ductility to "weld decay" is associated with the carbon content it is necessary to use low carbon steels for such purposes. When maximum ductility is important for deep drawing or cold spinning, or when maximum corrosion resistance after welding is required, low carbon is desirable. When high tensile strength after cold drawing is required, higher range of carbon is necessary.

Table 23.1

Country Standard	ISO ISO	INDIA IS	DEU DIN	USA AISI	GBR BS 970	FRA NFA35	USSR GOST	JPN JIS
1	Type-1	04Cr13	X7Cr13	—	403X17	Z6C13	08Ch13	SUS403
2	Type-2	—	X6CrAl13	405	—	Z6CA13	—	SUS405
3	Type-8	05Cr17	X8Cr17	430	430S15	Z8Cr17	12Ch17	SUS430
4	Type-8a	—	X12CrMoS17	430F	—	—	—	SUS430F
5	Type-8b	—	X6CrTi17	—	—	—	08Ch17T	—
6	Type-9c	—	—	434	—	28Cr17	—	—
7	Type-3	12Cr13	X10Cr13	410	410S21	Z12C13	12Ch13	SUS410
8	Type-7	—	—	—	416S21	Z12CF13	—	—
9	Type-4	20Cr13	X20Cr13	—	420S37	Z20C13	20Ch13	SUS4201
10	Type-9	15Cr16Ni2	X22CrNi17	—	431S29	—	14Ch17N2	SUS431
11	Type-9b	—	—	431	—	—	—	—
12	Type-5	—	X30Cr13	420	420S45	Z30C13	—	SUS4202
13	Type-6	—	X36Cr13	—	—	—	40Ch13	—
14	Type-6a	—	X40Cr13	—	—	—	40Ch13	SUS4202
15	Type-10	105Cr18MoX0	X105CrMo17	440C	—	Z100CD17	—	SUS440C
16	Type-10	02Cr18Ni11	X2CrNi189	304L	304S12	Z2CN18-10	04Ch18Ni10	SUS304L
17	Type-15	04Cr18Ni10Ti20	X10CrNiTi189	321	321S12	Z6CNT18-30	0KH18Ni10T	SUS321
18	Type-16	04Cr18Ni10Nb40	X6CrNiNb1810	347	347S17	Z6CENb18-10	08Ch18Ni12B	SUS347
19	Type-11	04Cr18Ni10	X5CrNi189	304	304S15	Z6CN18-09	0KH18Ni10	SUS304
20	Type-12	—	—	302	302S31	Z10CN18-09	—	SUS302
21	Type-17	07Cr18Ni19	X12CrNiS18-8	30303	303S21	—	12Ch18Ni10E	SUS303
22	Type-13	—	X5CrNi1812	308	—	—	06Ch18Ni11	—
23	Type-14	10Cr17Ni7	—	301	301S21	Z12CN17-07	—	SUS301
24	Type-19	02Cr17Ni12Mo2	X2CrNiMo1810	316L	316S11	Z2CND17-12	—	SUS316L
25	Type-19a	—	X2CrNiMo18143	316L	316S12	Z2CND17-13	—	SUS316L
26	Type-20	04Cr17Ni12Mo2	X5CrNiMo17122	316	—	Z6CND17-11	—	SUS316
27	Type-20a	—	X5CrNiMo17133	316	316S16	Z6CND17-12	—	SUS316
28	Type-21	04Cr17Ni12MoTi20	X6CrNiMoTi17122	321	320S31	Z6CND17-12	10Ch17Ni13M3T	—
29	Type-21a	—	—	—	320S33	—	—	—
30	Type-23	—	X6CrNiMoNb17122	—	—	Z6CNDNb17-12	08Ch16Ni13M2B	—
31	Type-24	—	X2CrNiMo18164	317	317S12	Z2CND19-15	—	SUS317L
32	Type-A-2	—	—	201	—	—	—	SUS201
33	Type-A-3	—	—	202	—	—	—	SUS202

23.4 Application

The different types of stainless steels mainly used are given in Table 23.1. Different types of applications, mechanical properties and chemical compositions are given in Data Sheets 23.1 to 23.3.

Data Sheet 23.1—Type-1 (ISO)

CHARACTERISTICS AND TYPICAL APPLICATIONS

This is a ferritic grade stainless steel. It is resistant to the corrosive action of the atmosphere, fresh water and steam, milder acids and alkalis. It is resistant to scaling up to 680°C in continuous service. Mainly used for gas turbine blades, furnace parts, valve parts, steam turbine blades and parts, etc. Table 23.2 gives the chemical composition and mechanical properties of International Standard steels.

HEAT TREATMENT

Annealing	750–800°C; followed by air or furnace cooling
Annealed hardness	HB 2192

Table 23.2

Steel	Standard	ISO R683/X111-74	IS 1570-72	DIN 17440-85	AISI	BS 970/1-83	NFA 574-81	GOST 5632-72	JIS G4303-81
	Designation	Type 1		X7Cr13		403S17	Z6C13	08Ch13	SUS 403
Chemical composition	≤ C %	0.08	—	0.08	—	0.08	0.08	0.08	0.15
	≤ Si %	1.0	—	1.0	—	0.80	1.0	0.80	0.50
	≤ Mn %	1.0	—	1.0	—	1.0	1.0	1.80	1.0
	≤ P %	0.04	—	0.045	—	0.040	0.040	0.030	0.040
	≤ S %	0.03	—	0.030	—	0.030	0.03	0.025	0.030
	Cr %	11.5–14.0	—	12–14	—	12–14	11.5–13.5	12–14	11.50–13.0
	Mo %	—	—	—	—	—	—	—	—
	Ni %	0.50	—	—	—	0.50	—	—	0.60
	Others	—	—	—	—	—	—	—	—
Mechanical properties	Dimensions	5–25	—	≤ 25	—	—	≤ 25	—	≤ 75
	0.2% proof stress N/mm ² min	250	—	250	—	245	225	—	302
	Tensile strength N/mm ²	440–640	—	450–650	—	420 min	420–620	—	588 min
	Elongation % min	20	—	20	—	20	20	—	25
	Reduction of area % min	—	—	—	—	—	—	—	—

Data Sheet 23.2—Type-2 (ISO)**CHARACTERISTICS AND TYPICAL APPLICATIONS**

This is a non-hardening steel with 12% chromium. It can be welded easily. It provides good corrosion resistance up to about 650°C and is resistant to the corrosive action of the atmosphere, mild acids, fresh waters and various alkalis. It can be easily formed, bent, spun, roll form, etc. and is mainly used for vessel linings, quenching racks, annealing boxes, steam turbine parts, etc. Table 23.3 gives the chemical composition and mechanical properties of International Standard steels.

HEAT TREATMENT

Forging temperature	1095–1205°C (Commence) 760°C (Finish)
Annealing	750–800°C (Air or water cooled)
Annealed hardness	187 (BHN)

Table 23.3

Steel	Standard	ISO R683/XIII-74	IS 1570-72	DIN 17403-85	AISI	BS 970/1-72	NFA 574-81	GOST	JIS G4303-81
	Designation	Type 2	04Cr13	X6CrAl13	405		Z36CA13		SUS 405
Chemical composition	C %	0.08	0.08	≤ 0.08	≤ 0.08	—	0.08	—	≤ 0.08
	Si %	1.0	1.0	≤ 1.0	1.0	—	1.0	—	1.0
	Mn %	1.0	1.0	1.0	1.0	—	1.0	—	1.0
	≤ P %	0.040	0.04	0.045	0.04	—	0.04	—	0.04
	≤ S %	0.030	0.030	0.030	0.03	—	0.03	—	0.03
	Cr %	11.5–14.0	11.5–14.0	12–14	11.5–14.5	—	11.5–13.5	—	11.5–14.5
	Mo %	—	—	—	—	—	—	—	—
	Ni %	≤ 0.50	0.1–0.3	—	—	—	—	—	—
	Others Al	0.1–0.3	0.1–0.3	0.1–0.3	0.1–0.3	—	0.1–0.3	—	0.1–0.3
Mechanical properties	Dimensions	5–25	5–25	≤ 25	—	—	≤ 25	—	≤ 75
	0.2% proof stress N/mm ² min	250	250	250	—	—	225	—	177
	Tensile strength N/mm ²	410–610	440–640	400–600	207 HB	—	420–620	—	412 min
	Elongation % min	20	20	20	—	—	20	—	20
	Reduction of area % min	—	—	—	—	—	—	—	—

Data Sheet 23.3—Type-8 (ISO)

CHARACTERISTICS AND TYPICAL APPLICATIONS

This is a ferritic grade stainless steel. It possesses excellent corrosion and heat resistance. It has a higher resistance to corrosion than the 13% chromium steels and is resistant to stronger oxidizing acids, caustic solutions, gasoline, lancing and soap solutions.

It is primarily used in the form of precision-ground, polished-strip or sheets for cutlery, table-ware and household ware.

It is also used for door handles, window catches, bumpers and sub-caps, as well as in certain chemical industries, especially nitric acid, acetic acid, etc. Table 23.4 gives the chemical composition and mechanical properties of International Standard steels.

HEAT TREATMENT

Annealing	750-850°C, followed by air or water cooling
Annealed	130-170 BHN

Table 23.4

Steel	Standard	ISO R683/XIII-74	IS 1570-72	DIN 17440-83	AISI	BS 970/4-70	NFA 35-374-81	GOST 5632-72	JIS G4303-81
	Designation	Type 8	05Cr17	X8Cr17	430	430S15	Z8C17	12Cr17	SUS430
Chemical composition	≤ C %	0.10	0.10 max.	0.10	0.12	0.10	0.08	0.12	0.12
	≤ Si %	1.0	1.0 max.	1.0	1.0	0.8	1.0	0.8	0.75
	≤ Mn %	1.0	1.0 max.	1.0	1.0	1.0	1.0	0.8	1.0
	≤ P %	0.04	0.045 max.	0.045	0.04	0.04	0.04	0.035	0.04
	≤ S %	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
	Cr %	16-18	16-18	15.5-17.5	16-18	16-18	16-18	16-18	16-18
	Mo %	—	—	—	—	—	—	—	—
	Ni %	0.5	0.50	—	—	0.5	—	—	—
	Others	—	—	—	—	—	—	—	—
Mechanical properties	Dimensions	5-25	5-25	≤ 25	—	≤ 63	≤ 25	—	—
	0.2% proof stress N/mm ² min	250	250	270	207	245	245	—	—
	Tensile strength N/mm ²	440-640	440-640	450-600	415 min	430 min	440-640	—	—
	Elongation % min	18	16	20	20	20	18	—	—
	Reduction of area % min	—	—	—	—	—	—	—	—

Data Sheet 23.4—Type-8a (ISO)**CHARACTERISTICS AND TYPICAL APPLICATIONS**

This stainless steel may be used to resist corrosion from the atmosphere, fresh water, dairy products, petroleum products, organic materials and nitric acid. The scale-forming temperature in continuous service is about 820°C, and for intermittent service up to 860°C.

This steel may be used for the manufacture of studs, nuts, bolts and for the production of parts in automatic screw machines, spindles, gear wheels, etc. Table 23.5 gives the chemical composition and mechanical properties of International Standard steels.

HEAT TREATMENT

Forging temp	1070–1150°C (Commence) 820°C (Finish)
Annealing temp	725–825°C (Air or water cooled)
Hardening	1025–1050°C (Oil quenching)
Hardness	100 kp/mm ²
Tempering	550–600 (Cooling in air)
BHN	190–235

Table 23.5

Steel	Standard	ISO R683/XIII 74	IS	DIN 17440-85	AISI	BS 970/1-72	NFA	GOST	JIS G4303-81
	Designation	Type 8a		X12CrMoS17	430F				SUS430F
Chemical composition	C %	0.12	—	0.1–0.17	0.12	—	—	—	≤ 0.12
	Si %	1.0	—	1.0	1.0	—	—	—	1.0
	Mn %	1.5	—	1.5	1.25	—	—	—	1.2
	≤ P %	0.06	—	0.045	0.06	—	—	—	0.06
	≤ S %	0.15–0.35	—	0.15–0.35	0.15	—	—	—	0.15
	Cr %	16.0–18.0	—	15.5–17.30	14–18	—	—	—	16–18
	Mo %	≤ 0.6	—	0.2–0.3	0.6	—	—	—	0.6
	Ni %	≤ 0.5	—	—	—	—	—	—	—
	Others	—	—	—	—	—	—	—	—
Mechanical properties	Dimensions	5–25	—	≤ 100	—	—	—	—	≤ 75
	0.2% proof stress N/mm ² min	250	—	450	—	—	—	—	206
	Tensile strength N/mm ²	440–640	—	640–840	285 HTB	—	—	—	≤ 451
	Elongation % min	15	—	11	1	—	—	—	22
	Reduction of area % min	—	—	—	—	—	—	—	—

Data Sheet 23.5—Type-8b (ISO)

CHARACTERISTICS AND TYPICAL APPLICATIONS

This is a ferritic stainless chromium steel with enhanced resistance to oxidising acids and to intercrystalline corrosion. It may be used for welded parts in the dairy, food and brewery industries, as well as for the manufacture and processing of products of acetic acid, nitric acid and the soap industries. This steel has been developed as a welding steel and heat treatment is not required to prevent intergranular corrosion. Table 23.6 gives the chemical composition and mechanical properties of International Standard steels.

HEAT TREATMENT

Forging temp	1050–750°C
Annealing temp	750–850°C
Annealed HB	192

Table 23.6

Steel	Standard	ISO 683/XIII-74	IS	DIN 17440-85	AISI	BS	NFA	GOST 5632-72	JIS
	Designation	Type 8b		X6CrTi17				08Ch17T	
Chemical composition	C %	≤ 0.1	—	≤ 0.08	—	—	—	≤ 0.08	—
	Si %	1.0	—	1.0	—	—	—	1.0	—
	Mn %	1.0	—	1.0	—	—	—	1.0	—
	≤ P %	0.04	—	0.045	—	—	—	0.040	—
	≤ S %	0.03	—	0.03	—	—	—	0.03	—
	Cr %	16–18	—	16–18	—	—	—	16–18	—
	Mo %	—	—	—	—	—	—	—	—
	Ni %	≤ 0.5	—	—	—	—	—	—	—
	Others	Ti ≥ 5x%C ≤ 0.8	—	Ti ≥ 7x%C ≤ 1.2	—	—	—	Ti ≥ 5x%C ≤ 0.8	—
Mechanical properties	Dimensions	5–25	—	≤ 25	—	—	—	—	—
	0.2% proof stress N/mm ² min	250	—	270	—	—	—	—	—
	Tensile strength N/mm ²	440–640	—	430–600	—	—	—	—	—
	Elongation % min	18	—	20	—	—	—	—	—
	Reduction of area % min	—	—	—	—	—	—	—	—

Data Sheet 23.6—Type-9c (ISO)**CHARACTERISTICS AND TYPICAL APPLICATIONS**

This is a non-hardening stainless steel containing molybdenum along with chromium. The presence of molybdenum increases the corrosion resistance, and the resistance to pitting by various dyeing chemicals. Mainly used for cold headed fasteners, television cones, nitric acid storage tanks, etc. Table 23.7 gives the chemical composition and mechanical properties of International Standard steels.

HEAT TREATMENT

Forging temp	1040–820°C
Annealing temp	750–850°C
Annealed HB	201

Table 23.7

Steel	Standard	ISO R683/XIII-74	IS	DIN	AISI	BS 970/1-72	NFA 35/573-81	GOST	JIS
	Designation	Type 9c			434		Z8C17		
Chemical composition	C %	0.10	—	—	≤ 0.12	—	≤ 0.08	—	—
	Si %	1.0	—	—	1.0	—	1.0	—	—
	Mn %	1.0	—	—	1.0	—	1.0	—	—
	≤ P %	0.040	—	—	0.04	—	0.04	—	—
	≤ S %	0.030	—	—	0.03	—	0.03	—	—
	Cr %	16–18	—	—	16–18	—	16–18	—	—
	Mo %	0.9–1.3	—	—	0.75–1.25	—	0.9–1.3	—	—
	Ni %	—	—	—	—	—	—	—	—
	Others	—	—	—	—	—	—	—	—
Mechanical properties	Dimensions	5–25	—	—	50	—	≤ 25	—	—
	0.2% proof stress N/mm ² min	250	—	—	—	—	245	—	—
	Tensile strength N/mm ²	440–640	—	—	517 min	—	440–640	—	—
	Elongation % min	18	—	—	25	—	—	—	—
	Reduction of area % min	—	—	—	—	—	—	—	—

Data Sheet 23.7—Type-3 (ISO)

CHARACTERISTICS AND TYPICAL APPLICATIONS

This is a martensitic type stainless steel. It can be heat treated for the desired mechanical properties. It possesses a good corrosion resistance, both in the annealed and hardened conditions and does not form scales up to 650°C. It will take on a high polish. Table 23.8 gives the chemical composition and mechanical properties of International Standard steels.

This steel is used mainly for gas turbine blades, jet engine parts, valve parts, furnace parts, etc.

HOT WORKING AND HEAT TREATMENT

Forging	700–780°C (Air cool)
Annealing	770–870°C (Furnace cool)
Annealed hardness	up to 180 HB
Hardening	950–1000°C (Oil or air cool)
Tempering	700–750°C
Annealed HB	212

Table 23.8

Steel	Standard	ISO 683/XIII-74	IS 1570-82	DIN 17440-85	AISI	BS 970/1-83	NFA 35-374-81	GOST 5632-72	JIS G4303-81
	Designation	Type 3	12Cr13	X10Cr13	410	410S21	Z12C13	12Ch13	SUS410
Chemical composition	C %	0.09–0.15	0.09–0.15	0.08–0.12	0.15	0.08–0.15	0.08–0.15	0.09–0.15	0.15
	Si %	10	1 max.	1.0	1.0	1.0	1.0	0.80	1.0
	Mn %	10	1 max.	1.0	1.0	1.0	1.0	0.80	1.0
	≤ P %	0.04	0.04	0.045	0.04	0.04	0.04	0.03	0.040
	≤ S %	0.03	0.03	0.03	0.03	0.030	0.03	0.025	0.030
	Cr %	11.5–14.0	11.5–14.0	12–14	11.5–13.5	11.5–13.5	11.5–1.35	12–14	11.5–13.5
	Mo %	—	—	—	—	—	—	—	—
	Ni %	1.0	1.0 max.	—	—	1.0	—	—	0.60
	Others	—	—	—	—	—	—	—	—
Mechanical properties	Dimensions	15–63	5–100	60–160	—	65–152	≤ 25	—	≤ 75
	0.2% proof stress N/mm ² min	410	410	420	550	335	440	—	343
	Tensile strength N/mm ²	590–780	590–780	600–800	690 min	540–700	630–830	—	539 min
	Elongation % min	16	16	18	15	20	16	—	25
	Reduction of area % min	—	—	—	—	—	—	—	—

Data Sheet 23.8—Type-7 (ISO)**CHARACTERISTICS AND TYPICAL APPLICATIONS**

This grade possesses good resistance to the corrosive action of the atmosphere, various alkalis and mild acids. It is most suitable for parts of automatic screw machines, such as screws, bolts and automobile trim, and also for shafts, valve parts, etc. Compared to Type 3, it has greater resistance to corrosion due to the presence of molybdenum. Table 23.9 gives the chemical composition and mechanical properties of International Standard steels.

HEAT TREATMENT

Forging temp	1160–820°C
Annealing temp	770–780°C
Annealed HB	223

Table 23.9

Steel	Standard Designation	ISO 683/XIII-74 Type 7	IS	DIN	AISI	BS 970/1-83 416S21	NFA 35 576-81 Z12CF13	GOST	JIS
Chemical composition	C%	0.08–0.15	—	—	—	0.09–0.15	0.08–0.15	—	—
	Si%	1.0	—	—	—	≤ 1.0	≤ 1.0	—	—
	Mn%	1.5	—	—	—	1.5	1.5	—	—
	≤ P%	0.060	—	—	—	0.04	0.06	—	—
	≤ S%	0.15–0.35	—	—	—	0.15–0.3	0.15	—	—
	Cr%	12–14	—	—	—	11.5–13.5	12–14	—	—
	Mo%	0.60 max.	—	—	—	0.60	0.15–0.6	—	—
	Ni%	≤ 1.0	—	—	—	≤ 1.0	≤ 0.5	—	—
	Others	—	—	—	—	—	—	—	—
Mechanical properties	Dimensions	5–100	—	—	—	63	—	—	—
	0.2% proof stress N/mm ² min	440	—	—	—	495	—	—	—
	Tensile strength N/mm ²	640–830	—	—	—	700–850	—	—	—
	Elongation % min	12	—	—	—	15	—	—	—
	Reduction of area % min	—	—	—	—	—	—	—	—

Data Sheet 23.9—Type-4 (ISO)

CHARACTERISTICS AND TYPICAL APPLICATIONS

This is a martensitic grade steel. It can be hardened to increase wear resistance and strength. It develops the maximum corrosion resistance when hardened and polished. It possesses good scaling resistance up to 650°C in continuous service.

This steel is used mainly for piston rods, shafts, pump parts, valve seats and valve cones, water plungers, connecting rods, gun barrels and surgical instruments. It is also used in general mechanical engineering where parts are exposed to humidity of the air, water and steam. Table 23.10 gives the chemical composition and mechanical properties of International Standard steels.

HEAT TREATMENT

Annealing	770–870°C, followed by furnace cooling 700–780°C (Air cooling).
Annealed	229 BHN
Hardening	980–1030°C (Air or oil quenching)
Maximum hardness	14RC33
Tempering	(a) 650–700°C (b) 700–750°C
Hardened and tempered	(a) 240–285 BHN (b) 195–200 BHN

Table 23.10

Steel	Standard	ISO 683/XIII-74	IS 1570-82	DIN	AISI	BS 970/1-83	NFA 35-551-75	GOST	JIS
	Designation	Type 4	20Cr13	X20Cr13		420S37	Z20C13	20Ch13	SUS 420J1
Chemical composition	C %	0.16–0.25	0.16–0.25	0.17–0.22	—	0.20–0.28	0.15–0.24	0.16–0.25	0.16–0.25
	Si %	1.0	1.0	1.0	—	0.8	1.0	0.80	1.0
	Mn %	1.0	1.0	1.0	—	1.0	1.0	0.80	1.0
	≤ P %	0.040	0.040	0.045	—	0.040	0.04	0.03	0.04
	≤ S %	0.030	0.03	0.030	—	0.030	0.03	0.025	0.030
	Cr %	12–14	12–14	12–14	—	12–14	12–14	12–14	12–14
	Mo %	—	—	—	—	—	—	—	—
	Ni %	1.0	1.0	—	—	1.0	—	—	(0.60)
	Others	—	—	—	—	—	—	—	—
Mechanical properties	Dimensions	5–100	5–100	60–160	—	≤ 152	≤ 25	—	≤ 75
	0.2% proof stress N/mm ² min.	490	490	450	—	560	540	—	441
	Tensile strength N/mm ²	690–880	690–830	650–800	—	770–920	730–930	—	637 min
	Elongation % min.	14	14	14	—	13	14	—	20
	Reduction of area % min.	—	—	—	—	—	—	—	—

Data Sheet 23.10—Type-9 (ISO)**CHARACTERISTICS AND TYPICAL APPLICATIONS**

This is a martensitic grade steel, a higher-chromium version of the nickel-bearing stainless steel. It may be hardened to increase wear resistance and toughness. It also has good oxidation resistance up to about 820°C in continuous service, and good corrosion resistance grade.

Mainly used for shafts, pump parts, water plungers, turbine blades, ship propellers, non-cutting surgical instruments such as forceps, clamps, beater knives in the paper industry etc. Table 23.11 gives the chemical composition and mechanical properties of International Standard steels.

HEAT TREATMENT

Annealing	750–800°C (Air cooling) 620–670°C (Air cooling)
Annealed BHN	262
Hardening	980–1030°C (Oil quenching)
Maximum hardness	HRC—32
Tempering	590–610°C

Table 23.11

Steel	Standard	ISO 683/XIII-74	IS 1570-72	DIN 17440-85	AISI	BS 970/1-83	NFA	GOST 5632-72	JIS G4303-81
	Designation	Type 9	15Cr16Ni2	X22CrNi17		431S29		14Ch17N2	SUS431
Chemical composition	C %	0.10–0.20	0.10–0.20	0.15–0.23	—	0.12–0.20	—	0.10–0.17	0.20
	Si %	1.0	1.0 max.	1.0	—	0.08	—	0.8	1.0
	Mn %	1.0	1.0 max.	1.0	—	1.0	—	0.8	1.0
	≤ P %	0.04	0.04	0.045	—	0.040	—	0.03	0.04
	≤ S %	0.03	0.03	0.030	—	0.030	—	0.025	0.03
	Cr %	15–18	15–18	16–18	—	15–18	—	16–18	15–17
	Mo %	—	—	—	—	—	—	—	—
	Ni %	1.5–3.0	1.5–3.0	1.5–2.5	—	2.0–3.0	—	1.5–2.5	1.25–2.50
	Others	—	—	—	—	—	—	—	—
Mechanical properties	Dimensions	15–63	5–100	60–160	—	63–152	—	—	≤ 75
	0.2% proof stress N/mm ² min.	640	640	600	—	635	—	—	588
	Tensile strength N/mm ²	830–1030	830–1030	800–950	—	850–1000	—	—	785 min.
	Elongation % min.	10	10	14	—	11	—	—	15
	Reduction of area % min.	—	—	—	—	—	—	—	—

Data Sheet 23.12—Type-5 (ISO)**CHARACTERISTICS AND TYPICAL APPLICATIONS**

This steel can be hardened to increase wear resistance and to attain excellent toughness. It develops corrosion resistance when hardened and polished. It has a resistance to oxidation up to 650°C in continuous service, intermittent up to 750°C. Mainly used for dental and surgical instruments, cutlery, hand tools, plastic mould steels, pump parts, valve seats and valve cones, parts exposed to humidity of the air, water and steam, etc. Parts should be pre-heated to 400°C before welding. Table 23.13 gives the chemical composition and mechanical properties of International Standard steels.

HOT WORKING AND HEAT TREATMENT

Forging	1150–750°C
Annealing	750–780°C
Annealed BHN	235
Hardening	950–1000°C (Oil quench)
Maximum hardness	50–52 RC
Tempering	100–200°C
Tempered hardness	46–50 HRC

Table 23.13

Steel	Standard	ISO 683/X141-74	IS	DIN 17440-85	AISI	BS 970/4-70	NFA 55-574-81	GOST	JIS G4303-81
	Designation	Type 5		X30Cr13	420	420S45	Z30C13		SUS420J2
Chemical composition	C %	0.26–0.35	—	0.28–0.35	≥ 0.15	0.28–0.36	0.25–0.34	—	0.26–0.4
	Si %	1.0	—	1.0	1.0	0.8	1.0	—	1.0
	Mn %	1.0	—	1.0	1.0	1.0	1.0	—	1.0
	≤ P %	0.04	—	0.044	0.04	0.04	0.04	—	0.04
	≤ S %	0.03	—	0.030	0.03	0.03	0.03	—	0.03
	Cr %	12–14	—	12–14	12–14	12–14	12–14	—	12–14
	Mo %	—	—	—	—	—	—	—	—
	Ni %	≤ 0.1	—	—	—	—	—	—	—
	Others	—	—	—	—	—	—	—	—
Mechanical properties	Dimensions	5–25	—	≤ 100	—	—	≤ 25	—	75
	0.2% proof stress N/mm ² min	590	—	600	—	560	635	—	539
	Tensile strength N/mm ²	780–980	—	800–1000	≥ 41 HB	780–920	830–1030	—	735
	Elongation % min.	11	—	11	11	—	11	—	12
	Reduction of area % min.	—	—	—	—	—	—	—	—

Data Sheet 23.13—Type-6

CHARACTERISTICS AND TYPICAL APPLICATIONS

This grade can be hardened to increase the hardness and toughness. It is used mainly with a mirror finish, in the hardened and polished condition, for cutting tools such as table, kitchen and machine vices, surgical instruments, razor blades, ice axes, saw blades and machine parts with high wear resistance such as valve sheets, plungers, measuring tools such as plug gauge, slide calipers, etc. Table 23.14 gives the chemical composition and mechanical properties of International Standard steels.

HOT WORKING AND HEAT TREATMENT

Forging	1100–800°C
Annealing	770–870°C
Annealed HB	255
Hardening	1000–1050°C (Oil quench)
Tempering	100–250°C
Tempered hardness	50 RC

Table 23.14

Steel	Standard Designation	ISO 683/X111-74 Type 6	IS	DIN 17440-85 X36Cr13	AISI	BS	NFA	GOST 5632-72 40Ch13	JIS
Chemical composition	C %	0.36–0.45	—	0.35–0.42	—	—	—	0.35–0.44	—
	Si %	1.0	—	1.0	—	—	—	0.8	—
	Mn %	1.0	—	1.0	—	—	—	0.8	—
	P %	0.04	—	0.04	—	—	—	0.03	—
	S %	0.03	—	0.03	—	—	—	0.025	—
	Cr %	12.5–14.5	—	12.5–14.5	—	—	—	12.0–14.0	—
	Mo %	—	—	—	—	—	—	—	—
	Ni %	—	—	—	—	—	—	—	—
	Others	—	—	—	—	—	—	—	—
Mechanical properties	Dimensions	—	—	—	—	—	—	—	—
	0.2% proof stress N/mm ² min	—	—	—	—	—	—	—	—
	Tensile strength N/mm ²	255HB	—	250HB	—	—	—	—	—
	Elongation % min	—	—	—	—	—	—	—	—
	Reduction of area % min	—	—	—	—	—	—	—	—

Data Sheet 23.14—Type-6a (ISO)**CHARACTERISTICS AND TYPICAL APPLICATIONS**

This is a martensitic type stainless steel containing carbon in the range of 0.42–0.50. This grade may be hardened to increase the wear resistance, compare to type-6 higher hardness may be attained 54 RC. After heat treatment component should be pickled, polished or ground to remove all scale followed by baking at 120–150°C to remove acid brittleness. This steel resist scales appreciably at temperatures above 750°C and has corrosion resistance similar to (AISI 410) Type 3.

Mainly used in dental and surgical instruments, cutlery, tool steels for cutting tools, piston rods, valve parts, etc., Table 23.15 gives the chemical composition and mechanical properties of International Standard steels.

HEAT TREATMENT

Annealing	700–870°C, followed by furnace cooling
Annealed hardness	269
Hardening	1000–1050°C, followed by quenching in oil or air
Maximum hardness RC	55–57
Tempering	100–250°C
Tempered hardness	50–54 RC

Table 23.15

Steel	Standard	ISO 683/XIII-74	IS 1570-72	DIN 17440-85	AISI	BS	NFA	GOST 5632-72	JIS G4303-81
	Designation	Type 6a	40Cr13	X40Cr13				40Ch13	SUS420J2
Chemical composition	C %	0.42–0.50	0.36–0.45	0.40–0.50	—	—	—	0.35–0.44	0.26–0.40
	Si %	1.0	1.0	1.0	—	—	—	0.08	1.0
	Mn %	1.0	1.0	1.0	—	—	—	0.08	1.0
	≤ P %	0.04	0.04	0.045	—	—	—	0.03	0.04
	≤ S %	0.03	0.03	0.03	—	—	—	0.25	0.03
	Ce %	12.5–14.5	12.5–14.5	12.5–14.5	—	—	—	12–14	12–14
	Mo %	—	—	—	—	—	—	—	—
	Ni %	1.0	1.0	—	—	—	—	—	(0.60)
	Others	—	—	—	—	—	—	—	—
Mechanical properties	Dimensions	—	—	≤ 15	—	—	—	—	≤ 75
	0.2% proof stress N/mm ² min.	—	—	—	—	—	—	—	339
	Tensile strength N/mm ²	RC 54/min	RC 50/min	RC 50/min	—	—	—	—	735 min
	Elongation % min.	—	—	—	—	—	—	—	12
	Reduction of area % min	—	—	—	—	—	—	—	—

Data Sheet 23.15—A-16 (ISO)

CHARACTERISTICS AND TYPICAL APPLICATIONS

This is a high carbon, high chromium steel. It may be hardened and tempered to increase wear resistance and also to acquire optimum corrosion resistance. It is used for wear resistant textile machine components, ball-bearings and races, valve seats, pump parts and cutlery. Table 23.16 gives the chemical composition and mechanical properties of International Standard steels.

HOT WORKING AND HEAT TREATMENT

Forging	1100-925°C
Full annealing	845-900°C
Process annealing	730-790°C
Annealed BHN	285
Hardening	1100-1050°C (Oil quench or air)
Maximum hardness	58 HRC
Tempering	100-250°C

Table 23.16

Steel	Standard	ISO 683/X13H-74	IS 1570-72	DIN 17440-85	AISI	B8	NFA 35-574-81	GOST	JIS G4303-81
	Designation	A-16	105Cr18Mn50	X105CrMo17	440C		Z100CD17		SUS440C
Chemical composition	C %	0.95-1.2	0.90-1.2	0.95-1.2	0.95-1.2	—	0.9-1.2	—	0.95-1.2
	Si %	1.0	1 max.	1	1	—	1.5-2.5	—	1.0
	Mn %	1.0	1 max.	1	1	—	≤ 0.8	—	1.0
	≤ P %	0.04	0.04	0.045	0.04	—	0.04	—	—
	≤ S %	0.03	0.03	0.03	0.03	—	0.03	—	—
	Cr %	16-18	16-19	16-18	16-18	—	16-18	—	16-18
	Mo %	≤ 0.75	0.75 max.	0.4-0.8	0.75 max.	—	0.35-0.75	—	≤ 0.75
	Ni %	≤ 0.55	0.5 max.	—	—	—	—	—	≤ 0.6
	Others	—	—	—	—	—	—	—	—
Mechanical properties	Dimensions	—	—	—	—	—	—	—	—
	0.2% proof stress N/mm ² min.	—	—	—	—	—	—	—	—
	Tensile strength N/mm ²	58 RC	58 RC	—	55 RC	—	58 RC	—	—
	Elongation % min.	—	—	—	—	—	—	—	—
	Reduction of area % min.	—	—	—	—	—	—	—	—

Data Sheet 23.16—Type-10 (ISO)**CHARACTERISTICS AND TYPICAL APPLICATIONS**

This is an austenitic stainless steel. Compare to Type-11 (AISI-304), it has superior resistance to intergranular corrosion after welding or stress relieving. It can be easily cold-worked and cold formed since it is very ductile. It has scaling resistance up to 900°C in continuous usage.

Mainly used in chemical handling equipment (nitric acid plants), nuclear power plants, winery tanks, oil refinery tubes, textile drying equipment, vacuum pump parts, etc. Table 23.17 gives the chemical composition and the mechanical properties of International Standard steels.

HEAT TREATMENT

Annealing 1000–1100°C, followed by water or air cooling
 Annealed BHIN 192

Table 23.17

Steel	Standard	ISO 683/XIII-74	IS 1530-72	DIN 17440-85	AISI 304L	BS 970/4-70	NFA 35-574-84	GOST 3632-72	JIS 4303-81
	Designation	Type 10	02Cr18Ni11	X2CrNi18 9	304L	304S-12	Z2CN18-10	04Ch18N10	SUS304L
Chemical composition	C %	0.030	0.03 max.	0.030	0.03	0.03	0.03	0.04	0.03
	Si %	1.0	1.0 max.	1.0	1.0	0.2-1.0	1.0	0.80	1.0
	Mn %	2.0	2.0 max.	2.0	2.0	0.5-2.0	2.0	2.0	2.0
	≤ P %	0.045	0.045	0.045	0.045	0.045	0.04	0.035	0.04
	≤ S %	0.03	0.03	0.030	0.03	0.03	0.03	0.020	0.03
	Cr %	17-19	17-20	17-20	18-20	17.5-19.0	17-19	17-19	18-20
	Mo %	—	—	—	—	—	—	—	—
	Ni %	9-12	9-13	11-12.5	8.0-12.0	9.0-12.0	9-12	9-11	9-13
	Others	—	—	—	—	—	—	—	—
Mechanical properties	Dimensions	5-100	5-100	—	—	—	25 26-100	—	≤ 180
	0.2% proof stress N/mm ² min.	180	180	175	205	165	185 175	—	177
	Tensile strength N/mm ²	440-640	440-650	450-700	515 min. 460 min.	460-650	460-650	—	481 min.
	Elongation % min.	40	40	50	40	40	40	—	40
	Reduction of area % min.	—	—	—	—	—	—	—	—

Data Sheet 23.17—Type-15 (ISO)**CHARACTERISTICS AND TYPICAL APPLICATIONS**

This is an austenitic stainless steel containing titanium along with high chromium-nickel content steel. Titanium combines with carbon and forms harmless titanium carbide and leaves the chromium in solution to maintain full corrosion resistance. It has excellent scale resistance up to 900°C for continuous application.

Due to its corrosion resistance when exposed to the humidity of the air, steam, water, food acids, as well as inorganic and organic acids, and its good deformability, this steel is especially suitable for all kinds of hollow ware, such as household appliances, sink hardware, equipment for food industry, e.g. in dairies, breweries, textile industry, aircraft collector rings, exhaust manifolds, high temperature chemical handling equipment, etc. Table 23.18 gives the chemical composition and mechanical properties of International Standard steels.

HEAT TREATMENT

Annealing	1000–1100°C followed by water or air cooling
Annealed hardness	192 BHN

Data Sheet 23.18—Type-16 (ISO)**CHARACTERISTICS AND TYPICAL APPLICATIONS**

This is an austenitic stainless steel containing chromium-nickel along with niobium and titanium. Addition of niobium and titanium stabilizes the stainless steel. As a result of this it resists intergranular corrosion. It is resistant to scaling up to about 900°C and, for intermittent service, to a temper of about 800°C.

Mainly used in tubes for superheaters, heat exchangers, aircraft exhaust manifolds and chemical handling equipment. Table 23.19 gives the chemical composition and mechanical properties of International Standard steels.

HEAT TREATMENT

Annealing	1000–1100°C, followed by quenching in water or air
Annealed HB	192

Table 23.18

Steel	Standard	ISO 683/X100-74 Type 15	IS 1570-72 04C218Ni10Ti20	DIN 17440-85 X10CrNiTi18 9	AISI 321	BS 970/4-70 321S12	NFA 15-574-81 Z6CNT18 10	GOST 5032-72 OKH18N10T	JIS G4303-81 SUS321
Chemical composition	C %	0.08	0.08	0.1	0.08	0.08	0.08	0.08	0.08
	Si %	1	1	1.0	1.0	0.2-1.0	1.0	0.8	1.0
	Mn %	2	2	2	2.0	0.5-2.0	2.0	1.0-2.0	2.0
	≤ P %	0.045	0.045	0.045	0.045	0.045	0.04	0.035	0.04
	≤ S %	0.03	0.03	0.03	0.03	0.03	0.03	0.02	0.03
	Cr %	17-19	17-19	17-19	17-19	17-19	17-19	17-19	17-19
	Mo %	—	—	—	—	—	—	—	—
Others Ti	Ni %	9-12	9-12	9-11.5	9-12	9-12	9-11	9-11	9-13
	Others Ti	$\geq 5 \times \%C$ ≤ 0.80	$\geq 5 \times \%C$ ≤ 0.80	Ti $\geq 5 \times \%C$	Ti $\geq 5 \times \%C$	Ti $\geq 5 \times \%C$ ≤ 0.70	Ti $\geq 5 \times \%C$ ≤ 0.60	Ti $\geq 5 \times \%C$ ≤ 0.60	Ti $\geq 5 \times \%C$
	Others Ti	$\geq 5 \times \%C$ ≤ 0.80	$\geq 5 \times \%C$ ≤ 0.80	Ti $\geq 5 \times \%C$	Ti $\geq 5 \times \%C$	Ti $\geq 5 \times \%C$ ≤ 0.70	Ti $\geq 5 \times \%C$ ≤ 0.60	Ti $\geq 5 \times \%C$ ≤ 0.60	Ti $\geq 5 \times \%C$
Mechanical properties	Dimensions	5-100	5-100	—	—	—	25 26-100	—	180
	0.2% proof stress N/mm ² min.	210	210	205	203	195	205 195	—	206
	Tensile strength N/mm ²	480-690	490-690	500-750	515 min.	490 min.	510-710	—	520 min.
	Elongation % min.	35	35	40	40	40	40 37	—	40
	Reduction of area % min.	—	—	—	—	—	—	—	—

Table 23.19

Steel	Standard	ISO 683/XIII-74 Type 16	IS 1570-72 04Cr18Ni10Nb40	DIN 17440-85 X6CrNiNb1810	AISI 347	BS 970:4-70 347S17	NFA 35-574.81 Z6C/Nb018-10	GOST 5632-72 08Ch18Ni2B	JIS G4303-81 SUS347
Chemical composition	C %	0.08	0.08 max.	0.08	0.08	0.08	0.08	0.08	0.08
	Si %	1.0	1.0 max.	1.0	1.0	0.2-1.0	1.0	0.8	1.0
	Mn %	2.0	2.0 max.	2.0	2.0	0.5-2.0	2.0	2.0	2.0
	≤ P %	0.045	0.045	0.045	0.045	0.045	0.04	0.35	0.045
	≤ S %	0.03	0.03	0.030	0.030	0.030	0.03	0.020	0.030
	Cr %	17-19	17-19	17-19	17-19	17-19	17-19	17-19	17-19
	Mo %	—	—	—	—	—	—	—	—
Others Nb	Ni %	9-12	9-12	9-12	9-13	9-12	9-11	11-13	9-13
	Others Nb	≥ 10×%C ≤ 1.0	≥ 10×%C ≤ 1.0	≥ 8×%C ≤ 1.0	(Nb + Ta) ≥ 10×%C ≤ 1.0	≥ 10×%C ≤ 1.0	(Nb + Ta) ≥ 10×%C ≤ 1.0	≥ 10×%C ≤ 1.10	≥ 10×%C
Mechanical properties	Dimensions	5-100	5-100	160-450	—	—	25-100	—	≤ 180
	0.2% proof stress N/mm ² min.	210	210	205	205	205	195	—	206
	Tensile strength N/mm ²	490-690	490-690	510-740	515 min.	510 min.	510-710	—	520 min.
	Elongation % min.	35	35	30	40	—	37	—	40
	Reduction of area % min.	—	—	—	—	—	—	—	—

Data Sheet 23.19—Type-11 (ISO)**CHARACTERISTICS AND TYPICAL APPLICATIONS**

This is a highly alloyed chrome-nickel stainless steel of the austenitic type. It possesses high ductility and excellent strength, performs well in roll forming, cold forming, deep drawing, is particularly well suited where welded construction is required and resists most severe forms of corrosion. It resists nitric acid well, sulfuric acid moderately and has good scaling resistance up to 860°C in continuous service.

Mainly used for valves and accessories for chemical handling equipment, dairy equipment, spindles, nuts, bolts, valves and accessories for chemical handling equipments. Table 23.20 gives the chemical composition and mechanical properties of International Standard steels.

HEAT TREATMENT

Annealing	1000–1100°C, followed by quenching in air or water
Annealed HB	192

Table 23.20

Steel	Standard	ISO 683/X111-74	IS 1570-72	DIN 17440-85	AISI	BS 970-4-70	NFA 35-574-81	GOST 5652-72	JIS G4303-81
	Designation	Type 11	04Cr18Ni10	X5CrNi18 9	304	304S15	Z6CN18-09	0Kh18N10	SUS 304
Chemical composition	C %	0.07	0.08	0.07	0.08	0.06	0.07	0.08	0.08
	Si %	1.0	1.0	1.0	1.0	0.2–1.0	1.0	0.8	1.0
	Mn %	2.0	2.0	2.0	2.0	0.5–2.0	2.0	1–2	2.0
	≤ P %	0.045	0.045	0.045	0.045	0.045	0.04	0.035	0.04
	≤ S %	0.03	0.03	0.03	0.03	0.03	0.03	0.02	0.03
	Cr %	17–19	17–20	17–20	18–20	17.5–19.0	17–19	17–19	18–20
	Mo %	—	—	—	—	—	—	—	—
	Ni %	8–11	8–12	8.5–10.0	8–10.5	8–11	8–10	9–11	8–10
	Others	—	—	—	—	—	—	—	—
Mechanical properties	Dimensions	5–100	5–100	—	—	—	25 26–100	—	≤ 180
	0.2% proof stress N/mm ² min.	200	200	185	205	165	195 185	—	206
	Tensile strength N/mm ²	490–690	490–690	500–700	515 min.	460	510–710	—	520 min.
	Elongation % min.	40	40	50	40	40	43 42	—	40
	Reduction of area % min.	—	—	—	—	—	—	—	—

Data Sheet 23.20—Type-12 (ISO)

CHARACTERISTICS AND TYPICAL APPLICATIONS

This is an austenitic chromium-nickel stainless steel. It has good resistance to acidic environments, atmospheric corrosion, a wide variety of chemicals sterilizing zinc solutions and all food stuffs. Mainly used for household appliances, hospital equipment, food processing machinery, camera parts, nitric acid vessels, wire ropes, etc. Table 23.21 gives the chemical composition and mechanical properties of International Standard steels.

HOT WORKING AND HEAT TREATMENT

Forging 1250–930°C
 Annealing 1020–1120°C (Water or air quench)
 Annealed HB 192

Table 23.21

Steel	Standard	ISO 683/XIII-74	IS 1570-72	DIN	AISI	BS 970/1-83	NFA 35-574-75	GOST	JIS G4303-81
	Designation	Type 12	07Cr18Ni9		302	302S31	Z10CN18.09		SUS302
Chemical composition	≤ C %	0.12	0.12	—	0.15	0.12	0.12	—	0.15
	≤ Si %	1.0	1.0	—	1.0	1.0	1.0	—	1.0
	≤ Mn %	2.0	2.0	—	2.0	2.0	2.0	—	2.0
	≤ P %	0.045	0.045	—	0.045	0.045	0.040	—	0.045
	≤ S %	0.030	0.03	—	0.03	0.03	0.03	—	0.030
	Cr %	17–19	17–19	—	17–19	17–19	17–19	—	17–19
	Mo %	—	—	—	—	—	—	—	—
	Ni %	8–10	8–10	—	8.0–10	8–10	7.5–9.5	—	8–10
	Others	—	—	—	—	—	—	—	—
Mechanical properties	Dimensions	5–100	5–100	—	—	≤ 160	≤ 25	—	—
	0.2% proof stress N/mm ² min.	210	210	—	—	190	215	—	—
	Tensile strength N/mm ²	490–690	490–690	—	—	510	530–730	—	—
	Elongation % min.	40	40	—	—	40	45	—	—
	Reduction of area % min.	—	—	—	—	—	—	—	—

Data Sheet 23.21—Type-17 (ISO)**CHARACTERISTICS AND TYPICAL APPLICATIONS**

This is an austenitic stainless steel containing molybdenum along with a high chromium-nickel content. Addition of molybdenum and sulphur improves machining and non-seizing characteristics. This grade may be easily machined, has scale resistance up to 900°C for continuous exposure and is used to minimize seizing and galling. It will withstand only moderate cold working, is not adoptable for cold-finishing and welding is not recommended because of the high sulphur. Machining of this steel calls for a rigid machine set up and positive cutting action to prevent work hardening of the surface. Finished machine parts should be passivated for optimum corrosion resistance.

Mainly used for valves and accessories for chemical handling equipment, machined shafts, fishline guides, equipment for the food industry, e.g. in dairies and breweries, the photographic industry, paper and textile industries, in the manufacture of explosives and synthetic fibres, etc. Table 23.22 gives the chemical composition and mechanical properties of International Standard steels.

HEAT TREATMENT

Annealing	1020–1120°C (water or air cooling)
Annealed HB	192

Table 23.22

Steel	Standard	ISO 683/X111-74	IS 1570-72	DIN 17440-85	AISI	BS 970/4-70	NFA	GOST 5632-72	JIS G4303-81
	Designation	Type 17	07Cr18Ni9	X12CrNi 18 8	30 303	303S21		12Ch18N 10E	SUS303
Chemical composition	≤ C %	0.12	0.12 max.	0.15	0.15	0.12	—	0.12	0.15
	≤ Si %	1.0	1.0	1.0	1.0	0.20–1.0	—	0.80	1.0
	≤ Mn %	2.0	2.0 max.	2.0	2.0	1.0–2.0	—	2.0	2.0
	≤ P %	0.20	0.045	0.045	0.20	0.045	—	0.035	0.20
	≤ S %	0.15–0.35	0.030	0.15–0.35	≤ 0.15	0.15–0.30	—	0.020	0.15
	Cr %	17–19	17–19	17–19	17–19	17–19	—	17–19	17–19
	Ni %	8–10	8–10	8–10	8–10	8–11	—	9–11	8–10
	Mo %	≤ 0.60	—	—	≤ 0.60	—	—	8C-18-35	≤ 0.60
	Others	—	—	—	—	—	—	—	—
Mechanical properties	Dimensions	5–100	5–100	—	—	—	—	—	≤ 180
	0.2% proof stress N/mm ² min.	210	210	215	—	205	—	—	205
	Tensile strength N/mm ²	490–690	490–690	500–700	—	510 min.	—	—	520 min.
	Elongation % min.	35	40	50	—	40	—	—	40
	Reduction of area % min.	—	—	—	—	—	—	—	—

Data Sheet 23.22—Type-13 (ISO)

CHARACTERISTICS AND TYPICAL APPLICATIONS

This is a high chromium-nickel (18-18) austenitic stainless steel. The presence of high alloying elements provides increased corrosion and heat resistance. Mainly used in the form of welding rods, industrial furnaces, equipment for handling sulphite liquor at elevated temperatures, etc. Table 23.23 gives the chemical composition and mechanical properties of International Standard steels.

HOT WORKING AND HEAT TREATMENT

Forging	1200-930°C
Annealing	1020-1120°C (Air or water quench)
Annealed HB	192

Table 23.23

Steel	Standard	ISO 683/XIII-74	IS	DIN 17440-85	AISI	BS	NFA	GOST 5632-72	JIS
	Designation	Type 13		X5CrNi18 12	308			06Ch18Ni11	
Chemical composition	≤ C %	0.1	—	0.07	0.08	—	—	0.06	—
	≤ Si %	1.0	—	1.0	1.0	—	—	0.8	—
	≤ Mn %	2.0	—	2.0	2.0	—	—	2.0	—
	≤ P %	0.045	—	0.045	0.045	—	—	0.035	—
	≤ S %	0.03	—	0.03	0.03	—	—	0.02	—
	Cr %	17-19	—	17-19	19-21	—	—	17-19	—
	Mo %	—	—	—	—	—	—	—	—
	Ni %	11-13	—	11-13	10-12	—	—	10-12	—
	Others	—	—	—	—	—	—	—	—
Mechanical properties	Dimensions	5-100	—	≤ 60	—	—	—	—	—
	0.2% proof stress N/mm ² min.	180	205	185	205	—	—	—	—
	Tensile strength N/mm ²	490-690	—	490-650	515 min.	—	—	—	—
	Elongation % min.	40	—	45	40	—	—	—	—
	Reduction of area % min.	—	—	—	—	—	—	—	—

Data Sheet 23.23—Type-14 (ISO)**CHARACTERISTICS AND TYPICAL APPLICATIONS**

This is an austenitic chromium-nickel stainless steel. It possesses good ductility and high tensile strength due to severe cold working. Mainly used in the cold rolled or cold drawn condition in the form of sheets, strips or wires. Best resistance to corrosion is obtained in the annealed or cold working condition. It resists scaling up to 900°C with continuous exposure. This steel is used mainly in automobile wheel covers, kitchen utensils, aircraft and missile structures, transportation equipments, etc. Table 23.24 gives the chemical composition and mechanical properties of International Standard steels.

HOT WORKING AND HEAT TREATMENT

Forging	1250-930°C
Annealing	1020-1120°C (Water or air quench)
Annealed HB	212

Table 23.24

Steel	Standard	ISO 683/X141-74	IS 1570-72	DIN	AISI	BS 970/2-83	NFA 25-574-81	GOST	JIS 4303-81
	Designation	Type 14	10Cr17Ni7		301	301S21	Z12CN-17.07		SUS301
Chemical composition	≤ C %	0.15	0.15	—	0.15	0.15	0.08-0.15	—	0.15
	≤ Si %	1.0	1.0	—	1.0	1.0	1.0	—	1.0
	≤ Mn %	2.0	2.0	—	2.0	2.0	2.0	—	2.0
	≤ P %	0.045	0.045	—	0.045	0.045	0.04	—	0.045
	≤ S %	0.030	0.030	—	0.30	0.03	0.03	—	0.030
	Cr %	16-18	16-18	—	16-18	16-18	16-18	—	16-18
	Mo %	—	—	—	—	—	—	—	—
	Ni %	6-8	6-8	—	6-8	6-8	6-8	—	6-8
	Others	—	—	—	—	—	—	—	—
Mechanical properties	Dimensions	3.3	≤ 20	—	—	—	25	—	—
	0.2% proof stress N/mm ² min.	490	490	—	—	—	245	—	—
	Tensile strength N/mm ²	850	830	40 RC	—	—	590-780	—	—
	Elongation % min.	25	20	—	—	—	40	—	—
	Reduction of area % min.	—	—	—	—	—	—	—	—

Data Sheet 23.24—Types-19, 19a (ISO)

CHARACTERISTICS AND TYPICAL APPLICATIONS

These are austenitic low carbon chromium-nickel-molybdenum stainless steels. Their welding properties are similar to those of AISI-316 steel and the low carbon content does not cause intercrystalline corrosion. These steels may be deep drawn, stamped, headed and upset without difficulty. The presence of higher molybdenum in Type-19a enhances the corrosion resistance as compared to Type-19.

Mainly used for processing equipment for producing photographic chemicals, inks, rayon, dyestuffs, rubber and high-temperature equipment. Tables 23.25 and 23.26 give the chemical composition and mechanical properties of International Standard steels.

HEAT TREATMENT

Annealing	1020–1120°C, followed by air or water quench
Annealed HB	192

Table 23.25

Steel	Standard	ISO 683/XIII- 74	IS 1570-72	DIN Stahlschlu- ssel-86	AISI	BS 970/1-83	NFA 35-574- 81	GOST	JIS G4303-81
	Designation	Type 19	02Cr17Ni 12-Mo2	X2CrNi Mo18 10	316L	316S11	Z2CND 17 12		SUS316L
Chemical composition	≤ C %	0.030	0.03 max.	0.03	0.03	0.03	0.03	—	0.03
	≤ Si %	1.0	1.0 max.	1.0	1.0	1.0	1.0	—	1.0
	≤ Mn %	2.0	2.0 max.	2.0	2.0	2.0	2.0	—	2.0
	≤ P %	0.045	0.045	0.045	0.045	0.045	0.040	—	0.045
	≤ S %	0.030	0.030	0.030	0.030	0.030	0.030	—	0.030
	Cr %	16–18.5	16–18.5	16.5–18.5	16–18	16.5–18.5	16.0–18.0	—	16–18
	Mo %	2.0–2.5	2.0–3.0	2.0–2.5	2.0–3.0	2.0–2.50	2.0–2.5	—	2.0–3.0
	Ni %	11.0–14.0	10–14	11–14	10–14	11.0–14.0	10.5–13.0	—	12–15
	Others	—	—	—	—	—	—	—	—
Mechanical properties	Dimensions	5–100	5–100	160 min.	—	—	50 51–100	—	≤ 180
	0.2% proof stress N/mm ² min.	200	200	190	205	165	195 185	—	177
	Tensile strength N/mm ²	440–640	440–640	490–690	515 min.	460 min.	480–680	—	481 min.
	Elongation % min.	40	40	35	40	40	45 42	—	40
	Reduction of area % min.	—	—	—	—	—	—	—	—

Table 23.26

Country	ISO	INDIA	DEU	USA	GBR	FRA	USSR	JPN
Standard norm	ISO 683/XIII-74	IS	DIN 17440-85	AISI A276-82a	BS970/ 4-70	NFA35- 574-81	GOST	JIS G4303-81
Designation	Type 19a		X2CrNiMo 18 14 3	316L	316S12	Z2CND 17-13		SUS316L
Chemical composition	C %	0.03	—	0.03	0.03	0.03	—	0.03
	Si %	1.0	—	1.0	0.2	1.0	—	1.0
	Mn	2.0	—	2.0	0.5-0.2	2.0	—	2.0
	P	0.045	—	0.045	0.045	0.04	—	0.045
	S	0.03	—	0.025	0.03	0.03	—	0.030
	Cr	16.0-18.5	—	17.0-18.50	16.0-18.0	16.5-18.5 16.0-18.0	—	16.0-18.0
	Mo	2.50-3.00	—	2.50-3.00	2.00-3.00	2.50-3.00	—	2.00-3.00
	Ni	11.5-14.5	—	12.5-15.0	10.0-14.0	11.0-14.0 11.5-14.5	—	12.0-15.0

Data Sheet 23.25—Types-20, 20a (ISO)

CHARACTERISTICS AND TYPICAL APPLICATIONS

These are austenitic steels containing molybdenum along with high chromium and nickel. They exhibit excellent ductility and may be readily cold worked using methods such as deep drawing, bending, roll-forming and upsetting. They are superior in corrosion resistance over other chromium nickel steels when exposed to many types of chemical corrosives and marine atmosphere. The presence of higher molybdenum in Type-20a further enhances the corrosion resistance compared to Type-20.

These steel are mainly used for food processing equipment, textile dyeing equipment, nuclear fuel cladding and heat exchangers, oil refining equipment, household appliances, etc. Tables 23.27 and 23.28 give the chemical composition and mechanical properties of International Standard steels.

HEAT TREATMENT

Annealing	1020-1120°C (Oil or water quench)
Annealed hardness	192

Table 23.27

Steel	Standard	ISO 683/X111-74	IS 1570-72	DIN 17440-85	AISI	BS 970/1-72	NFA 35-574-81	GOST	JIS G4303-81
	Designation	Type 20	04Cr17Ni 12Mo2	X5CrNi Mo17 12 2	316		Z6CND 17-11		SUS316
Chemical composition	≤ C %	0.07	0.08	0.07	0.08	—	0.07	—	0.08
	≤ Si %	1.0	1.0	1.0	1.0	—	1.0	—	1.0
	≤ Mn %	2.0	2.0	2.0	2.0	—	2.0	—	2.0
	≤ P %	0.045	0.045	0.045	0.045	—	0.04	—	0.04
	≤ S %	0.03	0.03	0.03	0.03	—	0.03	—	0.03
	Cr %	16-18.5	16-18.5	16-18.5	16-18	—	16-18	—	16-18
	Mo %	2.0-2.5	2.0-3.0	2-2.5	2.0-3.0	—	2-2.5	—	2.0-3.0
	Ni %	10.5-14.0	10-14	10.5-13.5	10-14	—	10-12.5	—	10-14
	Others	—	—	—	—	—	—	—	—
Mechanical properties	Dimensions	5-100	5-100	≤ 160	—	—	25 26-100	—	≤ 180
	0.2% proof stress N/mm ² min.	210	210	205	205	165	205 195	—	206
	Tensile strength N/mm ²	490-690	490-690	510-710	515 min.	460 min.	530-730	—	520 min.
	Elongation % min.	40	40	40	40	40	45 42	—	40
	Reduction of area % min.	—	—	—	—	—	—	—	—

Table 23.28

Country		ISO	INDIA	DEU	USA	GBR	FRA	USSR	JPN
Standard norm		683/X111-74	IS 1570-72	DIN 17440-85	AISI A276-82a	BS970/4-70	NFA35-574-81	GOST	JIS G4303-81
Designation		Type 20a	04Cr17Ni12Mo2	X5CrNiMo17 13 3	316	316S16	Z6CND17-12		SUS316
Chemical composition	C %	0.07	—	0.07	0.08	0.07	0.07	—	0.08
	Si %	1.0	—	1.0	1.0	0.2-1.0	1.0	—	1.0
	Mn	2.0	—	2.0	2.0	0.5-2.0	2.0	—	2.0
	P	0.045	—	0.045	0.045	0.045	0.040	—	0.045
	S	0.030	—	0.025	0.030	0.03	0.030	—	0.030
	Cr	16.0-18.5	—	16.5-18.5	16-18	16.5-18.5	16-18	—	16-18
	Mo	2.5-3.0	—	2.5-3.0	2-3	2.25-3.00	2.50-3.00	—	2-3
	Ni	11.00-14.50	—	11.50-14.00	10.00-14.00	10.00-13.00	11.00-13.00	—	10-14

Data Sheet 23.26—Types-21, 21a (ISO)**CHARACTERISTICS AND TYPICAL APPLICATIONS**

These are highly alloyed chromium-nickel, along with molybdenum and titanium content, stainless steels. The presence of molybdenum leads to a higher resistance to non-oxidizing acids and to chloride-bearing media than 18-8CrNi steels. The carbon in these steels combines with titanium to form a harmless titanium carbide and leaves the chromium in solution to maintain full corrosive resistance. These steels are extremely tough and ductile, and respond to deep drawing, bending, forming and upsetting. They are resistant to sealing up to 850°C for continuous service, 800°C for intermittent service. The presence of a higher range of molybdenum in Type-21a further enhances the corrosion resistance compared to Type-21.

These steels are preferably used in sulphite, rayon and textile industries, in dye-works, photographic, paint, synthetic resin and rubber industries, etc. Tables 23.29 and 23.30 give the chemical composition and mechanical properties of International Standard steels.

HEAT TREATMENT

Annealing	1020-1070°C, (Cooling in air or water)
Annealed hardness	192

Table 23.29

Steel	Standard	ISO 683/XIII-74	IS 1520-72	DIN 17440-85	AISI	BS 970/1-83	NFA 35-574-81	GOST 5632-72	JIS
	Designation	Type 21	04Cr17Ni12 MoTi20	X6CrNi MoTi1712	321	320S31	Z6CND 17-12	10Ch17N 13M3T	
Chemical composition	≤ C %	0.08	0.8 max.	0.08	—	0.08	0.08	0.10	—
	≤ Si %	1.0	1.0 max.	1.0	—	1.0	1.0	0.80	—
	≤ Mn %	2.0	2.0 max.	2.0	—	2.0	2.0	2.0	—
	≤ P %	0.045	0.045	0.045	—	0.045	0.04	0.035	—
	≤ S %	0.030	0.030	0.030	—	0.03	0.03	0.02	—
	Cr %	16.5-18.5	16.0-18.5	16.5-18.5	—	16.5-18.5	16-18	16-18	—
	Mo %	2.0-2.5	2.0-3.0	2.0-2.5	—	2.0-2.5	2.0-2.5	3.0-4.0	—
	Ni %	10.5-14.0	10.5-14.0	10.5-13.5	—	11-14	10.5-13.0	12.0-14.0	—
	Others Ti	≥ 5×%C ≤ 0.8	5C 0.8	≥ 5×%C ≤ 0.8	—	Ti5C-90	≥ 5×%C ≤ 0.6	≥ 3×%C ≤ 0.7	—
Mechanical properties	Dimensions	5-100	5-100	160-450	—	—	25 26-100	—	—
	0.2% proof stress N/mm ² min.	220	220	210	—	—	216 206	—	—
	Tensile strength N/mm ²	490-690	490-690	500-735	—	—	490-685	—	—
	Elongation % min.	35	35	35	—	—	40 37	—	—
	Reduction of area % min.	—	—	—	—	—	—	—	—

Table 23.30

Country	ISO	INDIA	DEU	USA	GBR	FRA	USSR	JPN
Standard norm	ISO R683/XIII-74	IS	DIN	AISI	BS970/ 2-83	NFA35- 551-75	GOST	JIS
Designation	Type 21a			316	320S33			
Chemical composition	C	0.05	—	—	≤ 0.08	≤ 0.08	—	—
	S	1.0	—	—	≤ 1.0	≤ 1.0	—	—
	Mn	2.0	—	—	≤ 2.0	≤ 2.0	—	—
	≤ P	0.045	—	—	0.045	0.045	—	—
	≤ S	0.030	—	—	0.03	0.03	—	—
	Cr	16-18.5	—	—	16-18	16.5-18.5	—	—
	Mo	2.5-3.0	—	—	2-3	2.5-3	—	—
	Ni	11-14.5	—	—	10-14	11.5-14.5	—	—
		5 × %C < Ti < 0.8	—	—	—	Ti 5 × %C ≤ 0.8	—	—

Data Sheet 23.27—Type 23 (ISO)

CHARACTERISTICS AND TYPICAL APPLICATIONS

This is a molybdenum-chromium-nickel content, heat resistant, stainless steel. It possesses super corrosion resistance compared to other chromium-nickel steels. In the annealed condition, it possesses excellent ductility and good cold working properties. It is mainly used for transportation tanks, chemical storage tanks, textile dyeing equipment, oil refining equipment, nuclear fuel cladding and heat exchangers, etc. Table 23.31 gives the chemical composition and mechanical properties of International Standard steels.

HOT WORKING AND HEAT TREATMENT

Forging	1250-930°C
Annealing	1000-1100°C (Water or air quench)
Annealed HB	192

Table 23.31

Steel	Standard	ISO 683/XIII-74	IS	DIN 17440-85	AISI	BS	NFA 35/374-81	GOST 5632-72	JIS
	Designation	Type 23	04Cr17Ni 12Mo2	X6CrNiMo Nb 17 12 2			Z6CNDNb 1712	08Ch16N 13M2B	
Chemical composition	≤ C %	0.08	0.08	0.08	—	—	0.08	0.06-0.12	—
	≤ Si %	1.0	1.0	1.0	—	—	1.0	0.08	—
	≤ Mn %	2.0	2.0	2.0	—	—	2.0	1.0	—
	≤ P %	0.045	0.045	0.04	—	—	0.04	0.035	—
	≤ S %	0.03	0.03	0.03	—	—	0.03	0.02	—
	Cr %	16-18.5	16-18.5	16-18.5	—	—	16-18	15-17	—
	Mo %	2-2.5	2-3	2.0-2.5	—	—	2-2.5	2.25	—
	Ni %	10.5-14.0	10.5-14.0	10.5-13.5	—	—	10.5-13.0	12.5-14.5	—
	Others	—	—	—	—	—	—	—	—
Mechanical properties	Dimensions	5-100	5-100	160	—	—	25	—	—
	0.2% proof stress N/mm ² min.	220	210	215	—	—	215	—	—
	Tensile strength N/mm ²	490-690	490-690	510-740	—	—	530-730	—	—
	Elongation % min.	35	40	35	—	—	40	—	—
	Reduction of area % min.	—	—	—	—	—	—	—	—

Data Sheet 23.28—Type-24 (ISO)

CHARACTERISTICS AND TYPICAL APPLICATIONS

This is a high chromium-nickel austenitic stainless steel with 3-4% molybdenum, which exhibits excellent resistance to corrosion. This steel can be cold worked by deep drawing, heading, stamping and upsetting without difficulty. In the annealed condition it possesses excellent intergranular corrosion resistance. It will not form scales up to 900°C in continuous service. It is mainly used on sulfite pulp mills to resist corrosion of sulfurous acid compounds more effectively. It is also used for paper pulp handling equipment, high temperature equipment, process equipment for producing photographic chemicals, inks, rubber, etc. Table 23.32 gives the chemical composition and mechanical properties of International Standard steels.

HEAT TREATMENT

Annealing	1020-1120°C, followed by water or air quench
Annealed HB	192

Table 23.32

Steel	Standard	ISO 683/X111-74	IS	DIN 17440-85	AISI A276-82a	BS 970/4-70	NFA 35-574-69	GOST	JIS G4303-81
	Designation	Type 24		X2CrNiMo 18 16 4	317	317S12	Z2CND19-15		SUS317L
Chemical composition	≤ C %	0.030	—	0.03	0.08	0.03	0.030	—	0.030
	≤ Si %	1.0	—	1.0	1.0	0.2-1.0	1.0	—	1.0
	≤ Mn %	2.0	—	2.0	2.0	0.5-2.0	2.0	—	2.0
	≤ P %	0.045	—	0.045	0.045	0.045	0.040	—	0.045
	≤ S %	0.030	—	0.025	0.030	0.030	0.030	—	0.030
	Cr %	17.5-19.5	—	17.5-19.5	18-20	17.5-19.5	17.5-19.5	—	18-20
	Mo %	3-4	—	3-4	3-4	3-4	3-4	—	3-4
	Ni %	14-17	—	14-17	11-15	14-17	14-16	—	11-15
	Others	—	—	—	—	—	—	—	—
Mechanical properties	Dimensions	5-100	—	≤ 160	—	—	25 25-100	—	≤ 180
	0.2% proof stress N/mm ² min.	200	—	195	205	165	205 195	—	177
	Tensile strength N/mm ²	490-690	—	490-690	515 min	460 min	480-680	—	481 min.
	Elongation % min.	35	—	35	40	40	40 37	—	40
	Reduction of area % min.	—	—	—	—	—	—	—	—

Data Sheet 23.29—Type-A2 (ISO)

CHARACTERISTICS AND TYPICAL APPLICATIONS

This is an austenitic chromium-nickel-manganese stainless steel. It resists corrosion attack over relatively long periods of exposure in both industrial and marine atmospheres. It can be subjected to forming methods such as drawing, press brake forming, stretch bending, bending, and forming, etc. It is scale resistant up to 845°C for continuous service, 790°C for intermittent service. It should not be subjected to severe deep drawing to avoid work hardening. It is used mainly for railroad, sub-way cars, automotive trim, architectural applications, shallow drawn cooling wear such as pans, lids, etc. Table 23.33 gives the chemical composition and mechanical properties of International Standard steels.

HEAT TREATMENT

Annealing	1000-1100°C (Oil or water quenching)
Annealed hardness	217

Table 23.33

Steel	Standard	ISO 683/X1H-74	IS	DIN	AISI	BS 970/1-72	NFA	GOST	JIS
	Designation	Type A3	10Cr17Mn6Ni4N20		201		35		SUS201
Chemical composition	C %	0.15	0.15	—	0.15	—	—	—	0.15
	Si %	1.0	1.0	—	1.0	—	—	—	1.0
	Mn %	5.5-7.5	5.5-8.5	—	5.5-7.5	—	—	—	5.5-7.5
	≤ P %	0.060	0.06	—	0.06	—	—	—	0.060
	≤ S %	0.030	0.03	—	0.03	—	—	—	0.03
	Cr %	16-18	16-18	—	16-18	—	—	—	16-18
	Mo %	—	—	—	—	—	—	—	—
	Ni %	3.5-5.5	3.5-5.5	—	3.5-5.5	—	—	—	3.5-5.5
	Others N	0.05-0.25	≤ 0.25	—	0.25	—	—	—	≤ 0.25
Mechanical properties	Dimensions	5-100	5-100	—	—	—	—	—	—
	0.2% proof stress N/mm ² min.	300	300	—	—	—	—	—	—
	Tensile strength N/mm ²	640-830	640-830	—	41 HRC	—	—	—	—
	Elongation % min.	40	38	—	—	—	—	—	—
	Reduction of area % min.	—	—	—	—	—	—	—	—

Data Sheet 23.30—Type-A3 (ISO)

CHARACTERISTICS AND TYPICAL APPLICATIONS

This is an austenitic chromium-nickel-manganese content steel which was developed to conserve nickel. It resists corrosion in moderate corrosive environments, marine atmospheres, strongly oxidizing acids, etc. It is also used in food stuff industries, dairy equipment, washing machine tubes, architectural trim, etc. This steel was designed as an alternative to (AISI 302) for good forming characteristics. Table 23.34 gives the chemical composition and mechanical properties of International Standard steels.

HEAT TREATMENT

Annealing	1000-1100°C (Oil or water quenching)
Annealed hardness	217

Table 23.34

Steel	Standard Designation	ISO 683/XIII-74 Type A3	IS	DIN	AISI 202	BS	NFA	GOST	JIS SUS202
Chemical composition	C %	0.15	—	—	0.15	—	—	—	0.15
	Si %	1.0	—	—	1.0	—	—	—	1.0
	Mn %	7.5-10.5	—	—	7.5-10.5	—	—	—	7.5-10.5
	≤ P %	0.060	—	—	0.060	—	—	—	0.06
	≤ S %	0.03	—	—	0.03	—	—	—	0.03
	Cr %	17-19	—	—	17-19	—	—	—	17-19
	Mo %	—	—	—	—	—	—	—	—
	Ni %	4-6	—	—	4-6	—	—	—	4-6
	Others N	0.05-0.25	—	—	0.25	—	—	—	0.25
Mechanical properties	Dimensions	5-100	—	—	≤ 50	—	—	—	0.25
	0.2% proof stress N/mm ² min.	300	—	—	—	—	—	—	—
	Tensile strength N/mm ²	640-830	—	—	655	—	—	—	600 min.
	Elongation % min.	40	—	—	40	—	—	—	40 min.
	Reduction of area % min.	—	—	—	—	—	—	—	—

REFERENCES

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10. JIS G4303—87, 1981, *Stainless Steel Bars*.
11. GOST 5632—1972, *High Alloyed, Wrought Corrosion, Heat and High Temperature Resisting Steels and Alloys*.
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13. *Stahlschlüssel—1986*, West Germany.

Heat Resisting Steels

Heat resisting steels are used where good resistance against heating in particular against gaseous products of combustion is required. The significance of heat resisting steels lies in their high resistance to scaling in temperature ranges above 600°C, at which their mechanical properties should still be adequate. Since these steels possess longer service life and greater durability of the steel stoppages and repair periods can be shortened so that productivity of the equipment is increased.

Heat resistance depends upon the strength of the inter atomic bonds and the structure of an alloy. The presence of alloying increases the heat resistance of steels by increasing the intensity of inter atomic attraction and raising the recrystallisation temperature. These changes impede the development of plastic deformation at elevated temperatures. The heat resistance of steels may be improved by addition of alloying elements that will increase the tendency to age as well as they are hardened by precipitation of microscopic particles that impede plastic deformation at high temperatures.

Heat resisting steels based on an alloy of iron with chromium. Apart from this, the most important elements nickel, aluminium, silicon, titanium are added. The presence of chromium, aluminium and silicon, which upon heating forms dense oxide films, such as $(Cr, Fe)_2O_3$, $(Al, Fe)_2O_3$, and others, that protect the base metal against oxidation. The band and density of the protective layers depends on the alloying properties or the element in question. If a heat resisting steel is continuously heated beyond its service temperature, the rate of diffusion or the oxygen penetrating to the steel becomes so large that protective elements (Cr, Si, Al) will no longer be adequate to form a protective skin on the surface of the workpiece. The presence of oxygen continuously diffuse inward. While iron diffuses outward. This process does not stop, so that the oxide layer becomes gradually stronger and finally flakes off.

Steels containing 5-8 per cent Cr resist scale formation up to 700-750°C, increasing the content to 15-17 per cent will prevent scaling up to 950-1000°C, and 25 per cent chromium will prevent scaling up to 1100°C. Apart from this the carbide phase formed $Cr_{23}C_6$ in these steels is associated with high heat resistance. If the steel is also intended to have a higher strength at elevated temperatures apart from its resistance to scaling, 10% nickel or more is added to alloy in addition to high chromium content. Nickel base alloys acquire their high heat resistance due to the precipitation hardening associated with the formation of intermetallic phases $(Ni_3(Al, Ti, Cr) Ni_3Ti, Ni_3Al)$. These steels are purely austenite ones, they cannot be magnetized; however austenitic chromium nickel steels are not resistant to

sulphur compounds because sulphur forms with nickel a eutectic of low melting point (700°C).

Heat resistance steels may be subjected to annealing operation in order to avoid embrittlement in ferritic steels. This may be due to the segregation of an FeCr compound on the grain boundaries. In the temperature range 400-500°C. This embrittlement may be removed by annealing around 600°C. Only steels with a chromium content of over 15% are subjected to this type of embrittlement, steels with chromium content over 20% are subjected to embrittlement in the temperature range 650-800°C due to the segregation of sigma phase when the steel remains for longer periods within this temperature range. This embrittlement may be removed by annealing over 850°C.

The austenitic steels tend to sigma phase embrittlement only between 600°C and 850°C. This is due to the segregation of carbides at the grain boundaries and form continuous paths for corrosion. This embrittlement may be obviated by quenching from 1050°C in water. At this high temperature the excess phases are put into the solid solution. Rapid cooling (quenching) fixes the supersaturated solid solution. This results in an increased resistance in the plastic deformation.

Heat resistance steels should be used in principle only at the specified temperature range to avoid embrittlement.

The different types of heat resistance steels that are mainly used are given in Table 24.1. The application, mechanical properties, chemical composition and heat treatments are given in Data Sheets 24.1-24.10.

Table 24.1

Country Standard	ISO ISO	INDIA IS	DEU DIN	USA AISI	GBR BS970	FRA NFA35	USSR GOST	JPN JIS
1	Type-H1	—	X5CrTi12	409	409S19	Z6CT12	—	SUH409
2	Type-H3	—	X10CrAl13	405	—	Z10C13	10Ch13S1U	SUS405
3	Type-H5	—	X10CrAl18	430	—	Z10CA818	—	SUS430
4	Type-H6	—	X10CrAl24	446	—	Z10CAS24	—	SUH446
5	Type-H11	—	X12CrNiTi 18-9	321	321S12	Z6CNT18-12	12Cb18N107	SUS321
6	Type-H13	—	X15CrNiSi 20-12	309	—	Z15NCS20-12	20Ch20N1482	SUH309
7	Type-H14	—	X7CrNi 23-14	309S	—	Z15CN24-13	—	SUH309
8	Type-H15	—	X12CrNi 25-21	310S	310S24	Z12CN25-20	—	SUS310S
9	Type-H16	—	X15CrNiSi 25-20	314	—	Z12CNS25-20	—	SUH310
10	Type-H17	—	X12NiCrSi 36-16	330	—	Z12NCS35-16	—	SUH330

Data Sheet 24.1—Type-H1 (ISO)**PROPERTIES AND TYPICAL APPLICATIONS**

This is a general-purpose heat resisting steel. It starts exhibiting destructive scaling in air at about 700°C. This temperature is considered the general maximum service temperature for continuous service in air. This steel can be welded by any method, will not air harden and is not prone to cracking during cooling. Consequently, preheating and post heating are not necessary. This steel has good fabricating characteristics and can be stamped and formed without difficulty.

Mainly used for industrial heater parts, furnace linings, automotive exhaust systems, bolts, nuts, studs, constructional parts subjected to the action of steam or water, etc. Table 24.2 gives the chemical composition and mechanical properties of International Standard steels.

HEAT TREATMENT

Annealing	750–850°C (Air cooling)
Annealed BHN	130–180

Table 24.2

Steel	Standard	ISO/DIS 4955/83	IS DIN SEW470-76	AISI	BS 1449/2-83	NFA 35-578-82	GOST	JIS G4312-81
	Designation	Type H1	X5CrTi12	409	409S19	Z6CT12		SUH409
Chemical composition	≤ C %	0.08	— 0.08	0.08	0.08	0.08	—	0.08
	≤ Si %	1.0	— 1.0	1.0	1.0	1.0	—	1.0
	≤ Mn %	1.0	— 1.0	1.0	1.0	1.0	—	1.0
	≤ P %	0.04	— 0.04	0.04	0.04	0.04	—	0.04
	≤ S %	0.03	— 0.03	0.03	0.03	0.03	—	0.03
	Cr %	10.50–12.50	— 10.50–12.50	10.50–11.75	10.5–12.5	10.5–12.5	—	10.5–11.75
	Mo % Ti	≥ 6×%C ≤ 1.0	— ≥ 6×%C ≤ 1.0	≥ 6×%C ≤ 0.75	≥ 6×%C ≤ 1.0	≥ 6×%C ≤ 1.0	—	≤ 6×%C to 0.75
	Ni %	—	—	—	—	—	—	—
	Others	—	—	—	—	—	—	—
Mechanical properties	Dimensions	5–15	— 5–15	—	—	16	—	—
	0.2% proof stress N/mm ² min.	210	— 210	—	—	180 min.	—	177
	Tensile strength N/mm ²	400–600	— 400–600	450	—	380 min.	—	363
	Elongation % min. 25	—	— 25	25	—	22	—	22
	Reduction of area % min.	—	—	—	—	—	—	—

Data Sheet 24.2—Type-H3 (ISO)

CHARACTERISTICS AND TYPICAL APPLICATIONS

This is a heat-resisting, non-scaling steel with a ferritic structure. Addition of a small amount of aluminium restricts the formation of austenite at high temperatures so that hardening does not occur upon quenching. Hence it is more suitable for welding and suitable to service in air up to 950°C. It also has very good resistance to sulphur-containing oxidizing gases and nitrogen-containing gases and medium for carburizing and sulphur-containing reducing gases.

Welding can be carried out by any method. However, electric welding is preferable. Preheat the parts to about 200°C before welding.

It is used for applications with moderate mechanical loading, for hardening boxes, annealing boxes, annealing pots, retorts, carriers, conveyor parts, burner grates, super heaters, etc. Table 24.3 gives the chemical composition and mechanical properties of International Standard steels.

HEAT TREATMENT

Annealing	800–850°C (Cooling in air or water)
Annealed BHN	160–210

Table 24.3

Steel	Standard	ISO/DIS 4955/83	IS	DIN SEW470-76	AISI	BS 970/1-72	NFA 35-378-82	GOST	JIS 4303/81
	Designation	Type-H3		X10CrAl13	405		Z10C13	10Ch13SJU	SUS405
Chemical composition	≤ C %	0.12	—	0.12	0.08	—	0.12	0.07–0.12	0.08
	≤ Si %	0.70–1.40	—	0.70–1.40	1.0	—	1.0	1.2–2.0	1.0
	≤ Mn %	1.0	—	1.0	1.0	—	1.0	0.80	1.0
	≤ P %	0.04	—	0.04	0.04	—	0.04	0.03	0.04
	≤ S %	0.03	—	0.03	0.03	—	0.03	0.25	0.03
	Cr %	12–14	—	12–14	11.5–14.5	—	12–14	1.0–1.8	11.5–14.5
	Al %	0.70–1.20	—	0.70–1.20	0.10–0.30	—	—	1.0–1.8	0.10–0.30
	Ni %	—	—	—	—	—	—	—	—
	Others	—	—	—	—	—	—	—	—
	Dimensions	5–15	—	5–15	—	—	—	—	—
Mechanical properties	0.2% proof stress N/mm ² min.	250	—	250	—	—	410	—	—
	Tensile strength N/mm ²	450–650	—	450–650	448	—	590 min	—	177
	Elongation % min.	15	—	15	30	—	16	—	412 min
	Reduction of area % min.	—	—	—	—	—	—	—	20

Data Sheet 24.3—Type-H5 (ISO)**CHARACTERISTICS AND TYPICAL APPLICATIONS**

This is a ferritic chromium steel of non-hardening, stainless steel with superior heat resistance and corrosion resistance. Addition of aluminium restricts the formation of austenite at high temperatures so that hardening does not occur upon quenching. This steel is non-sealing in air at temperatures up to 1050°C. It is also highly resistant to sulphur-bearing, reducing and carburizing gases. The given temperature is reduced, however, when the steel is exposed to combustion gases with high steam or sulphur contents or other aggressive media. Due to the growth of the ferrite grain, cold embrittlement occurs at temperatures above 950°C. Since the stress limit values are low, the steel can only be subjected to moderate mechanical stresses.

Mainly used for furnace fittings, bolts, annealing tubes, annealing pots, carburizing boxes, transport equipment, etc.

This steel has only limited weldability. Electric welding is to be preferred. Annealing is necessary after welding. Table 24.4 gives the chemical composition and mechanical properties of International Standard steels.

HEAT TREATMENT

Annealing	800–850°C (Air or water cool)
Obtainable hardness BHN	160–210

Table 24.4

Steel	Standard	ISO/DIS 4955/83	IS	DIN SEW470-76	AISI	BS 970/4-70	NFA 35-578-82	GOST	JIS 4303-81
	Designation	Type H5		X10CrAl24	430		Z10CAS18		SUS430
Chemical composition	≤ C %	0.12	—	0.12	0.12	—	0.12	—	0.12
	≤ Si %	0.70–1.40	—	0.70–1.48	1.0	—	0.50–1.50	—	0.75
	≤ Mn %	1.0	—	1.0	1.0	—	1.0	—	1.0
	≤ P %	0.04	—	0.04	0.04	—	0.04	—	0.04
	≤ S %	0.03	—	0.03	0.03	—	0.03	—	0.03
	Cr %	17–19	—	17–19	16–18	—	17–19	—	16–18
	Al %	0.70–1.20	—	0.70–1.20	—	—	0.70–1.20	—	—
	Ni %	—	—	—	—	—	—	—	—
	Others	—	—	—	—	—	—	—	—
Mechanical properties	Dimensions	5–15	—	5–15	—	—	16	—	—
	0.2% proof stress N/mm ² min.	270	—	270	207	—	290	—	206
	Tensile strength N/mm ²	500–700	—	500–700	415 min.	—	490 min.	—	451 min.
	Elongation % min.	15	—	12	20	—	18	—	22
	Reduction of area % min.	—	—	—	—	—	—	—	—

Data Sheet 24.4—Type-H6 (ISO)

CHARACTERISTICS AND TYPICAL APPLICATIONS

This is a high-chromium non-hardenable ferritic stainless steel. It is resistant to scaling in oxidizing atmospheres upto 1200°C. It has good resistance to carburization and combustion gases and also sulphur-containing gases. It may be used where high strength and toughness are not prime factors. When welding, the parts should be preheated to 150–200°C and after welding, should be annealed at 710–790°C, followed by air cooling. To avoid embrittlement, annealing may be done at 900°C, or prolonged periods of exposure at 400–550°C and 600–850°C, should be avoided.

Mainly used for baffle plates for steam super heaters, super heater suspensions, metal to glass seal, heaters, annealing boxes, etc. Table 24.5 gives the chemical composition and mechanical properties of International Standard steels.

HEAT TREATMENT

Annealing	800–850°C (Air or water cool)
Annealed hardness BHN	145–190

Table 24.5

Steel	Standard Designation	ISO/DIS 4955/83 Type H6	IS	DIN SEW470-76 X10CrAl18	ATSI	BS	NFA 35-578-82 Z10CA524	GOST	JIS G4311-81 SUH446
Chemical composition	≤ C %	0.12	—	0.12	0.20	—	0.12	—	0.20
	≤ Si %	0.70–1.40	—	0.70–1.40	1.0	—	0.50–1.50	—	1.0
	≤ Mn %	1.0	—	1.0	1.5	—	1.0	—	1.50
	≤ P %	0.04	—	0.04	0.04	—	0.04	—	0.04
	≤ S %	0.03	—	0.03	0.03	—	0.03	—	0.03
	Cr %	23–26	—	23–26	23–27	—	23–26	—	23–27
	Mo % Al	1.20–1.70	—	1.20–1.70	N 0.25	—	1.20–1.70	—	≤ 0.25 N
	Ni %	—	—	—	—	—	—	—	—
	Others	—	—	—	—	—	—	—	—
Mechanical properties	Dimensions	5–15	—	5–15	—	—	16	—	—
	0.2% proof stress N/mm ² min.	280	—	280	275	—	290	—	275
	Tensile strength N/mm ²	520–720	—	520–720	480 min.	—	490 min.	—	510 min.
	Elongation % min.	10	—	10	20	—	12	—	20
	Reduction of area % min.	—	—	—	—	—	—	—	—

Data Sheet 24.5—Type-H11 (ISO)**CHARACTERISTICS AND TYPICAL APPLICATIONS**

This is a heat-resisting non-scaling steel with austenitic structure. This grade is stabilized against carbide precipitation and designed for operation within the temperature range where carbide precipitation develops. It is suitable for service in air, up to 800°C. Its resistance is medium to sulphur-containing oxidizing gases and low to sulphur-containing reducing gases and carburizing.

This steel can be welded with all electrical welding processes; preheating and after-treatment are not required.

This material responds to drawing, forming, bending and upsetting.

Mainly used for higher mechanical loadings for hardening and annealing gases, pots, pipes, retorts, conveyor parts, super heaters, burner points, etc. Table 24.6 gives the chemical composition and mechanical properties of International Standard steels.

HEAT TREATMENT

Annealing	1000–1050°C (Cooling in water)
Annealed hardness BHN	130

Table 24.6

Steel	Standard	ISO/DIS 4955/83	IS	DIN SEW470/76	AISI	BS 970/4-70	NFA 35-578-82	GOST	JIS G4303-81
	Designation	Type H11		X12CrNi Ti18-9	321	321S-12	Z6CN Ti18-12	12Ch18 N30T	SUS321
Chemical composition	≤ C %	0.12	—	0.12	0.08	0.08	0.08	0.12	0.08
	≤ Si %	1.0	—	1.0	1.0	1.0	1.0	0.8	1.0
	≤ Mn %	2.0	—	2.0	2.0	2.0	2.0	2.0	2.0
	≤ P %	0.045	—	0.045	0.045	0.045	0.04	0.035	0.04
	≤ S %	0.03	—	0.03	0.03	0.03	0.03	0.02	0.03
	Cr %	17-19	—	17-19	17-19	17-19	17-19	17-19	17-19
	Mo %	—	—	—	—	—	—	—	—
	Ni %	9-12	—	9-12	9-12	9-12	11-13	9-11	9-13
	Others Ti	≥ 5 × %C ≤ 0.8	—	≥ 4 × %C ≤ 0.8	≥ 5 × %C	≥ 5 × %C ≤ 0.70	≥ 5 × %C ≤ 0.60	5 × %C ≤ 0.80	5 × %C
Mechanical properties	Dimensions	≤ 100	—	5-160	13 min.	—	16	—	≤ 180
	0.2% proof stress N/mm ² min.	210	—	210	205	195	205	—	206
	Tensile strength N/mm ²	500-700	—	500-750	515 min. 490 min.	—	510 min.	—	520 min.
	Elongation % min.	35	—	40	30	40	40	—	40
	Reduction of area % min.	—	—	—	—	—	—	—	—

Data Sheet 24.6—Type-H13 (ISO)

CHARACTERISTICS AND TYPICAL APPLICATIONS

This is an austenitic, chromium-nickel steel with high heat-resisting characteristics. It has scaling resistance up to 1050°C. It shows good resistance to oxidising and nitrogen-bearing gases as well as those poor in oxygen. The presence of sulphur in gases, however, affects its use. It is practically free from embrittlement in the temperature range 600–850°C.

Welding may be carried out by any method; subsequent treatment is not necessary. This type of steel can be deep-drawn, stamped and upset without any difficulty.

Mainly used for plates, girders and pipes in furnace building, and the manufacture of apparatus for air heaters, annealing muffles, super heaters, suspensions, annealing covers, hardening, boxes, covering plates, pyrometer protecting tubes, etc. Table 24.7 gives the chemical composition and mechanical properties of International Standard steels.

HEAT TREATMENT

Annealing 1050–1100°C (Water or air cool)

Annealed hardness BHN 145–200

Table 24.7

Steel	Standard	ISO/DIS 4955-83	IS	DIN SEW470-76	AISI	BS	NFA 35-378-82	GOST	JIS G4312-81
	Designation	Type H13		X15CrNiSi 20-12	309	—	Z15NCS 20-12	20Ch20 N-1482	SH309
Chemical composition	≤ C %	0.20	—	0.20	0.20	—	0.20	0.20	0.20
	≤ Si %	1.5–2.5	—	1.5–2.5	1.0	—	1.5–2.5	2.0–3.0	1.0
	≤ Mn %	2.0	—	2.0	2.0	—	2.0	1.5	2.0
	≤ P %	0.045	—	0.045	0.045	—	0.04	0.035	0.04
	≤ S %	0.030	—	0.030	0.03	—	0.03	0.025	0.03
	Cr %	19–21	—	19–21	22–24	—	19–21	19–22	22–24
	Mo %	—	—	—	—	—	—	—	—
	Ni %	11–13	—	11–13	12–15	—	11–13	12–15	12–15
	Others	—	—	—	—	—	TI ≤ 0.2	—	—
Mechanical properties	Dimensions	≤ 100	—	5–160	> 12.7	—	—	—	—
	0.2% proof stress N/mm ² min.	230	—	230	205	—	—	—	206 min.
	Tensile strength N/mm ²	550–750	—	500–750	515 min.	—	—	—	559 min.
	Elongation % min.	30	—	30	30	—	—	—	40
	Reduction of area % min.	—	—	—	—	—	—	—	—

Data Sheet 24.7—Type-H14 (ISO)**CHARACTERISTICS AND TYPICAL APPLICATIONS**

This is an austenitic, chromium-nickel steel with high heat-resisting characteristics. It is resistant to scaling up to 1000°C in continuous service. It can be deep drawn, stamped and upset without difficulty. Welding and brazing can be carried out by any method. However, electric welding is preferable. Further treatment is not required.

This steel may be used for hardening and annealing boxes, retorts, burner tips, segments and components of rotary and level kilns, grates and taps, etc. Table 24.8 gives the chemical composition and mechanical properties of International Standard steels.

HEAT TREATMENT

Annealing	1040–1120°C (Water quench)
Annealed BHN	170

Table 24.8

Steel	Standard	ISO/DIS 4955/83	IS	DIN SEW470/76	AISI	BS	NFA 35-531-75	GOST	JIS G4312-81
	Designation	Type H14		X7CrNi23-14	309S		Z15CN24-13		SUH309
Chemical composition	≤ C %	0.08	—	0.08	0.08	—	0.2	—	0.08
	≤ Si %	1.0	—	1.0	1.0	—	1.0	—	1.0
	≤ Mn %	2.0	—	2.0	2.0	—	2.0	—	2.0
	≤ P %	0.045	—	0.045	0.045	—	0.04	—	0.045
	≤ S %	0.03	—	0.03	0.03	—	0.03	—	0.03
	Cr %	22–24	—	22–23	22–24	—	22–25	—	22–24
	Mo %	—	—	—	—	—	—	—	—
	Ni %	12–15	—	12–15	12–15	—	11–14	—	12–15
	Others	—	—	—	—	—	—	—	—
Mechanical properties	Dimensions	≤ 100	—	5–16	—	—	16	—	—
	0.2% proof stress N/mm ² min.	210	—	210	205	—	240	—	206 min.
	Tensile strength N/mm ²	500–700	—	500–750	515 min.	—	540 min.	—	520 min.
	Elongation % min.	35	—	35	30	—	30	—	40
	Reduction of area % min.	—	—	—	—	—	—	—	—

Data Sheet 24.8—Type-H15 (ISO)

PROPERTIES AND TYPICAL APPLICATIONS

This is a heat-resisting non-scaling steel with an austenitic structure, suitable for service in air up to 1150°C. It has good resistance to nitrogen containing gases, medium resistance to sulphur-containing oxidizing gases and low resistance to carburizing and sulphur-containing reducing gases.

This steel can be deep drawn, stamped and leaded without any difficulty. Welding can be carried out by any methods. No preheating or after-treatment is necessary. It also has good resistance to molten salts such as tempering, neutral cyaniding and high-speed salts.

Mainly used for oil-burner parts, annealing and hardening boxes, annealing pots, annealing hoods, carrier and conveyor parts, recuperators, super heaters, suspensions, cementation boxes, pyrometer protecting tubes, heating conductors and many other components of steam installation and other equipment. Table 24.9 gives the chemical composition and mechanical properties of International Standard steels.

HEAT TREATMENT

Annealing	1050–1100°C (Cooled in water)
Annealed BHN	140–190

Table 24.9

Steel	Standard	ISO/DIS 4955/83	IS	DIN SEW 470-76	AISI	BS 970/4-70	NFA 35-578-82	GOST	JIS G4305-87
	Designation	Type H15		X12CrNi25-21	3105	310S24	Z12CN25-20		SUH310
Chemical composition	≤ C %	0.08	—	0.15	0.08	0.15	0.15	—	0.08
	≤ Si %	1.50	—	0.75	1.50	0.20	1.0	—	1.5
	≤ Mn %	2.0	—	2.0	2.0	0.50–2.0	2.0	—	2.0
	≤ P %	0.045	—	0.045	0.045	0.045	0.045	—	0.045
	≤ S %	0.03	—	0.03	0.03	0.03	0.03	—	0.03
	Cr %	24–26	—	24–26	24–26	23–26	23–26	—	24–26
	Mo %	—	—	—	—	—	—	—	—
	Ni %	19–22	—	19–22	19–22	19–22	19–22	—	19–22
	Others	—	—	—	—	—	—	—	—
Mechanical properties	Dimensions	≤ 100	—	5–160	—	—	16	—	—
	0.2% proof stress N/mm ² min.	210	—	210	205	215	240	—	—
	Tensile strength N/mm ²	500–700	—	500–750	515 min.	540 min.	540 min.	—	—
	Elongation % min.	35	—	35	30	40	30	—	—
	Reduction of area % min.	—	—	—	—	—	—	—	—

Data Sheet 24.9—Type-H16 (ISO)**CHARACTERISTICS AND TYPICAL APPLICATIONS**

This is an austenitic grade, high chromium-nickel, heat-resistant steel with the highest heat-resisting properties of any chromium-nickel steel. It has very good resistance to oxidizing gases as well as nitrogen bearing gases at temperatures up to 1200°C. It is also used when the maximum resistance to carburization is desired. It has good high-temperature strength, should be used at temperatures of 900–1200°C. It should not be used in the temperature range 600–850°C since embrittlement may occur. Welding may be carried out by any method; subsequent heat treatment is not necessary.

Mainly used for plates and pipes in furnace building and the manufacture of apparatus where the steel must meet higher requirements, e.g. in air heaters, super heaters, suspensions, annealing covers, cementation boxes, baffle plates, heating conductors, annealing and hardening boxes, etc. Table 24.10 gives the chemical composition of International Standard steels.

HEAT TREATMENT

Annealing	1050–1100°C (Water or air cool)
Annealed hardness BHN	145–200

Table 24.10

Steel	Standard	ISO/DIS 4955/83	IS	DIN SEW470-76	AISI	BS	NFA 35-578-82	GOST	JIS G4311-81
	Designation	Type H16		X15CrNiSi25-20	314		Z12CNS25-20		SUH310
Chemical composition	≤ C %	0.2	—	0.2	0.25	—	0.15	—	0.25
	≤ Si %	1.5–2.5	—	1.5–2.5	1.5–3.0	—	1.5–2.5	—	1.5
	≤ Mn %	2.0	—	2.0	2.0	—	2.0	—	2.0
	≤ P %	0.045	—	0.045	0.046	—	0.04	—	0.04
	≤ S %	0.03	—	0.03	0.03	—	0.03	—	0.03
	Cr %	24–26	—	24–26	23–26	—	23–26	—	24–26
	Mo %	—	—	—	—	—	—	—	—
	Ni %	19–22	—	19–22	19–22	—	18–21	—	19–22
	Others	—	—	—	—	—	—	—	—
Mechanical properties	Dimensions	≤ 100	—	5–100	—	—	16	—	—
	0.2% proof stress N/mm ² min.	250	—	230	205	—	240	—	206 min.
	Tensile strength N/mm ²	550–750	—	550–800	515 min.	—	540 min.	—	590 min.
	Elongation % min.	30	—	30	40	—	30	—	35
	Reduction of area % min.	—	—	—	—	—	—	—	—

Data Sheet 24.10—Type-H17 (ISO)

CHARACTERISTICS AND TYPICAL APPLICATIONS

This is a heat-resisting, austenitic, highly alloyed steel with good high-temperature strength. It is specially suited for application at temperatures from 815°C to about 1200°C. It is not susceptible to embrittlement in the temperature range 600–850°C and can be used at all temperatures up to 1200°C. Due to its high nickel content, it is susceptible to attack by sulphur-bearing furnace gases.

This steel is resistant to carburizing and carbonitriding atmospheres in the 870–950°C range, and up to 1170°C in reducing and neutral atmospheres. Weldability is good and worn areas and friction marks can be repaired by arc or gas welding. Subsequent treatment after welding is not necessary.

Mainly used for furnace parts, annealing and hardening fixtures, carburizing boxes, etc. Table 24.11 gives the chemical composition and mechanical properties of International Standard steels.

HEAT TREATMENT

Annealing	1050–1100°C (Air or water cool)
Annealed hardness BHN	150–200

Table 24.11

Steel	Standard Designation	ISO/DIS 4955/83 Type H17	IS	DIN SEW470-76 X12NiCrSi36-16	AISI	BS	NFA 35-378-82 Z12NC835-16	GOST	JIS G4311-81 SUH330
Chemical composition	≤ C %	0.15	—	0.15	0.08	—	0.15	—	0.15
	≤ Si %	1.0–2.0	—	1.0–2.0	0.75–1.5	—	1.0–2.0	—	1.5
	≤ Mn %	2.0	—	2.0	2.0	—	2.0	—	2.0
	≤ P %	0.045	—	0.03	0.04	—	0.04	—	0.04
	≤ S %	0.03	—	0.02	0.03	—	0.03	—	0.03
	Cr %	15–17	—	15–17	17–20	—	14–17	—	14–17
	Mo % Al	0.15–0.60	—	0.15–0.6	Cb + Ta 10 × C min.	—	0.15–0.60	—	—
	Ni %	33–37	—	33–37	34–37	—	33–36	—	33–37
	Others Ti	0.15–0.60	—	0.15–0.6	Cb + Ta 10 × C min.	—	0.15–0.60	—	—
Mechanical properties	Dimensions	≤ 100	—	5–100	—	—	16	—	0–180
	0.2% proof stress N/mm ² min.	230	—	230	2	—	240	—	206
	Tensile strength N/mm ²	550–750	—	550–800	—	—	590 min.	—	559 min.
	Elongation % min.	30	—	30	—	—	30	—	40
	Reduction of area % min.	—	—	—	—	—	—	—	—

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Appendices

Table 1 Hardness conversion: Approximate equivalent hardness numbers and tensile strengths for Rockwell C hardness numbers for steel

Rockwell C-scale hardness No.	Vickers hardness No.	Brinell hardness No.		A scale, 132-lb (60-kg) load, Brale indenter	B scale, 220-lb (100-kg) load, 1/16 in. (1.59-mm) diam ball	Rockwell superficial hardness No., Brale indenter			Knop hardness No. 18-oz (510-g) load and greater	Shore scleroscope hardness No.
		Standard ball	Tungsten carbide ball			15N scale, 33-lb (15-kg) load	30N scale, 66-lb (30-kg) load	45N scale, 99-lb (45-kg) load		
68	900	—	—	85.6	—	93.2	84.4	75.4	920	97
67	900	—	—	85.0	—	92.9	83.6	74.2	895	95
66	865	—	—	84.5	—	92.5	82.8	73.3	870	92
65	832	—	(739)	83.9	—	92.2	81.9	72.0	846	91
64	800	—	(722)	83.4	—	91.8	81.1	71.0	822	88
63	772	—	(705)	82.8	—	91.4	80.1	69.9	799	87
62	746	—	(688)	82.3	—	91.1	79.3	68.8	776	85
61	720	—	(670)	81.8	—	90.7	78.4	67.7	754	83
60	697	—	(654)	81.2	—	90.2	77.5	66.6	732	81
59	674	—	(634)	80.7	—	89.8	76.6	65.5	710	80
58	651	—	615	80.1	—	89.3	75.7	64.3	690	78
57	631	—	595	79.6	—	88.9	74.8	63.2	670	76
56	611	—	577	79.0	—	88.3	73.9	62.0	650	75
55	595	—	560	78.5	—	87.9	73.0	60.9	630	74
54	577	—	543	78.0	—	87.4	72.0	59.8	612	72
53	560	—	525	77.4	—	86.9	71.2	58.6	594	71
52	544	(500)	512	76.8	—	86.4	70.2	57.4	576	69
51	528	(487)	496	76.3	—	85.9	69.4	56.1	558	68
50	513	(475)	481	75.9	—	85.5	68.5	55.0	542	67
49	498	(464)	469	75.2	—	85.0	67.6	53.8	526	66
48	484	(451)	455	74.7	—	84.5	66.7	52.5	510	64

47	471	442	443	74.1	—	83.9	65.8	51.4	495	63
46	453	432	432	73.6	—	83.5	64.8	50.3	480	62
45	446	431	431	73.1	—	83.0	64.0	49.0	466	60
44	434	409	409	72.5	—	82.5	63.1	47.8	452	58
43	423	400	400	72.0	—	82.0	62.2	46.7	438	57
42	412	390	390	71.5	—	81.5	61.3	45.5	426	56
41	402	381	381	70.9	—	80.9	60.4	44.3	414	55
40	392	371	371	70.4	—	80.4	59.5	43.1	402	54
39	382	362	362	69.9	—	79.9	58.6	41.9	391	52
38	372	353	353	69.4	—	79.4	57.7	40.8	380	51
37	363	344	344	68.9	—	78.8	56.8	39.6	370	50
36	354	336	336	68.4	(190.0)	78.3	55.9	38.4	360	49
35	345	327	327	67.9	(108.5)	77.7	55.0	37.2	351	48
34	336	319	319	67.4	(108.0)	77.2	54.2	36.1	342	47
33	327	311	311	66.8	(107.5)	76.6	53.3	34.9	334	46
32	318	301	301	66.3	(107.0)	76.1	52.1	33.7	326	44
31	310	294	294	65.8	(106.0)	75.6	51.3	32.5	318	43
30	302	286	286	65.3	(105.5)	75.0	50.4	31.3	311	42
29	294	279	279	64.7	(104.5)	74.5	49.5	30.1	304	41
28	286	271	271	64.3	(104.0)	73.9	48.6	28.9	297	40
27	278	264	264	63.8	(103.0)	73.3	47.7	27.8	290	39
26	272	258	258	63.3	(102.5)	72.8	46.8	26.7	284	38
25	266	253	253	62.8	(101.5)	72.2	45.9	25.5	278	38
24	260	247	247	62.4	(101.0)	71.6	45.0	24.3	272	37
23	254	243	243	62.0	100.0	71.0	44.0	23.1	266	36
22	248	237	237	61.5	99.0	70.5	43.2	22.0	261	35
21	243	231	231	61.0	98.5	69.9	42.3	20.7	256	35

Source: *Metals Handbook*, 8th ed., Vol. 11, American Society for Metals, 1976.

Table 2 Hardness conversion: Approximate equivalent hardness numbers and tensile strengths for Rockwell B hardness numbers for steel

Rockwell B-scale hardness No.	Vickers hardness No.	Brinell hardness No., 0.39-in. (10-mm) diam ball		A scale, 132-lb (60 kg) load, Brale indenter	C scale, 330-lb (150-kg) load, Brale indenter	Rockwell superficial hardness No., 1/16-in. (1.59-mm) diam ball			Knoop hardness No., 18-oz (500-g) load and greater	Shore scleroscope hardness No.
		102-lb (50 kg) load	63.14-lb (3000-kg) load			15T scale, 34-lb (15-kg) load	30T scale, 66-lb (30-kg) load	45T scale, 99-lb (45-kg) load		
96	228	189	228	60.2	(19.9)	92.5	81.8	70.9	241	34
97	222	184	222	59.5	(18.6)	92.1	81.1	69.9	236	33
98	216	179	216	58.9	(17.2)	91.8	80.4	68.9	231	32
99	210	175	210	58.3	(15.7)	91.5	79.8	67.9	226	—
94	205	171	205	57.6	(14.3)	91.2	79.1	66.9	221	31
93	200	167	200	57.0	(13.0)	90.8	78.4	65.9	216	30
92	195	163	195	56.4	(11.7)	90.5	77.8	64.8	211	—
91	190	160	190	55.8	(10.4)	90.2	77.1	63.8	205	29
90	185	157	185	55.2	(9.2)	89.9	76.4	62.8	201	28
89	180	154	180	54.6	(8.0)	89.5	75.8	61.8	196	27
88	176	151	176	54.0	(6.9)	89.2	75.1	60.8	192	—
87	172	148	172	53.4	(5.8)	88.9	74.4	59.8	188	26
86	169	145	169	52.8	(4.7)	88.6	73.8	58.8	184	26
85	165	142	165	52.2	(3.6)	88.2	73.1	57.8	180	25
84	162	140	162	51.7	(2.5)	87.9	72.4	56.8	176	—
83	159	137	159	51.1	(1.4)	87.6	71.8	55.8	173	24
82	156	135	156	50.6	(0.3)	87.3	71.1	54.8	170	24
81	153	133	153	50.0	—	86.9	70.4	53.8	167	—
80	150	130	150	49.5	—	86.6	69.7	52.8	164	23
79	147	128	147	48.9	—	86.3	69.1	51.8	161	—
78	144	126	144	48.4	—	86.0	68.4	50.8	158	22

77	141	124	141	47.9	—	85.6	67.7	49.8	155	22
76	139	122	139	47.3	—	85.3	67.1	48.8	152	—
75	137	120	137	46.8	—	85.0	66.4	47.8	150	21
74	135	118	135	46.3	—	84.7	65.7	46.8	148	21
73	132	116	132	45.8	—	84.3	65.1	45.8	145	—
72	130	114	130	45.3	—	84.0	64.4	44.8	143	20
71	127	112	127	44.8	—	83.7	63.7	43.8	141	20
70	125	110	125	44.3	—	83.4	63.1	42.8	139	—
69	123	109	123	43.8	—	83.0	62.4	41.8	137	19
68	121	107	121	43.3	—	82.7	61.7	40.8	135	19
67	119	106	119	42.8	—	82.4	61.0	39.8	135	19
66	117	104	117	42.3	—	82.1	60.4	38.7	131	—
65	116	102	116	41.8	—	81.8	59.7	37.7	129	18
64	114	101	114	41.4	—	81.4	59.0	36.7	127	18
63	112	99	112	40.9	—	81.1	58.4	35.7	125	18
62	110	98	110	40.4	—	80.8	57.7	34.7	124	—
61	108	96	108	40.0	—	80.5	57.0	33.7	122	17
60	107	95	107	39.5	—	80.1	56.4	32.7	120	—
59	106	94	106	39.0	—	79.8	55.7	31.7	118	—
58	104	92	104	38.6	—	79.5	55.0	30.7	117	—
57	103	91	103	38.1	—	79.2	54.4	29.7	115	—
56	101	90	101	37.7	—	78.8	53.7	28.7	114	—
55	100	89	100	37.2	—	78.5	53.0	27.7	112	—

Source: *Metals Handbook*, 8th ed., Vol. II, American Society for Metals, 1976.

Table 3 Hardness conversion

Tensile strength					Tensile strength				
Vickers hardness (F \geq 98N)					Vickers hardness (F \geq 98N)				
Brinell hardness ¹					Brinell hardness ¹				
Rockwell hardness					Rockwell hardness				
N/mm ²	HV	HB	HRB	HRC	N/mm ²	HV	HB	HRB	HRC
200	63	60			550	172	163	85.5	
210	65	62			560	175	166	86	
220	69	66			570	178	169	86.5	
225	70	67			575	180	171	87	
230	72	68			580	181	172		
240	75	71			590	184	175	88	
250	79	75			595	185	176		
255	80	76			600	187	178	89	
260	82	78			610	190	181	89.5	
270	85	81	41		620	193	184	90	
280	88	84	45		625	195	185		
285	90	86	48		630	197	187	91	
290	91	87	49		640	200	190	91.5	
300	94	89	51		650	205	193	92	
305	95	90	52		660	205	195	92.5	
310	97	92	54		670	208	198	93	
320	100	95	56		675	210	199	93.5	
330	103	98	58		680	212	201		
335	105	100	59		690	215	204	94	
340	107	102	60		700	219	208		
350	110	105	62		705	220	209	95	
360	113	107	63.5		710	222	211	95.5	
370	115	109	64.5		720	225	214	96	
380	119	113	66		730	228	216		
385	120	114	67		740	230	219	96.5	
390	122	116	67.5		750	233	221	97	
400	125	119	69		755	235	223		
410	128	122	70		760	237	225	97.5	
415	130	124	71		770	240	228	98	
420	132	125	72		780	243	231		21
430	135	128	73		785	245	233		
440	138	131	74		790	247	235	99	
450	140	133	75		800	250	238	99.5	22
460	143	136	76.5		810	253	240		
465	145	138	77		820	255	242		23
470	147	140	77.5		830	258	245		
480	150	143	78.5		835	260	247		24
490	153	145	79.5		840	262	249		
495	155	147	80		850	265	252		
500	157	149	81		860	268	255		25
510	160	152	81.5		865	270	257		
520	163	155	82.5		870	272	258		26
530	165	157	83		880	275	261		
540	168	160	84.5		890	278	264		
545	170	162	85		900	280	266		27

Table 3 (contd.)

Tensile strength	Vickers hardness ($F \geq 98\text{N}$)	Brinell hardness ¹	Rockwell hardness		Tensile strength	Vickers hardness ($F \geq 98\text{N}$)	Brinell hardness ¹	Rockwell hardness	
N/mm ²	HV	HB	HRB	HRC	N/mm ²	HV	HB	HRB	HRC
910	283	269			1290	400	380		
915	285	271			1300	403	383		41
920	287	273		28	1310	407	387		
930	290	276			1320	410	390		
940	293	278		29	1330	413	393		42
950	295	280			1340	417	396		
960	299	284			1350	420	399		
965	300	285			1360	423	402		43
970	302	287		30	1370	426	405		
980	305	290			1380	429	408		
990	308	293			1385	430	409		
995	310	295		31	1390	431	410		
1000	311	296			1400	434	413		44
1010	314	299			1410	437	415		
1020	317	301		32	1420	440	418		
1030	320	304			1430	443	421		
1040	323	307			1440	446	424		45
1050	327	311		33	1450	449	427		
1060	330	314			1455	450	428		
1070	333	316			1460	452	429		
1080	336	319		34	1470	455	432		
1090	339	322			1480	458	435		46
1095	340	323			1485	460	437		
1100	342	325			1490	461	438		
1110	345	328		35	1500	464	441		
1120	349	332			1510	467	444		
1125	350	333			1520	470	447		
1130	352	334			1530	473	449		47
1140	355	337		36	1540	476	452		
1150	358	340			1550	479	455		
1155	360	342			1555	480	(456)		
1160	361	343			1560	481	(457)		
1170	364	346		37	1570	484	(460)		48
1180	367	349			1580	486	(462)		
1190	370	352			1590	489	(465)		
1200	373	354		38	1595	490	(466)		
1210	376	357			1600	491	(467)		
1220	380	361			1610	494	(470)		
1230	382	363		39	1620	497	(472)		49
1240	385	366			1630	500	(475)		
1250	388	369			1640	503	(478)		
1255	390	371			1650	506	(481)		
1260	392	372		40	1660	509	(483)		
1270	394	374			1665	510	(485)		
1280	397	377			1670	511	(486)		

Table 3 (Contd.)

Tensile strength	Vickers hardness ($F \geq 98\text{ N}$)	Brinell hardness ¹	Rockwell hardness		Tensile strength	Vickers hardness ($F \geq 98\text{ N}$)	Brinell hardness ¹	Rockwell hardness	
N/mm ²	HV	HB	HRB	HRC	N/mm ²	HV	HB	HRB	HRC
1680	514	(488)		50	2000	602	(572)		
1690	517	(491)			2010	605	(575)		
1700	520	(494)			2020	607	(577)		
1710	522	(496)			2030	610	(580)		
1720	525	(499)			2040	613	(582)		
1730	527	(501)		51	2050	615	(584)		56
1740	530	(504)			2060	618	(587)		
1750	533	(506)			2070	620	(589)		
1760	536	(509)			2080	623	(592)		
1770	539	(512)			2090	626	(595)		
1775	540	(513)			2100	629	(598)		
1780	541	(514)			2105	630	(599)		
1790	544	(517)		52	2110	631	(600)		
1800	547	(520)			2120	634	(602)		
1810	550	(523)			2130	636	(604)		
1820	553	(525)			2140	639	(607)		57
1830	556	(528)			2145	640	(608)		
1840	559	(531)			2150	641	(609)		
1845	560	(532)		53	2160	644	(612)		
1850	561	(533)			2170	647	(615)		
1860	564	(536)			2180	650	(618)		
1870	567	(539)			2190	653	(620)		
1880	570	(542)			2200	655	(622)		58
1890	572	(543)				675			59
1900	575	(546)				698			60
1910	578	(549)		54		720			61
1920	580	(551)				745			62
1930	583	(554)				773			63
1940	586	(557)				800			64
1950	589	(560)				829			65
1955	590	(561)				864			66
1960	591	(562)				900			67
1970	594	(564)				940			68
1980	596	(567)		55					
1990	599	(569)							
1995	600	(570)							

¹Calculated from : HB = 0.95 HV.

Table 4 Centigrades-Degrees Fahrenheit-Centigrades

Basic formula: $^{\circ}\text{F} = (^{\circ}\text{C} \cdot 9/5) + 32$; $^{\circ}\text{C} = (^{\circ}\text{F} - 32) \cdot 5/9$

The values in the middle column are either degrees Fahrenheit or centigrades, depending on the direction of conversion. For conversion from $^{\circ}\text{C}$, the $^{\circ}\text{F}$ value is to be found in the right-hand column and for conversion from $^{\circ}\text{F}$, the $^{\circ}\text{C}$ value is to be found in the left-hand column, e.g. $4^{\circ}\text{C} = 39.2^{\circ}\text{F}$, $4^{\circ}\text{F} = -15.6^{\circ}\text{C}$. The Kelvin scale starts at absolute zero -273.15°C .

Conversion: $\text{K} = ^{\circ}\text{C} + 273.15$ Unit: $1\text{K} = 1^{\circ}\text{C} = 1.8^{\circ}\text{F}$

$^{\circ}\text{C}$	$^{\circ}\text{F}$	$^{\circ}\text{C}$	$^{\circ}\text{F}$	$^{\circ}\text{C}$	$^{\circ}\text{F}$
-273.15	-459.67				
-268	-450	-28.9	-20	4.44	40
-262	-440	-23.3	-10	5.00	41
-257	-430	-17.8	0	5.56	42
-251	-420			6.11	43
				6.67	44
-246	-410	-17.2	1	7.22	45
-240	-400	-16.7	2	7.78	46
-234	-390	-16.1	3	8.33	47
-229	-380	-15.6	4	8.89	48
-223	-370			9.44	49
-218	-360	-15.0	5	10.0	50
-212	-350	-14.4	6	10.6	51
-207	-340	-13.9	7	11.1	52
-201	-330	-13.3	8	11.7	53
-196	-320	-12.8	9	12.2	54
-190	-310	-12.2	10	12.8	55
-184	-300	-11.7	11	13.3	56
-179	-290	-11.1	12	13.9	57
-173	-280	-10.6	13	14.4	58
-169	-273.15	-10.0	14	15.0	59
	-459.67				
-168	-270	-9.44	15	15.6	60
-162	-260	-8.89	16	16.1	61
-157	-250	-8.33	17	16.7	62
-151	-240	-7.78	18	17.2	63
-146	-230	-7.22	19	17.8	64
-140	-220	-6.67	20	18.3	65
-134	-210	-6.11	21	18.9	66
-129	-200	-5.56	22	19.4	67
-123	-190	-5.00	23	20.0	68
-118	-180	-4.44	24	20.6	69
-112	-170	-3.89	25	21.1	70
-107	-160	-3.33	26	21.7	71
-101	-150	-2.78	27	22.2	72
-95.6	-140	-2.22	28	22.8	73
-90.0	-130	-1.67	29	23.3	74
-84.4	-120	-1.11	30	23.9	75
-78.9	-110	-0.56	31	24.4	76
-73.3	-100	0.00	32	25.0	77
-67.8	-90	0.56	33	25.6	78
-62.2	-80	1.11	34	26.1	79
-56.7	-70	1.67	35	26.7	80
-51.1	-60	2.22	36	27.2	81
-45.6	-50	2.78	37	27.8	82
-40.0	-40	3.33	38	28.3	83
-34.4	-30	3.89	39	28.9	84

Table 4 (Contd.)

°C		°F	°C		°F	°C		°F
29.4	85	185.0	254	490	914	538	1000	1832
30.0	86	186.8	260	500	932	543	1010	1850
30.6	87	188.6	266	510	950	549	1020	1868
31.1	88	190.4	271	520	968	554	1030	1886
31.7	89	192.2	277	530	986	560	1040	1904
32.2	90	194.0	282	540	1004	566	1050	1922
32.8	91	195.8	288	550	1022	571	1060	1940
33.3	92	197.6	293	560	1040	577	1070	1958
33.9	93	199.4	299	570	1058	582	1080	1976
34.4	94	201.2	304	580	1076	588	1090	1994
35.0	95	203.0	310	590	1094	593	1100	2012
35.6	96	204.8	316	600	1112	599	1110	2030
36.1	97	206.6	321	610	1130	604	1120	2048
36.7	98	208.4	327	620	1148	610	1130	2066
37.2	99	210.2	332	630	1166	616	1140	2084
37.8	100	212.0	338	640	1184	621	1150	2102
43	110	230	343	650	1202	627	1160	2120
49	120	248	349	660	1220	632	1170	2138
54	130	266	354	670	1238	638	1180	2156
60	140	284	360	680	1256	643	1190	2174
66	150	302	366	690	1274	649	1200	2192
71	160	320	371	700	1292	654	1210	2210
77	170	338	377	710	1310	660	1220	2228
82	180	356	382	720	1328	666	1230	2246
88	190	374	388	730	1346	671	1240	2264
93	200	392	393	740	1364	677	1250	2282
99	210	410	399	750	1382	682	1260	2300
100	212	413	404	760	1400	688	1270	2318
104	220	438	410	770	1418	693	1280	2336
110	230	446	416	780	1436	699	1290	2354
116	240	464	421	790	1454	704	1300	2372
121	250	482	427	800	1472	710	1310	2390
127	260	500	432	810	1490	716	1320	2408
132	270	518	438	820	1508	721	1330	2426
138	280	536	443	830	1526	727	1340	2444
143	290	554	449	840	1544	732	1350	2462
149	300	572	454	850	1562	738	1360	2480
154	310	590	460	860	1580	743	1370	2498
160	320	608	466	870	1598	749	1380	2516
166	330	626	471	880	1616	754	1390	2534
171	340	644	477	890	1634	760	1400	2552
177	350	662	482	900	1652	766	1410	2570
182	360	680	488	910	1670	771	1420	2588
188	370	698	493	920	1688	777	1430	2606
193	380	716	499	930	1706	782	1440	2624
199	390	734	504	940	1724	788	1450	2642
204	400	752	510	950	1742	793	1460	2660
210	410	770	516	960	1760	799	1470	2678
216	420	788	521	970	1778	804	1480	2696
221	430	806	527	980	1796	810	1490	2714
227	440	824				816	1500	2732
232	450	842				821	1510	2750
238	460	860	532	990	1814	827	1520	2768
243	470	878				832	1530	2786
249	480	896				838	1540	2804

1. The first part of the paper is devoted to a general
 discussion of the problem. It is shown that the
 problem is of great importance in the theory of
 functions of a complex variable. The problem is
 solved in the case of a certain class of functions.
 The result is then extended to the case of a
 more general class of functions. The paper
 concludes with a summary of the results.

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