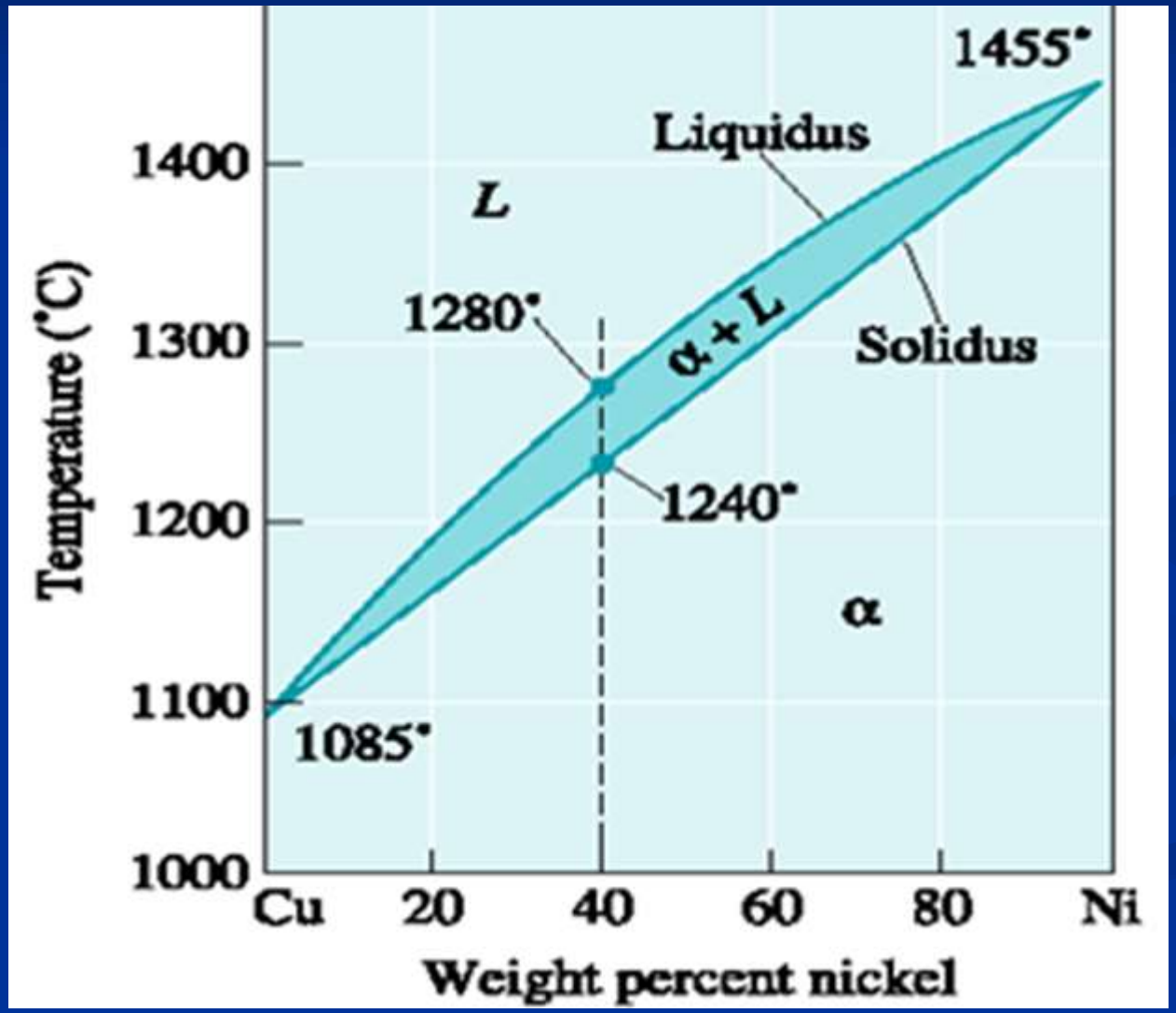
DIAGRAMA DE EQUILÍBRIO FERRO CARBONO

Engenharia e Ciência dos Materiais I

Profa.Dra. Lauralice Canale

REVISÃO


1455°
Liquidus
1400
L
1280°
α + L
Solidus
1300
Temperature (°C)
1200
1240°
α
1100
1085°
1000
Cu
20
40
60
80
Ni
Weight percent nickel

REVISÃO

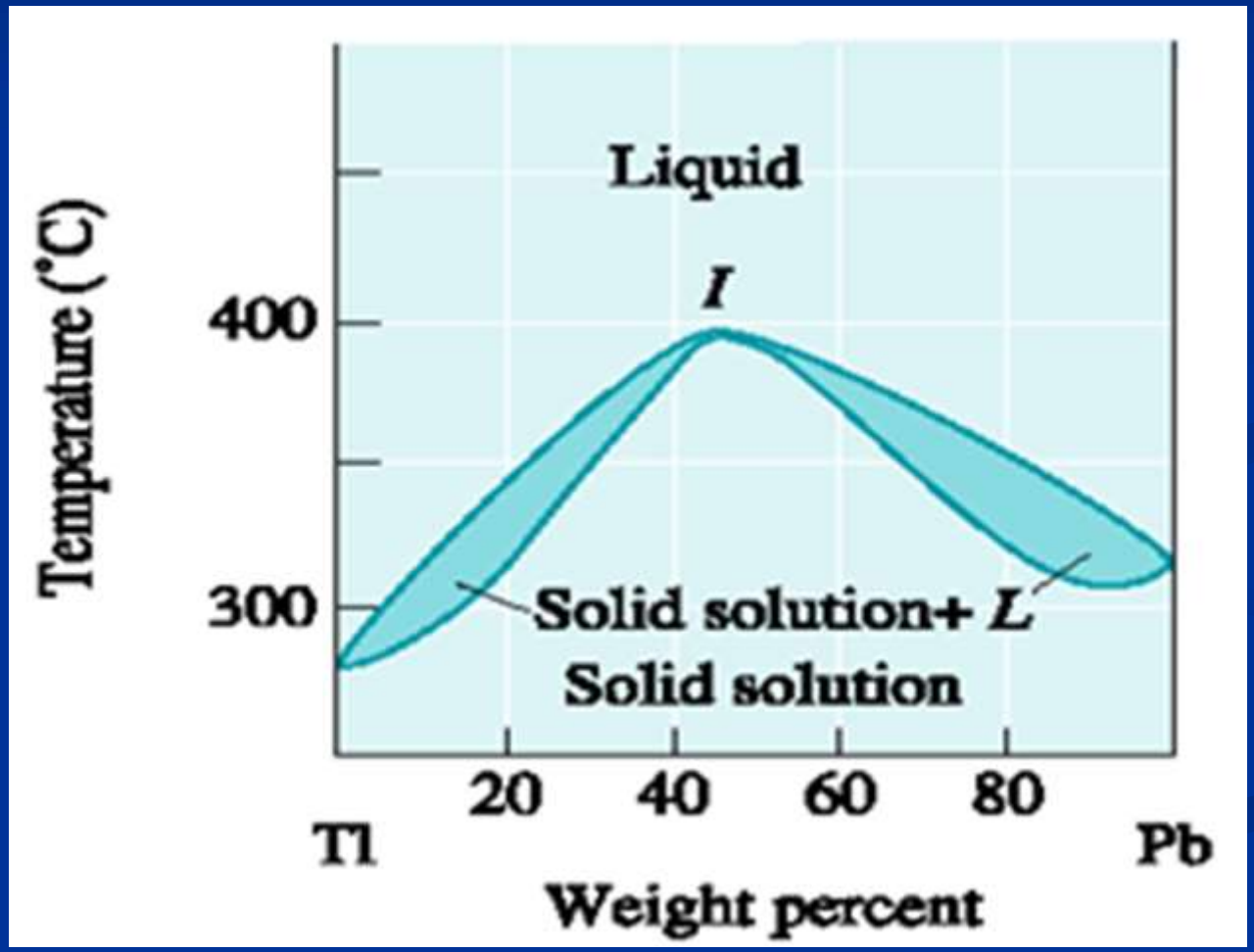
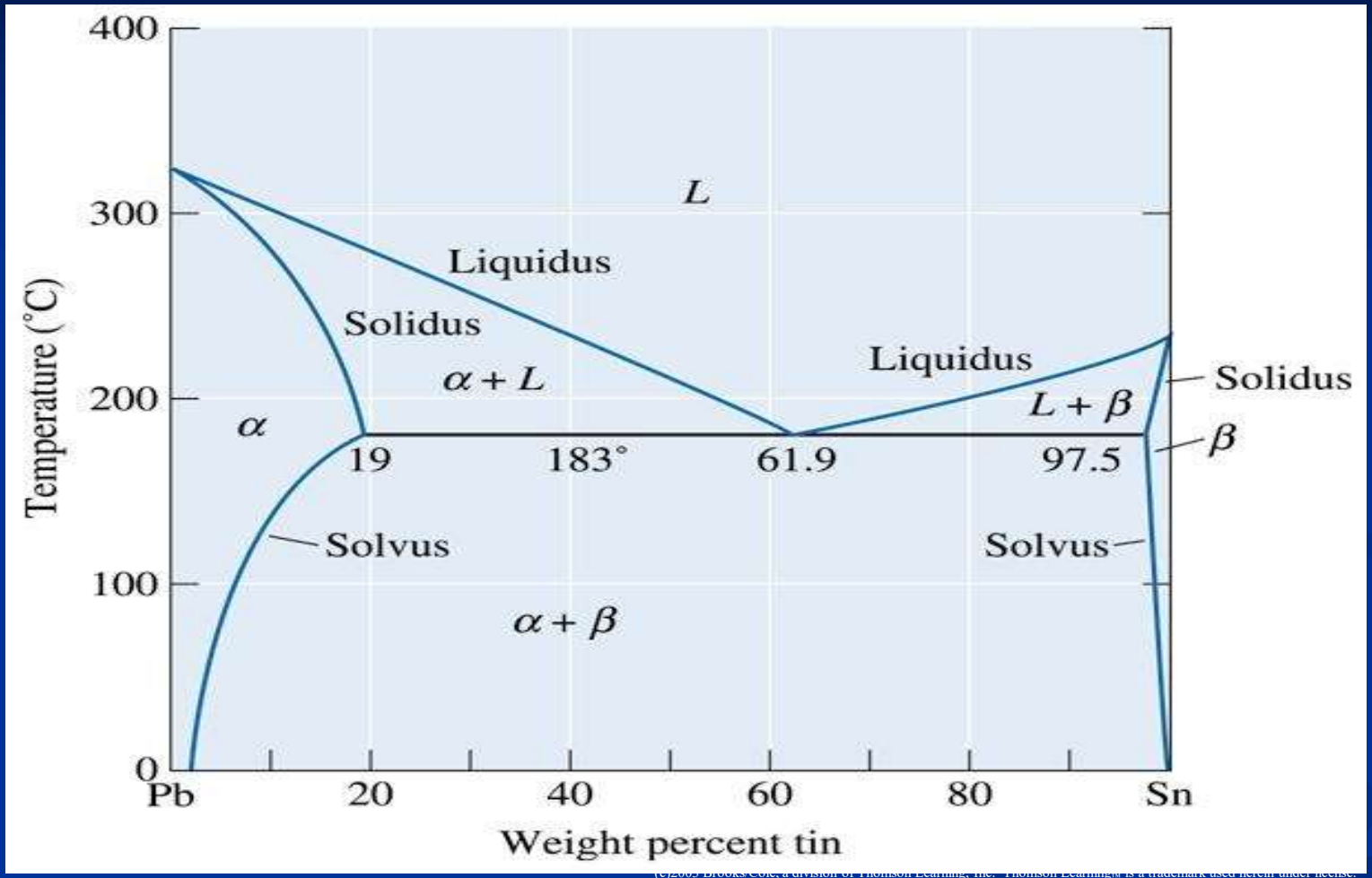

Liquid
L
400
300
Solid solution+ L
Solid solution
20
40
60
80
Tl
Pb
Weight percent
Temperature (°C)

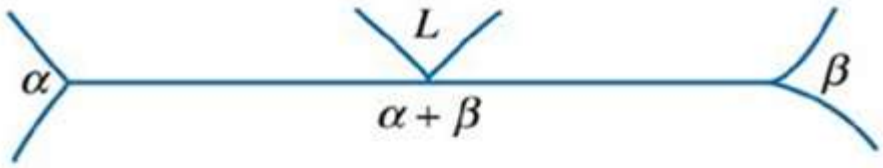
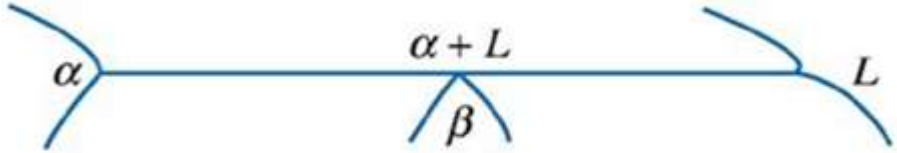
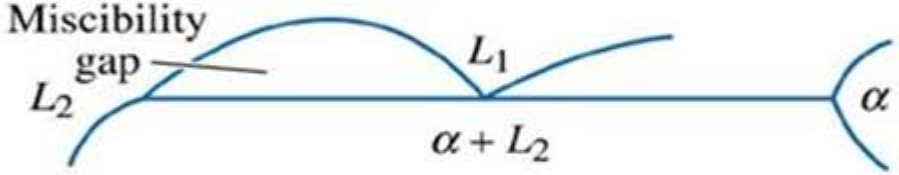
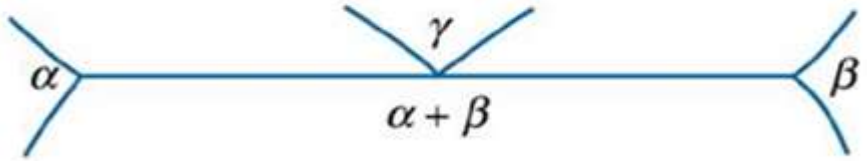
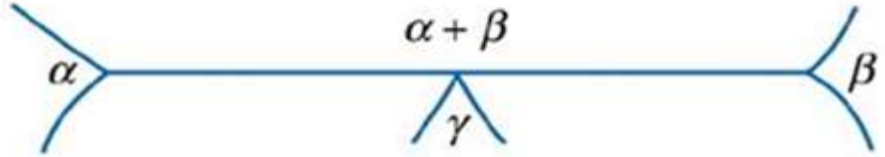
Diagrama de fase eutético

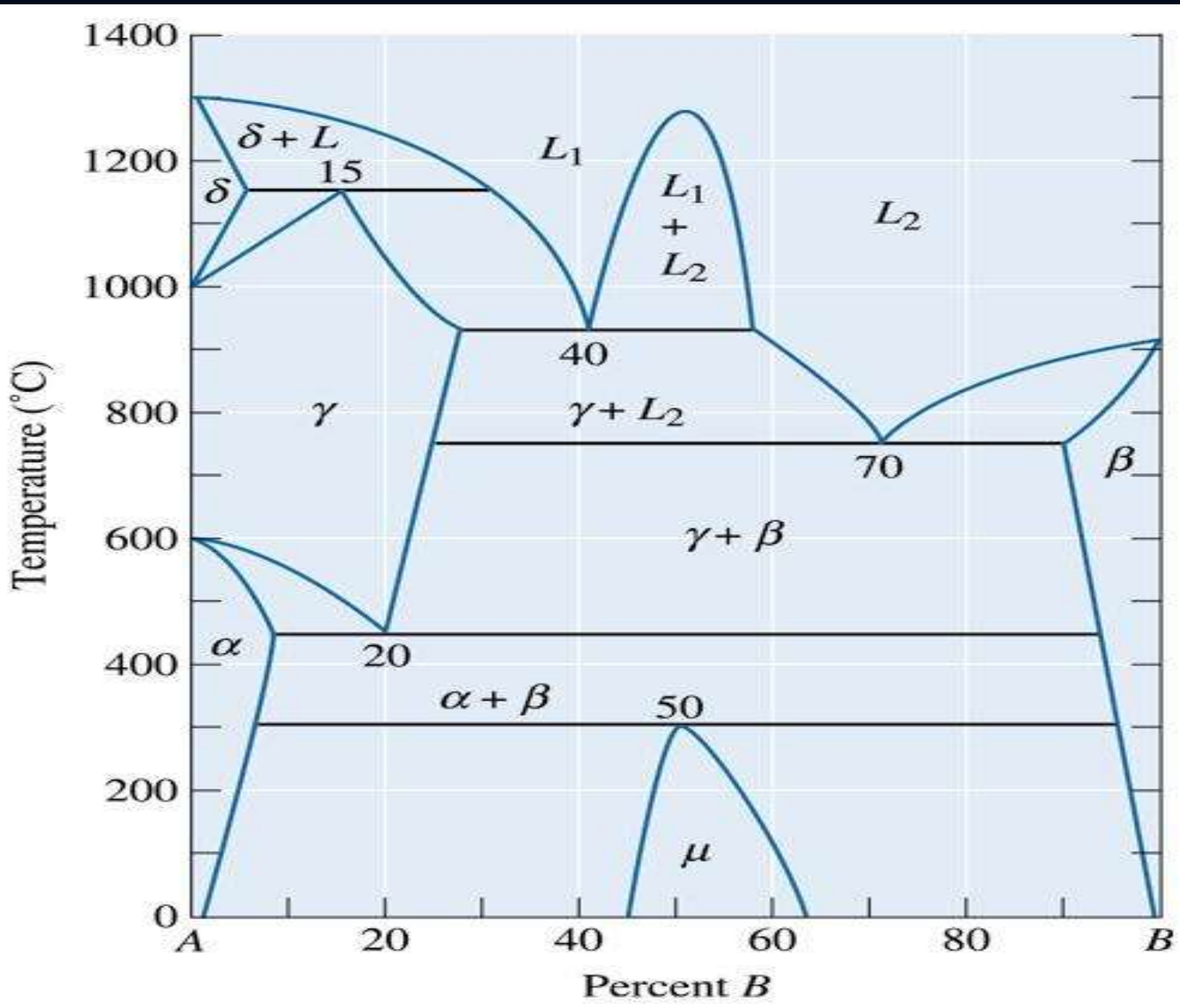


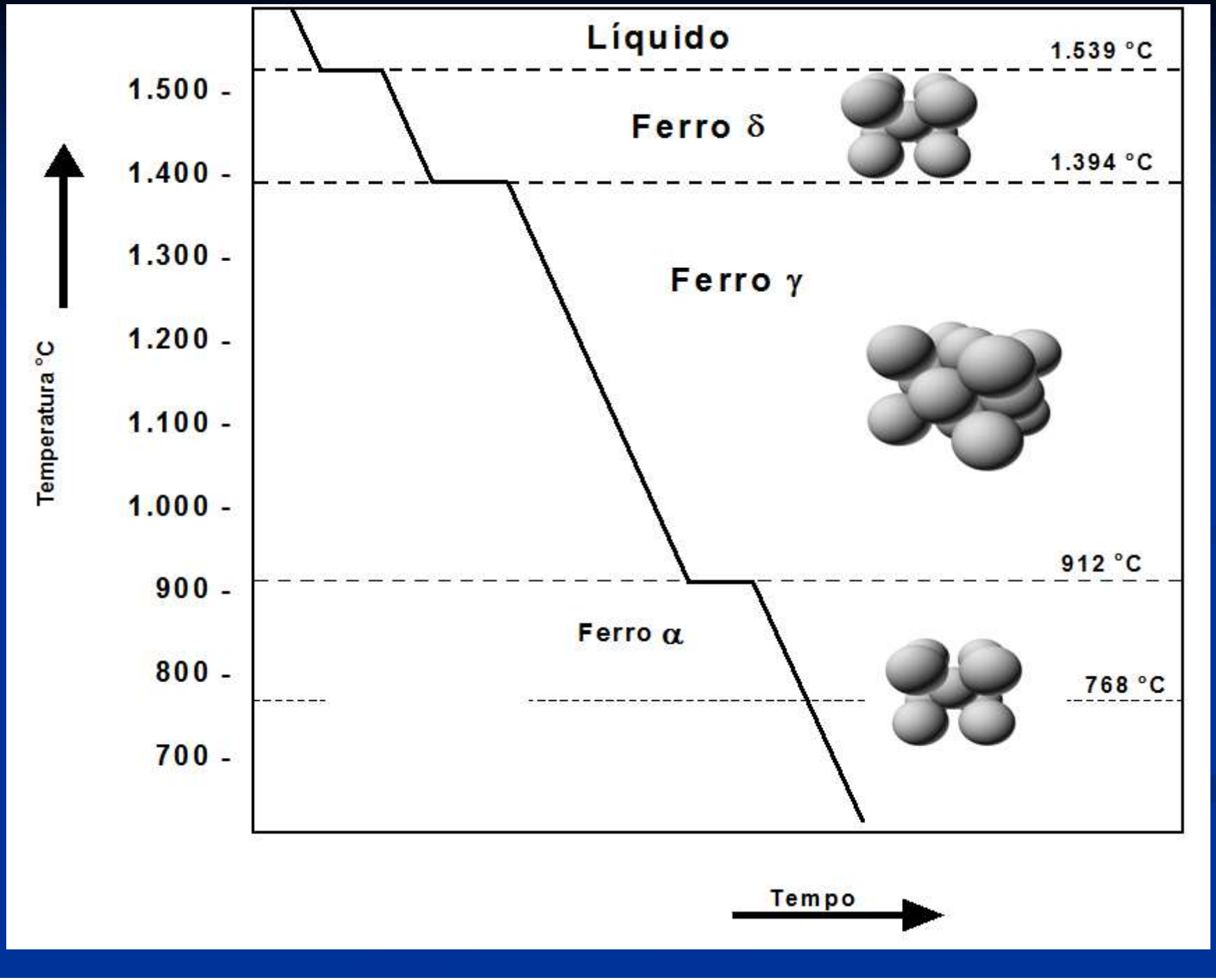
SOLVUS –

Uma curva de solubilidade que separa uma região de uma única fase para uma região de duas fases .

REAÇÕES ENVOLVENDO 3 FASES

EUTÉTICO	$L \rightarrow \alpha + \beta$	
PERITÉTICO	$\alpha + L \rightarrow \beta$	
MONOTÉTICO	$L_1 \rightarrow L_2 + \alpha$	
EUTETÓIDE	$\gamma \rightarrow \alpha + \beta$	
PERITETÓIDE	$\alpha + \beta \rightarrow \gamma$	



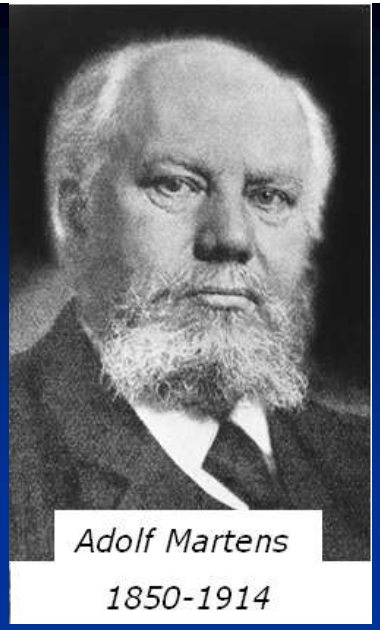

Líquido
1.539 °C
Ferro δ
1.394 °C
Ferro γ
912 °C
Ferro α
768 °C
1.500 -
1.400 -
1.300 -
1.200 -
1.100 -
1.000 -
900 -
800 -
700 -
Temperatura °C
Tempo

LIGAS FERRO-CARBONO

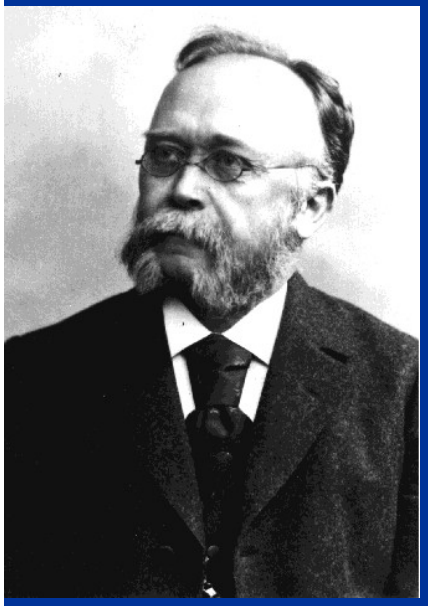
- De todos os sistemas de ligas binárias, o que é possivelmente o mais importante é aquele formado pelo ferro e o carbono. Tanto os aços como os ferros fundidos, que são os principais materiais estruturais em toda e qualquer cultura tecnologicamente avançada, são essencialmente ligas ferro-carbono.

- As ligas com até 2,0% de carbono são chamadas aços e acima deste teor, ferros fundidos.

Edgar Bain 1891-1971



Sir William Chandler Roberts-Austen (1843-1902).

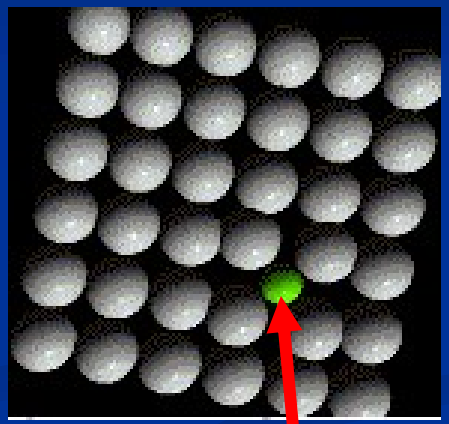


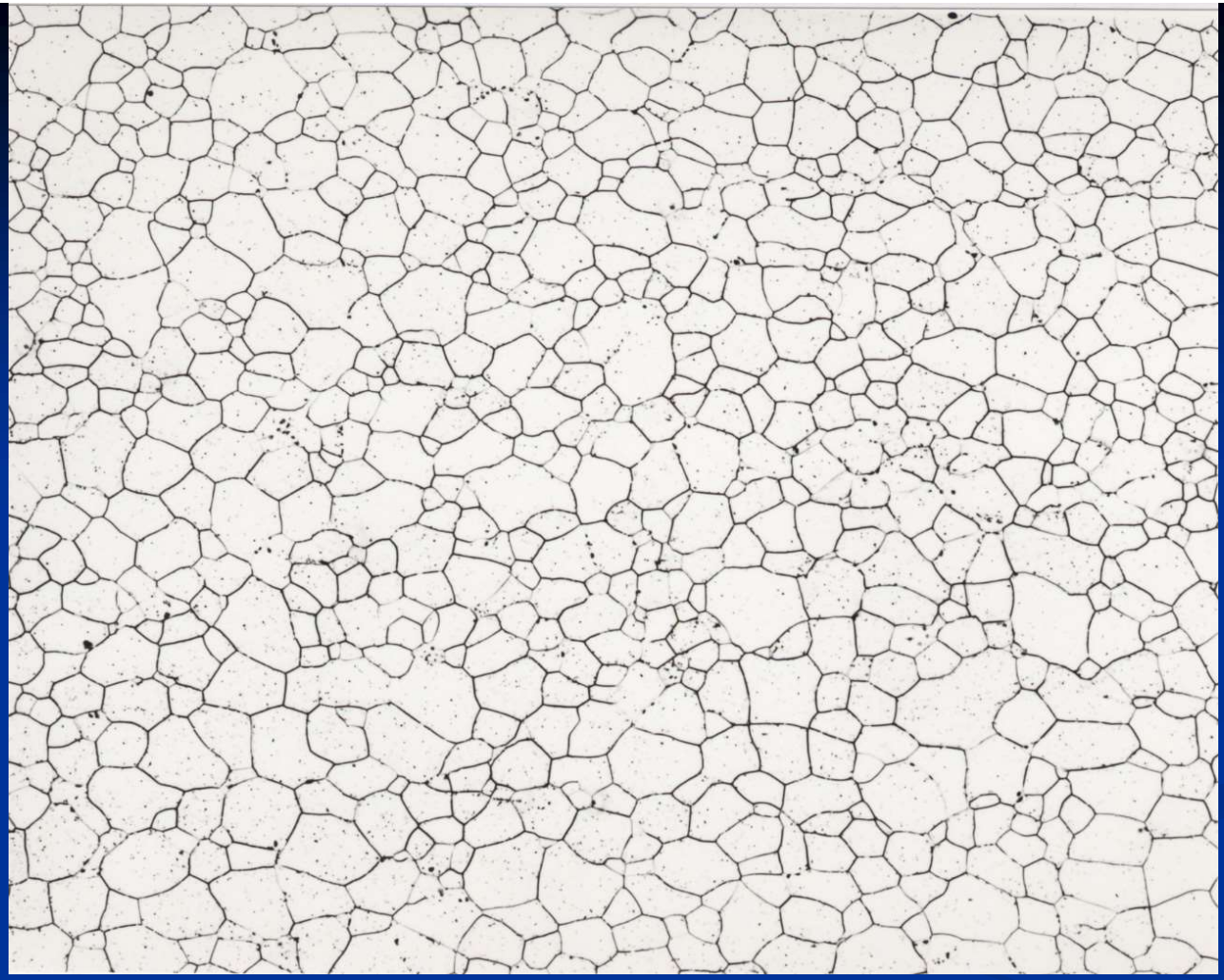
Adolf Ledebur (**1837-1916**).

- Durante o processo de solidificação dos aços, é possível verificar no aço o aparecimento de microconstituintes como ferrita, cementita, perlita e austenita.

FERRO PURO

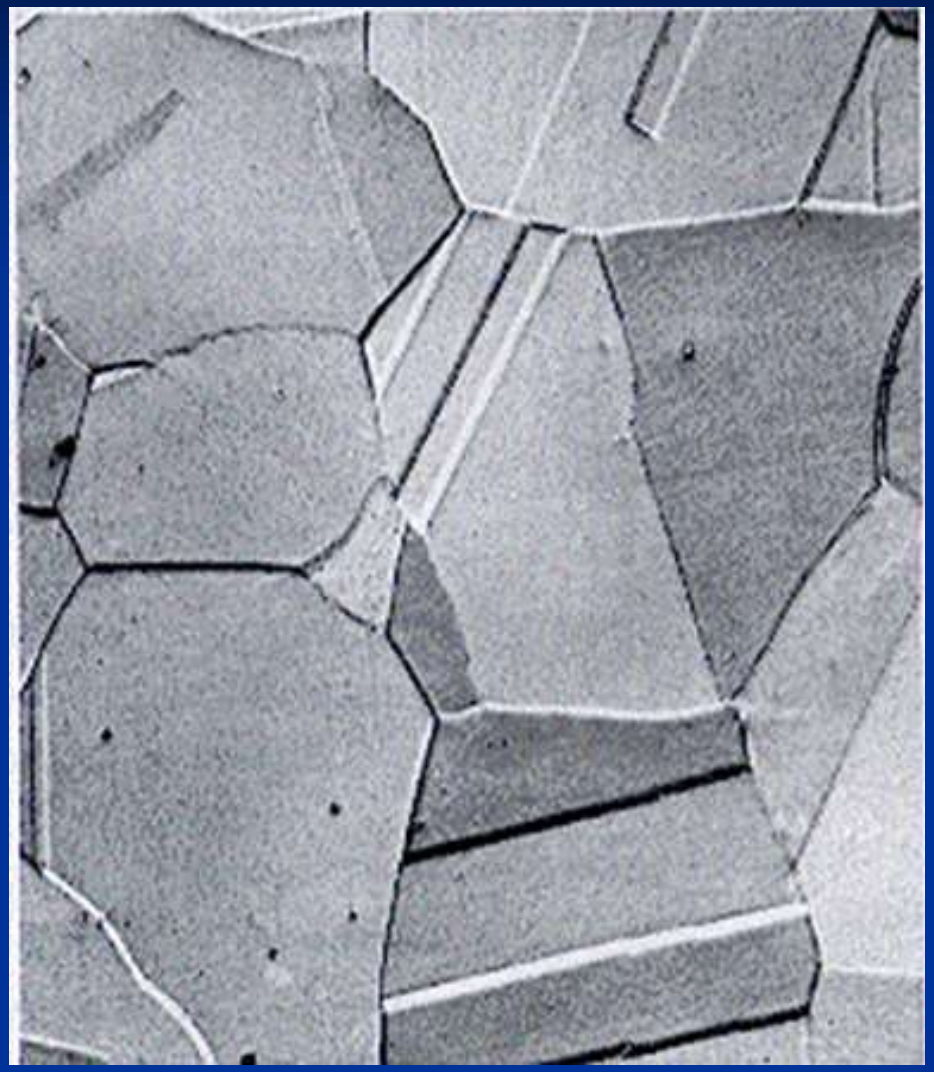
- FERRO α = FERRITA
- FERRO γ = AUSTENITA
- FERRO δ = FERRITA δ
- TF= 1534 °C
- As fases α, γ e δ FORMAM soluções sólidas com Carbono intersticial



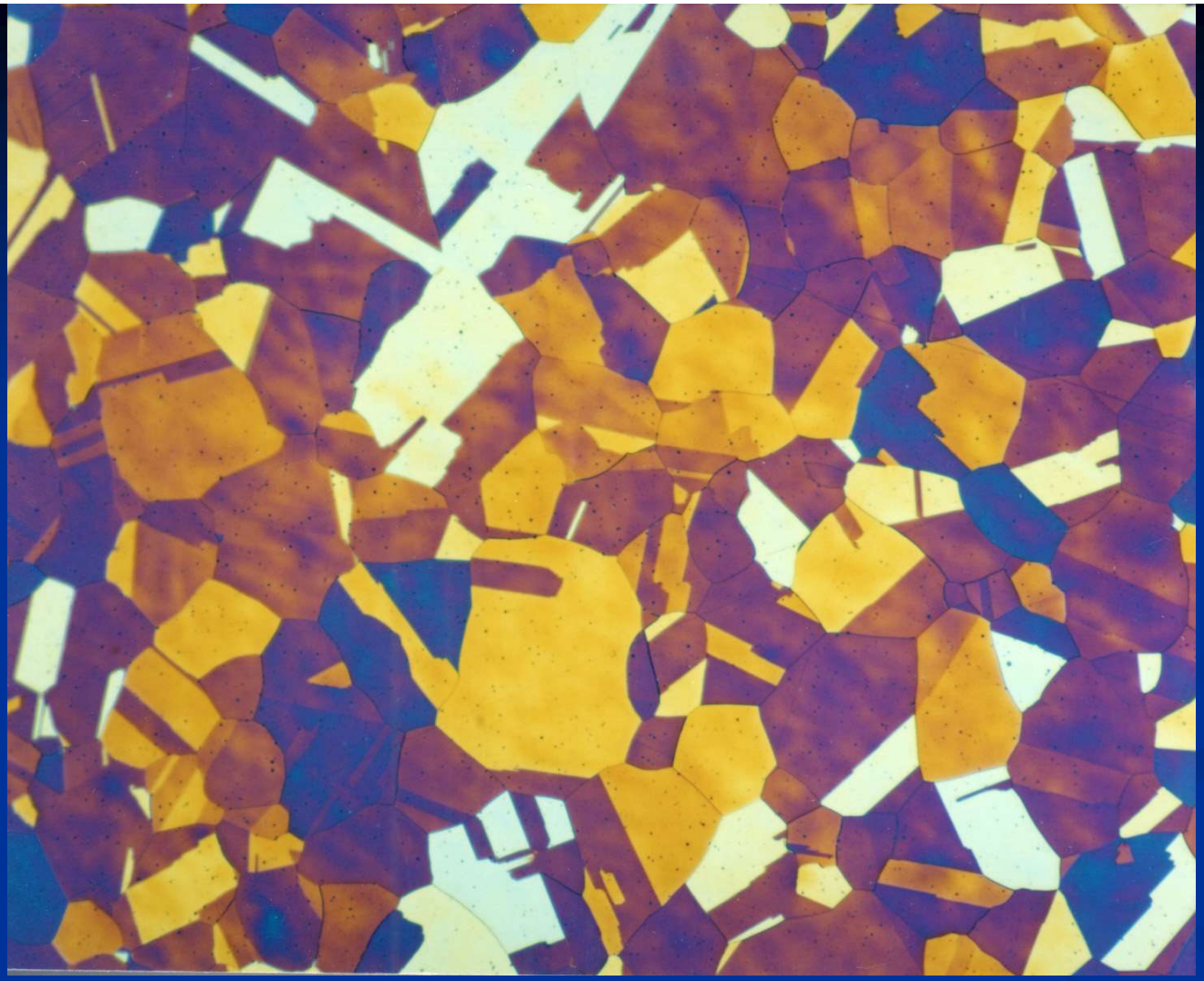


Ferrite grain boundaries in an interstitial-free sheet steel. Etched with Marshall's Reagent + HF. Original at 200X.

Ferrite grains (in the interior of the lamination sheet steel) revealed using Klemm's I tint etch. Original magnification was 100X. Viewed with polarized light plus sensitive tint.



AUSTENITA



Austenite grains, with annealing twins, in type 316 stainless steel (Fe - <0.08% C - <2% Mn - <1% Si – 17% Cr – 12% Ni – 2.5% Mo) color etched with Beraha's reagent.

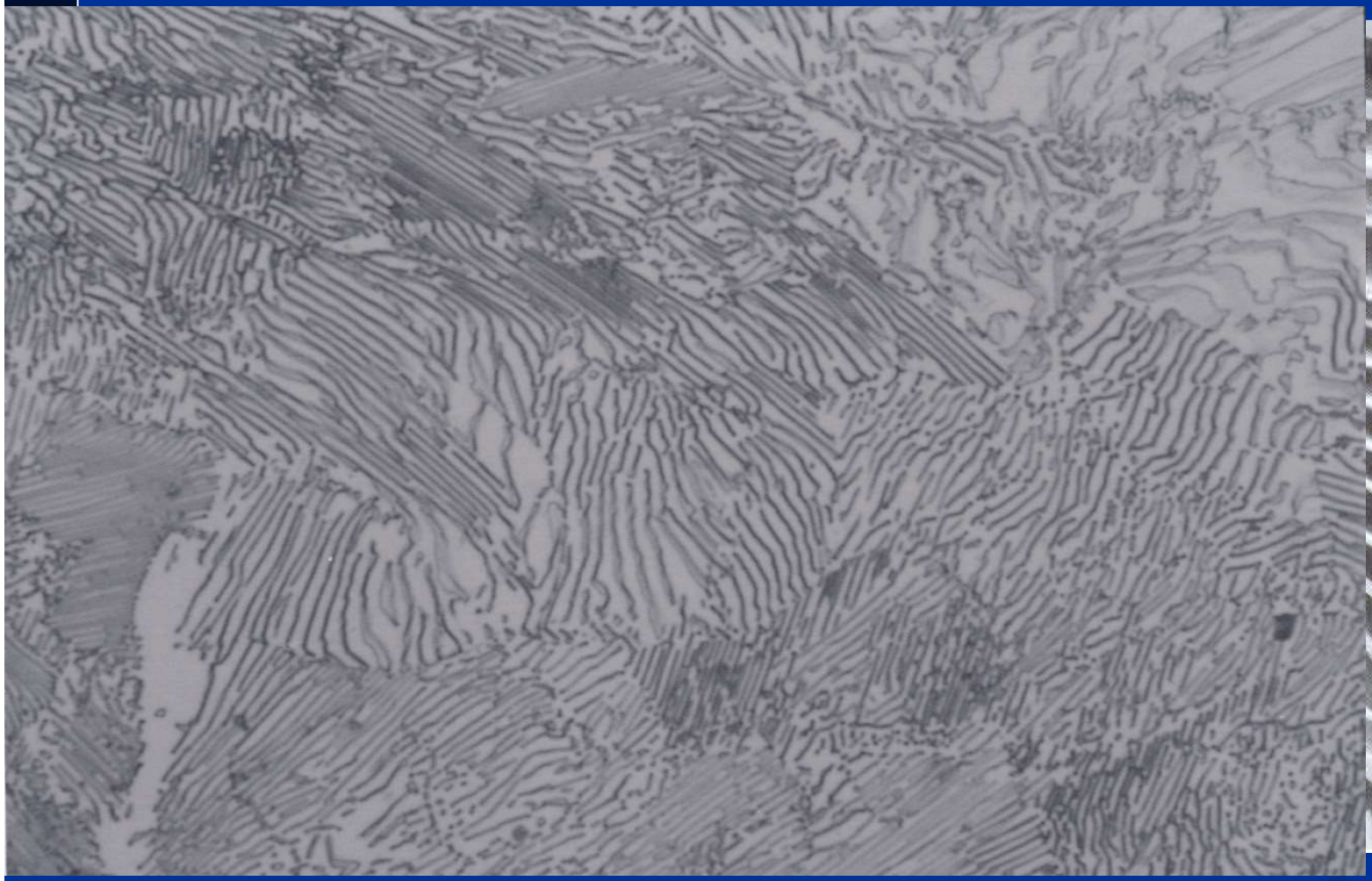
CEMENTITA

- Forma-se quando o limite de solubilidade do carbono é ultrapassado (6,7% de C)
- É dura e frágil
- Cristaliza no sistema ortorrômbico (com 12 átomos de Fe e 4 de C por célula unitária)
- Fe_3C

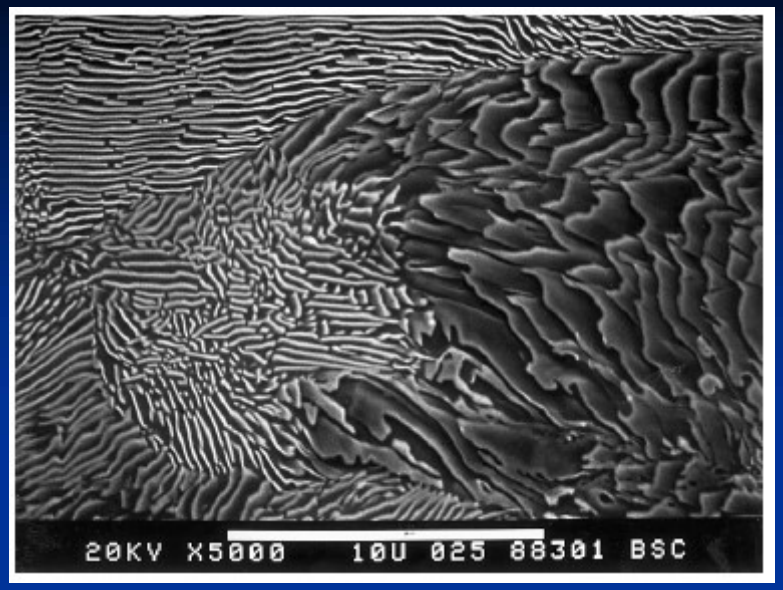
PERLITA

- Essa microestrutura formada nos aços eutetóides abaixo da temperatura do eutetóide composta por camadas alternadas de lamelas de ferrita e cementita é conhecida por perlita, pois quando vista ao microscópio possui uma aparência que lembra madrepérola

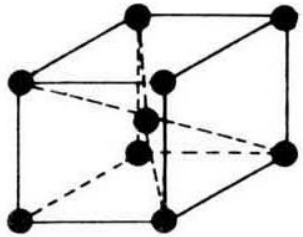
PERLITA



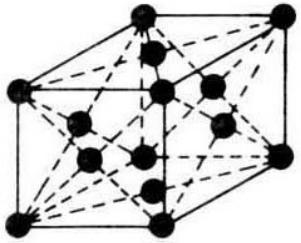
Coarse pearlitic structure in isothermally annealed (780 °C, 1436 °F – 1 h, isothermally transformed) 1080 steel (Fe – 0.8% C – 0.75% Mn) etched with 4% picral. All of the lamellae are resolvable. Original at 1000X.


20KV X5000 10U 025 88301 BSC

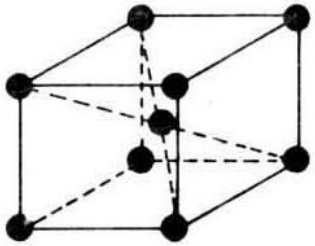
1) - Redes Atômicas



(Fe – δ)
a = 2,93 A° C.C.C.



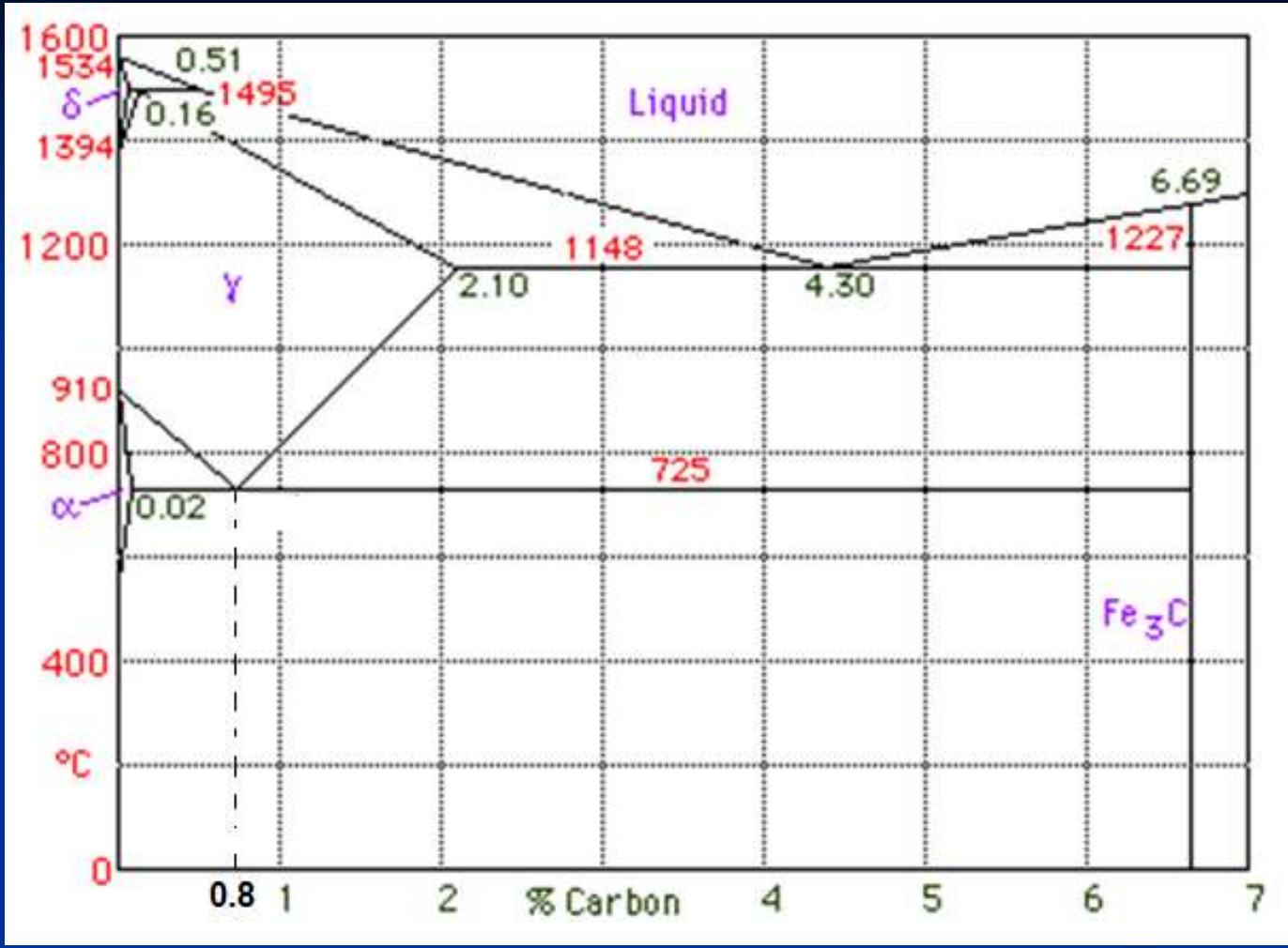
(Fe – γ)
a = 3,64 A° C. F. C.



(Fe – α)
a = 2,88 A° C.C.C.

Propriedades Mecânicas

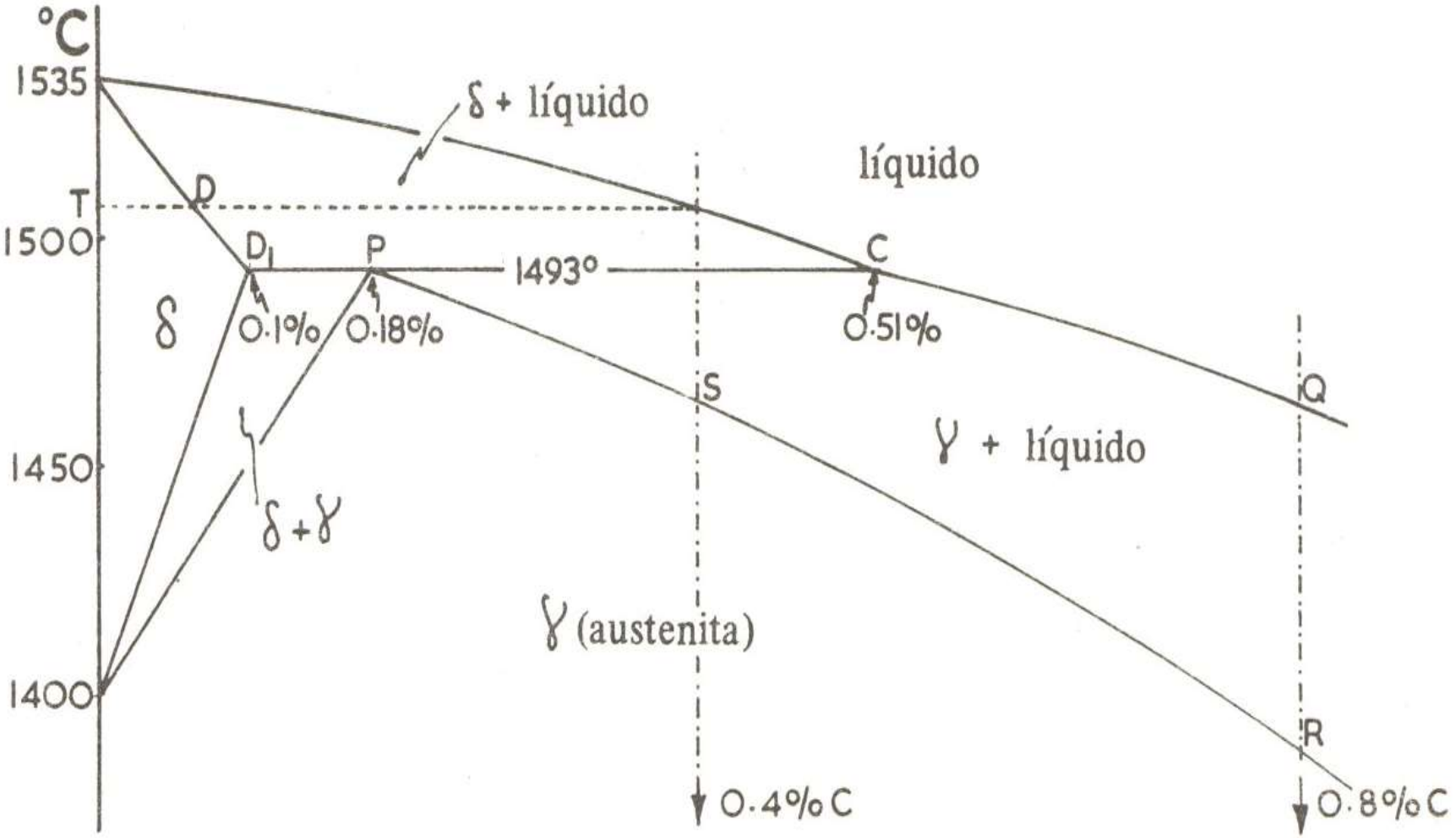
	DUREZA (HB)	R. TRAÇÃO	ALONGAM.
FERRITA	80	30 kgf/mm²	40%
PERLITA	200	85 " "	10%
CEMENTITA	800	100 " "	0%

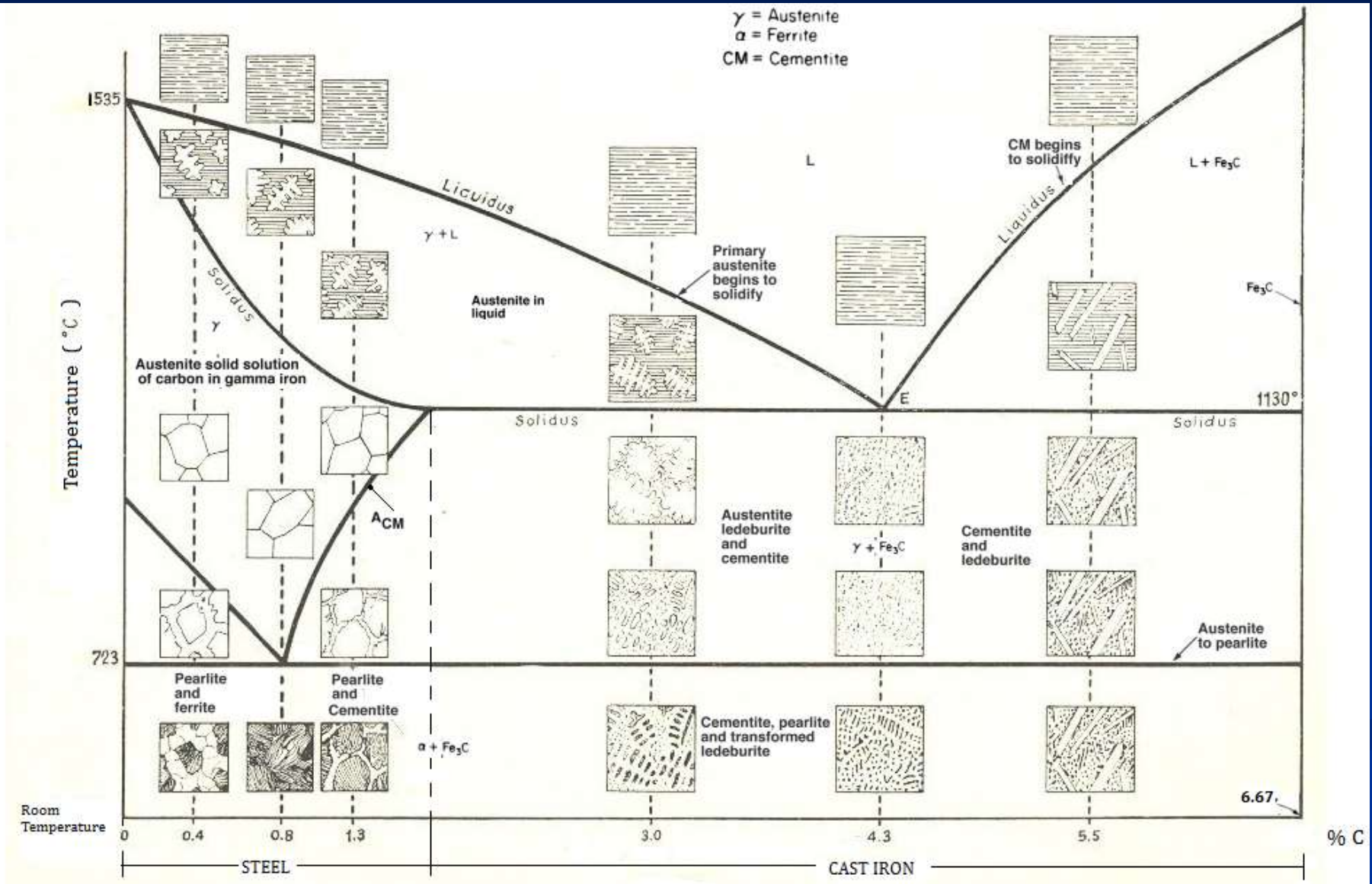


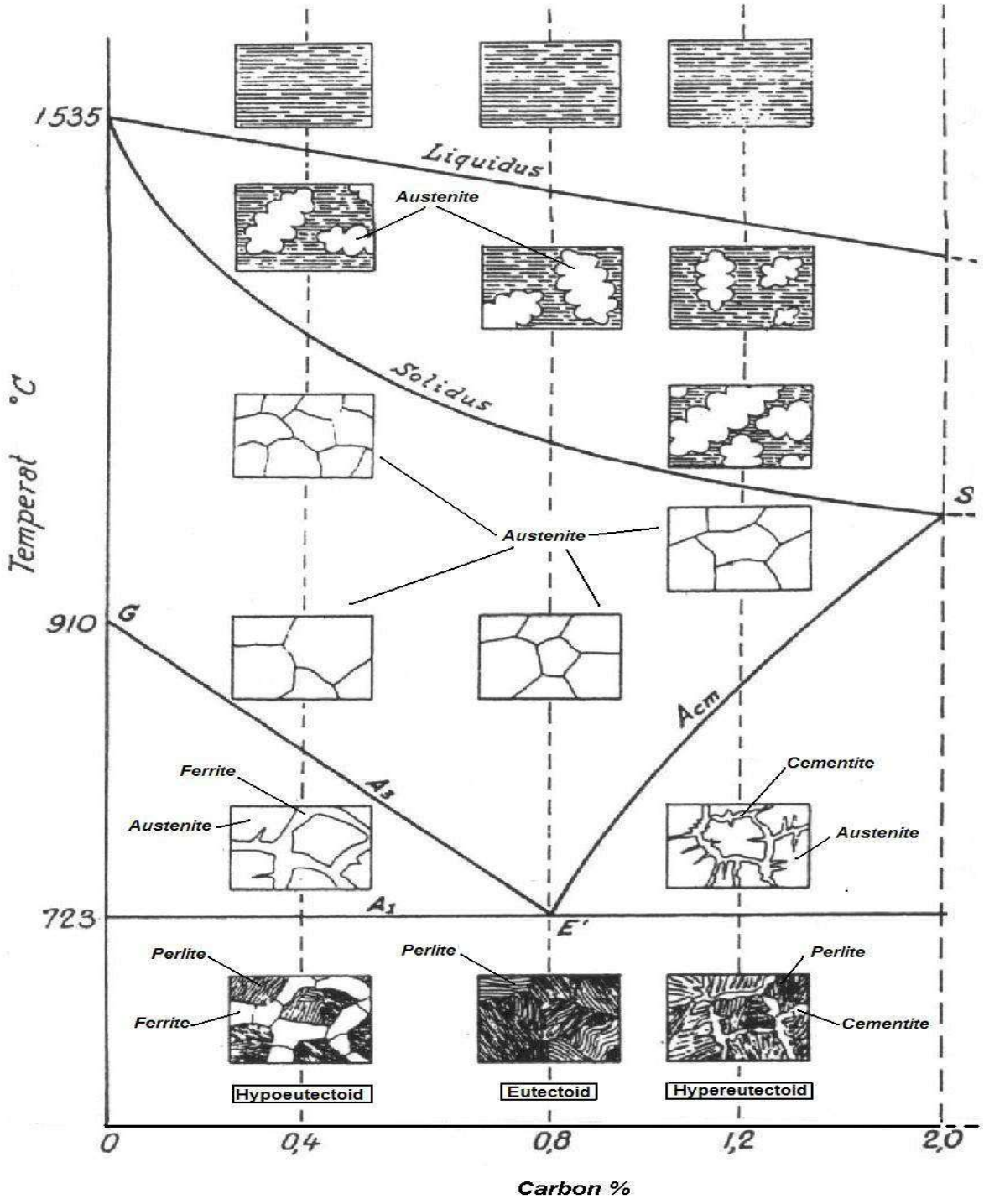
AÇO

FERRO FUNDIDO


EXTRA
OFERTA
MESA
DE FERRO
FUDIDO
5
X
31,80
À VISTA
150,00
TOTAL A PRAZO
CARTÃO EXTRA
5 JUROS

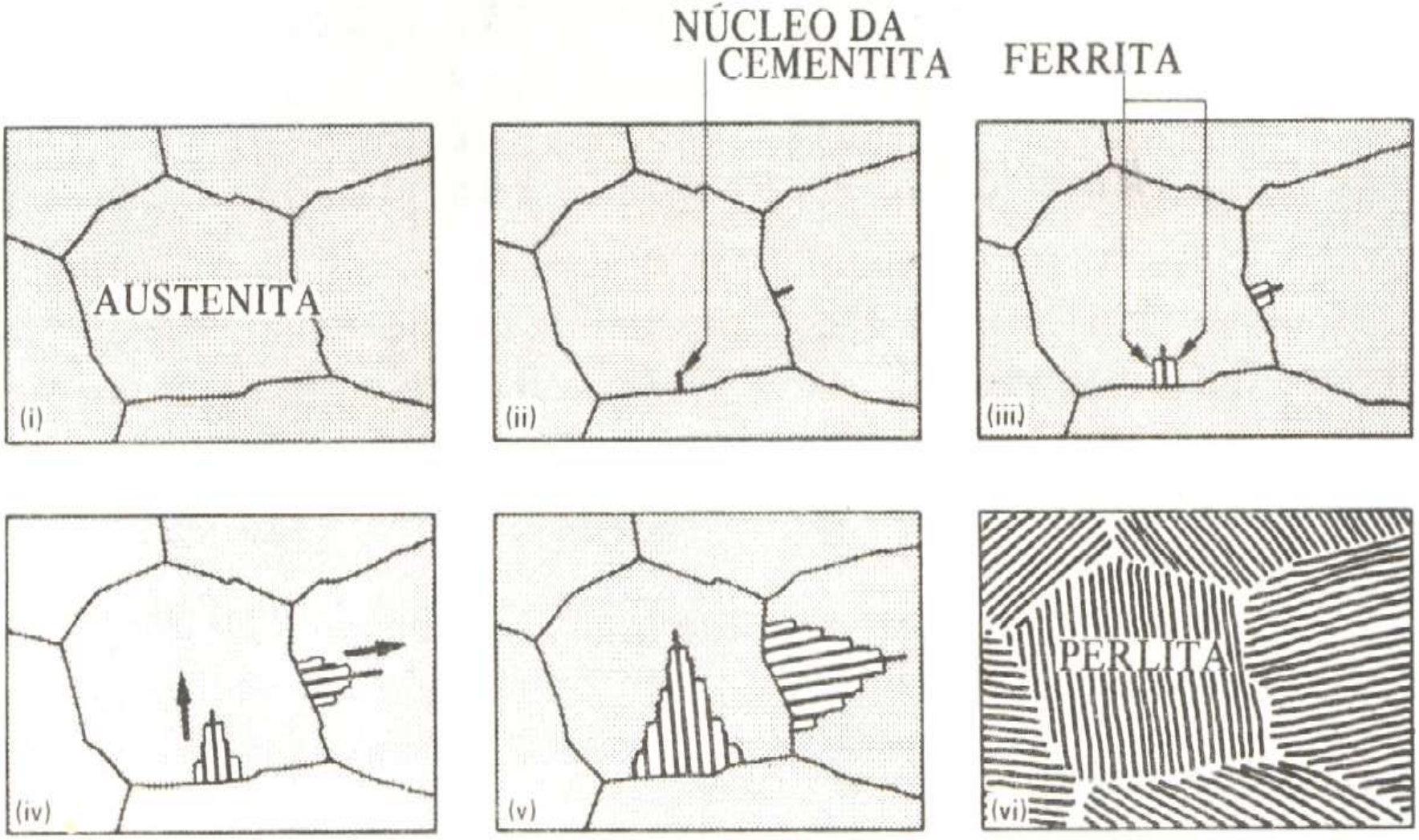

°C
1535
T
1500
1450
1400
δ + líquido
líquido
D
D1
P
1493°
C
δ
0.1%
0.18%
0.51%
S
Q
γ + líquido
δ + γ
γ (austenita)
R
0.4% C
0.8% C

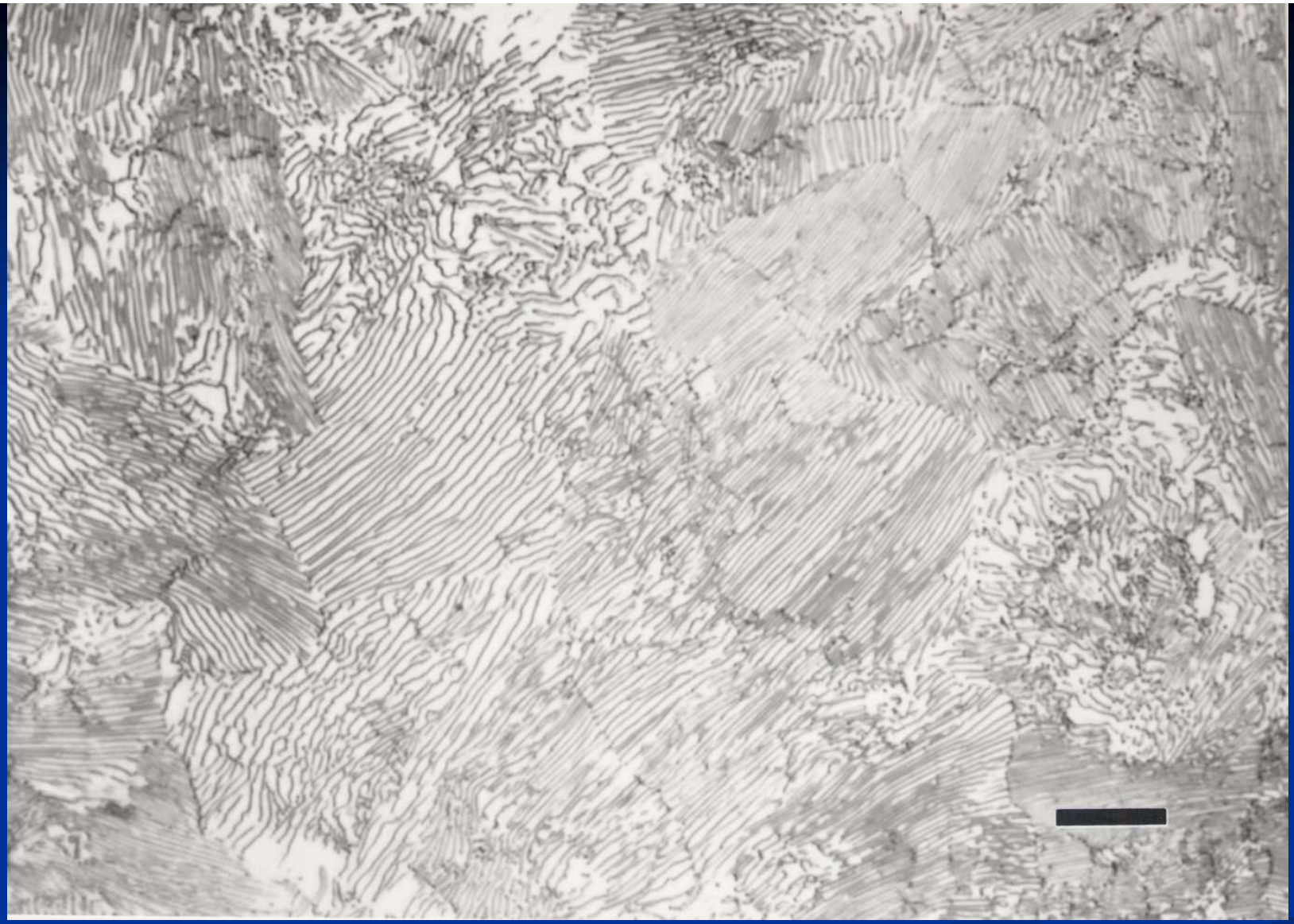

γ = Austenite
α = Ferrite
CM = Cementite
1535
Liquidus
γ + L
L
CM begins to solidify
Liquidus
L + Fe3C
Solidus
γ
Primary austenite begins to solidify
Austenite in liquid
Fe3C
Austenite solid solution of carbon in gamma iron
E
1130°
Solidus
Solidus
Temperature (°C)
ACM
Austentite ledeburite and cementite
γ + Fe3C
Cementite and ledeburite
Austenite to pearlite
723
Pearlite and ferrite
Pearlite and Cementite
α + Fe3C
Cementite, pearlite and transformed ledeburite
6.67
Room Temperature
0
0.4
0.8
1.3
3.0
4.3
5.5
% C
STEEL
CAST IRON



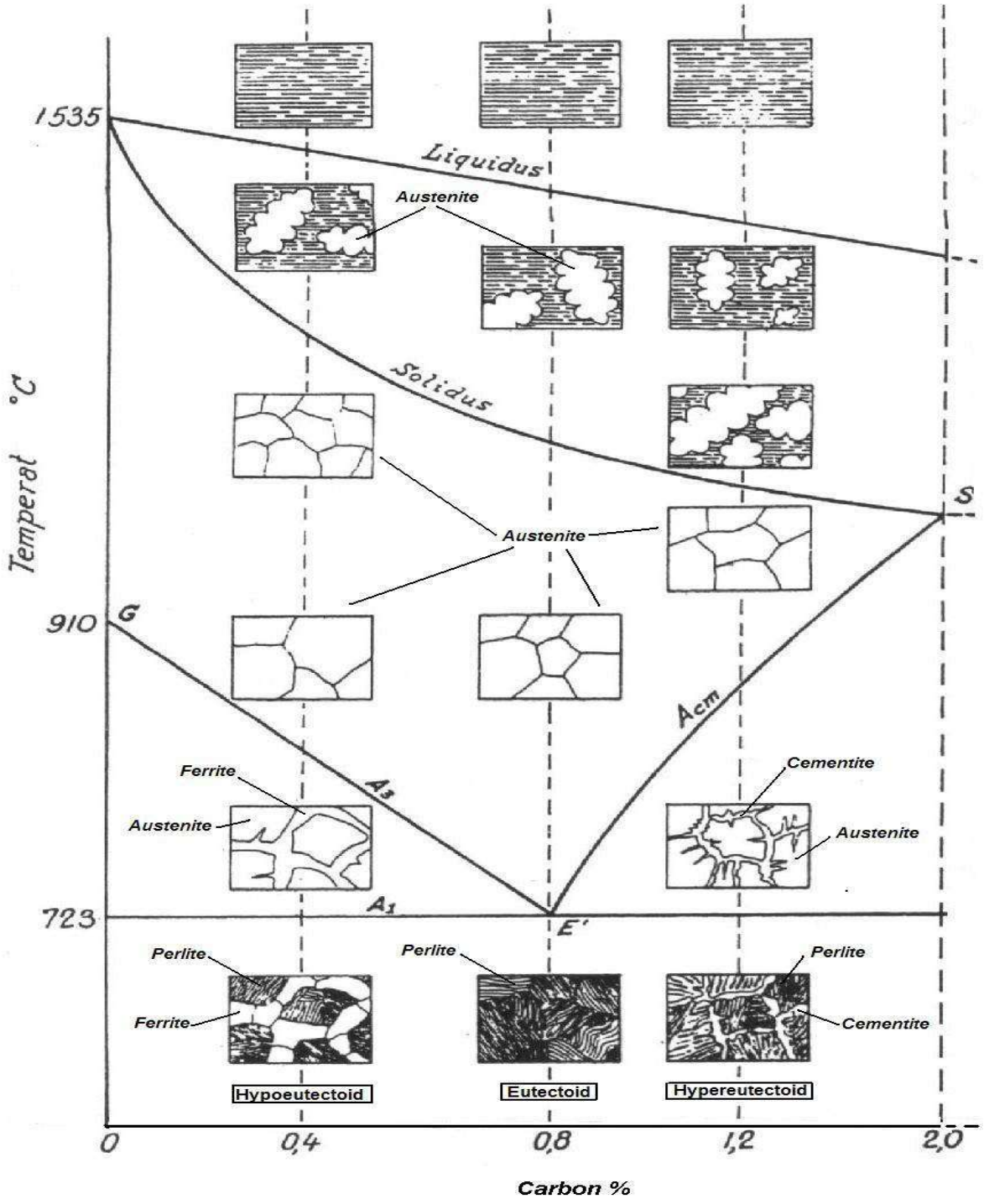
A1:
Temperatura de equilíbrio de início de austenitização

A3: Temperatura de equilíbrio de fim de austenitização


NÚCLEO DA CEMENTITA
FERRITA
AUSTENITA
(i)
(ii)
(iii)
(iv)
(v)
PERLITA
(vi)



Coarse lamellar pearlite in a hot-rolled Fe – 0.8% C binary alloy. Picral etch. Magnification bar is 20 μm in length.



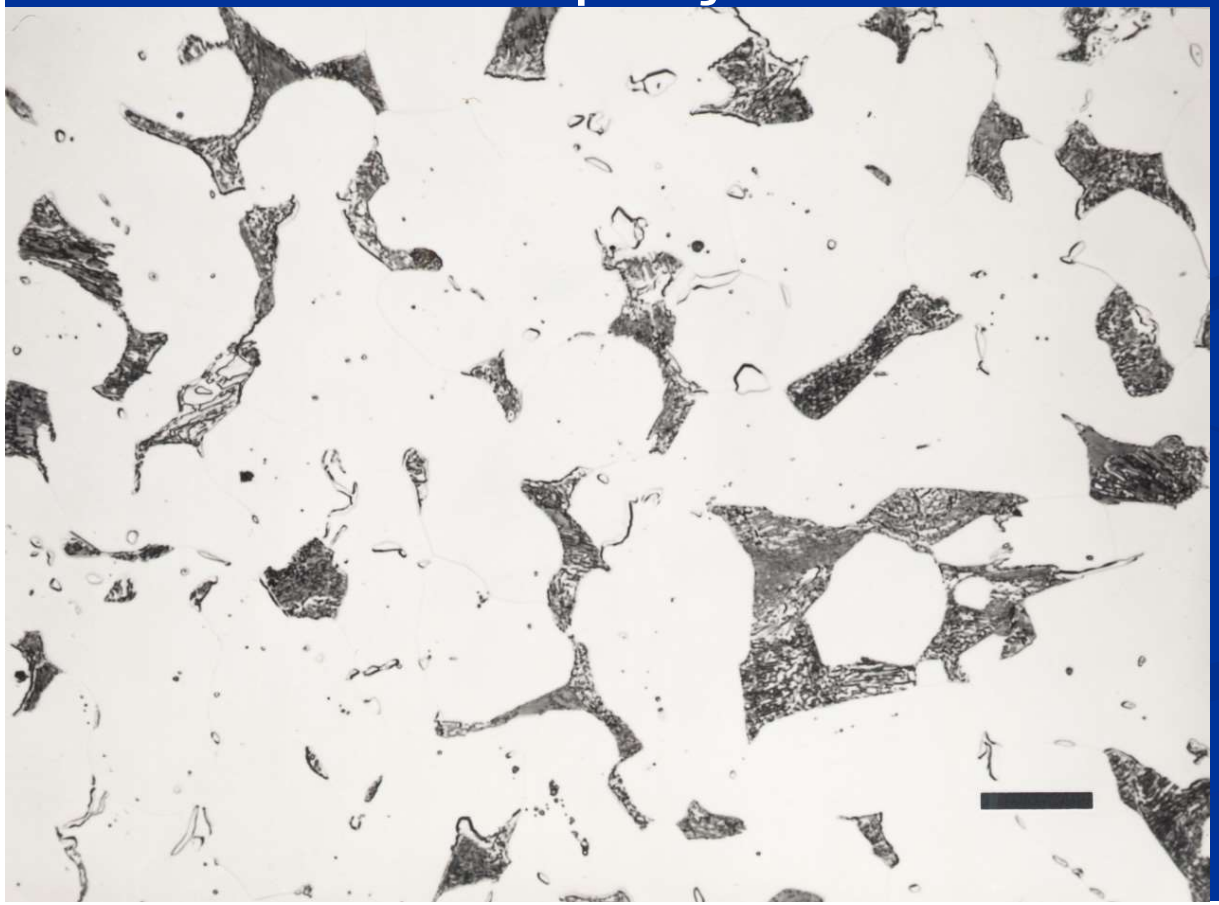
A1:
Temperatura de equilíbrio de início de austenitização

A3: Temperatura de equilíbrio de fim de austenitização

LIGAS HIPOEUTETÓIDES

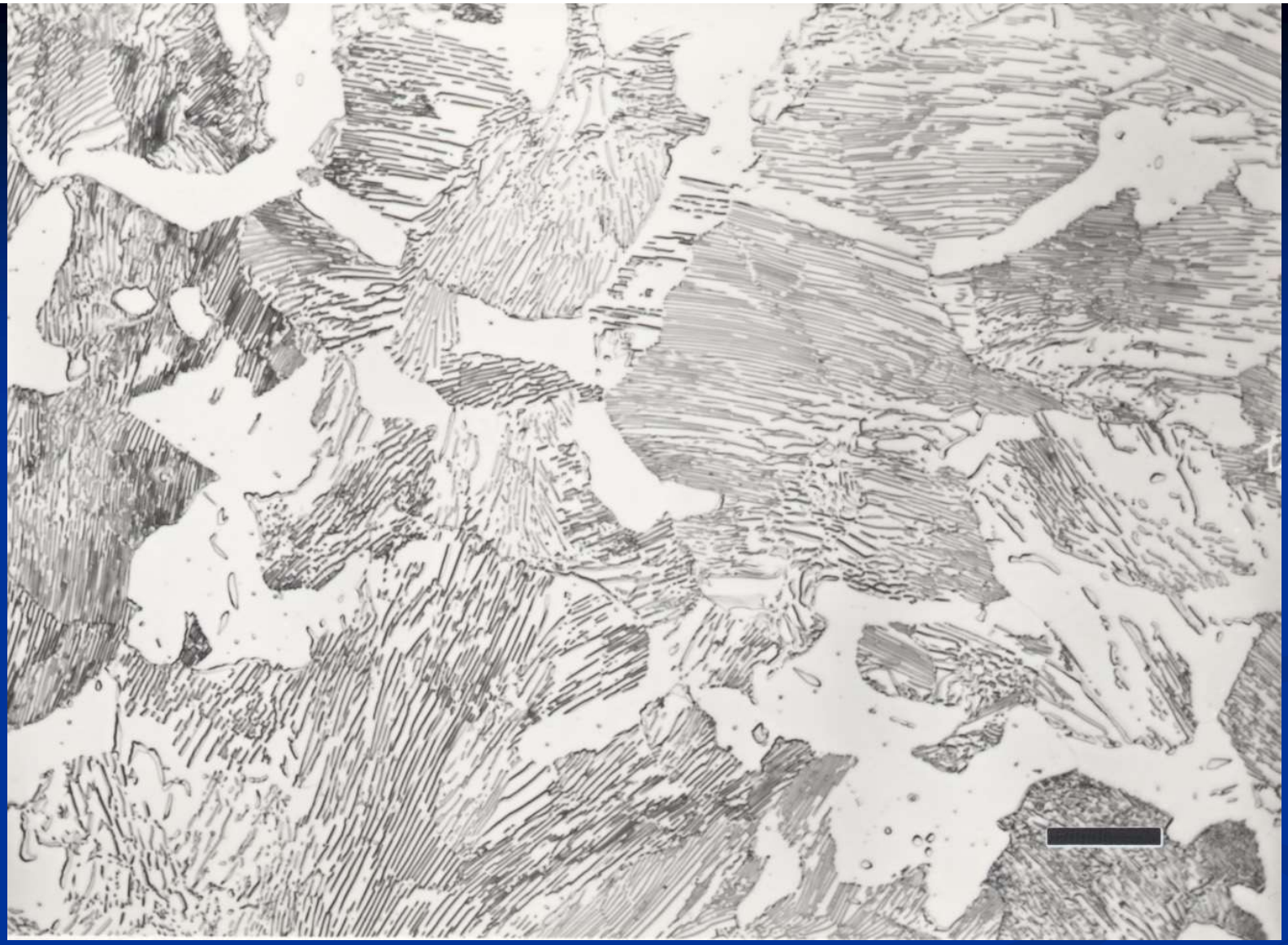
- A ferrita estará presente tanto na perlita como na fase que se formou enquanto se resfriava antes da temperatura do eutetóide. A ferrita que está presente na perlita é chamada ferrita eutetóide e a ferrita que se formou antes da temperatura do eutetóide é chamada ferrita proeutetóide.

•As regiões brancas correspondem à ferrita proeutetóide. Para a perlita, o espaçamento entre as camadas α e Fe_3C varia de grão para grão; uma parte da perlita parece escura, pois as muitas camadas com pequeno espaçamento não estão resolvidas e definidas na ampliação da fotomicrografia abaixo.

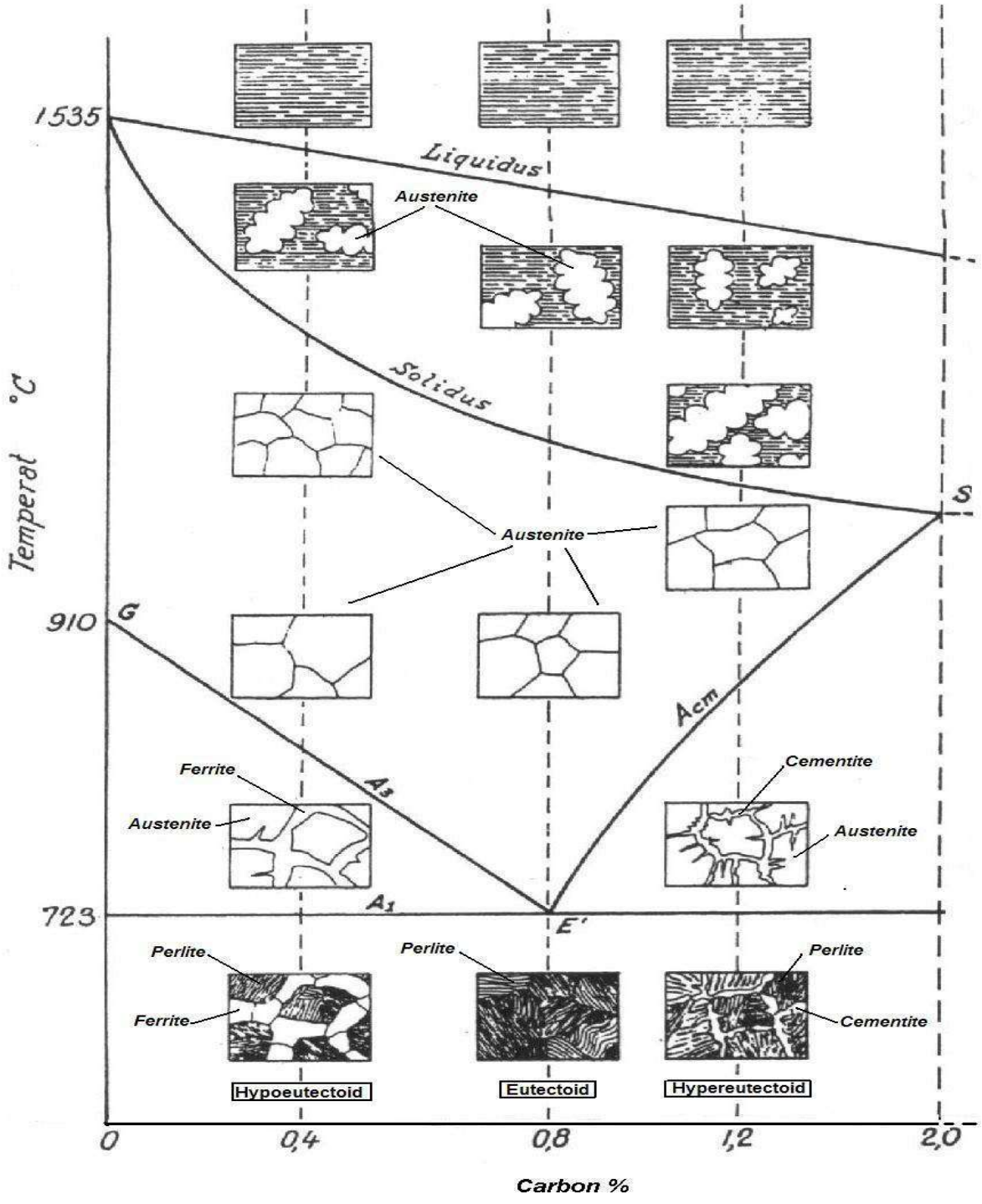


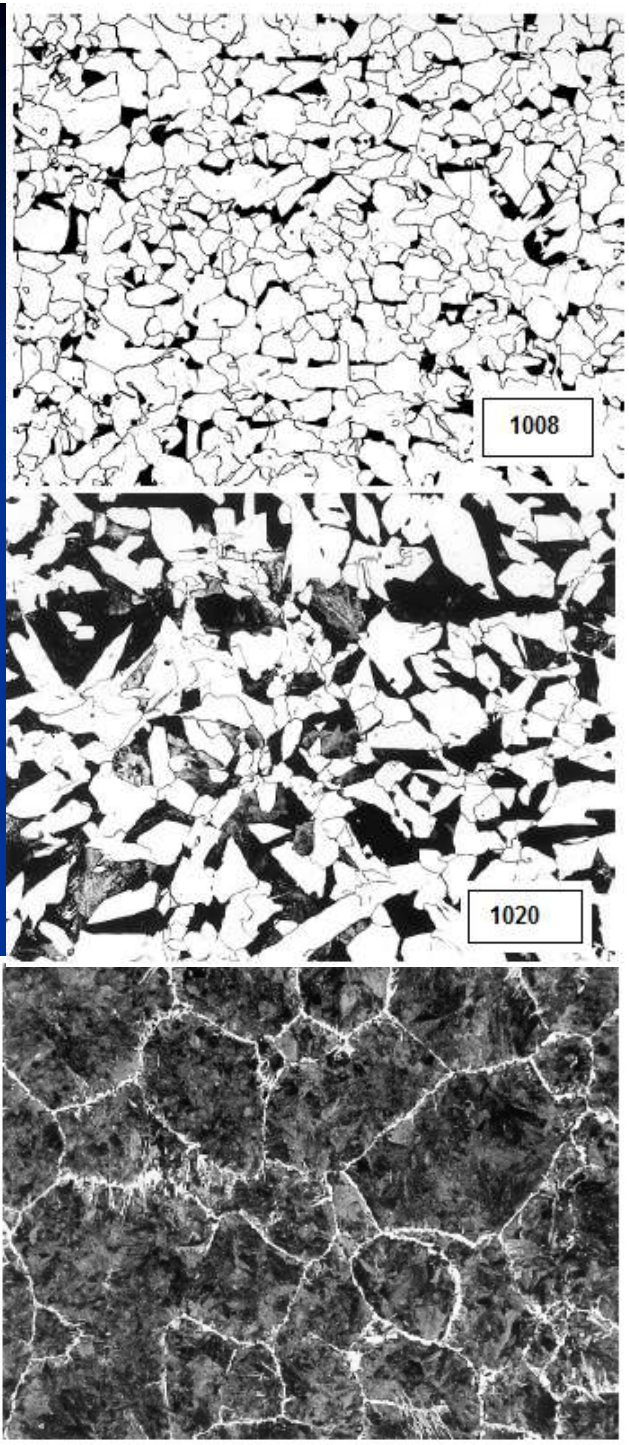
Ferrite (white) and pearlite in a hot-rolled Fe – 0.2% C binary alloy. Picral etch. Magnification bar is 20 μm in length.

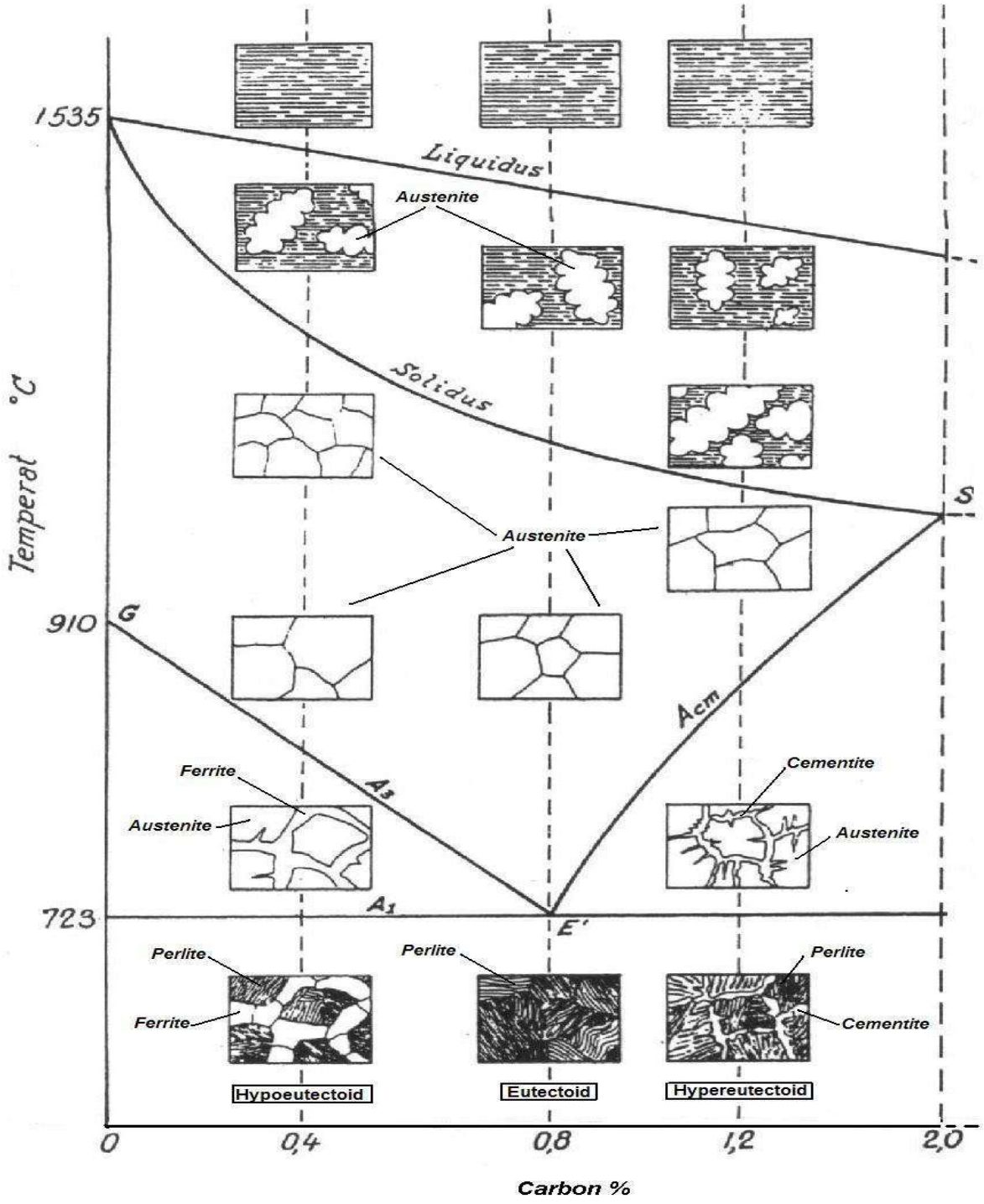
Ferrite (white) and pearlite in a hot-rolled Fe – 0.4% C binary alloy.
Picral etch. Magnification bar is 20 μm in length.



Ferrite (white) and pearlite in a hot-rolled Fe – 0.6% C binary alloy. Picral etch. Magnification bar is 20 μm in length.


1535
Liquidus
Austenite
Solidus
S
Temperat °C
Austenite
910
G
Acm
Ferrite
A3
Cementite
Austenite
Austenite
723
A1
E'
Perlite
Perlite
Perlite
Ferrite
Cementite
Hypoeutectoid
Eutectoid
Hypereutectoid
0
0,4
0,8
1,2
2,0
Carbon %


1008
1020



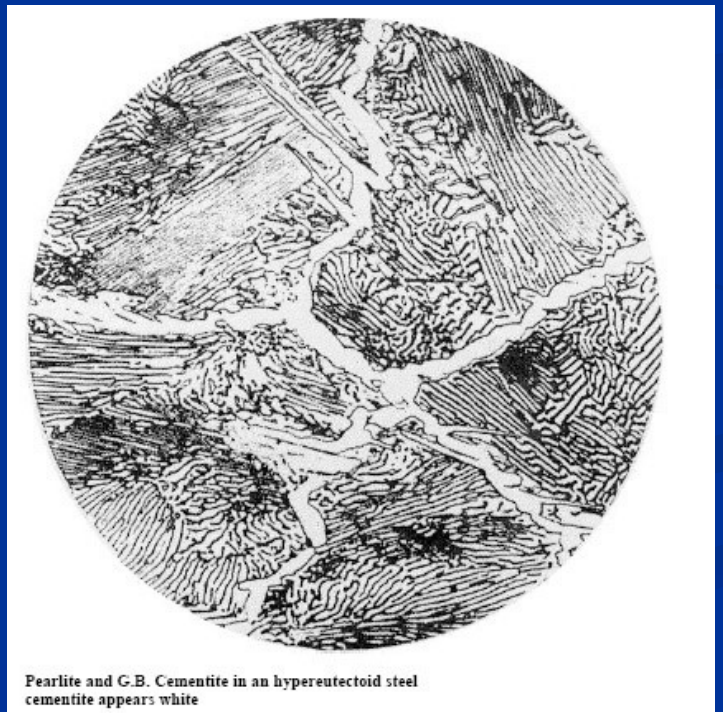
A1:
Temperatura de equilíbrio de início de austenitização

A3: Temperatura de equilíbrio de fim de austenitização

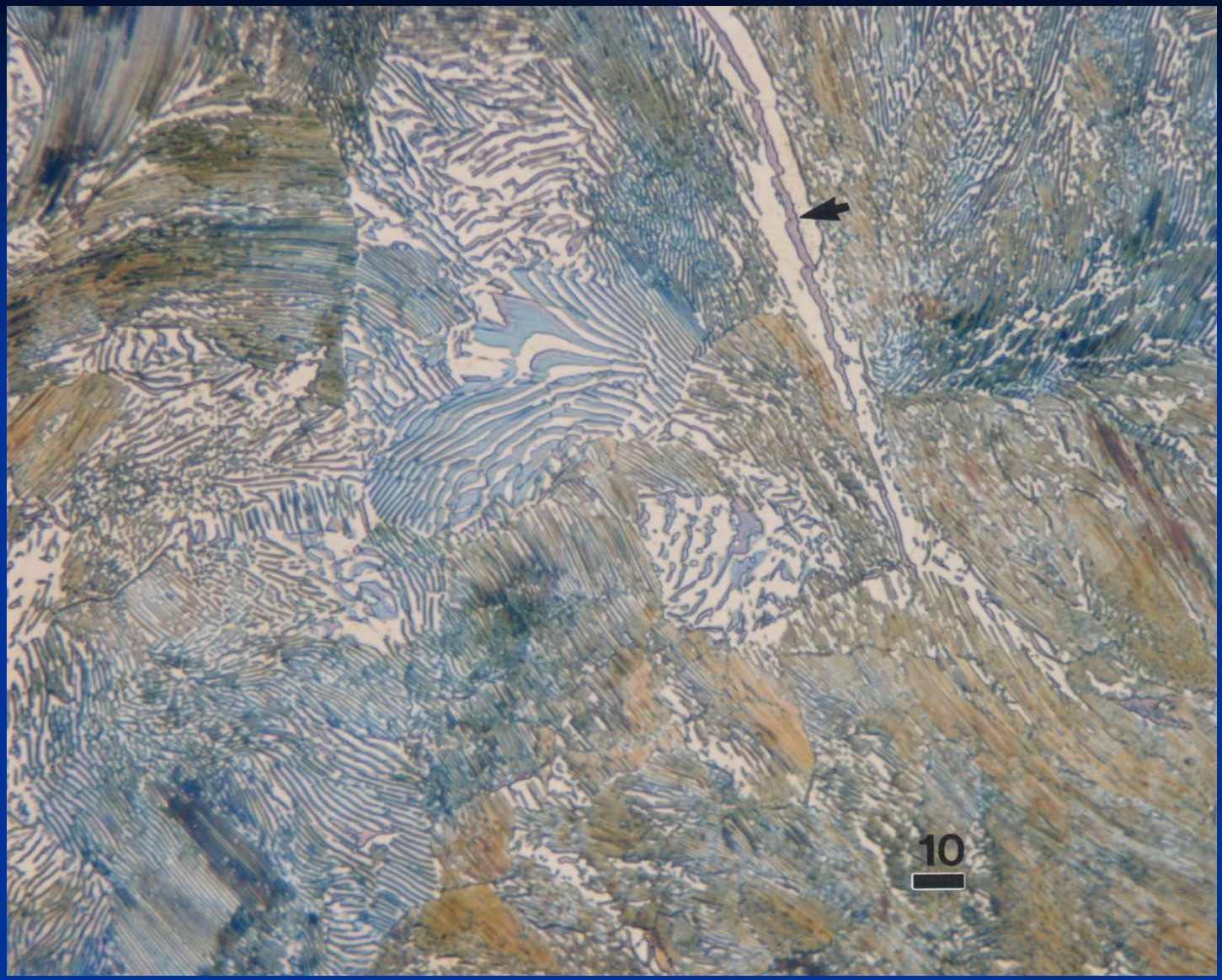
LIGAS HIPEREUTETÓIDES

- A cementita formada antes do eutetóide é chamada cementita proeutetóide e a microestrutura das ligas hipereutetóides resultam em perlita + cementita proeutetóide

- Na fotomicrografia de um aço hipereutetóide a cementita proeutetóide aparece clara e nos contornos de grãos.

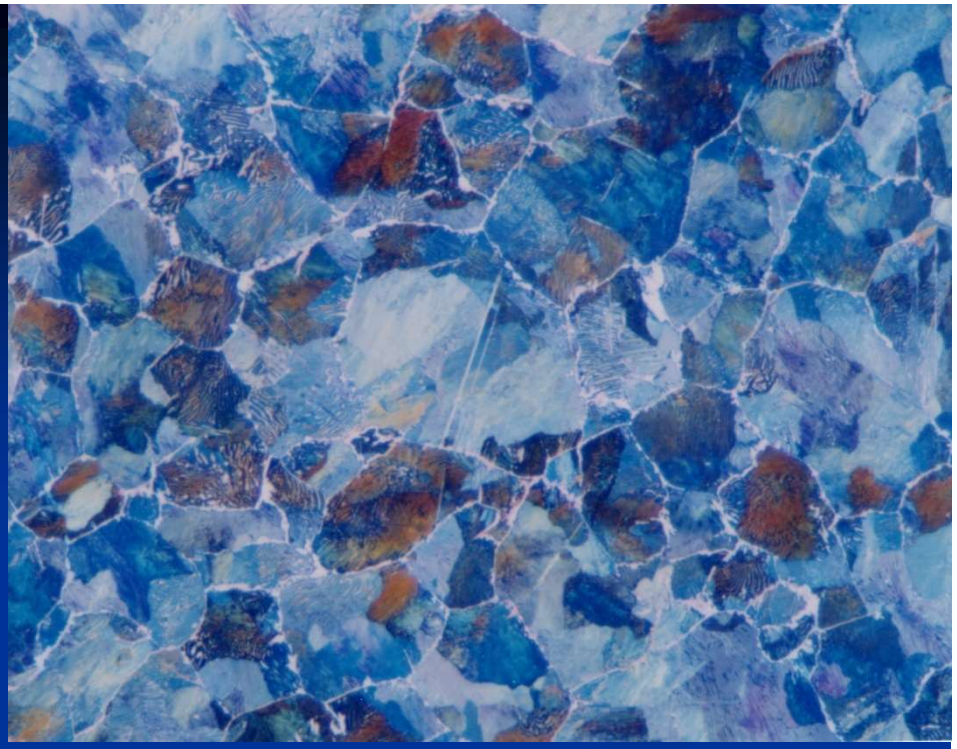


Pearlite and G.B. Cementite in an hypereutectoid steel cementite appears white



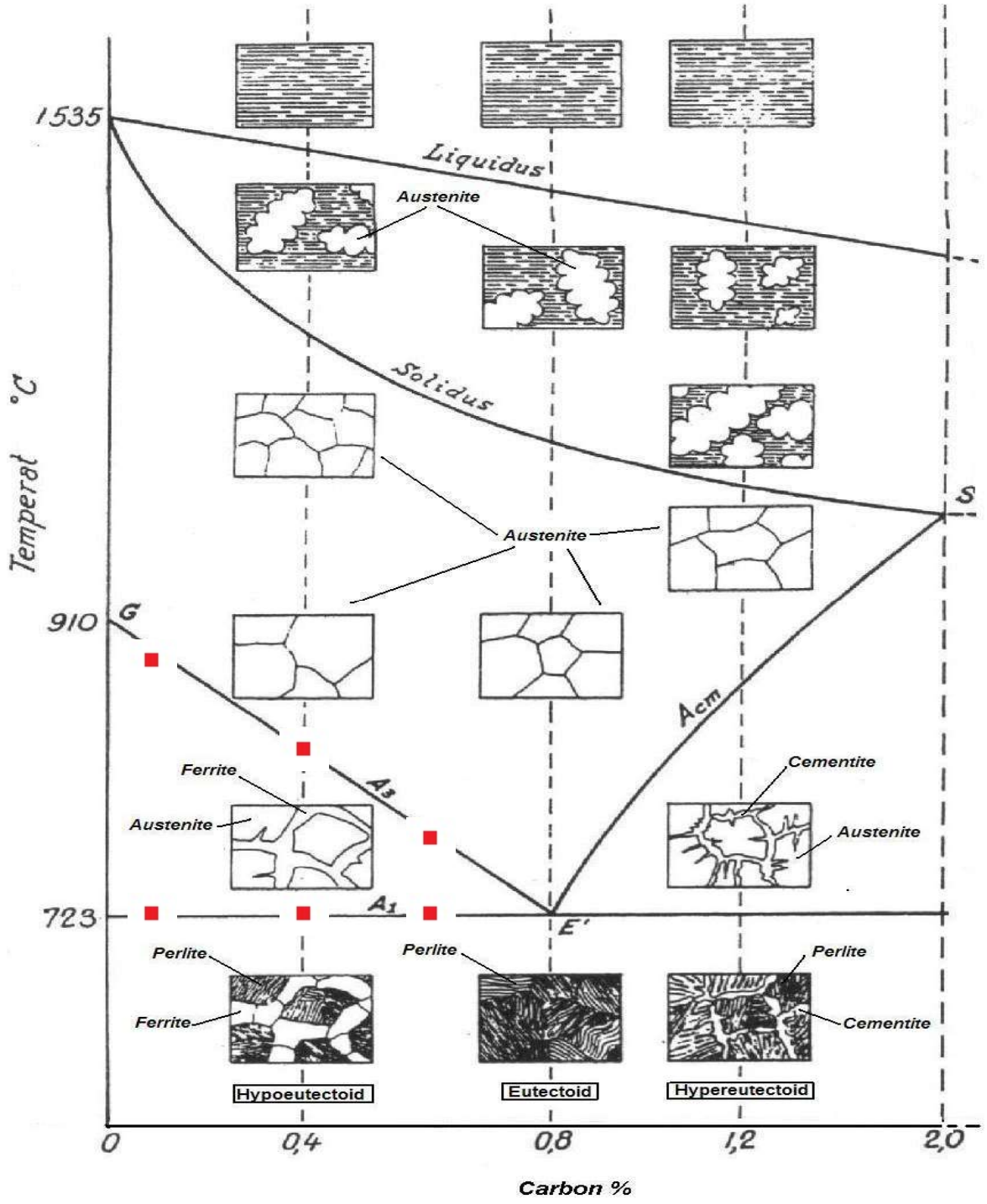
Microstructure of as-rolled Fe – 1% C binary alloy tint etched with Beraha's sodium molybdate reagent to color cementite. The arrow points of proeutectoid cementite that precipitated on a prior-austenite grain boundary before the eutectoid reaction (austenite forms ferrite and cementite in the form of lamellar pearlite). Magnification bar is 10 μm long.

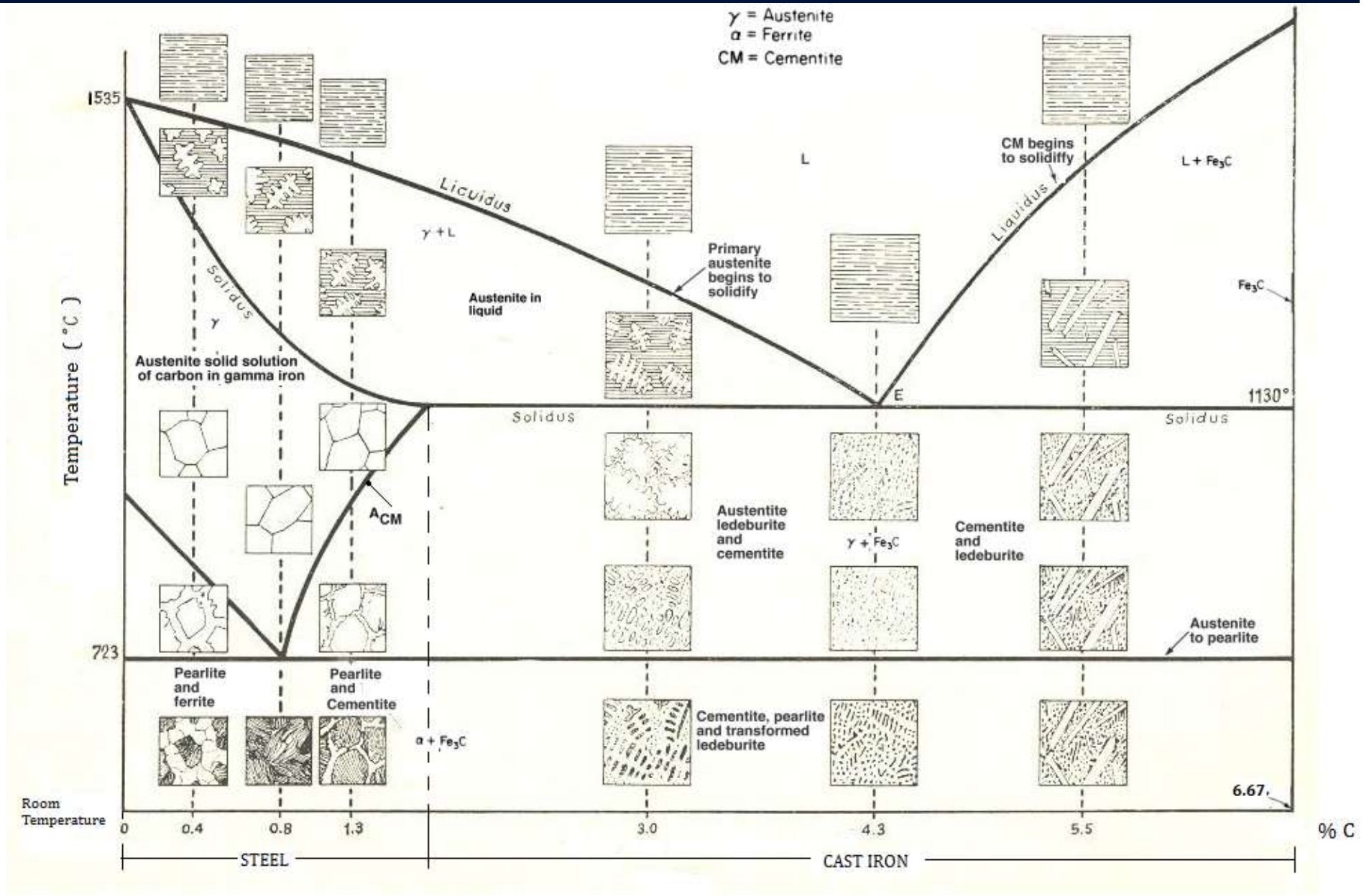
Microstructure of the as-rolled Fe – 1.31% C – 0.35% Mn – 0.25% Si specimen with the intergranular carbide network clearly visible after etching with alkaline sodium picrate, 90 °C – 60 s. Original at 500X magnification.



Color etching of the as-rolled hypereutectoid Fe-1.31% C – 0.35% Mn – 0.25% Si specimen clearly revealed the intergranular cementite films. Beraha's sulfamic acid etch (100 mL water, 3 g $K_2S_2O_5$ and 2 g NH_2SO_3H) (left) and Klemm's I reagent (right) were used. Original magnifications were 500X. Taken with polarized light and sensitive tint.

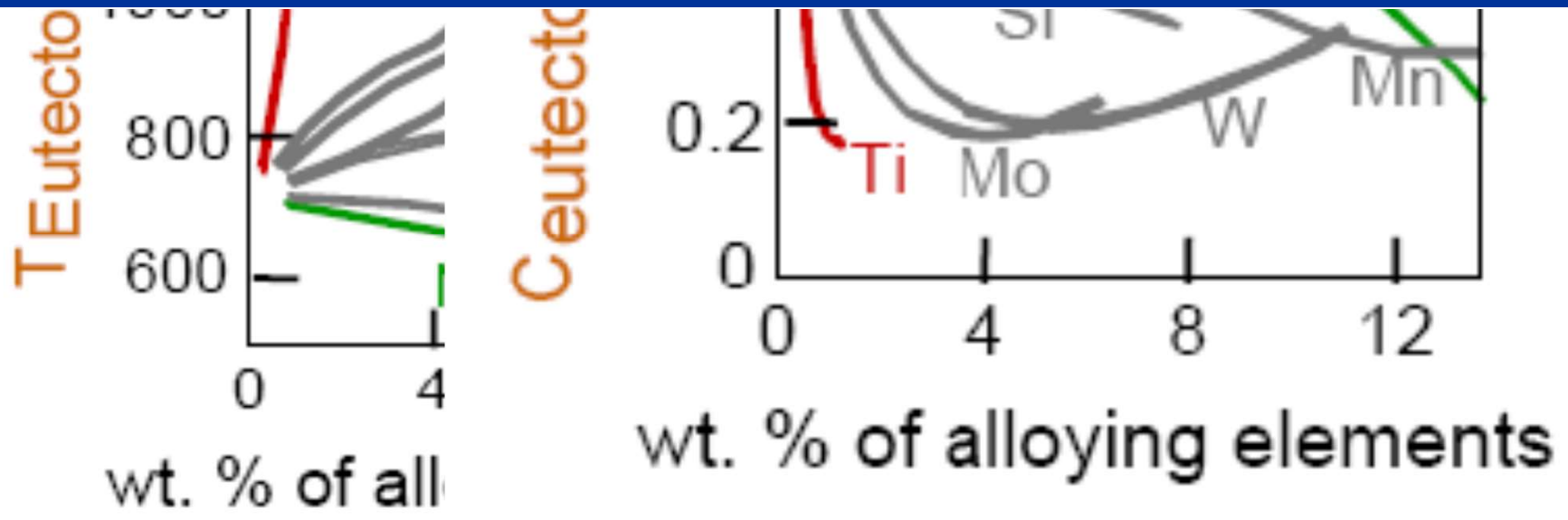
ZONA CRÍTICA

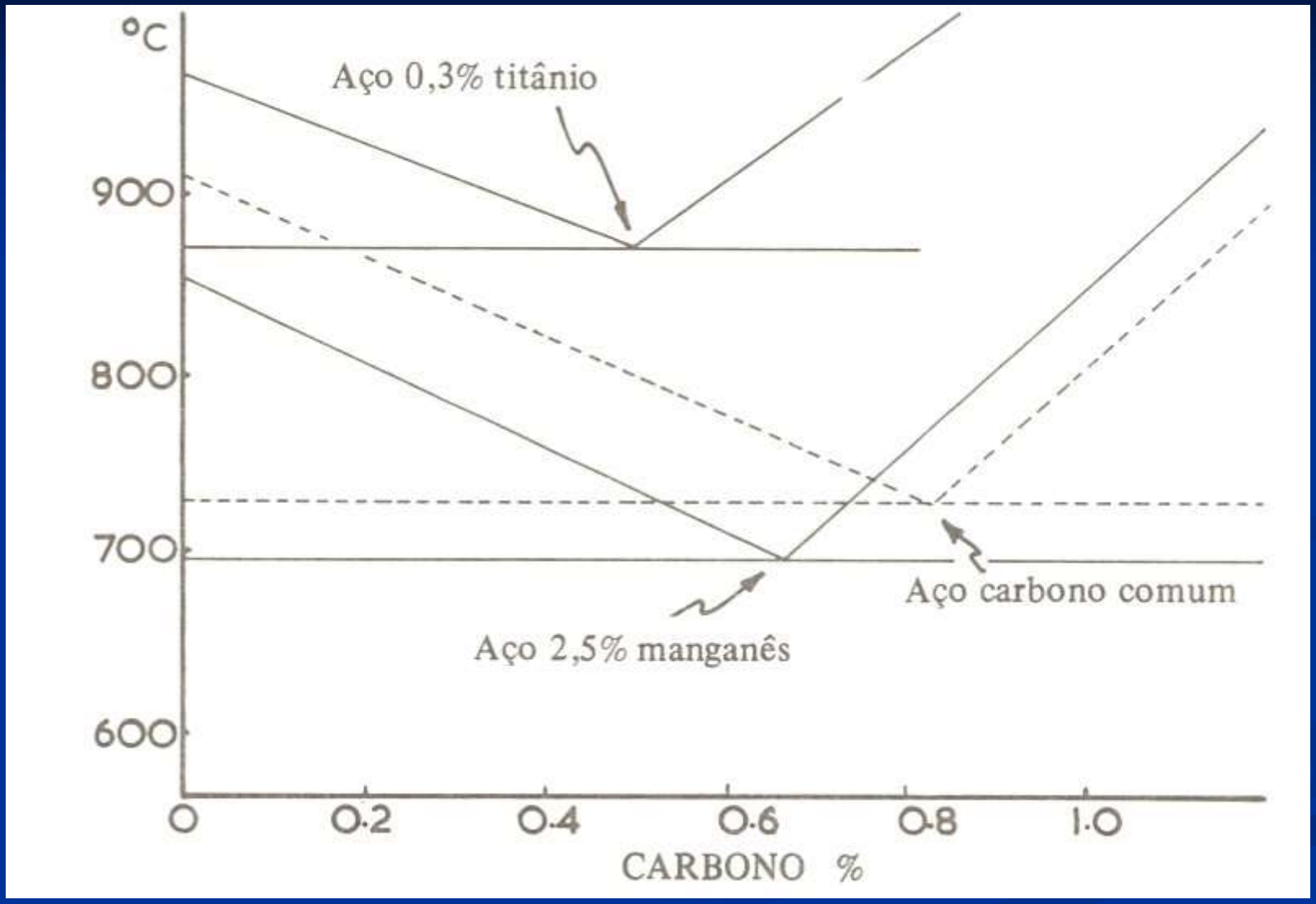


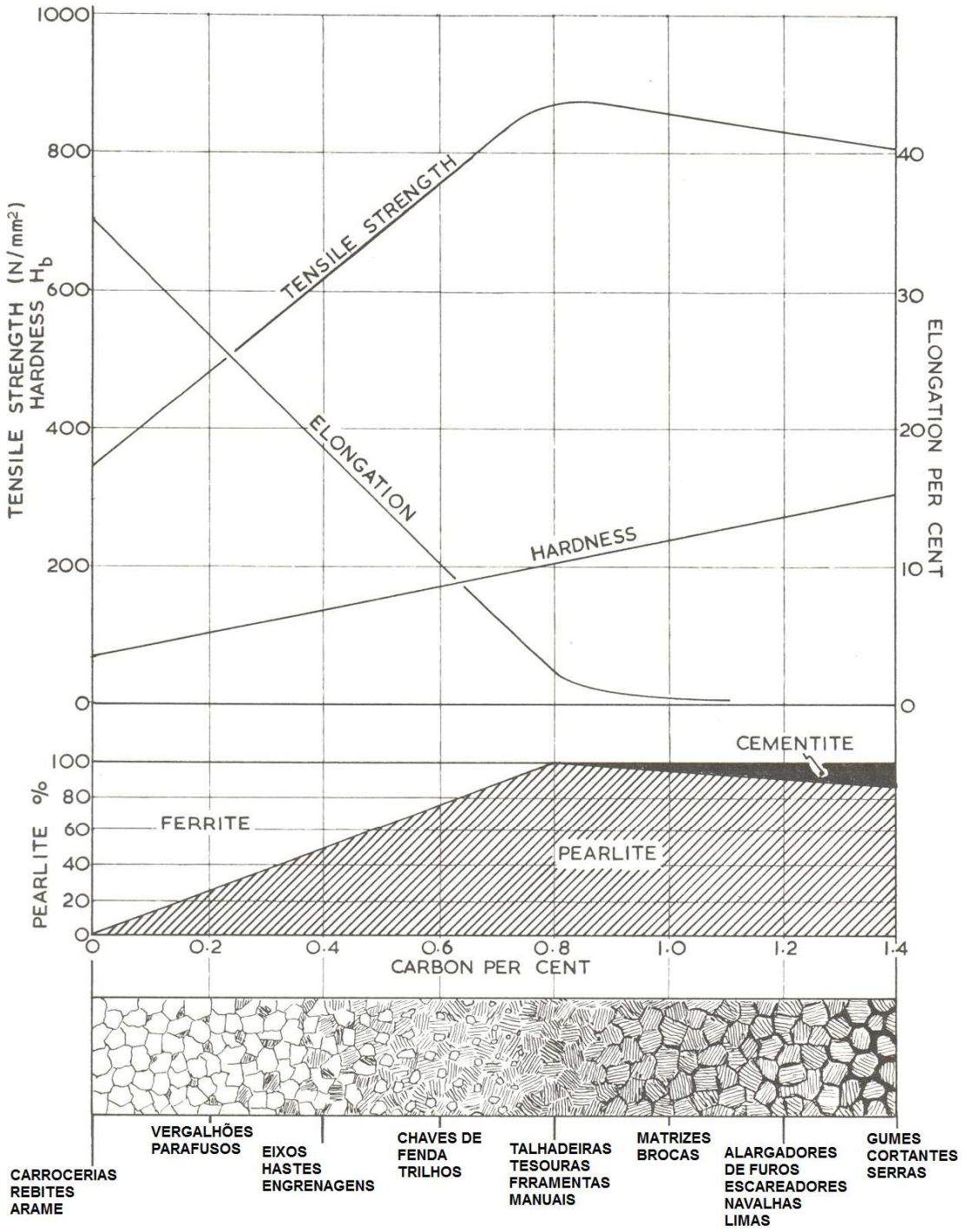

γ = Austenite
α = Ferrite
CM = Cementite
1535
Liquidus
γ + L
L
CM begins to solidiffy
L + Fe3C
Liquidus
Solidus
γ
Austenite in liquid
Primary austenite begins to solidify
Fe3C
Austenite solid solution of carbon in gamma iron
E
1130°
Solidus
Solidus
Temperature (°C)
ACM
Austentite ledeburite and cementite
γ + Fe3C
Cementite and ledeburite
723
Austenite to pearlite
Pearlite and ferrite
Pearlite and Cementite
α + Fe3C
Cementite, pearlite and transformed ledeburite
6.67
Room Temperature
0
0.4
0.8
1.3
3.0
4.3
5.5
% C
STEEL
CAST IRON

ELEMENTOS DE LIGA NOS AÇOS

- As adições de elementos de ligas (Cr, Ni, Ti, etc.) trazem alterações no diagrama de fases binário para o sistema ferro-cementita. Uma das importantes alterações é o deslocamento da posição eutetóide em relação à temperatura e à concentração de carbono.




°C
900
800
700
600
Aço 0,3% titânio
Aço carbono comum
Aço 2,5% manganês
0
0·2
0·4
0·6
0·8
1·0
CARBONO %


TENSILE STRENGTH (N/mm²)
HARDNESS H_b
ELONGATION PER CENT
TENSILE STRENGTH
ELONGATION
HARDNESS
CEMENTITE
FERRITE
PEARLITE
PEARLITE %
CARBON PER CENT
CARROCERIAS
REBITES
ARAME
VERGALHÕES
PARAFUSOS
EIXOS
HASTES
ENGRENAGENS
CHAVES DE
FENDA
TRILHOS
TALHADEIRAS
TESOURAS
FRRAMENTAS
MANUAIS
MATRIZES
BROCAS
ALARGADORES
DE FUROS
ESCAREADORES
NAVALHAS
LIMAS
GUMES
CORTANTES
SERRAS

Classificação dos aços

	Specifications
SAE-AISI	Society of Automotive Engineers – American Iron and Steel Institute
ASTM (UNS)	American Society for Testing and Materials (www.astm.org)
ASME	American Society of Mechanical Engineers
MIL	U.S. Department of Defense
AMS	Aerospace Materials Specification
BS	British Standards Institution (**http://www.bsi-global.com/index.xalter**)
EN	European Committee for Standardization (http://www.cenorm.be)

- ABNT – ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS.

MESMA CLASSIFICAÇÃO SAE

Os sistemas mais amplamente usados: SAE AISI

- Numérico
  - Society of Automotive Engineers (SAE)
  - American Iron and Steel Institute (AISI)
- Dois primeiros dígitos indicam o tipo do aço
  - 2nd dígito geralmente dão a quantidade aproximada do elemento de liga predominante
- Os últimos dois dígitos geralmente indicam a quantidade aproximada de carbono

AISI-SAE	Type and Description
	Carbon steels
10xx	Plain Carbon (Mn. 1.00% max.)
11xx	Resulfurized
12xx	Resulfurized and rephosphorized
15xx	Plain Carbon (max. Mn. range 1.00-1.65%)

Manganese steels	
13xx	Mn 1.75
Nickel steels	
23xx	Ni 3.50
25xx	Ni 5.00
Nickel-chromium steels	
31xx	Ni 1.25; Cr 0.65, 0.80
32xx	Ni 1.75; Cr 1.07
33xx	Ni 3.50; Cr 1.50, 1.57
34xx	Ni 3.00; Cr 0.77

Molybdenum steels	
40xx	Mo 0.20, 0.25
44xx	Mo 0.40, 0.52
Chromium-molybdenum steels	
41xx	Cr 0.50, 0.80, 0.95; Mo 0.12, 0.20, 0.25, 0.30

Nickel-chromium-molybdenum steels

43xx	Ni 1.82; Cr 0.50, 0.80; Mo 0.25
47xx	Ni 1.05; Cr 0.45; Mo 0.20, 0.35
81xx	Ni 0.30; Cr 0.40; Mo 0.12
86xx	Ni 0.55; Cr 0.50; Mo 0.20
87xx	Ni 0.55; Cr 0.50; Mo 0.25
88xx	Ni 0.55; Cr 0.50; Mo 0.35
93xx	Ni 3.25; Cr 1.20; Mo 0.12
94xx	Ni 0.45; Cr 0.40; Mo 0.12
97xx	Ni 1.00; Cr 0.20; Mo 0.20
98xx	Ni 1.00; Cr 0.80; Mo 0.25

Nickel-molybdenum steels	
46xx	Ni 0.85, 1.82; Mo 0.20, 0.25
48xx	Ni 3.50; Mo 0.25
Chromium steels	
50xx	Cr 0.27, 0.40, 0.50, 0.65
51xx	Cr 0.80, 0.87, 0.92, 0.95, 1.00, 1.05
50xxx	Cr 0.50; C 1.00 min.
51xxx	Cr 1.02; C 1.00 min.
52xxx	Cr 1.45; C 1.00 min.

Chromium-vanadium steels	
61xx	Cr 0.60, 0.80, 0.95; V 0.10, 0.15
Tungsten-chromium steels	
72xx	W 1.75; Cr 0.75
Silicon-manganese steels	
92xx	Si 1.40, 2.00; Mn 0.65, 0.82, 0.85; Cr 0.00, 0.65
High-strength low-alloy steels	
9xx	Various SAE grades
Boron steels	
xxBxx	B denotes boron steels
Leaded steels	
xxLxx	L denotes leaded steels

Aços ao C mais frequentemente usados

- SAE 1010: chapas para conformação
- SAE 1020: aplicações de máquinas em geral
- SAE 1040: componentes para têmpera superficial
- ASTM A36: aço estrutural
- SAE 4140: partes de máquinas de alta resistência
- SAE 4340: partes de máquinas de alta resistência
- SAE 8620: componentes para cementação