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WAL 630/7-2

# WATERTOWN ARSENAL LABORATORY

## MEMORANDUM REPORT

NO. WAL 630/7-2

# TENSILE STRESS-STRAIN CURVES OF A 70-30 BRASS.

BY

John H. Hollomon
Captain, Ordnance Department

DATE 1 October 1944

WATERTOWN ARSENAL
WATERTOWN, MASS.

# ERRATA

Memorandum Report Number WAL 630/7-2.

Page 5:------Change: "-----but the slope is very small (.01)----".
to "-----but the slope is very small (.1)-----".

and: "-----during the later stages of plastic flow is about 50 times the value-----".
to: "-----during the later states of plastic flow is about 5 times the value-----".

Table II:-----Column 6 - Strains to Fracture should be 1.40 instead of .140, etc.

Figure 5:----Ordinate - Strain-Hardening Exponent should be .2, .3, etc., instead of 2, 3, etc.

Watertown Arsenal Laboratory
Memorandum Report WAL 630/7-2
Problem Number H-3.4 1 October 1944

## SUBJECT

## TENSILE STRESS-STRAIN CURVES OF A 70-30 BRASS.

## ABSTRACT

Tensile stress-strain curves of alpha brass specimens of several grain sizes were determined. A simple relation between yield strength and grain size, such as the one suggested between hardness and grain size by Wood and Gough for iron, was not found. Wood and Gough suggested that the hardness varied linearly with the reciprocal of the square of the average grain diameter. The stress-strain curves showed two regions in which the nature of the plastic flow was different, suggesting that the initial yielding of even alpha brass is similar to that which occurs in mild steel. The results from these specimens indicate that the logarithm of the stress is a linear function of the logarithm of the strain (at least from strains of .06 to the strain to fracture). The slope of these logarithmic stress-strain curves was found to decrease with increasing yield strength (decreasing grain size). The stress required for fracture appeared to be relatively unaffected by grain size, except when the size of the grain became very large. For the very large grain-size specimens, the deformation was very irregular and the fracture strengths were comparatively low.

## INTRODUCTION

The necessity for Ordnance designers and engineers to understand the plastic behavior of metals has been emphasized in numerous reports from this Laboratory. In order to implement this understanding several studies[1, 2] of the stress-strain relations during plastic deformation have been made on steels having various metallurgical structures. The interpretation of such studies is complicated by the immense number of microstructural variables which are possible with steel. An important structural variable in steels is grain size, and it was desired to study its effect on the plastic properties. However, with steels, such a study is complicated by the nature of the structures which occur. The structures of steel found at room temperature generally consist of two phases and are the result of transformation from the single phase, austenite. Just what grain size is important to the mechanical properties is difficult to determine, particularly since changes in austenitic grain size affect changes in the structures formed upon its transformation. A fundamental study of the effect of the variable grain size should logically begin with a metal or alloy consisting of a single phase which does not undergo transformation when solid. In order for such studies to be of direct importance to Ordnance, 70-30 brass was chosen, since it has many Ordnance applications.

## MATERIAL AND PROCEDURE

A brass containing 69.46 per cent OFHC copper, and the remainder zinc, was obtained in the annealed condition, with an average grain size of .015 mm. in the form of half-inch diameter bar stock. Certain preliminary annealing experiments were performed in order to determine the annealing temperatures which would produce a range of grain size, and, on the basis of these experiments, the annealing temperatures listed in Table I were chosen. The resulting grain sizes determined by metallographic examination and comparison with the ASTM standards, are also listed in this table.

After the annealing treatments, standard .357-inch diameter tensile specimens having a 2-inch uniform gauge length were machined from bar stock receiving all treatments. The specimens were then pulled in tension at a strain rate of approximately $10^{-4}$ sec.$^{-1}$. The load and elongation were measured up to approximately a strain of .008, the elongation being measured with an Olsen extensometer. The gauge was then removed and replaced with a special diameter gauge. The diameter and load were then measured simultaneously to fracture. These measurements were made with the apparatus and by the technique described in a previous report[3].

## RESULTS AND DISCUSSION

As has been pointed out many times (at least indirectly), the yield strength and the tensile strength of single-phase alloys increase with decreasing grain size. In Figure 1, the initial portions of the stress-strain curves as obtained with load-elongation measurements are plotted for the specimens of different grain sizes*. The yield strength (stress at a given strain or strain offset) increases with decreasing grain size. Several investigators[4, 5] have shown that the hardness of single-phase alloys varies directly with the reciprocal of the square of the average grain diameter. In Figure 2, taken from the paper of Gough[5], the hardness of iron is plotted as a function of this parameter. No simple relation of this type was found between the yield strength and the grain size for these specimens over grain-size range investigated.

The curves of Figure 1, as well as the data found in the standard compilations of mechanical properties of commercial single-phase alloys indicate that the stress-strain curves during the initial yielding rise only very slowly even though it was well-known that

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*Throughout this report, by stress is meant the load divided by the instantaneous area and by strain is meant the ln $\frac{l}{l_0}$ or ln $\frac{A_0}{A}$ (for large strains) where $l_0$ and $A_0$ are the initial length and area of the specimen and $l$ and $A$ are the instantaneous length and area.

these materials are extremely work-hardenable. Wilkins and Bunn[6] for example, in their recently published compilation of data for the coppers and brasses indicate that the yield strengths of copper and alpha brass in the annealed condition, as measured at different small strains, are very nearly the same. The significance of this behavior during the initial plastic flow has, however, not been discussed.

This anomalous behavior can be vividly illustrated by the stress-strain curves over the whole range of plastic deformation from yield to fracture. In Figure 3, such a curve is presented for the brass having the largest grain size*. This initial slowly rising portion of the stress-strain curve followed by a second more sharply rising portion suggests that the nature of the initial yielding of copper and brass is similar to that of mild steel**. That is to say, that an initial inhomogeneous deformation is induced by the difference in properties of the strain boundaries and the grains themselves. That the deformation does not occur completely by the formation of local inhomogeneous flow is evidenced by the fact that the initial yielding is not sharply defined, as in the case of steel. It is, however, most significant that there are two regions of plastic deformation of fundamentally different characteristics. Recent English work[7] has demonstrated that this inhomogeneous type of yielding occurs in metals other than steel.

In a previous report[2], it was shown that during plastic deformation and over a rather wide range of strains, the stress varied as a linear function of the strain raised to a fractional power. For steels, this power relation does not extend to fracture. From the data for copper and brass obtained in tests performed in this Laboratory, it appears that this power relation*** between stress and strain is valid

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*Similar curves were obtained for all of the brass specimens tested. Figure 3 is typical.

**It is not correct to imply that only mild steel exhibits this inhomogeneity of yielding (Piobert effect). Steels containing higher carbon contents and structures other than proeutectoid ferrite and pearlite also exhibit this phenomenon.

***This relation differs from that presented for cold-deformed brass and copper by MacGregor.

at least from strains of about .06 to fracture. Therefore, when plotted on logarithmic paper, the stress-strain curves are linear. The slope of such curves (the fractional power) has been termed the strain-hardening exponent. To illustrate this relation between stress and strain, the data for the brasses of various grain sizes are plotted on logarithmic paper in Figure 4. Because the grain size of the two specimens annealed at the highest temperatures were large (Table I), the deformation of specimens was very irregular, and the stress-strain curves are somewhat erratic. This method of presenting the relation between stress and strain emphasizes the difference in behavior during the two regions of plastic flow. From a strain of about .002 to a strain of about .06, the logarithm of the stress is essentially a linear function of the logarithm of the strain, but the slope is very small (.01); from a strain of about .06 to fracture, the logarithmic stress-strain curves are also linear, with a slope of approximately .5. Thus, the strain-hardening exponent during the later stages of plastic flow is about 50 times the value during the initial yielding. For steels, the strain-hardening exponent appears to vary with the yield strength of the material. The relation between the slope of the logarithmic stress-strain curves and the yield strength of brass (varied by changing the grain size) is plotted in Figure 6. As indicated in Table II, the reduction of area is almost independent of grain size, until the size becomes very large. The stress required for fracture appears to decrease with increasing size, but with the greatest change occurring with a change from a grain size of .035 mm. to a size of .12 mm.

John H. Hollomon
Captain, Ordnance Department

# TABLE I

## ANNEALING TEMPERATURES AND GRAIN SIZE OF BRASS

| Specimen Number | Annealing Temperature (°C.) | Grain Size mms. |
|---|---|---|
| 1 | As Rec'd. | .015 |
| 2 | 505 | .02 |
| 3 | 515 | .025 |
| 4 | 575 | .035 |
| 5 | 680 | .12 |
| 6 | 800 | .20 |

## TABLE II

## PROPERTIES OF BRASS SPECIMENS

| Specimen Number | Diameter of Average Grain (mms.) | Yield Strength (Strain of .005) (1000 p.s.i.) | Tensile Strength (1000 p.s.i.) | Fracture Strength (1000 p.s.i.) | Strain to Fracture | Reduction of Area (%) |
|---|---|---|---|---|---|---|
| 1 | .015 | 24.6 | 54.9 | 150.7 | .140 | 75.3 |
| 2 | .020 | 22.8 | 52.1 | 141.1 | .138 | 74.5 |
| 3 | .025 | 20.8 | 51.7 | 138.0 | .138 | 74.7 |
| 4 | .035 | 17.2 | 47.7 | 139.8 | .143 | 75.9 |
| 5 | .12 | 13.0 | 46.3 | 120.1 | .128 | 72.7 |
| 6 | .20 | 12.4 | 44.7 | 122.4 | .119 | 69.7 |

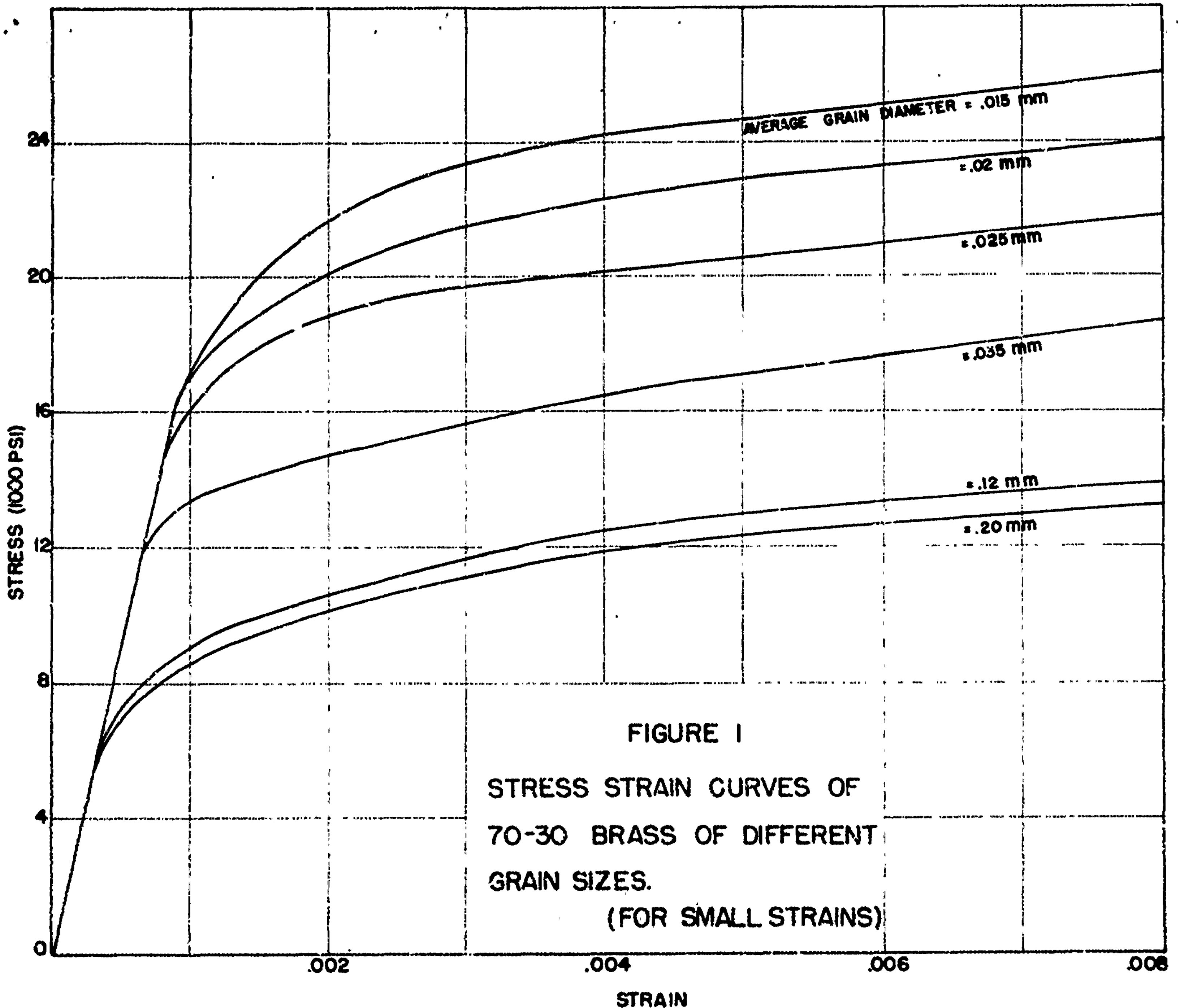

FIGURE I

STRESS STRAIN CURVES OF
70-30 BRASS OF DIFFERENT
GRAIN SIZES.
(FOR SMALL STRAINS)

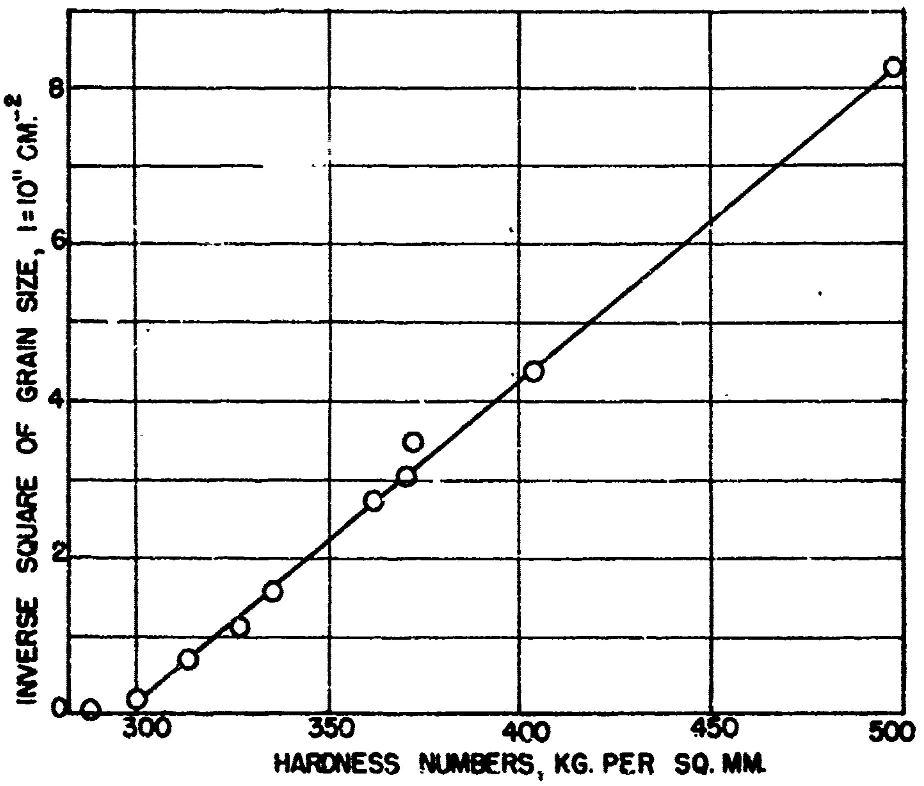

FIGURE 2

RELATION BETWEEN GRAIN SIZE AND HARDNESS FOR STEEL. (AFTER GOUGH)

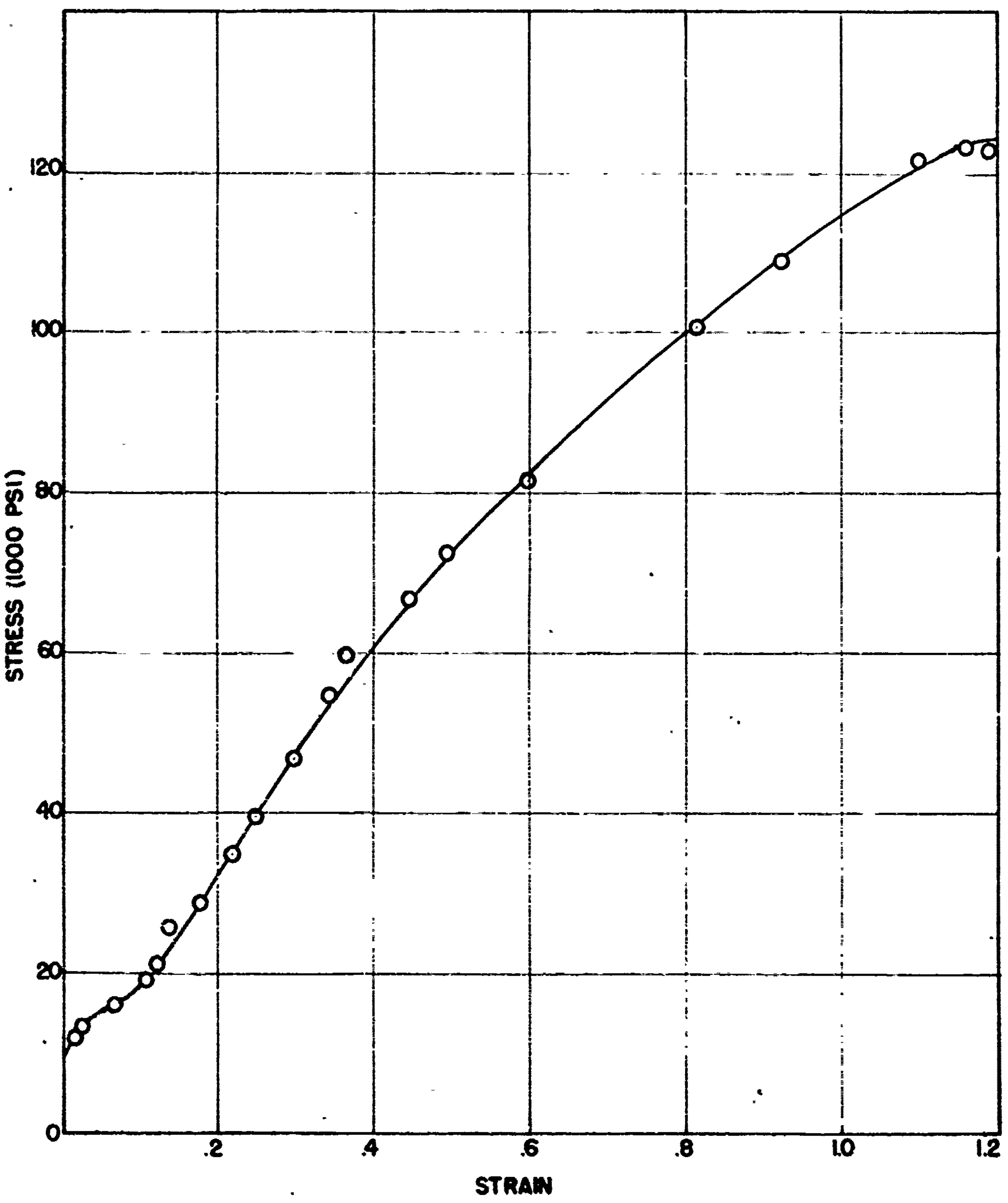

FIGURE 3

TYPICAL STRESS STRAIN CURVE OF BRASS (SPECIMEN NUMBER 6)

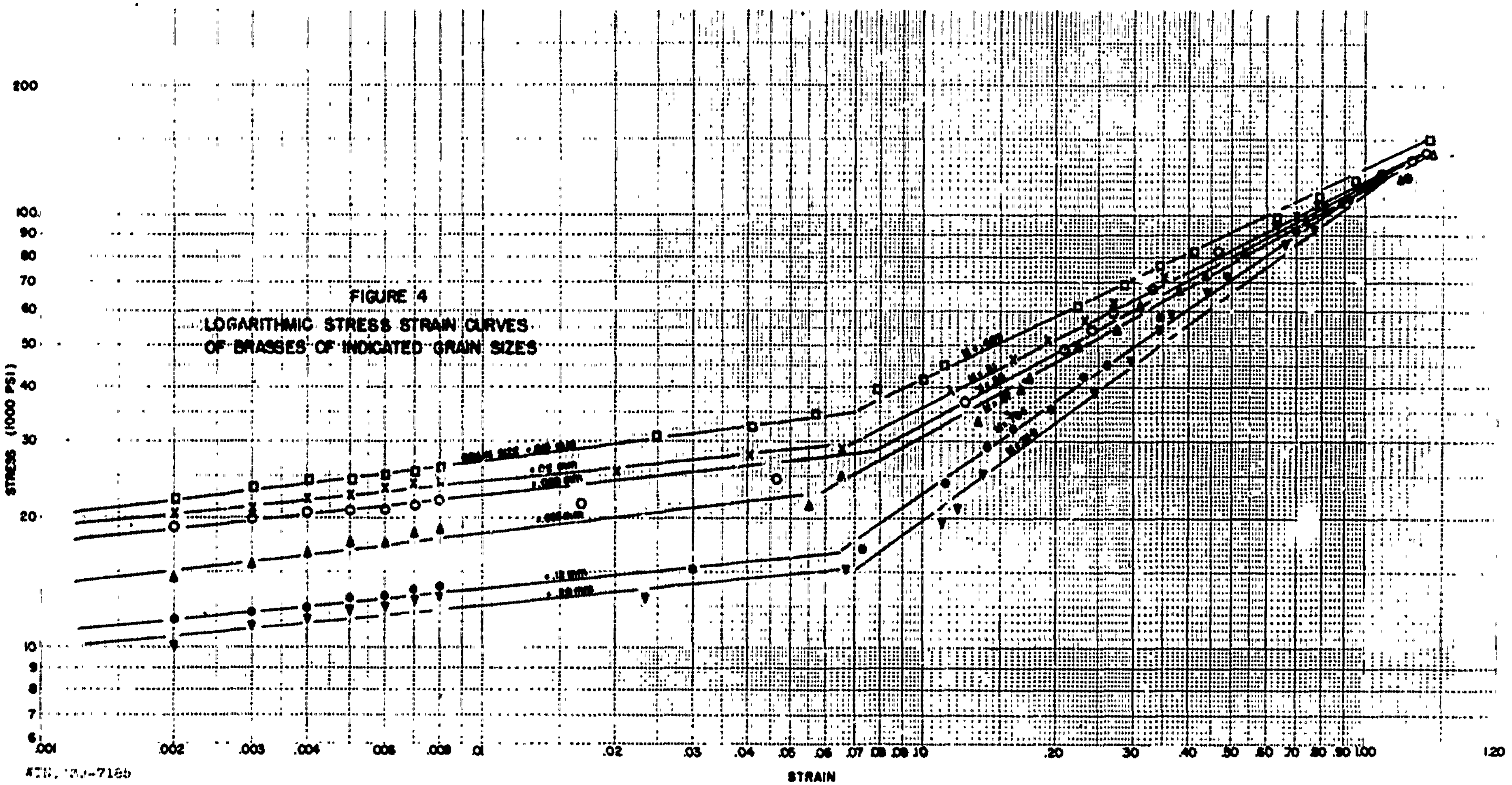

FIGURE 4

LOGARITHMIC STRESS STRAIN CURVES OF BRASSES OF INDICATED GRAIN SIZES

[illegible]-7186

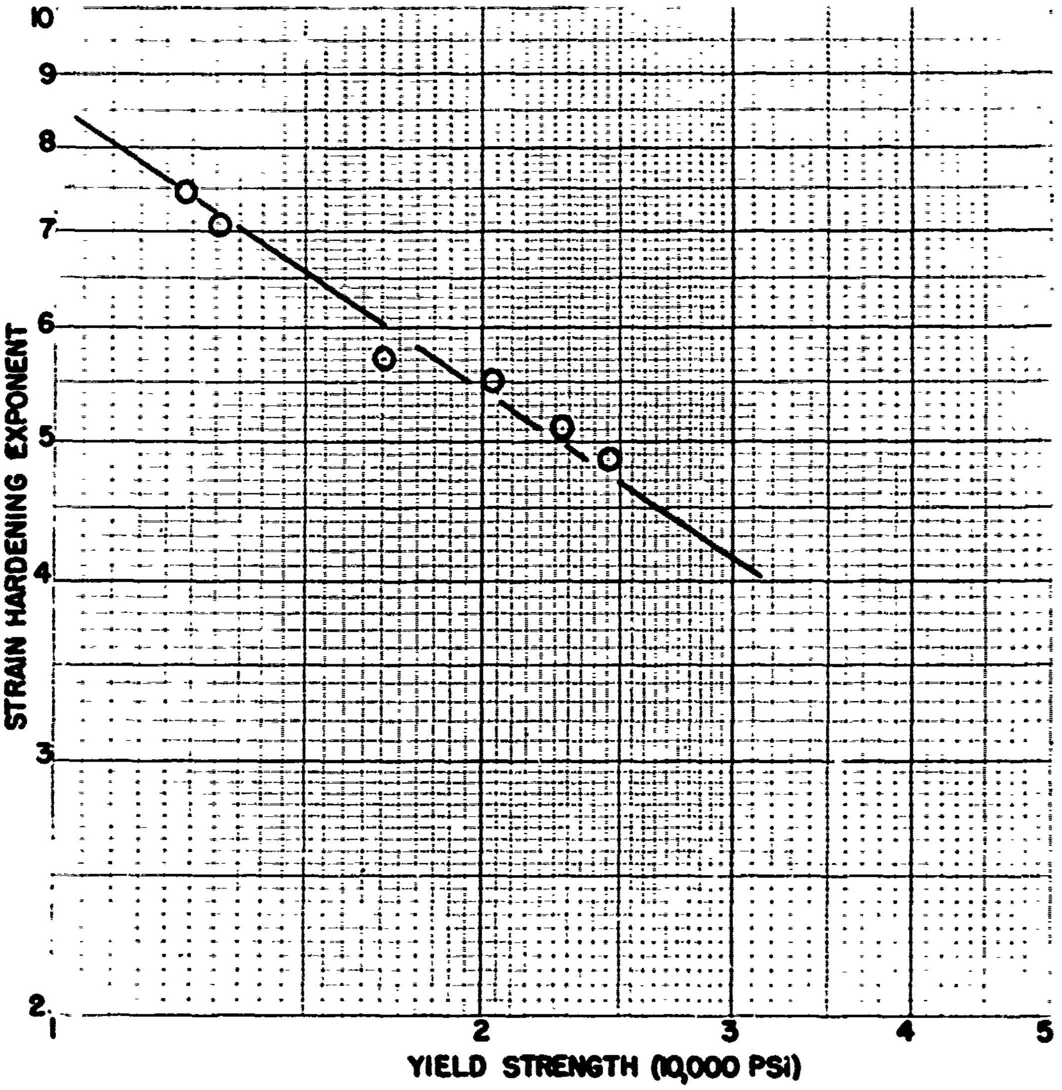

FIGURE 5

VARIATION OF STRAIN HARDENING EXPONENT
WITH YIELD STRENTH

WTN.639-7184

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