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UNIVERSITY OF MICHIGAN
ANN ARBOR

REPORT NO. 2

MECHANICAL PROPERTIES OF MACHINABILITY PROGRAM WORK MATERIALS

By

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Project M993

U. S. ARMY, ORDNANCE CORPS
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SUMMARY SHEET

I. Engineering Research Institute, University of Michigan, Ann Arbor, Michigan.

II. U. S. Army, Ordnance Corps.

III. Project No. TB4-15
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IV. Report No. WAL 401/109-2.

V. Priority No.

VI. Investigation of **machinability of titanium-base alloys.**

VII. Object:

The object is to investigate the machinability of commercially pure titanium and three alloys of titanium.

VIII. Summary:

Tensile tests and Brinell Hardness tests were made on five of the six machinability work materials. Tensile test data are plotted as stress versus natural strain. Hardness tests over a range of loads provides Meyer exponents. The materials tested were SAE 1045 hot-rolled steel, type 304 stainless steel, and titanium grades Ti 75A, RC 130B, and Ti 150A.

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MECHANICAL PROPERTIES OF MACHINABILITY PROGRAM WORK MATERIALS

Four alloys of titanium (one alloy not yet specified), hot-rolled SAE 1045 steel, and type 304 stainless steel were selected as work materials to be studied in the machinability investigation. Tensile specimens have been made and tested and Brinell hardness tests run to provide supporting information on the materials as machined. The results of these tests are presented below. In addition to these mechanical property tests, work is under way to determine tension impact and combined compression and torsion properties. The latter will be presented in a later report.

Tensile Properties

Standard 0.505-inch diameter tensile specimens were prepared and tested in a 60,000-pound Baldwin Tate Emery Universal Testing Machine. The titanium specimens were prepared from 1-inch diameter bars in the "as-received" condition. The SAE 1045 specimens were prepared from the center of 4-inch diameter hot-rolled bars. The type 304 stainless specimens were prepared from the center of 3-inch diameter hot-rolled bars. Three specimens were tested of each material except in the case of the stainless, for which only two were tested.

The results of the tensile tests are given in Table I. The data in Table I are self-explanatory. Substantial anisotropy was observed in the RC-130B and the Ti-150A titanium alloys, as manifested in elliptical fractures with the major axis approximately one-third greater than the minor axis.

Curves of average stress versus average strain are shown in Figures 1 to 14 inclusive for each of the fourteen tensile tests. All three titanium alloys exhibited a very sharp yield point followed by a slight yield point elongation.

TABLE I

TENSILE PROPERTIES OF WORK MATERIALS

Material	Sample Number	Yield Strength*	Tensile Strength	Breaking Strength	Per Cent Elongation	Per Cent Reduction of Area
304 S. S.	1	37,500	85,500	55,000	64.5	77.4
304 S. S.	2	41,000	85,700	54,500	62.7	77.4
SAE 1045	1	48,600	101,200	91,000	21.5	33.0
SAE 1045	2	48,800	101,800	92,500	21.7	34.4
SAE 1045	3	53,000	101,700	93,500	22.5	34.6
Ti-75A	1	60,000	82,000	66,000	28.0	47.1
Ti-75A	2	57,400	82,100	65,500	28.5	48.6
Ti-75A	3	57,700	82,000	65,500	27.7	45.8
RC-130B	1	139,000**	155,500	122,500	18.5	41.9
RC-130B	2	139,400**	155,000	126,200	17.7	37.9
RC-130B	3	139,400**	155,200	121,700	18.3	45.3
Ti-150A	1	131,700	141,000	97,200	25.0	55.8
Ti-150A	2	132,500	140,200	99,200	24.7	54.5
Ti-150A	3	130,000	140,400	97,400	25.0	55.1

* Yield strength determined by 0.2% offset method.
** Yield point value.

Composite results from all specimens for each material are shown plotted as average stress versus natural strain (i.e., the logarithm of one plus the engineering strain) in the five curves of Figures 15 to 19 inclusive. There appears to be a good correlation between the slopes of these curves near fracture with the steepness of the curves of tool life versus side rake angle (Figure 11, Report No. 1) as the side rake angle is increased toward the optimum. The type 304 stainless steel shows the sharpest optimum, while the SAE 1045 steel shows the least. There is a theoretical basis for this correlation, providing it can be demonstrated that the shear strain is of the same magnitude in the chip formation and near the fracture of the tensile test.

Brinell Hardness Tests

Brinell hardness tests were made over a range of loads on all five work materials. The results are summarized in Table II.

TABLE II

BHN AND MEYER EXPONENTS

Work Material	BHN*	Meyer Exponent, n**
Ti 75A	217	2.41
RC 130B	331	2.37
Ti 150A	302	2.27
304 S.S.	174	2.32
SAE 1045	201	2.25

* 3000-kg load.
** Load = ad^n.

Hardness values are reported in the second column for a 3000-kg testing load. The third column gives the Meyer exponents as used in the formula:

$$\text{Load} = ad^n,$$

where d = diameter of impression in m.m.

a = proportionality constant determined by material and load units.

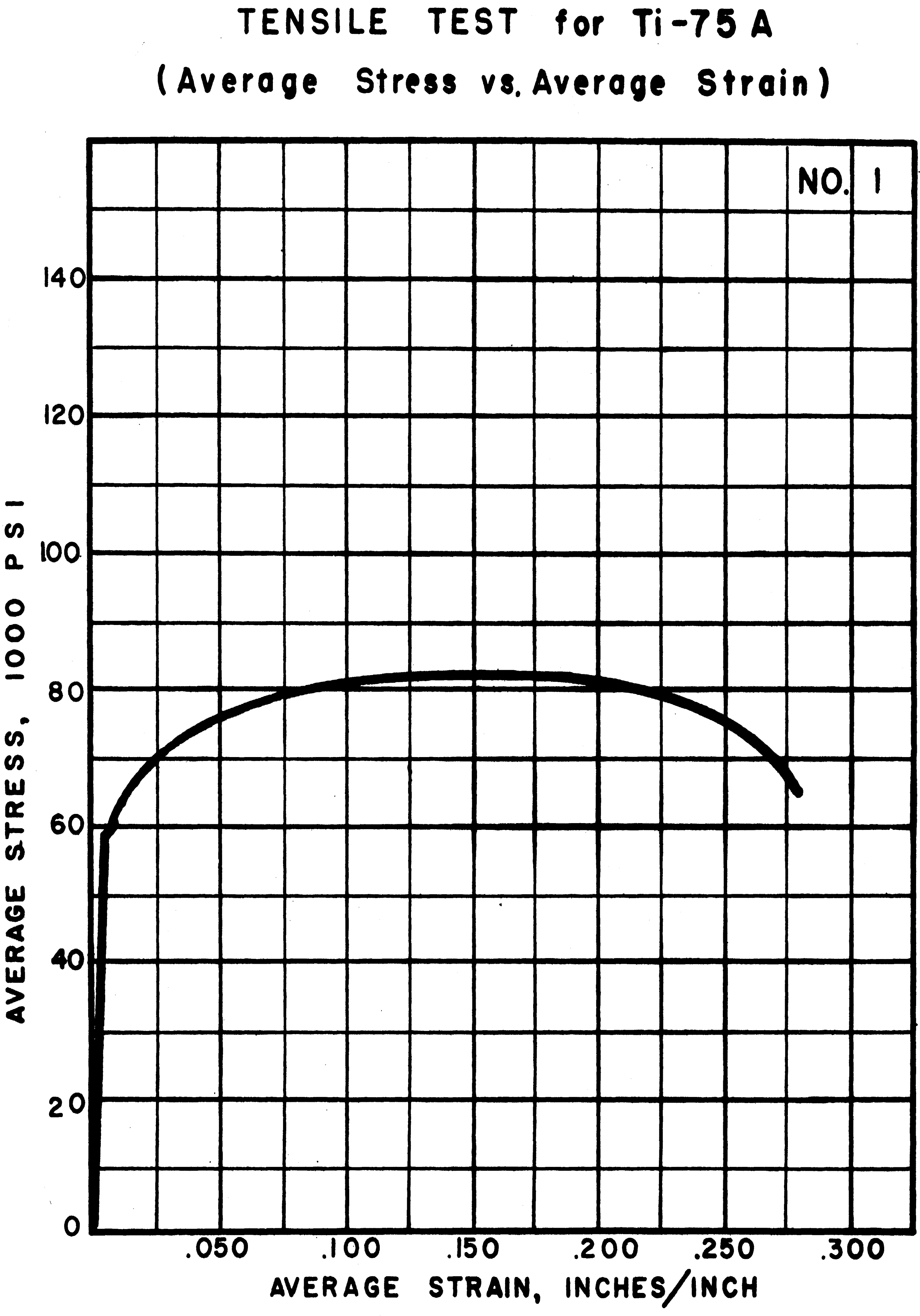

TENSILE TEST for Ti-75 A
(Average Stress vs. Average Strain)
NO. 1
AVERAGE STRESS, 1000 PSI
0
20
40
60
80
100
120
140
.050
.100
.150
.200
.250
.300
AVERAGE STRAIN, INCHES/INCH

Fig. 1

TENSILE TEST for TI-75A

(Average Stress vs. Average Strain)

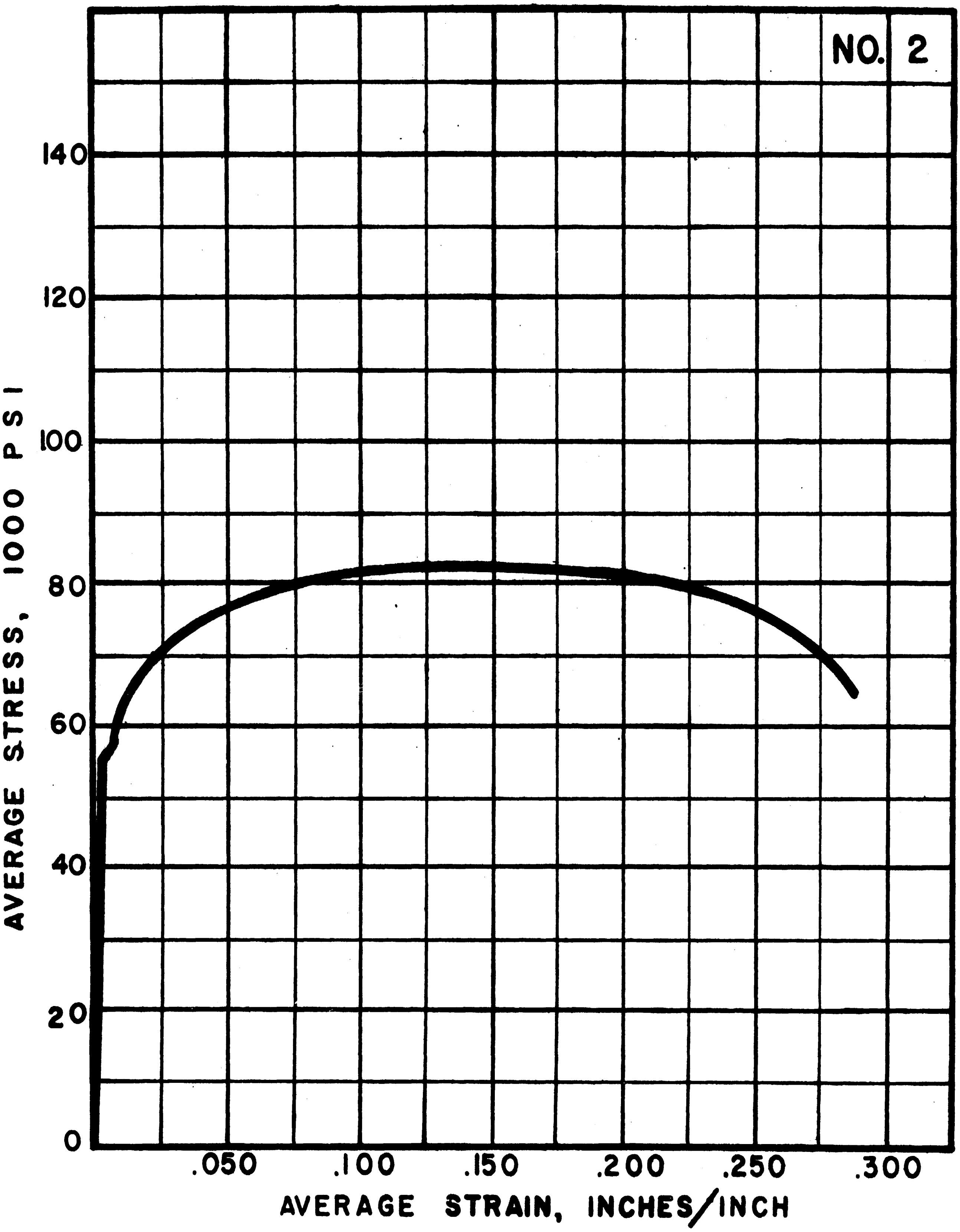


Fig. 2

TENSILE TEST for Ti-75A
(Average Stress vs. Average Strain)

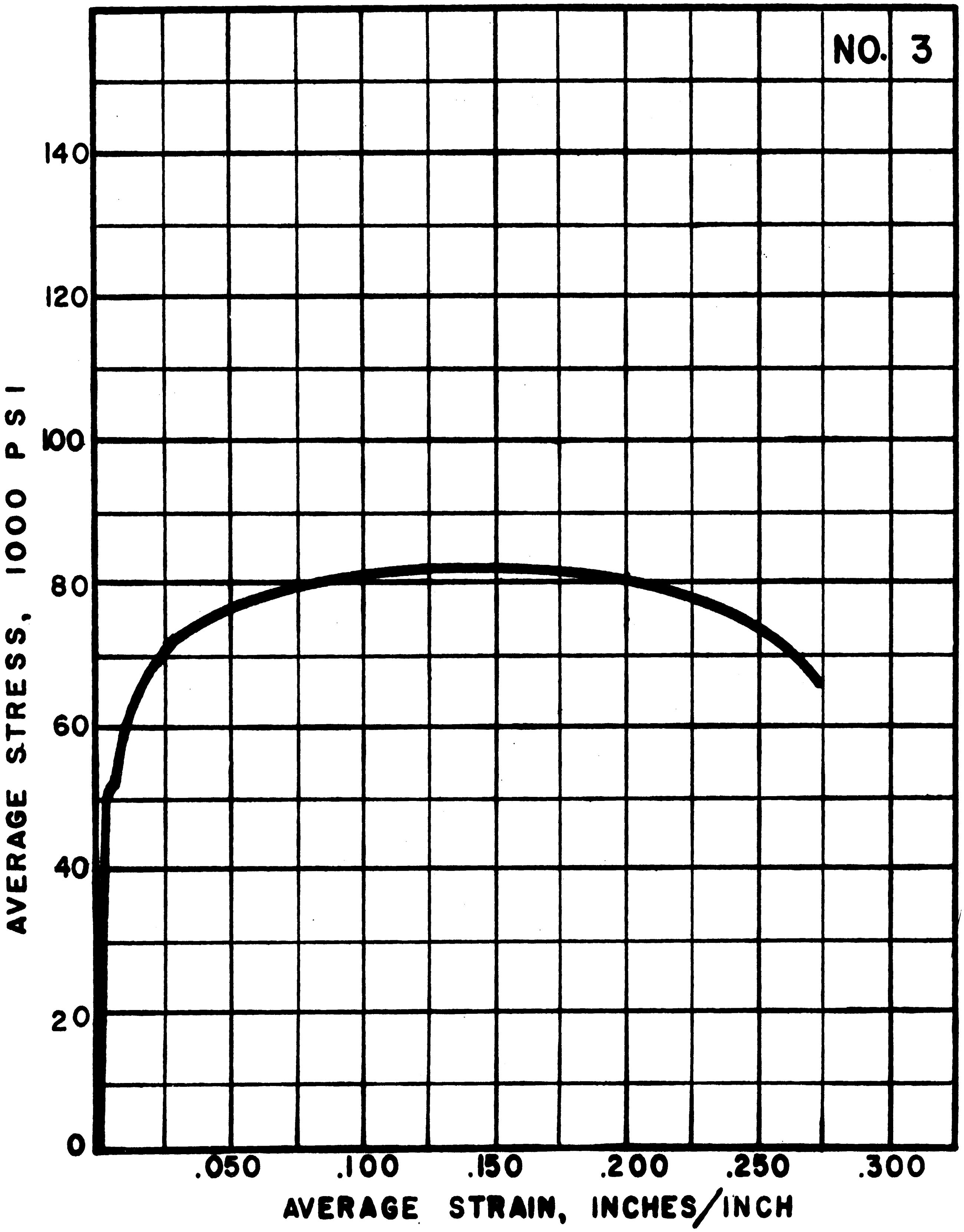


Fig. 3

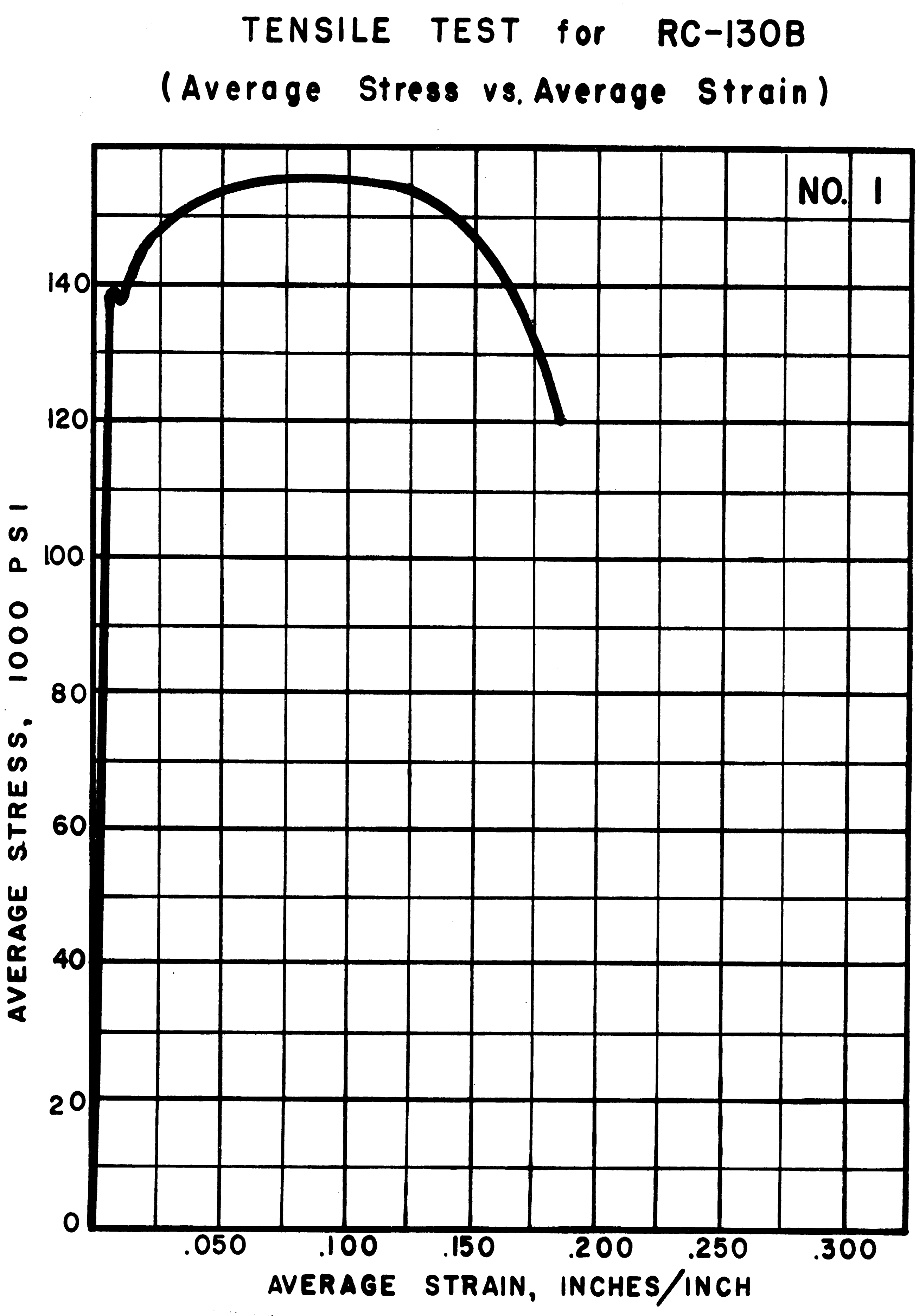

TENSILE TEST for RC-130B
(Average Stress vs. Average Strain)
NO. 1
140
120
100
80
60
40
20
0
AVERAGE STRESS, 1000 PSI
.050
.100
.150
.200
.250
.300
AVERAGE STRAIN, INCHES/INCH

Fig. 4

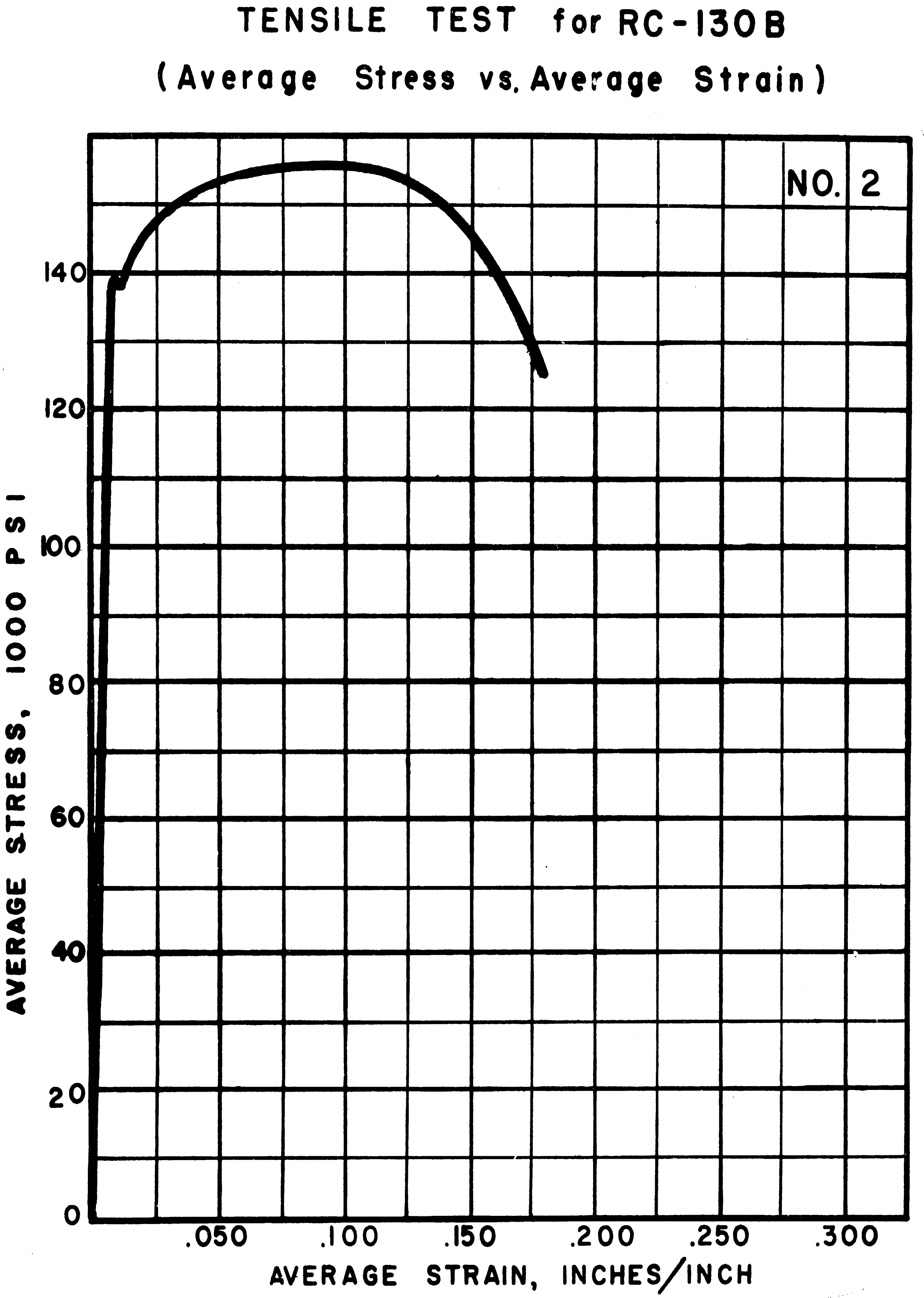

TENSILE TEST for RC-130B
(Average Stress vs. Average Strain)
NO. 2
AVERAGE STRESS, 1000 PSI
0
20
40
60
80
100
120
140
.050
.100
.150
.200
.250
.300
AVERAGE STRAIN, INCHES/INCH

Fig. 5

TENSILE TEST for RC-130B

(Average Stress vs. Average Strain)

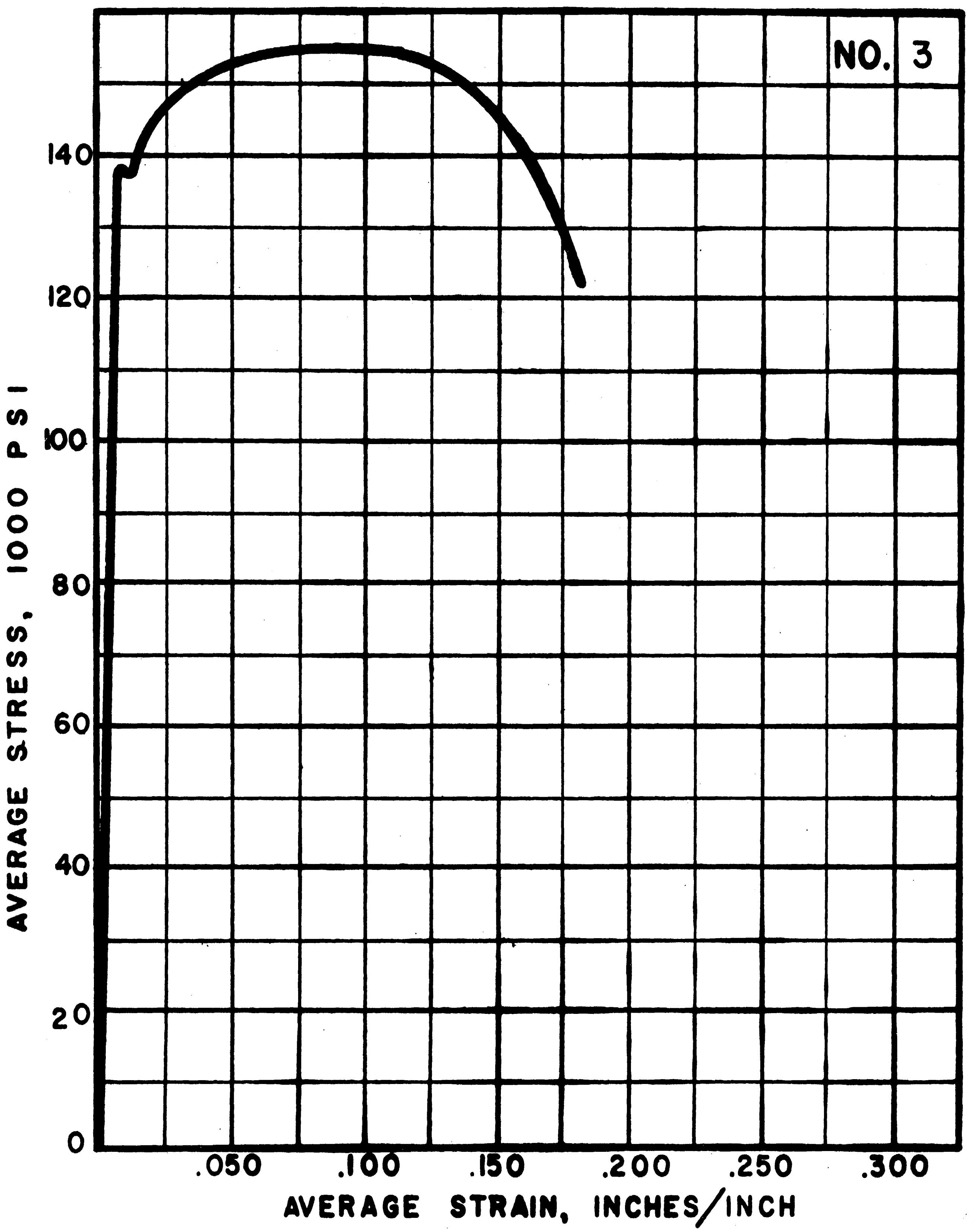
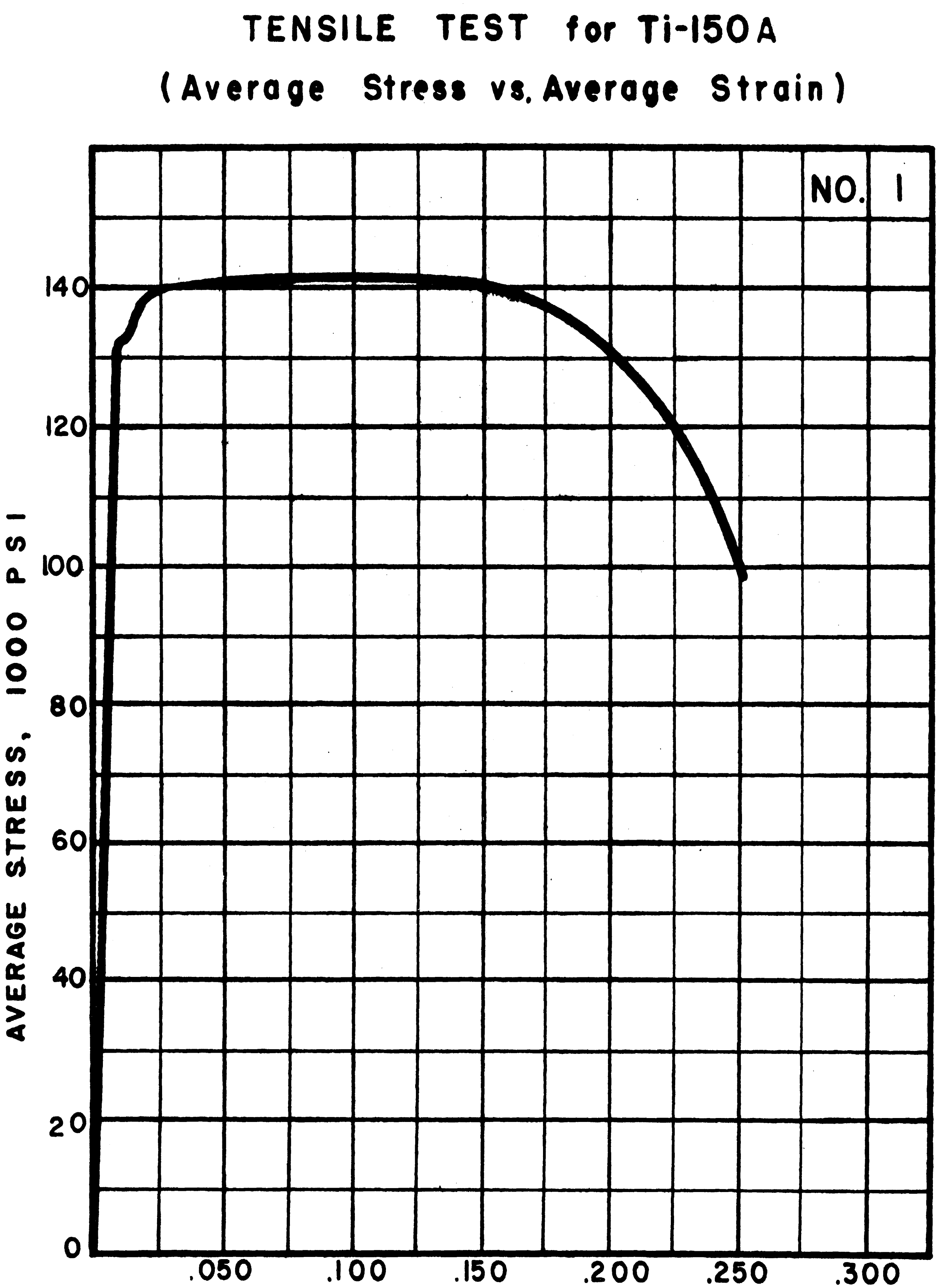


Fig. 6



TENSILE TEST for Ti-150A
(Average Stress vs. Average Strain)
NO. 1
140
120
100
80
60
40
20
0
.050
.100
.150
.200
.250
.300
AVERAGE STRAIN, INCHES/INCH
AVERAGE STRESS, 1000 PSI

Fig. 7

TENSILE TEST for Ti-150A

(Average Stress vs. Average Strain)

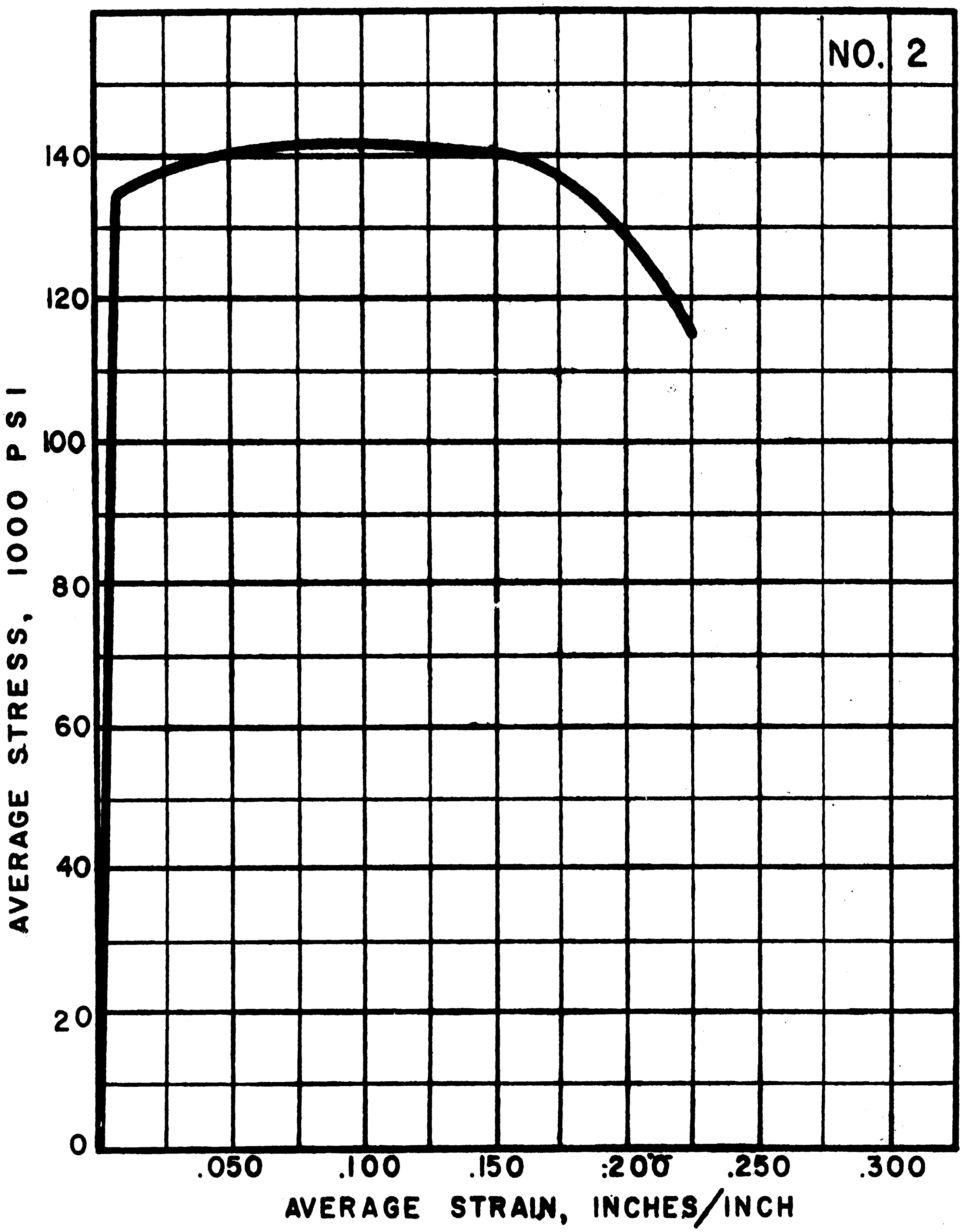


Fig. 8

TENSILE TEST for Ti-150A
(Average Stress vs. Average Strain)

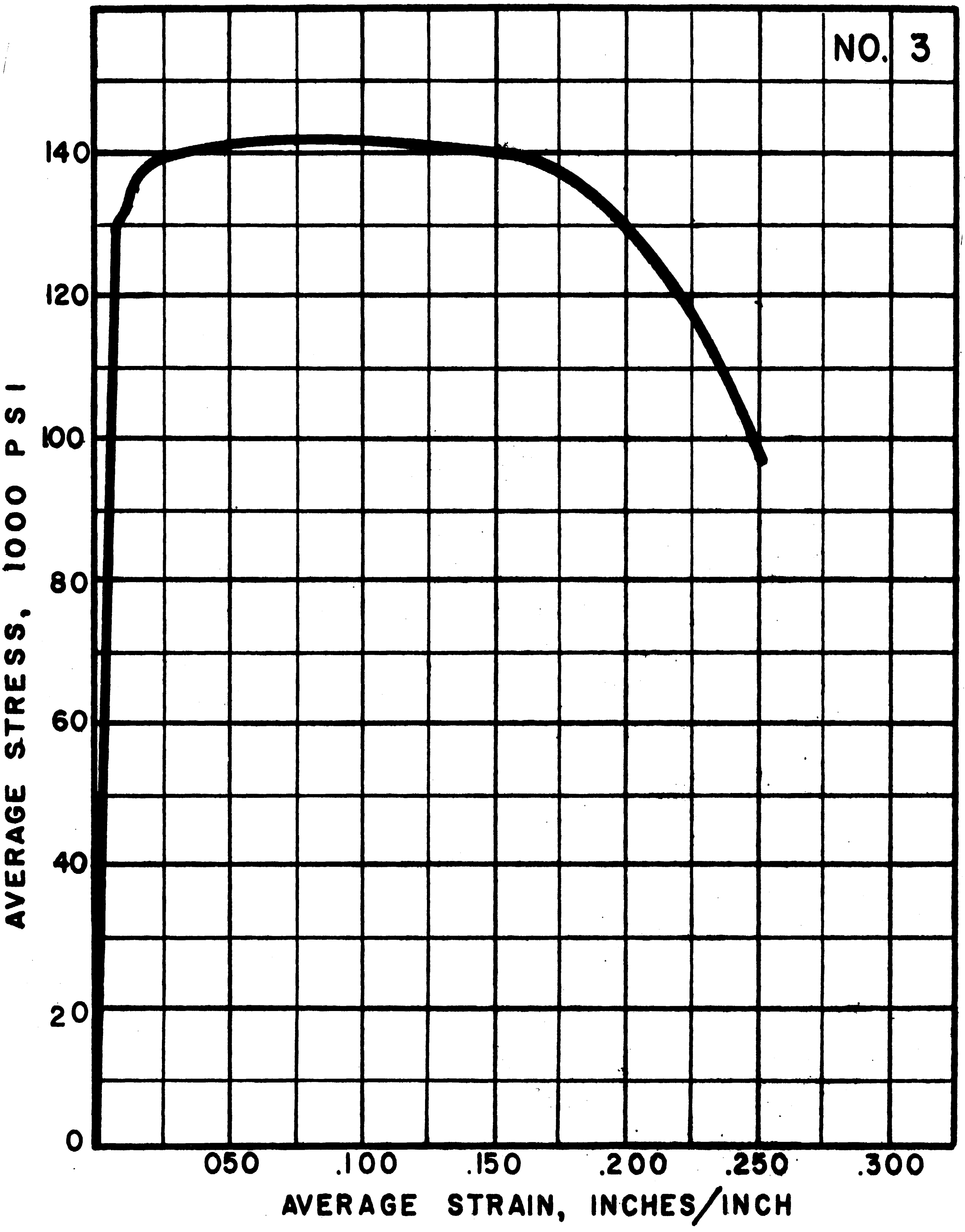


Fig. 9

TENSILE TEST for S.A.E. 1045
(Average Stress vs. Average Strain)

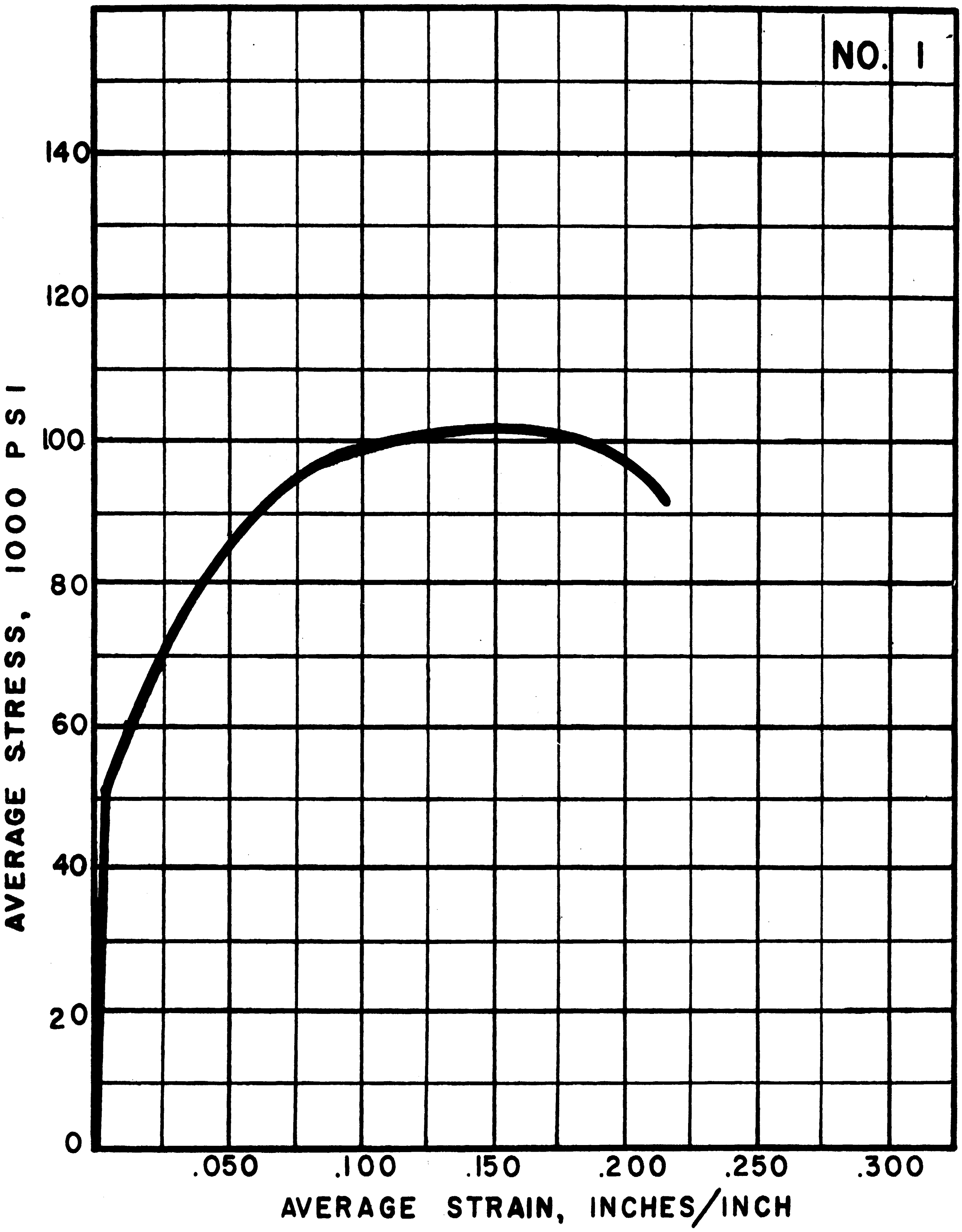


Fig. 10

TENSILE TEST for S.A.E. 1045

(Average Stress vs. Average Strain)

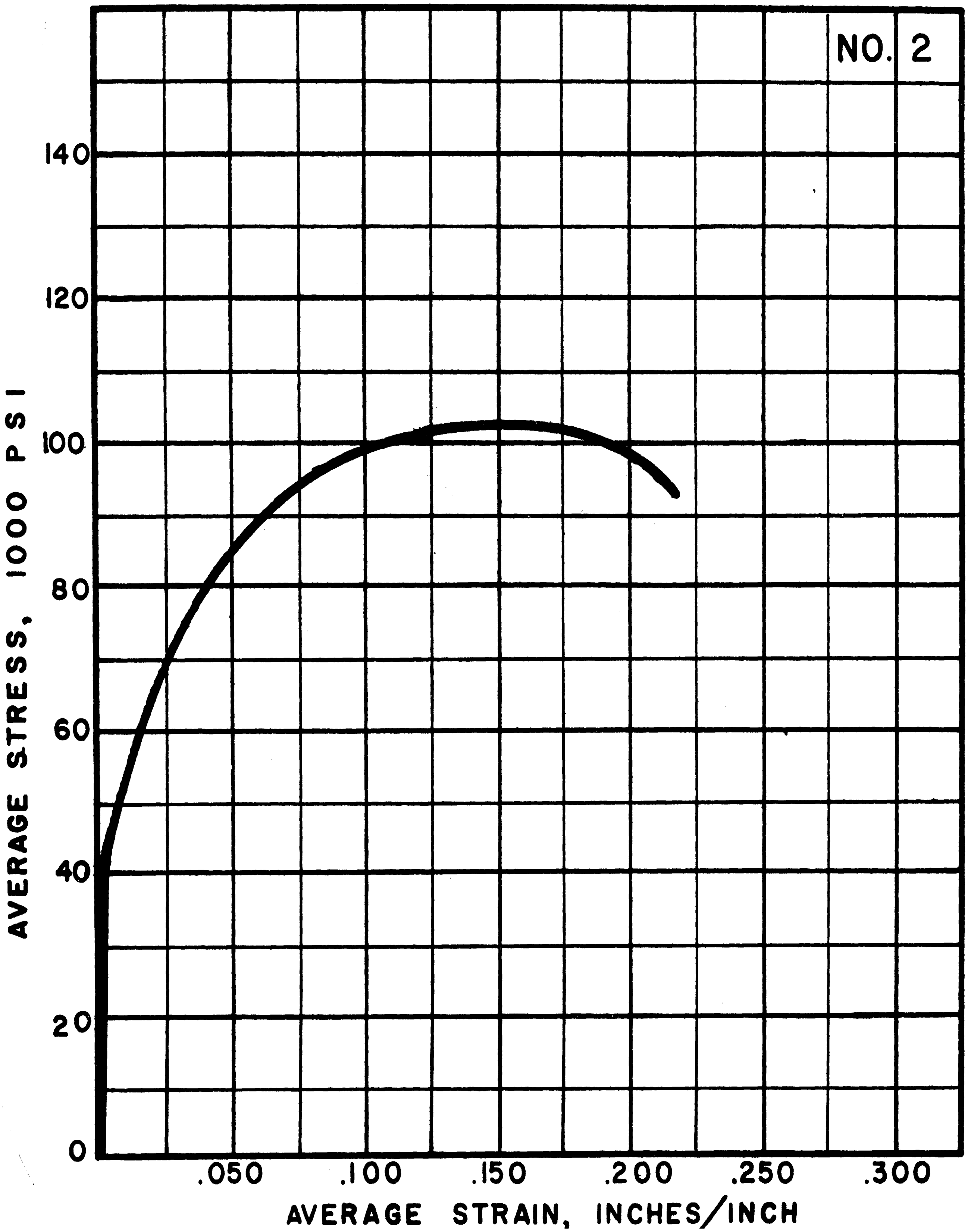


Fig. 11

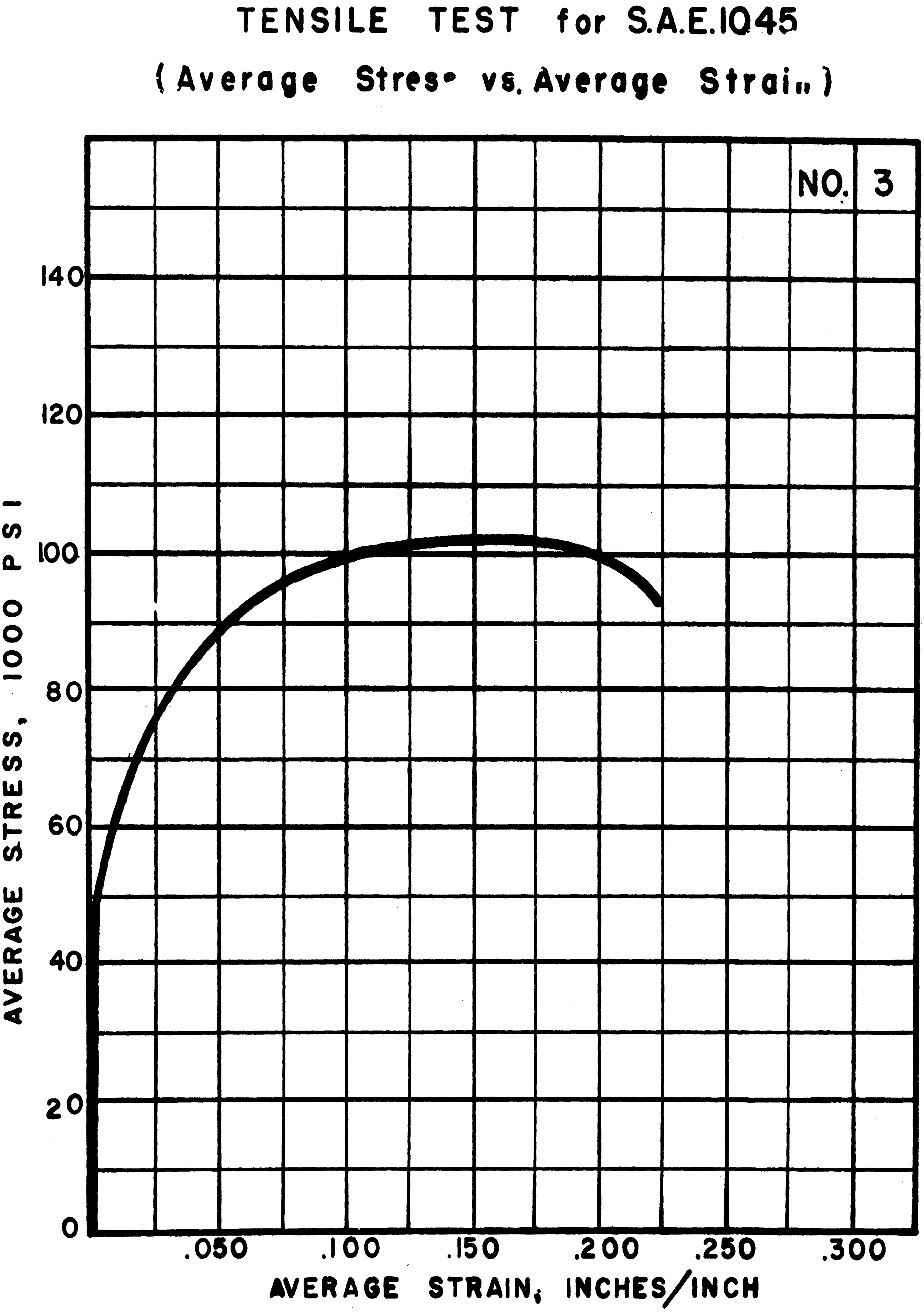

TENSILE TEST for S.A.E.1045
(Average Stress vs. Average Strain)
NO. 3
140
120
100
80
60
40
20
0
AVERAGE STRESS, 1000 PSI
.050
.100
.150
.200
.250
.300
AVERAGE STRAIN, INCHES/INCH

Fig. 12

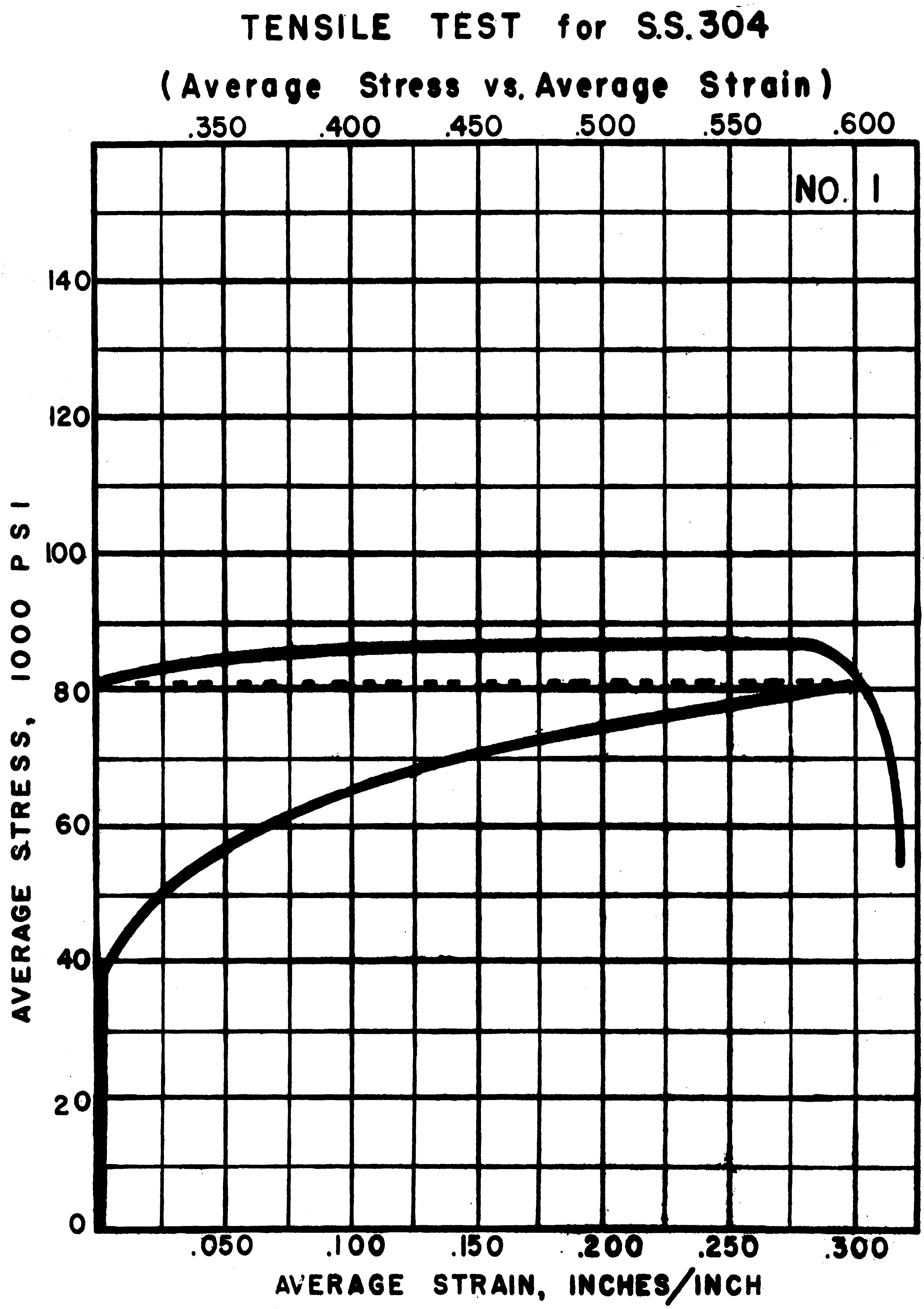

TENSILE TEST for S.S. 304
(Average Stress vs. Average Strain)
.350
.400
.450
.500
.550
.600
NO. 1
140
120
100
80
60
40
20
0
AVERAGE STRESS, 1000 PSI
.050
.100
.150
.200
.250
.300
AVERAGE STRAIN, INCHES/INCH

Fig 13

TENSILE TEST for S.S. 304

(Average Stress vs. Average Strain).

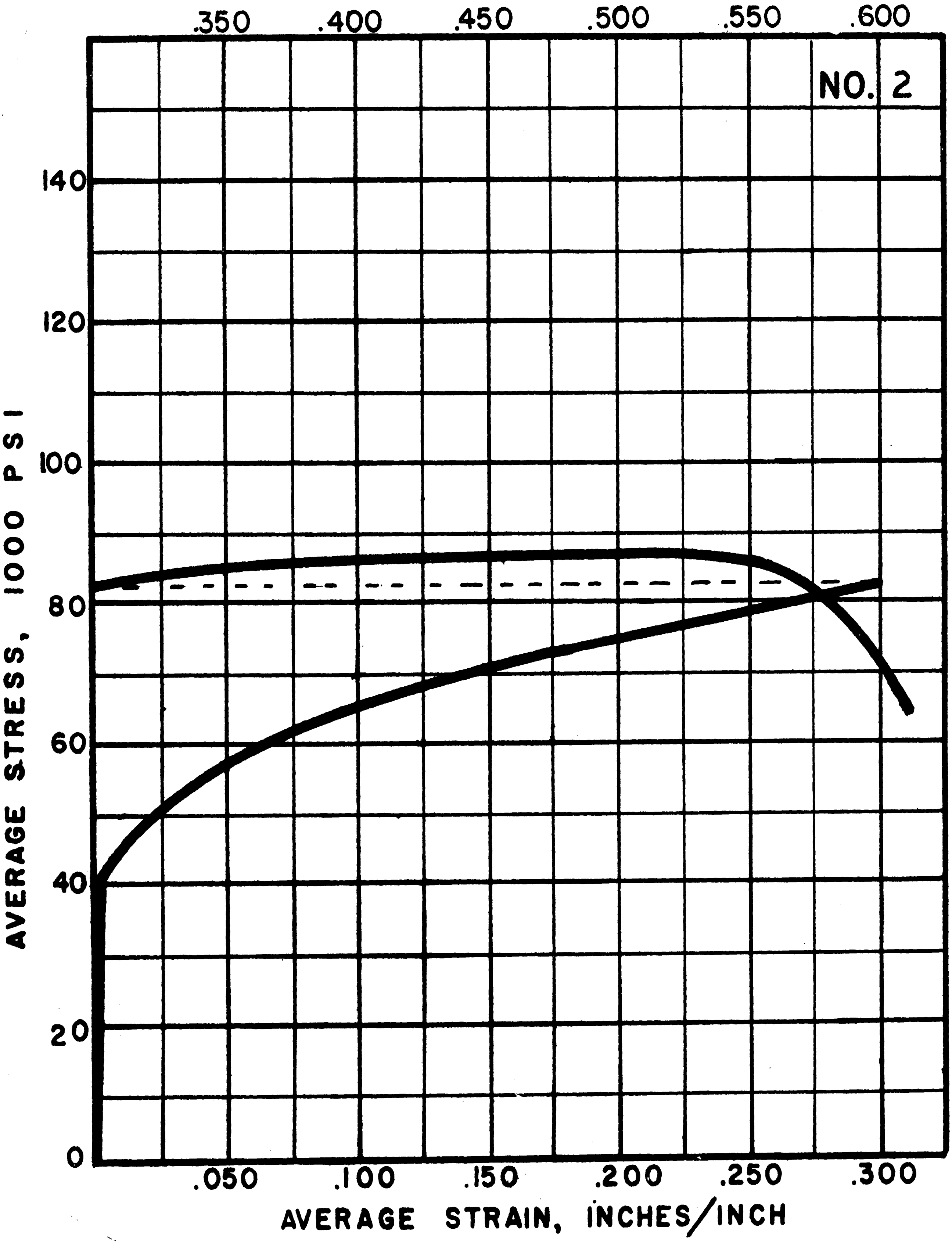
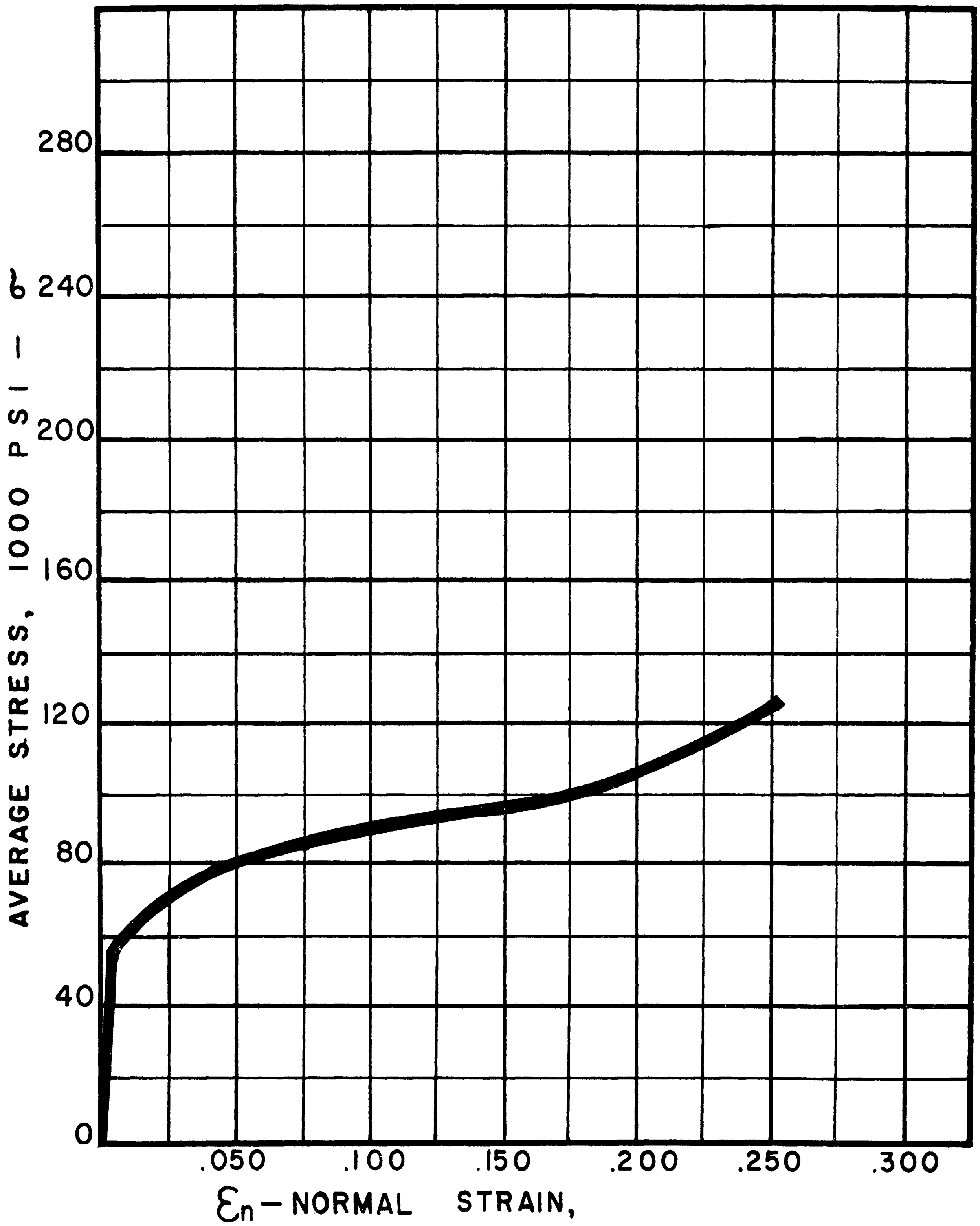


Fig. 14

TENSILE TEST for TI. 75A

(Average Stress vs. Average Strain)

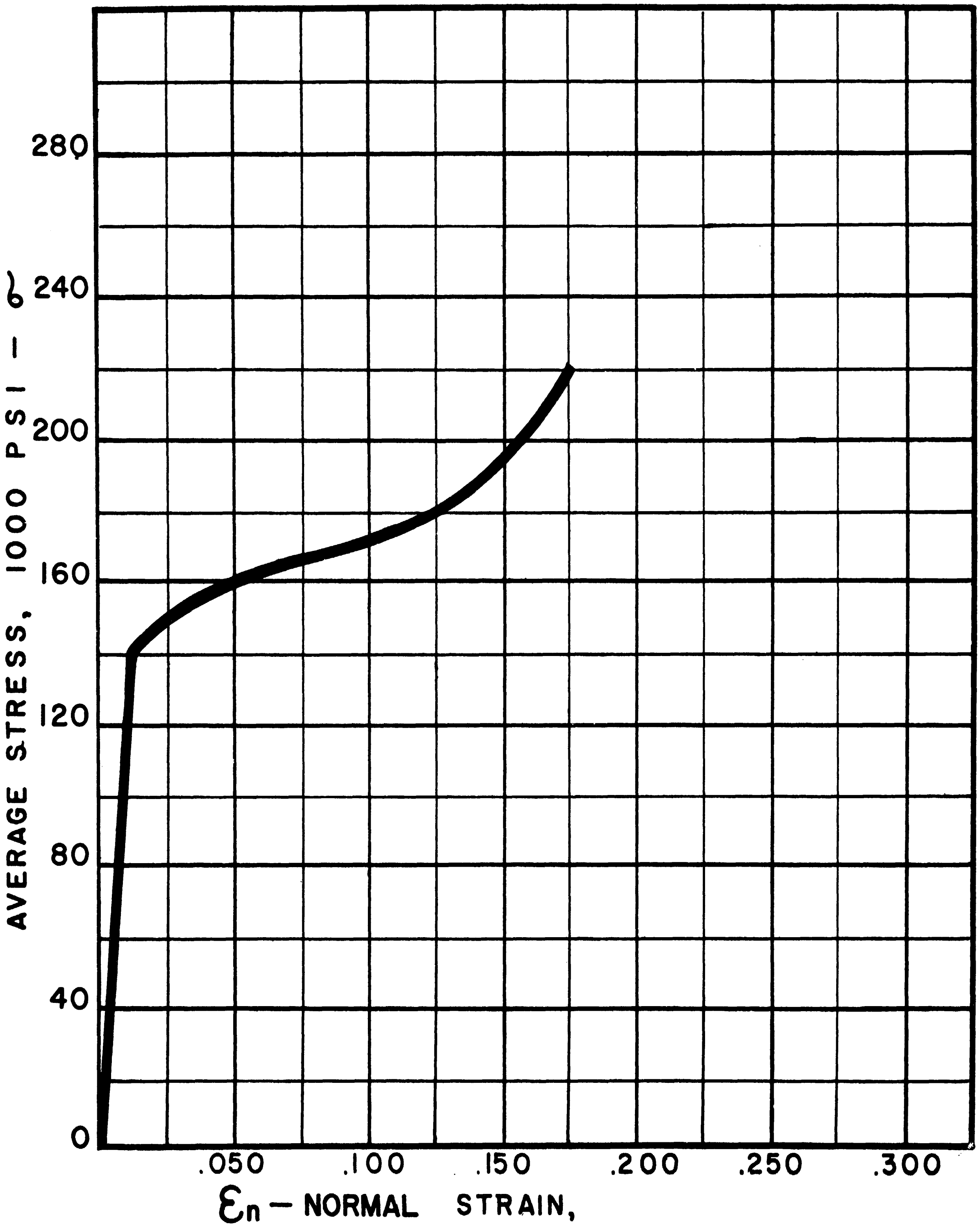


$$\mathcal{E}_n = \log_e\left(\frac{1+e}{\ }\right)$$

Fig. 15

TENSILE TEST for RC. 130 B

(Average Stress vs. Average Strain)

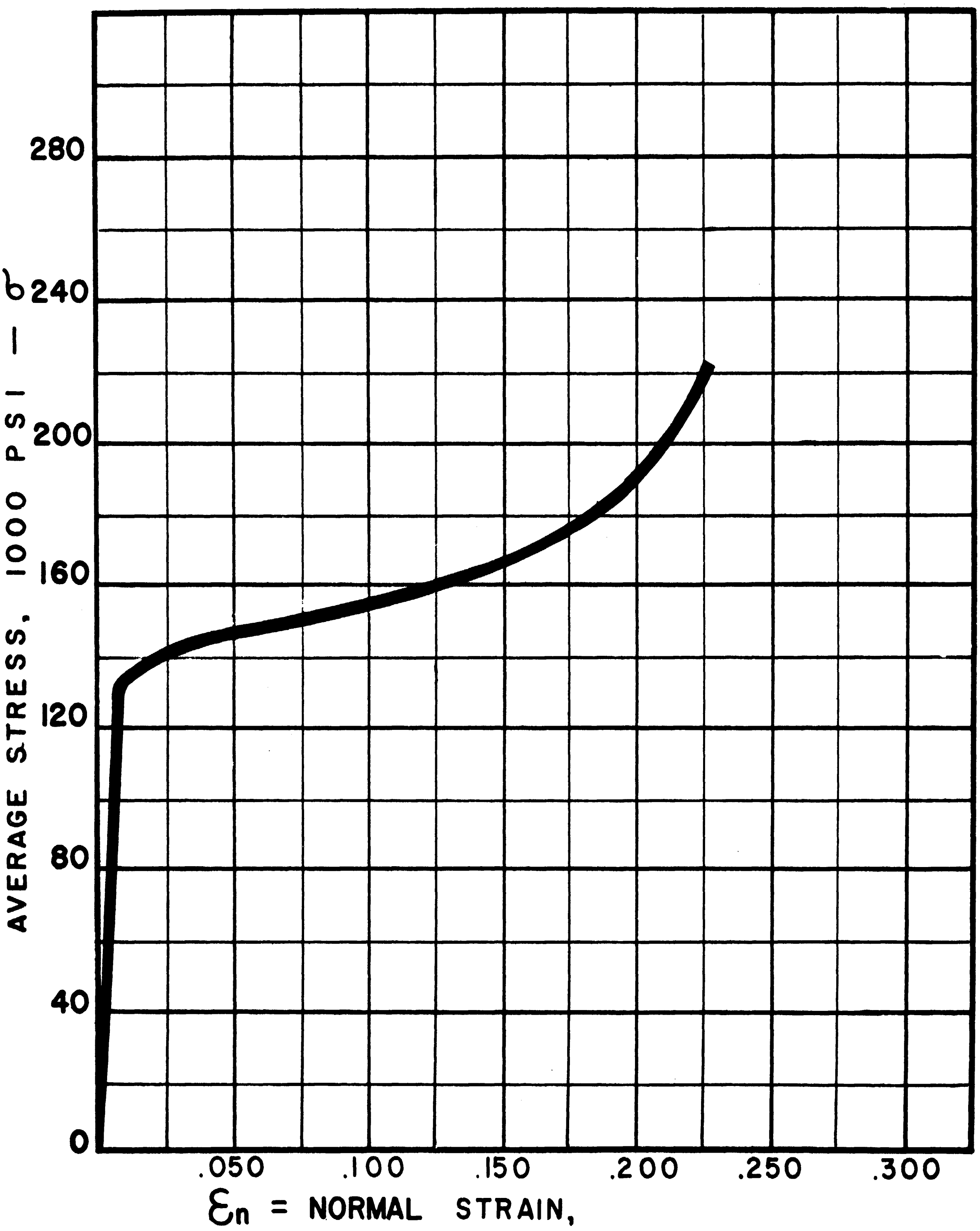


$\varepsilon_n = \log_e\left(\frac{1+e}{\ }\right)$

Fig. 16

TENSILE TEST for TI. 150A

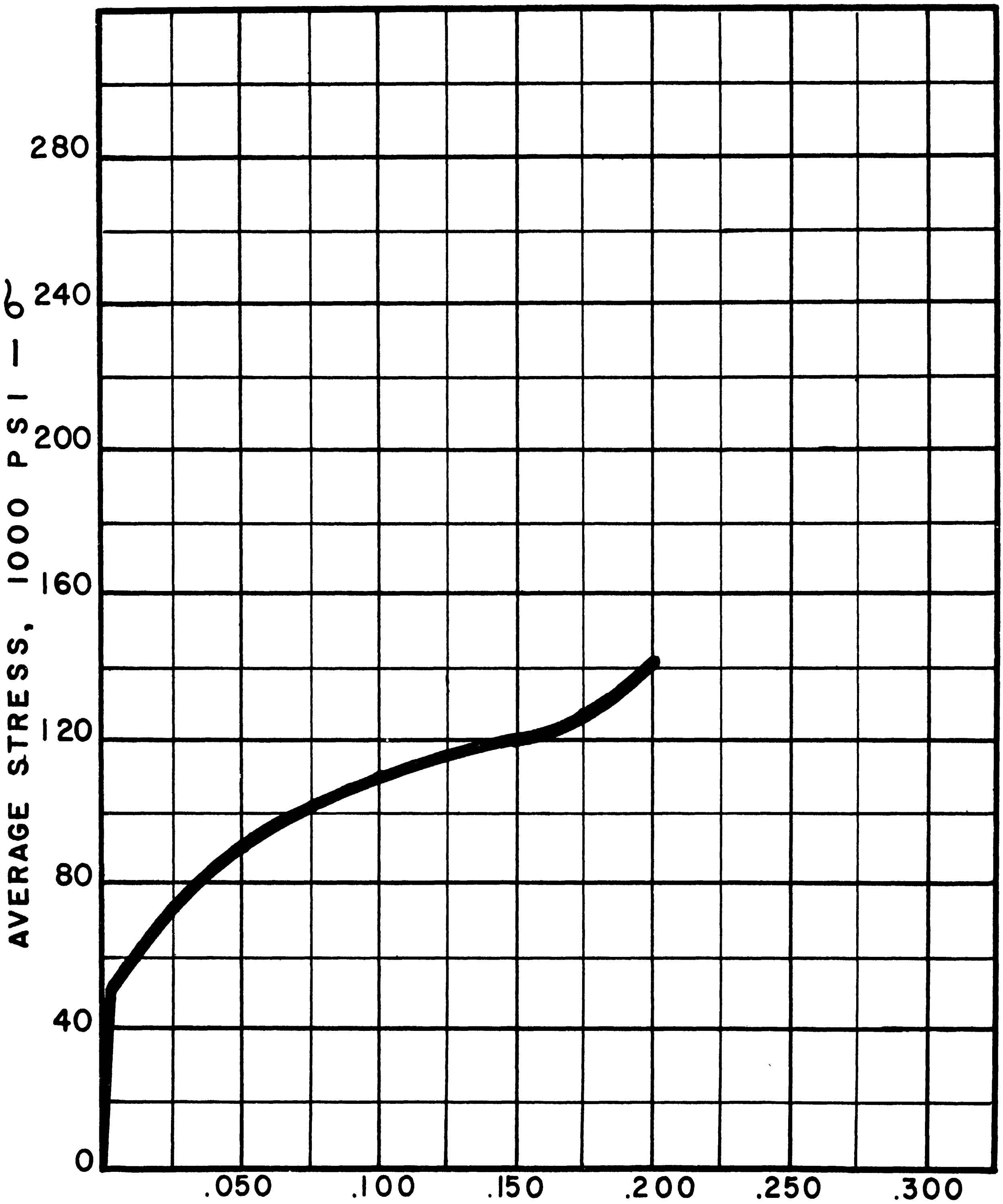
(Average Stress vs. Average Strain)



$$\varepsilon_n = \log_e \left(\frac{1+e}{} \right)$$

Fig. 17

TENSILE TEST for S.A.E. 1045
(Average Stress vs. Average Strain)



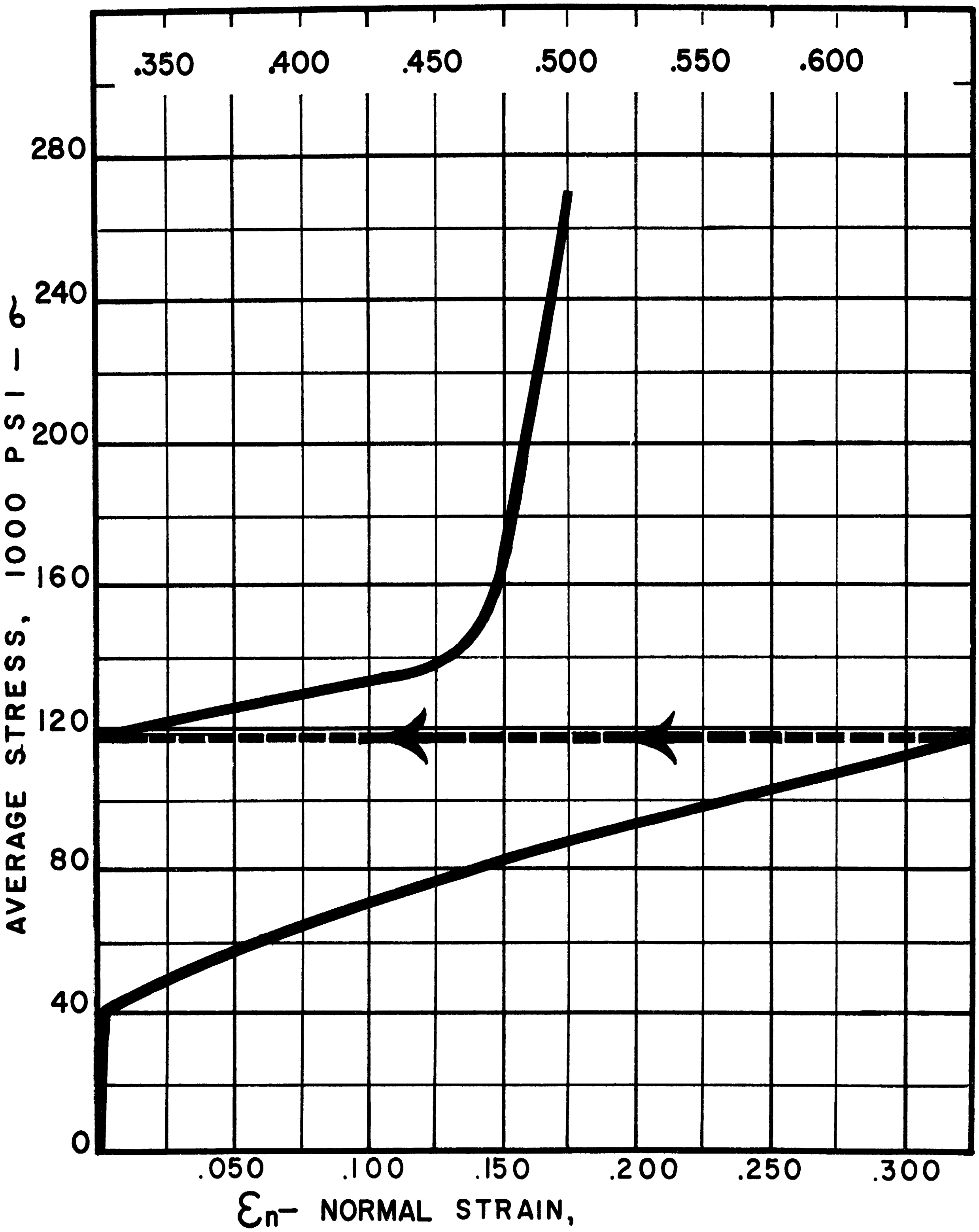
$\mathcal{E}_n$ = NORMAL STRAIN,

$$\mathcal{E}_n = \log_e\left(\frac{1+e}{\quad}\right)$$

Fig. 18

TENSILE TEST for S.S. 304

(Average Stress vs. Average Strain)



$$\varepsilon_n = \log_e\left(\frac{1+e}{}\right)$$

Fig. 19