THE MECHANICAL PROPERTIES OF REINFORCING STEEL BARS AT LOW TEMPERATURE

by

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ABSTRACT

The mechanical properties of four reinforcing steel bars were evaluated in the temperature range from -40°C (-40°F) to 40°C (104°F). The steel bars were: #9G60 (σ_{ys} = 60 ksi), #9G40 (σ_{ys} = 40 ksi), #6G60 (σ_{ys} = 60 ksi), and #6G40 (σ_{ys} = 40 ksi). Both tension and Charpy V-notch Impact tests were performed in the present study. The tensile tests were carried out using a portable loading frame. A hydraulic cylinder was used to provide the force necessary to pull the specimen to rupture and the load on the specimen was measured by means of three calibrated load cells. The strains were measured with a 2" gage length extensometer, and the fracture strain was measured with calipers.

The results of the tension tests showed that the yield and fracture stresses increase with decreasing temperature. The magnitude of the fracture strain does not change markedly with temperature. No consistent pattern can be discerned for the variations of yield strain with temperature.

The Charpy impact tests were conducted by an Avery Charpy Impact Testing machine with a striking velocity of 16.5 ft per sec and an initial energy 220 ft lb loaded as a simple beam configuration. The Charpy impact test showed that the steel bar lost impact resistance when the testing temperature was decreased.

In this report, the results of the tests were summarized to show the relationships between (1) yield stress vs temperature behavior curves, (2) fracture stress vs temperature curves, (3) yield strain vs temperature, (4) fracture strain vs temperature, (5) stress-strain curves at each temperature, and (6) the Charpy Impact energy vs various temperature curves.

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CHAPTER 1

INTRODUCTION

The reinforcing steel bar is one of the most important and widely used materials in the field of civil engineering. The environmental conditions under which they are being used range from the warm tropics to the extreme cold of the polar regions. Thus, great attention is being given to the changes in their physical and mechanical properties in relationship to environmental conditions. The vast amount of literature and papers on the subject of brittle fracture in steel and metals, deals essentially with notch-impact testing, both in tension and bending. The tests point out the fact that the material structure and testing temperature are important variables. The main finding of these investigations is that steel or metal become brittle at low temperature and at high strain rates, and ductile at high temperatures. However, many civil engineering structures built of steel successfully function in the extreme cold of the Canadian North. Hence either steel loaded at extremely low strain rates is unaffected by low temperatures or safety factors against yield are so high the steel is relatively unstressed. Either way it is important to determine the usefulness of the Charpy tests.

This report presents the results of four types of reinforcing steel bars tests conducted at temperatures ranging from -40°C to 40°C. Both tension and Charpy V-notch Impact tests were performed in this study.

The materials tested included: #9G60 (σ_{ys} = 60 ksi), #9G40 (σ_{ys} = 40 ksi), #6G60 (σ_{ys} = 60 ksi), and #6G40 (σ_{ys} = 40 ksi), manufactured by Lesco Inc., Montreal, Canada and Dosco Ltd., Montreal, Canada. These grades are representative of steel bars used in a broad range of civil engineering applications. Tests performed on specimens taken from bars conformed to ASTM specification A370-68.

The mechanical properties studied in this investigation include the following:

(a) Yield stress versus various temperatures
(b) Fracture stress versus various temperatures
(c) Yield strain versus various temperatures
(d) Fracture strain versus various temperatures
(e) Elongation in 2 inches
(f) Reduction of area
(g) Initial slope of the stress-strain curve (modulus of elasticity-Young's Modulus)
(h) Charpy Impact energy versus various temperatures.

CHAPTER 2

HISTORICAL REVIEW

The problem of brittle fracture of steel subjected to tensile testing at low temperature has been investigated by various testing methods. Many papers have been published on this subject since as long as seventy years ago. Unexpected brittle failure of mild steel structures is a serious problem. There are innumerable cases of brittle failures of a disastrous nature. Most publicized of these are welded ships which have broken in two, at sea or even in the dock, where over a thousand cases of severe damage as a result of brittle failure have been reported. Other steel structures have experienced the same phenomenon. These include bridges, storage tanks, pressure vessels, gas containers and pipe lines. By investigating the failure of these disasters it was shown that they seemed to have three elements in common - they occurred at reduced temperatures, fractured without appreciable elongation (brittle fracture) and were subject to unfavorable stress conditions in the welded joints.

From these investigations, much has been learned about the brittle behavior of steel, and the prevention of brittle fracture. From these theoretical analysis and experimental investigations, an important fact about the behavior of steel emerged has been brought to this study; i.e. steel becomes brittle at low temperature, and ductile at high temperature.

A wide variety of fracture problems arising during World War II stimulated re-examination of these ideas, as well as the introduction of new ones. From the viewpoint of steel structures, progress in the understanding of fracture up to the end of 1947 is summarized in the proceedings of two Conferences: the 1945 British Admiralty Conference on "Brittle Fracture of Mild-Steel Plate" at Cambridge [5] and the American Society of Metals Symposium on "Fracturing of Metals" at Chicago in 1947 [6]. Also noteworthy are two 1947 review papers by Gensamer et al., [7] citing more than 250 references. In the A.S.M. Symposium, Irwin [8] proposed that an understanding of the onset of crack propagation should be sought in terms of the development of an unbalance between the Griffith [4] - theory strain - energy release rate and the plastic-strain work rate required for crack extension. A large proportion of the material presented in the two conferences is still of interest and value.

The lively interest in fracture, coupled with the lack of a dominating accepted viewpoint, resulted in a substantial confusion which is reflected in the 1948-1959 literature. Metallurgists regarded the ductile-brittle transition behavior as predictable in terms of a "transition temperature", but no general agreement existed on how to define and use this property in practical engineering applications. In the light of the well-established effect of dimensions, some regarded any "transition-temperature" concept as a dangerous oversimplification.

A forceful summary of serious fracture failures by Shank (1954), [9] coupled with the prospects for control of such failures, provided no assurance that disastrous fracture failures would not continue as in the past.

After 1900, notched-bar impact testing became of increasing interest to metallurgists and engineers, primarily because of the sensitivity of such tests to the ductile-brittle transition. Ludwick [16] proposed an explanation of the transition behavior. He regarded the plastic-flow stress and the fracture stress as separately determined.

An important programme of notched-bar impact tests was carried out at the National Physical Laboratory, Teddington, after the First World War. Stanton and Batson (1921) [17] reporting this work, emphasized the fact that, with increase in specimen dimensions, a substantial decrease in the fracture work per unit volume was observed. The serious implications of this finding as regards the general applicability of notched-bar testing, and upon structural-strength estimates based upon the usual scaling laws as well, were not overlooked in the published discussions of the Stanton-Batson paper.

In 1959, the American Society for Testing Materials established a special committee for fracture testing of high-strength metals. The first report of this committee [10] stated that "the validity of the analytical methods of fracture mechanics is sufficiently well established" to permit their use in determining whether a fracture test "is measuring the significant quantities governing performance" and extent to which a fracture test result "may be generalized to predict the behaviour of the more complex structure existing in service." The A.S.T.M. Committee provided tentative recommendations on crack-toughness and screening measurement procedures which have been extensively applied. See Appendix C.

CHAPTER 3

TENSION TEST

3.1 General

By far, the great majority of commercial specifications, insofar as they are concerned with the physical properties of the material at hand, are based on tensile tests. Usually, the properties considered in such a test are stress-strain relationship, yield stress, fracture stress, percent elongation, Young's Modulus and percent reduction in area at fracture.

3.1.1 Stress-Strain Relations for Uniaxial Tensile Loading [18]

Uniaxial tensile loading provides the simplest way to develop the stresses required to produce large elongation, mechanical instability, and fracture. Suppose that a given material is loaded in simple tension and that:

ℓ_o = initial length of specimen or gage length
A_o = initial uniform cross-sectional area
p = applied tensile load
A = instantaneous uniform cross-sectional area after deformation has occurred
ℓ = instantaneous length after some deformation has occurred.
α = angle

The engineering stress is defined [19] as $\sigma_E = P/A_o$ and is based on the original cross-sectional area, whereas the true tensile stress $\sigma = P/A$ takes into account the fact that the load-bearing area decreases with increasing strain. The engineering strain ε_E is defined [19,20,21] as the change in length divided by the initial length

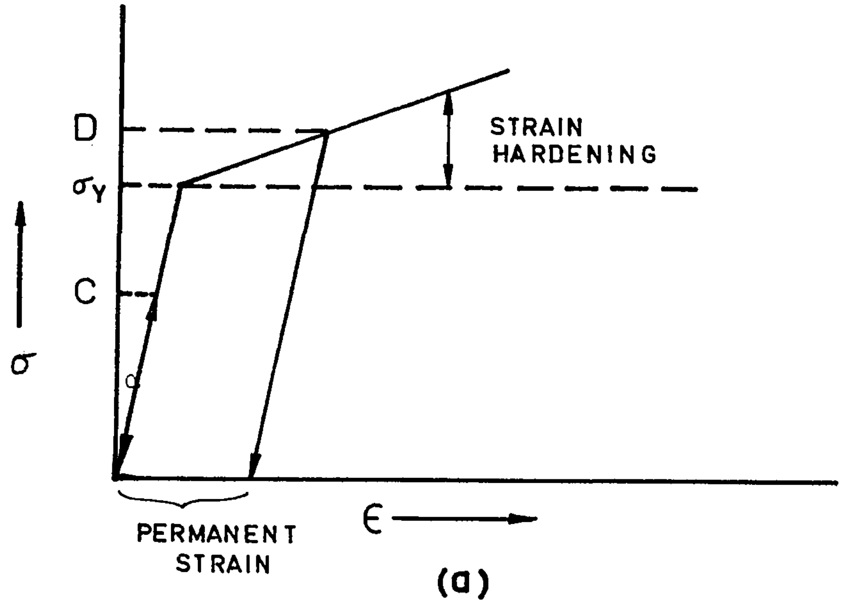
$$\varepsilon_E = \frac{\ell - \ell_o}{\ell_o} = \frac{\Delta\ell}{\ell_o}$$

whereas the true plastic strain ε is the sum of all the instantaneous increments of an element of length ℓ

$$\varepsilon = \int_{\ell_o}^{\ell} \frac{d\ell}{\ell} = \ell n \frac{\ell}{\ell_o} = \ell n\left(\frac{\ell_o + \Delta\ell}{\ell_o}\right) = \ell n(1 + \varepsilon_E)$$

Since $\ell n\ (1 + x) \simeq x$ for $x < 0.10$, the engineering strain and the true plastic strain are approximately the same for plastic strains less than about 10%.

At low stresses and for short-time loading most materials exhibit elastic behavior and stress is proportional to strain. Hooke's Law $\sigma = E_\varepsilon$ then applies, where E is the elastic modulus. In the elastic range, the strains are reversible with stress, that is, if the load is removed when $\sigma = C$ (Fig. 3-1a), the material returns to its original shape.



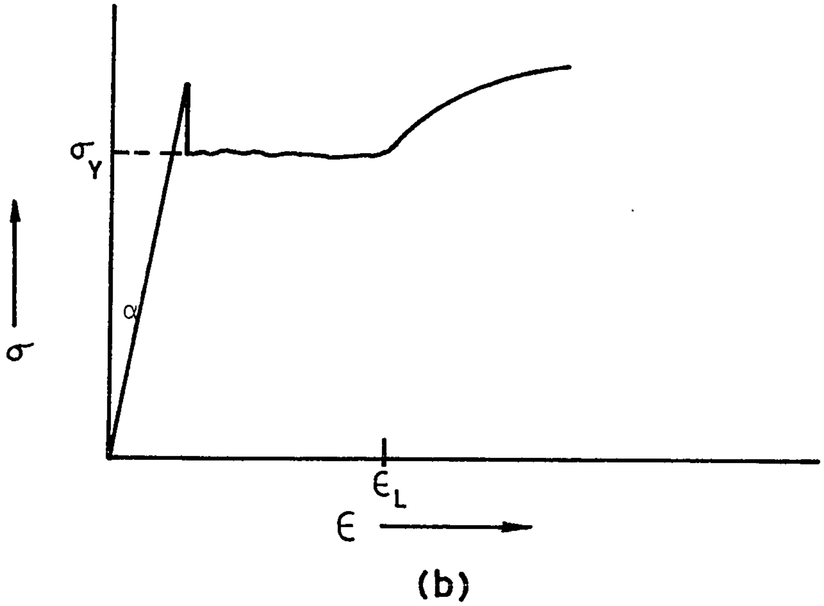


FIG. 3-1 TYPICAL STRESS STRAIN BEHAVIOR OF POLYCRYSTALLINE MATERIALS.
(a) Generalized curve. (b) Curve for material that does have a sharp yield point and Luders strain ϵ_L

The shape of the stress-strain curve in the plastic region varies from one material to the next. In general, the stress required to produce additional strain after yielding begins increases with strain. This is referred to as strain-hardening (i.e., the material becomes stronger as it deforms). The rate of strain hardening d_σ/d_ε is much less than the elastic modulus so that the stress-strain curve appears flatter in the plastic range (Fig. 3-1a).

Because plastic deformation occurs by a process of shear, there is essentially no change in the volume of the specimen during deformation. After the specimen has elongated to a length ℓ,

$$A\ell = A_o\ell_o$$

so that

$$\varepsilon = \ell n(\frac{\ell}{\ell_o}) = \ell n(\frac{A_o}{A})$$

As plastic deformation continues, the cross-sectional area decreases, but the load-carrying capacity increases because of strain hardening. Eventually an elongation is reached (point E, Fig. 3-2a) where the incremental increase in load-carrying capacity (Ad_σ) due to strain hardening becomes less than the incremental decrease load-bearing area. At this point mechanical instability (necking) begins and further deformation takes place only in the necked region. The load is a maximum at point E

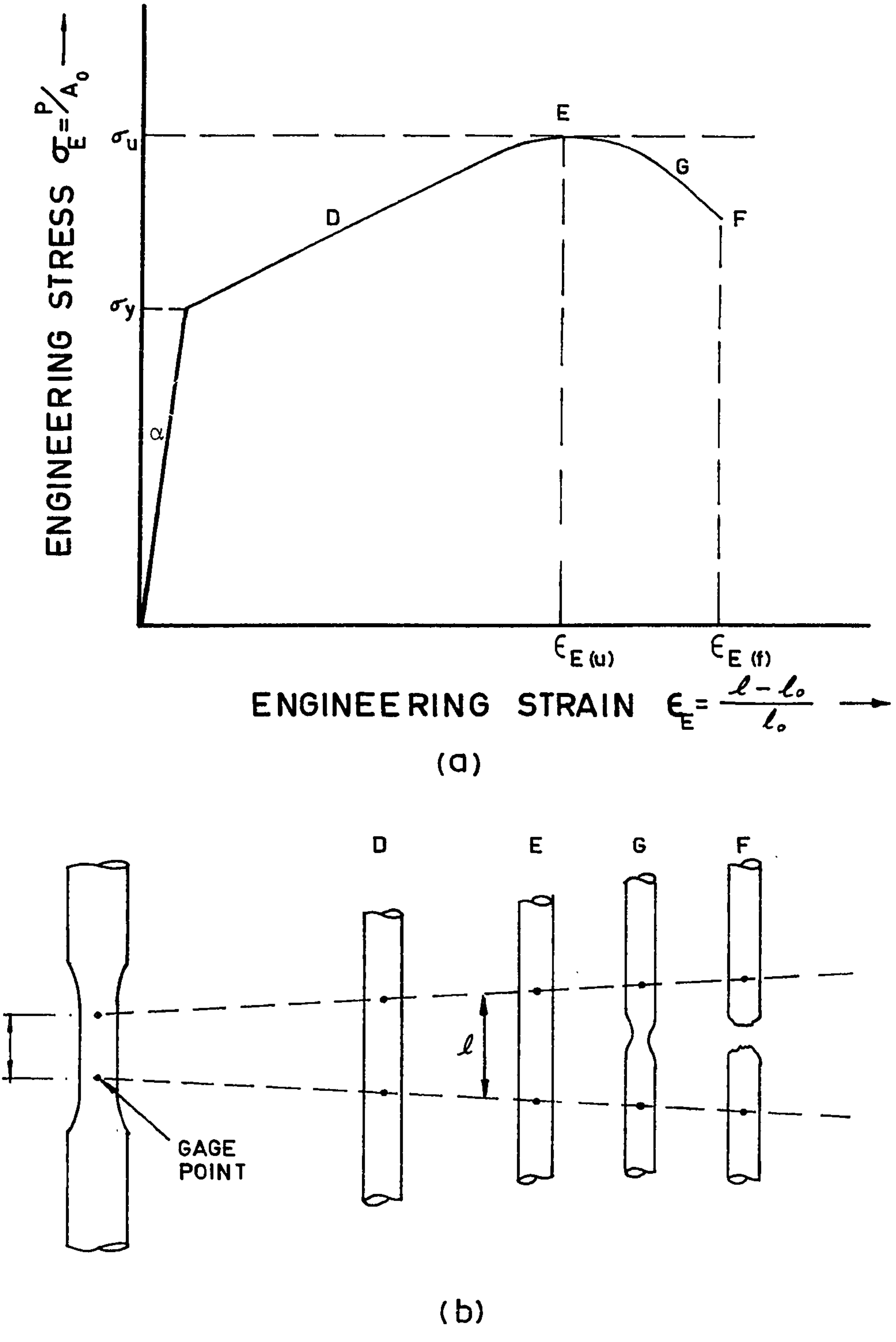


FIG. 3-2 (a) The engineering stress engineering strain curve of a material that does not show a yield point

(b) The appearance of the gage length of a tensile specimen at the indicated stages of strain and the ultimate tensile stress UTS) is defined as $\sigma_u = P_{max}/A_o$. Further elongation in the necked region eventually leads to fracture at point F. The engineering strain at this point is $\varepsilon_{E(f)}$. Fig. 3-2b shows the shape of the tensile specimen at various stages of the deformation process.

3.1.2 Elongation

In most instances, the elongation during testing is measured over a 2" gage length using some form of extensometer. The elongation after fracture may be obtained with sufficient accuracy by matching together the parts of broken specimen. These must be pressed firmly together. The distance between gage marks may then be measured with dividers as the fracture length of the test piece

$$\frac{\text{final length - original length}}{\text{original length}} \times 100 = \text{percent elongation}$$

3.1.3 Reduction of Area

The area of the narrowest section after fracture is measured as the area at fracture.

$$\frac{\text{original area-area at fracture}}{\text{original area}} \times 100 = \text{percent reduction in area}$$

3.1.4 Young's Modulus

Modulus of elasticity is defined as the ratio of stress to strain. Because the results of the test are recorded in the form of a stress-strain diagram, E is the slope of the graph within the elastic range, i.e., $E = \tan \alpha$ The results of Young's Modulus at various temperature was presented in Table 1.

3.2 Materials

The material used in this study was supplied by Lesco Inc., Montreal, Canada and Dosco Ltd., Montreal, Canada in the form of 3/4" (#6) and 1-1/8" (#9) diameter reinforcing steel bars. Four types of steel bars were investigated; namely, #9G60, #9G40, #6G60 and #6G40. These grades are representative of steel bars used in a broad range of civil engineering applications.

3.3 Apparatus

The tensile testing equipment and associated apparatus used in this study is shown in Fig. 3-3 and the arrangement of the test at low temperature laboratory is shown in Fig. 3-4. This equipment designed as a loading frame employs a 60-ton hydraulic RCH-603 hollow cylinder to store the energy necessary to pull a specimen to rupture in about 0.1" per min. The load was produced by a hydraulic pump which was set up separately from the frame, connected to it with a flexible rubber hose, was filled with Esso Univis J-43 Hydraulic Fluid H-515 (which can stand temperature at -40°C). The load of the specimen was measured by means of three calibrated load cells which were placed between the top and middle plates. The 1.5" dia. x 4.5" long load cells were made of cast iron pipe, both ends were mounted with hardened yellow copper brass caps. A photograph of the details of the load cell is shown in Fig. 3-5. The calibration was carried out using a Tinius Olsen machine at room temperature in the structural laboratory. In order to eliminate the critical temperature effect, the strain gauges which were mounted at the load cells were chemically coated with M-Coat A Air-drying Polyurethane Coating (can stand from -100°F to 300°F within one year's time). A photograph of the load cell calibration is presented in Fig. 3-6. The load vs. strain curve from the calibration was developed as shown in Fig. 3-7. The advantages of this set up are: (1) easy to move the testing equipment from one place to the other, (2) after rupture the specimens sometimes jump up in the air, so the pumping system was set up separately for the sake of safety.

3.4 Specimens

All specimens were steel bars 3 ft. long with the middle section reduced into 0.5 in. in diameter over a 2-in.

gage length. The dimensions of the gage length section was conformed to the A.S.T.M. Specification A370-68 as shown in Fig. 3-8. The ends of the specimens outside of the gage length section was reduced to 5/8" in diameter for the purpose of gripping. A sectional view of the assembly is shown in Fig. 3-9. The specimen at the gage length section was gage marked with ink. The purpose of these gage marks is to determine the percent elongation. Both ends are approximately equidistant from the center of the length of the reduced section. All specimens were fabricated by the technical staff at the machine shop under the room temperature.

3.5 Temperature

In buildings the structure is usually inside the curtain wall line, so that the columns and beams are protected from the temperature fluctuations of the weather. However, some structures, such as Place Ville Marie, Montreal have partly exposed columns where the inside face of the columns is heated but the outside face(s) is at the ambient external temperature. Measurements taken on the columns at Place Ville Marie have shown the temperature on the inside face of the column to be 75°F and the temperature on the ouside face to be -20°F. These are fairly typical temperatures encountered in Canada. Thus, the testing temperatures selected in this study ranged from -40° to 40°C. The mechanical properties of steel bars developed under these range of temperatures was good enough to cover the temperature range applicable for most building applications.

The test temperatures were obtained in the following facilities:

40°C	at hot temperature laboratory
20°C	at structural laboratory
0°C	at low temperature laboratory
-20°C	at low temperature laboratory
-40°C	at low temperature laboratory

3.6 Testing Procedure

The specimens in all cases were pulled to fracture in tension by using a hydraulically operated 60-ton capacity tensile testing frame. Two test specimens were made from each grade of steel bars. The specimens were kept at the desired temperature at least 6 hours. The specimens were gripped between a hardened steel platen at the top and the cylinder of the hydraulic jack at bottom. It is the function of the gripping device of the testing frame to transmit the load from the heads of the cylinder to the specimen under test.

In examining the tensile properties of the specimens, the load is obtained by measuring the change in resistance of the strain gauges which are appropriately mounted on the load cells. Then, the loading applied to the specimen can be obtained from the calibration curve. Elongation of the specimen was obtained directly with a

Metzer mechanical extensometer at the section of the gage length. The final length of the specimen was obtained with sufficient accuracy by matching together the parts of broken specimen. The distance between gage marks was then measured with dividers. The reduction in area of the specimen was measured with thin-pointed calipers and read from a steel scale. The strain gauge readings of deformations were conducted with a SR-4 Type "N" Portable Strain Indicator through which a Switching and Balancing Unit, Model 225. The strain gauges were mounted at the mid-height of each load cell, one longitudinal and one transverse electrical resistance foil type strain gauges, 5 mm gage length, type EA-06-250BG-120 from Micro-Measurements, Romulus, Michigan.

CHAPTER 4

IMPACT TEST

4.1 Apparatus and Specimens

Charpy V-notch tests of four reinforcing steel bars, which correlated to the tensile tests, were tested at temperatures ranging from -40°C to 40° using the Avery Charpy Impact Testing Machine with a striking velocity of 16.5 ft. per sec. and an initial energy 220 ft-lb loaded as a simple beam condition as shown in Fig. 4-1. The steel bars being tested were: #9G60, 9#G40, #6G60, and #6G40. The V-notch specimens were machined at room temperature to the A.S.T.M. dimensions. In arriving at the 0.394" by 0.394" cross section, the notches were machined with $2\frac{3}{4}$" multiple-tooth milling cutters. The dimensions and shapes of specimens is shown in Fig. 4-2.

4.2 Testing Procedure

Three test specimens were made from each steel bar. Tests carried out at 20°C were conducted in the structure laboratory at room temperature. Tests at 40°C were carried out in the concrete curing chambers in the concrete laboratory. Tests at 0°C, -20°C and -40°C were carried out in the low temperature laboratories in the Colonel By Building. In carrying out the tests the specimens were brought to the desired temperature for at least 6 hours and then followed by a quick transfer to the testing machine which is set at room temperature with immediate release of the pendulum. The test specimens were then fractured by means of a full blow of the pendulum. Stop watch measurements showed that the completed operation was carried out in less than five seconds. The rate of temperature loses during this testing period have been shown by many investigators to be negligible [38].

The purpose of the investigation was as follows: (a) to evaluate the ability of reinforcing steel bars, at various temperatures, to withstand shock loading, by measuring the absorbed energy and (b) to study the type of fracture.

CHAPTER 5

DISCUSSION AND RESULTS

The main object of this study was to determine the effect of temperature and rate of loading on the mechanical properties of reinforcing steel bars. A secondary object of the study was to determine the validity of the Charpy V-notch test as an indication of the ductility or otherwise of the reinforcing steel bar. A systematic series of tests were carried out at different temperatures to determine the tensile characteristics and the Charpy V-notch energies of specimens made from reinforcing steel bars.

All test specimens, tensile and Charpy, were cut out of long bars of reinforcing steel. All bars were delivered from the one supplier at the same time and all bars of one size were specified to be from the same heat to minimize uncontrolled between specimen variations.

Tests were carried out at 20°C temperature increments from -40°C to 40°C. All tension test results were duplicated to ensure reliability while the Charpy tests results are the average results of three specimens.

The results presented consider (1) the tension yield stress, fracture stress, yield strain and fracture strain and (2) the Charpy V-notch impact energy with variation of temperature. Table 1 presents the significant data from the tension tests and Table 2 gives the results of the Charpy test.

The stress-strain diagrams to the same scale for all test specimens are given in Figures 5-17 to 5-36 in Appendix A.

Figures 5-1 through 5-4 show the variation of yield stress with temperature for specimens made from bars #9G60, #9G40, #6G60 and #6G40 respectively. All four types of bars show approximately a 20% increase in yield stress with a temperature decrease from +20°C to -40°C.

Figures 5-5 through 5-8 show the variation of fracture stress with temperature. All four types of specimens also demonstrate an increase in fracture stress of approximately 25% with a temperature decrease from +20°C to -40°C, obviously temperature effects yield stress and fracture stress to approximately the same extent.

Figures 5-9 through 5-11 show the variation of yield strain and fracture strain with temperature. No consistent pattern can be discerned for the variation of yield strain with temperature. No reason has been found to explain this behaviour.

The magnitude of the fracture strain does not change markedly with temperature. Hence these steels do not, in an engineering sense, become more brittle with decrease in temperature.

The failed tensile specimens are shown in Figures 5-37 to 5-41. The failure phenomena are the same for all specimens.

The results from the Charpy V-notch tests are presented in Figures 5-13 to 5-16. The transition from brittle to ductile fracture which is characterized by a sharp change in the slope of the plot of Charpy energy against temperature can easily be seen in these figures. The transition temperature is seen to be in the vicinity of $0^{\circ}C$. The Charpy energy appears to monotonically increase for all four groups of specimen with increasing temperature. No direct correlation can be made between the Charpy results and any of the tension test results.

Figures 5-42 to 5-46 show typical failure phenomena from the Charpy test specimens. In Figure 5-42 the specimens tested at $-40^{\circ}C$ can be seen to have broken in an almost entirely brittle fracture, i.e. about 98% of the fracture area was of the brittle type. In contrast, in Figure 5-46, the specimens tests at $40^{\circ}C$ show approximately 60% of the failure zone to have failed in a ductile manner.

CHAPTER 6

CONCLUSIONS

Insufficient knowledge about the brittle fracture of reinforcing steel bars is one of the basic problems of contemporary engineering because of the immense practical importance of these properties. Tensile tests at low temperatures are one of the most realistic means of determining the desired characteristics of reinforcing bars which in practice are subjected to a tensile stress.

The mechanical properties of more than 40 reinforcing steel bars were evaluated at various temperatures. A minimum of two specimens were tested at each temperature investigated, extra tests being conducted when duplicate runs gave unsatisfactory correspondence. A number of experiments concerning properties were conducted in the temperature range from $-40^{\circ}C$ to $40^{\circ}C$ under study.

The conclusions derived from this study are as follows:

(1) Yield stress and fracture stress were found to increase with decreasing temperature. This is in agreement with previously published results.

(2) Young's modulus was found not appreciably changed with temperature over the temperature range tested. Previous investigators have commented that the modulus of elasticity appeared to increase with a lowering temperature

but the change was only 16% over a temperature drop from 20°C to -200°C. This would indicate that the change in modulus of elasticity over a temperature range of 40°C to -40°C would be small agreeing with the results obtained.

(3) The strain at yield appears to increase with decreasing temperature - as would be expected if the modulus of elasticity remains constant and the yield stress increase. This is in agreement with previous investigations.

(4) The fracture strain remained constant irrespective of temperature. This conclusion can also be made with respect to the test results of other investigations (Miklowitz [39]).

(5) Examination of the rupture surfaces of the tensile specimens indicated the specimen at 40°C failed in a ductile manner. The specimens ruptured at -40°C exhibited brittle rupture surfaces.

(6) Examination of the Charpy test specimens after failure show the specimens tested at -40°C have failed in a brittle manner while those tested at 40°C failed in a ductile manner.

(7) The Charpy results show a classic transition from ductile to brittle if the definition of brittle is taken to be the marked change in slope of the Charpy diagram. The transition temperature was approximately 0°C.

(8) The Charpy V-notch test results do not correlate with the results from the tension tests. Consequently, it

is advised that low strain rate determination of the low temperature mechanical properties be undertaken by tension tests when the results will be applied to a structure where the loads are applied slowly.

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TABLES

Table 1 Mechanical Properties of Reinforcing Steel Bars at Various Temperatures

Specimen No	Temp. °C	Yield Stress psi.	Fracture Stress psi.	Young's Modulus $\#/in^2 x10^7$	Elongation at Fracture in. %	Reduction of area at fracture in^2. %
#9G60	-40	24,200	184,000	3.06	21.6	11.6
	-40	82,000	186,000	2.86	21.7	11.3
	-20	70,800	165,000	2.84	22.5	11.8
	-20	70,000	165,000	3.66	22.0	11.0
	0	69,000	156,000	3.20	20.5	11.0
	0	67,200	158,000	3.17	20.2	10.9
	0	64,000	154,000	3.75	20.7	11.2
	20	61,200	151,000	2.86	21.1	10.4
	20	63,400	154,000	3.00	21.6	11.0
	20	62,300	153,000	3.07	21.0	11.2
	40	55,700	134,000	3.06	21.8	11.2
	40	56,000	137,000	3.06	22.0	11.5
	40	59,000	130,000	3.50	21.1	11.8
#9G40	-40	67,000	176,000	3.01	25.6	9.9
	-40	68,000	175,000	2.87	25.5	10.3
	-20	55,600	172,000	3.48	26.2	9.6
	-20	57,600	170,000	3.80	26.4	9.7
	0	48,000	157,000	3.30	23.8	10.0
	0	51,500	154,000	3.70	24.5	10.1
	0	51,000	150,000	3.50	23.5	10.0
	20	48,000	149,000	2.94	22.6	10.3
	20	49,500	151,000	3.00	22.5	10.0
	40	43,000	148,000	2.95	23.7	10.2
	40	43,500	149,500	3.00	24.7	10.1
	40	42,500	147,000	3.40	24.7	10.3

Table 1 - continued

Specimen No	Temp °C	Yield Stress psi.	Fracture Stress psi.	Young's Modulus #/in^{2}x10^7	Elongation at Fracture in. %	Reduction of area at fracture in^2 %
#6G60	-40	85,500	197,000	3.46	21.0	10.8
	-40	83,000	214,000	3.00	21.1	10.5
	-20	79,500	181,000	3.47	17.0	11.8
	-20	81,000	182,000	3.86	17.4	11.8
	0	78,500	174,000	3.05	19.0	10.1
	0	77,000	178,000	3.18	19.6	10.1
	20	65,000	170,000	3.45	17.4	10.5
	20	63,000	172,000	3.05	17.5	10.0
	40	63,000	166,000	3.05	21.2	11.1
	40	65,000	170,000	2.90	20.0	11.0
#6G40	-40	65,600	162,000	3.44	26.2	10.9
	-40	63,000	164,000	3.60	26.0	11.0
	-20	62,200	153,000	2.90	23.5	11.1
	-20	61,300	150,000	3.00	24.0	11.3
	0	57,800	145,000	2.90	22.5	11.2
	0	55,000	145,000	3.36	21.5	10.8
	0	59,200	147,000	3.06	22.5	11.2
	20	50,300	130,000	3.20	23.0	11.0
	20	49,500	133,000	3.06	23.1	11.2
	40	46,000	132,000	3.06	21.4	11.4
	40	42,500	132,000	3.02	22.0	11.5

Table 2 Charpy Impact Tests at Various Temperatures on V-notch Specimens of Four Kinds of Steel Bars

Steel	Charpy V-notch Impact at -					ft lb	
	$-40^{\circ}C$	$-20^{\circ}C$	$-10^{\circ}C$	$0^{\circ}C$	$10^{\circ}C$	$20^{\circ}C$	$40^{\circ}C$
G40 #6	7 4(6) 6	11 11(11)		17 19(18) 16		29 30(30) 31	34 33(34) 34
G60 #6	4 4(4) 5	7 9(8) 8		14 16(15) 14		30 31(29) 28	36 39(37) 35
G40 #9	5 7(6) 6	9 11(10) 10		16 16(16) 17		30 32(30) 28	36 34(35) 37
G60 #9	3 7(5) 5	7 8(9) 12		16 16(17.5) 19		27 25(27) 28	36 37(36) 34

The numbers in brackets show the average result

Table 3 Material Tested

Specimen No.	Size in.dia.	Point of Origin	Type of Steel	Producers	Yield Strength psi.	Tensile Strength psi.
#9G60	$1\frac{1}{8}$	60L9	Deformed Billet-steel bar	Lesco Inc., Montreal, Canada	60,000	75,000
#9G40	$1\frac{1}{8}$	9D	Deformed Billet-steel bar	Dosco Ltd., Montreal Canada	40,000	70,000
#6G60	0.75	6D60	Deformed Billet-steel bar	Dosco Ltd., Montreal, Canada	60,000	75,000
#6G40	0.75	L6	Deformed Billet-steel bar	Lesco Inc., Montreal, Canada	40,000	70,000

FIGURES

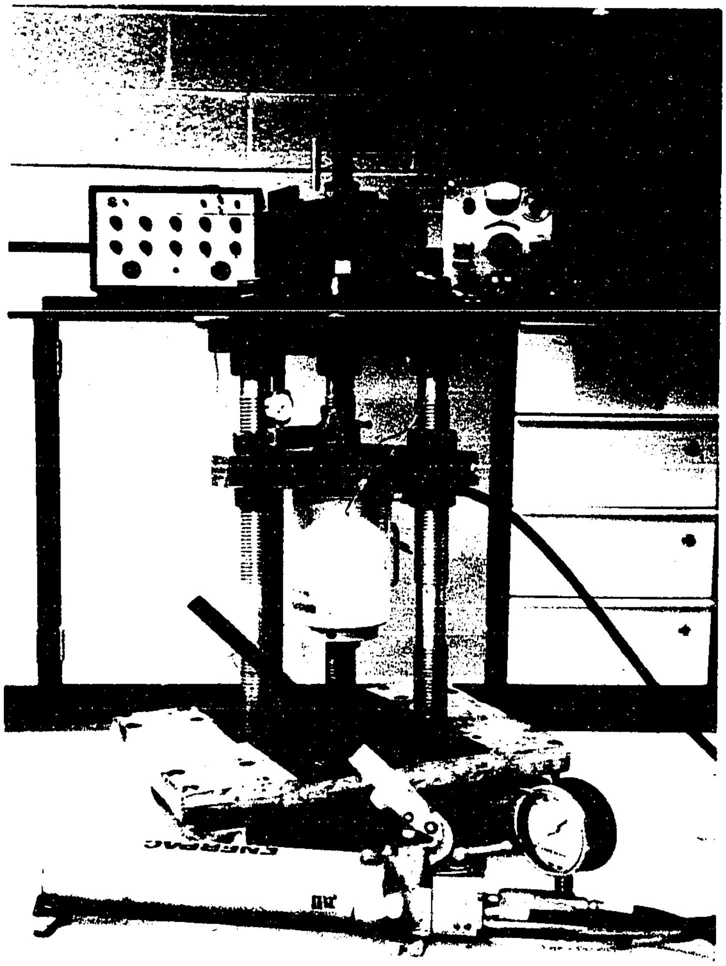


FIG. 3-3 ARRANGEMENT OF APPARATUS USED FOR TENSILE TESTING AT VARIOUS TEMPERATURE

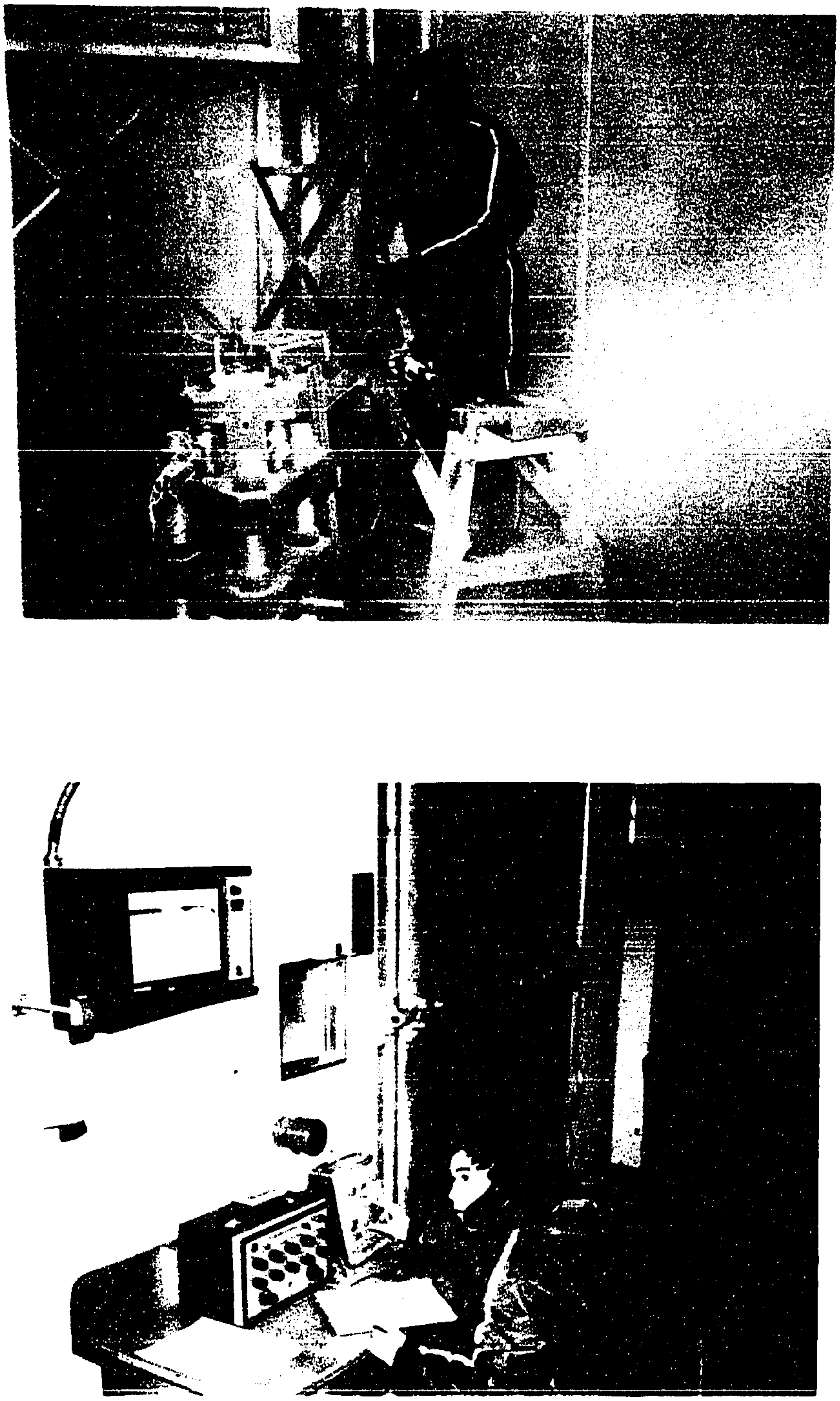
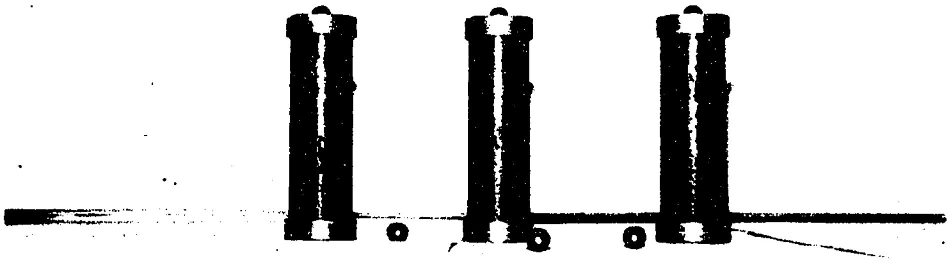


FIG. 3-4 TENSION TEST ARRANGEMENT AT LOW TEMPERATURE LABORATORY



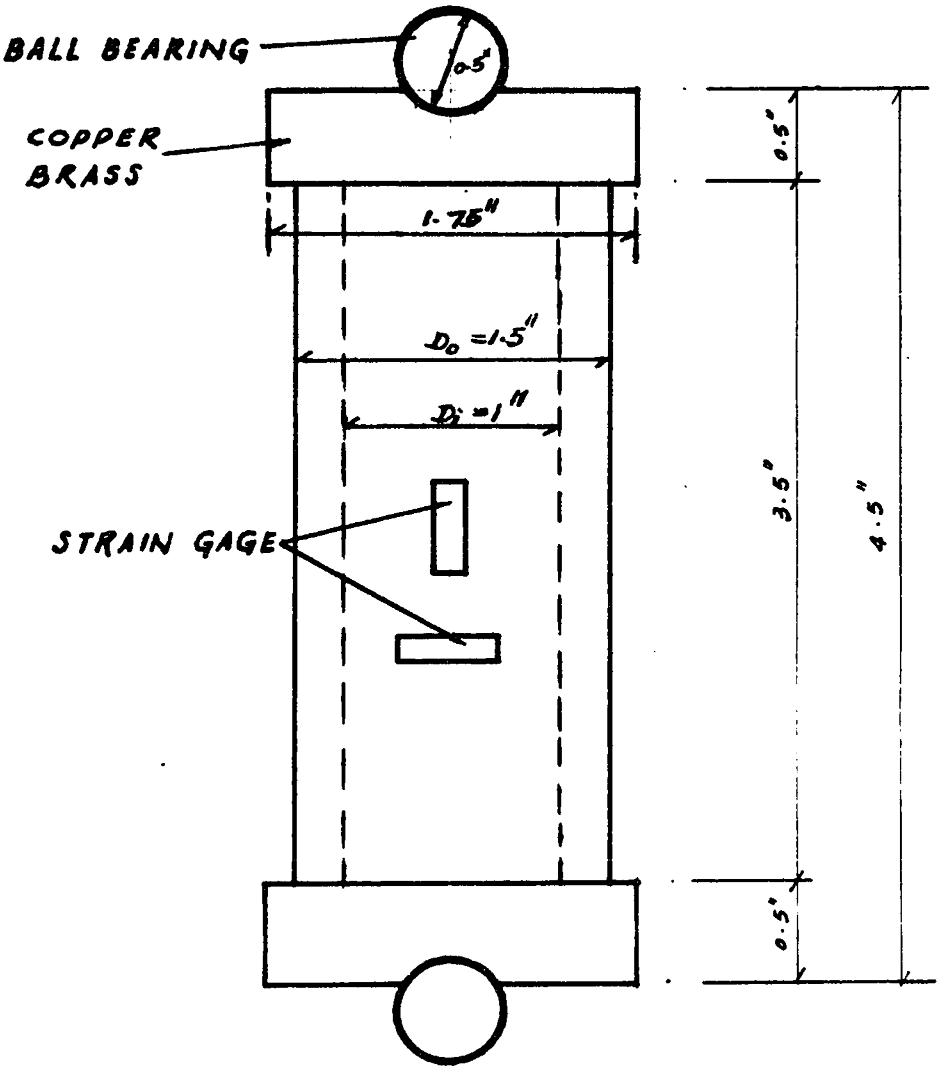


FIG. 3-5 DETAILS OF LOAD CELL

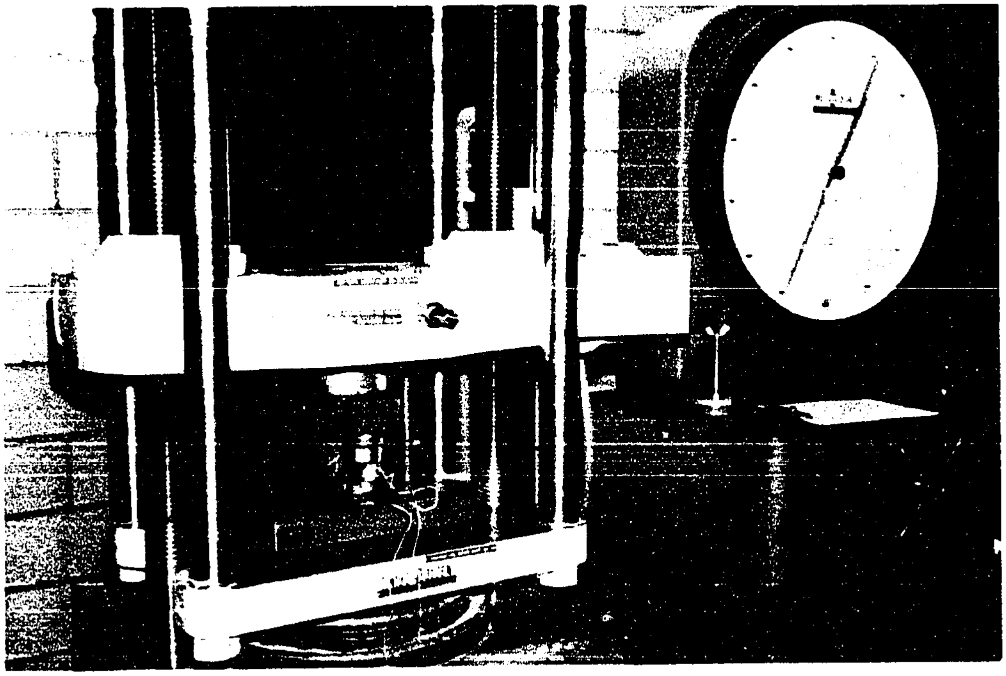


FIG. 3-6 TEST ARRANGEMENT FOR LOAD CELL CALIBRATING

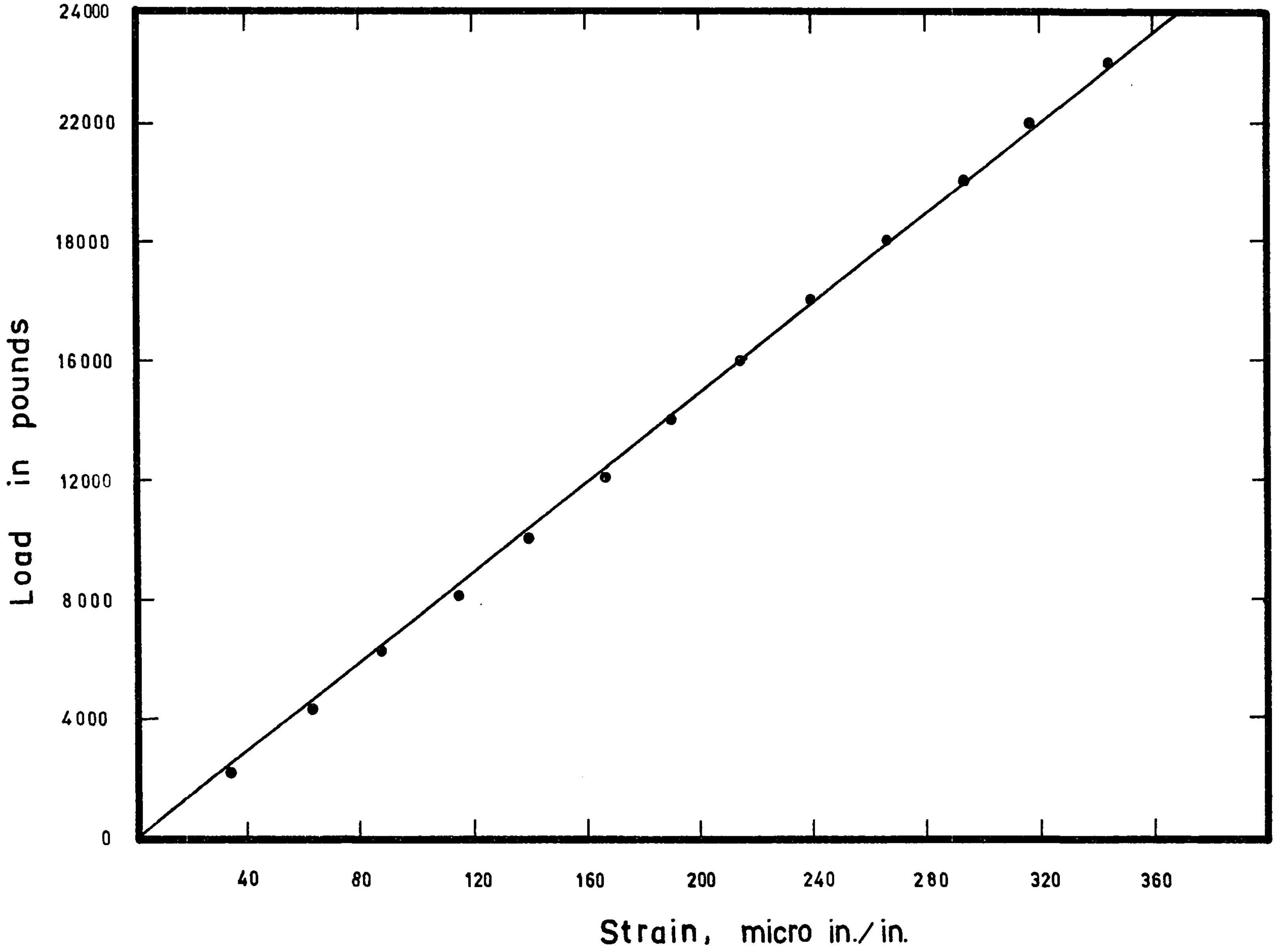


FIG. 3-7 CALIBRATION CURVE FOR LOAD CELL

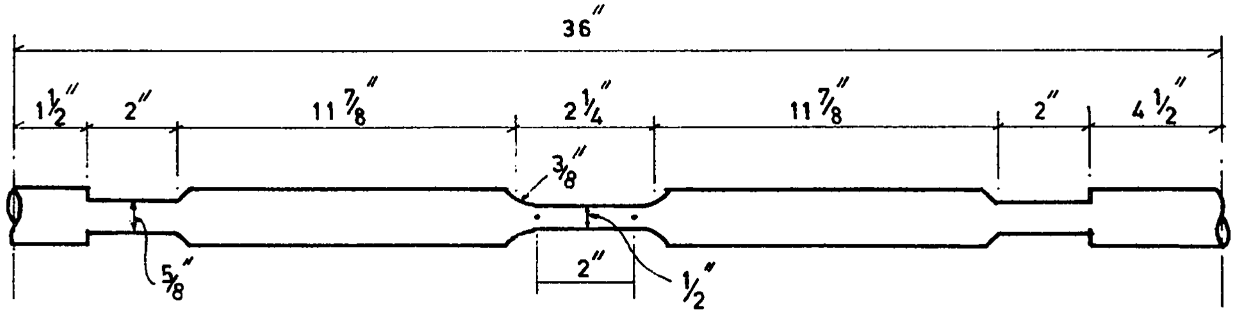


FIG. 3-8 DIMENSIONS OF TENSION TEST SPECIMEN

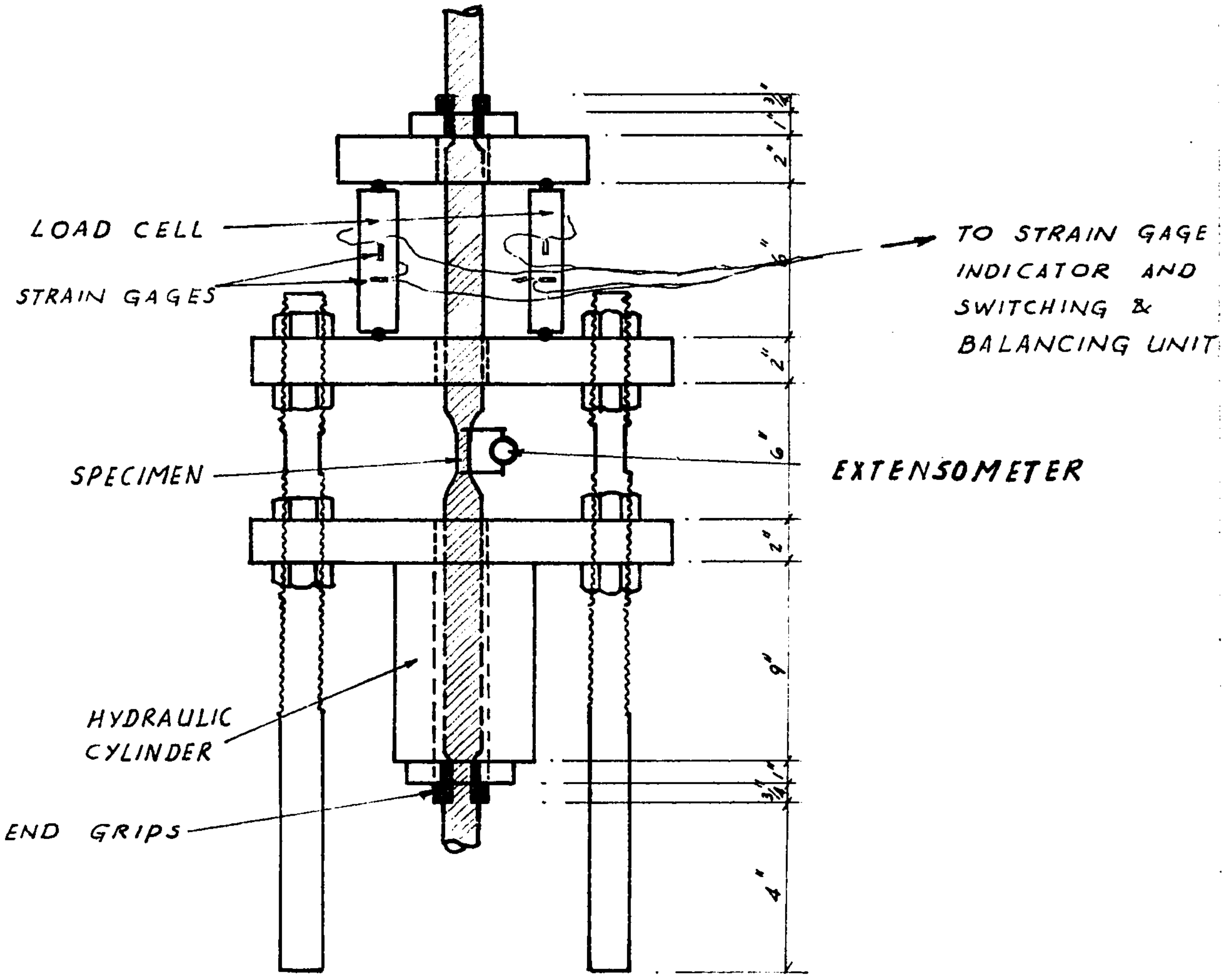
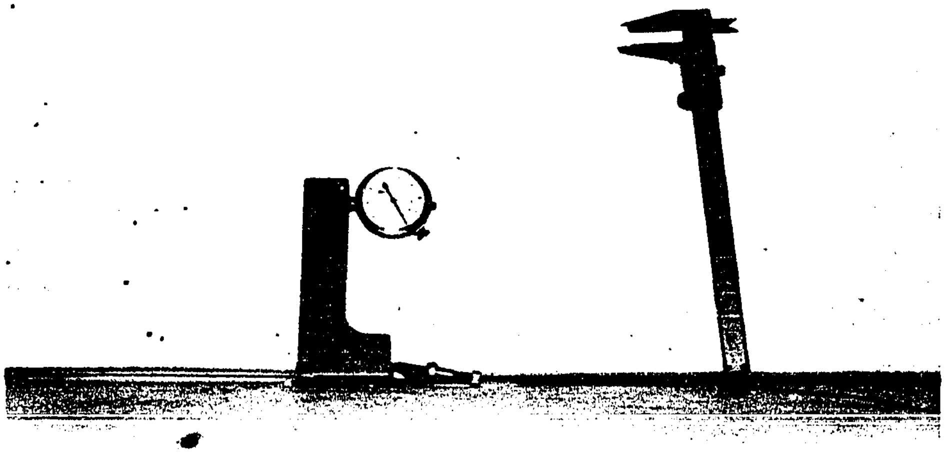


FIG. 3-9 TENSILE TEST EQUIPMENT & A SECTION VIEW OF SPECIMEN UNDER TEST



LEFT : METZGER MECHANICAL EXTENSOMETER

RIGHT : CALIPER

FIG. 3-10 MEASURING EQUIPMENT

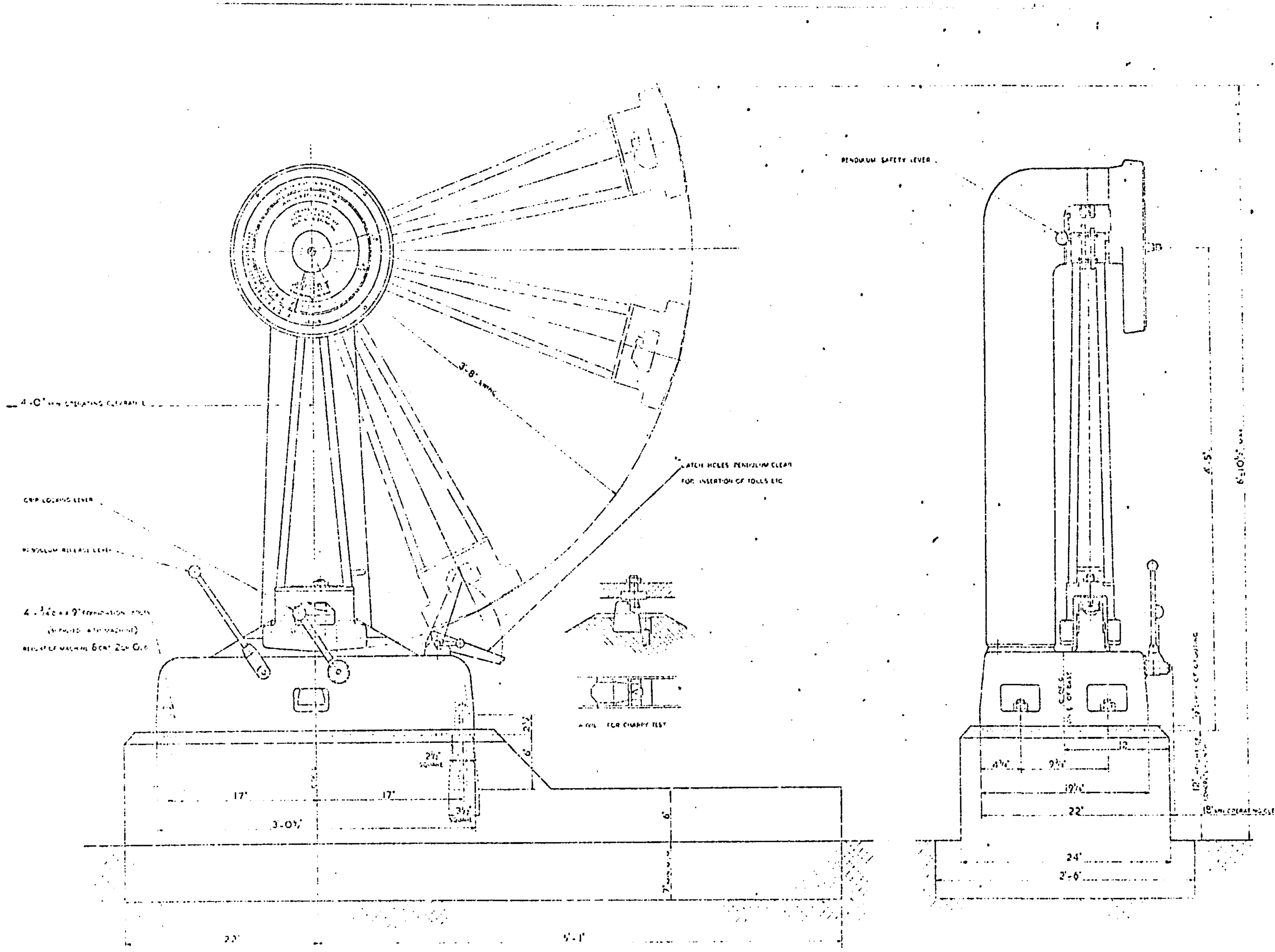


FIG. 4-11 CHARPY IMPACT TEST MACHINE

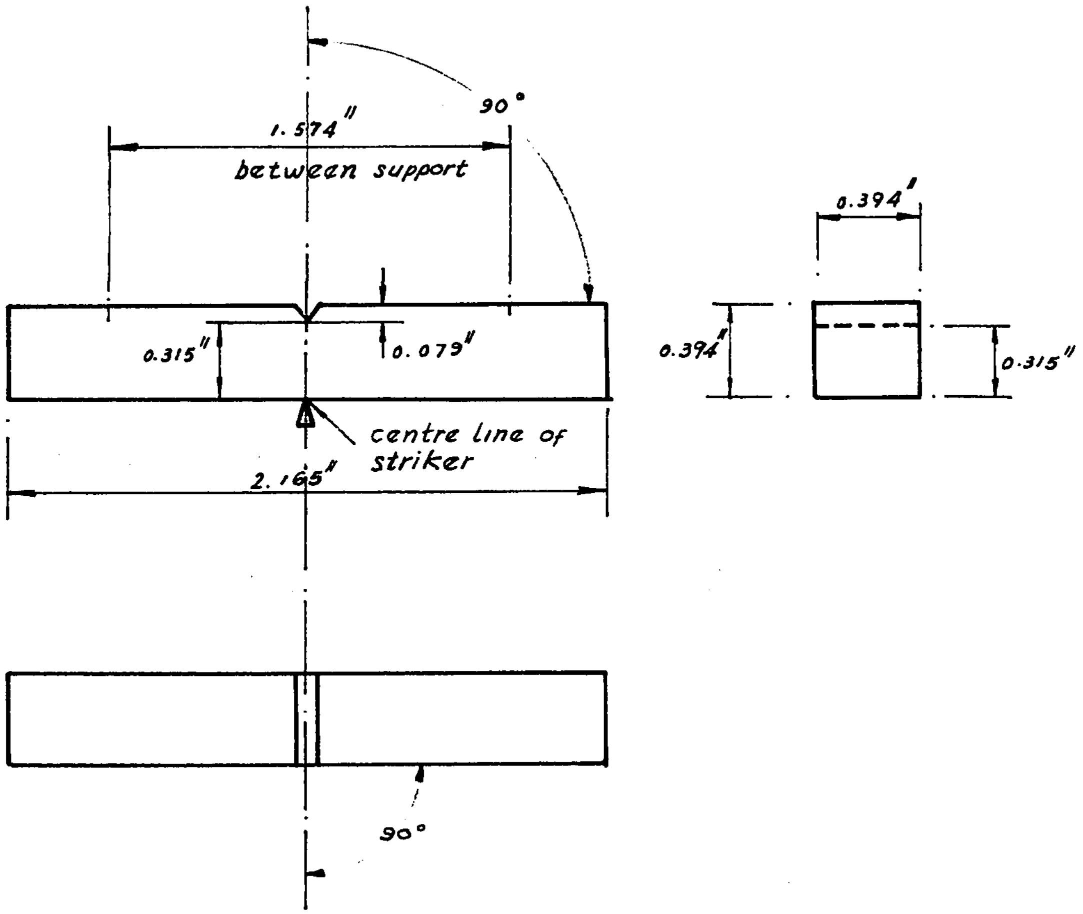


FIG. 4-2a THE DIMENSIONS AND SHAPES OF V-NOTCH IMPACT TEST SPECIMENS

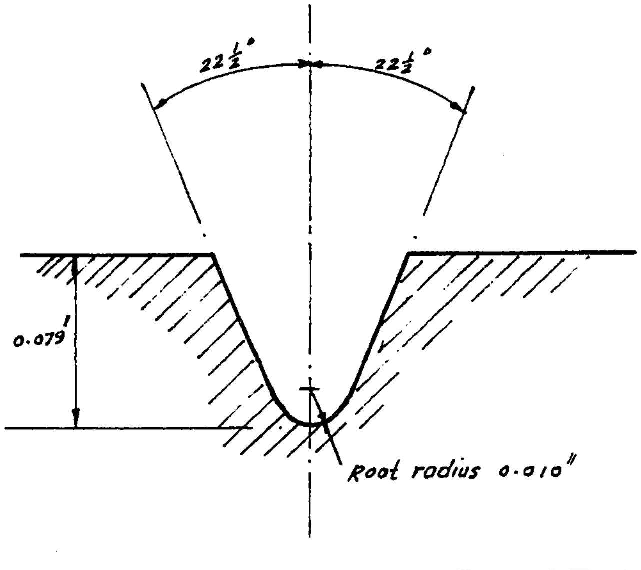


FIG. 4-2b ENLARGED VIEW OF NOTCH FOR TEST SPECIMENS

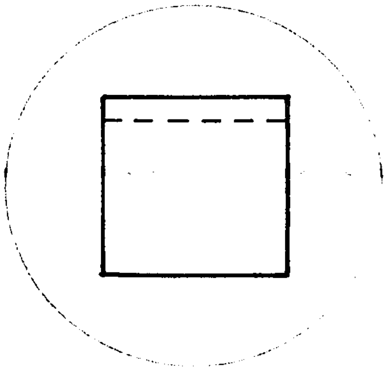


FIG. 4-2c CROSS-SECTION OF STEEL BAR SHOWING METHOD OF CUTTING AND NOTCHING SPECIMENS.

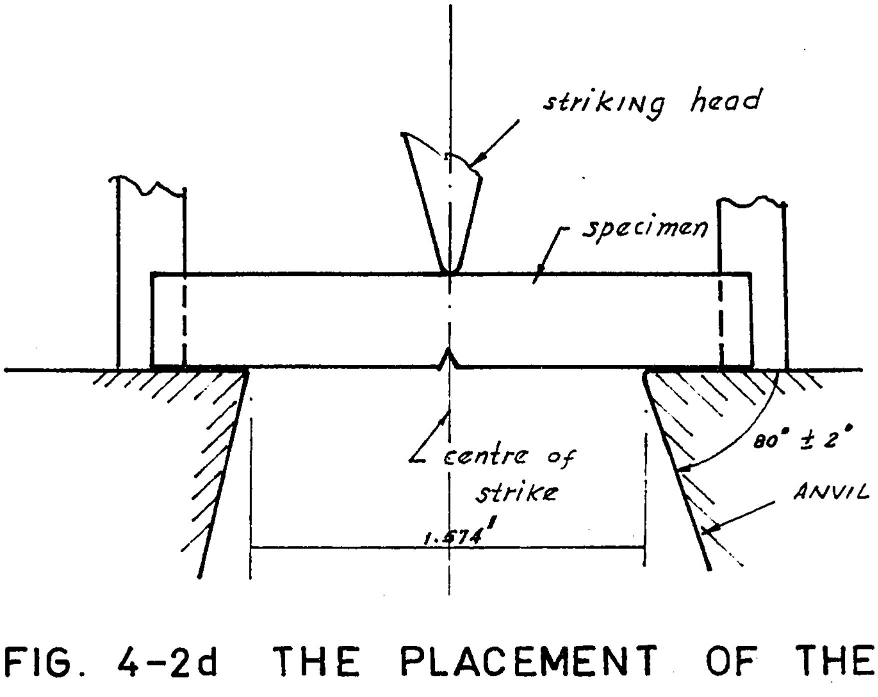


FIG. 4-2d THE PLACEMENT OF THE IMPACT TEST SPECIMENS

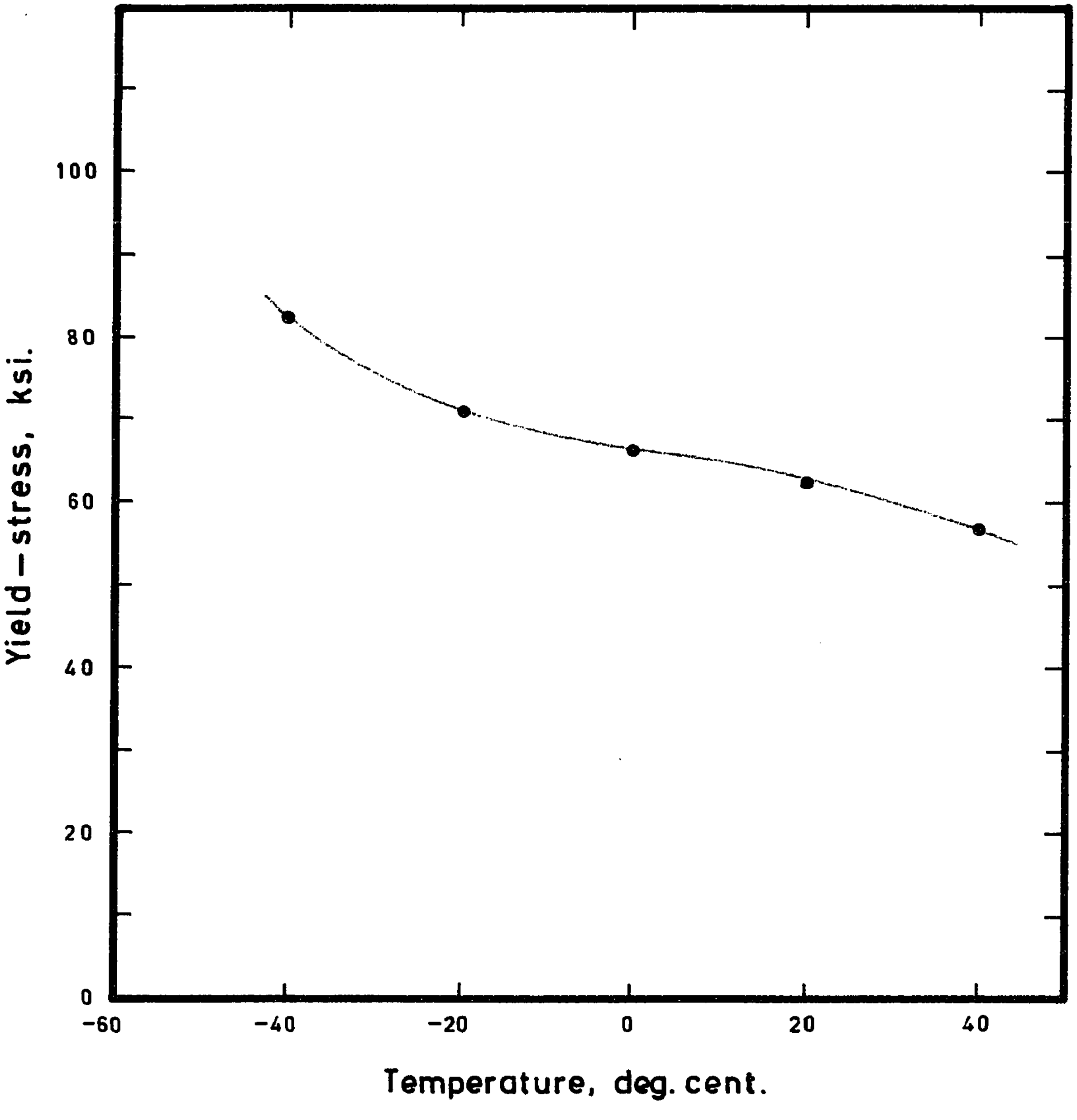


FIG. 5-1 TENSILE TESTS ON SPECIMEN NO.9G60 AT VARIOUS TEMPERATURE

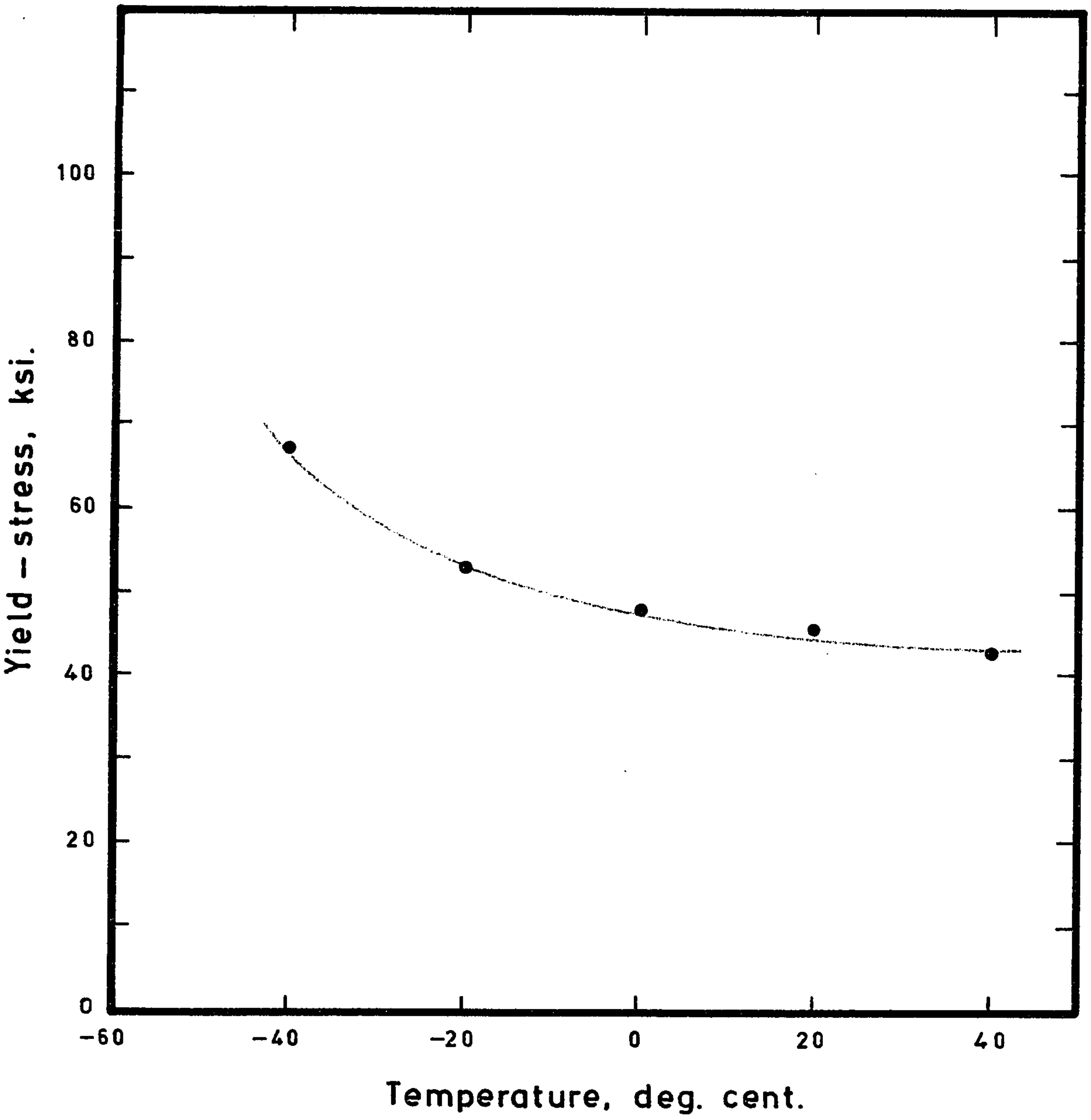


FIG. 5-2 TENSILE TESTS ON SPECIMEN NO. 9G40 AT VARIOUS TEMPERATURE

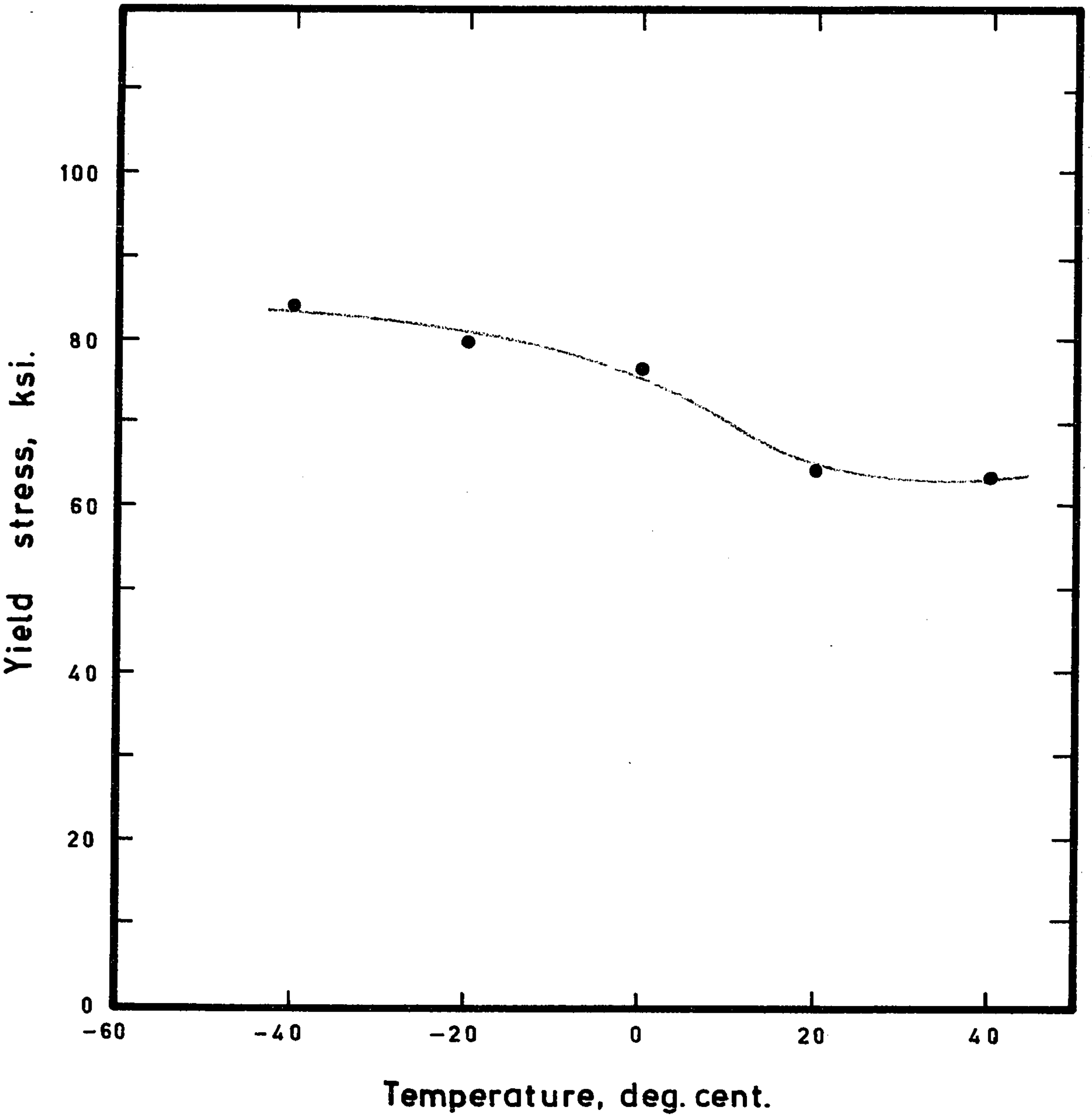


FIG. 5-3 TENSILE TESTS ON SPECIMEN NO.6G60 AT VARIOUS TEMPERATURE

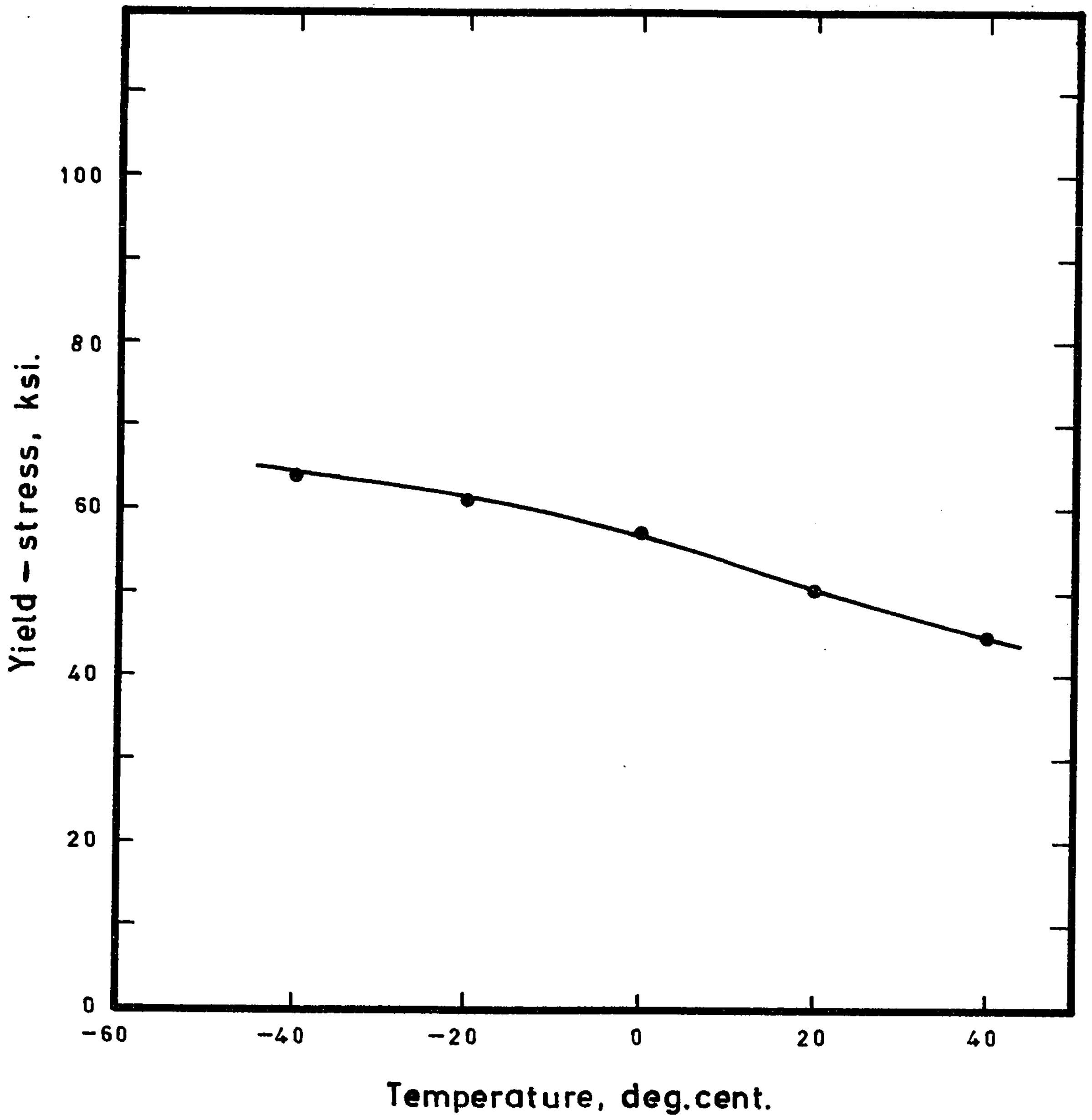


FIG. 5-4 TENSILE TESTS ON SPECIMEN NO.6G40 AT VARIOUS TEMPERATURE

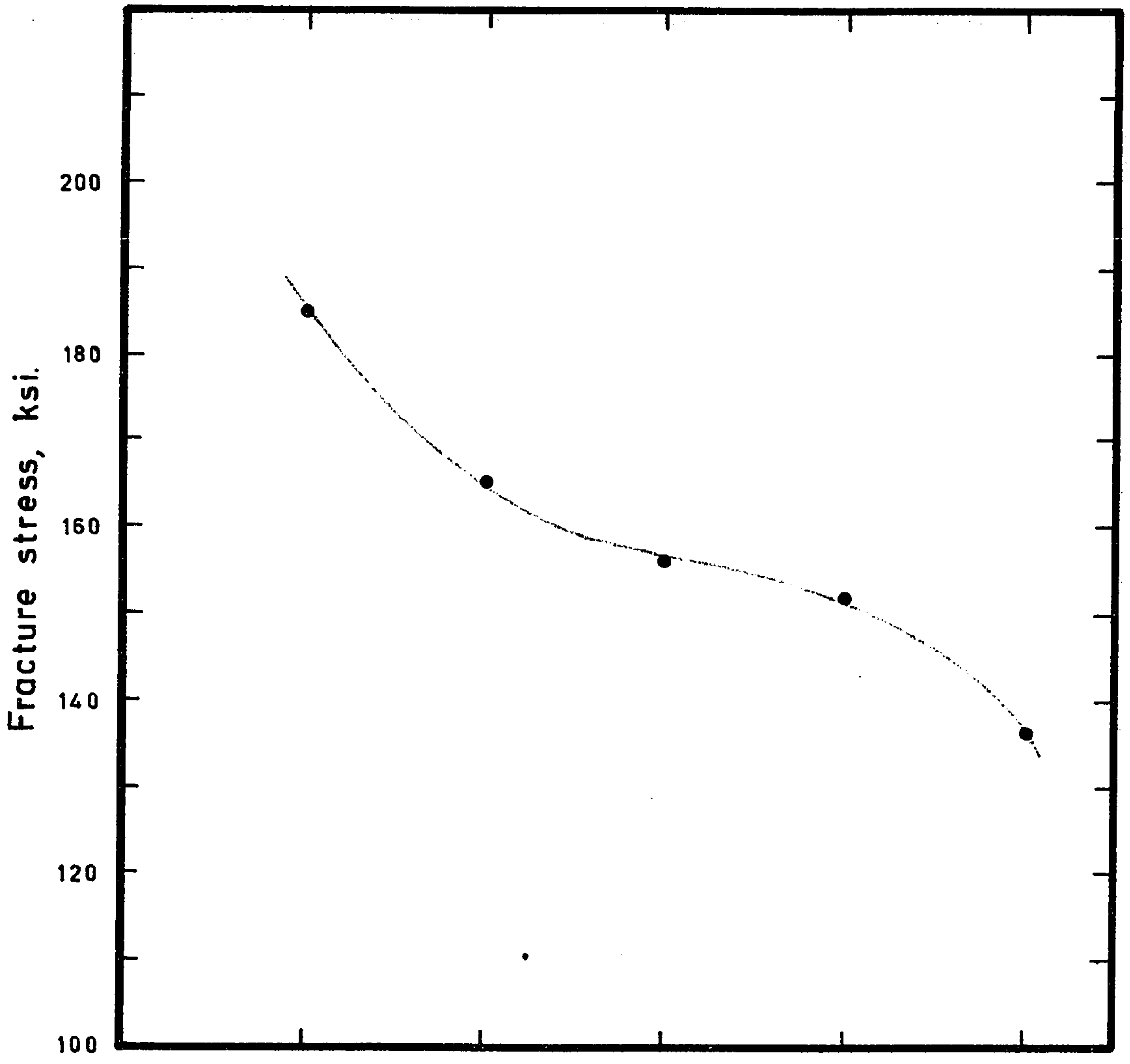


FIG. 5-5 TENSILE TESTS ON SPECIMEN NO. 9G60 AT VARIOUS TEMPERATURE

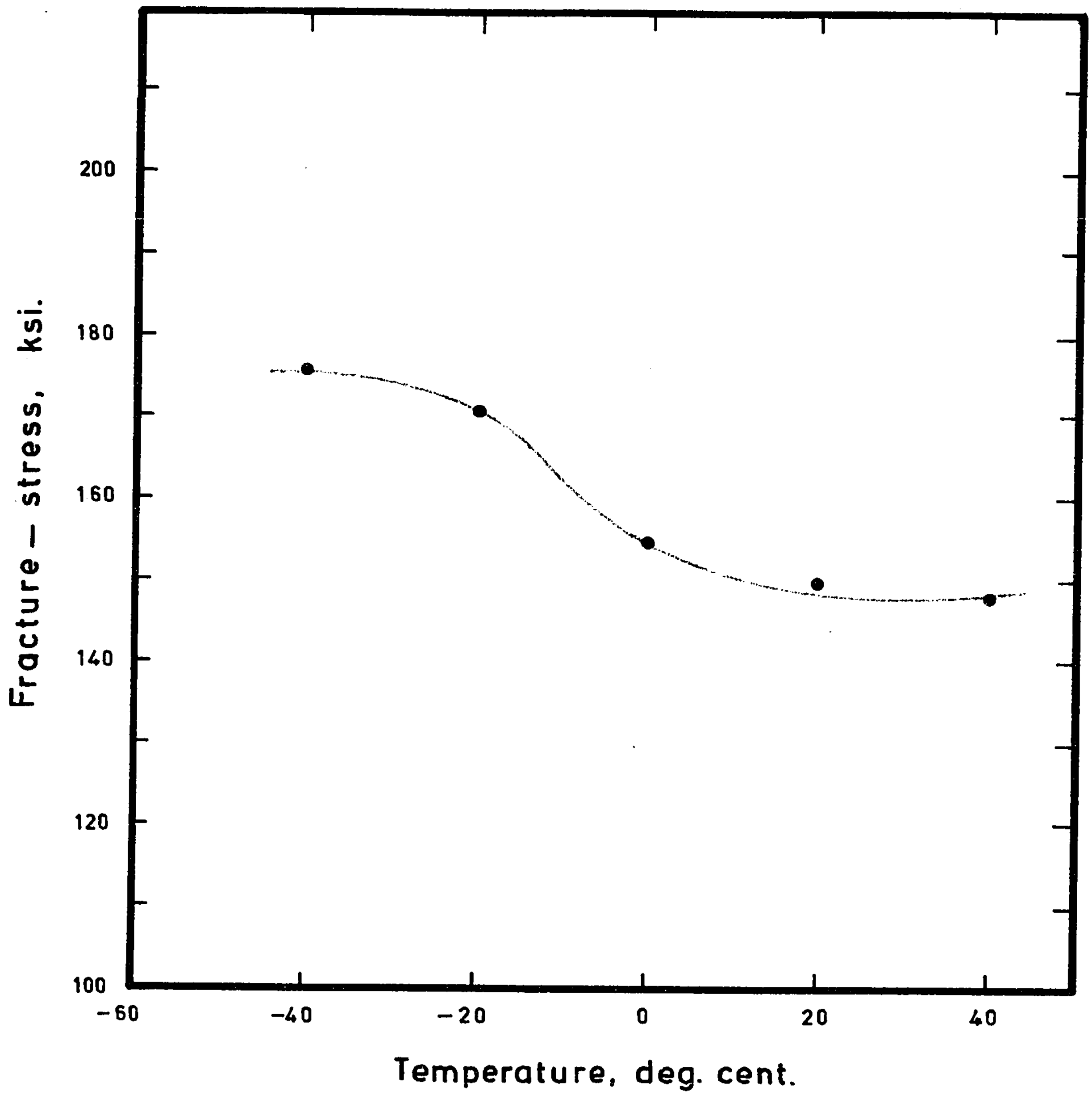


FIG. 5-6 TENSILE TESTS ON SPECIMEN NO. 9G40 AT VARIOUS TEMPERATURE

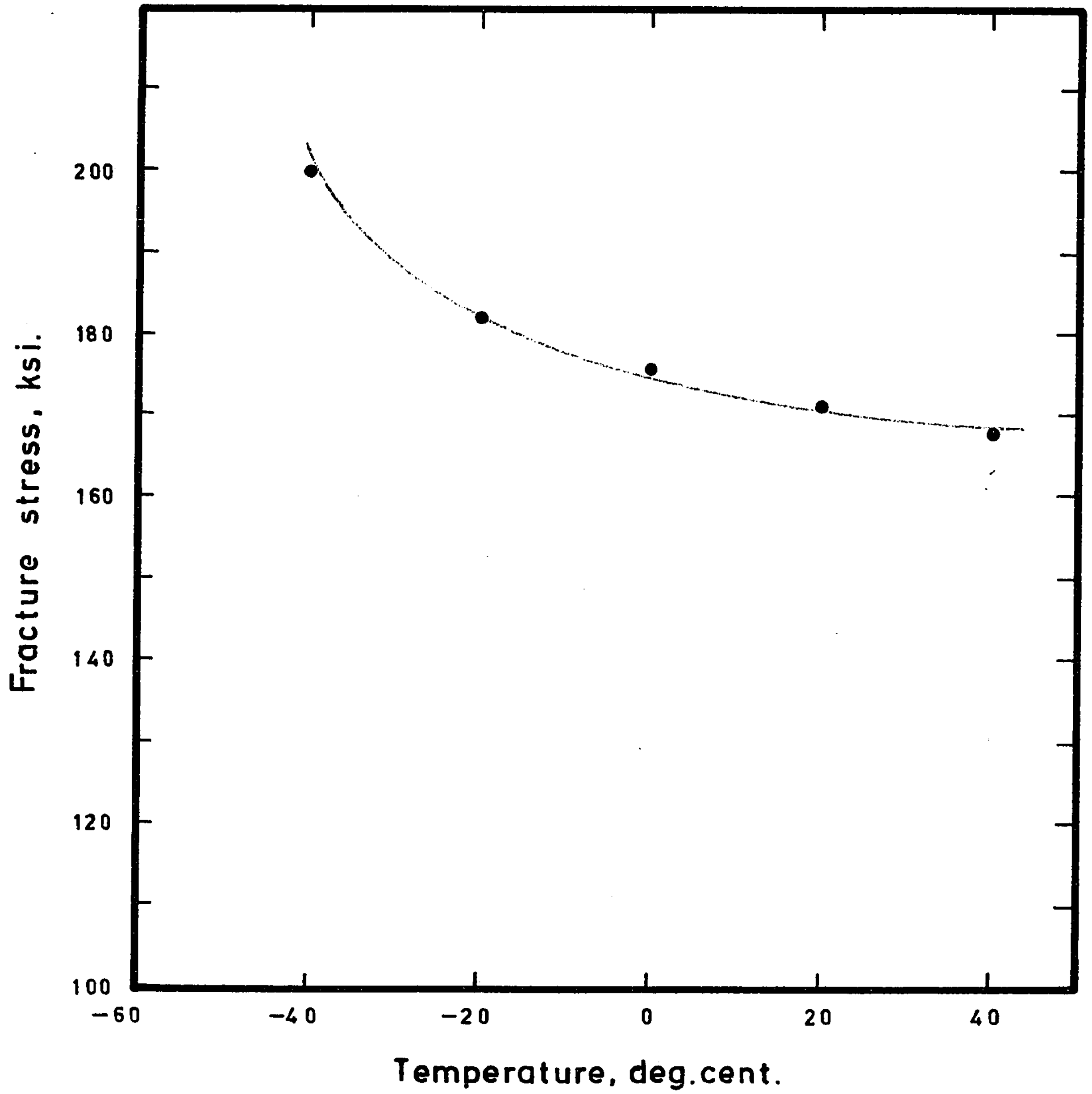


FIG. 5-7 TENSILE TESTS ON SPECIMEN NO.6G60 AT VARIOUS TEMPERATURE

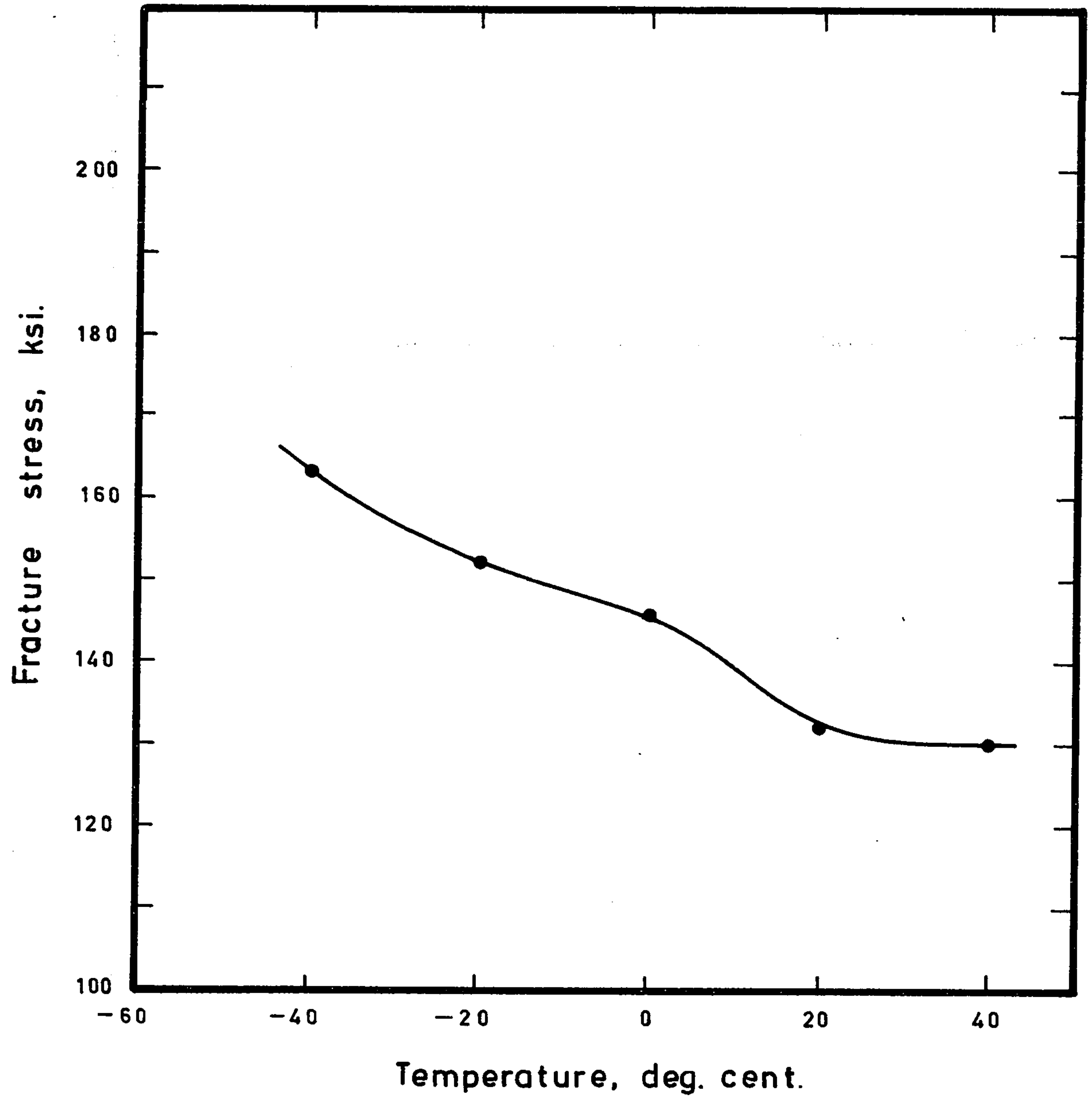


FIG. 5-8 TENSILE TESTS ON SPECIMEN NO. 6G40
AT VARIOUS TEMPERATURE

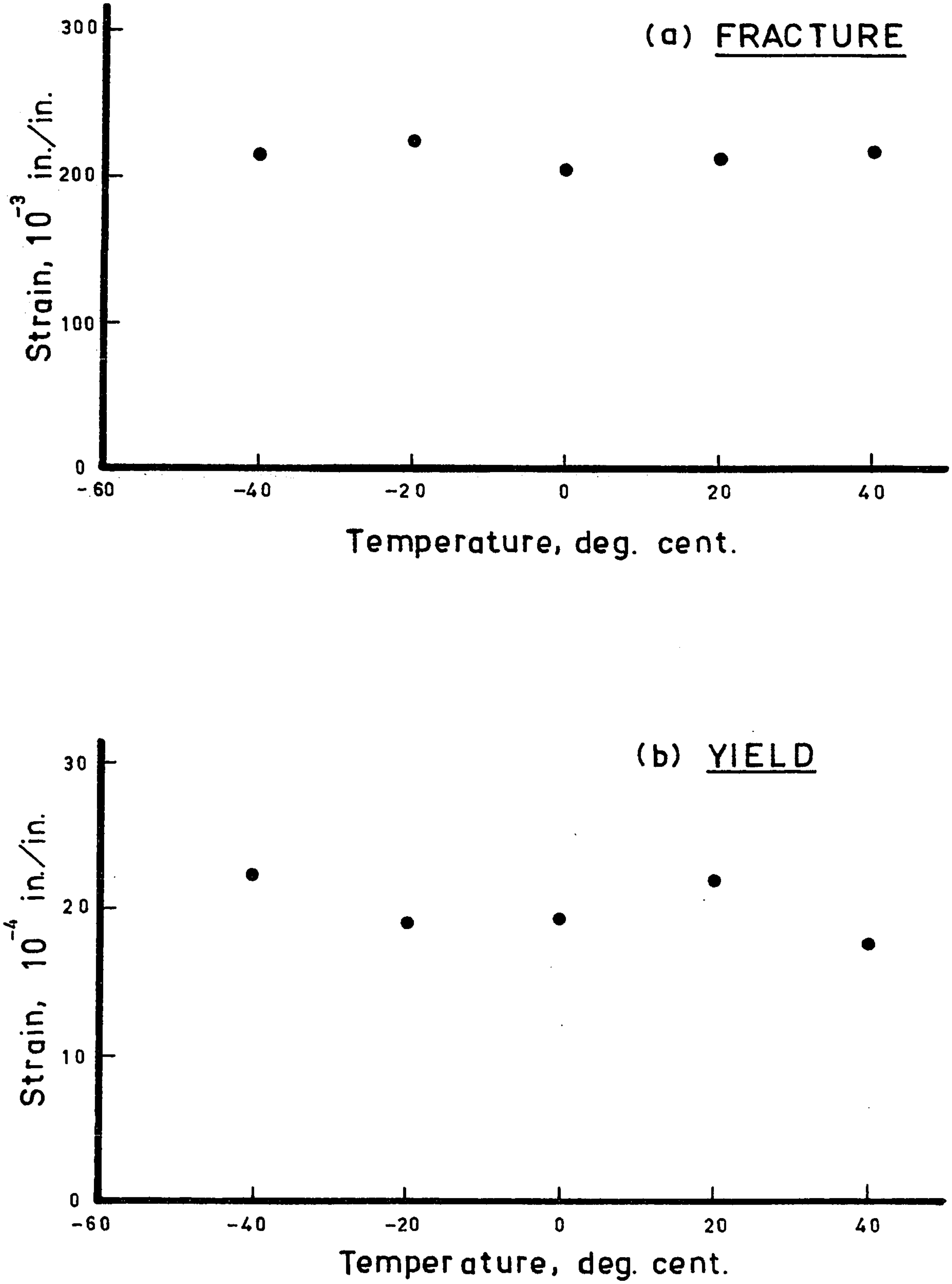


FIG. 5-9 STRAIN — TEMPERATURE CURVE OF SPECIMEN NO. 9G60.

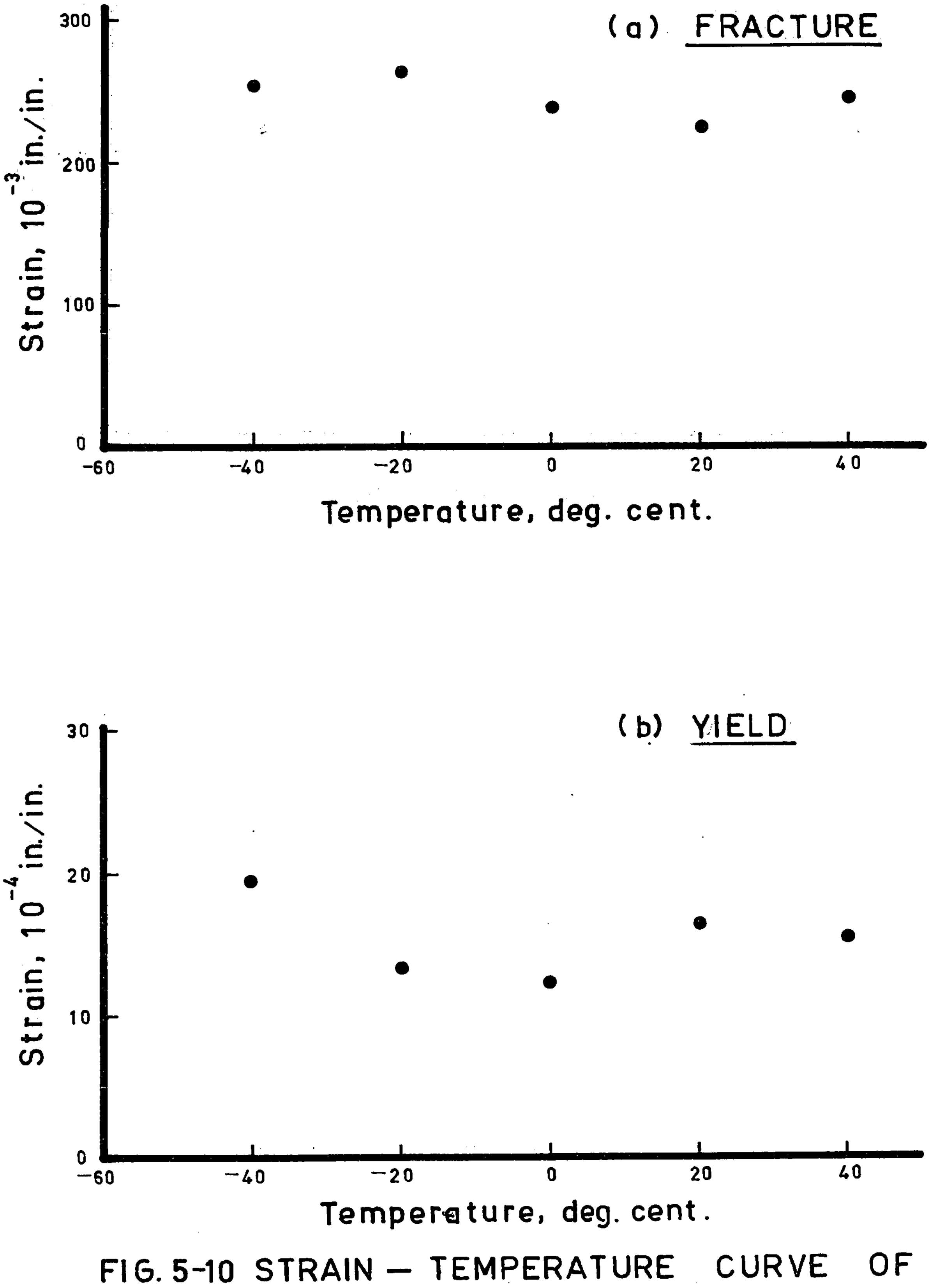


FIG. 5-10 STRAIN — TEMPERATURE CURVE OF SPECIMEN NO. 9G40

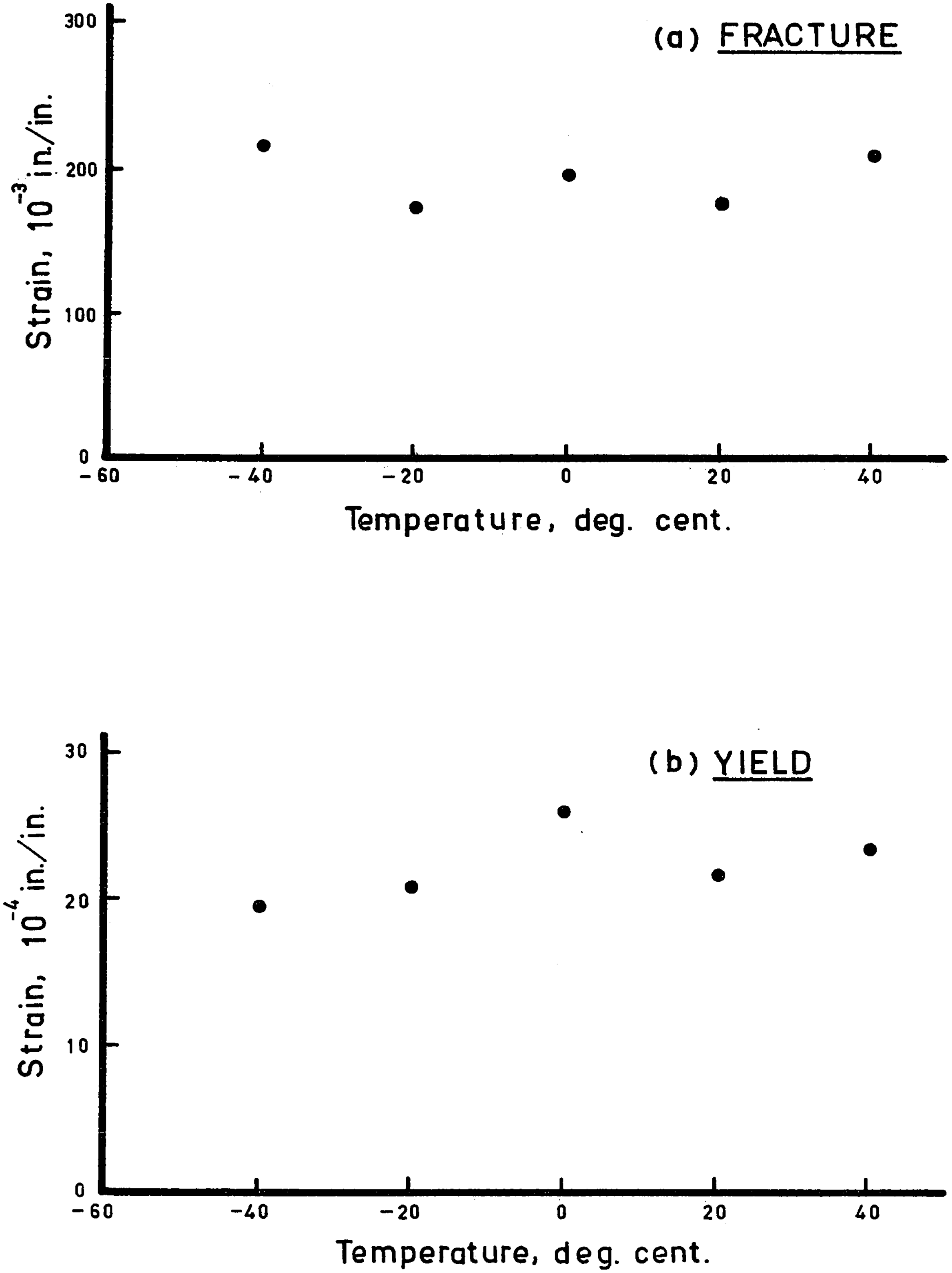


FIG. 5-11 STRAIN – TEMPERATURE CURVE OF SPECIMEN NO. 6G60.

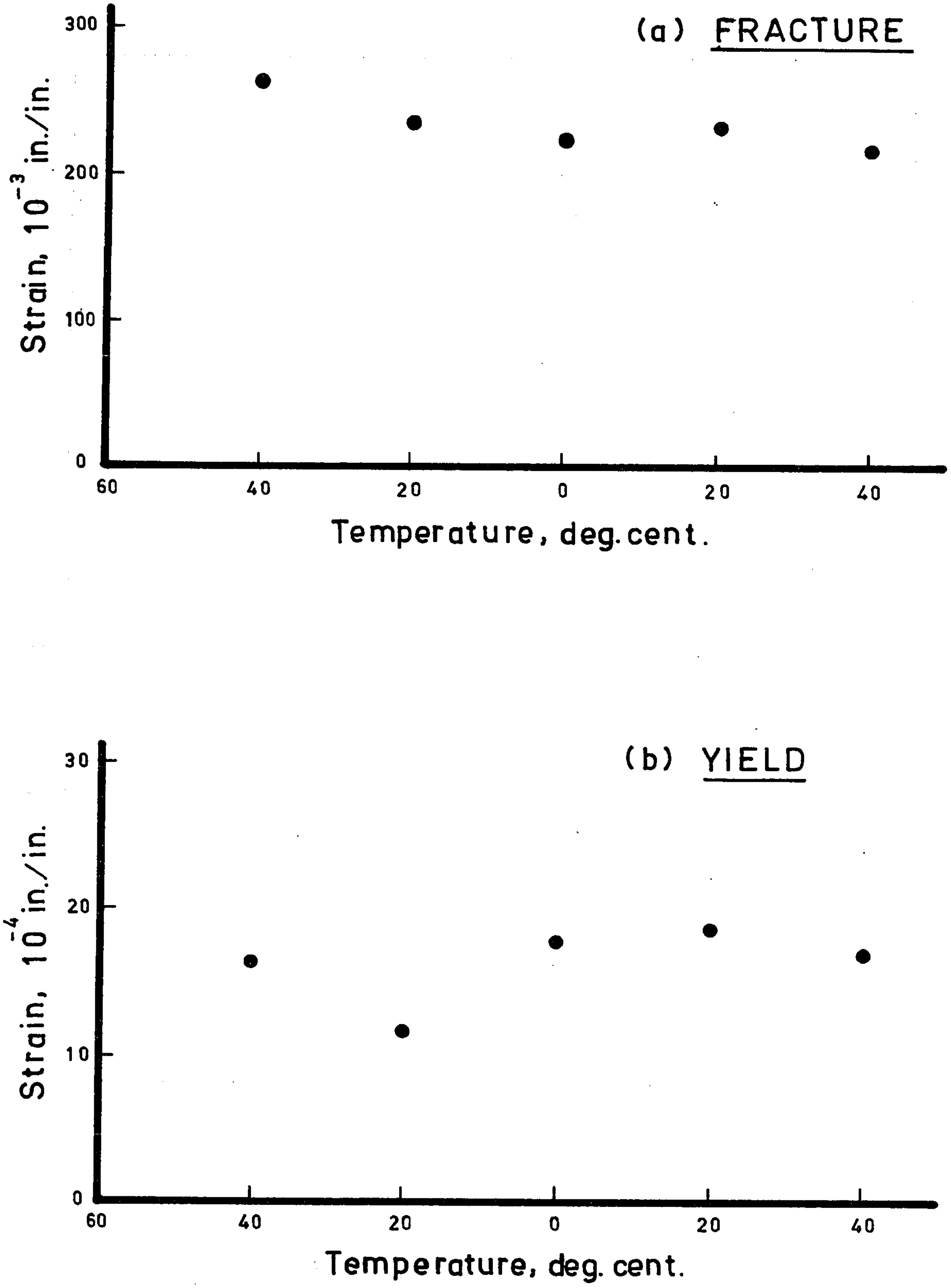


FIG. 5-12 STRAIN — TEMPERATURE CURVE OF SPECIMEN NO. 6G40

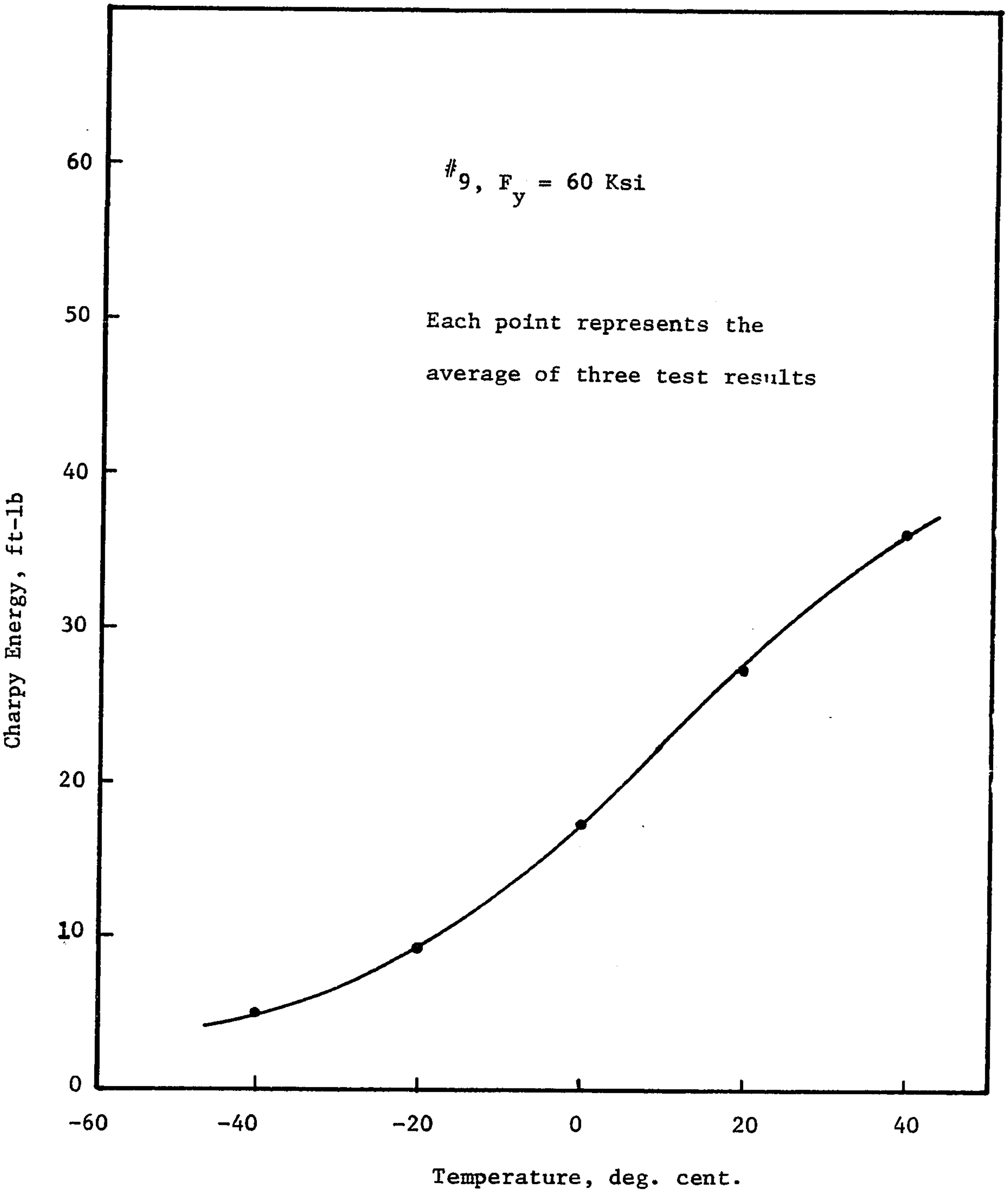


FIG. 5-13 TYPICAL CHARPY V-NOTCH ENERGY VERSUS TEMPERATURE BEHAVIOR OF SPECIMEN NO. 9G60

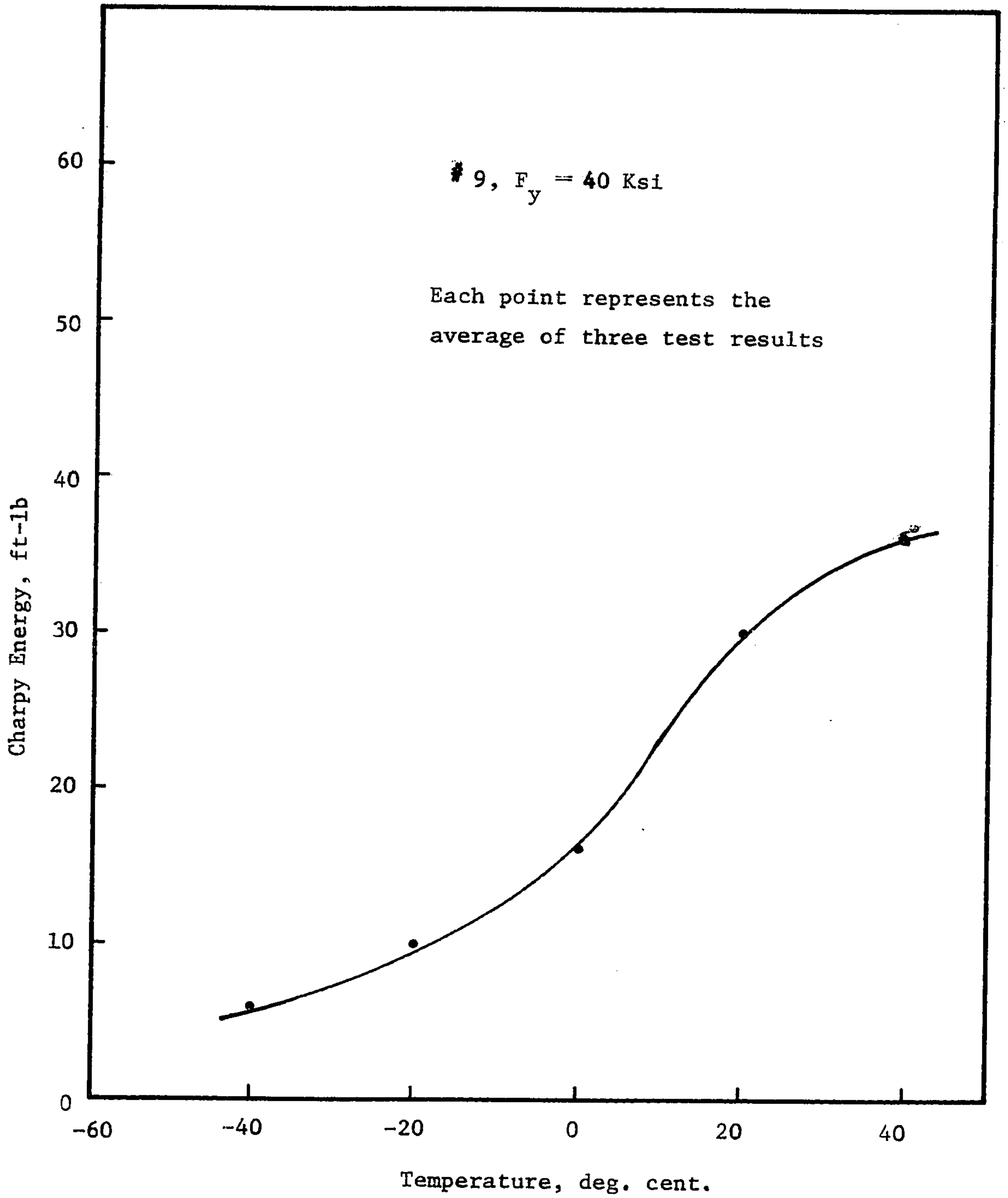


FIG. 5-14 TYPICAL CHARPY V-NOTCH ENERGY VERSUS TEMPERATURE BEHAVIOR OF SPECIMEN NO. 9G40

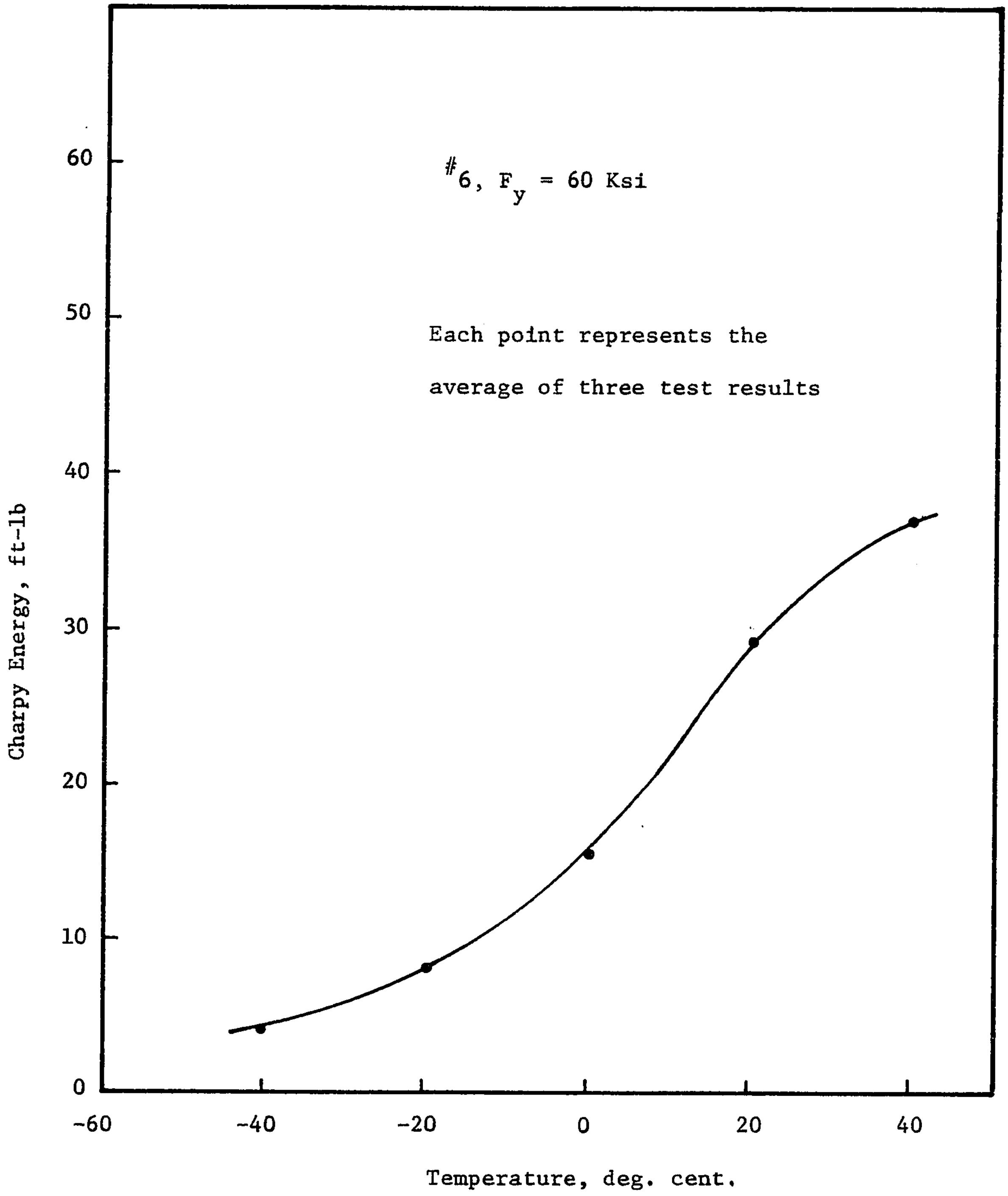


FIG. 5-15 TYPICAL CHARPY V-NOTCH ENERGY VERSUS TEMPERATURE BEHAVIOR OF SPECIMEN NO. 6G60

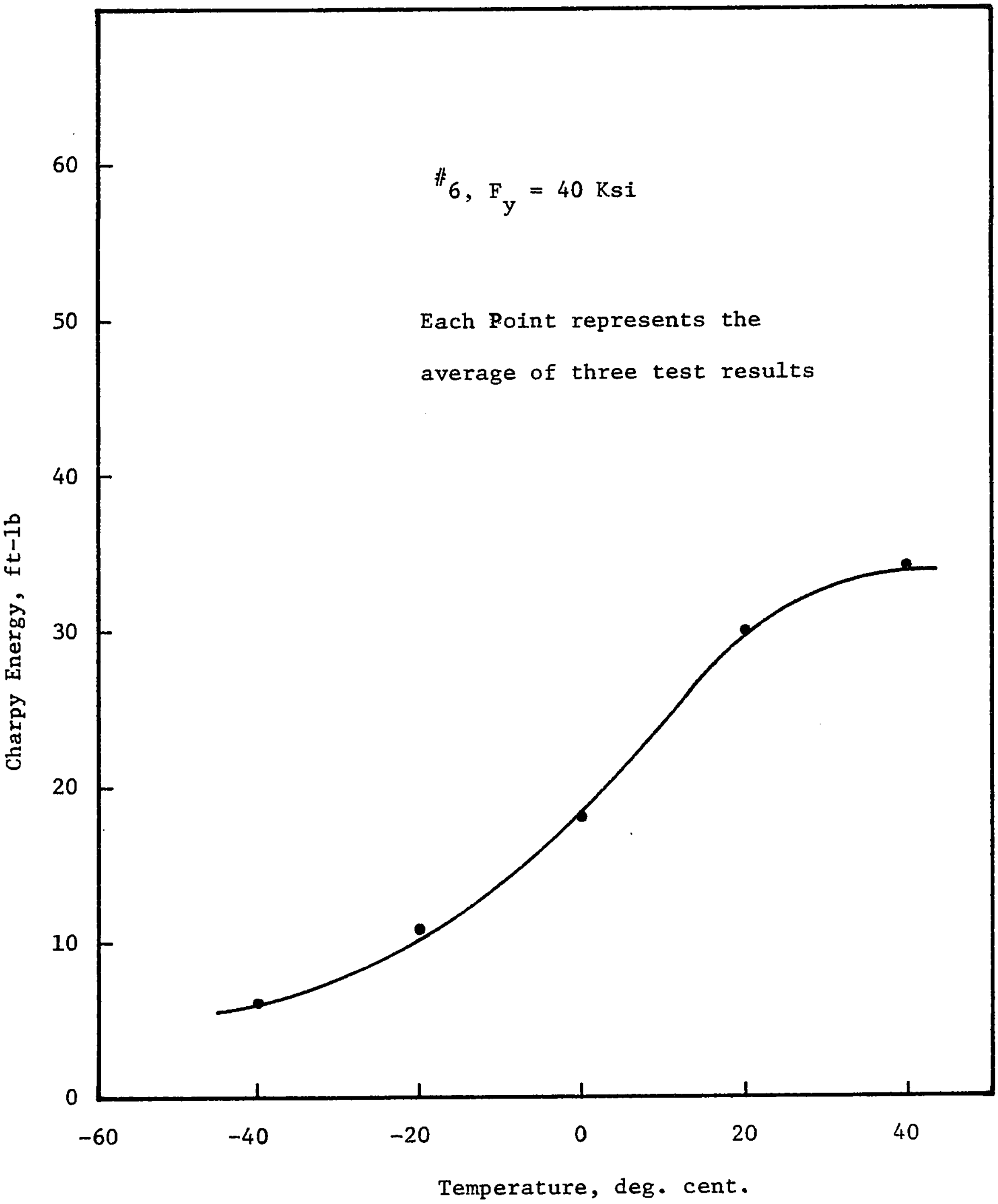


FIG. **5-16** TYPICAL CHARPY V-NOTCH ENERGY VERSUS TEMPERATURE BEHAVIOR OF SPECIMEN NO. **6**G40

APPENDICES

APPENDIX A

STRESS-STRAIN DIAGRAMS

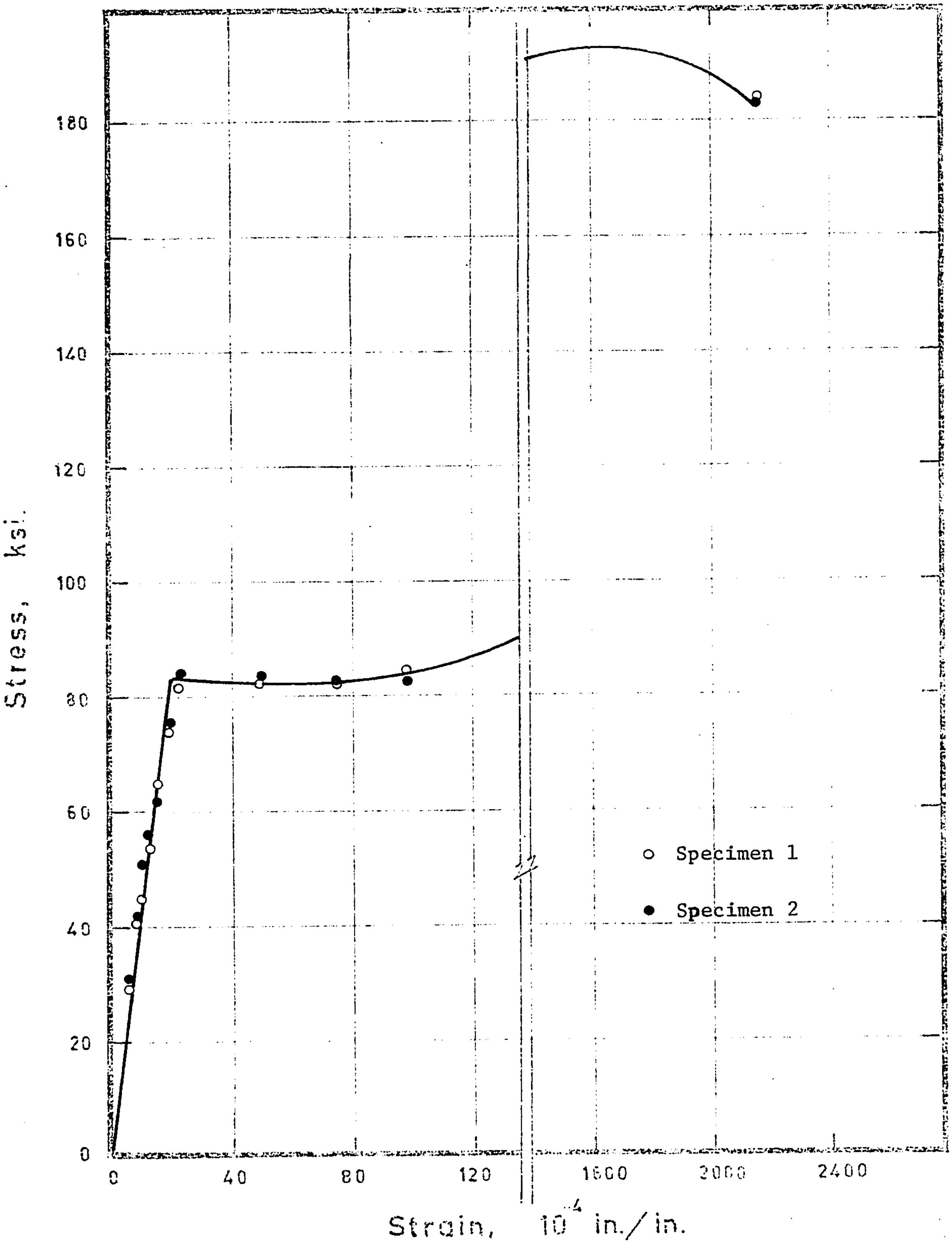


FIG. 5.17 STRESS—STRAIN CURVE AT -40 °C OF SPECIMEN NO. 9G60

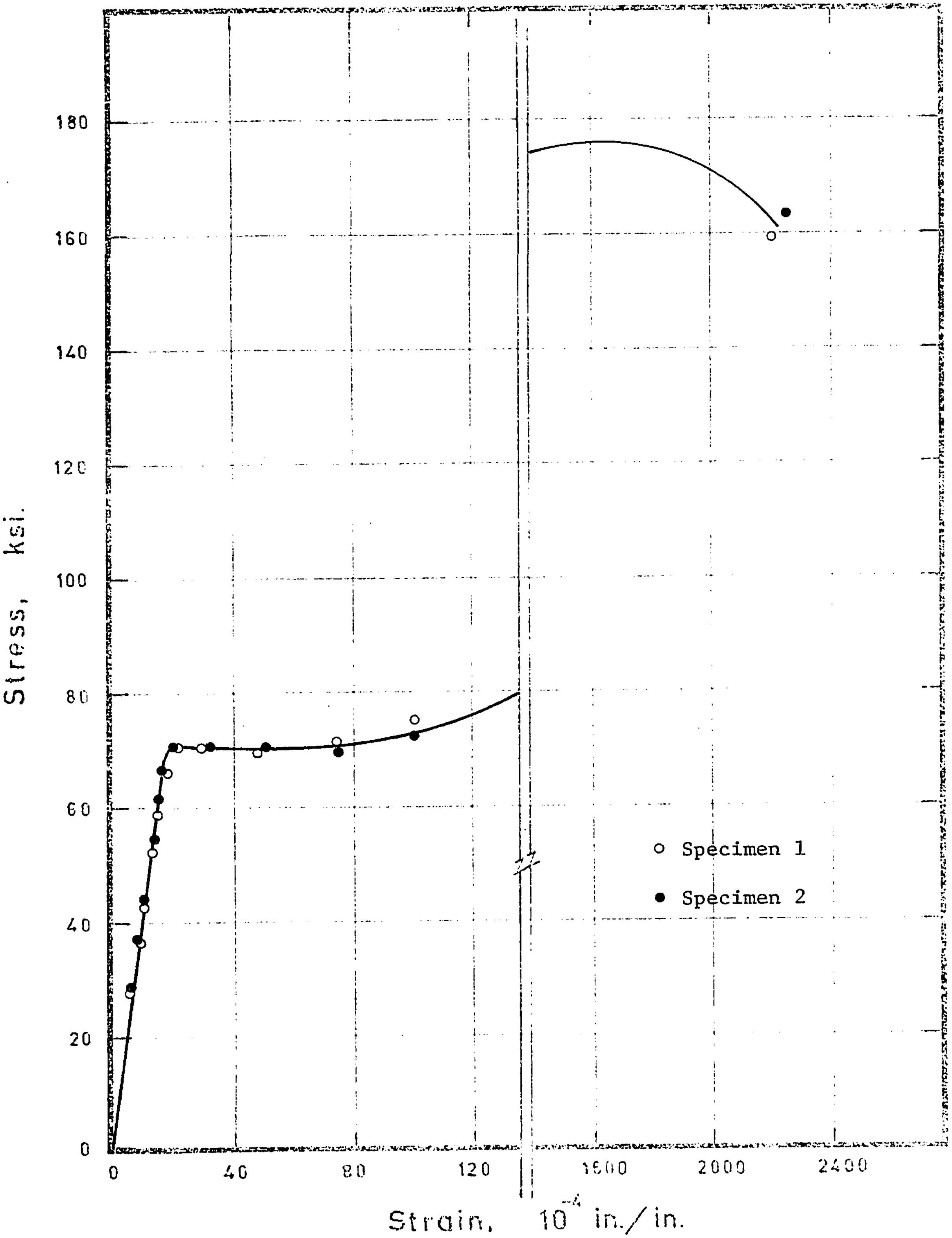


FIG. 5.18 STRESS—STRAIN CURVE AT −20° C OF SPECIMEN NO. 9G60

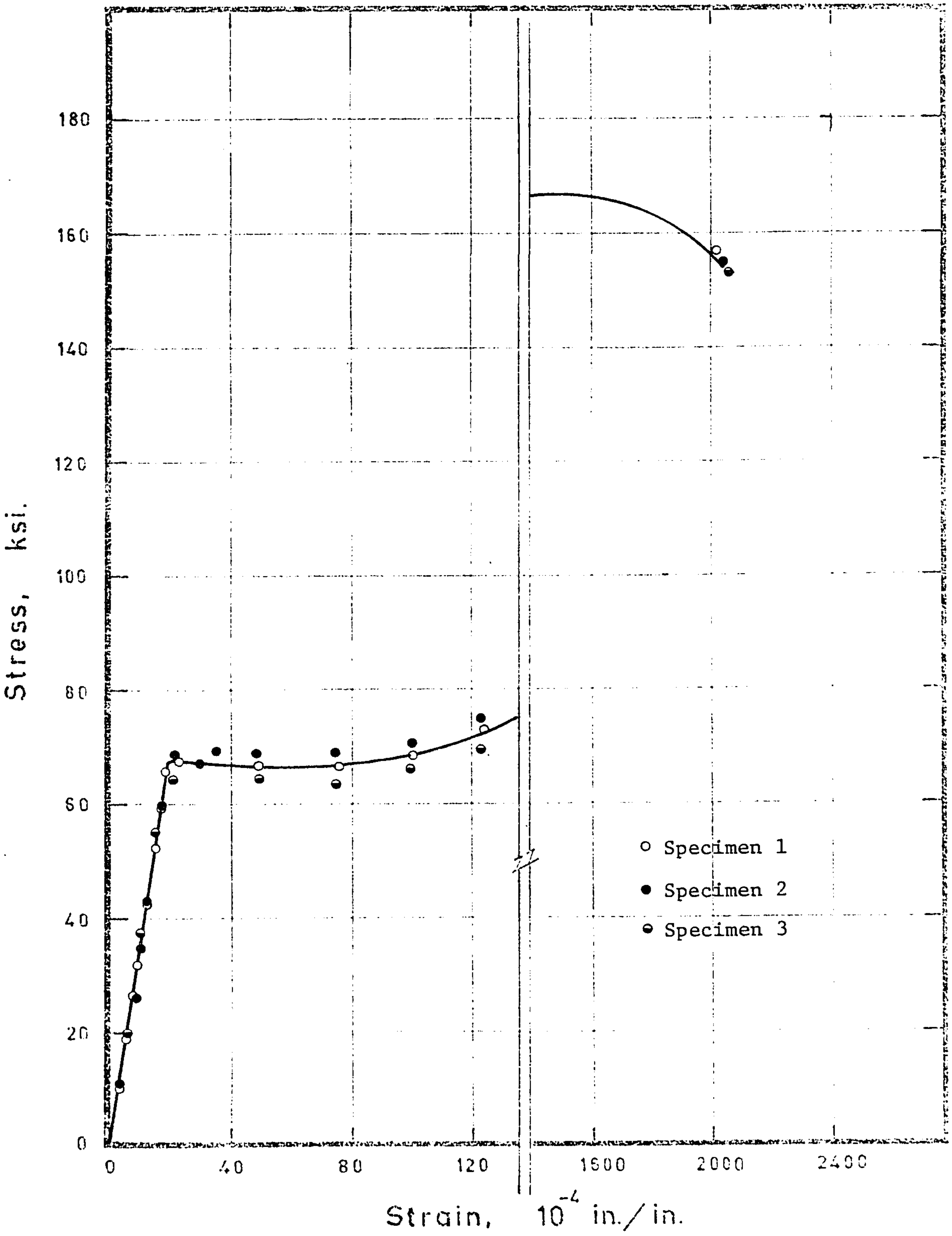


FIG. 5.19 STRESS—STRAIN CURVE AT 0° C
OF SPECIMEN NO. 9G60

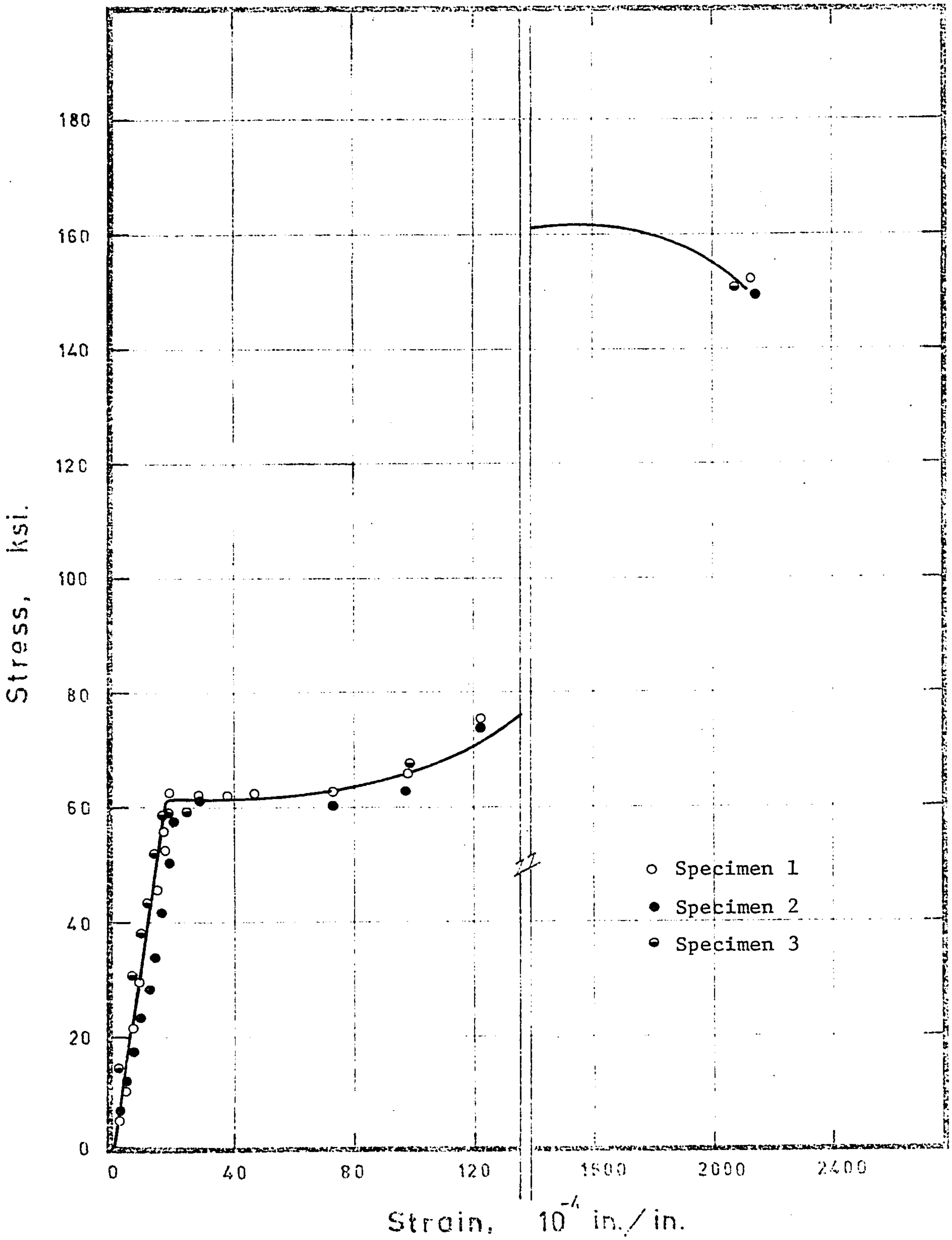


FIG. 5.20 STRESS—STRAIN CURVE AT 20°C OF SPECIMEN NO. 9060

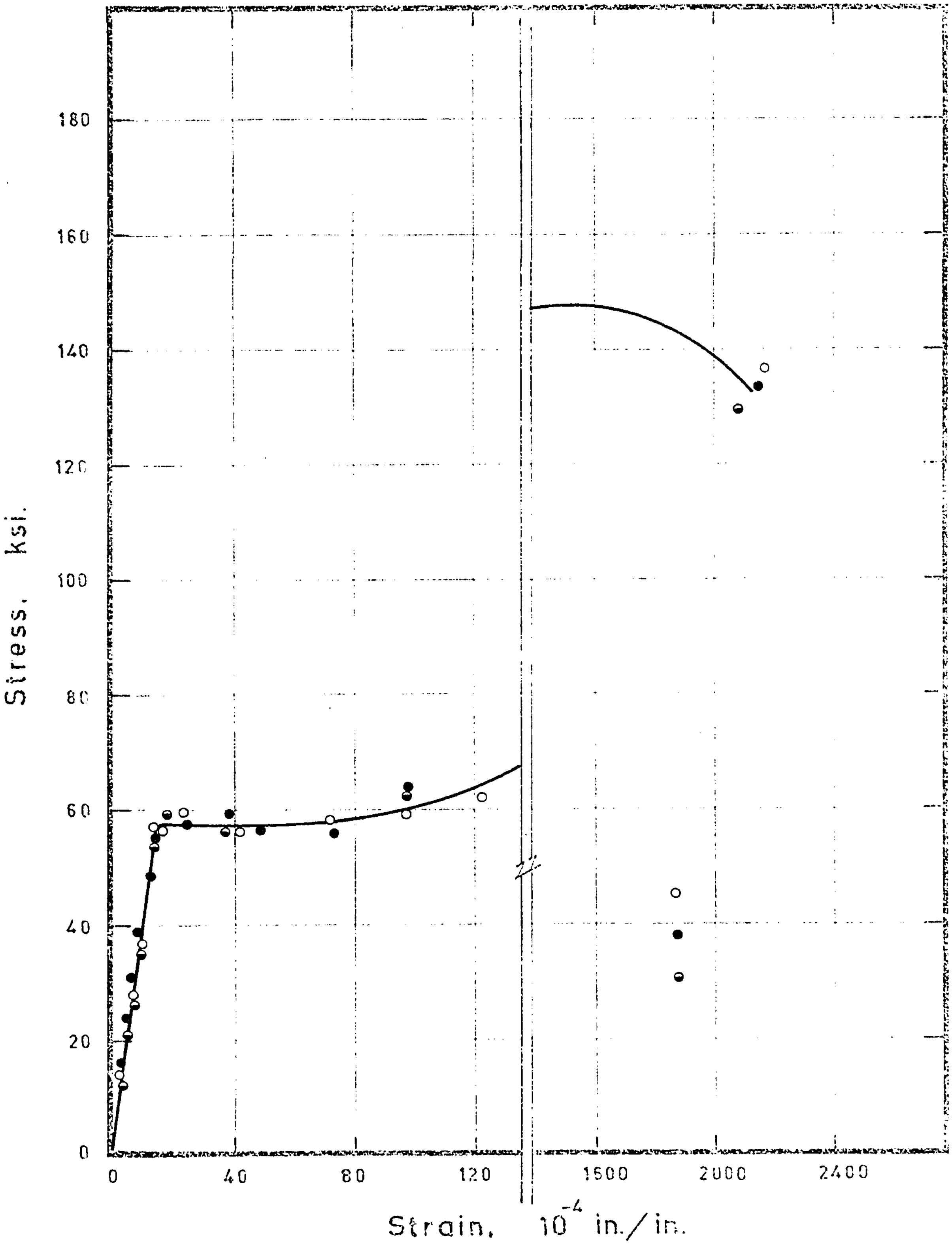


FIG. 5.21 STRESS—STRAIN CURVE AT 40°C OF SPECIMEN NO. 9G60

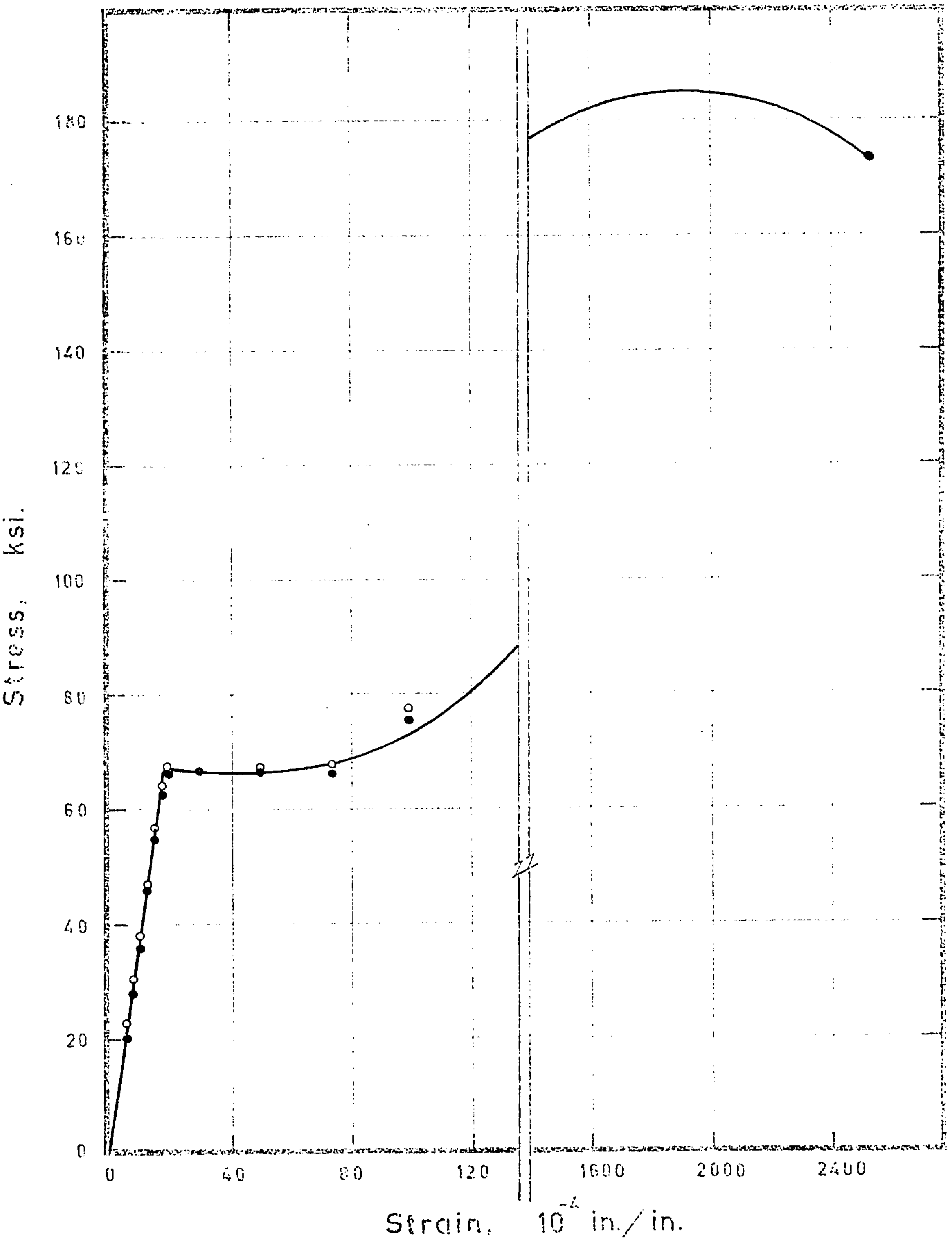


FIG. 5.22 STRESS--STRAIN CURVE AT -40°C OF SPECIMEN NO. 9G40 .

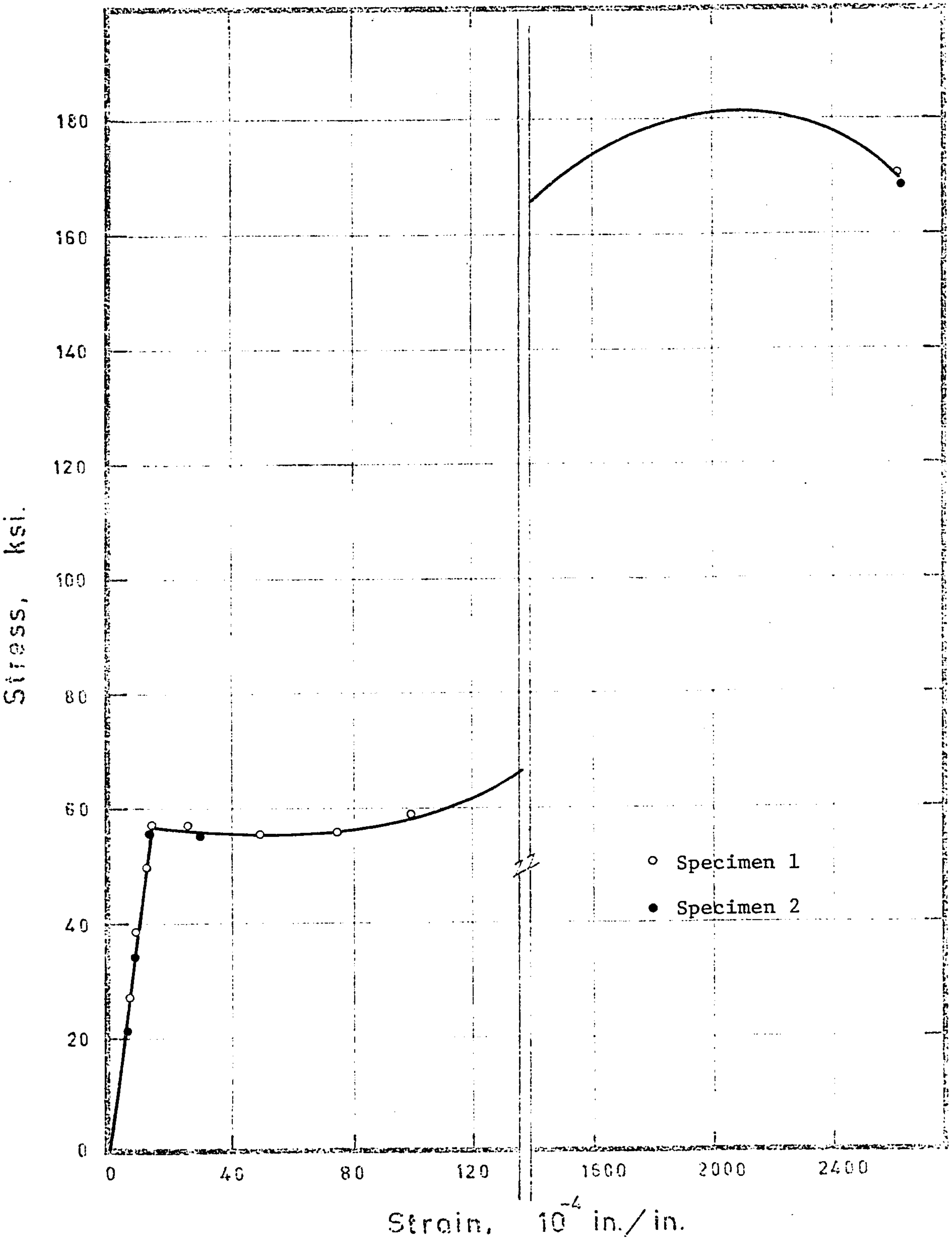


FIG. 5.23 STRESS—STRAIN CURVE AT -20°C OF SPECIMEN NO. 9G40

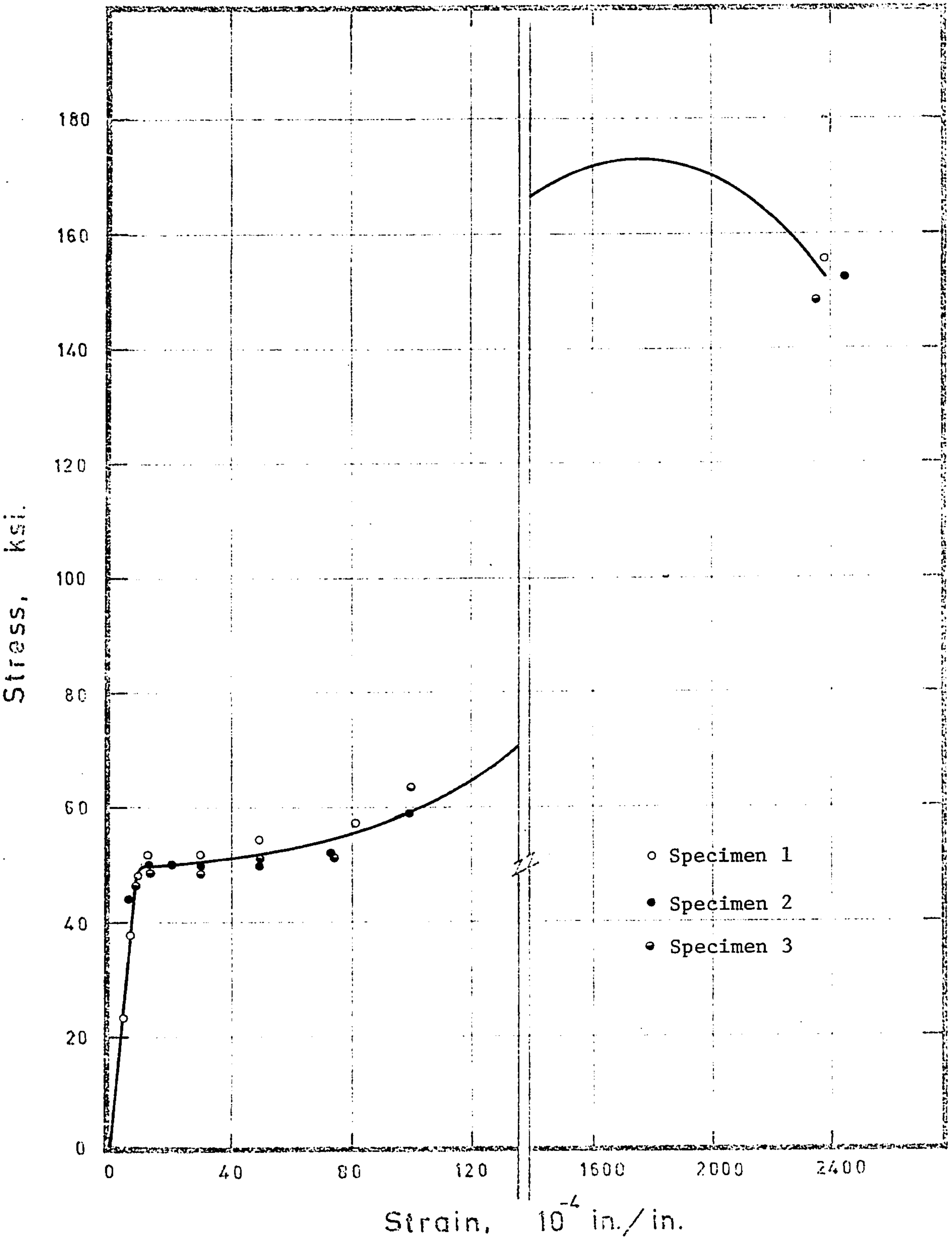


FIG. 5.24 STRESS—STRAIN CURVE AT 0°C OF SPECIMEN NO. 9G40

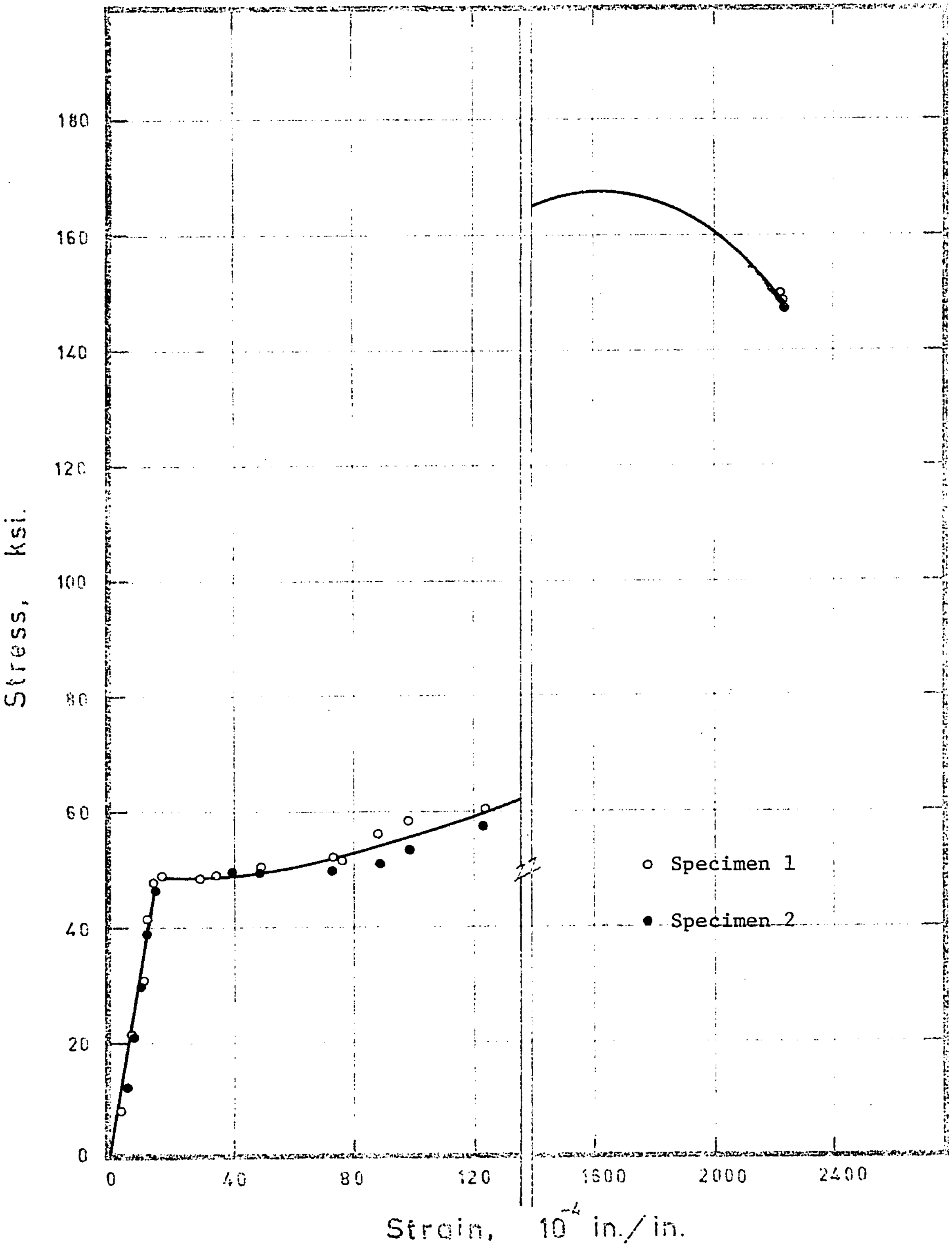


FIG. 5.25 STRESS--STRAIN CURVE AT 20°C OF SPECIMEN NO. 9640

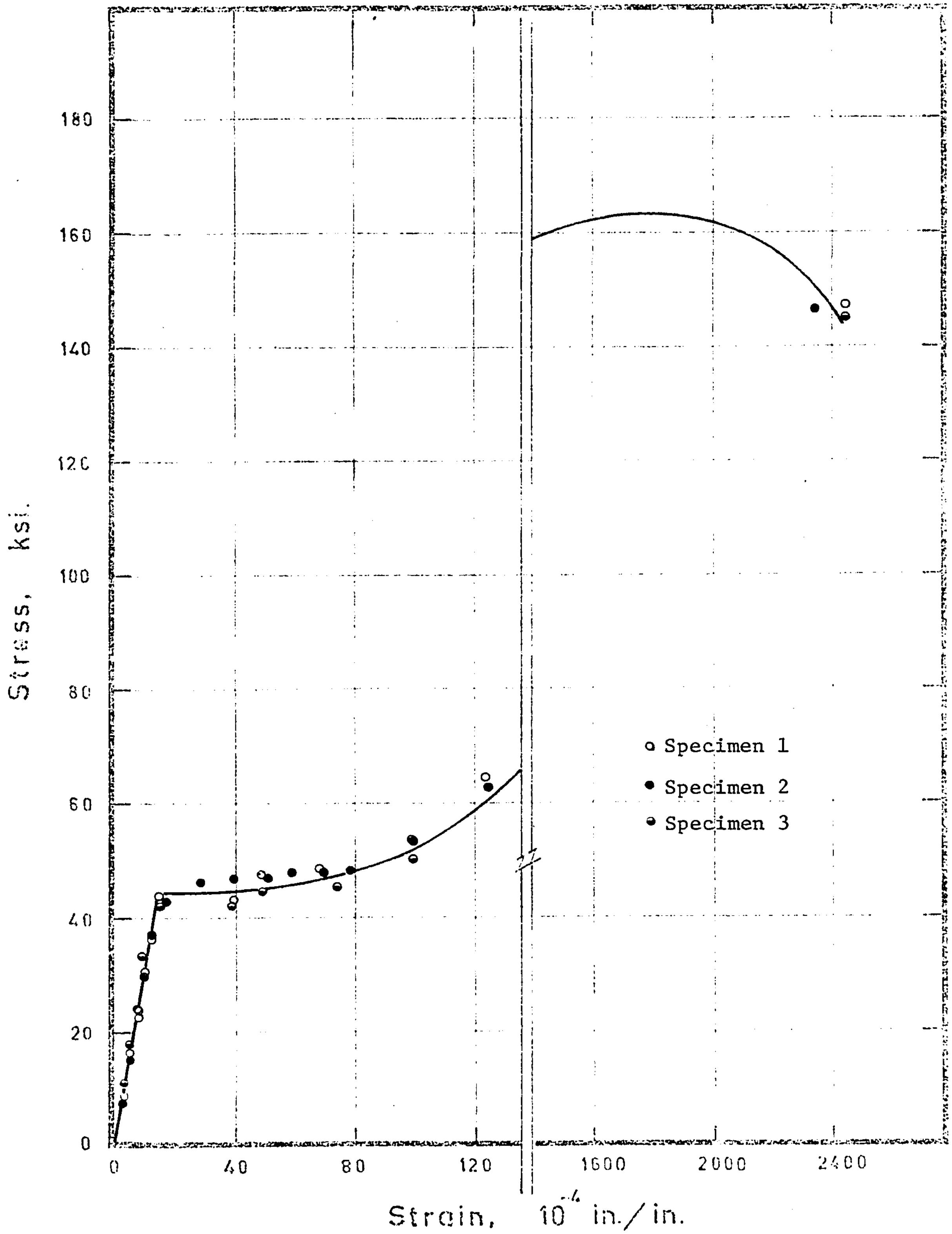


FIG. 5.26 STRESS—STRAIN CURVE AT 40°C OF SPECIMEN NO. 9G40

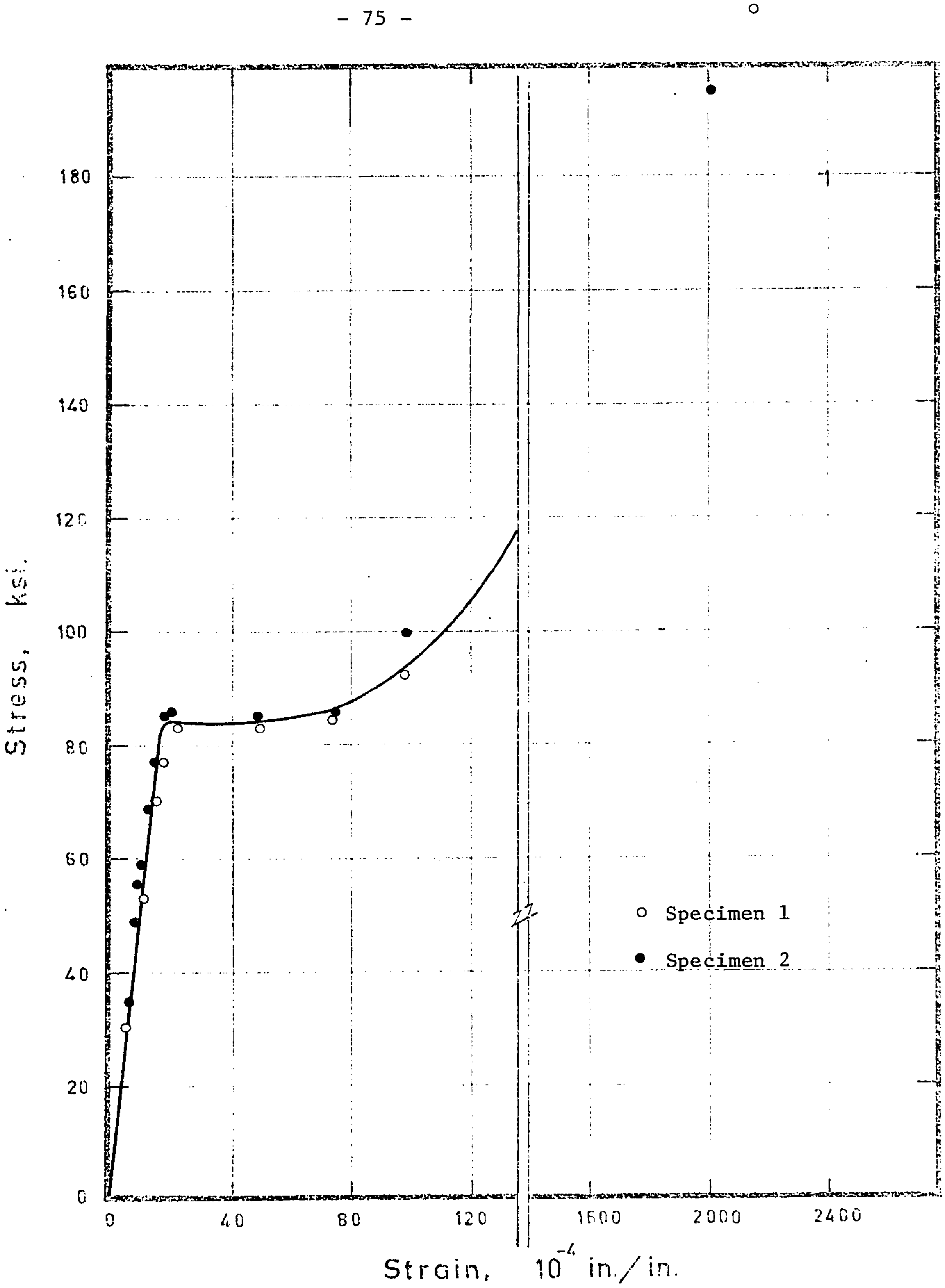


FIG. 5.27 STRESS–STRAIN CURVE AT –40°C OF SPECIMEN NO. 6G 60

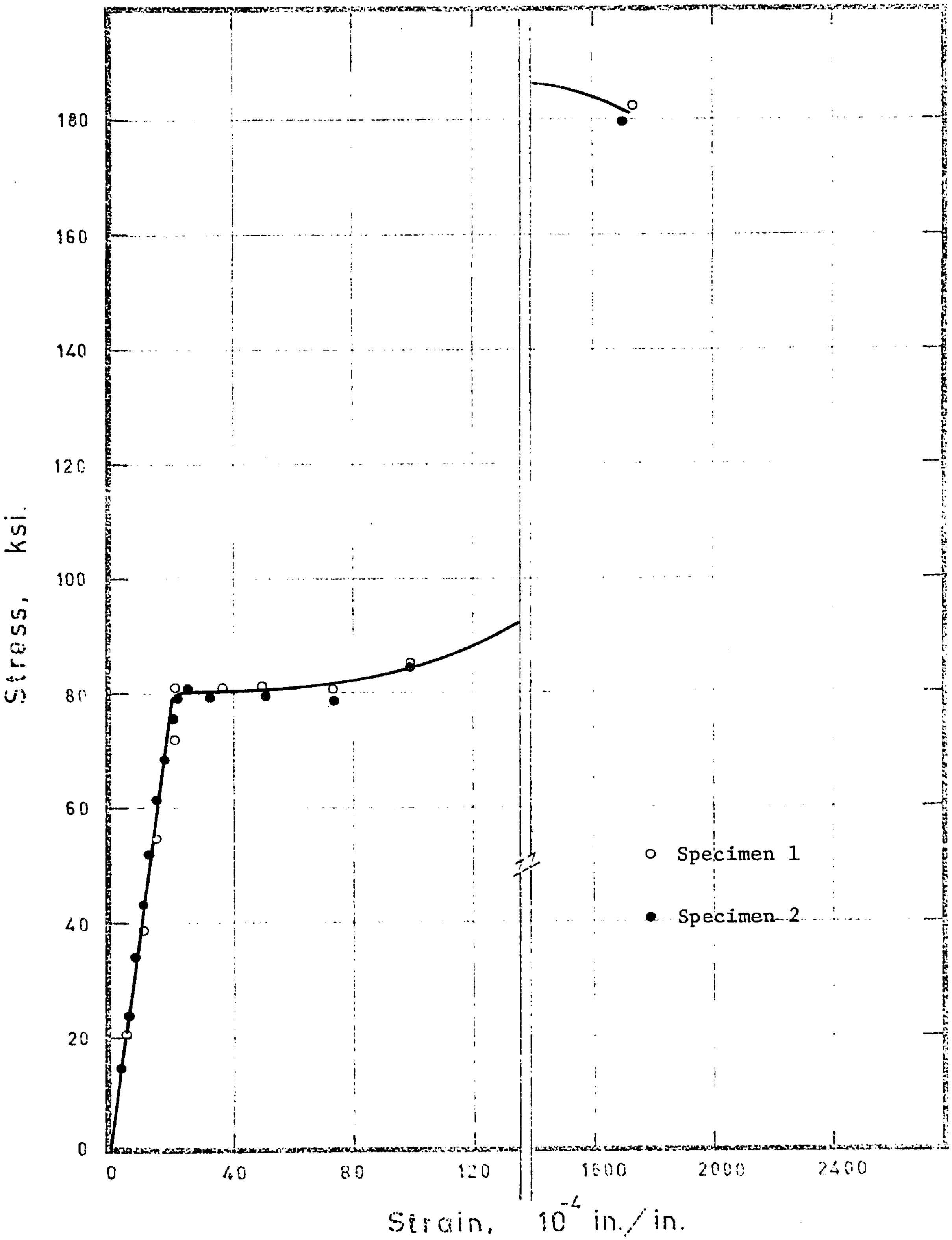


FIG. 5.28 STRESS—STRAIN CURVE AT −20°C OF SPECIMEN NO. 6660

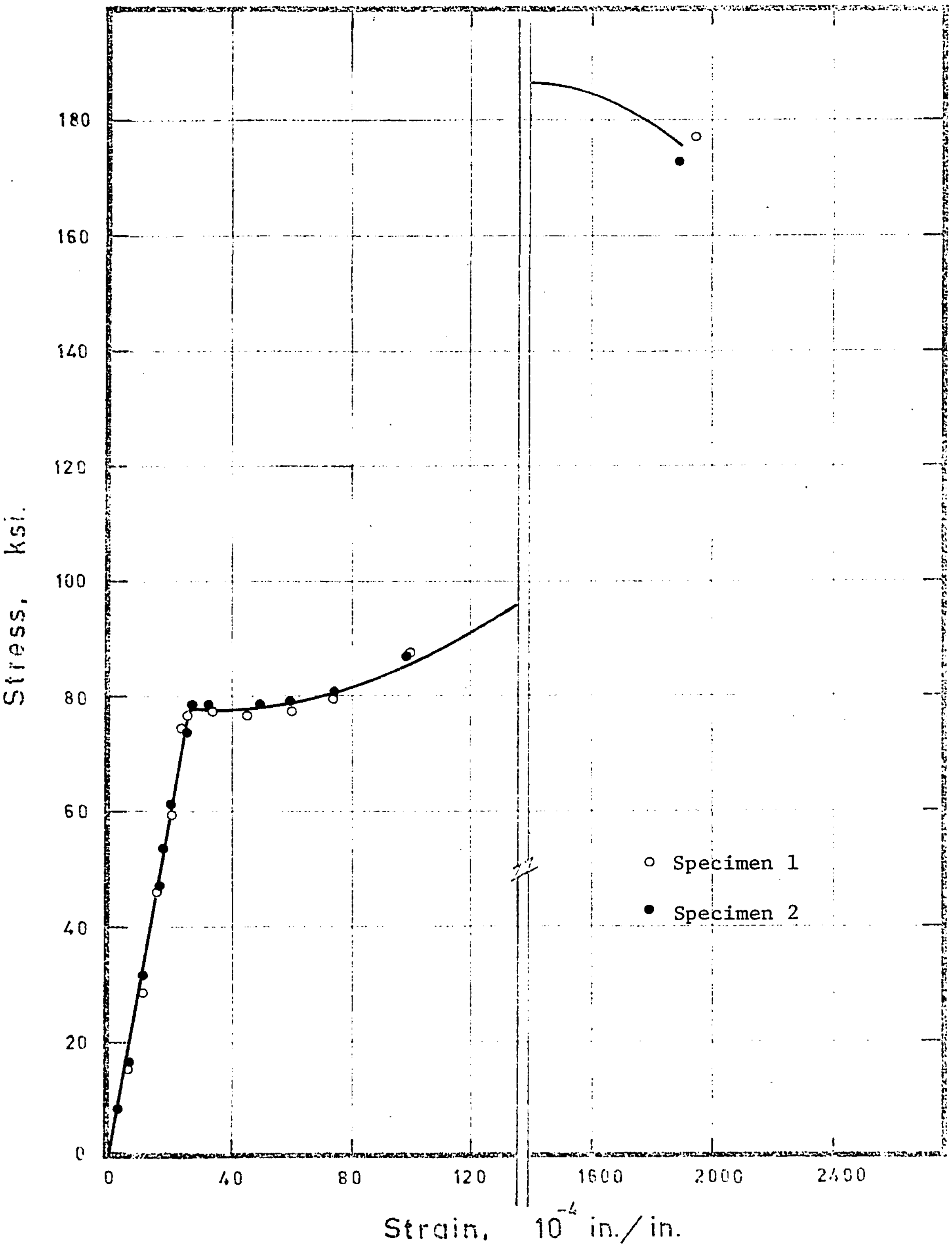


FIG. 5.29 STRESS—STRAIN CURVE AT 0° C OF SPECIMEN NO. 6G 60

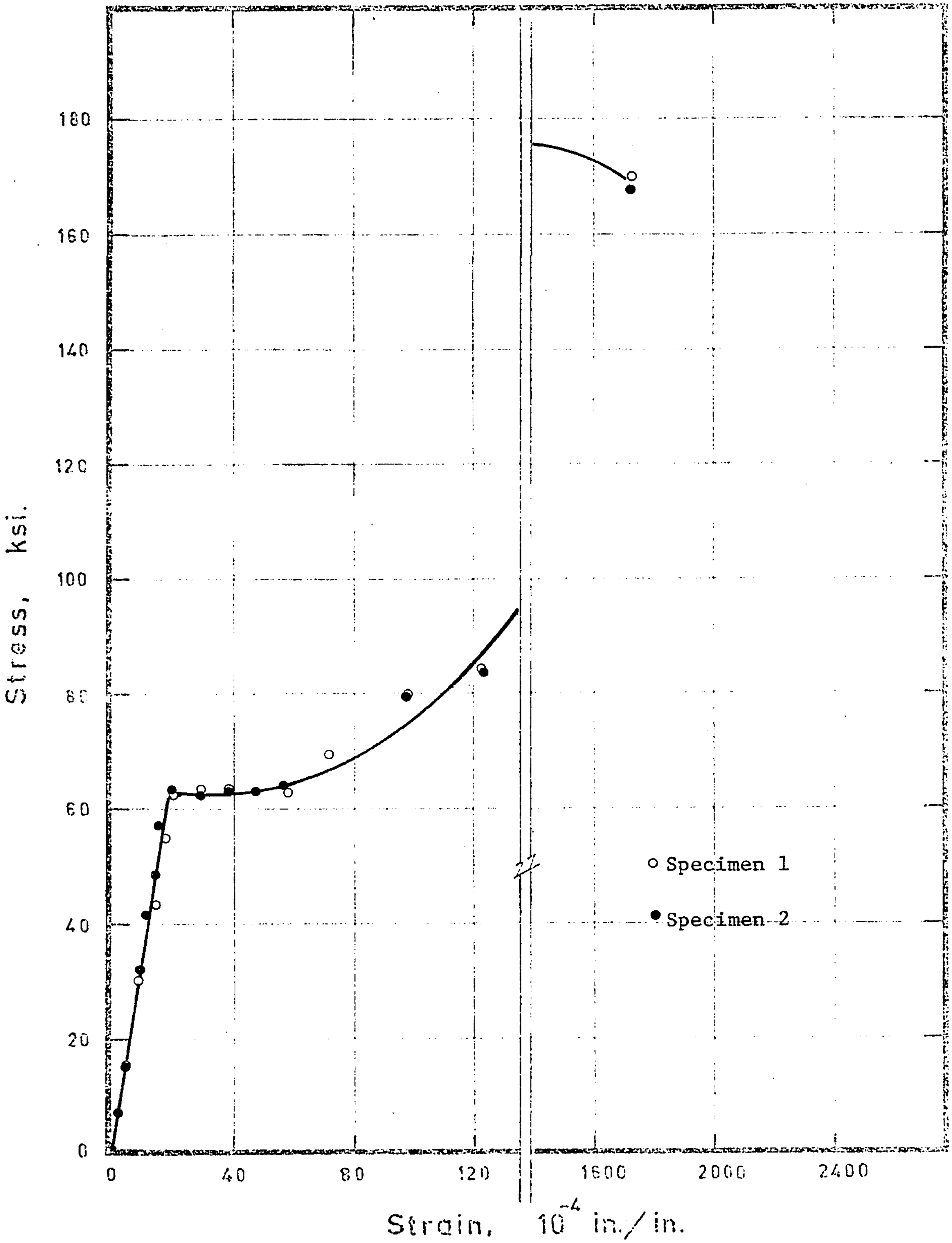


FIG. 5.30 STRESS--STRAIN CURVE AT 20°C OF SPECIMEN NO. 6G 60

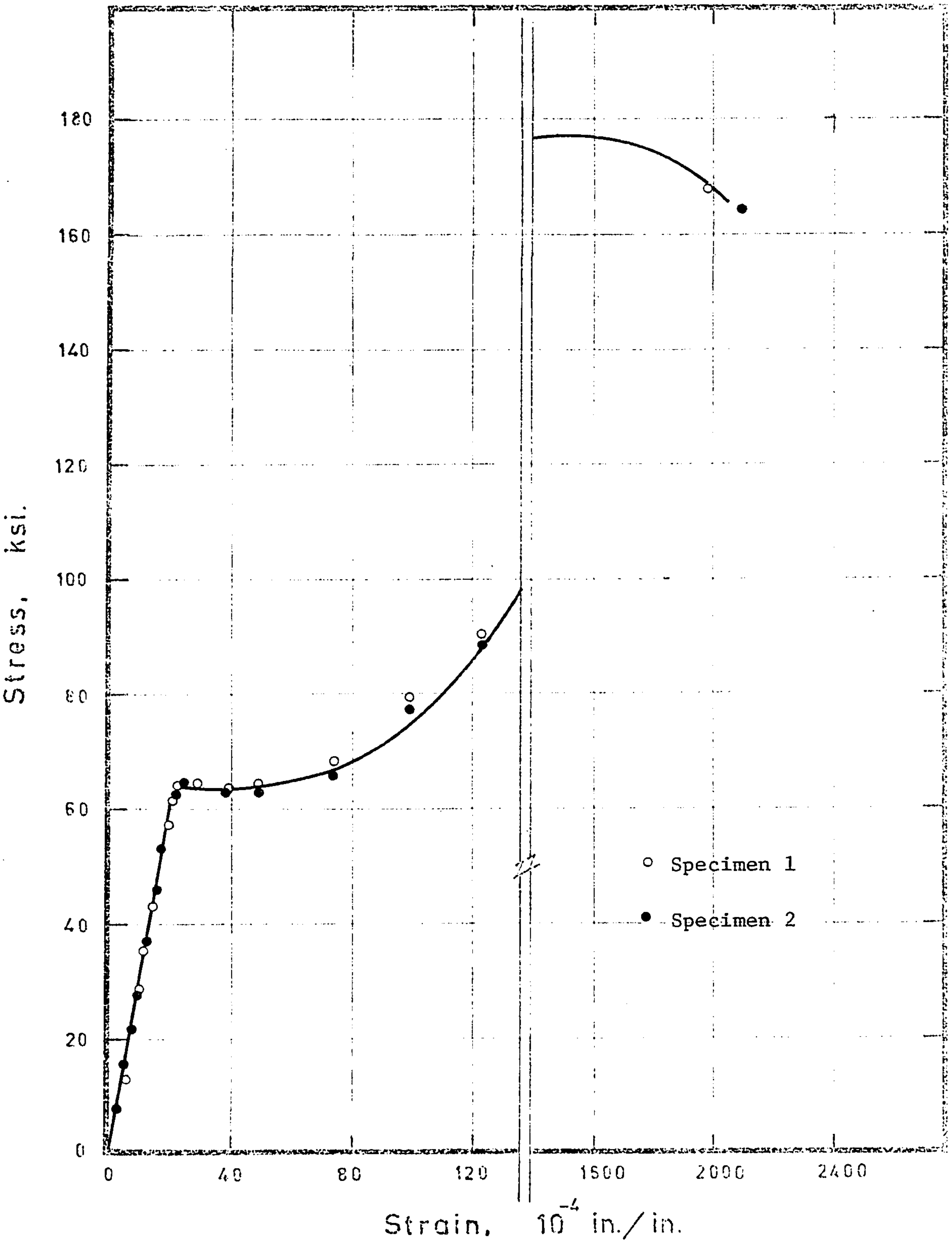


FIG. 5.31 STRESS—STRAIN CURVE AT 40° C OF SPECIMEN NO. 6G60

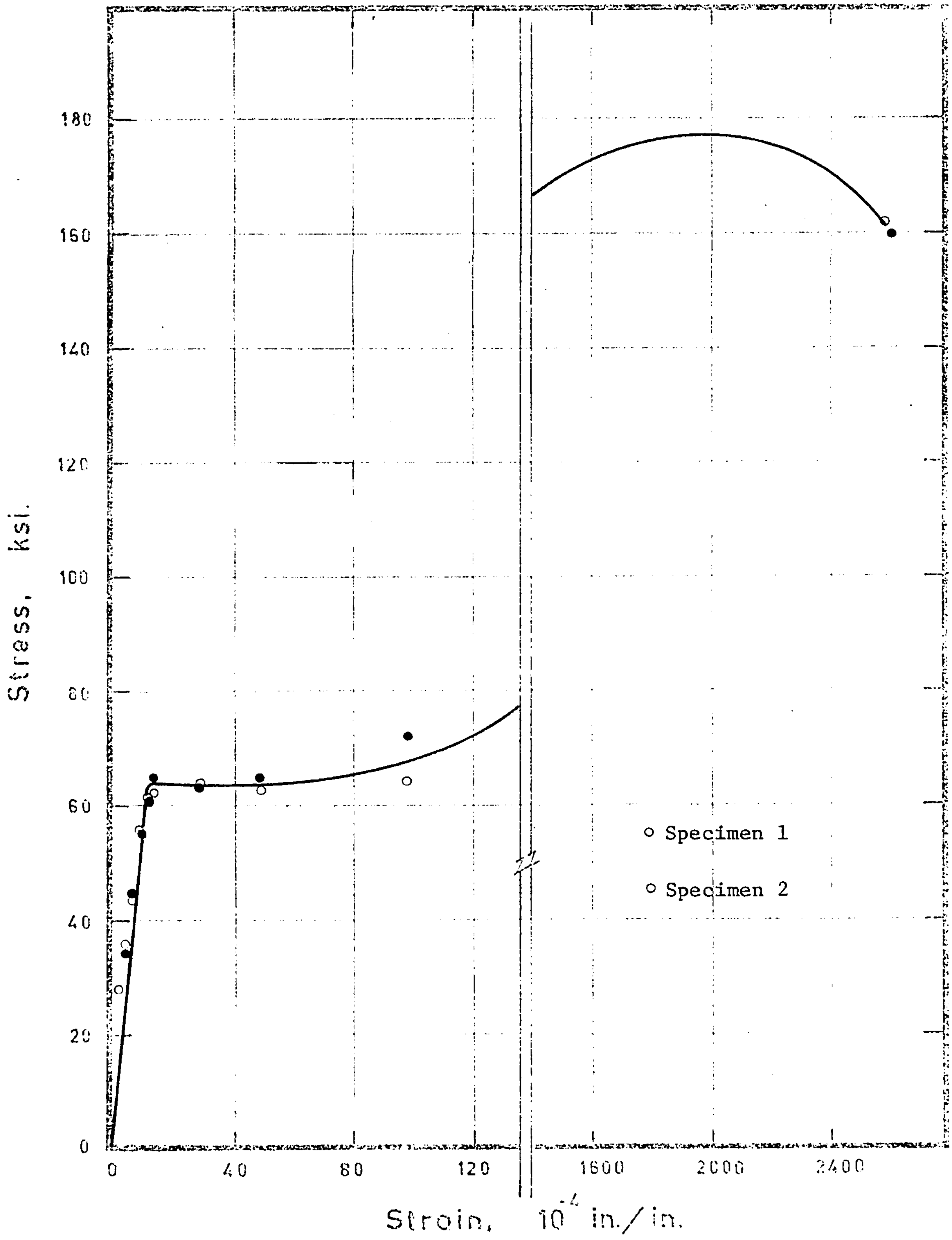


FIG. 5.32 STRESS—STRAIN CURVE AT −40°C OF SPECIMEN NO. 6G40

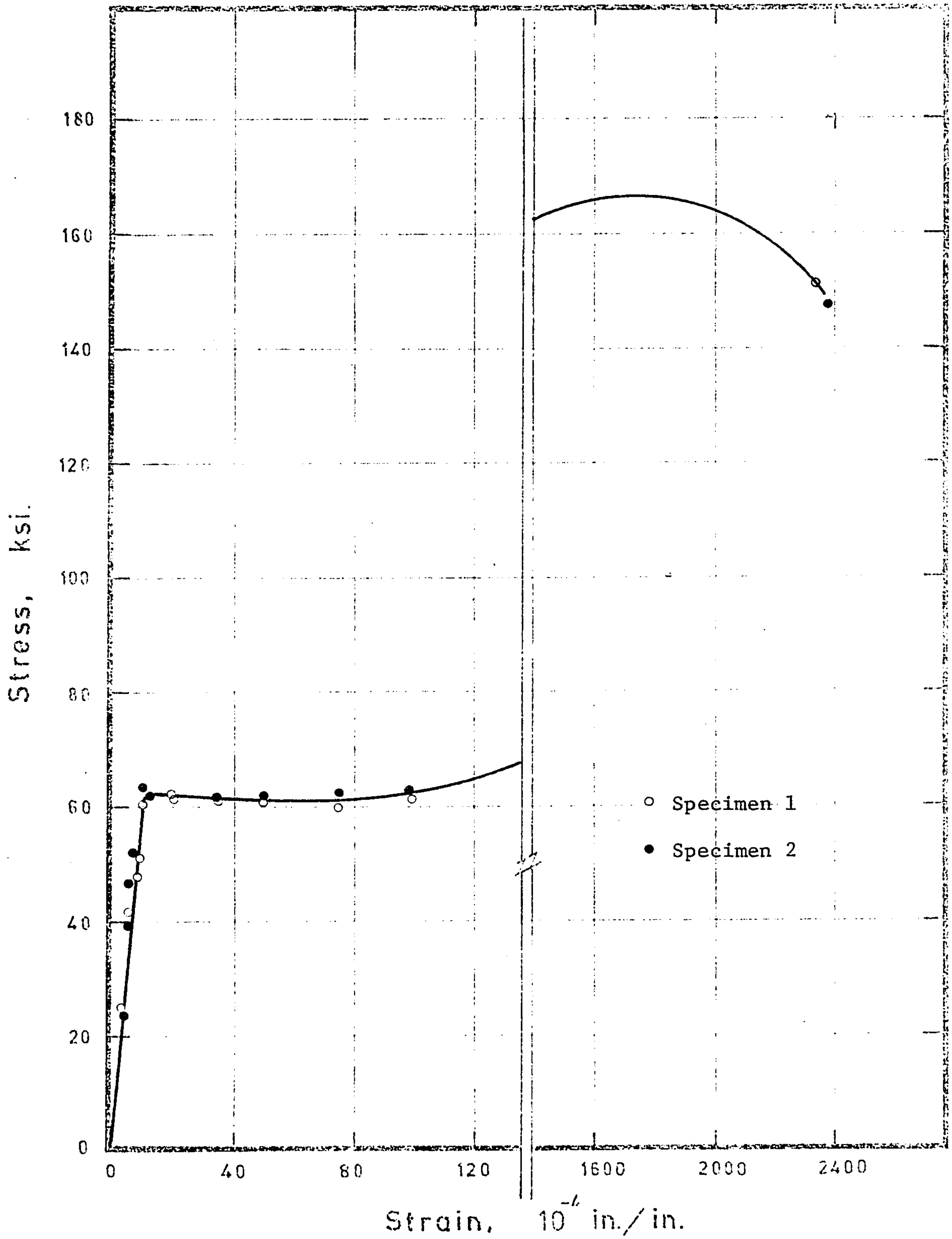


FIG. 5.33 STRESS—STRAIN CURVE AT -20°C OF SPECIMEN NO. 6640

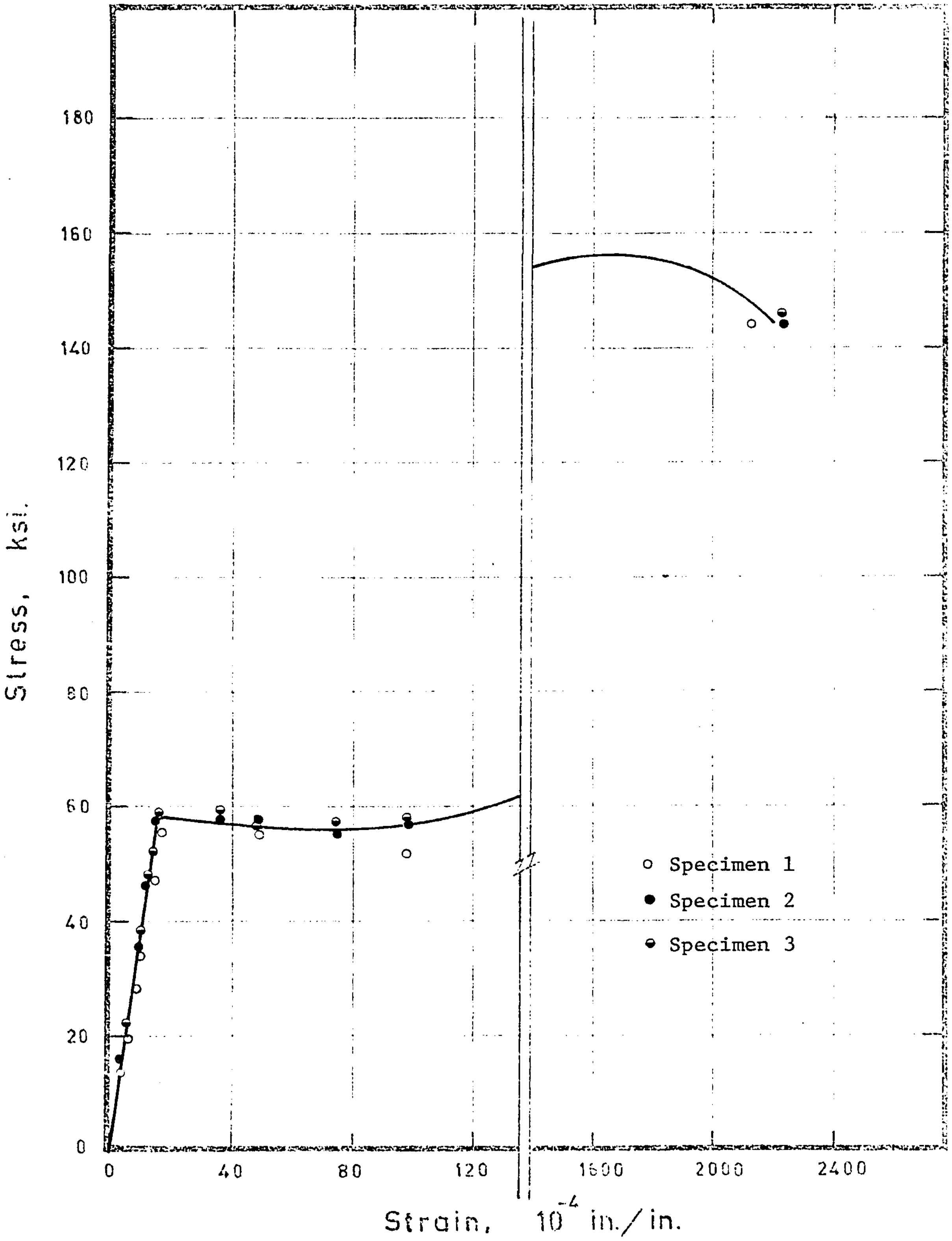


FIG. 5.34 STRESS—STRAIN CURVE AT 0° C
OF SPECIMEN NO. 6G40

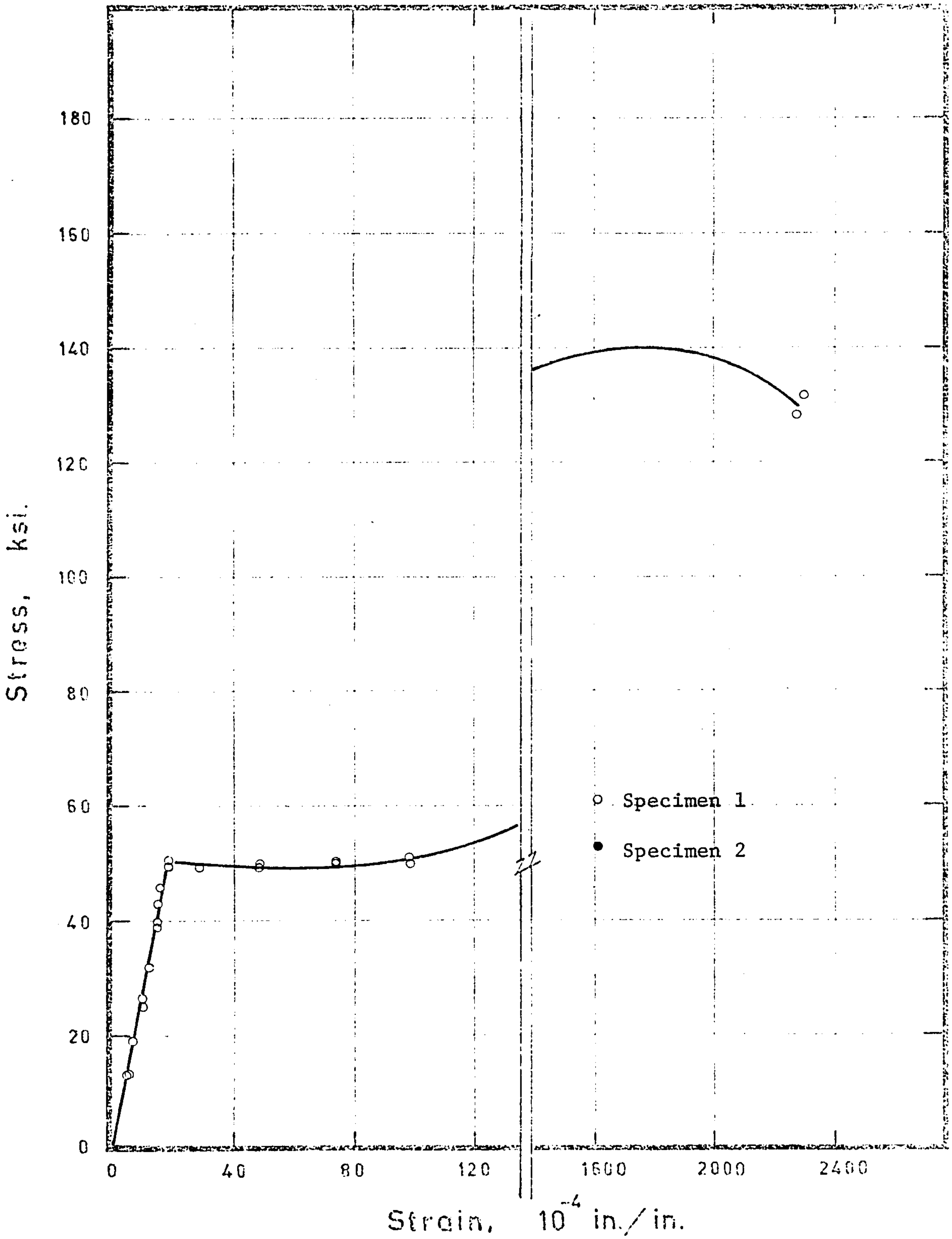


FIG. 5.35 STRESS--STRAIN CURVE AT 20°C OF SPECIMEN NO. 6G40

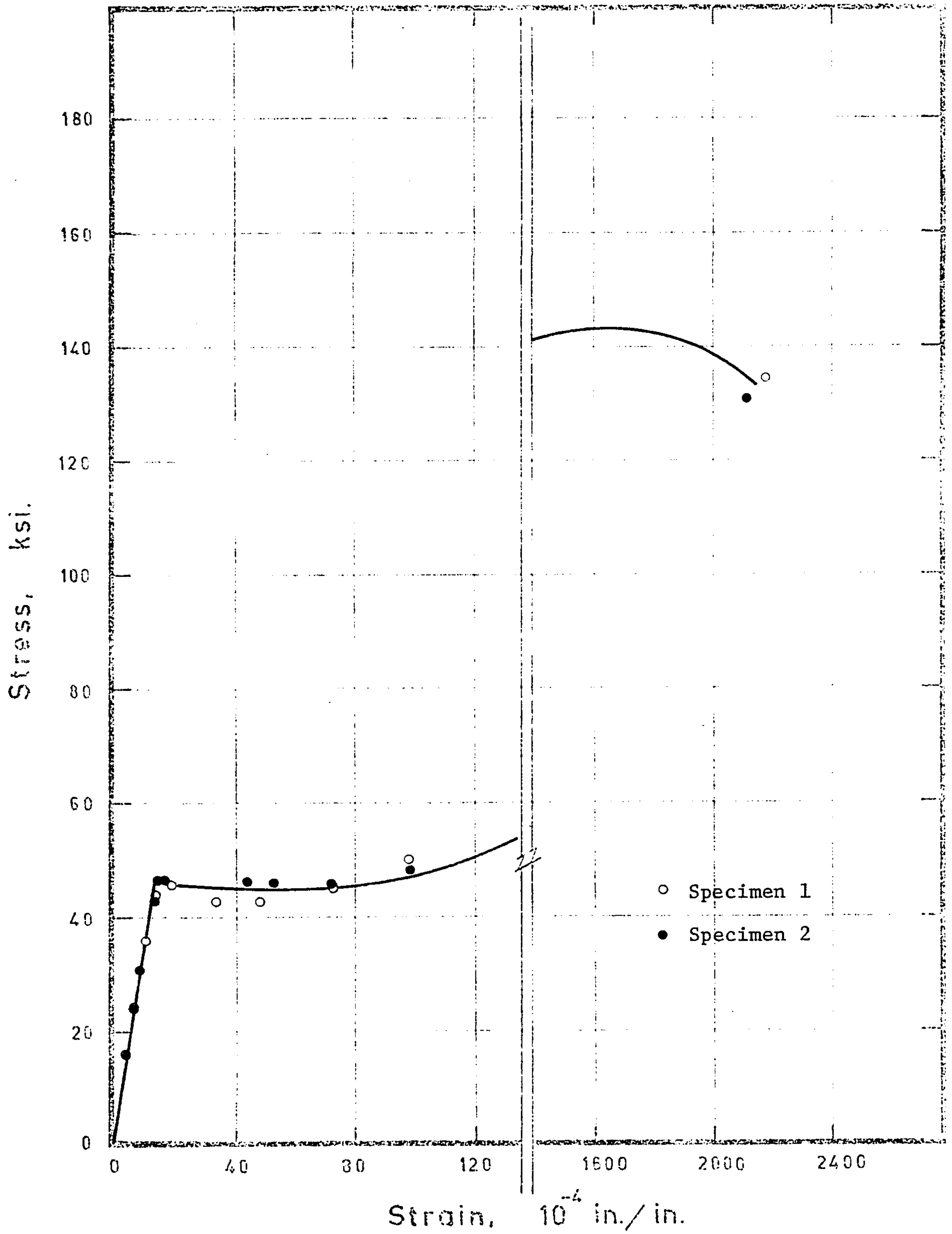


FIG. 5.36 STRESS–STRAIN CURVE AT 40°C
OF SPECIMEN NO. 6G40

APPENDIX B

TYPICAL FAILURE PHENOMENA OF SPECIMENS

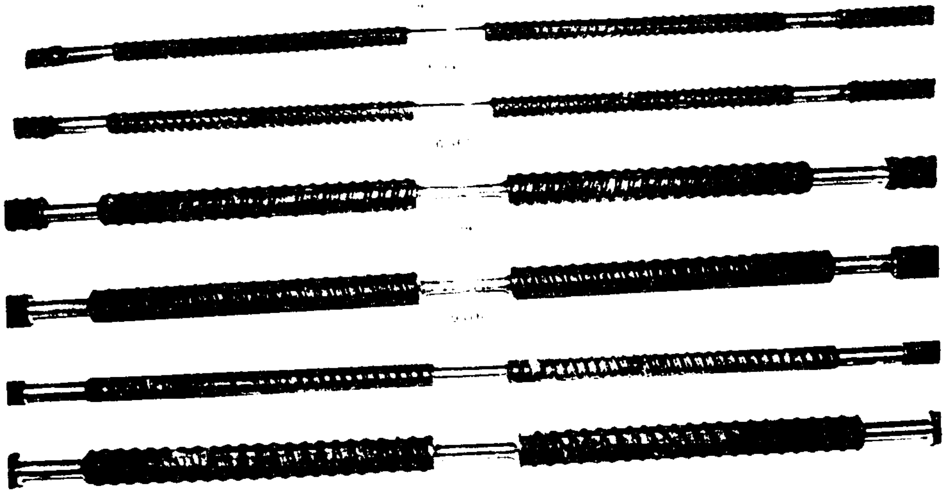


FIG. 5.37 VARIOUS FRACTURED SPECIMENS DEFORMED AT -40°C AND TWO UNDEFORMED TENSILE SPECIMENS

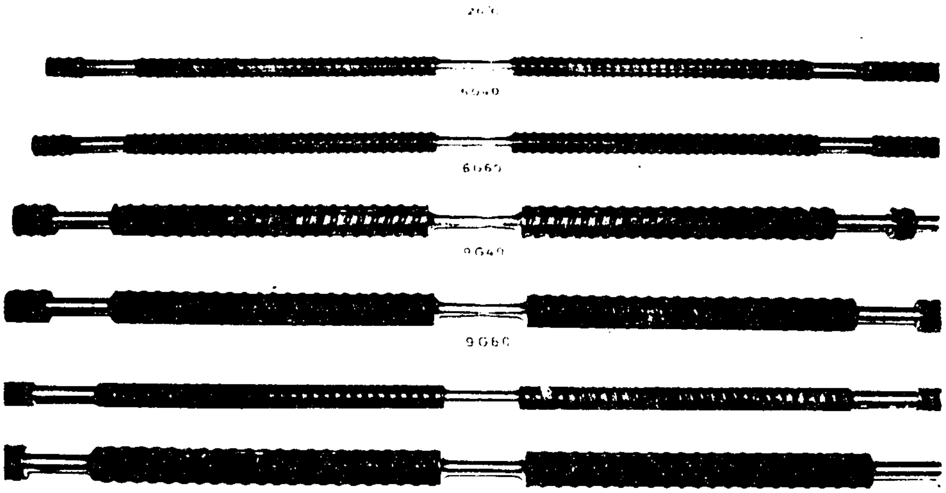


FIG. 5.38 VARIOUS FRACTURED SPECIMENS DEFORMED AT −20°C AND TWO UNDEFORMED TENSILE SPECIMEN

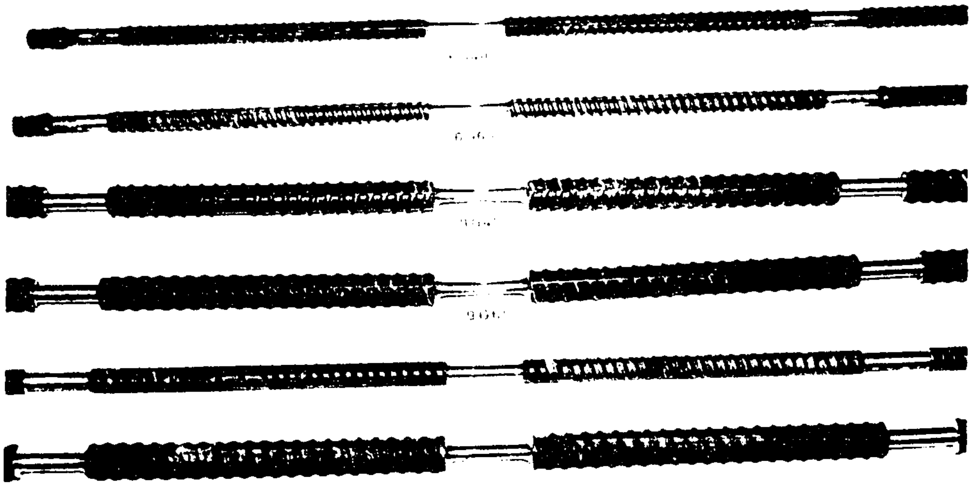


FIG. 5.39 VARIOUS FRACTURED SPECIMENS DEFORMED AT 0°C AND TWO UNDEFORMED TENSILE SPECIMENS

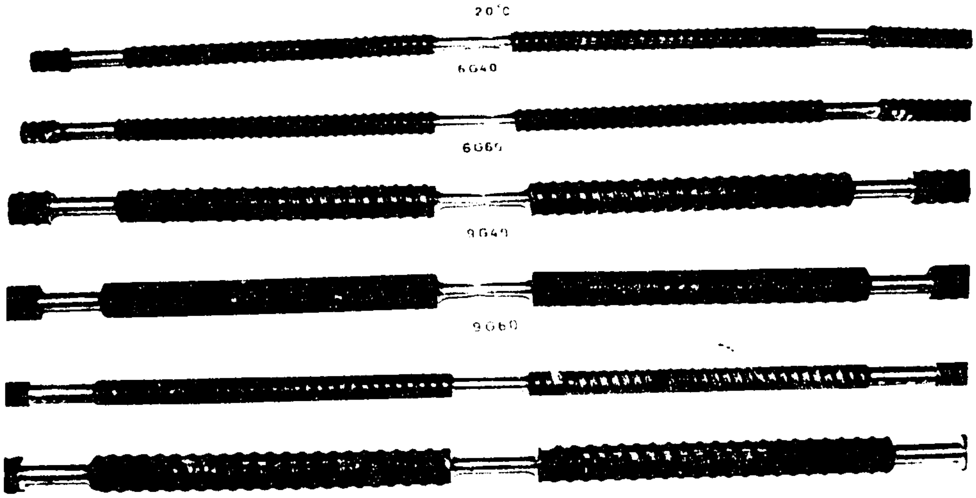


FIG. 5.40 VARIOUS FRACTURED SPECIMENS DEFORMED AT 20°C AND TWO UNDEFORMED TENSILE SPECIMENS

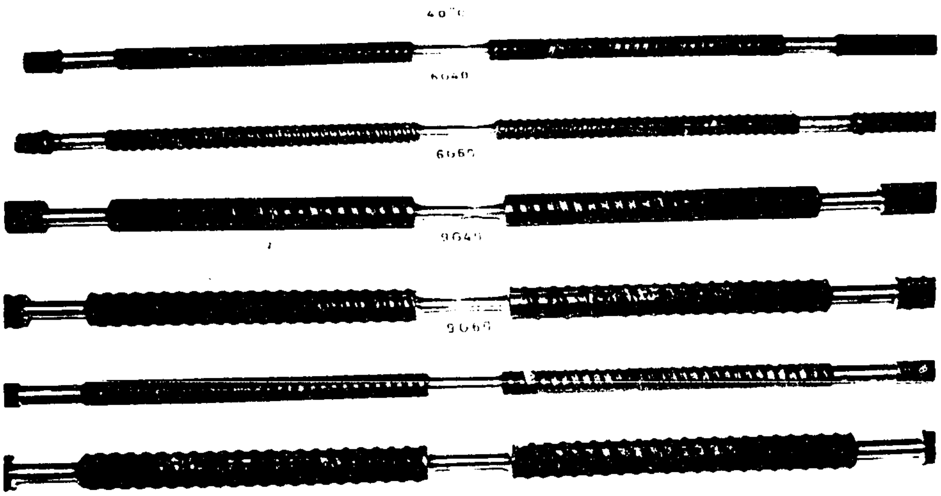


FIG. 5.41 VARIOUS FRACTURED SPECIMENS DEFORMED AT 40°C AND TWO UNDEFORMED TENSILE SPECIMENS

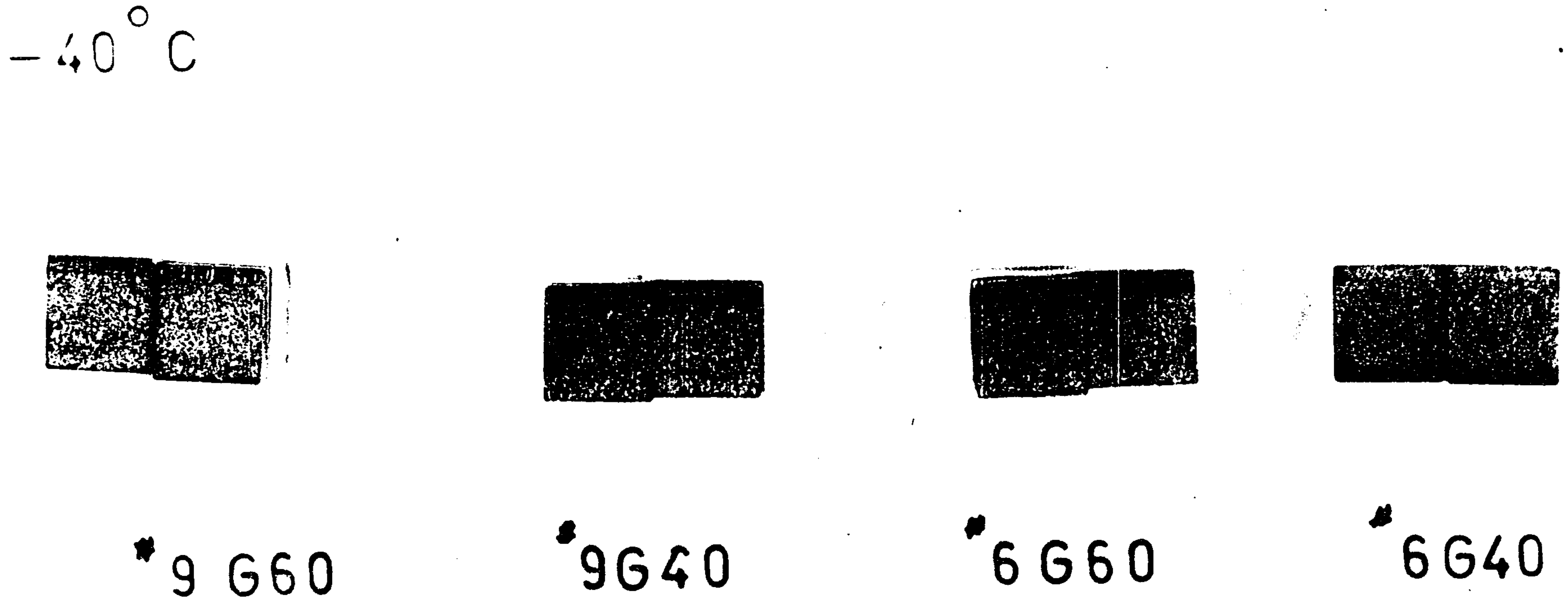


FIG. 5.42 TYPICAL FAILURE PHENOMENA OF CHARPY V-NOTCH IMPACT TEST SPECIMENS AT -40°C

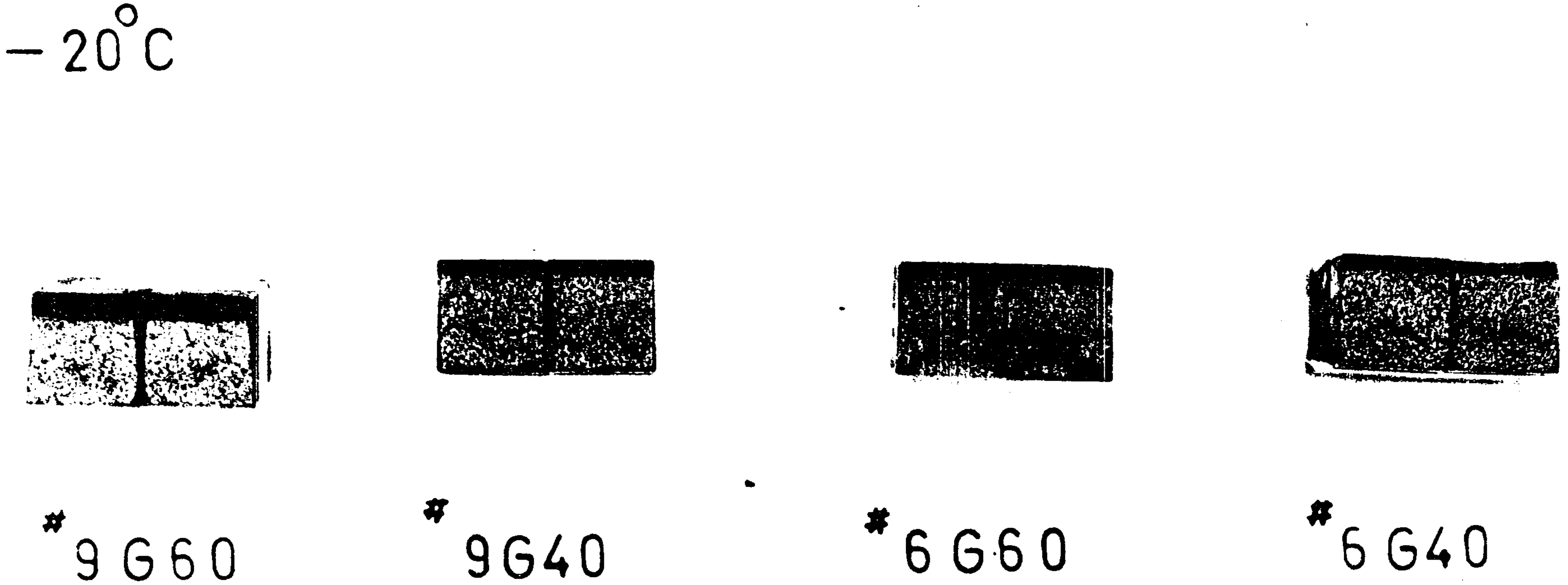


FIG. 5.43 TYPICAL FAILURE PHENOMENA OF CHARPY V-NOTCH IMPACT TEST SPECIMENS AT - 20°C

FIG. 5.44 TYPICAL FAILURE PHENOMENA OF CHARPY V-NOTCH IMPACT TEST SPECIMENS AT 0°C

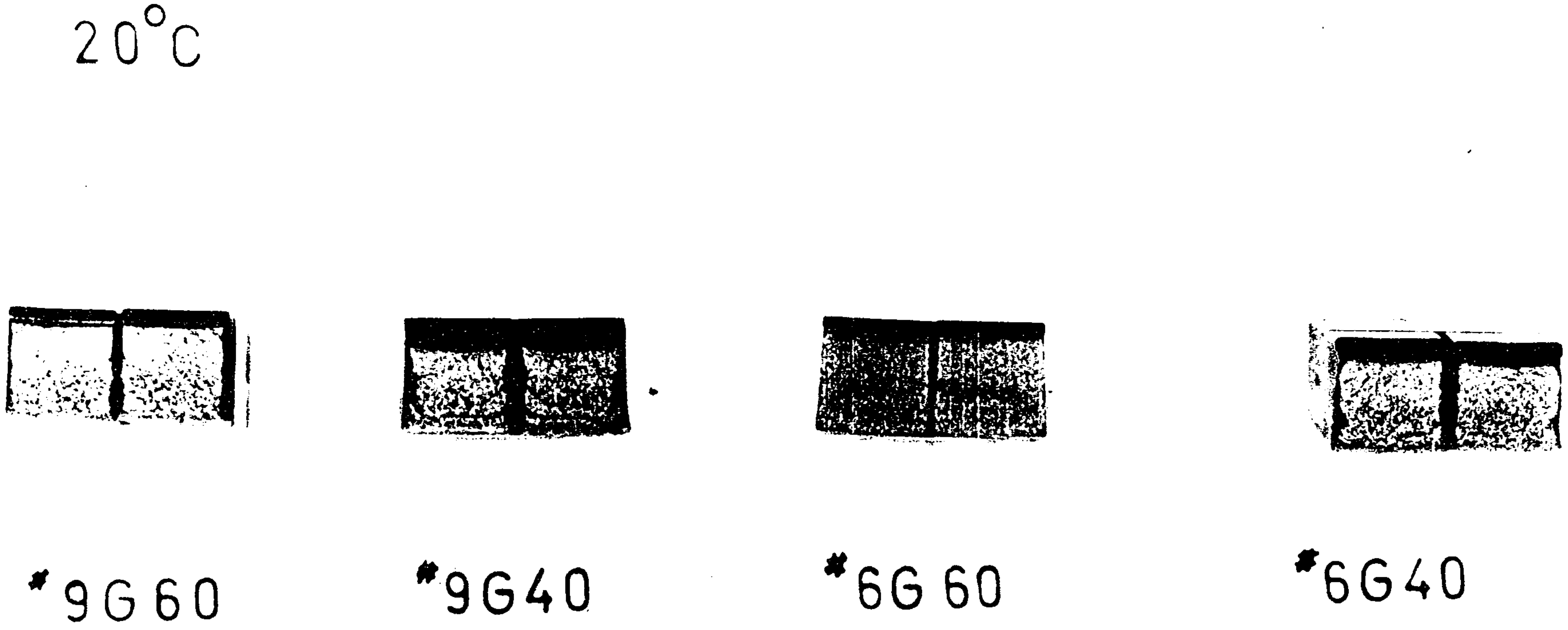


FIG. 5.45 TYPICAL FAILURE PHENOMENA OF CHARPY V-NOTCH IMPACT TEST SPECIMENS AT 20°C

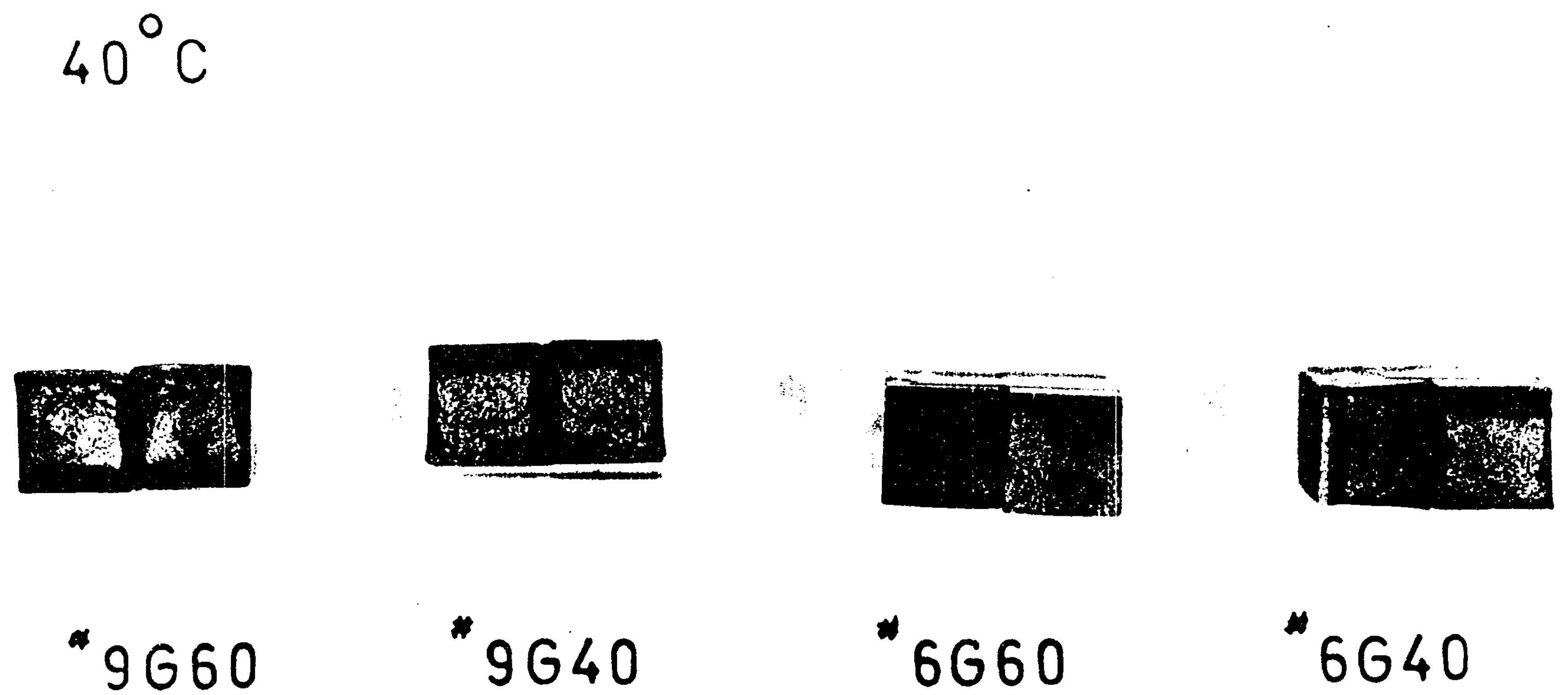


FIG. 5.46 TYPICAL FAILURE PHENOMENA OF CHARPY V-NOTCH IMPACT TEST SPECIMENS AT 40°C

APPENDIX C

TENTATIVE RECOMMENDATIONS

by

ASTM Committee - see Ref. [10]

TENTATIVE RECOMMENDATIONS

1. It is the view of the committee that the best available method of quantitatively evaluating a high-strength sheet material for its resistance to brittle fracture is by determing K_c, the characteristic fracture toughness. The requirements of a test method for determining K_c have been given in detail in the first chapter of this report. It should be noted that K_c is strongly influenced by temperature. This effect and the usefulness of fracture-appearance measurements are discussed in the second chapter.

2. Recognizing that a preliminary screening test for ranking a large number of materials may be required, the committee recommends tests with the fixed-width sharp edge-notch or the center-notched specimens discussed in the third chapter. The recommended measure of merit is the notch-strength ratio at the minimum possible service temperature. The limitations of this test method are discussed in the third chapter. It is also recommended that the fracture appearance be used in conjunction with the notch strength in evaluating materials.

3. One other type of screening test has been described: the instrumented bend test. This description has been included because preliminary work with this test

has demonstrated some correlation with the more complex test methods. This test has the advantage of a considerable saving in specimen preparation time, in testing time, and in the amount of material used. However, experience with the test is limited; its inclusion in this report serves the purpose of stimulating further experimentation over a broader range of materials.

APPENDIX D

SPECIFICATION FOR STEEL

Ref. ASTM Standard, Part 4, Jan. 1969, pp.890-895

Standard Specification for

DEFORMED BILLET-STEEL BARS FOR CONCRETE REINFORCEMENT[1]

ASTM Designation: A 615 - 68

This Standard of the American Society for Testing and Materials is issued under the fixed designation A 615; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval.

1. Scope

1.1 This specification covers deformed billet-steel concrete-reinforcement bars A deformed bar is defined as a bar which is intended for use as reinforcement in reinforced concrete construction. The surface of the bar is provided with lugs or protrusions (hereinafter called "deformations") which inhibit longitudinal movement of the bar relative to the concrete which surrounds the bar in such construction and conform to the provisions of this specification. The standard sizes and dimensions of deformed bars and their number designations shall be those listed in Table 1.

1.2 Bars are of three minimum yield levels: namely, 40,000 psi, 60,000 psi and 75,000 psi, designated as Grade 40, Grade 60, and Grade 75, respectively.

1.3 The weldability of the steel is not part of this specification, but may be subject to agreement between a particular supplier and user.

2. Process

2.1 The steel shall be made by one or more of the following processes: open-hearth, basic-oxygen, or electric-furnace.

2.2 The bars shall be rolled from billets or ingots of properly identified heats of open-hearth, basic-oxygen, or electric-furnace steel.

3. Chemical Composition

3.1 The steel shall conform to the following requirements as to chemical composition:

Phosphorus, max, percent:
Open-hearth, basic-oxygen, or electric-furnace 0.05

4. Ladle Analysis

4.1 An analysis of each heat of open-hearth, basic-oxygen, or electric-furnace steel shall be made to determine the percentages of carbon, manganese, phosphorus, and sulfur, and, for Grade 75, any other elements the manufacturer considers essential to meet the mechanical properties of this specification.

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[1] Under the standardization procedure of the Society, this specification is under the jurisdiction of the ASTM Committee A-1 on Steel and is the direct responsibility of Subcommittee V on Steel Reinforcement Bars. A list of committee members may be found in the ASTM Year Book.

Accepted February 14, 1968. Replaces A 15, A 408, A 431, A 432, and portions of A 305.

4.2 The analyses prescribed in 4.1 shall be made by the manufacturer from test ingots taken during the pouring of the heats. The chemical composition thus determined shall be reported on request to the purchaser or his representative, and the percentage of phosphorus shall conform to the requirements specified in 3.1.

5. Check Analysis

5.1 An analysis may be made by the purchaser from finished bars representing each heat of open-hearth, basic-oxygen, or electric-furnace steel. The phosphorus content thus determined shall not exceed that specified in 3.1 by more than 25 percent.

TABLE 1—DEFORMED BAR DESIGNATION NUMBERS, UNIT WEIGHTS, NOMINAL DIMENSIONS, AND DEFORMATION REQUIREMENTS[a]

Bar Designation No.[b]	Nominal Dimensions[a]				Deformation Requirements, in.		
	Unit Weight, lb/ft	Diameter, in.	Cross-Sectional Area, in.^{2}	Perimeter, in.	Maximum Average Spacing	Minimum Average Height	Maximum Gap (Chord of 12½ percent of Nominal Perimeter)
3..........	0.376	0.375	0.11	1.178	0.262	0.015	0.143
4..........	0.668	0.500	0.20	1.571	0.350	0.020	0.191
5..........	1.043	0.625	0.31	1.963	0.437	0.028	0.239
6..........	1.502	0.750	0.44	2.356	0.525	0.038	0.286
7..........	2.044	0.875	0.60	2.749	0.612	0.044	0.334
8..........	2.670	1.000	0.79	3.142	0.700	0.050	0.383
9..........	3.400	1.128	1.00	3.544	0.790	0.056	0.431
10..........	4.303	1.270	1.27	3.990	0.889	0.064	0.487
11..........	5.313	1.410	1.56	4.430	0.987	0.071	0.540
14..........	7.65	1.693	2.25	5.32	1.185	0.085	0.648
18..........	13.60	2.257	4.00	7.09	1.58	0.102	0.864

[a] The nominal dimensions of a deformed bar are equivalent to those of a plain round bar having the same weight per foot as the deformed bar.

[b] Bar numbers are based on the number of eighths of an inch included in the nominal diameter of the bars.

6. Requirements for Deformations

6.1 Deformations shall be spaced along the bar at substantially uniform distances. The deformations on opposite sides of the bar shall be similar in size and shape.

6.2 The deformations shall be placed with respect to the axis of the bar so that the included angle is not less than 45 deg. Where the line of deformations forms an included angle with the axis of the bar of from 45 to and including 70 deg, the deformations shall alternately reverse in direction on each side, or those on one side shall be reversed in direction from those on the opposite side. Where the line of deformation is over 70 deg a reversal in direction is not required.

6.3 The average spacing or distance between deformations on each side of the bar shall not exceed seven tenths of the nominal diameter of the bar.

6.4 The over-all lengths of deformations shall be such that the gap between the extreme ends of the deformations on opposite sides of the bar shall not exceed 12½ percent of the nominal perimeter of the bar. Where the extreme ends terminate in a longitudinal rib, the width of the longitudinal rib shall be considered the gap. Where more than two longitudinal ribs are involved, the total width of all longitudinal ribs shall not exceed 25 percent of the nominal perimeter of the bar; furthermore, the summation of gaps shall not exceed 25 percent of the nominal perimeter of the bar. The nominal perimeter of the bar shall be 3.14 times the nominal diameter.

6.5 The spacing, height, and gap of deformations shall conform to the requirements prescribed in Table 1.

7. Measurements of Deformations

7.1 The average spacing of deformations shall be determined by dividing a measured length of the bar specimen by the number of individual deformations and fractional parts of deformations on any one side of the bar specimens. A measured length of the bar specimen shall be considered the distance from a point on a deformation to a corresponding point on any other deformation on the same side of the bar. Spacing measurements shall not be made over a bar area containing bar marking symbols involving letters or numbers.

TABLE 2—TENSILE REQUIREMENTS FOR DEFORMED BARS,[a] GRADE 40

Tensile strength, min. psi	70 000
Yield point, min, psi	40 000
Elongation in 8 in., min, percent:	
Bar No.	
3	11
4, 5, 6	12
7	11
8	10
9	9
10	8
11, 14, 18	7
Elongation in 2 in., min, percent (test Fig. 6 of A 370):	
Bar No.	
14, 18	9

[a] Plain round bars are available under ASTM Specification A 306, for Carbon Steel Bars Subject to Mechanical Property Requirements.[2]

7.2 The average height of deformations shall be determined from measurements made on not less than two typical deformations. Determinations shall be based on three measurements per deformation, one at the center of the over-all length and the other two at the quarter points of the over-all length.

7.3 To indicate adequately the conformity to the dimensional requirements, measurements shall be selected as follows on representative bars taken at random:

7.3.1 For bars No. 3 to 11, inclusive, one bar for each 10 tons of each lot or fraction thereof.

7.3.2 For bars No. 14 and 18, one bar for each 25 tons of each lot or fraction thereof.

7.4 Insufficient height, insufficient circumferential coverage, or excessive spacing of deformations shall not constitute cause for rejection unless it has been clearly established by determinations on each lot that typical deformation height, gap, or spacing do not conform to the minimum requirements prescribed in 6. Requirements for Deformations. No rejection may be made on the basis of measurements if fewer than ten adjacent deformations on each side of the bar are measured.

8. Tensile Properties

8.1 *Grade 40:*

8.1.1 The material shall conform to the requirements as to tensile properties prescribed in Table 2.

8.1.2 The yield point shall be determined by the drop of the beam or halt in the gage of the testing machine.

8.2 *Grade 60 and Grade 75:*

8.2.1 The material shall conform to the requirements as to tensile properties prescribed in Table 3.

8.2.2 The yield strength shall be determined by one of the following methods:

8.2.2.1 Extension under load using dividers with an 8-in. gage length. The extension under load shall be 0.04 in. for Grade 60, and 0.047 in. for Grade 75, and shall be determined by scribing on the specimen an 8-in. gage length,

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[2] *1968 Book of ASTM Standards*, Part 3.

pivoting from a prick-punch mark. The yield load shall be recorded when the total gage length under load becomes 8.04 or 8.047 in., respectively, as measured by the dividers.

8.2.2.2 Extension under load using an autographic diagram method or an extensometer as described in Item (*2*) of Section 12(*a*) and (*b*) of ASTM Methods and Definitions A 370, for Mechanical Testing of Steel Products.[3] However, the extension under load shall be 0.006 in./in. of gage length (0.6 percent) for Grade 75 or 0.005 in./in. (0.5 percent) for Grade 60.

TABLE 3—TENSILE REQUIREMENTS

	Grade 60	Grade 75[a]
Tensile strength, min, psi...	90 000	100 000
Yield strength, min, psi....	60 000	75 000
Elongations in 8 in., min, percent (full size or reduced diameter test specimen):		
Bar No.		
3, 4, 5, 6............	9	...
7, 8.................	8	...
9, 10, 11............	7	...
14, 18..............	7	...
11, 14, and 18........	...	5
Elongation in 2 in., min, percent (Fig. 6 of Methods of A 370):		
Bar Nos.		
9, 10, 11, 14, 18	9	...
11, 14, and 18..	...	6

[a] Grade 75 bars are furnished only in sizes 11, 14, and 18.

8.2.2.3 *For Grade 60*—Drop of the beam method, Section 12(*a*)(*1*) of Methods A 370, may be applied where the steel tested has a sharp-kneed or well-defined type of yield point.

8.2.3 The percentage of elongation shall be as prescribed in Table 3.

9. Bending Properties

9.1 For bar sizes No. 3 to 11, inclusive, the bend test specimen shall stand being bent, at room temperature, around a pin without cracking on the outside of the bent portion. The requirements for degree of bending and sizes of pins prescribed in Table 4 shall be observed.

9.2 The bend test shall be made on specimens of sufficient length to ensure free bending and with apparatus which provides:

9.2.1 Continuous and uniform application of force throughout the duration of the bending operation,

9.2.2 Unrestricted movement of the specimen at points of contact with the apparatus, and

TABLE 4—BEND TEST REQUIREMENTS

NOTE—d = diameter of pin around which specimen is bent and
t = diameter of the specimen.

Bar Designation No.	Diameter of Pin for 90-deg Bend		
	Grade 40	Grade 60	Grade 75
3, 4, 5........	$d = 3t$	$d = 4t$	...
6, 7..........	$d = 4t$	$d = 5t$	...
8............	$d = 4t$	$d = 5t$	...
9............	$d = 5t$	$d = 6t$	...
10...........	$d = 5t$	$d = 6t$	...
11...........	$d = 5t$	$d = 6t$	$d = 8t$

9.2.3 Close wrapping of the specimen around the pin or mandrel during the bending operation.

9.3 Other methods of bend testing may be used, but failures due to such methods shall not constitute a basis for rejection.

9.4 Bars of size Nos. 14 and 18 shall not be subject to bend test requirements.

10. Test Specimens

10.1 Tension test specimens may be either the full section of the bar as rolled or at the option of the manufacturer one of the reduced section type of tests following:

10.1.1 Standard 0.505-in. diameter

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[3] Appears in this publication.

test specimen, with 2-in. gage length, as described in Fig. 6 of Methods A 370 and from a position in the bar as outlined in Table B-1 of Methods A 370.

10.1.2 Specimens machined to a reduced diameter of not less than $\frac{3}{4}$ in. for a length of not less than 9 in. with an 8-in. gage length.

10.1.3 The unit stress determinations on full size specimens shall be based on the nominal cross-sectional areas shown in Table 1.

10.2 The bend test specimens, when required, shall be the full section of the bar as rolled.

TABLE 5—PERMISSIBLE VARIATIONS FROM THEORETICAL WEIGHTS

NOTE 1—The theoretical weights for deformed bars listed in Table 1 shall be used to establish conformance to this table.

NOTE 2—Reinforcing bars are evaluated on the basis of nominal weights. In no case shall the overweight of any bar or lot of bars be cause for rejection.

Diameter of Bars	Lot[a] Under, percent	Individual Bar, Under, percent
All.............	3.5	6

[a] The term "lot" means all bars of the same nominal weight per linear foot contained in an individual shipping release or shipping order.

11. Number of Tests

11.1 For bar sizes No. 3 to 11, inclusive, one tension test and one bend test shall be made of the largest size rolled from each heat. If, however, material from one heat differs by three or more designation numbers one tension and one bend test shall be made from both the highest and lowest designation number of the deformed bars rolled.

11.2 In case of Nos. 14 and 18 bars, one tension test shall be made of each size rolled from each heat.

11.3 If any test specimen develops flaws, it may be discarded and another substituted.

11.4 If the percentage of elongation of any tension test specimen is less than that specified in 8. Tensile Properties, and any part of the fracture is outside the middle third of the gage length, as indicated by scribe scratches marked on the specimen before testing, a retest shall be allowed.

12. Permissible Variation in Weight

12.1 The permissible variation in weight shall not exceed the limits prescribed in Table 5.

13. Finish

13.1 The bars shall be free from injurious defects and shall have a workmanlike finish.

14. Marking

14.1 When loaded for mill shipment, all bars shall be properly separated and tagged with the manufacturer's heat or test identification number.

14.2 Each producer shall identify the symbols of his marking system.

14.3 All bars produced to this specification shall be identified by a distinguishing set of marks legibly rolled into the surface of one side of the bar to denote in the following order:

14.3.1 *Point of Origin*—Letter or symbol established as the producer's mill designation.

14.3.2 *Size Designation*—Arabic number corresponding to bar designation number of Table 1.

14.3.3 *Type of Steel*—Letter N indicating that the bar was produced from billet steel.

14.3.4 *Minimum Yield Designation*—For Grade 60 bars, either the number 60 or a single continuous longitudinal line through at least 5 spaces offset from the center of the bar side. For Grade 75 bars, either the number 75 or two continuous longitudinal lines through at least 5 spaces offset each direction from the center of the bar.

15. Inspection

15.1 The inspector representing the purchaser shall have free entry, at all times while work on the contract of the purchaser is being performed, to all parts of the manufacturer's works that concern the manufacture of the material ordered. The manufacturer shall afford the inspector, without charge, all reasonable facilities to satisfy him that the material is being furnished in accordance with these specifications. All test (except check analysis) and inspection shall be made at the place of manufacture prior to shipment, unless otherwise specified, and shall be so conducted as not to interfere unnecessarily with the operation of the works.

16. Rejection

16.1 Unless otherwise specified, any rejection based on tests made in accordance with 5. Check Analysis, shall be reported to the manufacturer within 5 working days from the receipt of samples by the purchaser.

16.2 Material that shows injurious defects subsequent to its acceptance at the manufacturer's works will be rejected, and the manufacturer shall be notified.

17. Rehearing

17.1 Samples tested in accordance with 5. Check Analysis, that represent rejected material shall be preserved for two weeks from the date rejection is reported to the manufacturer. In case of dissatisfaction with the results of the tests, the manufacturer may make claim for a rehearing within that time.