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The effects of fabrication processes on steels used in pressure vessels, Progress Report No. 6, Further Tests on Effects of Plastic Strain and Heat Treatment

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The Effect of Fabrication Processes on Steels Used in Pressure Vessels

Further Tests on Effects of Plastic Strain and Heat Treatment

Progress Report No. 6

by

Sadun S. Tör, Robert D. Stout, and Bruce G. Johnston

Lehigh University

Pressure Vessel Research Committee

Welding Research Council

(A)

(C)

(B)

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FOREWORD

This report is the sixth in a series describing results of the research conducted at Lehigh University for the Pressure Vessel Research Committee of the Welding Research Council. The aim of the research project is to determine the effects of fabrication operations such as welding, forming and heat treating on the mechanical and physical properties of pressure vessel steels.

In the earlier reports, methods of transition temperature determination; metallurgical and physical variations between heats and within heats of two pedigreed steels[2], the effect of plastic strain up to 10% and heat treatments[3], the effects of welding[4], the relation between transition temperatures and tensile test results[5] were described. (A)

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Bruce G. Johnston, Professor of Structural Engineering, University of Michigan, formerly Director of Fritz Laboratory, Lehigh University. (B)

This report covers transition temperature test results of two pressure vessel steels in the following conditions: (1) as-received, (2) after 20% permanent tensile strain, (3) after cylindrical bending and (4) after hot or cold spherical pressing. In addition, the pilot-series results of repeated loading above the yield point on these same steels are also reported.

TESTING PROCEDURE

Testing for this project was divided into two main parts:

Part 1 - Transition Temperature Determinations ~~on~~:

a) 5/8" material as received, followed by heat treatments.

b) 5/8" material 20% tensile strained followed by heat treatments.

c) $1\frac{1}{4}$" material, cylindrically bent to give 5% tensile strain under the V-notch.

d) 5/8" material spherically pressed hot and cold.

Part 2 - Repeated Load Tests on:

a) 5/8" material as received.

b) 5/8" material tensile strained 5%

c) 5/8" material welded.

STEELS

The steels used in the investigation were 5/8" and $1\frac{1}{4}$" plain carbon-steel from two different heats. One of the steels was aluminum-killed ASTM A-201 steel, the other was rimmed ASTM A-70 (now ASTM A-285) steel. These are pedigreed steels and complete heat records were given in an earlier report[2].

The only tests where 1¼" material was used was in the 5% cylindrically bent tests. This was done to afford a basis of comparison of 5% cylindrical strained material results with those of the 5% tensile strained 1¼" material reported in Progress Report No.[3] A complete chemical analysis of the steels used is given below:

Chemical Composition of Materials

	A-201	A-70
Carbon	0.15	0.20
Manganese	0.53	0.35
Sulphur	0.025	0.028
Phosphorus	0.020	0.018
Silicon	0.19	0.02
Nickel	0.05	0.10
Chromium	0.04	0.05
Copper	0.08	0.14
Tungsten	0.04	0.04
Vanadium	0.02	0.02
Molybdenum	0.01	0.01
Aluminum	0.026	0.021
Alumina	0.002	0.003
Nitrogen	0.003	0.003

SPECIMEN PREPARATION

1. Slow-Notch-Bend Specimens of As Received and As 20% Tensile Strained Material:

The specimen used for determining the transition temperature of plates in the as received and as 20% cold strained conditions is represented in Fig. 1. In the case of the strained specimens the straining was done prior to heat treatment and machining. Six-foot strips of the steels 3.3 inches wide were scribed at 6-inch intervals, and stretched in a Baldwin-Southwark 300,000# machine until the desired 20% strain was obtained. Occasionally certain portions of the strip had to be reinforced by clamping lengths of steel bars to prevent local necking. The final strain obtained was 20% $\pm$ $1\frac{1}{2}$%. From each end, one foot of material was discarded and the middle section was then cut into 12-inch lengths. The specimens to be tested after room temperature aging were notched immediately. The other specimens were heat treated first and then notched. Transition temperature tests were run 7 days after the heat treatment operation. Twelve double notched specimens or 24 slow notch-bend tests were run to determine the transition temperature. Two series of tests were made; the first series were strained parallel to the rolling direction and the second series were strained transverse to the rolling direction. Testing was done in the direction of straining.

2. Slow-Notch Bend Specimens of 5% Cylindrically Bent Material:

The material used for 5% cylindrically bent specimens was A-70 and A-201 steels in the $1\frac{1}{4}$" thickness. Since in the previous project[3] only $1\frac{1}{4}$" material was used in testing the 5% tensile strained condition it was decided to use the same material in the 5% cylindrically strained tests as well so as to obtain data which could be correlated with the earlier work.

The specimens for this investigation were 9 inches long, 3 inches wide and $1\frac{1}{4}$" thick, with the middle 3 inches machined down on one side to a thickness of 5/8", Figs. 2a and 2b. A special bending jig, which would bend the specimen cylindrically to give a permanent tensile strain of 5% at a distance of 0.08" from the unmachined side was designed and built. After bending, the specimens were heat treated at room temperature, at 500°F, 1150°F and 1600°F and tested seven days after heat treatment.

3. Spherical Test Specimens:

The conditions for this test were such that the type of specimens used in the slow-notch bend tests could not be readily adapted; therefore, a completely new specimen had to be developed to study the effect of spherical forming on these steels.

The specimens used in this test were 16-inch circular plates made out of 5/8" A-70 and A-201 steels, Figs. 3a and 3b. They were tested in the as-received and as-hot and cold pressed condition. The specimens had a circular V-notch, 0.12-inches deep machined at a radius of $2\frac{1}{4}$-inches. The specimens were first pressed and then notched on the convex side. No post heat treatment was used. A pilot series of 6 specimens was cold pressed to a spherical radius of 16" at Lukens Steel Company, Coatsville, Penna. The series used for the main testing program were pressed at the Commercial Shearing and Stamping Company, Youngstown, Ohio. The cold forming was done in one stroke in an 800 ton mechanical press having a 16" stroke and hitting at a rate of 5 strokes per minute.

The hot forming was done in the same press, but prior to being formed the specimens were heated in an oil furnace adjacent to the press. They were removed from the furnace at a temperature of between 1550 and 1650°F and immediately formed. An optical pyrometer was used to determine the furnace temperature. The specimens were still red hot when they were removed from the press and cooled in air.

4. Repeated Load Specimens:

The type of specimen used for the preliminary repeated-load tests is given in Fig. 4. The throat of the specimen was milled and then ground to give an uncut portion of 1 inch. The sharp edges were then rounded to a radius of about 1/8". In the case of the welded or strained specimens, machining of the throat was done after straining or welding and heat treatment.

A 4-inch longitudinal weld bead was layed in the center on one surface of the specimen using 5/32" inch 6010 electrode with 175 amps. at 10 inches per/min. The weld reinforcement was machined as flush with the surface of specimens as possible without touching the original surface.

The 5% tensile straining was performed on each individual specimen, on the 300,000 lb tensile machine.

TRANSITION TEMPERATURE TESTS

1. Tests on Straight and Cylindrically Bent Specimens

Transition temperature tests on the straight and cylindrically bent specimens were performed on the standard, Lehigh-slow-notch-bend testing jig, Fig.5.

The technique of testing followed in these tests has been reported in detail in earlier reports[1,3]. The only variation from that technique was; instead of using four notch-bend tests as 6 equally spaced temperature levels; once the general trend of the curve was established by spot tests, the rest of the specimens were used in establishing the transition zone more accurately by testing them at closer temperature intervals in that region.

2. Tests on Spherically Pressed Specimens:

The testing jig used for these tests is shown in Figs. 6a and 6b. The results of spherically pressed specimen tests could not be correlated with the straight slow-notch-bend specimens, therefore a series of tests were run both on A-70 and A-201 5/8" steels in the unpressed condition. The specimens were placed in a constant temperature bath of gasoline and dry ice for tests below room temperature, and a hot water bath was used for tests above room temperature. When the desired temperature was attained the specimens were kept at this temperature for 15 minutes before testing. Due to the geometry of the specimen, contraction measurements could not be made. Autographic load-deflection curves were obtained for each specimen and from these total-energy-to-fracture values were obtained. This energy is the criterion used in plotting the transition-temperature curves. The circular notch was visible to the observer throughout the test.

The same procedure was used in testing the pressed specimens.

REPEATED LOAD MACHINE AND ITS CALIBRATION

1. The Machine:

The repeated-load machine was designed and built at Fritz Engineering Laboratory for the Fabrication Division of the PVRC. Figs. 7, 8 and 9 show different views of the machine. The design permits the use of this machine either as a constant load or a constant deflection machine merely by replacing the coil spring between the horizontal bars with a solid link.

The power is supplied by a $1\frac{1}{2}$ HP three-phase motor at 1750 RPM. This speed is reduced to about 110 RPM at the loading crank; however, any number of speeds are available by the proper choice of pulleys. The test is automatically stopped when the broken end of the specimen falls on a microswitch, which operates a relay.

The crank arm is on a graduated eccentric so that any deflection from 0- to $\pm$ 4 inches can be obtained.

2. Calibration of the Machine:

Four SR-4 strain gages were mounted on the loading link, Fig. 10a, and connected in series. This link then was calibrated in tension and compression on the 60,000# tensile machine. When placed in the repeated load machine it was possible to obtain the actual load applied by the machine at the end of the specimen through this link.

One strain gage was placed on the top and one on the bottom of the throat section of the specimen along the long axis and a dial gage was attached to the moving end of the specimen in line with the loading link, Fig. 10b. In this way a direct correlation was established between the strain at the throat of the specimen, the deflection of the moving end, the load applied and the eccentric setting. From these relationships it is possible to obtain any desired percent overstrain above yield point at the throat of the specimen by setting the eccentric to the desired value.

REPEATED LOAD TESTS

A series of A-70 steel was tested to determine the limits of loading the specimen. From the correlation data thus obtained it was decided that a strain of 10,000 microinches per inch or 1% strain on the outermost fibers would be used as the maximum loading limit. For the minimum limit about 1,000 microinches per inch or, 0.1% strain would be used.

A complete series of duplicate specimens was tested under constant load condition, after the following treatments:

a) As-received,-heat treated at Room Temperature, 500°F, 1150°F.

b) 5% Tensile Strain, Parallel to Rolling Direction - heat treated at Room Temperature, 500°F, 1150°F.

c) 5% Tensile Strain, Transverse to Rolling Direction - heat treated at Room Temperature, 500°F, 1150°F.

d) Welded (175 amps. at 10 in/min), heat treated at Room Temperature, 500°F, 1150°F.

The setting of the eccentric was for 1% strain at the outermost fibers of the critical section of the specimen in reverse bending. The speed of testing was 110 cycles per minute. The number of cycles to complete fracture was recorded, Table II.

DISCUSSION OF THE RESULTS: TRANSITION CURVES

1. As-Received Material:

The transition curves for A-201 and A-70 steels in the as-received condition are given in Figs. 11, 12, 13 and 14 - transition temperatures are given in Table 1A. In the case of A-70 steel, Figs. 11 and 13, it is interesting to note that the transition temperatures were not affected to any great extent by the post heat treatments. Steel A-201 was only slightly affected by 1600°F heat treatment. Steel A-201 has an average transition temperature of about 60°F lower than A-70 steel. This, substantiates the data established and reported in the earlier tests[3].

2. 20% Strained Material:

In Figs. 15, 16, 17 and 18 are given the transition curves for 5/8" A-201 and A-70 steels strained parallel to the rolling direction. In Figs.19, 20, 21 and 22 are given the transition curves of the same steels strained transverse to the rolling direction.

In the case of material, strained parallel to the rolling direction, the transition temperature T_N is increased by about 80°F and T_B is increased by about 30°F for room temperature and after 500°F heat treated tests as compared to unstrained material. When tested after 1150°F heat treatment, T_N transition temperature of both steels is lowered considerably, T_B slightly. Heat treating at 1600°F lowers the transition temperatures T_N and T_B of both steels down to, or even beyond the level of unstrained material.

The transition temperature level for material strained 20% transverse to the rolling direction is raised considerably more than those strained parallel to the rolling direction. It should be noted that straining 20% in either direction reduces the ductility of these steels as shown by the percent contraction T_N values in Figs. 17, 18, 21 and 22, and only normalizing restores the original ductility level.

In Figs. 27, 28, and 29 the data is presented graphically to illustrate the effects of heat treatment more clearly. The lines connecting the points do not indicate the trend between the heat treatment levels but are intended merely to tie one point with the other to facilitate their study.

Fig. 27 compares the T_N transition temperatures at different heat treatment levels of both steels in the as received, 5% and 20% tensile strain parallel to the rolling direction. Fig. 28 is a comparison of the T_B transition temperatures.

3. 5% Cylindrically Strained Material

The material that was 5% cylindrically bent was $1\frac{1}{4}$" A-70 and A-201 steel. Therefore, to study the effect of 5% cylindrical bending on these steels, they must be compared with 5% axially strained $1\frac{1}{4}$" material reported in PVRC Progress Report No. 3. Such a comparison shows that the transition temperatures T_N and T_B for the cylindrically bent specimens agree within $\pm$ 15°F of those axially bent. Normalizing heat treatment at 1600°F was omitted in this series to save time and material since its beneficial fact has already been established through earlier tests.

4. Spherical Forming:

In order to be able to determine the effect of spherically forming 5/8" A-201 and A-70 steels, on their cold brittleness, a new specimen and testing jig had to be developed. Therefore the results of this test series cannot be correlated with our other test results.

Unpressed specimens of 5/8" A-201 and A-70 steels were tested in duplicate in the spherical testing jig to establish their cracking level, Fig. 30. These percent energy transition curves differentiate between the two steels. However, the difference between the transition temperatures of these steels is only half as great as that determined by the Lehigh-slow-notch-bend test. The difference in the energy absorbing capacity of the steels is brought out quite clearly when one considers the general shape of the transition curves.

In Figs. 31 and 32 are presented the transition curves for A-201 and A-70 steels respectively after hot and cold forming operation. Because the number of specimens tested in this series was too few to determine the transition curves with accuracy, best fitting curves were drawn through the points rather than joining the averages of the points with straight lines. These curves are superimposed in Fig. 33 to afford a better comparison of the response of the two steels to hot and cold forming. An interesting point is brought out in this plot - if one were to judge these steels on the basis of their transition temperatures determined by the criterion of 50% of the maximum energy it would seem that there was little difference either between the steels or hot and cold forming. However, the shape of the curves indicate that a difference does exist which is not brought out by this criterion. This difference is brought out quite sharply when the transition temperatures are determined by taking them at a definite energy level of 10,000 foot-pounds. The transition temperatures determined by these two methods are given in Table I-D and E. Cold forming increases the transition temperature of both steels, and the energy absorbing capacity is reduced considerably. Hot forming, on the other hand, reduces the transition temperature and the energy absorbing capacity is raised to a level higher than that of the as received plate. Fig. 34 and 35 represent the mode of failure of the spherical specimens. It is interesting to note that brittle fractures always progress into the unnotched steel rather than follow the notch all the way around.

REPEATED LOAD TEST RESULTS

Preliminary tests on A-70 5/8" steel were made using the constant load arrangement and maximum loading condition of 1% strain at the throat of the specimen. During this test it became evident that the constant load system was not as positive a way of loading as constant deflection at strains above yield point. This was due to the fact that the specimen stiffened as it work hardened, thus reducing the strain at the throat continuously even though the load remained constant. As soon as the first crack developed on one side, the deflection of the specimen became uneven causing the fracture to occur prematurely. In the current program constant deflection is being used in all repeated load tests.

The results as given in Table II are the averages of 2 specimens. Since these tests were of exploratory nature no conclusion can be drawn. It is sufficient to say that the cycles to fracture in the unwelded specimens were between 3000 and 4000, as compared to about 2000 for the welded specimens. The effect of straining 5% is not evident at this load level.

CONCLUSIONS

1. A tensile strain of 20% raises the transition temperatures of both 5/8" A-201 and A-70 steels by approximately 85°F above the unstrained steels. This is only 35°F above those strained 5%.

2. Steels strained 20% parallel to rolling direction had lower transition temperatures than those strained transverse to it by about 50°F.

3. Transition temperatures T_N for both steels, cylindrically strained 5%, agree within experimental error with those 5% axially strained as reported in Progress Report No. 3.

4. Transition temperature tests on spherically hot and cold pressed specimens indicate that cold pressing definitely raises the transition temperature whereas hot pressing results in transition temperatures that are equal or better than those of the unpressed steels.

5. Preliminary fatigue tests above yield point show promise in evaluating these two steels as to their resistance to repeated bending in the plastic range and the effects of straining, welding, and heat treatments on this resistance.

ACKNOWLEDGEMENTS

This project was carried out jointly by the Fritz Engineering laboratory of the Civil Engineering Department and by the Metallurgy Department of Lehigh University. Prof. W.J. Eney is the Director of the Laboratory and also head of the Civil Engineering and Mechanics Department. It was sponsored by the Pressure Vessel Research Committee of the Welding Research Council. Mr. P.R. Cassidy is the Chairman of the Pressure Vessel Research Committee and Mr. B.E. Rossi is the Executive Secretary. The Fabrication Division of PVRC under the chairmanship of Mr. F.L. Plummer gave technical guidance and approval of various stages of the work.

Acknowledgements are also due to Mr. Kenneth Harpel, Foreman of the machine shop and to the entire laboratory staff.

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3. Osborn, C.J., Scotchbrook, A.F., Stout, R.D., Johnston, B.G., "Effect of Plastic Strain and Heat Treatment," Ibid., 28 (8), Research Suppl., 337-s to 353-s (1949)
4. Scotchbrook, A.F., Eriv, L., Stout, R.D., Johnston, B.G., "Effect of Welding on Pressure-Vessel Steels," presented at the A.S.M.E. Annual fall meeting, New York City, Nov. 27, 1949. (July, 1950, Transactions, A.S.M.E.)
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TABLE I

LEHIGH-SLOW-NOTCH-BEND TESTS

5/8" Material

As Received

A. Tested Par. to R.D.

Heat Treatment	Transition Temperature °F T_N A-201	A-70	T_E A-201	A-70	T_B A-201	A-70
Room Temp.	-93	-46	-103	-48	34	103
500°F	-29 & -68	-26	-23 & -75	-36	49	103
1150°F	-82	-28	-78	-33	51	94
1600°F	-92	-39	-91	-32	-32	64

5/8" Material

20% Strained

B. Strained Par. to R.D.

As Strained	-12	43	-27	27	66	140
500°F	21	71	- 8	53	78	161
1150°F	-34	-56	-57	-49	69	118
1600°F	-108	-65	-112	-60	-24	30

Strained Transverse to R.D.

As Strained	58	39	-	-	82	147
500°F	132	133	-	-	137	173
1150°F	25	76	-	-	76	150
1600°F	-90	-36	-100	-39	-67	29

1¼" Material

Machined Down to 5/8" - Strained 5% Cylindrical

C. Strained Par. to R.D.

As Strained	-73	-42	-83	-22	-90	163
500°F	-52	- 9	-27	17	101	148
1150°F	-43	-15	-60	-33	88	149

TABLE I

(Continued)

SPHERICAL TESTS

5/8" Material-Circular Specimens

D. Transition Temperature - T_E (At 50% of Maximum Energy)

	A-201	A-70
As Received	-18	10
Hot Pressed	-20	- 5
Cold Pressed	- 5	13

E. Transition Temperature T_E at 10,000 ft.-lb. Level

	A-201	A-70
As Received	-16	45
Hot Pressed	-23	- 8
Cold Pressed	30	82

TABLE II

REPEATED LOAD TESTS ON 5/8" ASTM A-70 STEEL

Averages of 2 Specimens

Condition	Heat Treatment	Cycles to Fracture
As Received	R.T.	3817
	500°F	2805
	1150°F	2222
Strain 5% Parallel to Rolling Direction	R.T.	3722
	500°F	3307
	1150°F	2843
Strain 5% Transverse to Rolling Direction	R.T.	3093
	500°F	3053
	1150°F	3051
Welded, on one side	R.T.	1884
175 amps. 10 in./min.	500°F	2148
5/32" 6010 Electrode	1150°F	2105

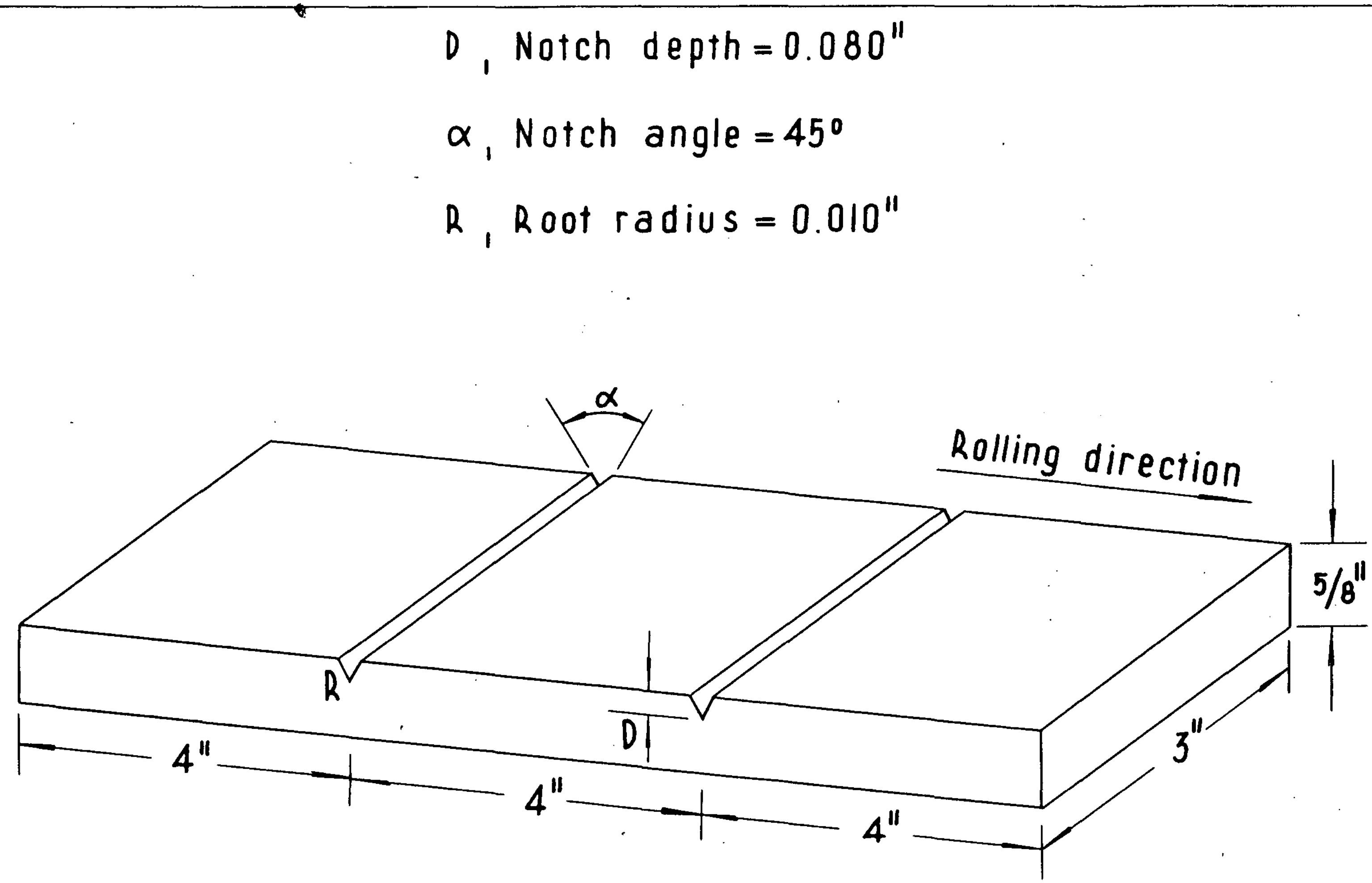
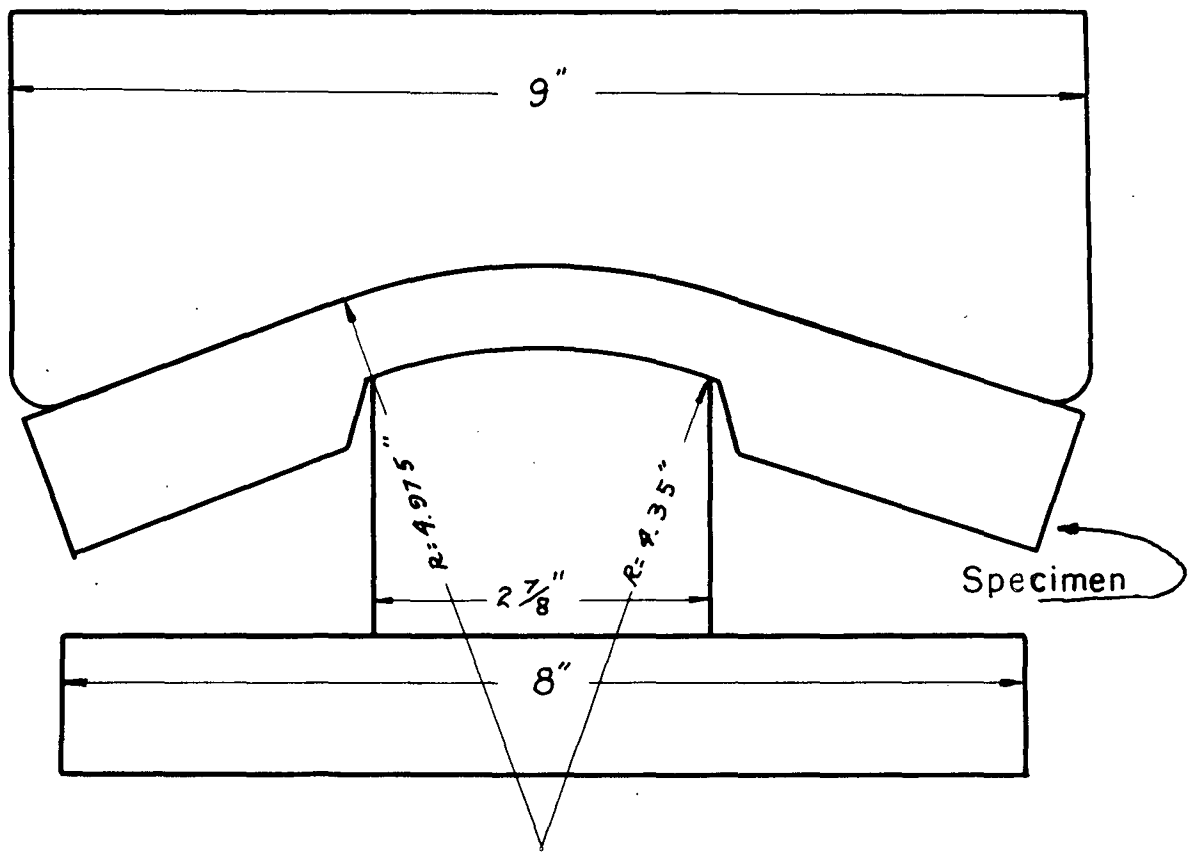


Fig. I. Lehigh-slow-notched-bend specimen



CYLINDRICAL BEND JIG AND SPECIMEN

FIG. 2

Fig. 2b Cylindrically Bent
Specimen

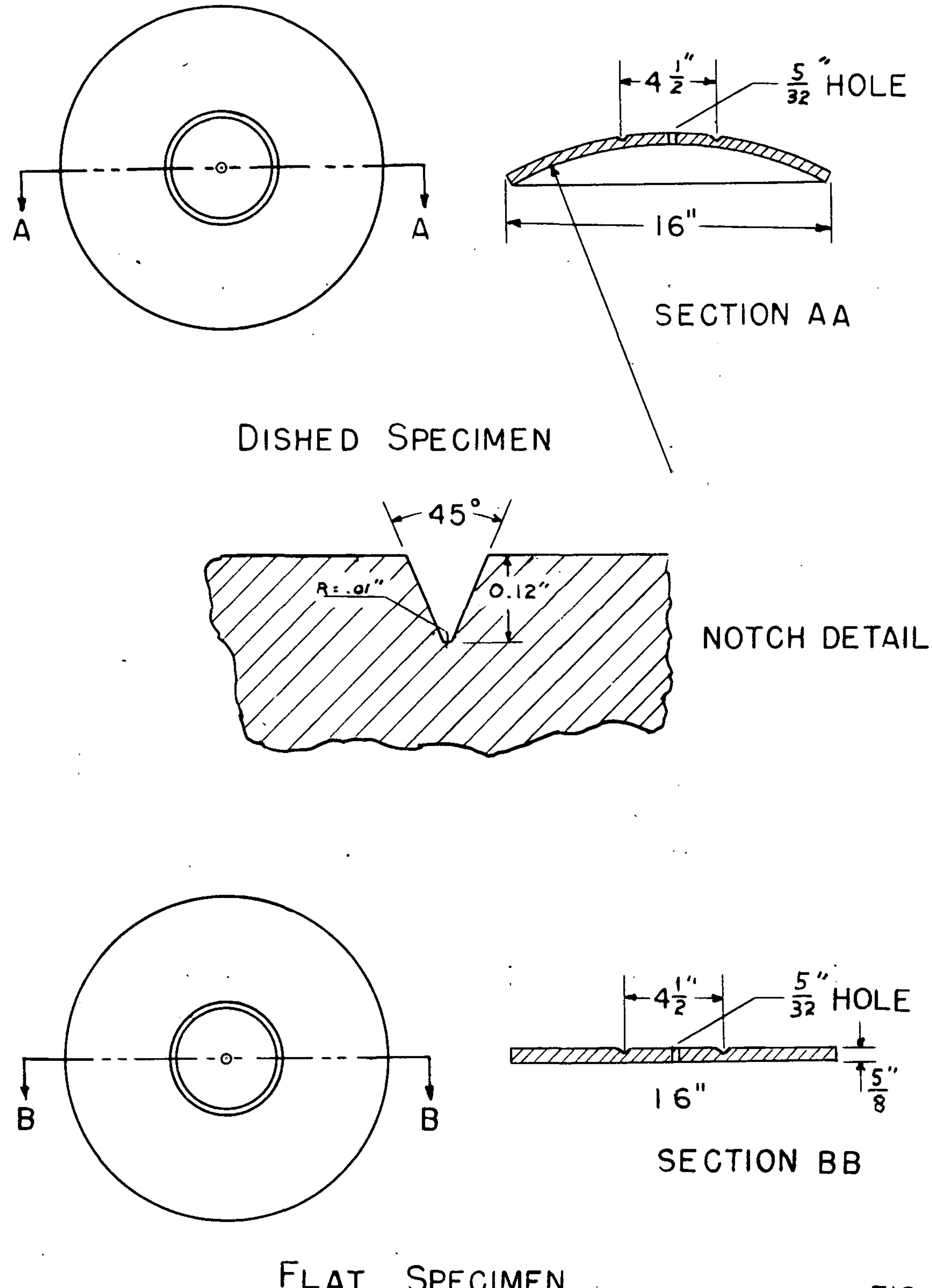
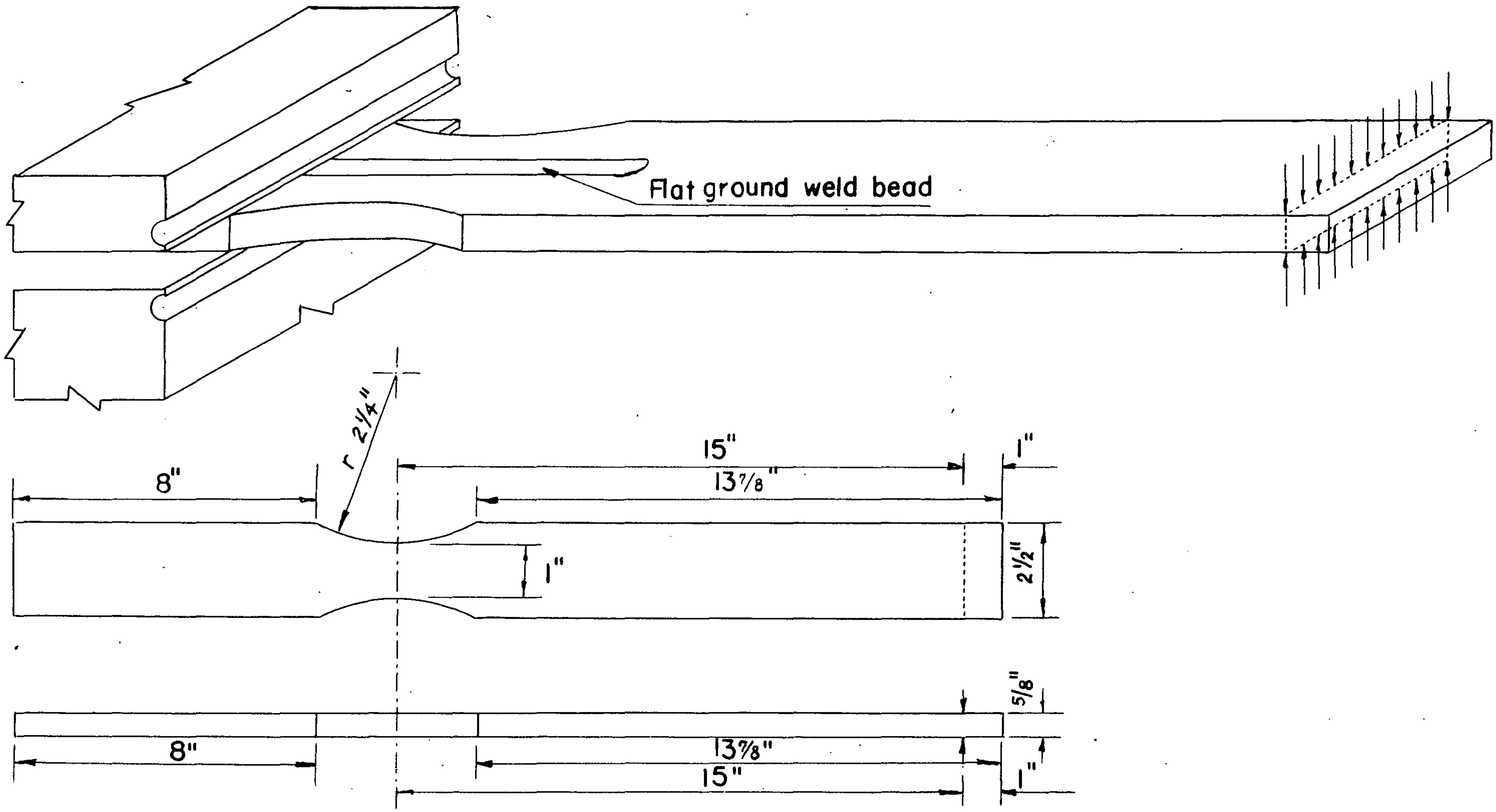

4 1/2"
5/32" HOLE
A
A
16"
SECTION AA
DISHED SPECIMEN
45°
R = .01"
0.12"
NOTCH DETAIL
4 1/2"
5/32" HOLE
B
B
16"
5/8"
SECTION BB
FLAT SPECIMEN

FIG. 3



Repeated Load Specimen

Fig. 4

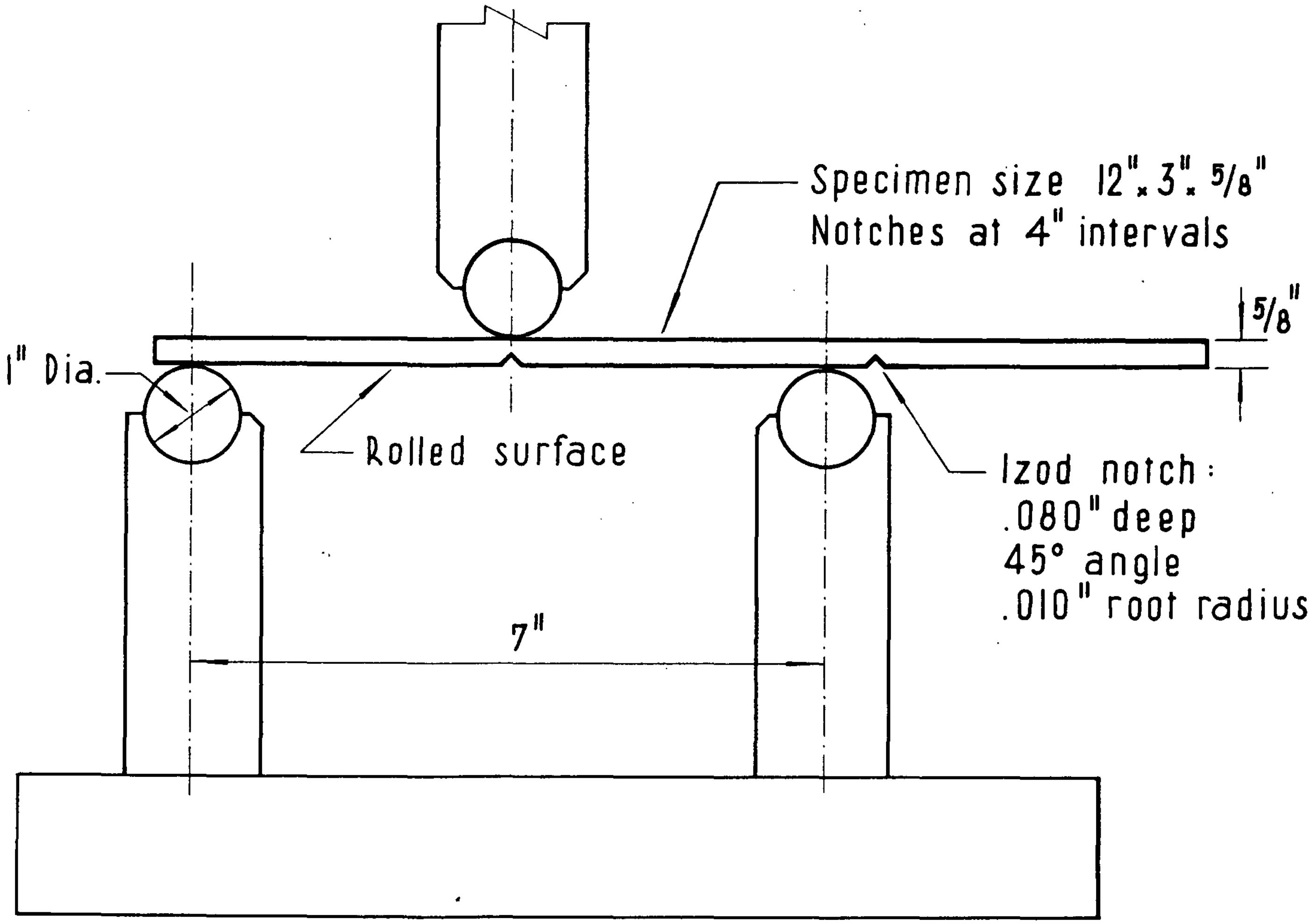


Fig. 5 The Lehigh slow notched bend test.

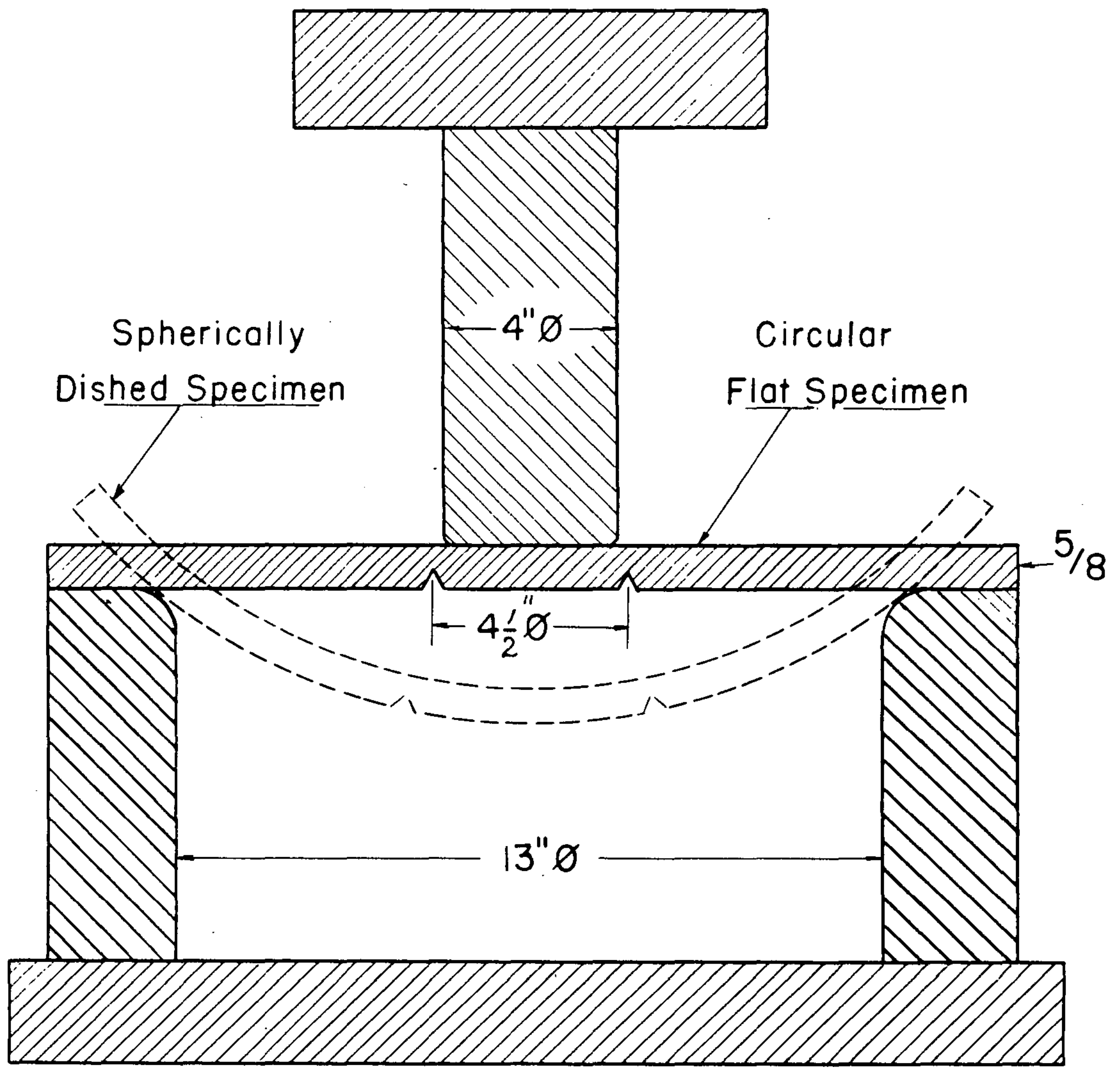


Fig. 6 a

Cross Section of Bending Jig Showing the Relative Positions of Piston, Specimen and Support

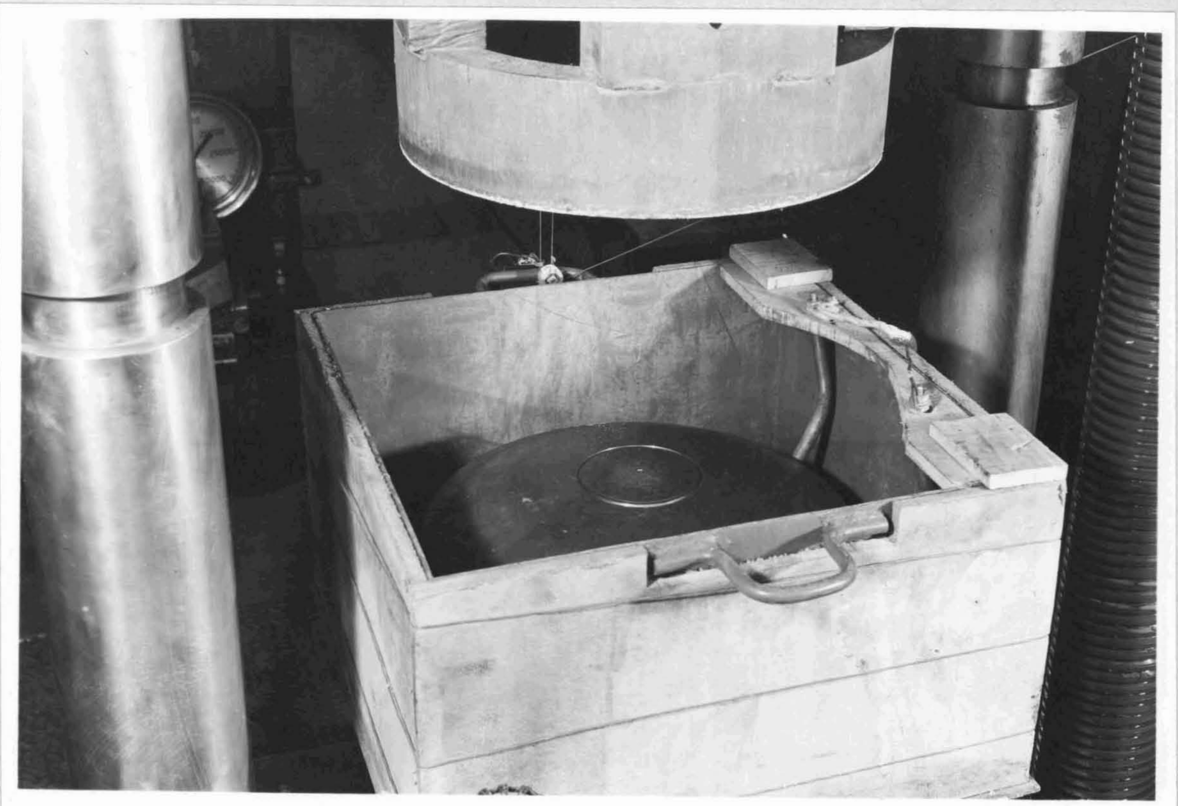


Fig. 6b. SPHERICAL TESTING SET-UP
Showing Constant Temperature Bath
with the Specimen Ready to be Tested.

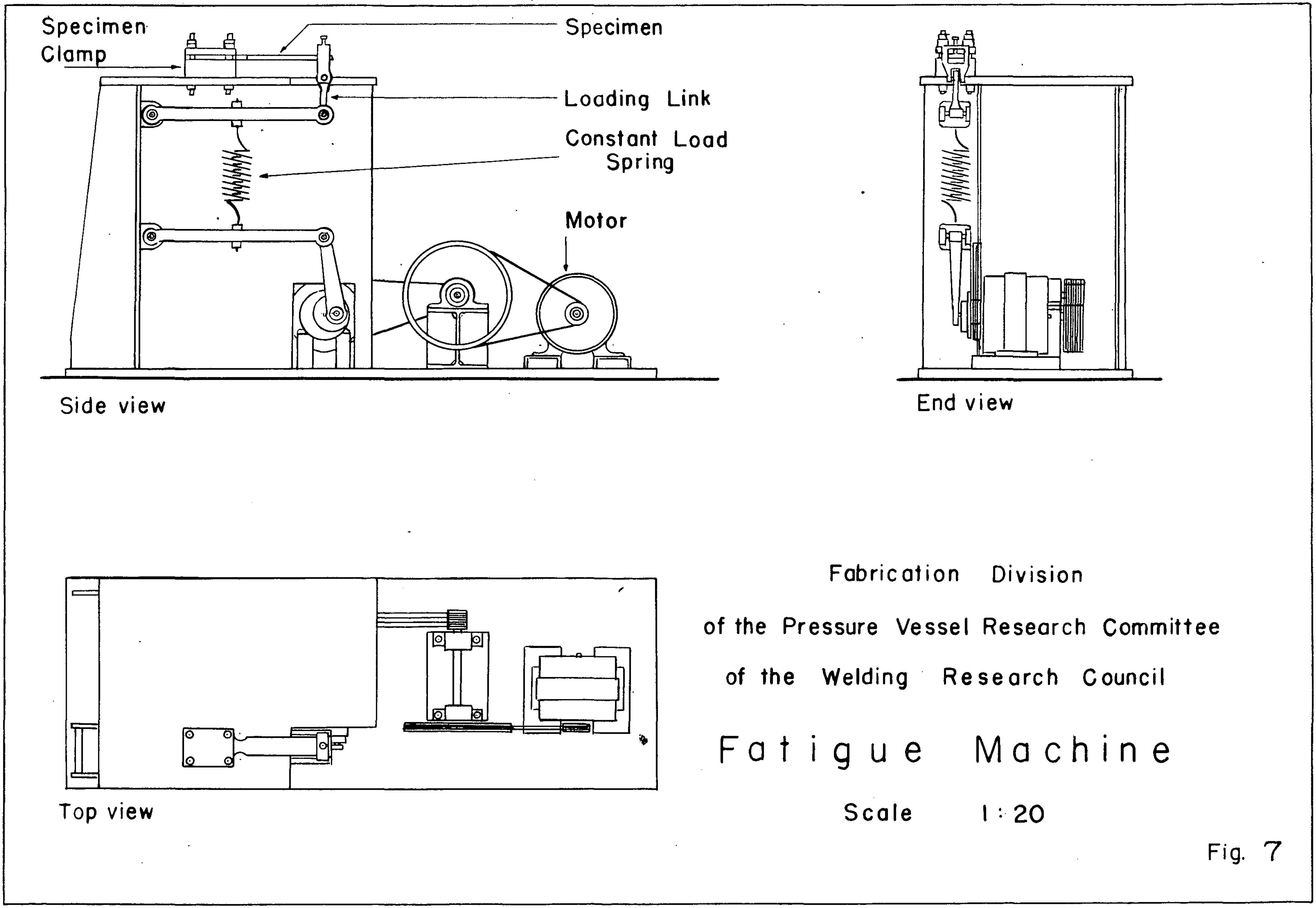

Specimen Clamp
Specimen
Loading Link
Constant Load Spring
Motor
Side view
End view
Top view
Fabrication Division
of the Pressure Vessel Research Committee
of the Welding Research Council
Fatigue Machine
Scale 1 : 20

Fig. 7

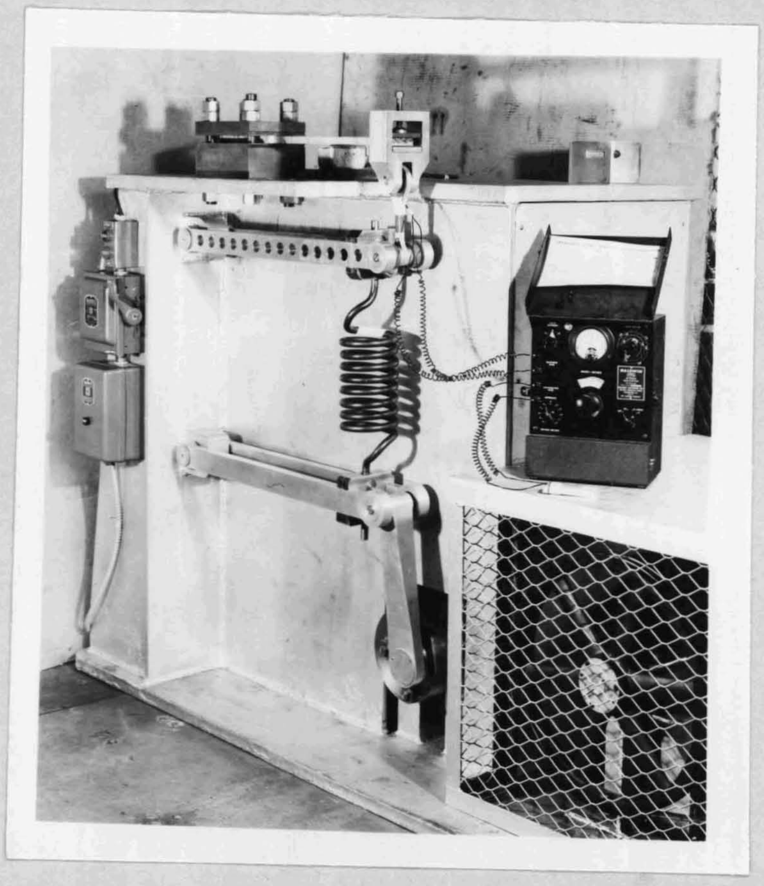


Fig. 8. FATIGUE MACHINE
Showing the Arrangement for Measuring
Load, through the SR-4 Strain Gage

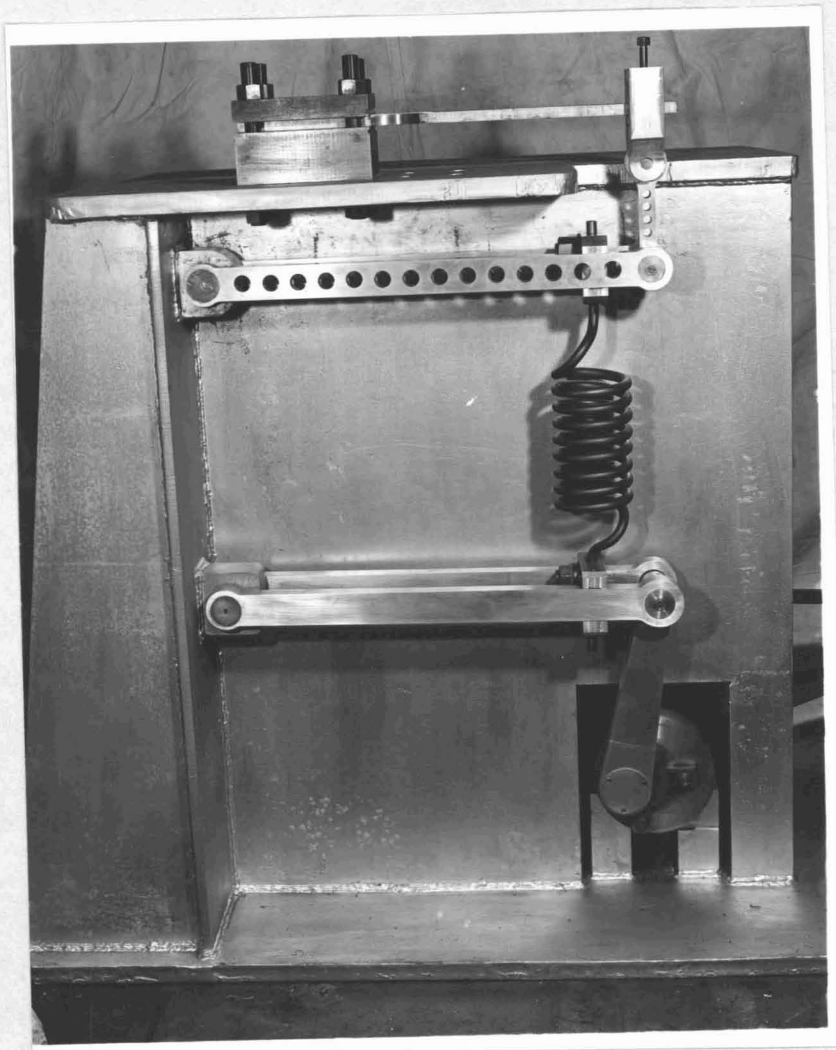


Fig. 9. Close-up View of the Fatigue Machine. Specimen is in place.

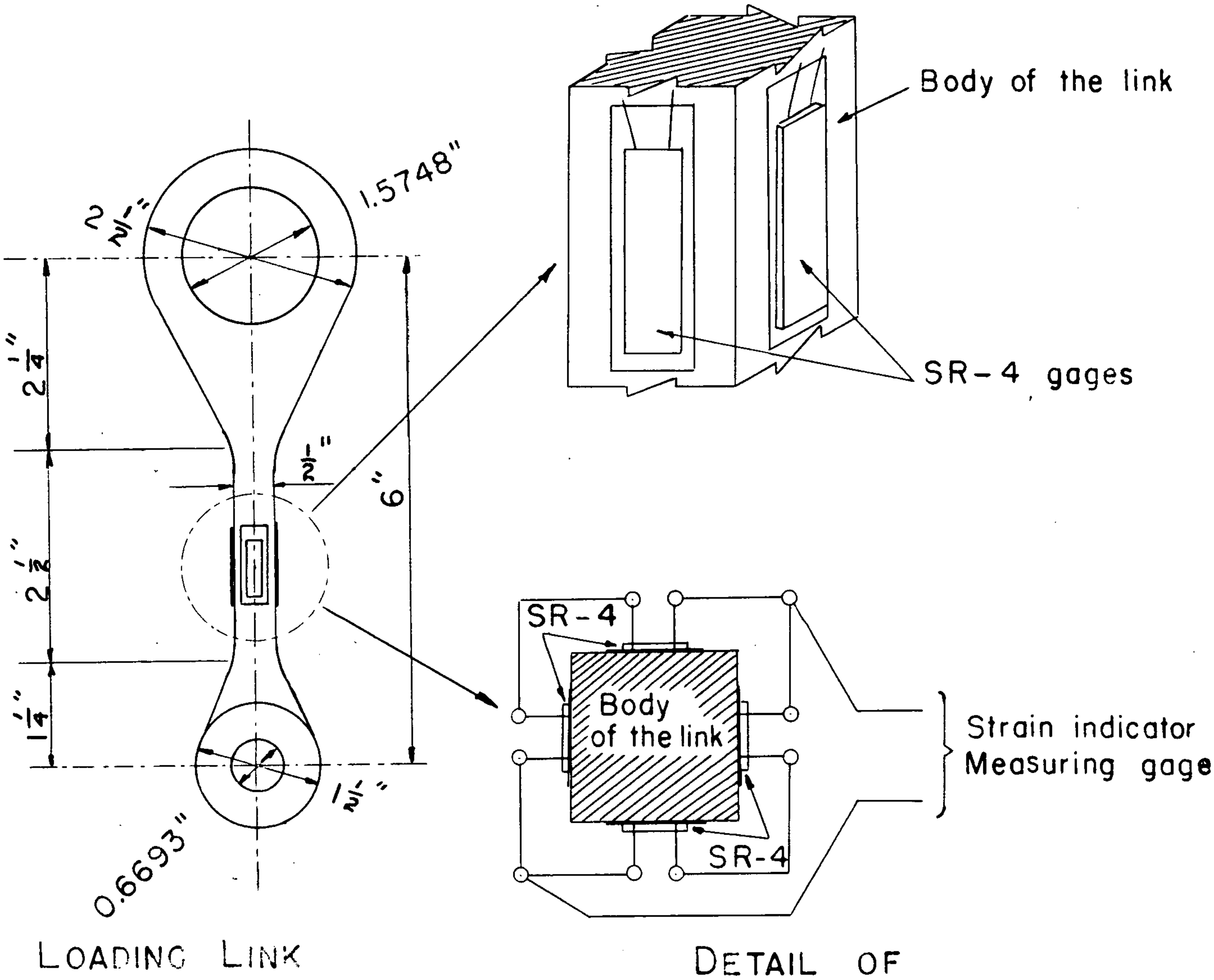


FIG. 10a SCHEMATIC CONNECTION OF SR-4 GAGES ON CALIBRATION LINK

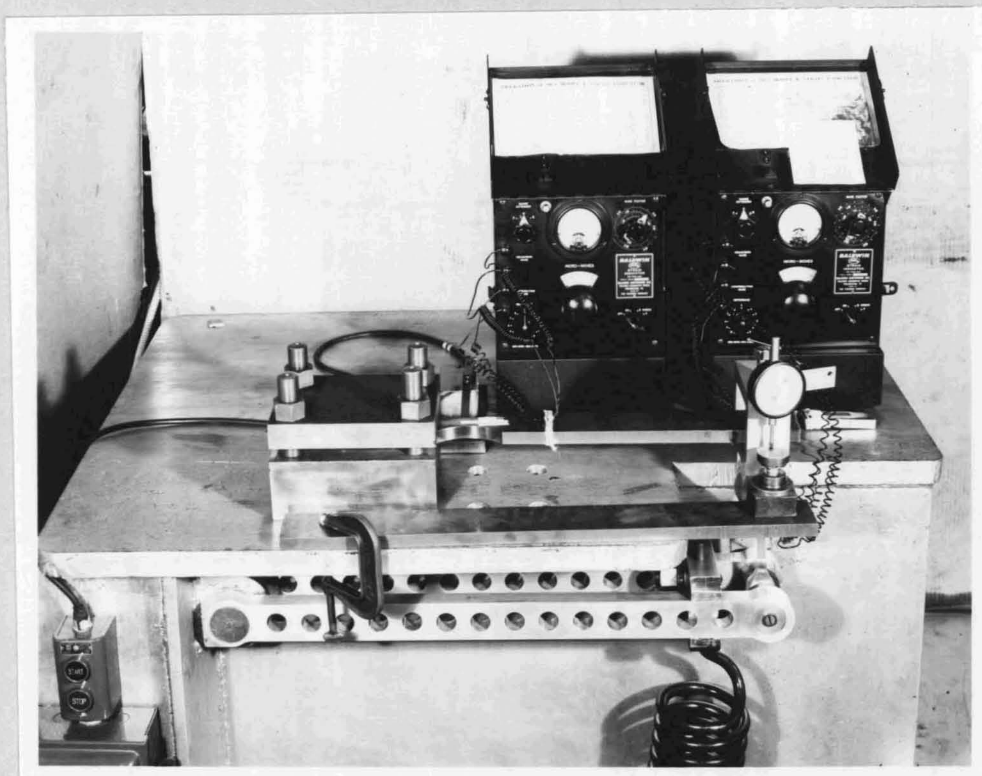


Fig. 10b. FATIGUE MACHINE CALIBRATION SET-UP

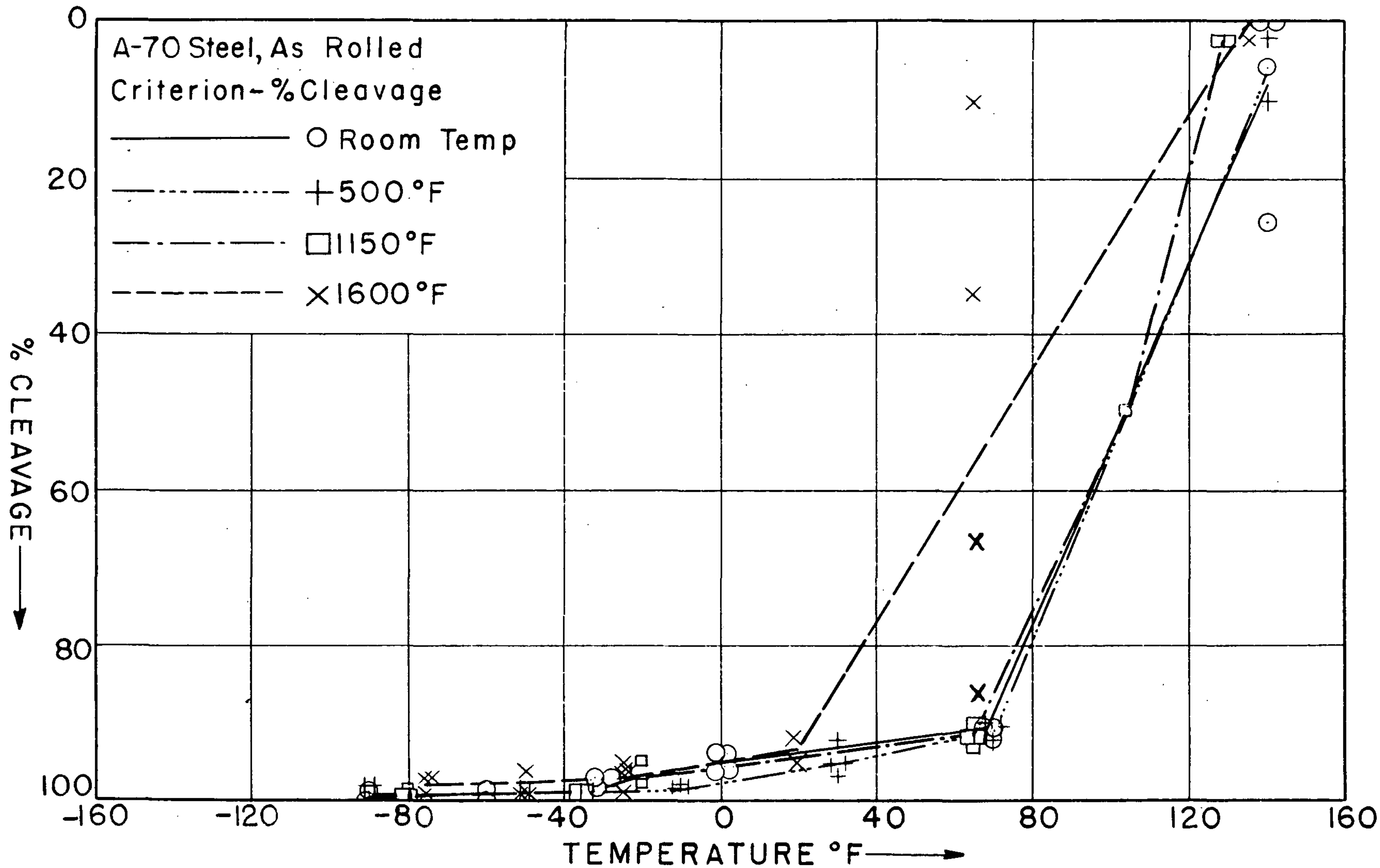


FIG. 11 Transition Temperatures Showing the Effects of Heat Treatment on 5/8" A-70 Steel, As Rolled

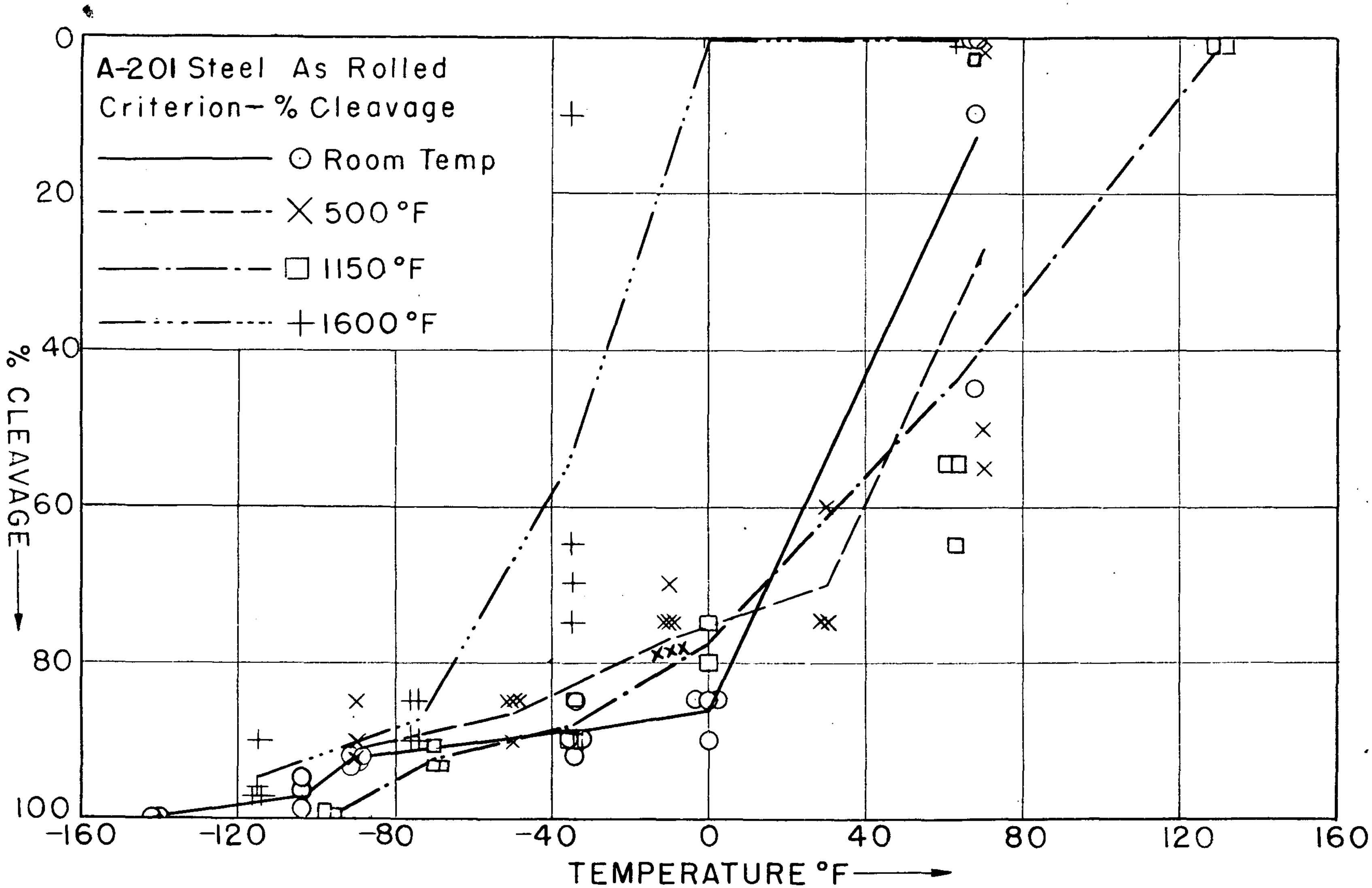


FIG. 12 Transition Temperatures Showing the Effects of Heat Treatment on 5/8" A-201 Steel, As Rolled

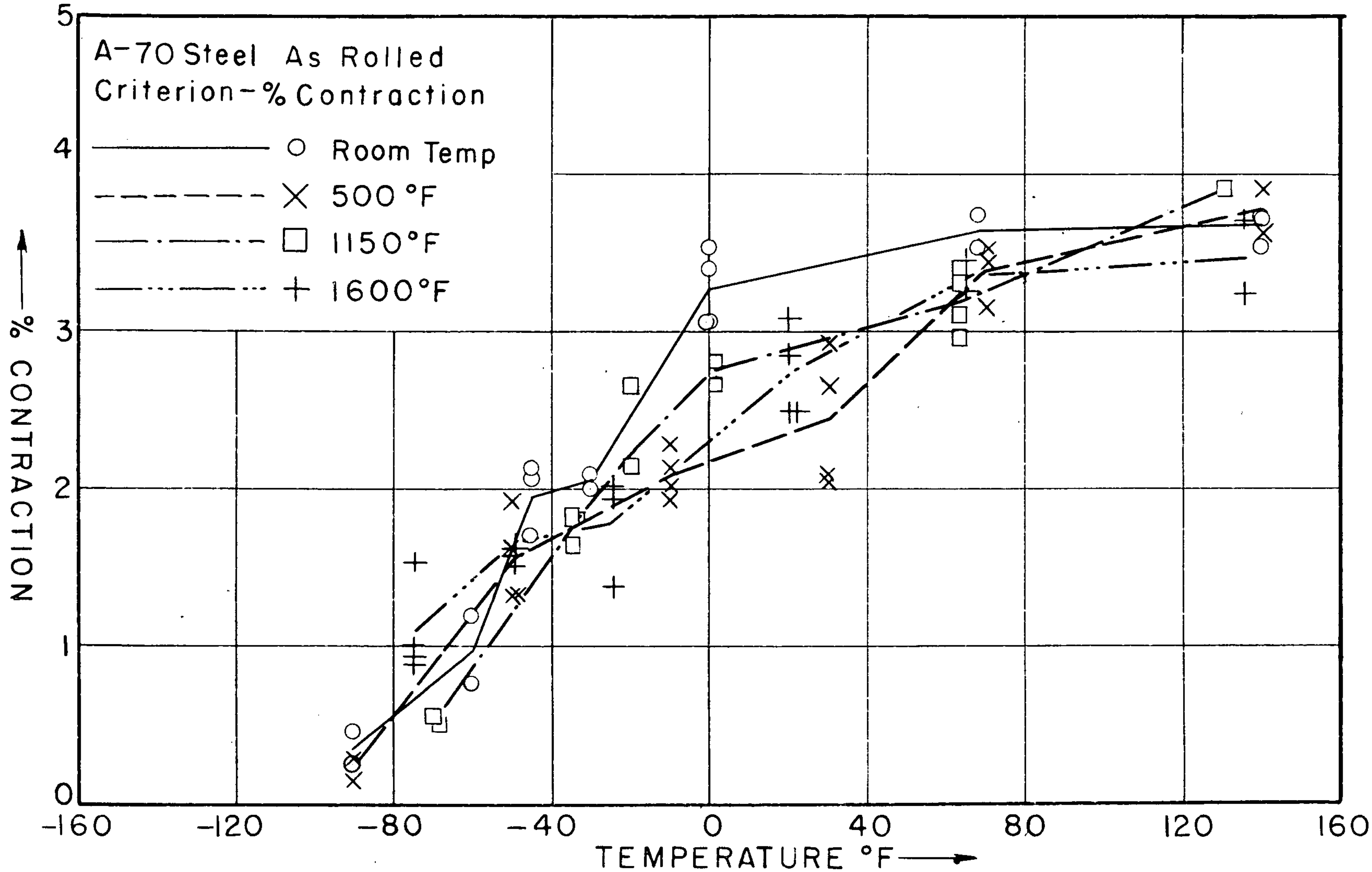


FIG. 13 Transition Temperatures Showing the Effects of Heat Treatment on 5/8" A-70 Steel, As Rolled

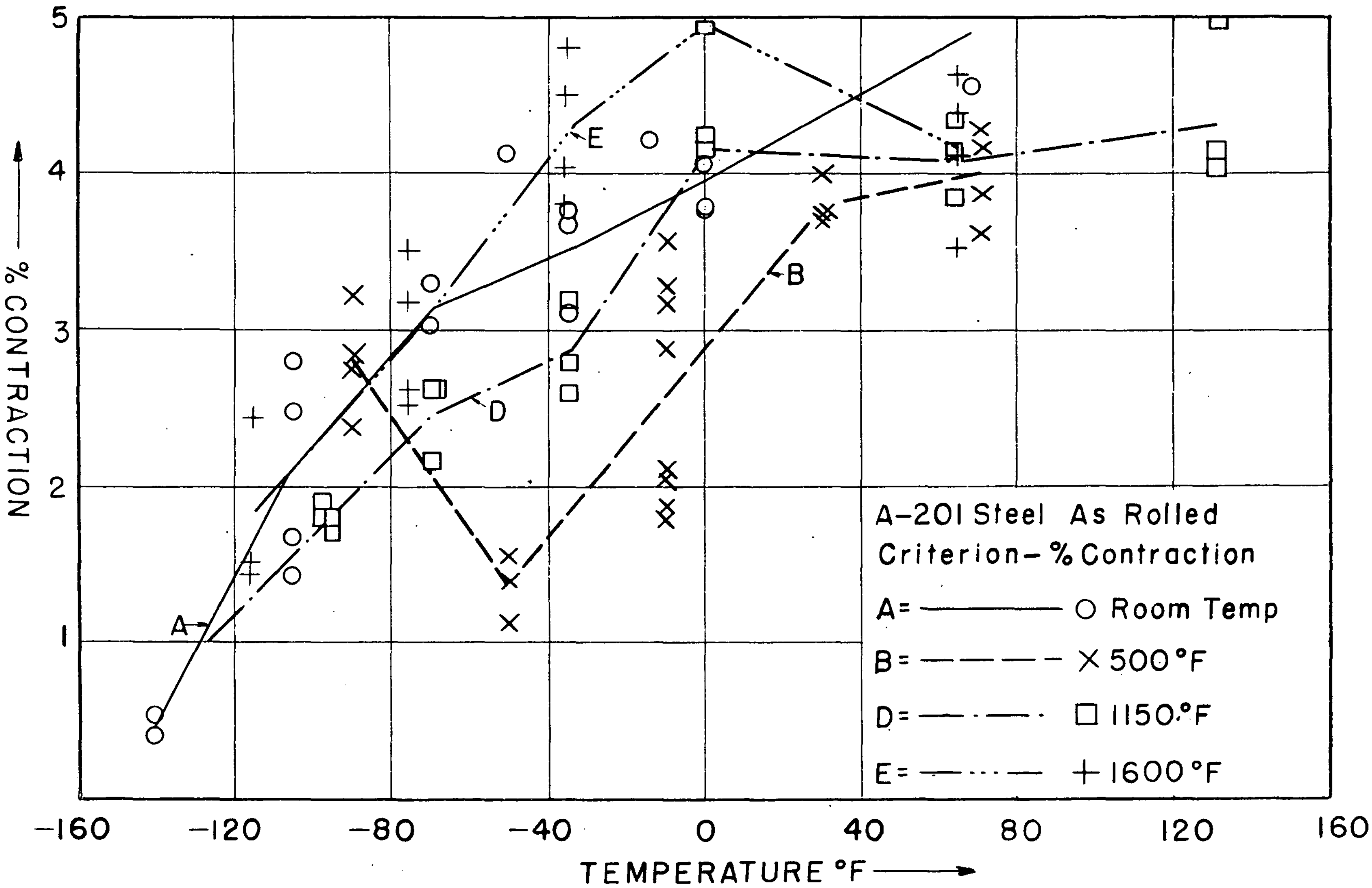


FIG. 14 Transition Temperatures Showing the Effects of Heat Treatment on 5/8"-201 Steel, As Rolled

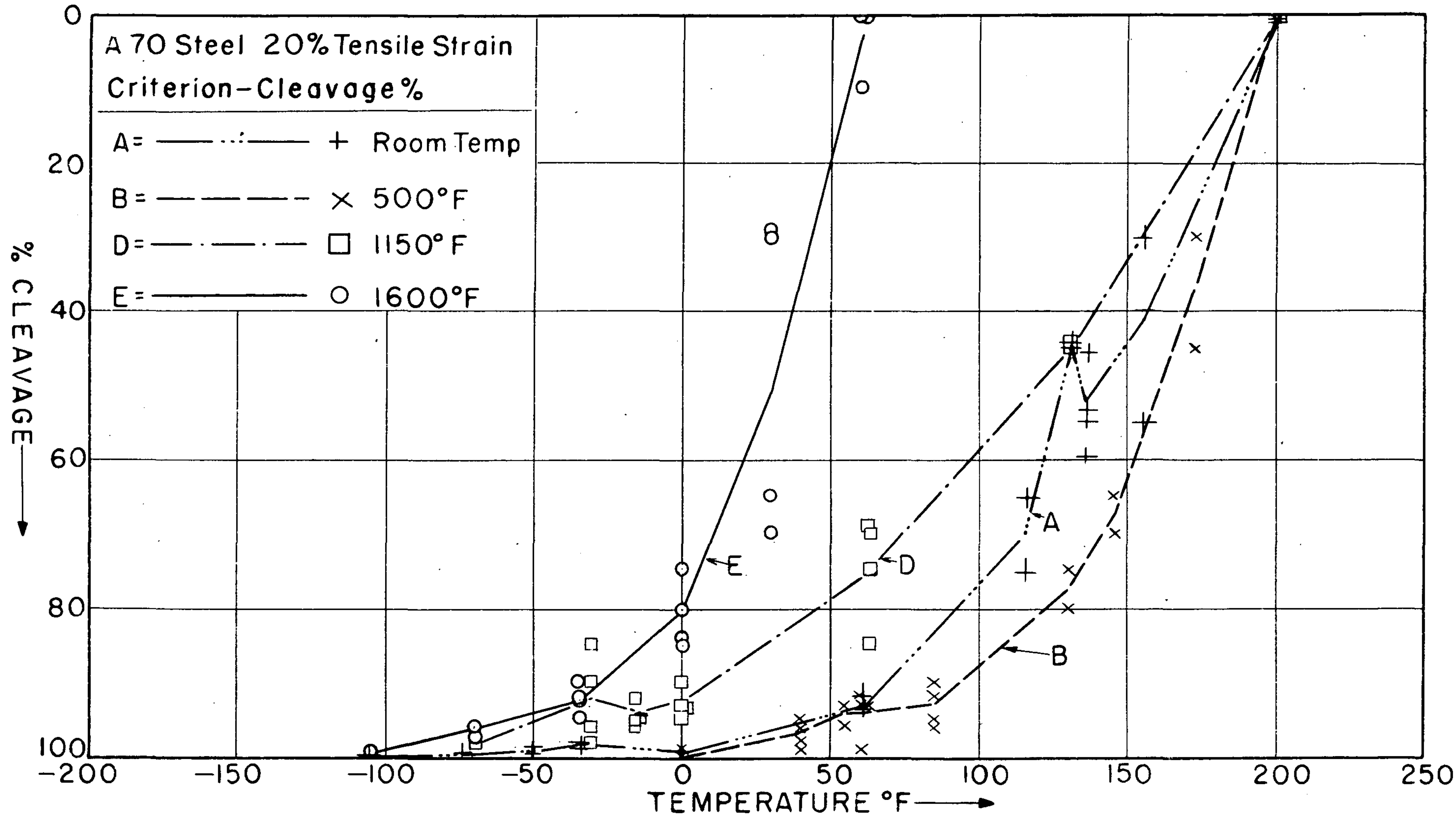


FIG. 15 Transition Temperatures Showing the Effects of Heat Treatment on 20% Tension Par R.D. A-70 Steel

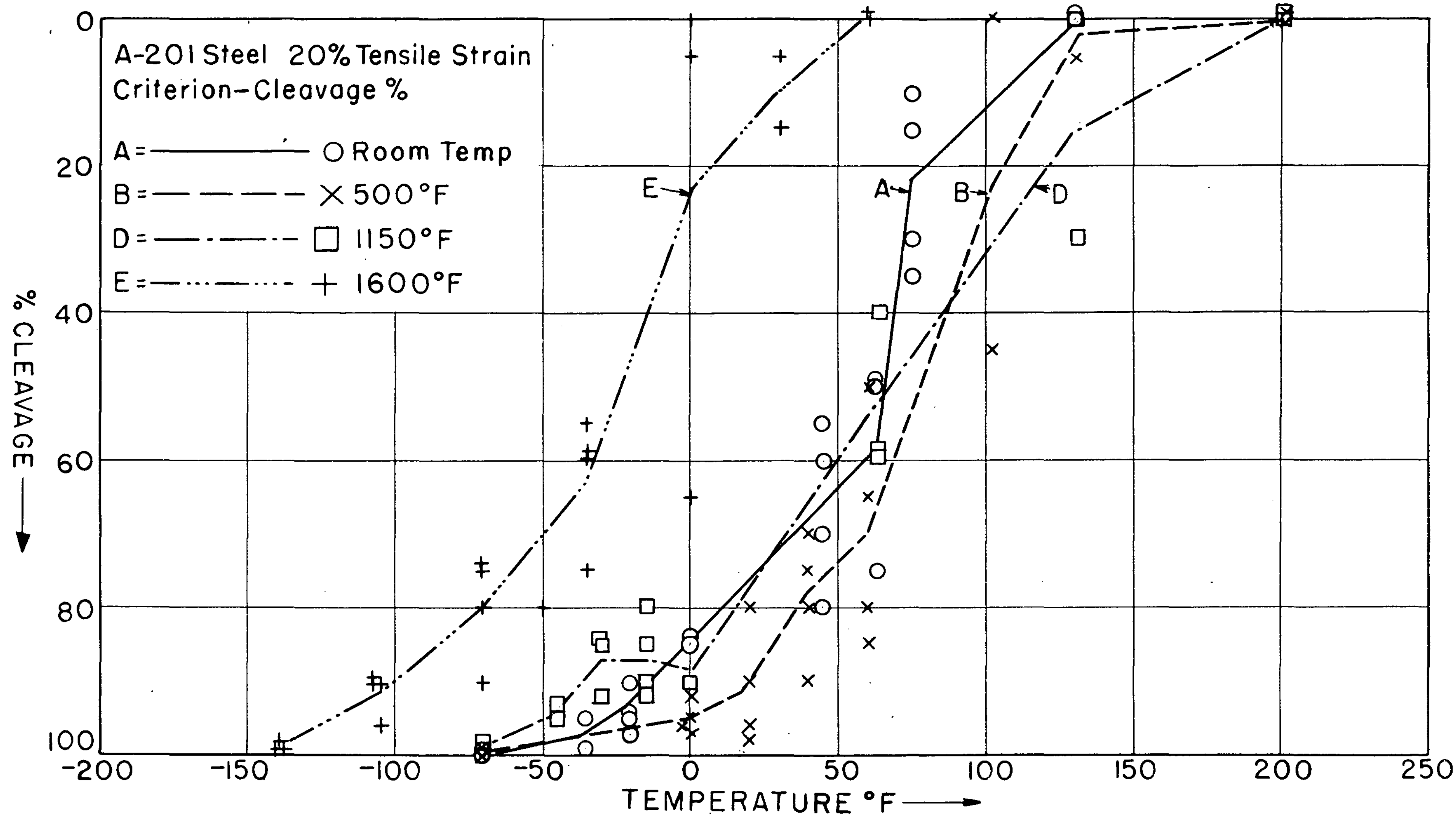


FIG. 16 Transition Temperatures Showing the Effects of Heat Treatment on 5/8" A-201 Steel, 20% Tensile Strain Parallel to Rolling Direction

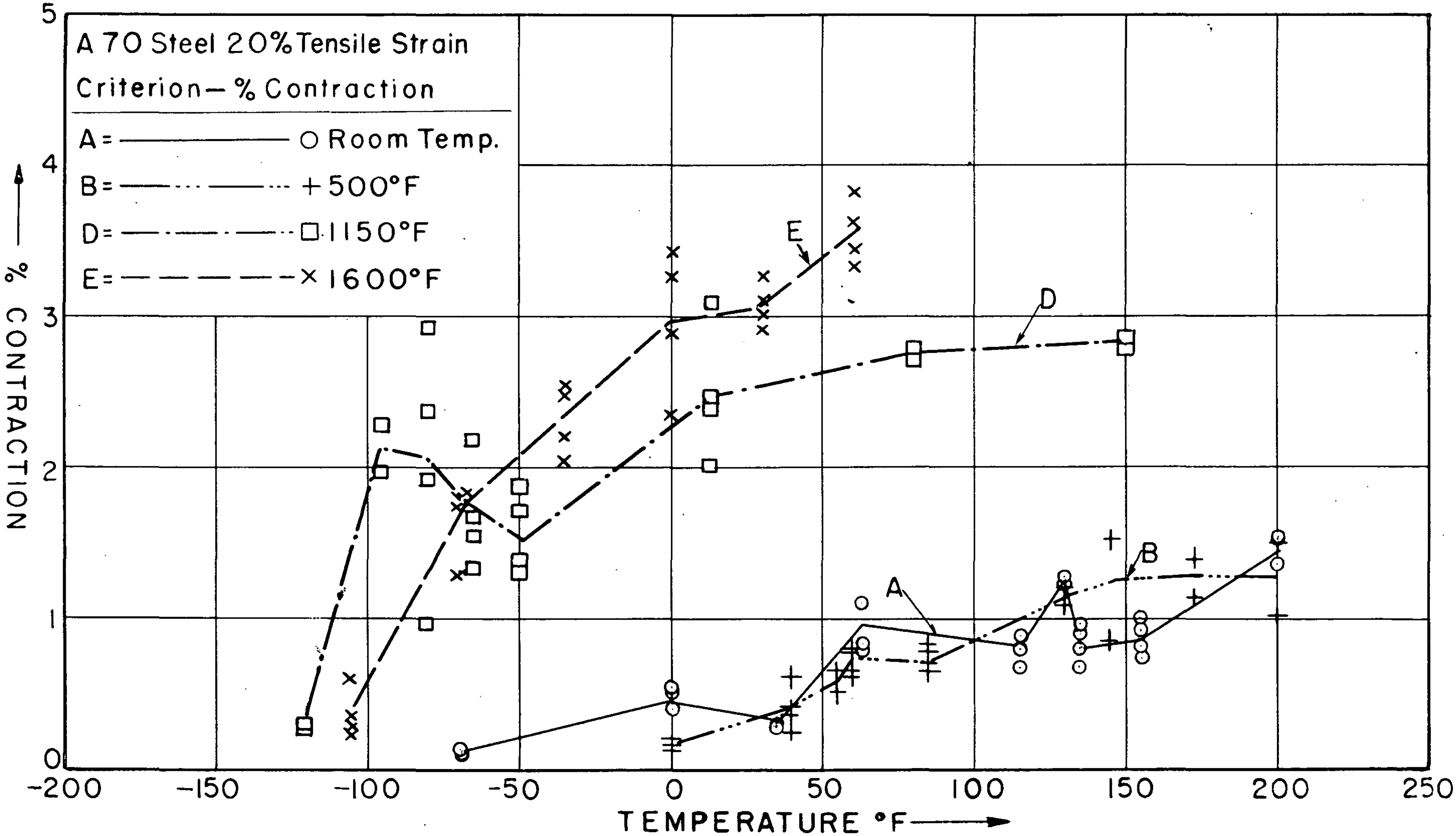


FIG. 17 Transition Temperatures Showing the Effects of Heat Treatment on 5/8" A-70 Steel, 20% Tensile Strain Parallel to Rolling Direction

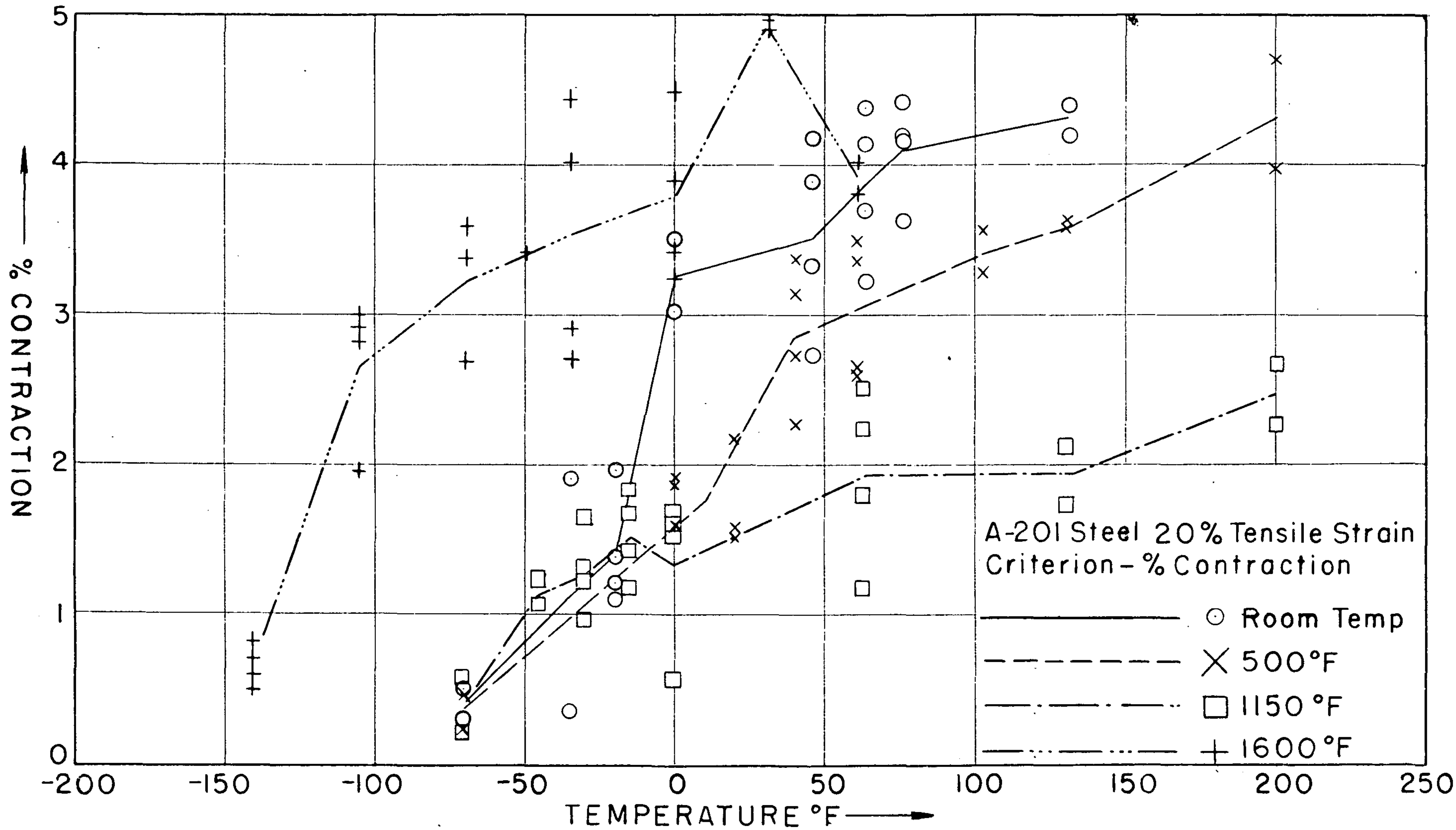


FIG. 18 Transition Temperatures Showing the Effects of Heat Treatment on 5/8" A-201 Steel, 20% Tension Parallel to Rolling Direction.

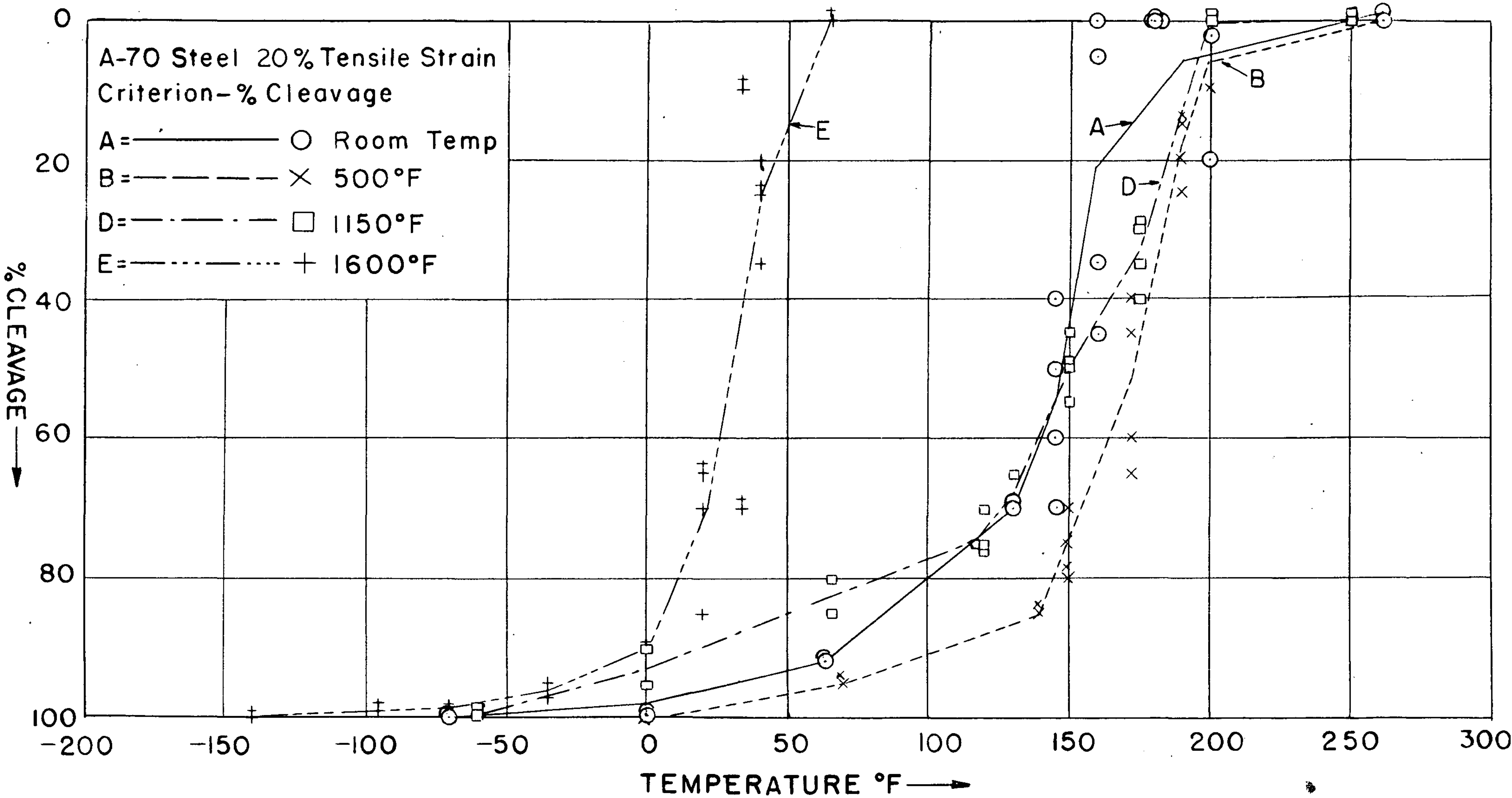


FIG. 19 Transition Temperatures Showing the Effects of Heat Treatment on 5/8" A-70 Steel, 20% Tensile Strain Perpendicular to Rolling Direction

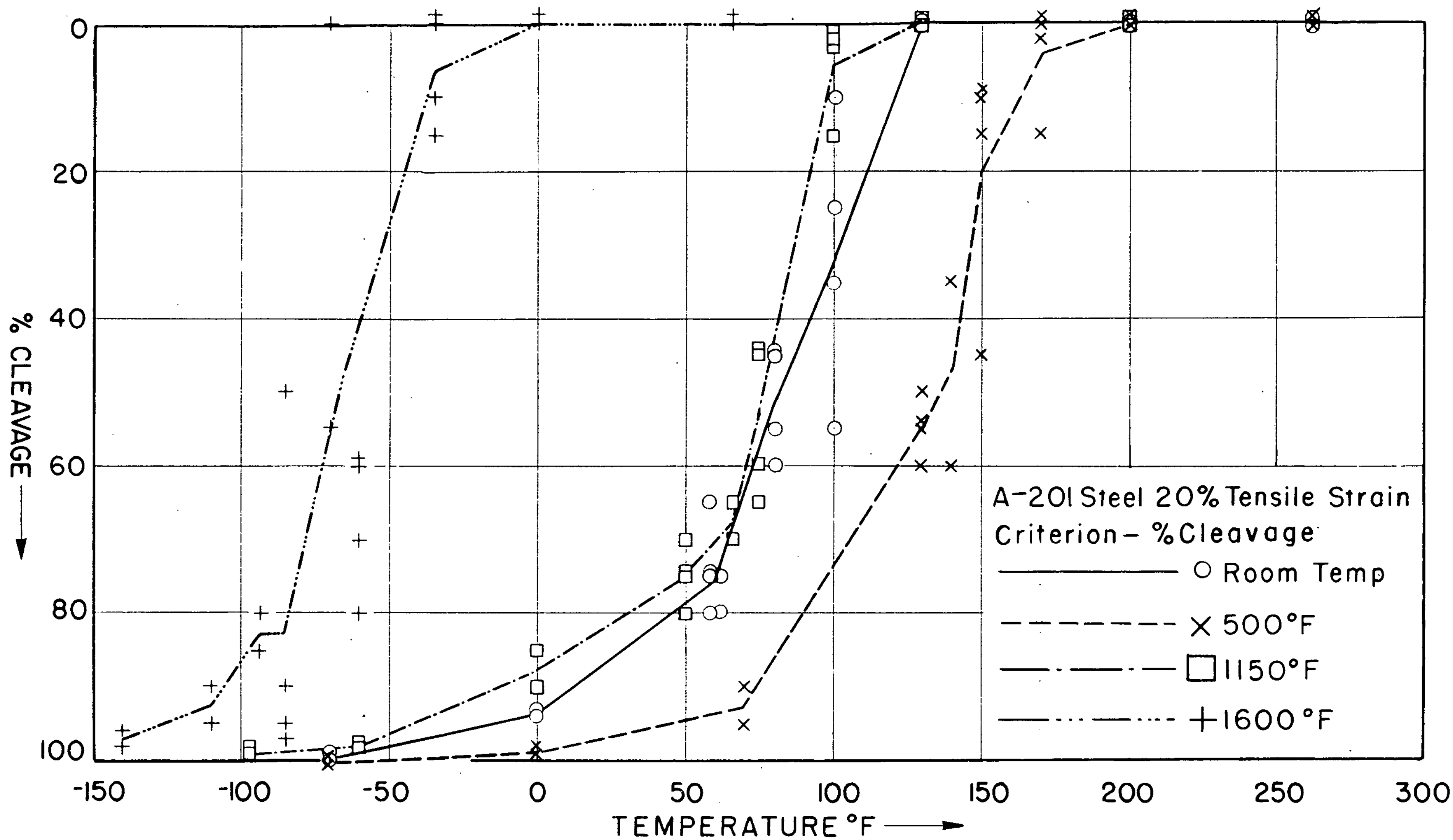


FIG. 20 Transition Temperatures Showing the Effects of Heat Treatment on 5/8" A-201 Steel, 20 % Tension Perpendicular to Rolling Direction.

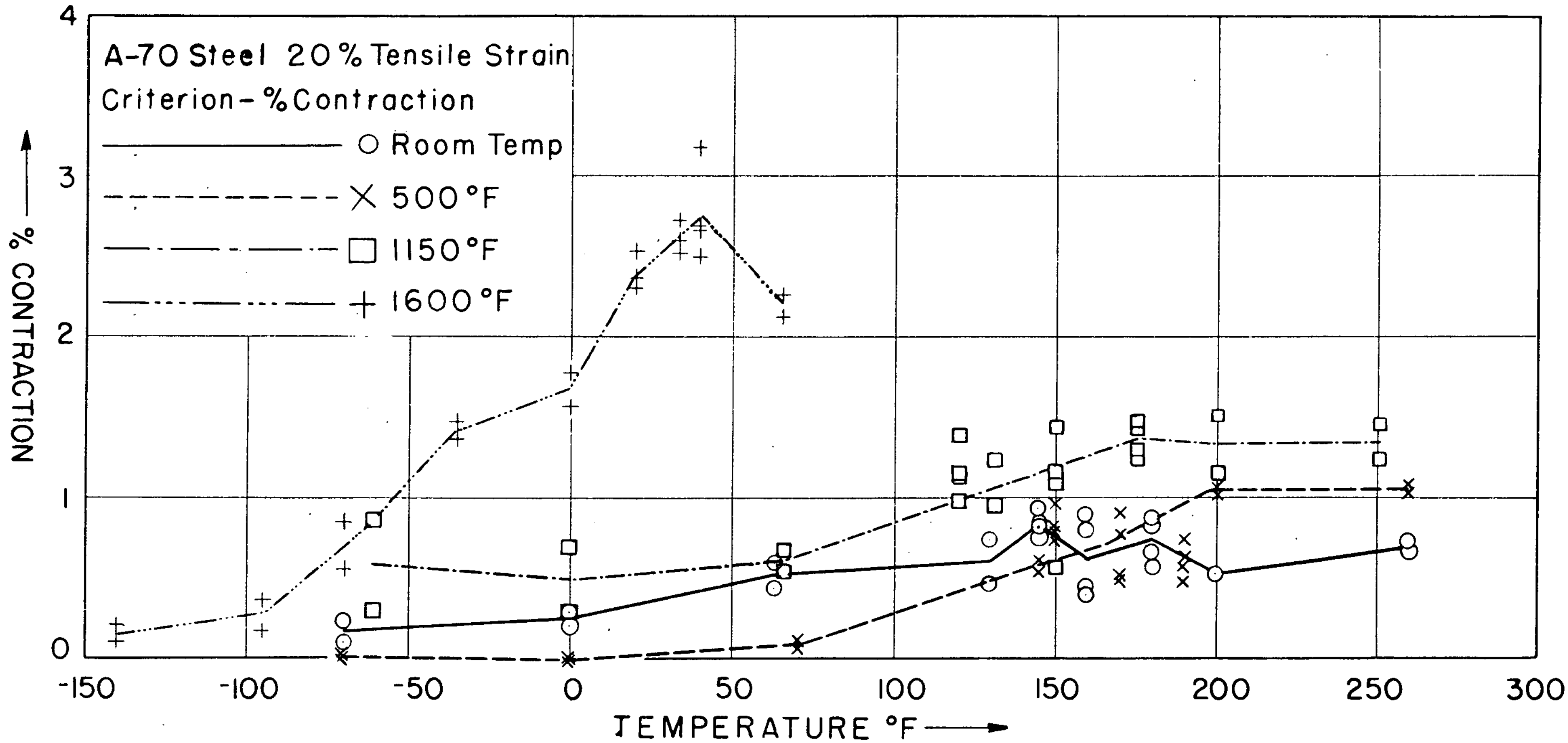


FIG. 21 Transition Temperatures Showing the Effects of Heat Treatment on 5/8" A-70 Steel, 20% Tension Perpendicular to Rolling Direction

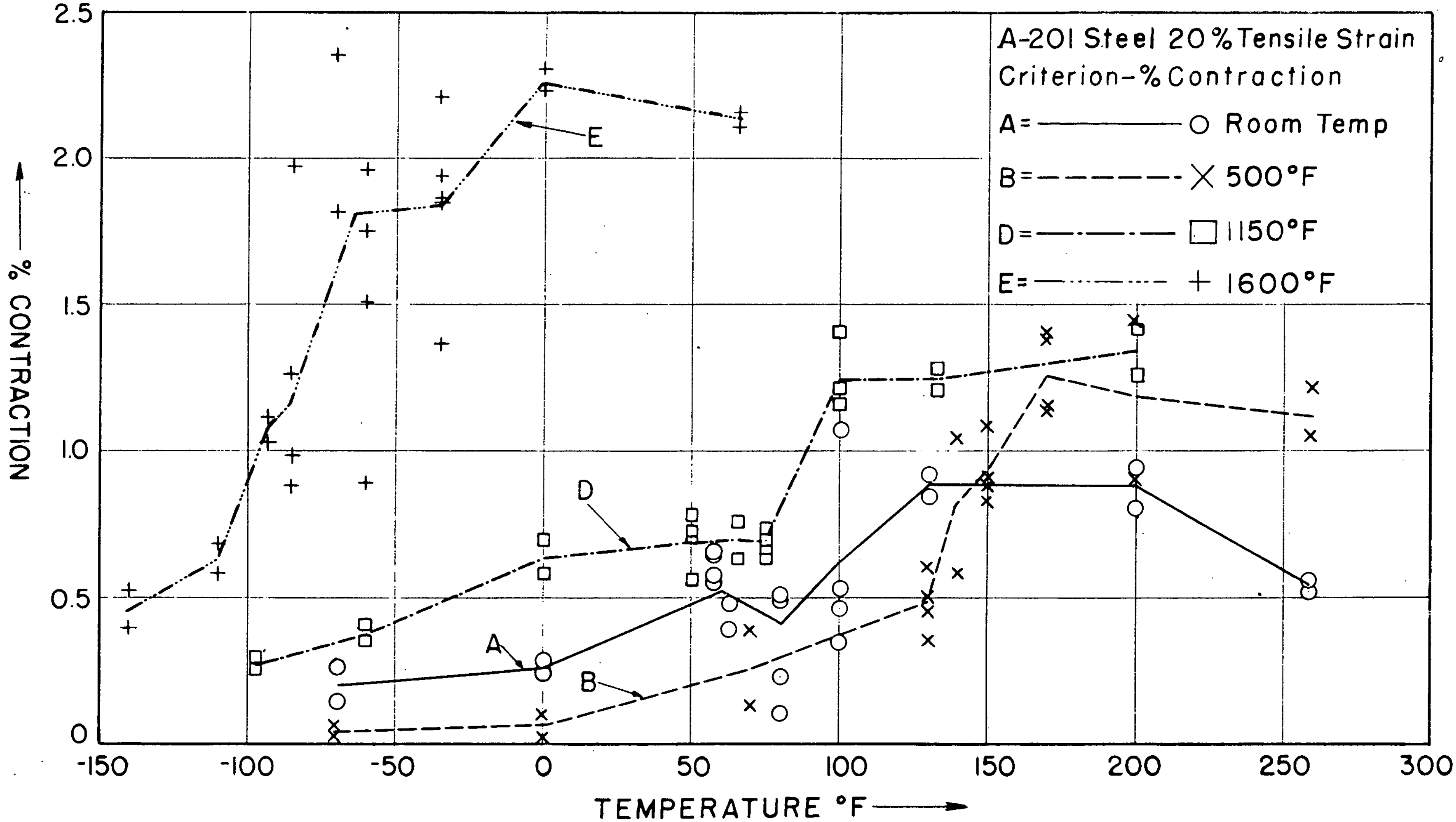


FIG. 22 Transition Temperatures Showing the Effects of Heat Treatment on 5/8" A 201 Steel, 20% Tension Perpendicular to Rolling Direction

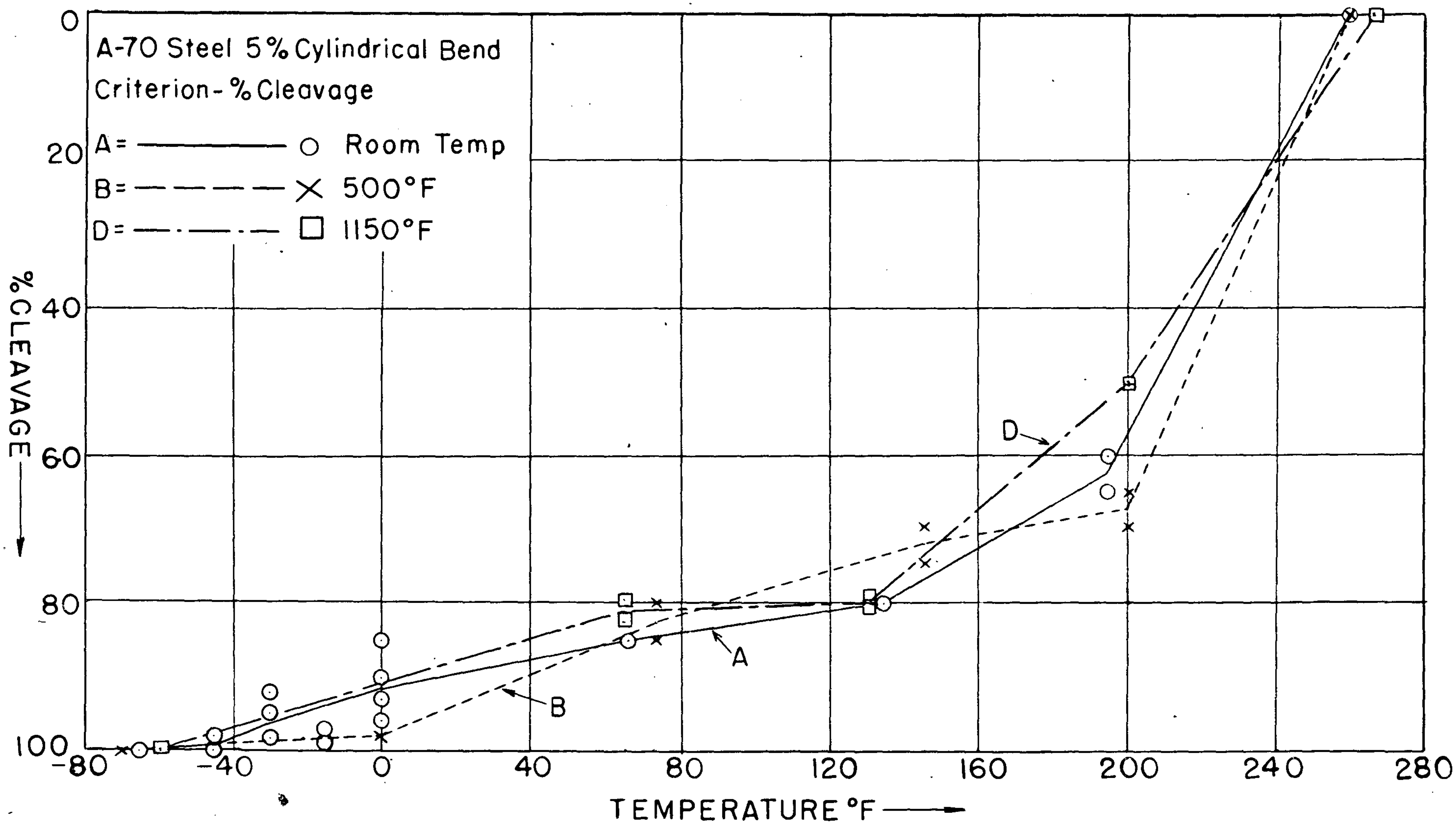


FIG. 23 Transition Temperatures Showing the Effects of Heat Treatment on 5/8" A-70 Steel, 5 % Cylindrical Bend

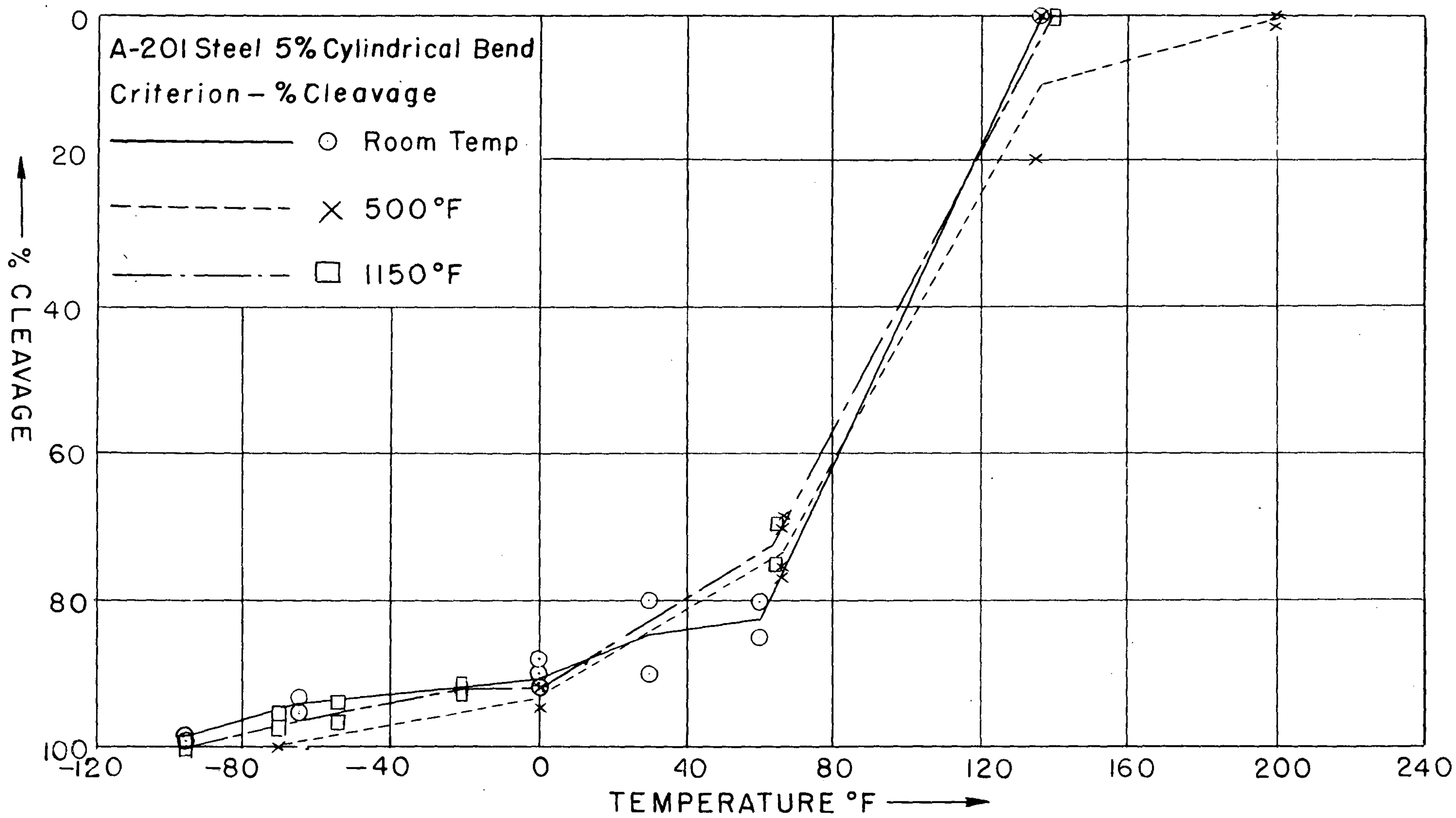


FIG. 24 Transition Temperatures Showing the Effects of Heat Treatment on 5/8" A-201 Steel, 5% Cylindrical Bend

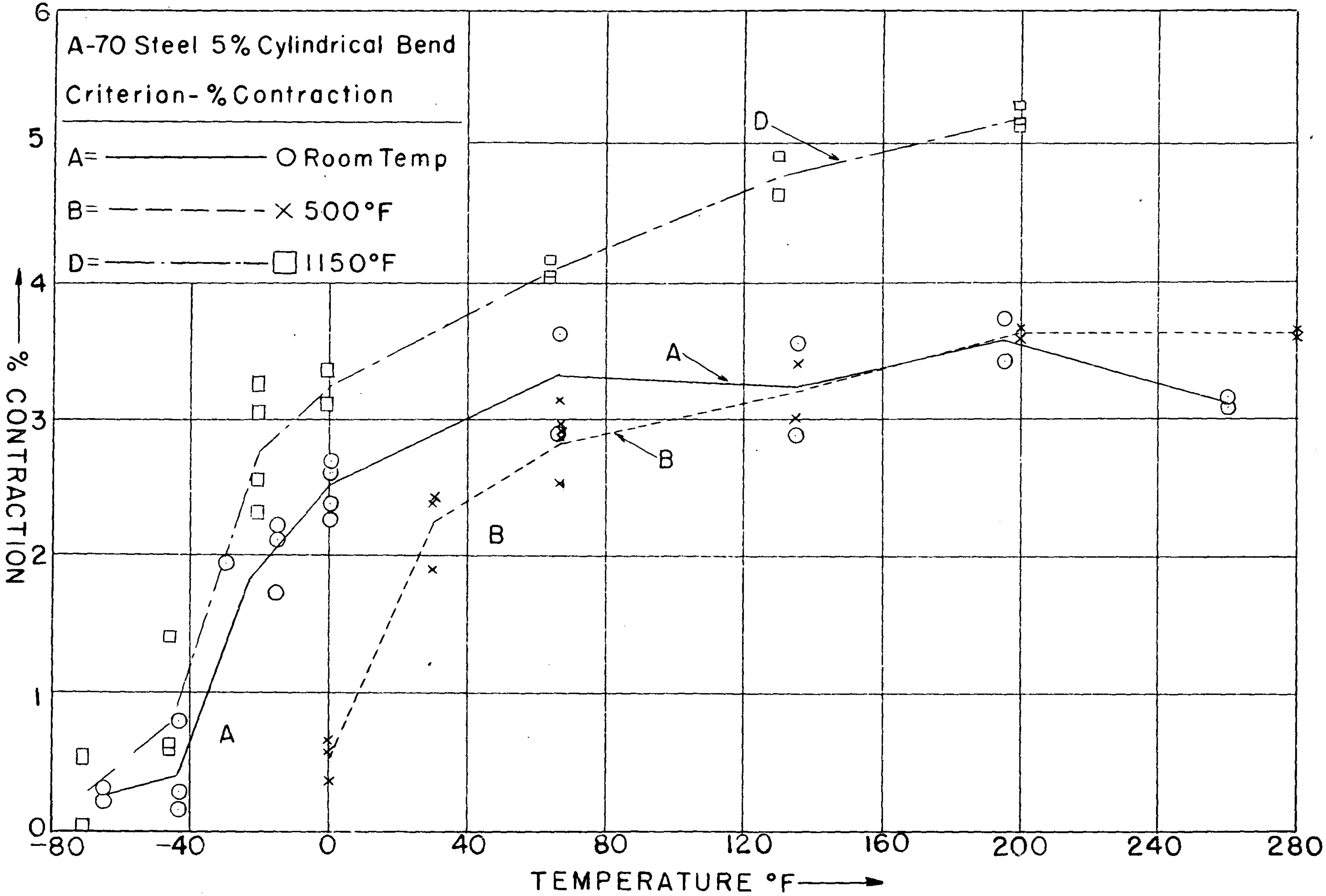


FIG. 25 Transition Temperatures Showing the Effects of Heat Treatment on 5/8" A-70 Steel, 5% Cylindrical Bend

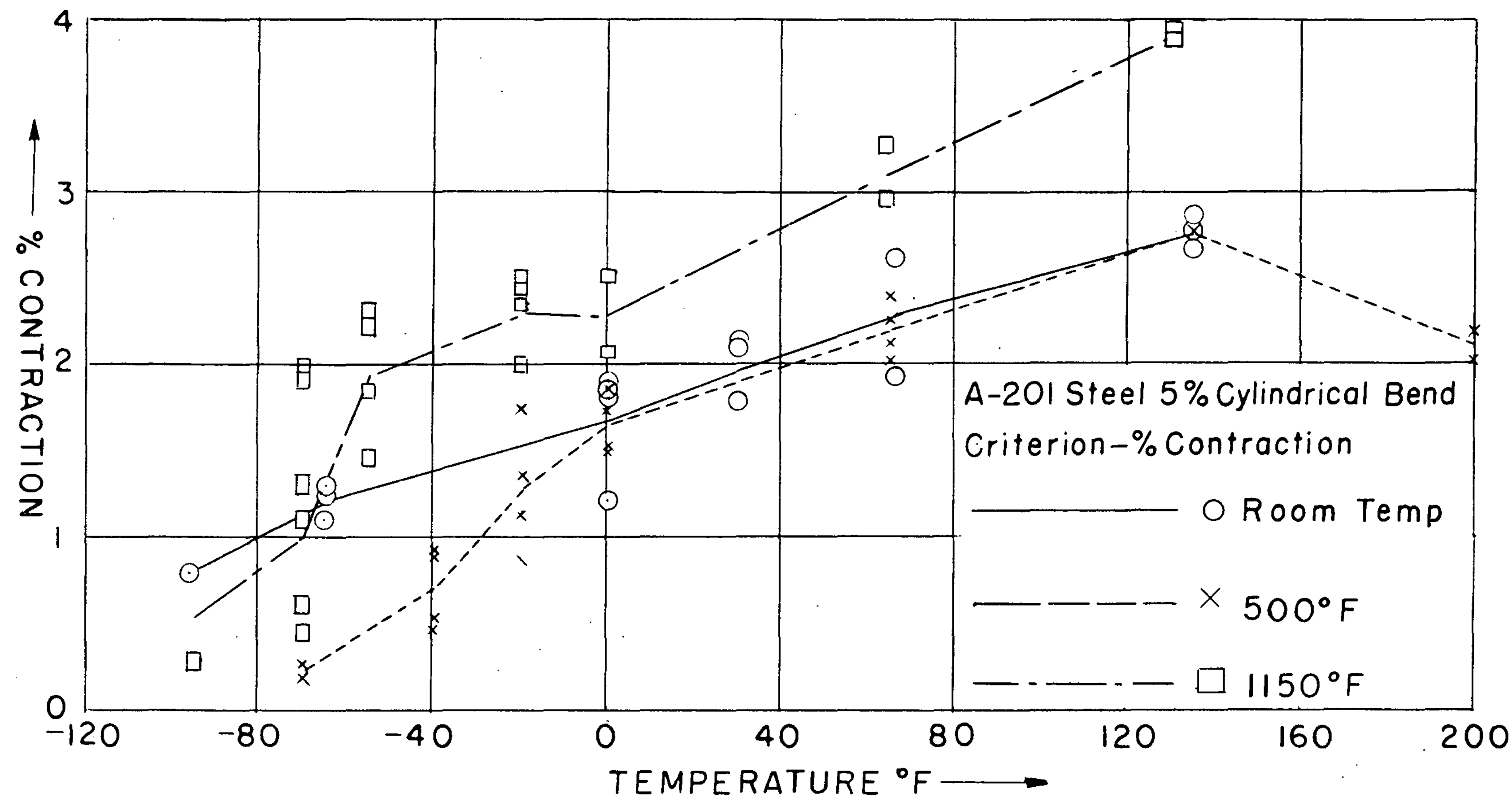
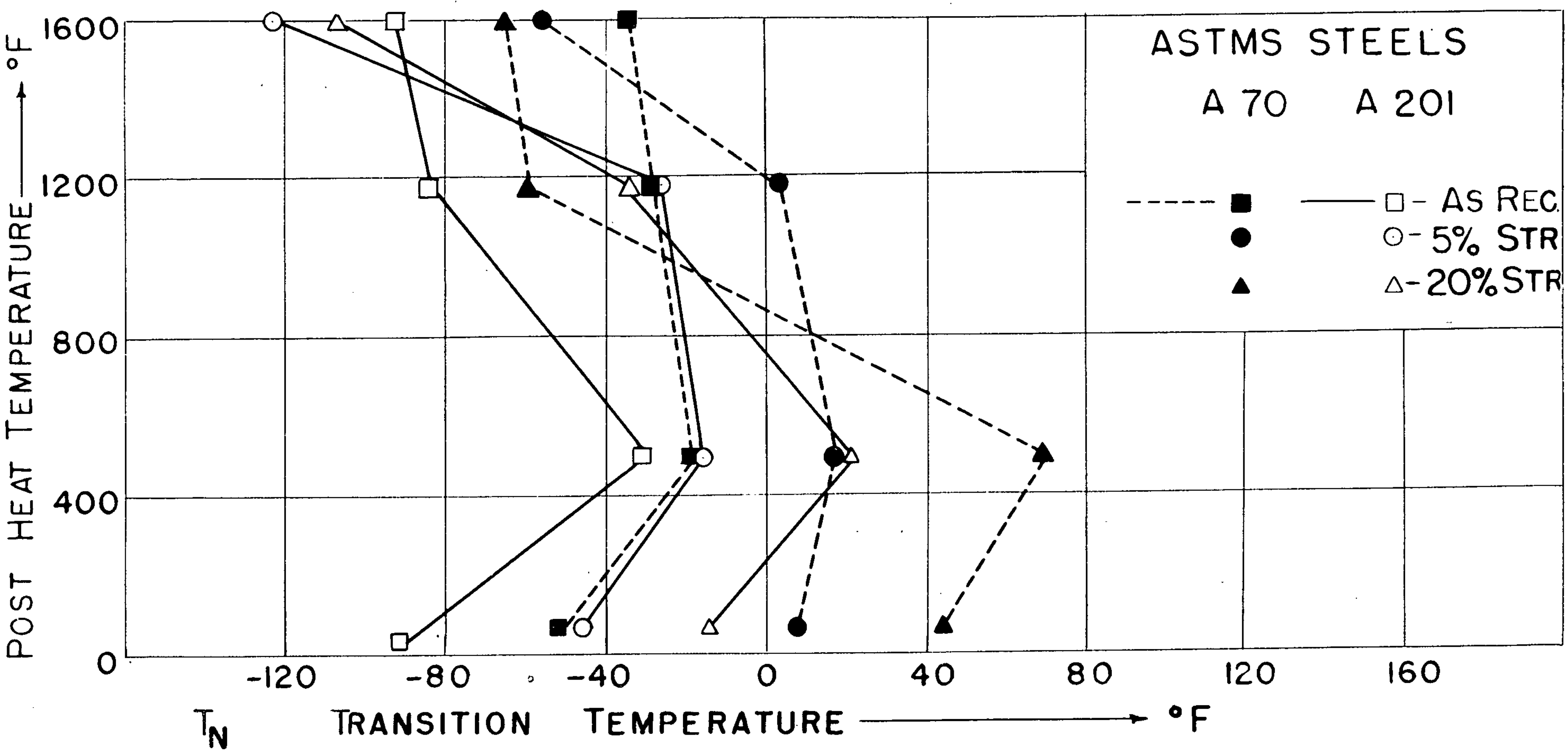
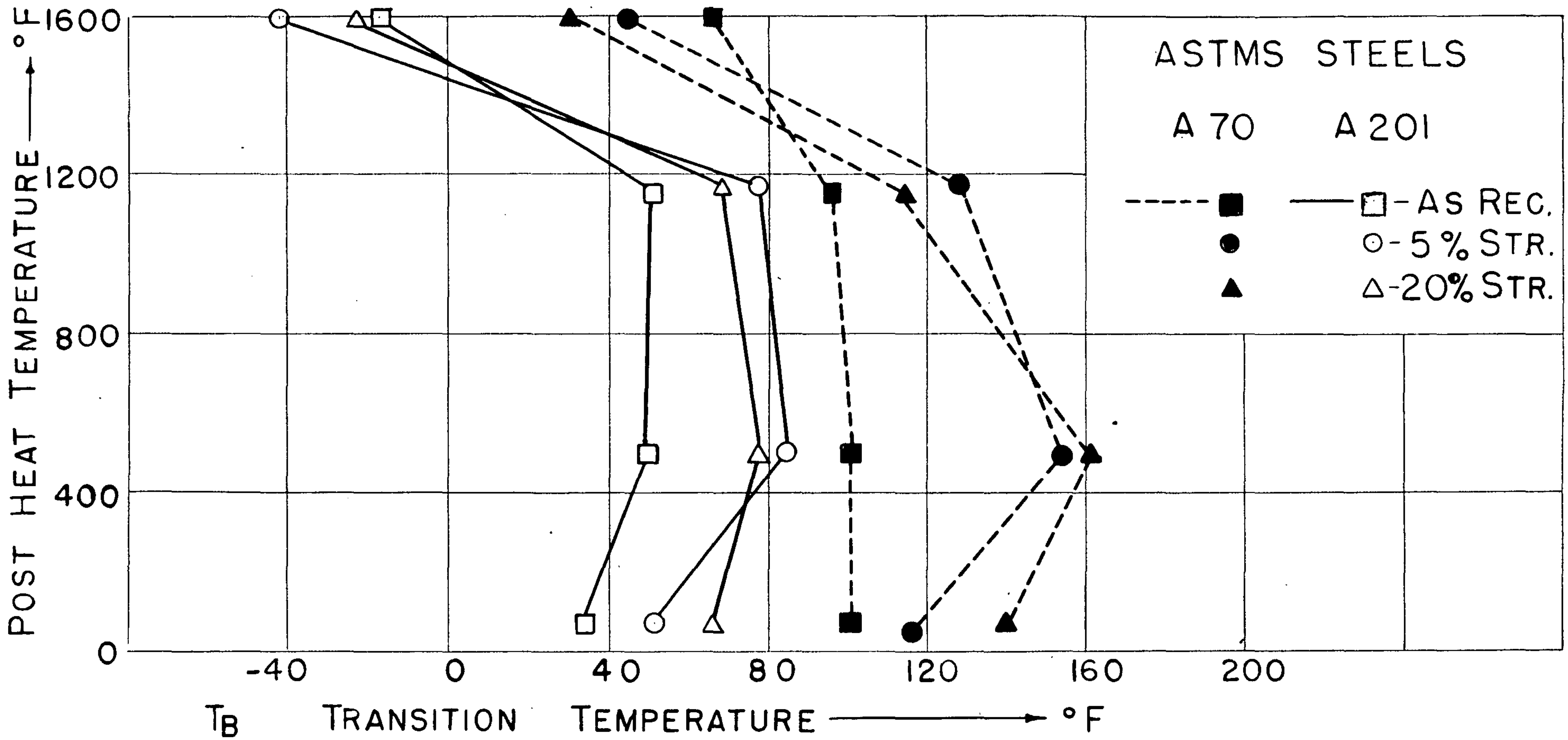


FIG. 26 Transition Temperatures Showing the Effects of Heat Treatment on 5/8" A-201 Steel, 5% Cylindrical Bend



A 201 and A 70, $\frac{5}{8}$" Steels, as Received and as Strained 20% and 5% Parallel to the Rolling Direction

FIG. 27



A 201 and A 70, $\frac{5}{8}$" Steels, as Received and as Strained 20% and 5% Parallel to the Rolling Direction

FIG. 28

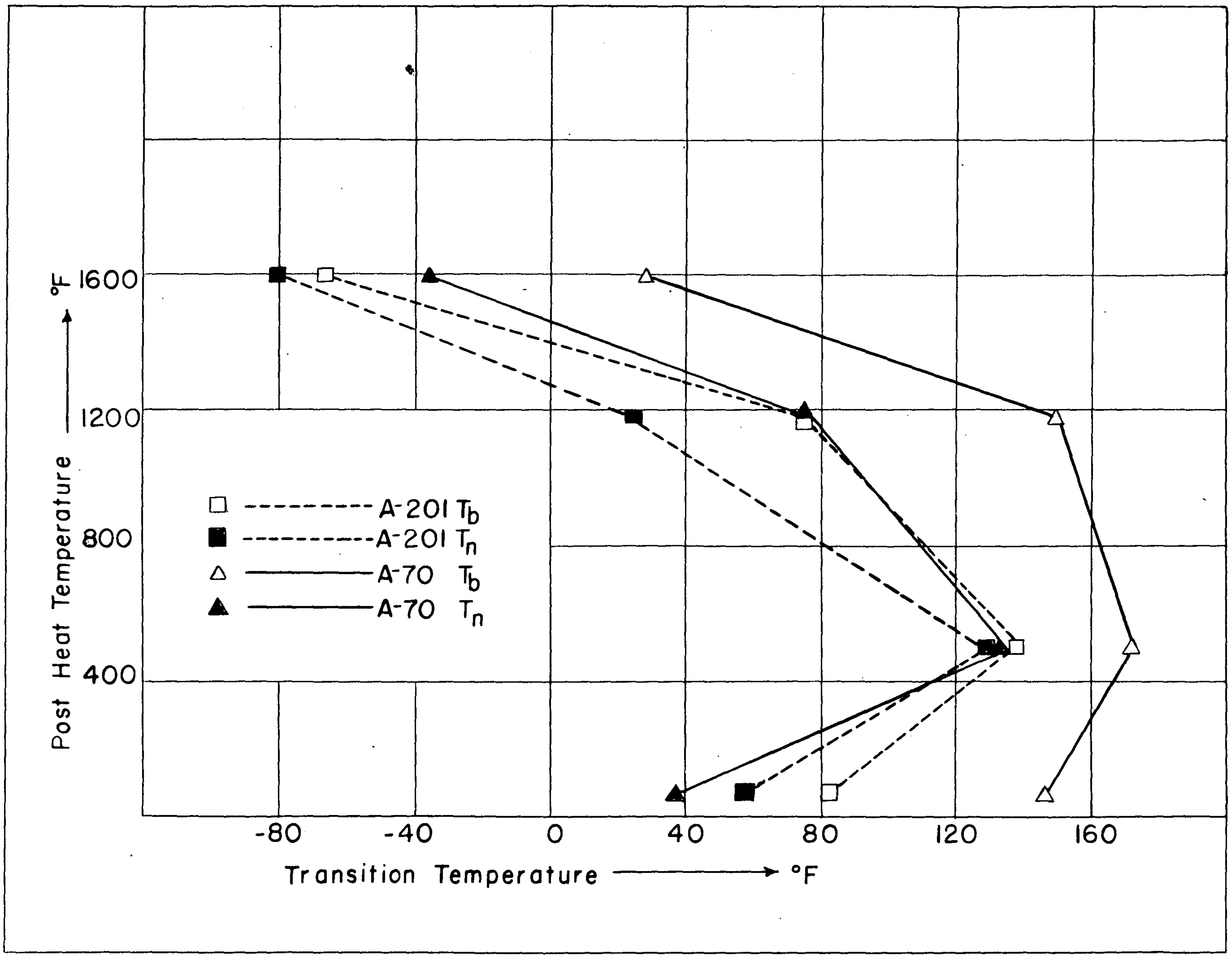


FIG. 29 A 201 and A 70, $\frac{5}{8}$" Steels Strained 20% Transverse To Rolling Direction

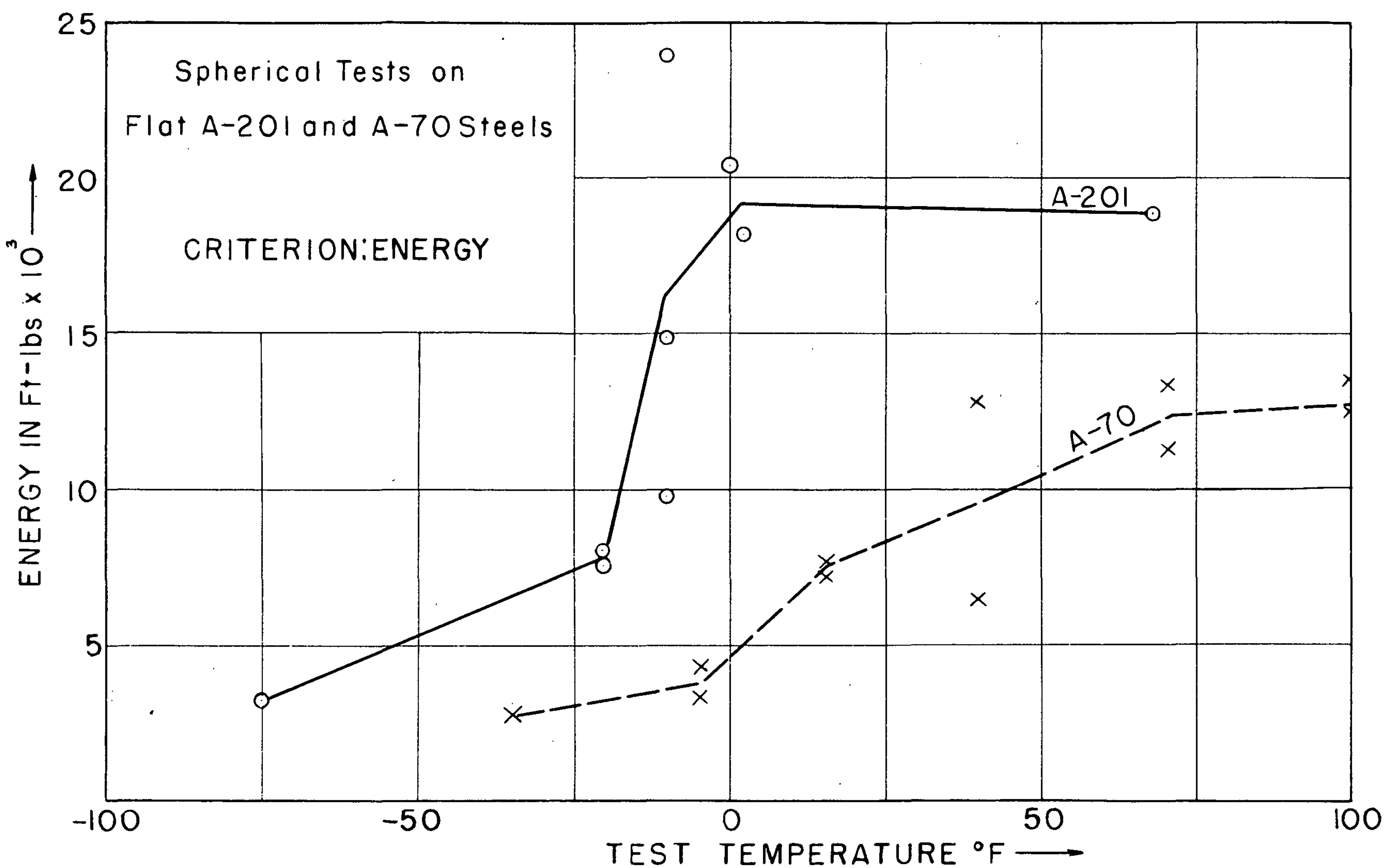


FIG. 30 Spherical Transition Curves on Flat Specimens Showing the Relationship between 5/8" A-70 and A-201 Steels

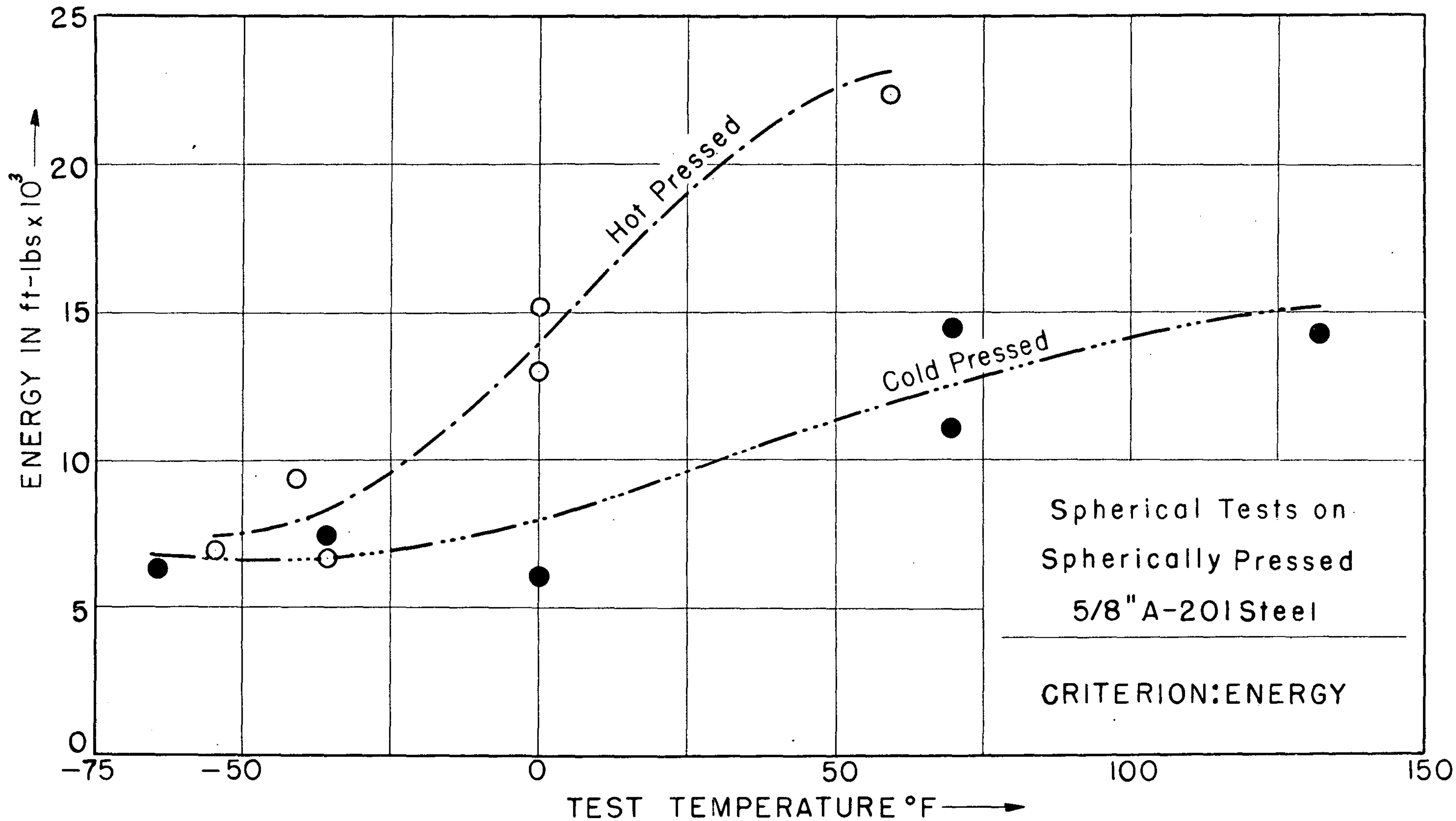


FIG. 31 Spherical Transition Temperature Tests on Spherically Pressed Specimens, With Circular V-Notch. 5/8" A-201 Steel V-Notch: 4 1/2" dia. 0.12" deep

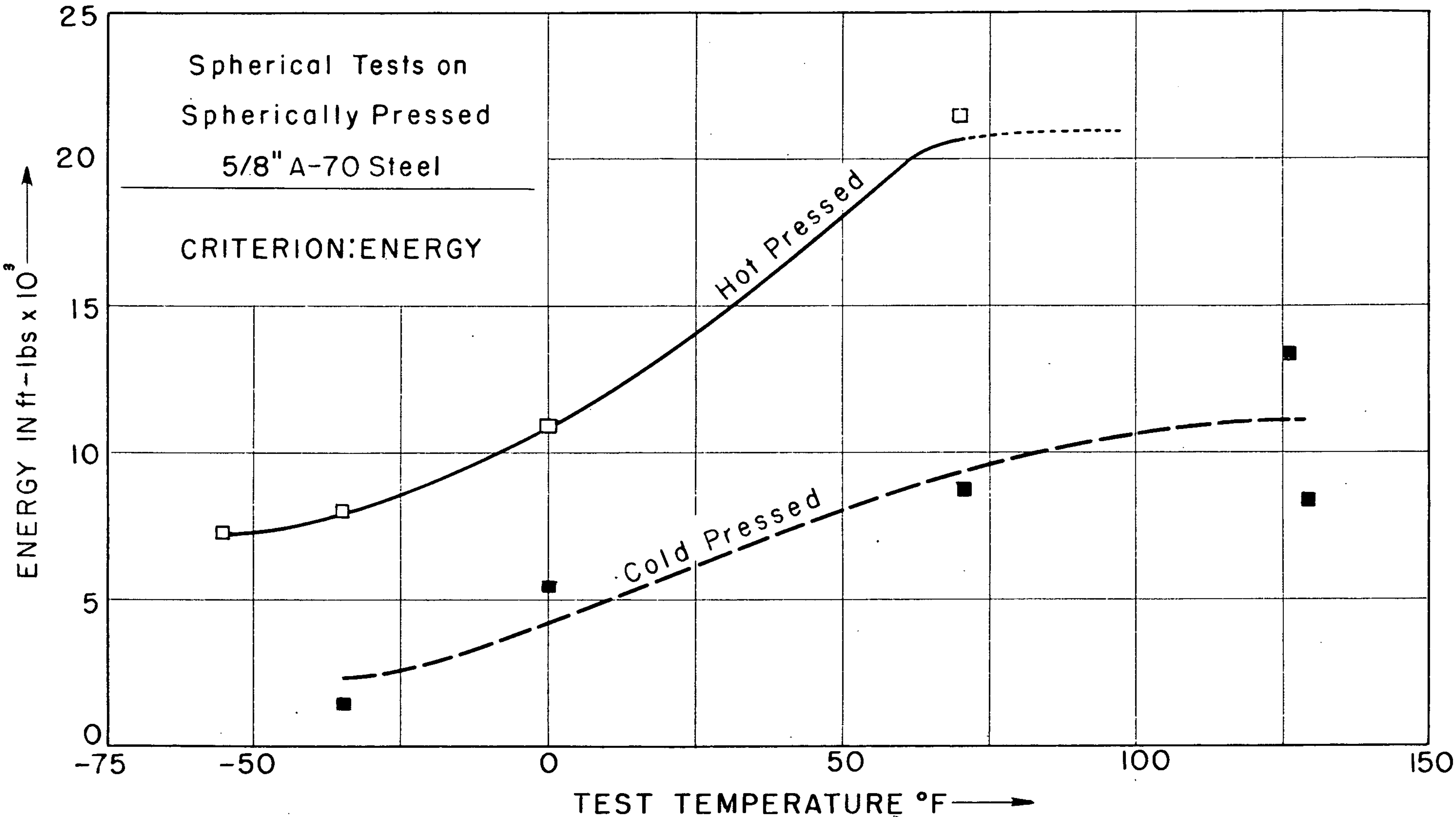


FIG. 32 Spherical Transition Temperature Tests on Spherically Pressed Specimens, With Circular V-Notch 5/8" A-70 Steel V-Notch: 4 1/2" dia. 0.12" deep

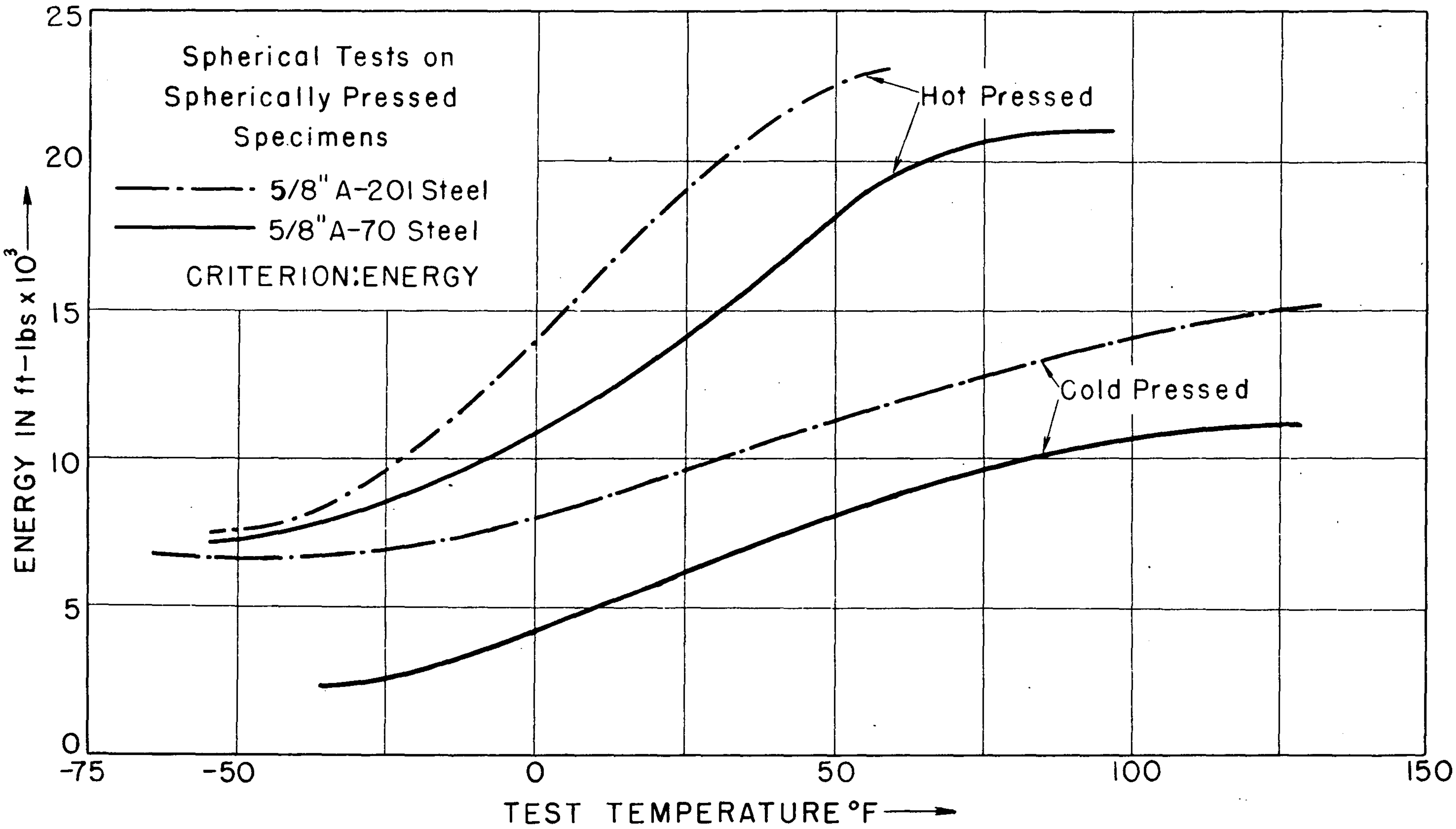


FIG. 33 Transition Temperature Curves Showing Relationship Between Hot and Cold Pressed A-201 and A-70 Steels

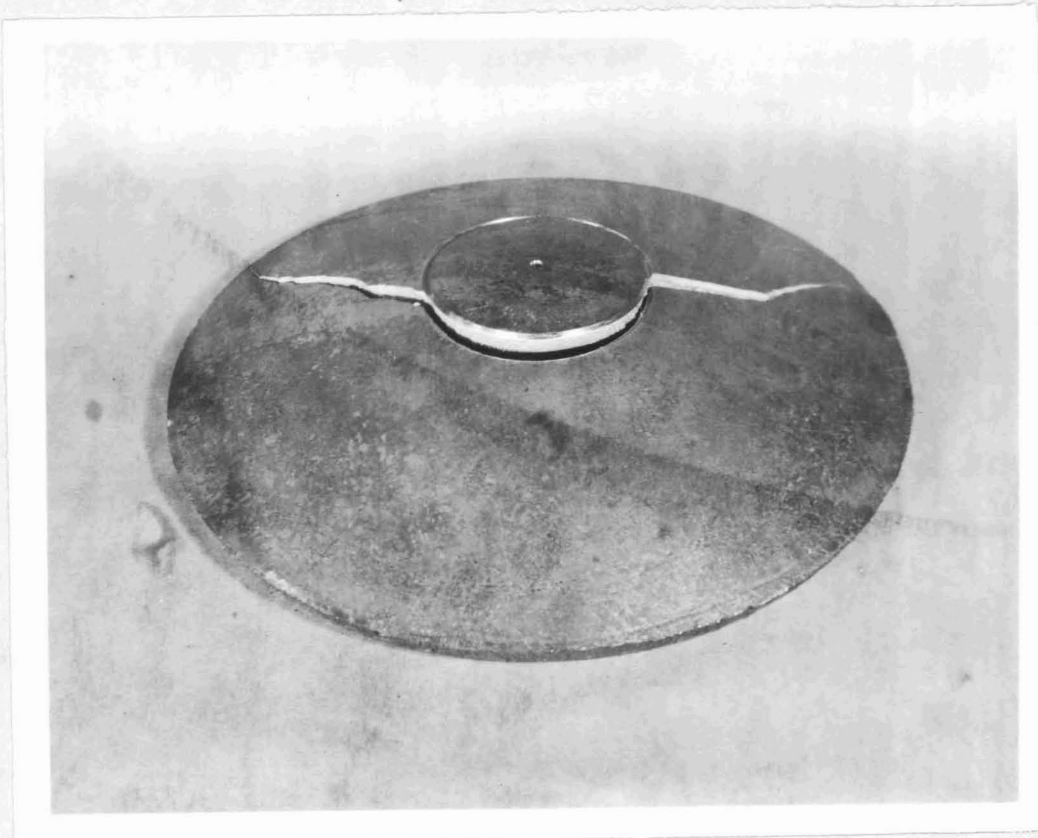


Fig. 34 SPHERICAL SPECIMEN
Showing Typical Brittle Fracture

Fig. 35 SPHERICAL SPECIMENS
Showing Typical Shear Fracture