THIRD

PROGRESS REPORT

(Project SR-99)

on

THE FUNDAMENTAL FACTORS INFLUENCING THE BEHAVIOR OF WELDED STRUCTURES UNDER CONDITIONS OF MULTIAXIAL STRESS AND VARIATIONS OF TEMPERATURE

by

E. B. Evans and L. J. Klingler
CASE INSTITUTE OF TECHNOLOGY

Under Bureau of Ships Contract NObs-45470
(Index No. NS-011-067)

Transmitted through

NATIONAL RESEARCH COUNCIL'S
COMMITTEE ON SHIP STEEL

Advisory to

SHIP STRUCTURE COMMITTEE

under

Bureau of Ships, Navy Department
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(Index No. - NS-731-036)

Division of Engineering and Industrial Research
National Academy of Sciences - National Research Council
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SERIAL NO. **SSC-54**

NATIONAL RESEARCH COUNCIL

2101 CONSTITUTION AVENUE, WASHINGTON 25, D. C.

COMMITTEE ON SHIP STEEL

OF THE

DIVISION OF ENGINEERING AND INDUSTRIAL RESEARCH

October 31, 1952

Dear Sir:

Attached is Report Serial No. SSC-54 entitled "The Fundamental Factors Influencing the Behavior of Welded Structures Under Conditions of Multiaxial Stress and Variations of Temperature" by Evans and Klingler. This report has been submitted by the contractor as a Third Progress Report on Contract NObs-45470, Index No. NS-011-067, between the Bureau of Ships, Department of the Navy and the Case Institute of Technology.

The report has been reviewed and acceptance recommended by representatives of the Committee on Ship Steel, Division of Engineering and Industrial Research, NRC, in accordance with the terms of the contract between the Bureau of Ships, Department of the Navy and the National Academy of Sciences (Contract NObs-50148, Index No. NS-731-036).

Very truly yours,

Peter E. Kyle

P. E. Kyle, Chairman
Committee on Ship Steel

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The Fundamental Factors Influencing the Behavior of Welded Structures under Conditions of Multiaxial Stress and Variations of Temperature

to

SHIP STRUCTURE COMMITTEE
via
Bureau of Ships
Department of the Navy
Contract NObs-45470
Index No. NS-011-078
Project SR-99

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CASE INSTITUTE OF TECHNOLOGY

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ABSTRACT

The eccentric notch tensile test previously employed in exploring the relative ductility at the midthickness level of A and C steel* weldments has been applied to an evaluation of the ductility at the surface level and at various positions in the weld metal of a C steel weldment.

The surface tests at various low temperatures located a zone of low ductility at a distance of 0.4 inch from the weld centerline of 3/4 inch plate. This zone was outside the so-called heat affected zone and appeared to have the same metallographic structure as the base plate. These findings are in agreement with those previously reported at the midthickness level of both A and C steel weldments. Low temperature probe tests in the weld metal failed to detect any zones of low ductility.

In addition, data are presented comparing the notched (eccentric and concentric) and unnotched tensile properties at the midthickness level of an A steel weldment. Various low temperature tests revealed that the concentric notch ductility varied across the welded plate in the same manner as the eccentric notch strength, thus confirming that the eccentric notch strength is a measure of notch ductility. In contrast, the variation in concentric notch strength and unnotched tensile properties across the welded

*The designations A and C refer to steels "A" and "C" in the series of Ship Structure Committee "Project" Steels.

plate failed to detect zones of low ductility in the subcritically heated plate.

A comparison with other investigations of welded plate indicates that the eccentric notch tensile test is not unique in defining a region of minimum ductility in the subcritically heated parent plate and that this region may play an important role in the fracture behavior of welded plate.

THIRD PROGRESS REPORT

on

The Fundamental Factors Influencing the Behavior of Welded Structures under Conditions of Multiaxial Stress, and Variations of Temperature, Stress Concentration, and Rates of Strain

to

SHIP STRUCTURE COMMITTEE

via

Bureau of Ships
Department of the Navy

by

E. B. Evans and L. J. Klingler

INTRODUCTION

This report summarizes the work completed on commercial ship plate weldments on a project sponsored by the Ship Structure Committee under U. S. Navy contract NObs-45470 and covers the period from July 1, 1949 to January 1, 1950. Two Technical Progress Reports SSC-24 (1)* and SSC-34 (2) covered the progress of the investigation to July 1, 1949.

The previous work was concerned with establishing the existence of zones of low ductility in welded ship plate, and the dependence of these zones upon material, variations in the welding process, and heat treatment. The ductility throughout the weldments was evaluated by means of eccentric notch tensile tests conducted at various low temperatures, using the notch strength as the criterion.

* Numbers in parentheses refer to the bibliography at the end of the report.

The two previous reports contained the test results of specimens taken from the midthickness level of 3/4-inch plate of A and C steels, two of the project steels which had been investigated by other groups. A brief summary of this work is presented below.

Eccentric notch tensile tests of as-received plate established a transition temperature of -80°F for A steel and -65°F for C steel. After welding, using a 100°F pre-heat and interpass temperature, a zone of minimum ductility was located at a distance of 0.3-0.4 inch from the weld centerline of both the A and C steel weldments. The transition temperature of this critical zone was -40°F for A steel and -20°F for C steel, thus indicating an appreciable embrittlement in both steels. The transition temperature of the weld metal was not determined but it was definitely lower than that of the parent plate.

In order to investigate the possible beneficial effects of preheating and postheating, weldments of C steel were made using (1) a 400°F preheat and interpass temperature, and (2) a postheat treatment at 1100°F to a weldment which had been welded with a 100°F preheat. The 400°F preheat improved the ductility in the critical zone, lowering the transition temperature to -45°F. The 1100°F postheat completely eliminated the zone of minimum ductility, the transition temperature being lowered to -70°F.

Temperature measurements during welding and the microstructure of the critical zone showed that this region was not heated above the lower critical temperature at any time and, therefore, the critical region was outside the so-called "heat affected" zone. Consequently, the embrittlement (and the improvement brought about by preheat and postheat treatments) was thought to be due to some subcritical temperature phenomena which may be the supersaturation and precipitation of carbides and/or nitrides from the alpha phase.

In view of the fact that the previous work was confined to tests at the plate midthickness, it was considered advisable to continue the investigation at the surface level to determine any difference due to gross inhomogeneity of the plate. This study was limited to a C steel weldment made with a 100°F preheat and interpass temperature. The same weldment also supplied specimens for an evaluation of the ductility at selected locations in the weld metal.

This report also presents data comparing the notched (eccentric and concentric) and unnotched tensile properties at the mid-thickness level of an A steel weldment. This phase of the investigation was carried out at low temperatures and at various distances from the weld centerline with two objectives in view:

1. To confirm that the eccentric notch tensile strength is a measure of the notch ductility of ship plate steel.
2. To determine if the unnotched tensile test can be made sufficiently severe, by the use of low temperatures to detect ductility variations in ship plate steel.

The findings of this investigation are discussed with those of other investigations of welded plate with particular reference to the origin of fracture.

MATERIAL

The A and C ship plate steels selected for the present investigation were the same two "project steels" which had been used in the earlier work at this laboratory. Both were semi-killed steels in the as-rolled condition. The properties reported for these steels are as follows: (3)

TABLE I

Properties of A and C Steel Plate

Chemical Analysis

	Carbon	Manganese	Phosphorous	Sulfur	Silicon
C Steel	0.24	0.48	0.012	0.026	0.05
A Steel	0.26	0.50	0.012	0.039	0.03

	Aluminum	Nickel	Copper	Chromium	Molybdenum
C Steel	0.016	0.02	0.03	0.03	0.005
A Steel	0.012	0.02	0.03	0.03	0.006

	Tin	Nitrogen	Vanadium	Arsenic
C Steel	0.003	0.009	0.02	0.01
A Steel	0.003	0.004	0.02	0.01

Mechanical Properties

	Yield Point Psi	Tensile Strength Psi	Elongation Per Cent
C Steel	39,000	67,400	25.5 (8" Gauge)
A Steel	37,950	59,910	33.5 (2" Gauge)

PROCEDURE

Welding Procedure

The plates were at Battelle Memorial Institute, following the same closely controlled procedure used previously (1)(2). Details of the plate preparation and welding procedure are given in Figs. 1 and 2.

Each weldment was 18" x 24" x 3/4", constructed of two plates 9" x 24" x 3/4" in dimensions*. These plates were flame cut from the same large plate and 3/4-inch was machined from the edges to be welded in order to eliminate the heat effect of the flame cutting. The edges to be welded were then machined to a 30° bevel and 1/8-inch root face.

The plates were tack welded using one-inch tacks at each end and at the center of the plate, leaving 3/16-inch clearance between the root faces. A copper back-up bar coated with a thin layer of wollastonite was used for the first weld pass.

No restraint other than the tack welds was used on the weldments and because two inches from each end of the plate were to be discarded, no runnoff tabs were required. The welding was manual; six passes were made using 3/16-inch diameter E6010 electrodes with DC reverse polarity. The welding data are given in Table II.

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* The 24" dimension was the rolling direction of the plate.

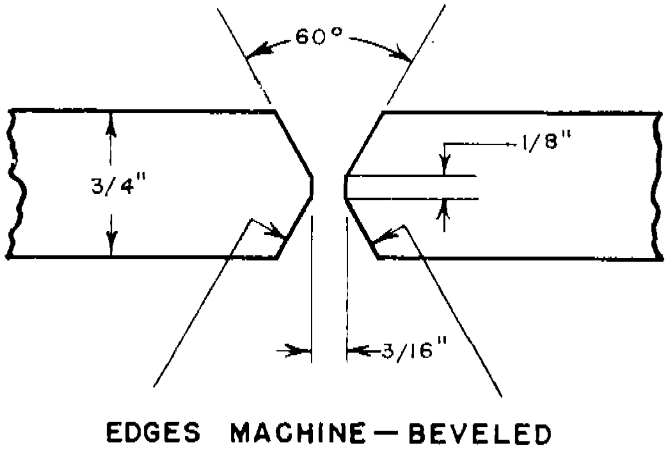


FIG. 1: PLATE PREPARATION

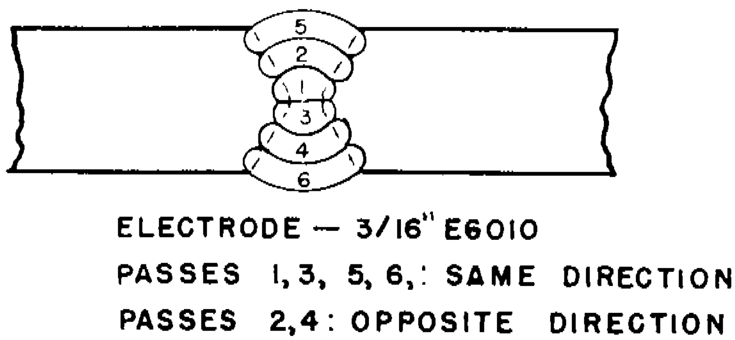


FIG. 2: WELDING PROCEDURE

TABLE II

Welding Data

Harnischfeger - D. C. Welder

Electrode: 3/16" E6010 Reversed Polarity

Current	150 amps 165 amps	Pass 1 Passes 2 - 6
Voltage	25 volts	Passes 1 - 6
Welding Speed	3.6 in/min 4.8 in/min	Pass 1 Passes 2 - 6
Electrode Burn-Off Rate	8.5 in/min	Passes 1 - 6

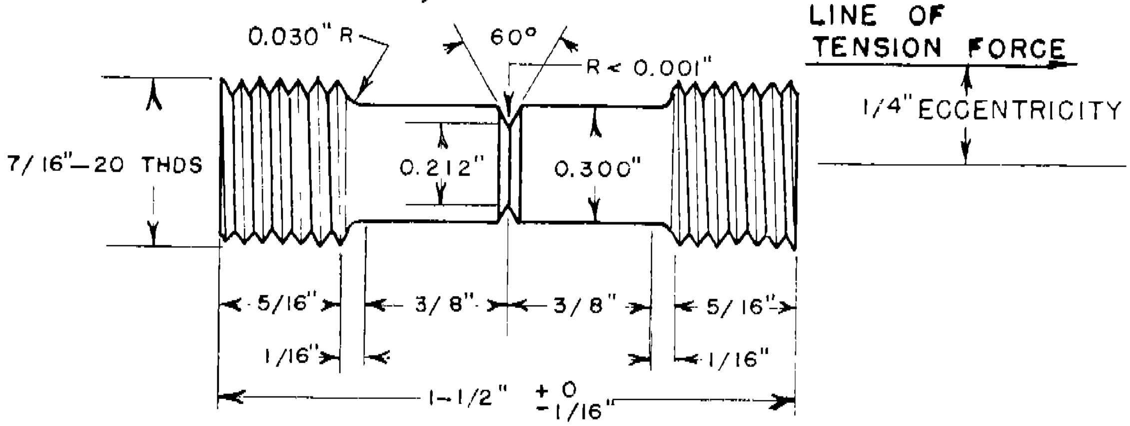
The weldments were preheated to 100°F prior to the first weld pass. After each pass the weld joint was cooled in still air to 100°F and then the next pass was made.

After completion of welding, the welded joint was sand blasted and then radiographed for weld imperfections.

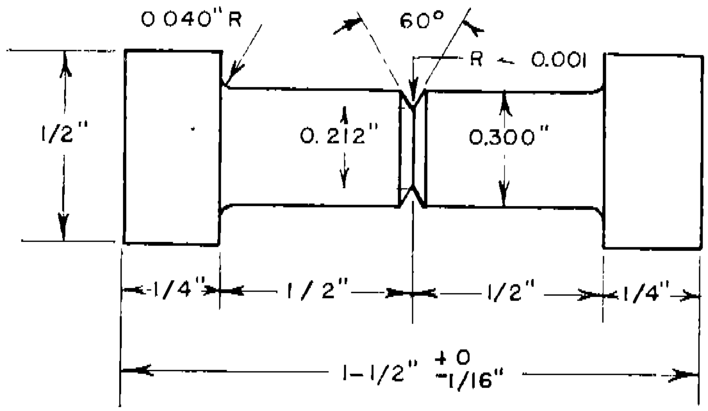
Test Specimens

The three types of tension specimens obtained from the weldments are shown in Fig. 3.

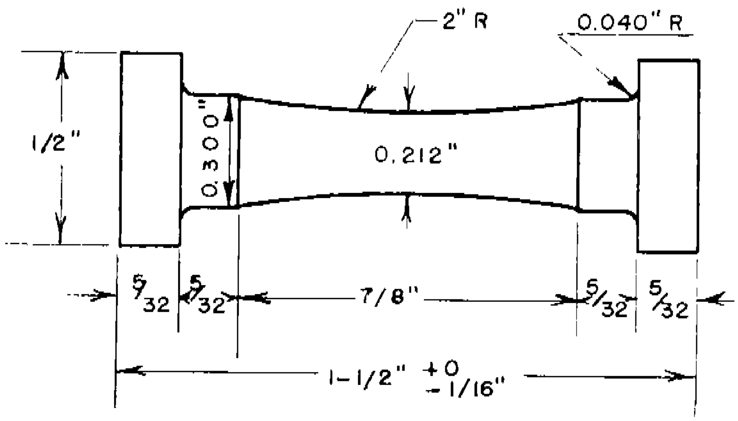
The two notched test specimens had 60° V-notches removing 50 per cent of the cross sectional area, and a root radius less than 0.001 inch. The buttonhead notch specimen was employed in the concentric tests and the threaded end notch specimen in the eccentric tests.



ECCENTRIC NOTCH TENSILE SPECIMEN



CONCENTRIC NOTCH TENSILE SPECIMEN



UNNOTCHED TENSILE SPECIMEN

FIG. 3: TEST SPECIMENS

The unnotched test specimen had a two-inch radius, with the same minimum diameter (0.212 inch) as the notch diameter of the notched specimens.

Specimen Preparation

All of the test specimens were obtained from strips, 1/2-inch wide, which were cut from the welded plates perpendicular* to the weld. Each strip was etched so that the weld area was visible and the weld centerline could be located. The specimen locations for each type of test specimen were then laid out as follows:

(a) Eccentric Notch Tensile - The notch bottom was positioned at the desired distance from the weld centerline and so that the fiber carrying the highest tension load was at the desired distance from the plate reference surface. For the surface investigation, the fiber carrying the highest tension load was 0.05 inch from the surface. This close approach to the surface resulted in specimens with a flat on the threaded ends, as shown in Fig. 4. A number of specimens were also prepared so that the critical fiber was at the midthickness of the plate (longitudinal axis 0.48 inch from the reference surface), and at selected locations in the weld metal.

(b) Concentric Notch Tensile - The notch bottom was at the desired distance from the weld centerline with the long axis of the specimen 0.48 inch from the surface.

* The long axis of each test specimen was, therefore, perpendicular to the rolling direction of the base plate.

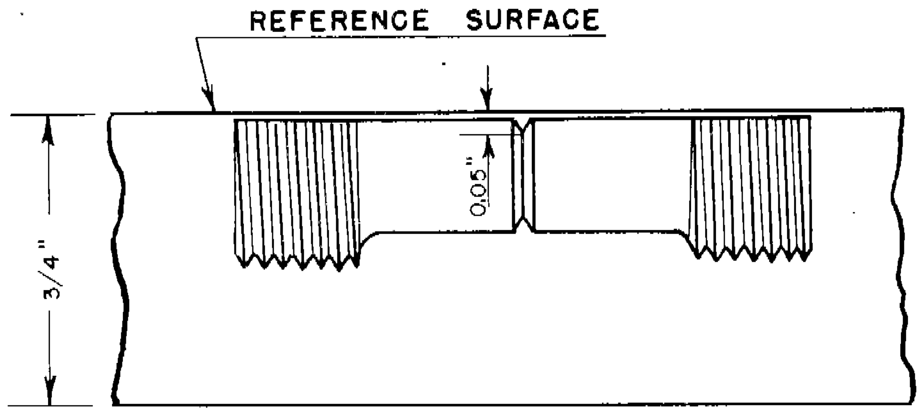


FIG. 4: LOCATION OF ECCENTRIC NOTCH SPECIMEN AT THE SURFACE LEVEL

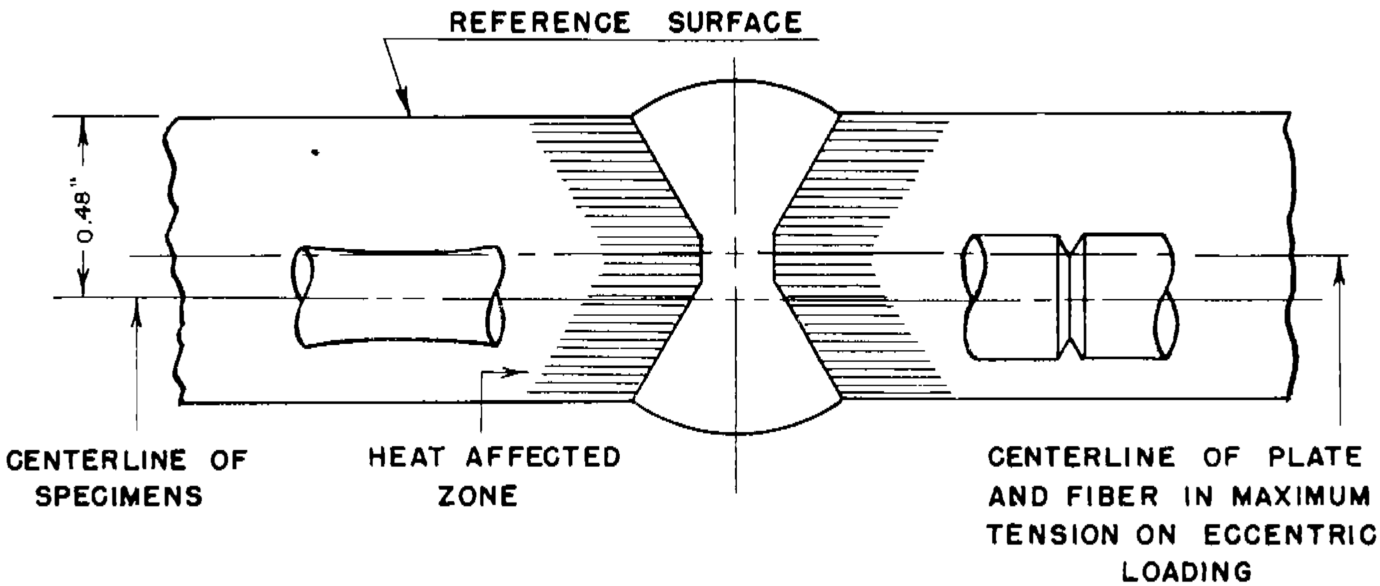


FIG. 5: LOCATION OF UNNOTCHED AND NOTCHED SPECIMENS AT THE MIDTHICKNESS OF WELDMENT

(c) Unnotched Tensile - The minimum diameter was at the desired distance from the weld centerline with the long axis of the specimen 0.48 inch from the surface.

The location of these specimens at the mid thickness level (away from the weld) is shown in Fig. 5.

Testing Procedure

The test equipment and procedure for the eccentric notch tensile tests were the same as those used previously (1) (2).

The specimens were placed in the fixtures, Fig. 6, so that the critical fiber received the maximum tensile stress. The initial eccentricity was set at 1/4 inch, that is, the centerline of the specimen was displaced 1/4 inch from the loading axis of the tensile machine as shown in Fig. 6.

The specimen was cooled to about 5°F below the desired testing temperature, allowed to warm up to the testing temperature and then tested. The tests were performed at constant temperature since the testing time was about 30 seconds, whereas, the warming-up rate was about 1°F per minute. The specimens were cooled by means of isopentane, dry ice, and liquid nitrogen contained in an insulated tank. Temperatures were measured by a copper-constantan thermocouple wrapped around the specimen. All

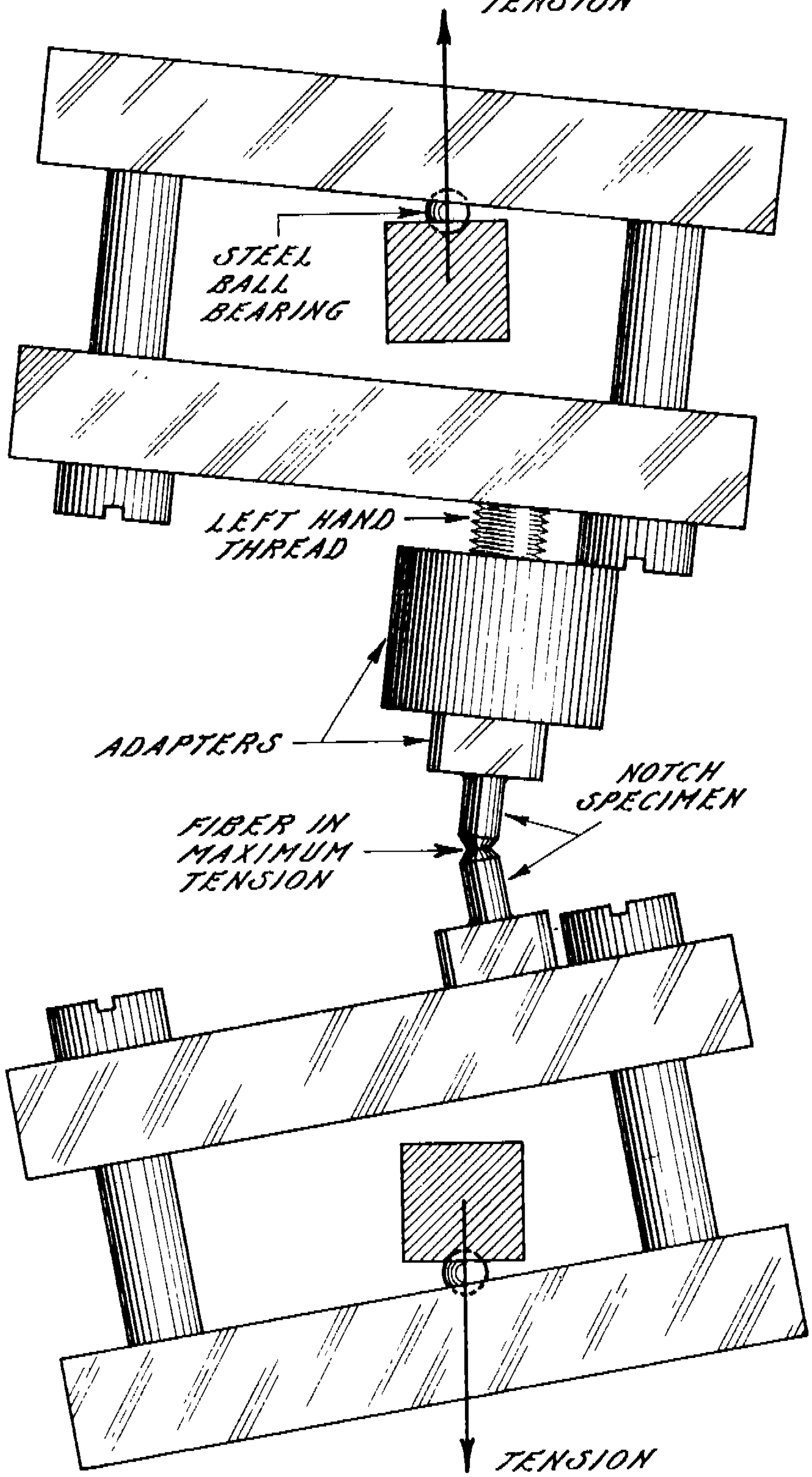


FIG. 6: METHOD OF LOADING TO OBTAIN 1/4 INCH ECCENTRICITY (ECCENTRICITY AND THE POSITION OF FIXTURES ARE EXAGGERATED).

of the tests were carried out at a low strain rate; the crosshead speed of the tensile machine was approximately 0.1 inch per minute.

The testing procedure for the concentric notch and unnotched tensile tests was generally the same as described above with the exception that the specimens were tested in a fixture, Fig. 7, designed to yield an eccentricity of less than 0.001 inch (4). The crosshead speed of the tensile machine in these tests was approximately 0.05 inch per minute.

For the eccentric and concentric notch specimens, the conventional notch strength was determined (maximum load divided by the original area at the notch bottom). Also, for the concentric notch specimens the contraction in area at the root of the notch or "notch ductility" was obtained by measuring the initial and final notch diameters by means of a microcomparator (at 20x).

The conventional tensile strength and reduction in area were calculated for the unnotched tensile specimens.

RESULTS

Eccentric Notch Tests at the Plate Surface

The results obtained from the tests at the plate surface of a "C" steel weldment made with a 100°F preheat and interpass temperature are graphically presented in Figs. 8 and 9. For purposes of comparison the previous results at the midthickness (2) are also shown. The data

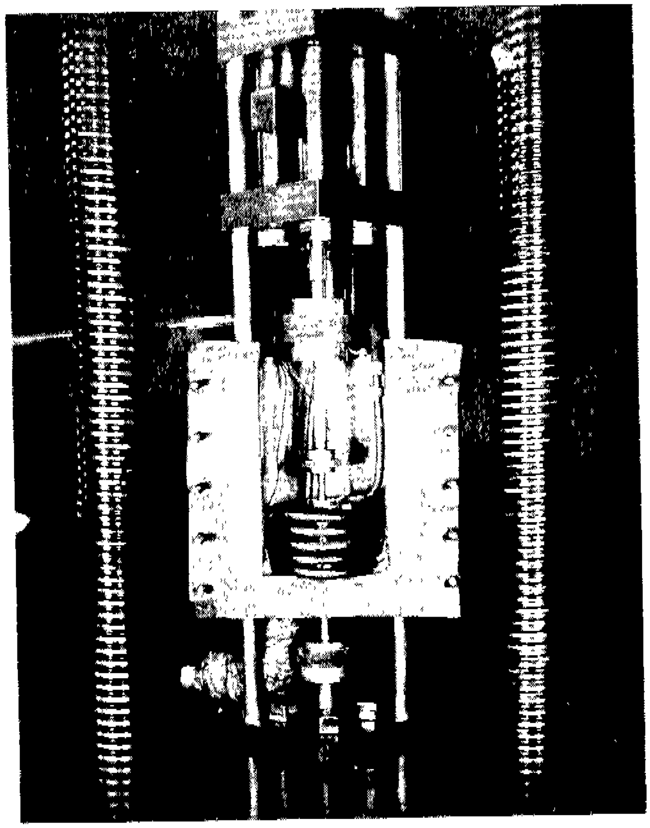


Fig. 7: - CONCENTRIC FIXTURE SHOWING UNNOTCHED TENSILE SPECIMEN IN POSITION FOR LOW TEMPERATURE TESTING.

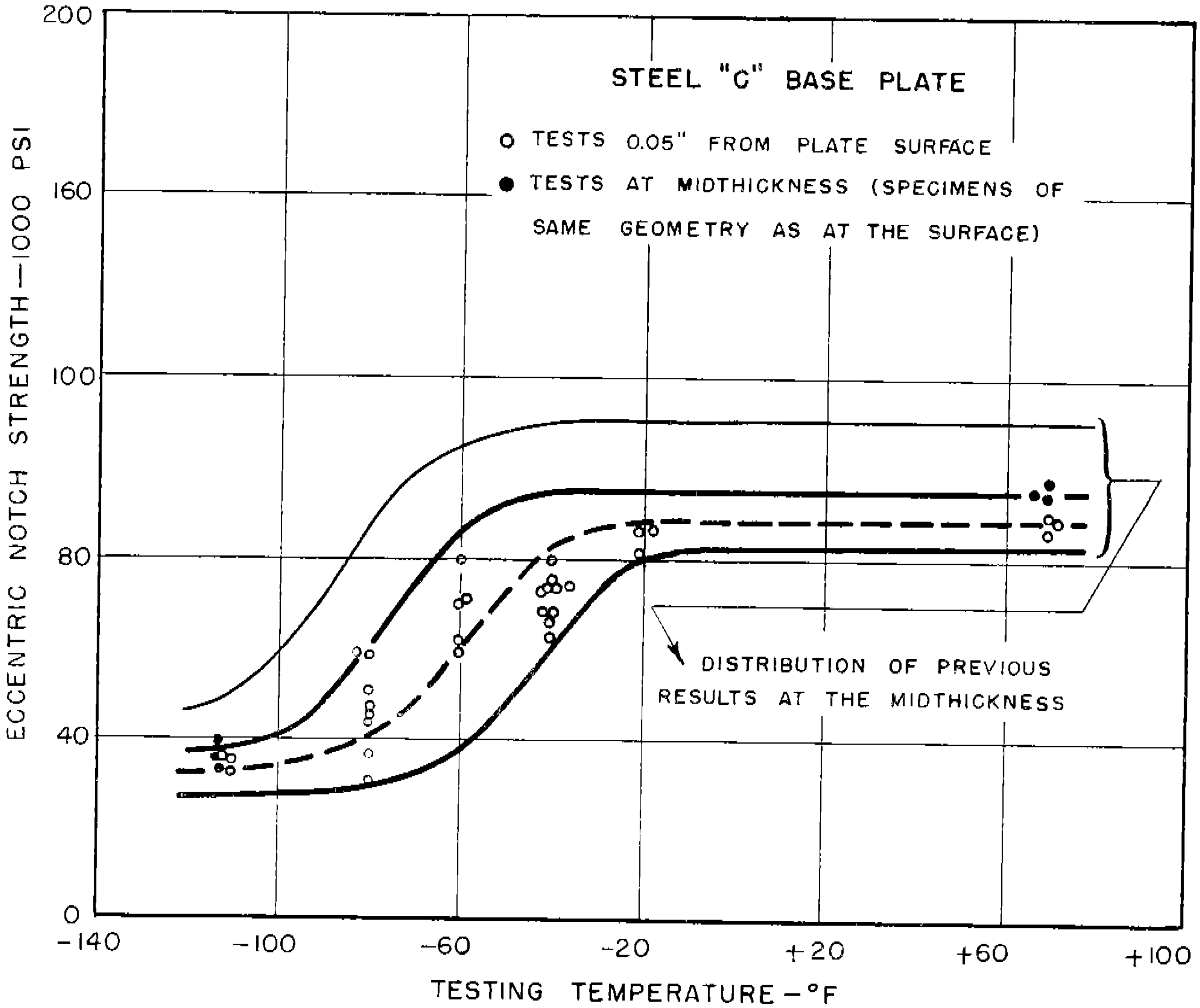


FIG. 8: ECCENTRIC NOTCH STRENGTH OF THE UNAFFECTED BASE PLATE AS A FUNCTION OF TESTING TEMPERATURE.

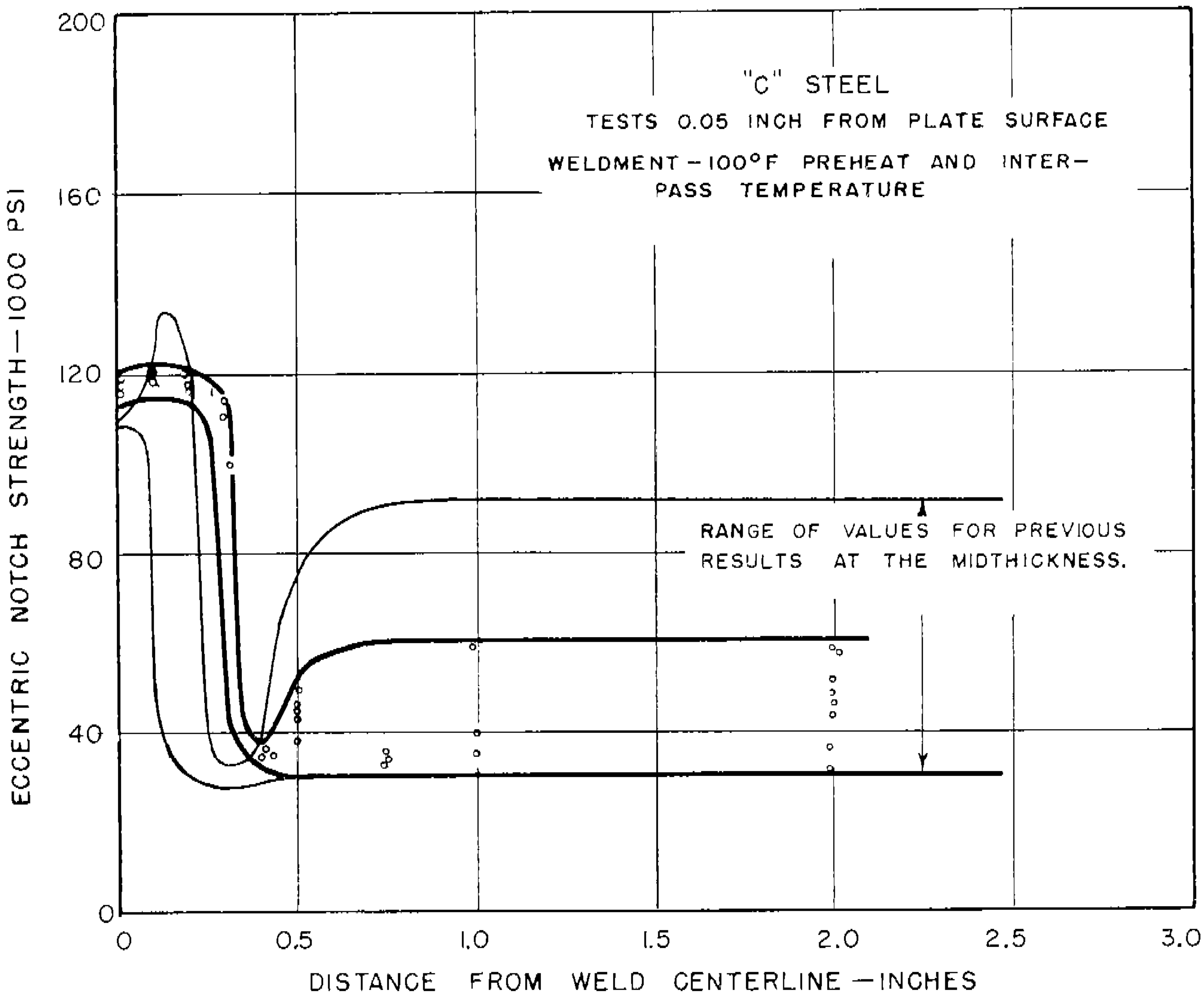


FIG. 9: DISTRIBUTION OF ECCENTRIC NOTCH STRENGTH AT -80°F

for the surface tests appear in Table I of the Appendix.

In Fig. 8 the eccentric notch strength values for the unaffected base plate * are shown as a function of testing temperature. All of the surface results fall in the lower two-thirds of the midthickness distribution, indicating that the high values have been lowered. Consequently, the transition temperature** at the surface (-60°F) is slightly higher than at the midthickness (-65°F).

In order to check the possibility that the specimen geometry was the cause of the lowered values, a number of specimens from the midthickness of the plate, but with the same geometry as at the surface, were tested at -110°F and room temperature. Slightly higher results (plotted as filled circles in Fig. 8) were obtained, indicating that the lower values obtained at the surface were not the result of specimen geometry but probably due to slight decarburization.

In Fig. 9, the distribution of eccentric notch strength at various distances from the weld centerline is shown for a testing temperature of -80°F. The surface tests show the same general behavior as the

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* Unaffected base plate specimens were taken at a distance of two inches or more from the weld centerline and thus were unaffected by the welding, since the maximum temperature reached in this zone was less than 600°F.

** Transition temperature is here defined as the temperature at the mid-point of the average notch strength curve (dashed line in the figure).

midthickness tests, i.e., a minimum at a location outside the weld area. The minimum at the surface level (0.4 inch from the weld centerline) was shifted approximately 0.1 inch further from the centerline but this is due to the geometry of the double-V weld. The microstructure at the minimum was the same as that found previously at the mid-thickness minimum, and no change in structure was noted between the critical zone and the unaffected base plate.

The same behavior would be expected for the "A" steel at the surface level, based on the similar behavior of A and C steel at the midthickness (2).

Eccentric Notch Tests at Selected Locations in the Weld Metal

In order to investigate the possibility of zones of low ductility in the weld structure, a number of probe tests were conducted at -80°F at selected locations in the weld metal of the same "C" steel weldment. The results are given below in Table III and the positions under test are shown in Fig. 10.

TABLE III

Tests in "Coarse Structure" Weld Metal

Position in Weld Metal	Eccentric Notch Strength, 1000 psi
A. The coarse structure at the junction of the hardness peak from pass 5.	121.3 121.4
B. The Coarse structure at the weld centerline, approximately 0.03 inch from the plate surface	112.9 112.8 113.3
C. The coarse structure of pass 2 at the weld centerline	121.3 123.6

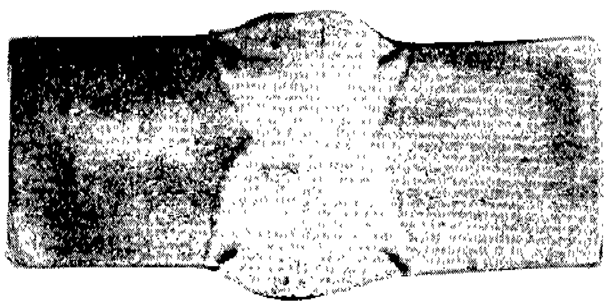

Fig. 10:- TESTS AT SELECTED LOCATIONS IN WELD METAL

At all these positions (and also at the midthickness and surface levels) only high eccentric notch strength values were obtained, which would seem to preclude the existence of zones of low ductility in the weld metal.

Comparison Tests

The use of the eccentric notch tensile test to detect changes in ductility throughout ship plate weldments was based on the results of previous investigations (4) (5) which showed that the eccentric notch strength was dependent upon the concentric notch ductility for heat treated low alloy steel at various strength levels. To confirm this dependency for ship plate steel, concentric and eccentric notch tensile tests at various low temperatures were made at the midthickness level of an A steel weldment (100°F preheat and interpass temperature). Unnotched tensile tests were also made on the same weldment to determine whether this test could be made sufficiently severe, by the use of very low temperatures, to detect ductility variations in ship plate steel.

The data are given in Tables II - IV in the Appendix.

Unaffected Base Plate - In Fig. 11 the distribution of the concentric notch strength and concentric notch ductility of unaffected base plate is shown as a function of the testing temperature. For comparison purposes the results of the eccentric notch tests, previously reported (2) are also shown.

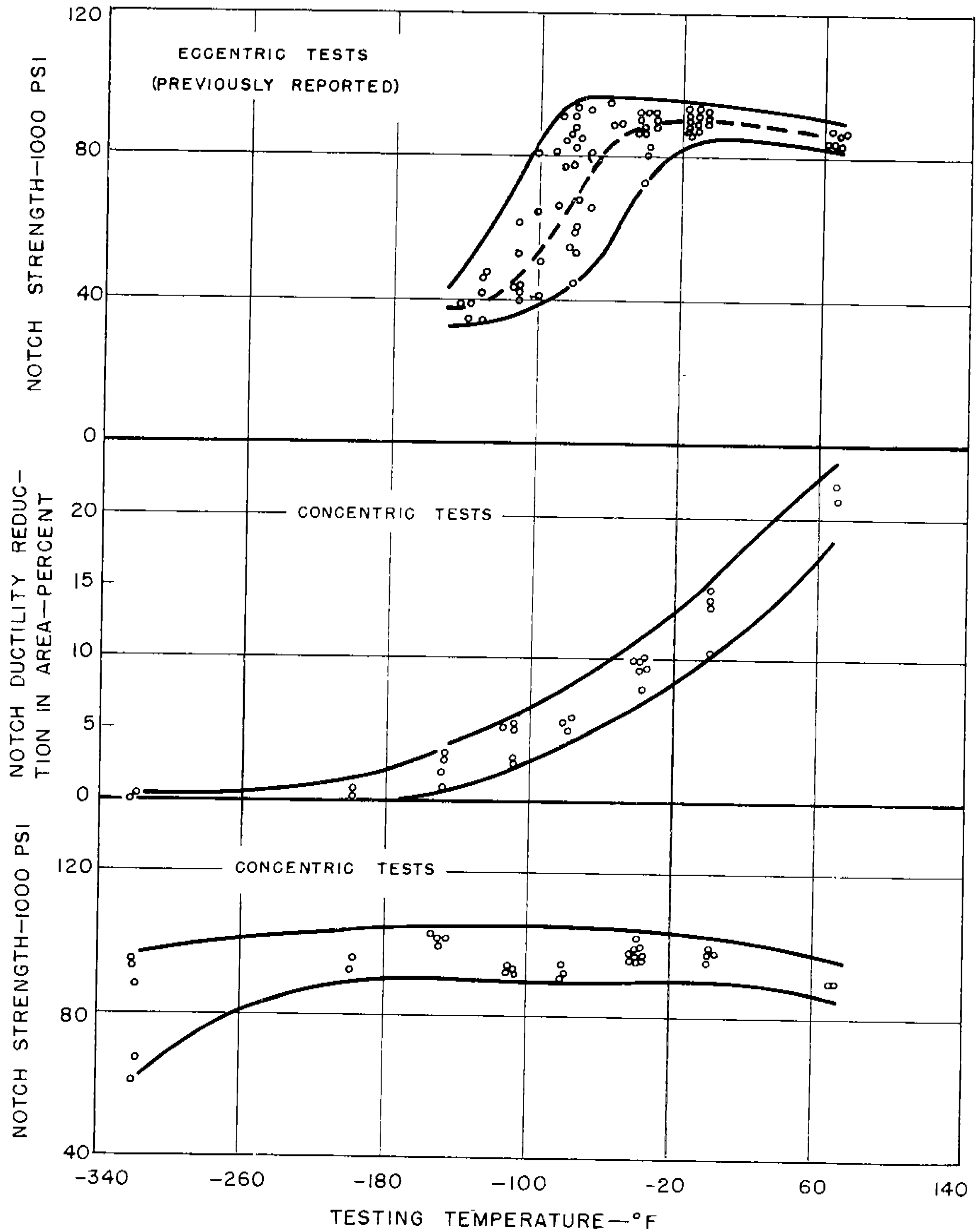

FIG. 11: COMPARISON OF THE ECCENTRIC AND CONCENTRIC NOTCH PROPERTIES AS A FUNCTION OF TESTING TEMPERATURE. MIDTHICKNESS TESTS OF "A" STEEL BASE PLATE.

It can be seen in Fig. 11 that the eccentric notch results define a relatively narrow temperature range in which the strength values decrease rapidly with decreasing temperature. The concentric notch strength values, however, are relatively constant over this same temperature range, and only at -321°F is there a decrease in notch strength. Thus, the ductile-brittle type of behavior or transition curve is not defined by the concentric notch strength, at least down to -321°F. On the other hand, the concentric notch ductility (per cent reduction in area at the root of the notch) decreases continuously with decreasing temperature, but with no definite upper level as in the eccentric notch strength distribution.

A closer examination of these curves shows that the concentric notch strength appears to be dependent upon the ductility at low values. Specimens strained over, say two per cent, have lost their high initial stress concentration, which was one of the embrittling factors, and consequently the concentric notch strength is independent of the ductility. The eccentric notch test, however, extends the dependence of the notch strength upon ductility up to approximately 12 per cent by the addition of another embrittling factor, eccentric loading.

In Fig. 12 the unnotched tensile properties (tensile strength and per cent reduction in area) of unaffected base plate are plotted as a function of testing temperature. The tensile strength increases slowly and continuously with decreasing temperature over the range from room temperature down to liquid nitrogen (-321°F); however, the ductility decreases slowly down to about -150°F, at which point the ductility drops off rapidly to about one per cent at -321°F. These results indicate that for the unaffected base plate the test is not sufficiently severe to define a ductile-brittle type of behavior with the tensile strength as a criterion. The per cent reduction in area does define this type of behaviour but only at very low temperatures.

As-Welded Plate - The distribution of the concentric notch properties at various distances from the weld centerline at testing temperatures of -40°F and -110°F are shown in Fig. 13. For comparison purposes the eccentric notch properties at -70°F* and at -110°F are also shown. The concentric notch ductility shows up the region of low ductility (0.3-0.4 inch from the weld centerline) in the same manner as the eccentric notch strength in spite of the relatively large portion of metal under test. In both cases the minimum became more pronounced as the testing temperature was lowered. In contrast, the concentric notch strength distribution did not define a zone of minimum ductility, even at a testing temperature of -110°F.

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* Previously reported (2).

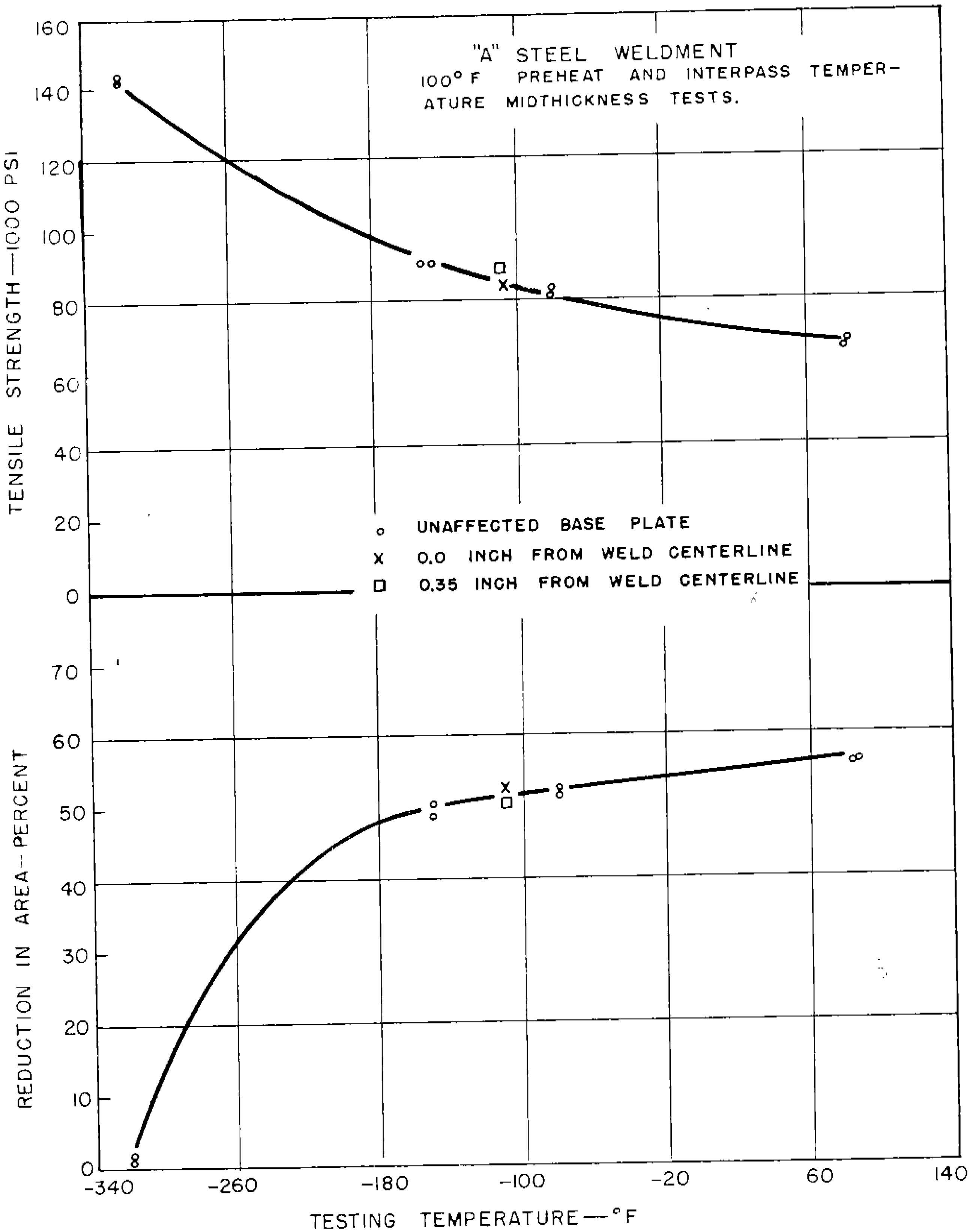

FIG. 12: REGULAR TENSILE PROPERTIES OF "A" STEEL AS A FUNCTION OF TESTING TEMPERATURE.

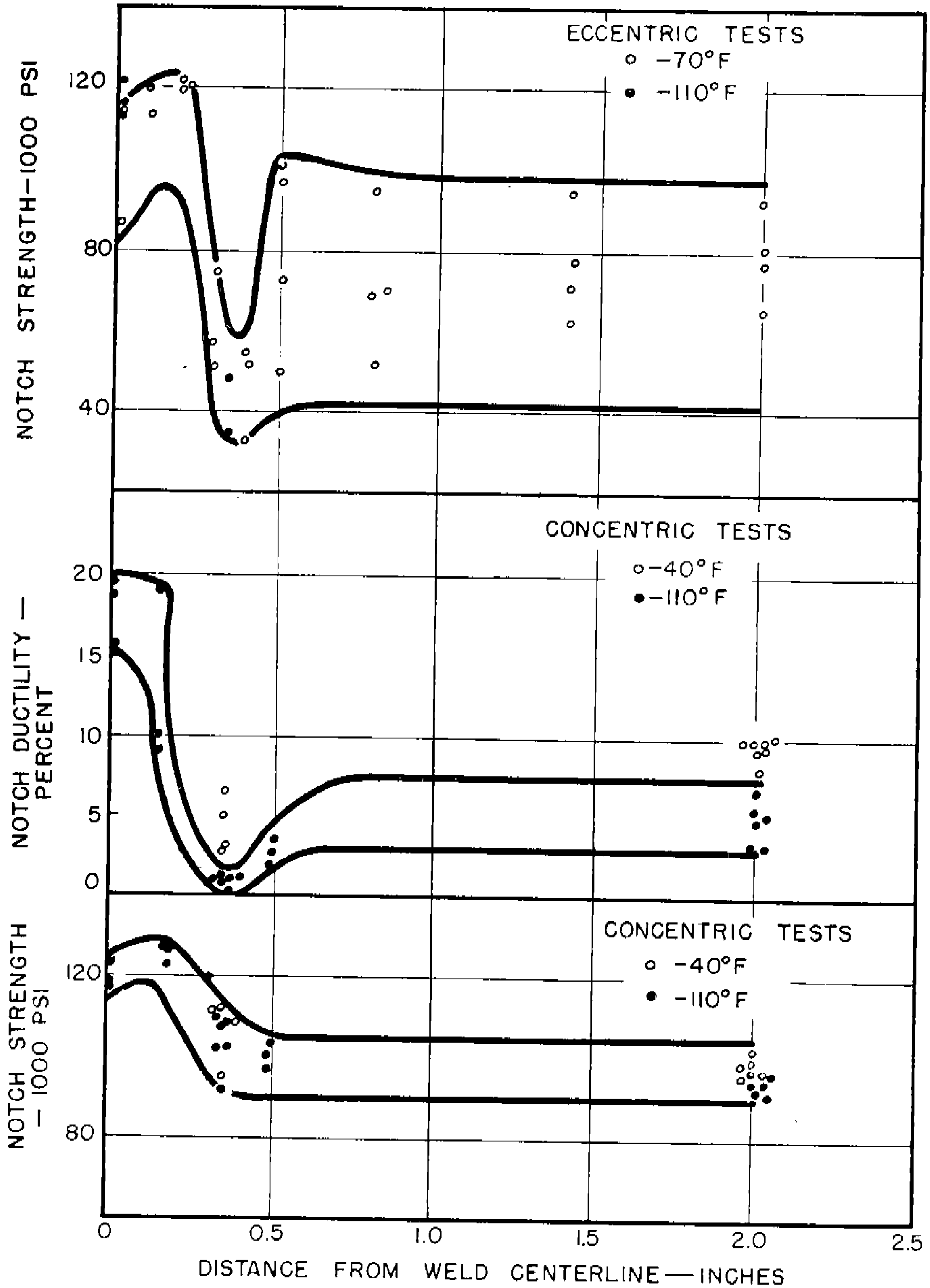

FIG. 13: DISTRIBUTION OF CONCENTRIC AND ECCENTRIC NOTCH PROPERTIES AT VARIOUS LOW TEMPERATURES-MIDTHICKNESS TESTS OF "A" STEEL WELDMENTS, (100°F PREHEAT AND INTERPASS TEMPERATURES)

The unnotched tensile properties at -110°F (average of duplicate tests) at 0.0 and 0.35 inch from the weld centerline are shown in Fig. 12, superimposed on the results of the unaffected base plate. Both the tensile strength and the per cent reduction in area at these positions are about the same as that for the unaffected base plate. From this limited data it would appear that the unnotched tensile test is not severe enough to detect ductility variations in welded plate.

DISCUSSION

The occurrence of the region of highest transition temperature outside the so-called heat affected zone in weldments has been observed by other investigators.

Grossman and Shepler (6) using a notched slow bend test on weldments of 1 inch thick A212 plate found a peak in transition temperature at distances of 1/2 to 1 1/2 inches from the weld centerline, or about 1/4 or 3/4 inch from the edge of the weld. Twelve different welding techniques were used, with E6010, E6020 and HTS Unionmelt electrodes.

A later report by Grossman and MacGregor (7) in which seven low carbon steels were tested with unionmelt joints showed that the transition temperatures determined by the slow bend test passed through a maximum outside the heat affected zone in all cases except for one semi-killed steel which was brittle in the heat affected zone.

Nippes and Savage (8) reproduced in Charpy specimen blanks the exact heating and cooling cycle which occurred during welding at various distances from the weld centerline in arc welds of 1/2 inch aluminum killed steel plate. The results of the impact tests showed that the highest transition temperature was located in a region which was heated to a maximum temperature of only 950°F during the heating and cooling cycle.

These investigation which were conducted on a number of different welding techniques and different test methods show that the results with the eccentric notch test on the A and C steels are not unique.

A number of investigations (9)(10)(11) have been made using bead-on-plate notched slow bend tests. Variations of this test have differed in the specimen dimensions and the depth and shape of the notch. The most work has been done using the so-called "Kinzel" and Lehigh" specimens. In both of these specimens the notch root surface exposes weld metal, heat affected zone, and parent plate.

Transition curves from these tests show an increase in transition temperature over those found for the same specimens without the weld bead. Higher heat input, preheat, and postheat have all been shown to reduce the embrittling effect caused by the laying of the weld bead. Studies of the origin and progress of the cracks leading to fracture have shown that the cracks usually originate either in the weld metal or in the coarse grained structure adjacent to the weld deposit at bend angles of only a few degrees, regardless of the test temperature. It has not been determined whether these first indications of failure are of a ductile or brittle type.

In one investigation (12), the notch in a Lehigh specimen was cut so as to eliminate the coarse grained structure, but the first cracking was found to occur in the structure heated above the critical at the same bend angle as when it started previously in the coarse grained structure, and the transition temperatures were the same for the two types of notch.

In a paper by Fountain and Stout (13) tests were made in which the notch depth was varied so that the structure at the notch bottom under the weld bead varied from weld metal - coarse grained structure - structure heated above the critical - structure heated to the range between 900 - 1200°F (below the critical). Transition curves were made only for the standard notch (which exposes weld metal) and the notch located in the region heated above the critical. In addition, two specimens which were notched in the subcritical region were tested at 0°F. These data along with the two transition curves are shown in Fig. 14. The curve for the notch in the region heated above the critical appears to have a lower transition temperature than the standard notch specimen curve, but the bend angle above the transition temperature is considerably lower than that for the standard notch. However, the two tests which were made with the subcritical region at the notch bottom indicate that a transition curve through these points might fall at a higher temperature than that found for the standard specimen. The somewhat similar impact tests conducted by Schnadt as described by R. Weck (14) also show the subcritically heated region to be more subject to brittle failure. Consequently, if these indications are true, the region which is heated below the critical temperature plays an important role in the behavior of the standard notch bend test on plate specimens even though the cracks which eventually lead to failure may originate in the weld metal or the adjacent coarse grained structure.

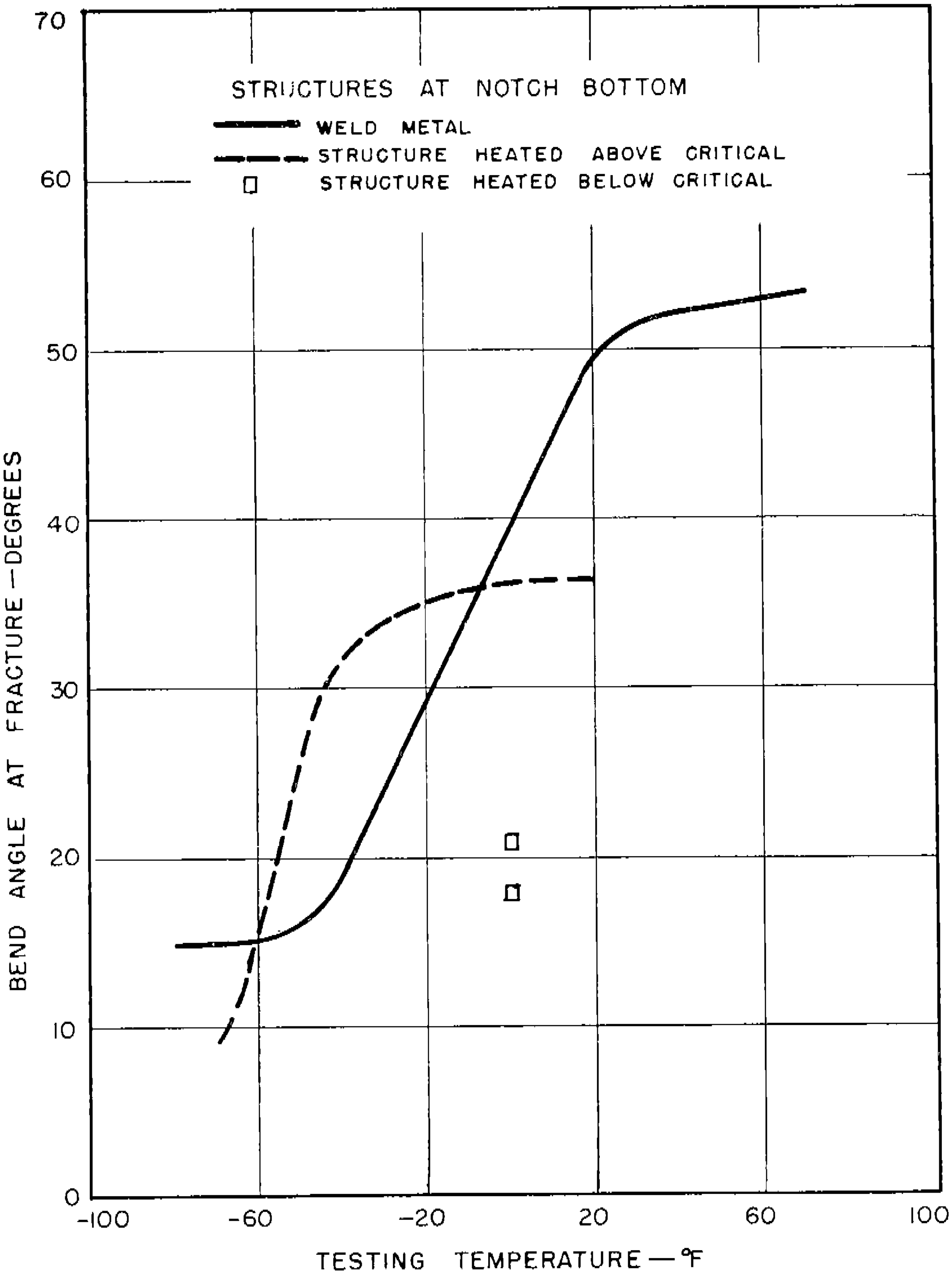

FIG. 14: EFFECT OF TEMPERATURE ON DUCTILITY OF SINGLE BEAD-ON-PLATE SPECIMEN (FOUNTAIN AND STOUT)

CONCLUSIONS

1. At the surface level of a C steel weldment a zone of minimum ductility was located at about 0.4 inch from the weld centerline.

2. The eccentric notch tensile tests at the plate surface showed the same behavior as previous midthickness tests, thus eliminating any difference due to gross inhomogeneity of the plate.

3. The zone of low ductility was also defined by means of concentric notch tensile tests at low temperature.

4. The unnotched tensile test was not sufficiently severe to detect variations in ductility across welded plate.

FUTURE WORK

As one approach to the problem of embrittlement of steel when welded, this laboratory is at present engaged in an investigation in which as-received C steel plate is being subjected to various subcritical isothermal temperatures for varying periods of time and employing various rates of cool. Tests to date have shown that the transition temperature can be raised by this means, even higher than the highest transition temperature previously found in welded plates of C steel. It is hoped that this investigation will give an insight into the basic mechanism which is responsible for the embrittling of steel when welded and suggest possible methods of improving or eliminating this condition.

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APPENDIX

Table I

Eccentric Notch Tensile Data at the Surface Level "C" Steel Weldment 100°F Preheat

Distance from Weld Centerline Inches	Testing Temperature °F	Eccentric Notch Strength 1000 Psi
0.0	-80	116.8
0.0	-80	118.5
0.0	-80	114.3
0.1	-80	121.3
0.1	-80	118.6
0.1	-80	117.3
0.2	-80	118.9
0.2	-80	117.4
0.2	-80	120.9
0.3	-80	110.9
0.3	-80	110.7
0.3	-80	114.5
0.35	-80	100.0
0.4	-80	36.8
0.4	-80	35.3
0.4	-80	37.0
0.5	-80	49.8
0.5	-80	38.7
0.5	-80	43.9
0.5	-80	48.0
0.75	-80	32.6
0.75	-80	35.4
0.75	-80	35.2
1.0	-80	40.2
1.0	-80	35.2
1.0	-80	59.3

TABLE I (Continued)

Distance from Weld Centerline Inches	Testing Temperature °F	Eccentric Notch Strength 1000 Psi
2.0	RT	90.4
2.0	RT	87.3
2.0	RT	89.1
2.0	RT	97.1 *
2.0	RT	96.0 *
2.0	RT	96.6 *
2.0	-40	64.0
2.0	-40	67.3
2.0	-40	68.7
2.0	-40	74.3
2.0	-40	73.7
2.0	-40	73.1
2.0	-40	76.7
2.0	-40	68.1
2.0	-60	70.6
2.0	-60	71.2
2.0	-60	60.0
2.0	-80	51.6
2.0	-80	48.4
2.0	-80	46.8
2.0	-80	37.1
2.0	-80	58.9
2.0	-80	43.8
2.0	-80	58.1
2.0	-80	31.0
2.0	-110	35.7
2.0	-110	36.3
2.0	-110	34.7
2.0	-110	33.5 *
2.0	-110	35.3 *
2.0	-110	40.2 *
4.0	-20	86.7
4.0	-20	87.3
4.0	-20	81.6
4.0	-40	74.3
4.0	-40	80.3
4.0	-60	62.0
4.0	-60	80.1

* Specimens of same geometry but taken from the center of the plate.

TABLE II

Unnotched Tensile Data at the Midthickness
A Steel Weldment 100°F Preheat

Distance from Weld Centerline Inches	Test Temperature °F	Tensile Strength 1000 Psi	Reduction in Area Per Cent
0.0	-110	88.2	43.0
0.0	-110	87.9	63.7
0.35	-110	91.5	48.5
0.35	-110	88.5	53.1
4.0	RT	68.7	56.5
4.0	RT	68.5	56.5
4.0	-80	83.2	52.7
4.0	-80	82.4	52.3
4.0	-150	92.2	50.8
4.0	-150	92.0	49.0
4.0	-321	142.1	1.5
4.0	-321	144.1	1.1

TABLE III

Concentric Notch Tensile Data at the Midthickness
A Steel Weldment 100°F Preheat

Distance from Weld Centerline Inches	Test Temperature °F	Concentric Notch Strength 1000 Psi	Concentric Notch Ductility Red. in Area Per Cent
0.0	-110	119	19.4
0.0	-110	118	15.6
0.0	-110	124	18.5
0.15	-110	128	10.1
0.15	-110	124	9.0
0.15	-110	129	19.2
0.35	-40	112.2	5.1
0.35	-40	109.6	2.8
0.35	-40	112.1	6.7
0.35	-40	94.7	3.0
0.35	-110	108.	1.2
0.35	-110	109.	1.1
0.35	-110	110.	0.8
0.35	-110	102.5	1.05
0.35	-110	102.4	1.28
0.35	-110	92.	0.3
0.5	-110	97.3	1.69
0.5	-110	103.1	3.46
0.5	-110	100.3	2.30
2.0	0	97.7	14.2
2.0	0	96.3	10.4
2.0	-40	99.1	10.2
2.0	-40	97.3	10.1
2.0	-40	96.7	8.1
2.0	-80	94.8	5.4
2.0	-80	92.1	5.6
2.0	-80	91.0	4.9
2.0	-110	93.0	5.4
2.0	-110	92.7	2.8
2.0	-110	92.3	3.2
2.0	-110	90.7	4.98
2.0	-110	94.0	5.23
2.0	-145	102.	3.5
2.0	-150	102.	0.8
2.0	-152	99.4	3.24
2.0	-155	103.8	2.3
2.0	-200	96.0	0.84
2.0	-200	93.4	0.10
2.0	-321	96.3	0.5

TABLE III (Continued)

Distance from Weld Centerline Inches	Test Temperature °F	Concentric Notch Strength 1000 Psi	Concentric Notch Ductility Red. in Area Per Cent
2.0	-321	68.0	0.0
2.0	-321	89.0	-
2.0	-321	62.4	-
2.0	-321	95.	-
4.0	RT	90.3	21.4
4.0	RT	90.2	22.3
4.0	0	99.4	13.9
4.0	-40	103.5	10.0
6.0	0	98.1	15.1
6.0	-40	96.0	10.2
6.0	-40	100.0	9.3
6.0	-40	97.4	9.6

TABLE IV

Eccentric Notch Tensile Data at the Midthickness
A Steel Weldment 100°F Preheat

Distance from Weld Centerline Inches	Test Temperature °F	Eccentric Notch Strength 1000 Psi
0.0	-110	119.1
0.0	-110	116.1
0.0	-110	122.2
0.35	-110	34.4
0.35	-110	47.4