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SERIAL NO. SSC-33

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PROGRESS REPORT

ON

EVALUATION OF IMPROVED MATERIALS AND METHODS OF FABRICATION FOR WELDED STEEL SHIPS

BY

R. W. BENNETT, R. G. KLINE, M. FORMAN,
P. J. RIEPPEL AND C. B. VOLDRICH

Battelle Memorial Institute
Under Bureau of Ships Contract NObs-45543

Transmitted through
NATIONAL RESEARCH COUNCIL'S

COMMITTEE ON SHIP STEEL
Advisory to

SHIP STRUCTURE COMMITTEE
under
Bureau of Ships, Navy Department
Contract NObs-50148

Division of Engineering and Industrial Research
National Research Council
Washington, D. C.
November 15, 1949

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2101 CONSTITUTION AVENUE, WASHINGTON 25, D. C.

COMMITTEE ON SHIP STEEL

November 15, 1949

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Dear Sir:

Attached is Report Serial No. SSC-33 entitled "Evaluation of Improved Materials and Methods of Fabrication for Welded Steel Ships." This report has been submitted by the contractor as a Progress Report of the work done on Research Project SR-100 under Contract NObs-45543 between the Bureau of Ships, Navy Department and Battelle Memorial Institute.

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, Navy Department and the National Academy of Sciences.

Very truly yours,

RFM:mh

R. F. Mehl, Chairman
Committee on Ship Steel

PREFACE

The Navy Department through the Bureau of Ships is distributing this report for the SHIP STRUCTURE COMMITTEE to those agencies and individuals who were actively associated with the research work. This report presents results of part of the research program conducted under the Ship Structure Committee's directive "to investigate the design and methods of construction of welded steel merchant vessels."

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PROGRESS REPORT

on

CONTRACT NObs-45543

EVALUATION OF IMPROVED MATERIALS AND METHODS OF FABRICATION FOR WELDED STEEL SHIPS

to

Bureau of Ships,
Navy Department

by

R. W. Bennett, R. G. Kline, M. Forman,
P. J. Rieppel, and C. B. Voldrich

BATTELLE MEMORIAL INSTITUTE

TABLE OF CONTENTS

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ABSTRACT

This report covers work done during the period February 1, 1948, to December 30, 1948.

During the early part of this investigation, a survey was made of published and unpublished reports to appraise the various kinds of tests used to study strength, ductility, and transition temperatures of welded joints in structural steels. On the basis of this survey, the Project Advisory Committee selected the tee-bend test, the longitudinally welded and transversely notched bead-bend tests (Kinzel and Lehigh types), and the transversely welded and transversely notched bead-bend tests (Naval Research Laboratory high constraint and Jackson types). The "B_r" and "C" steels which were known to be different in behavior were to be used in studies of these tests. The results were to be compared with those obtained from the hatch-corner tests made at the University of California on the same steels. It was thought by the Committee that, should one of these small-scale

tests give the same transition temperatures for "B_r" and "C" steels as were obtained with the hatch-corner tests with these steels, then the test would be worthy of further study as a possible acceptance test of steels for ship plate.

In work described by the first report (172)*, the transition temperatures of unwelded and welded "B_r" and "C" steels were obtained by using the various specimens mentioned above. Transition temperatures were obtained for these steels which were both above and below those obtained from the hatch-corner tests; however, those obtained by the Kinzel-type and tee-bend specimens were closer to the hatch-corner transition temperatures than those obtained by other specimens.

On the basis of these results, the Project Advisory Committee recommended that further studies with various modifications of the Kinzel-type and tee-bend specimens be conducted in an attempt to match the hatch-corner test of the "B_r" and "C" steels with a small-scale test. Also, it was decided to make transition-temperature tests with the two steels using notched tension specimens.

The modifications of the Kinzel-type specimen used were: (a) E6020 electrodes were used instead of E6010; (b) specimens 1-1/2 and 6 inches wide were used instead of the standard 3-inch wide specimen; and (c) a notch depth of 0.090 inch was used instead of standard 0.050-inch notch. The change in weld metal had little effect upon the transition temperature. The 6-inch specimens and the standard 3-inch specimens gave the same transition temperature, but the 1-1/2-inch specimen had a transition temperature about 40 F lower for the "B_r" steel than was obtained by standard specimens. The increase in notch depth to 0.090 inch raised the transition temperature for the "B_r" steel about 60 F, but had little influence on the transition temperature of the "C" steel. In addition to being deeper than standard, the 0.090-inch notch left very little or no weld metal at the root of the notch.

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* See bibliography

Modifications of the tee-bend specimen used were: (a) modification of welding procedure, and (b) modification of specimen width. The modification of welding procedure did not change the transition temperature from that obtained with standard specimens. The increase in width of specimen from 1-7/8 inches to 3 inches raised the transition temperatures of both the "B_r" and "C" steels. For the "B_r" steel, it was raised about 20F, and for the "C" steel, it was raised about 60F.

Tests with the modified Kinzel-type and tee-bend specimens showed, generally, that the transition temperature of a single steel could be shifted up or down by modifications of the specimen. However, the "B_r" and "C" steels were usually not influenced in the same way or to the same degree by any given modification. Therefore, if the hatch-corner transition temperature of "B_r" steel, for example, should be matched by a certain modification of the Kinzel-type or tee-bend specimens, there would be no assurance that the hatch-corner transition temperature of "C" steel or any other steel would be duplicated by the same test specimen. On the basis of these results, it seems doubtful that specimens such as the Kinzel-type and tee-bend would be of much value in predicting the transition temperature of large weldments such as a hatch corner made of various types of steel.

Tests made with notched tension specimens differentiated between "B_r" and "C" steel in about the same manner that all other tests have. The transition temperatures obtained for the two steels were considerably below those obtained by the hatch-corner tests. This type of test specimen did not have any distinct advantages, for this work, over the bend-test specimens used previously, except, perhaps, that it gave sharper transitions.

A study of the all-weld-metal specimens (Kinzel-type) showed that E6010 and E6020 weld metal have a much lower transition temperature when tested alone than when tested as in a standard Kinzel-type (bead on plate) specimen.

A few preliminary studies of fracture initiation in welded bend specimens showed that fracture started in the weld area at a little above the yield point of the specimen and usually far below the maximum load. Further studies along this line are being conducted.

INTRODUCTION

This is the second progress report on the investigation entitled, "Evaluation of Improved Materials and Methods of Fabrications for Welded Steel Ships", being conducted for the Ship Structure Committtee, under Navy Department, Bureau of Ships, Contract NObs-45543 (Project SR-100).

The principal objective of this project is to evaluate the usefulness of various mechanical tests of small welded steel specimens for indicating the performance of large welded structures. Another objective is to study fundamental factors contributing to the performance of such welded laboratory specimens.

The first progress report on this project contained a summary of a survey of published and unpublished reports which was made to appraise the various kinds of tests used to study strength, ductility, and transition temperature of welded joints in structural steels. Also, the details of the test specimens selected for use in studying the properties of project steels*, the welding and testing procedures used, and results obtained from the initial phases of the experimental work were described.

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* The various heats of steel used in the investigation, sponsored by the Ship Structure Committee, have been designated alphabetically and are termed "project steels".

This report covers tests made on the project steels using various modifications of the test specimens employed in the work described by the first progress report and with notched tension specimens. It was the object of these modifications to obtain the same transition temperatures for the project steels ("B_r" and "C") that were obtained from the full-scale hatch-corner test specimens studied at the University of California(143). Other tests of all-weld-metal specimens and specimens welded with E6020 electrodes are included. A few preliminary observations on the initiation of fracture in the test specimens used are described.

A bibliography of all literature studied up to December 30, 1948, which pertains to the subject of this investigation is included in the Appendix. However, the first progress report, dated March 30, 1949, is also listed.

MATERIALS

Two semi-killed, as-rolled, medium-carbon ship steels, designated as "B_r" and "C", were used in this phase of the investigation. These steels were selected for this work because they previously exhibited differing properties when used in the full-scale hatch-corner and other tests to determine their mechanical properties. A supply of the two steels, 3/4 inch thick, was received from the University of California. The mechanical properties and chemical compositions of these steels are as follows:

Steel Code Letter	Type of Steel	Steel Condition	Mechanical Properties (1)(2)				Red. in Area, %	Hardness Rockwell B
			Yield Point, psi	Ultimate Strength, psi	Elongation			
					in 2 In., %	in 8 In., %		
B_r	Semikilled	As rolled	32,200 - 34,600	55,600 - 58,600	46-42	35-33	71-58	58-63
C	Semikilled	As rolled	34,500 - 37,600	61,500 - 68,500	43-25	32-28	63-50	66-69

Steel Code Letter	Chemical Composition, Per Cent(1)											
	C	Mn	Si	P	S	Cr	Ni	Mo	Cu	Al	Sn	N
B_r	0.18	0.73	0.07	0.008	0.030	0.03	0.05	0.006	0.07	0.015	0.012	0.005
C	0.24	0.43	0.05	0.012	0.026	0.03	0.02	0.005	0.03	0.016	0.003	0.009

(1) Boodberg, A., H. E. Davis, E. R. Parker, and G. E. Troxell, "Causes of Cleavage Fracture in Ship Plate - Tests of Wide Notched Plates", Welding Journal, April 1948.

(2) The data for the mechanical properties are the lowest and highest values obtained for each steel.

Electrodes

The electrodes used throughout this phase of the investigation were 3/16-inch-diameter Class E6010 and E6020 electrodes. The welding schedules used for the various tests will be discussed later in this report.

DEFINITION AND INTERPRETATION OF TRANSITION TEMPERATURE

The term "transition temperature" has been broadly used to mean that temperature at which the behavior of a given material, in the shape of a specific test specimen, changes from ductile to brittle behavior. Since, in most cases, this change in behavior occurs gradually over a temperature range, it is not possible to assign a specific temperature to represent the change, except by using an arbitrary definition. The use of different criteria for determining the transition temperature influences the actual numerical transition temperature obtained for a material and a given specimen design. Also, in using a certain criterion, different methods can be used to locate the transition temperature. Because each criterion represents a different aspect of the behavior of a specimen, no single standard criterion has been chosen for universal use in determining transition temperature.

The most commonly used criteria used in the determination of the transition temperature are listed as follows:

1. Energy absorbed by specimen.
    a. Energy absorbed to maximum load.
    b. Energy absorbed after maximum load.
    c. Total absorbed energy.
2. Bend angle of specimen.
    a. Bend angle at maximum load.
    b. Bend angle after maximum load.
    c. Total bend angle.

3. Lateral contraction of specimen at root of notch.

4. Fracture appearance.

Some definitions commonly used for "transition temperature" follows:

Type 1. The highest temperature at which the first significant decrease occurs in the measurements of absorbed energy, bend angle, lateral contraction, etc., obtained by testing a series of specimens of a given design and material at various temperatures.

Type 2. The temperature on the average curve at the midpoint between the upper and lower limits of the curve.

Type 3. The temperature coordinate of the point on a transition-temperature curve which represents half of the maximum value of the curve.

Type 4. The temperature at which the fracture changes from a fibrous ductile to a bright crystalline (brittle) structure.

Figures 1 through 4 illustrate the variations in transition temperature that are obtained when the same data are analyzed on the basis of the various definitions of transition temperature given above.

The transition temperature determined from the curve in Figure 1 ranges from -90F to 20 F depending upon which definition is used. The Type 1 transition could not be accurately located because the limited number of tests did not properly establish the scatter in the plotted data that indicate the beginning of the ductile-to-brittle transition of a material.

The bend angle (at maximum load) vs. temperature curve of "B_r" steel for unwelded Kinzel specimens, shown in Figure 2, shows the same general variations in transition temperature when different definitions are used. Depending on the definition, the transition temperatures vary from -75 F to 20 F. Although the accuracy of the Type 1 transition is restricted by the small amount of test data, it can be reasonably located at 20 F.

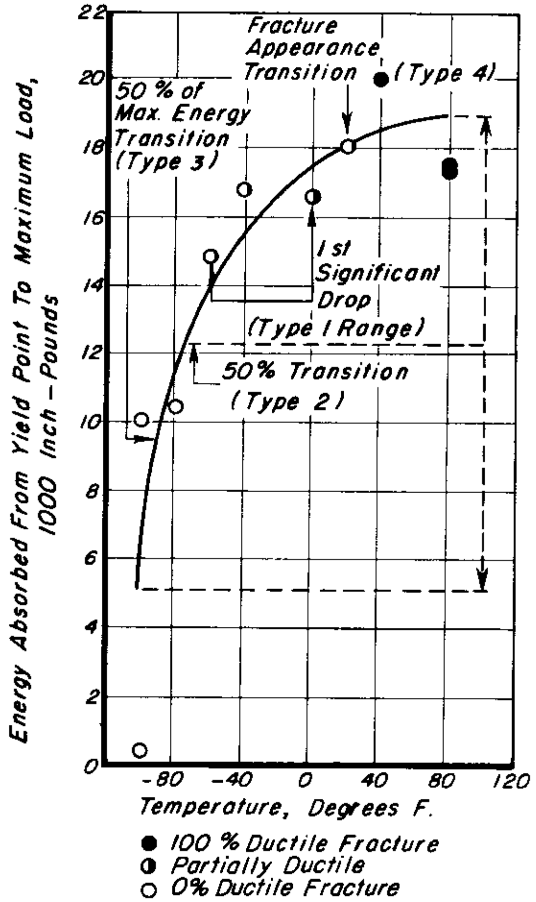

FIGURE I. LOCATION OF TRANSITION TEMPERATURE FOR UNWELDED KINZEL-TYPE SPECIMENS OF "Br" STEEL DETERMINED BY VARIOUS METHODS AND USING ABSORBED ENERGY AS THE CRITERION

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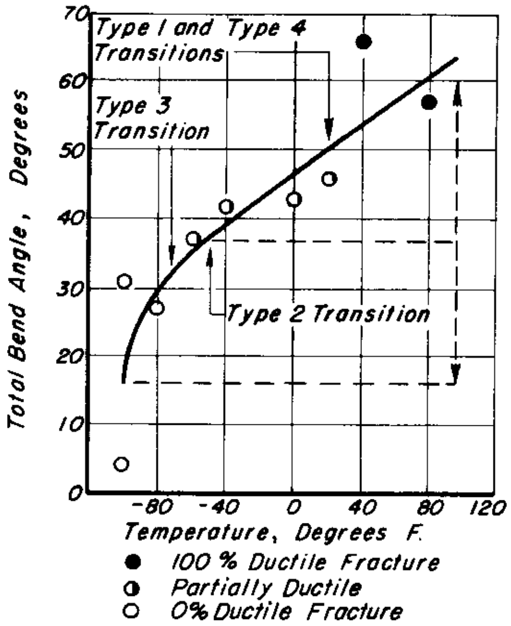

FIGURE 2. LOCATION OF TRANSITION TEMPERATURE FOR UNWELDED KINZEL-TYPE SPECIMENS OF "Br" STEEL DETERMINED BY VARIOUS METHODS AND USING BEND ANGLE AS THE CRITERION

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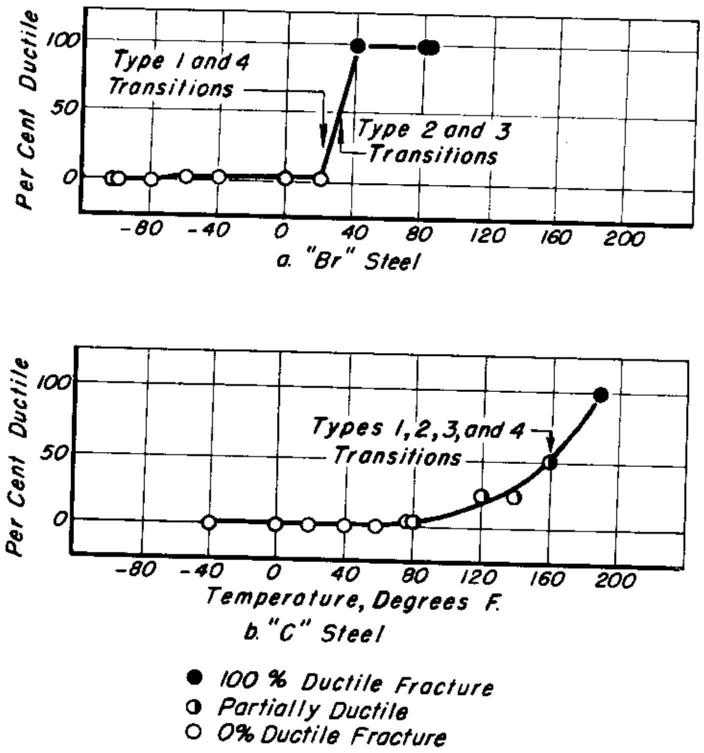

FIGURE 3. TRANSITION TEMPERATURES OF UNWELDED KINZEL-TYPE SPECIMENS OF "Br" and "C" STEEL DETERMINED BY VARIOUS METHODS AND USING FRACTURE APPEARANCE AS THE CRITERION

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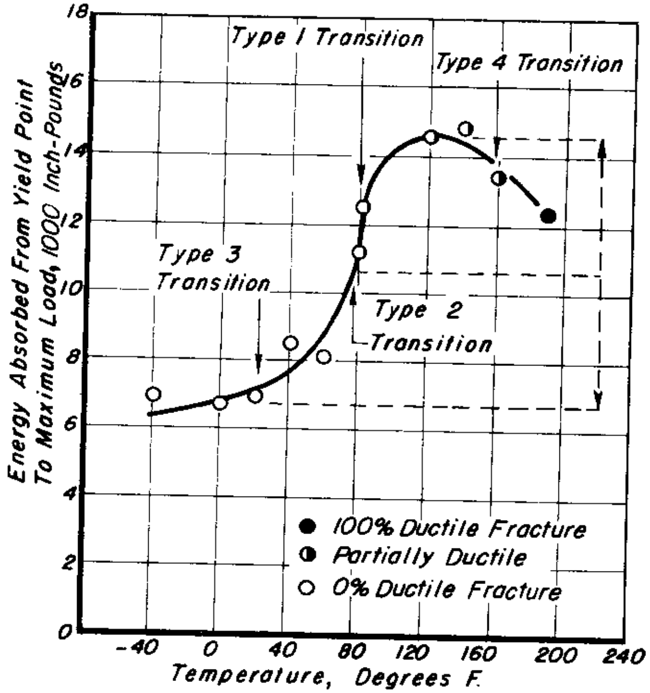

FIGURE 4. LOCATION OF TRANSITION TEMPERATURE OF UNWELDED KINZEL-TYPE SPECIMENS OF "C" STEEL DETERMINED BY VARIOUS METHODS AND USING ABSORBED ENERGY AS THE CRITERION

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The transition range shown by the curve in Figure 3, which was based on fracture appearance vs. temperature for the same type specimen and steel, was considerably narrower than those shown by the curves in Figures 1 and 2, which were established on the basis of absorbed energy and bend angle. From a practical standpoint, however, the transition temperature from the curves in Figure 3 would be the same regardless of the method used for determining it.

Figure 4 shows an absorbed energy vs. temperature curve for unwelded Kinzel specimens of "C" steel. In this particular case, the Type 1 and Type 2 transition temperatures coincide. The transition temperature determined by fracture appearance (Type 4) is quite different from those obtained by other methods of establishing transition temperature. This indicates that transition temperature determined by fracture appearance alone may be misleading. It is significant, however, that the fracture-appearance (Type 4) transition temperature is usually higher than that obtained by the other methods. The transition temperature of the fracture appearance vs. temperature curve for the unwelded "C" steel is the same when determined by all methods, as shown by Figure 3 (b).

In light of the above discussion, the transition temperature by Type 1 definition is used as extensively as possible throughout this report for consistency. The Type 2 and Type 4 transitions are used when supplementary data are required for correlation with other tests. Type 3 transition is not used in the report.

INFLUENCE OF SPECIMEN DETAILS AND PREPARATION ON TRANSITION TEMPERATURE OF "B_r" AND "C" STEELS

In the first progress report (172), the transition temperatures of "B_r" and "C" ship plate for several laboratory-size specimens were compared with results of the hatch-corner tests made at the University of California, as shown in Figure 5. The tests of welded and unwelded specimens rated the two steels in

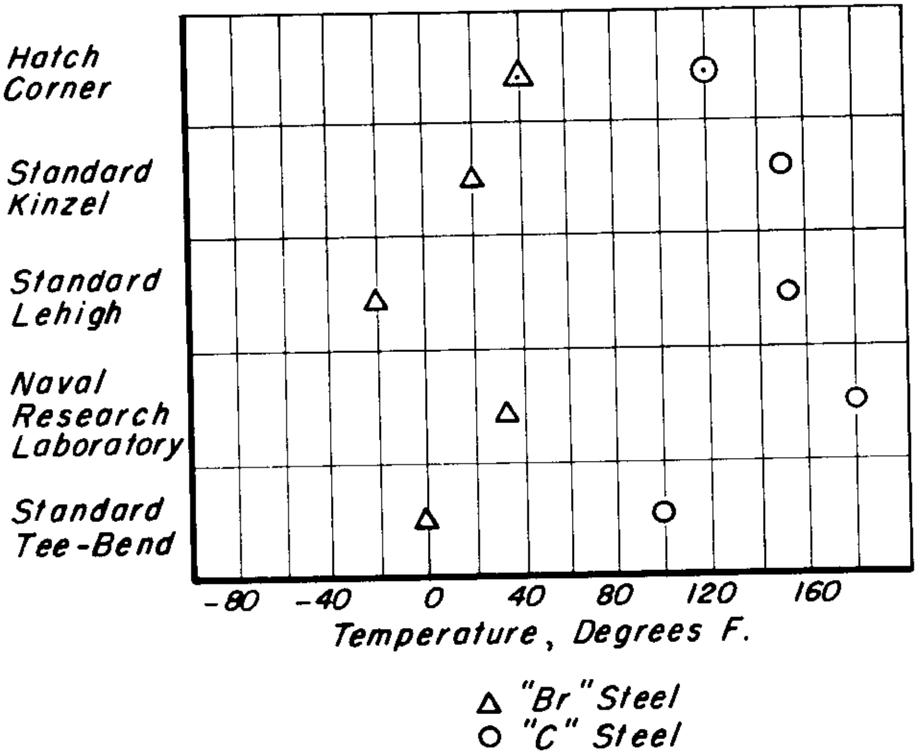


FIGURE 5. TRANSITION TEMPERATURES OF NOTCHED-BEAD BEND SPECIMENS, TEE-BEND SPECIMENS, AND HATCH-CORNER WELDMENTS OF "Br" AND "C" STEELS ON THE BASIS OF TOTAL ABSORBED ENERGY (TYPE I TRANSITION)

the same qualitative order as the hatch corners, i.e., the "B_r" steel had a lower transition temperature than the "C" steel. On the basis of the results from these tests, the Project Advisory Committee asked that further studies be made of various modifications of longitudinally welded and transversely notched bead-bend (Kinzel or Lehigh) and tee-bend specimens of "B_r" and "C" steels in an attempt to find a small specimen to match the transition temperatures of hatch-corner weldments made with the same steels.

The Kinzel specimen was chosen for further study, because the transition temperature for the "B_r" steel obtained with it, as shown by Figure 5, was closer to the hatch-corner transition temperature for "B_r" steel than that obtained by the Lehigh specimen. Furthermore, the weld on the Kinzel specimen was deposited under normal conditions that produced a larger and more typical weld with slightly deeper penetration than the weld on the Lehigh spcimen. For the "C" steel, however, the transition temperatures determined by the Kinzel and Lehigh specimens were the same and, thus, did not influence the specimen choice.

The immediate objective, then, was to modify the Kinzel specimen in an attempt to raise the transition temperature of the "B_r" steel from 20 F to 40 F, and lower the "C" steel transition temperature from 150 F to 120 F.

The tee-bend specimen was also chosen for further work because the transition temperatures for the "B_r" and "C" steels obtained with them were both lower than the respective hatch-corner transition temperatures, as shown by Figure 5. Thus, it seemed feasible that a modification of this type of specimen could be made so that the hatch-corner transition temperatures could be duplicated.

Transition-Temperature Studies With Modified Kinzel-Type Specimens

Various modifications of the Kinzel-type specimen were used in attempts to find conditions by which transition temperatures obtained from the hatch-corner tests could be duplicated with this type of test specimen. The modifications were in the type of weld metal used, width of specimen, and depth of notch. The details of the modifications in the welding procedure and the specimen design, and their influence on the transition temperature of "B_r" and "C" steels are discussed in following sections of the report.

Preparation of Specimens

The coupons for the test specimens were saw cut from the plates of "B_r" and "C" steel and the surface was cleaned by grit blasting.

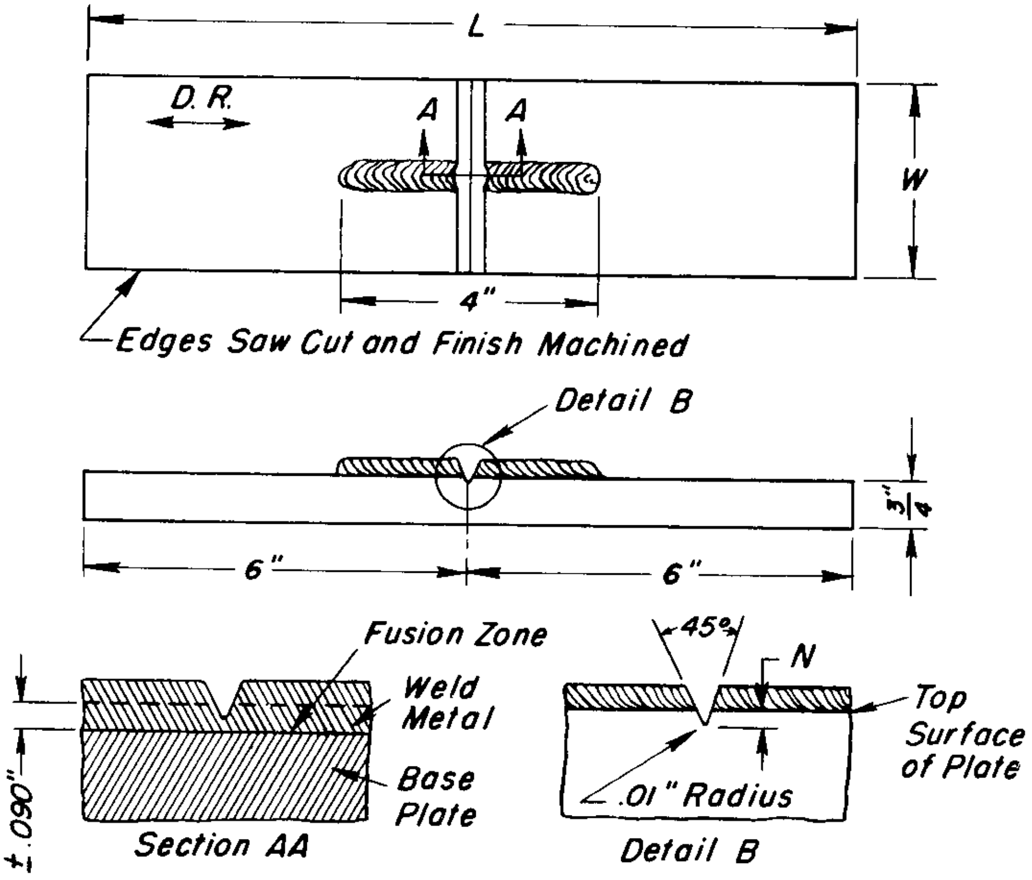
The weld beads were deposited on the coupons by automatic welding using 3/16-inch-diameter E6010 or E6020 electrodes. All of the specimens were welded at room temperature and cooled in air. The aging time for all specimens between welding and testing was eight days at room temperature.

During the aging period, the finishing machining of the specimens was done according to the sketch shown in Figure 6.

Testing Procedure

A mixture of alcohol and dry ice was used to obtain testing temperatures down to -90F. Lower temperatures were attained by cooling methyl cyclohexane with liquid nitrogen introduced through a heat exchanger coiled around the inside and bottom of the tank containing the test specimen and bending jig. Temperatures above 80 F were obtained by heating a water or oil bath with resistance immersion heaters.

The load was applied to the bend specimens at a rate of one inch per minute, free displacement of the platen. Load-deflection curves, lateral contraction measurements, and fracture appearance appraisals were made for all specimens.



Design	Length, L	Width, W	Notch Depth, N
A*	12	3	.050"
B	12	1½	.050"
C	12	6	.050"
D	12	3	.090"

*Standard Kinzel Design

FIGURE 6. BEND SPECIMEN WITH LONGITUDINAL WELD BEAD AND TRANSVERSE NOTCH (BASIC KINZEL DESIGN)

The various tests and summary of the results from each series are discussed in the following sections.

Influence of Weld Metal on Transition Temperature

A series of standard Kinzel-type specimens, as shown by Design A, Figure 6, was made using E6020 electrodes, to determine if the transition temperature would be changed from that obtained when E6010 electrodes were used. The data from standard Kinzel specimens welded with E6010 electrodes and those from unwelded Kinzel-type specimens were reported previously (172). These data are repeated in this report for comparison with those obtained from specimens welded with E6020 electrodes.

The welding schedule used for the previous series of specimens welded with E6010 electrodes and that used for specimens welded with E6020 are shown below for comparison:

	E6010	E6020
Electrode diameter - in.	3/16	3/16
Amperes	175	198
Arc voltage	27	33
Speed - in./min	6	8-1/4
Arc time - seconds	40	29
Length of weld bead - in.	4	4
Heat input - joules/in.	44,750	44,750

As shown by the above table, the heat input per inch of deposited weld metal was made the same for specimens welded with the two types of electrodes. This variable was controlled closely so that transition-temperature changes could be attributed to differences in type of weld metal.

The transition temperatures of unwelded Kinzel specimens of "B_r" steel, the standard Kinzel specimens of "B_r" steel welded with E6010, and those welded with E6020 electrodes are shown in Figure 7. The detailed data from these tests and those used for comparison are given in

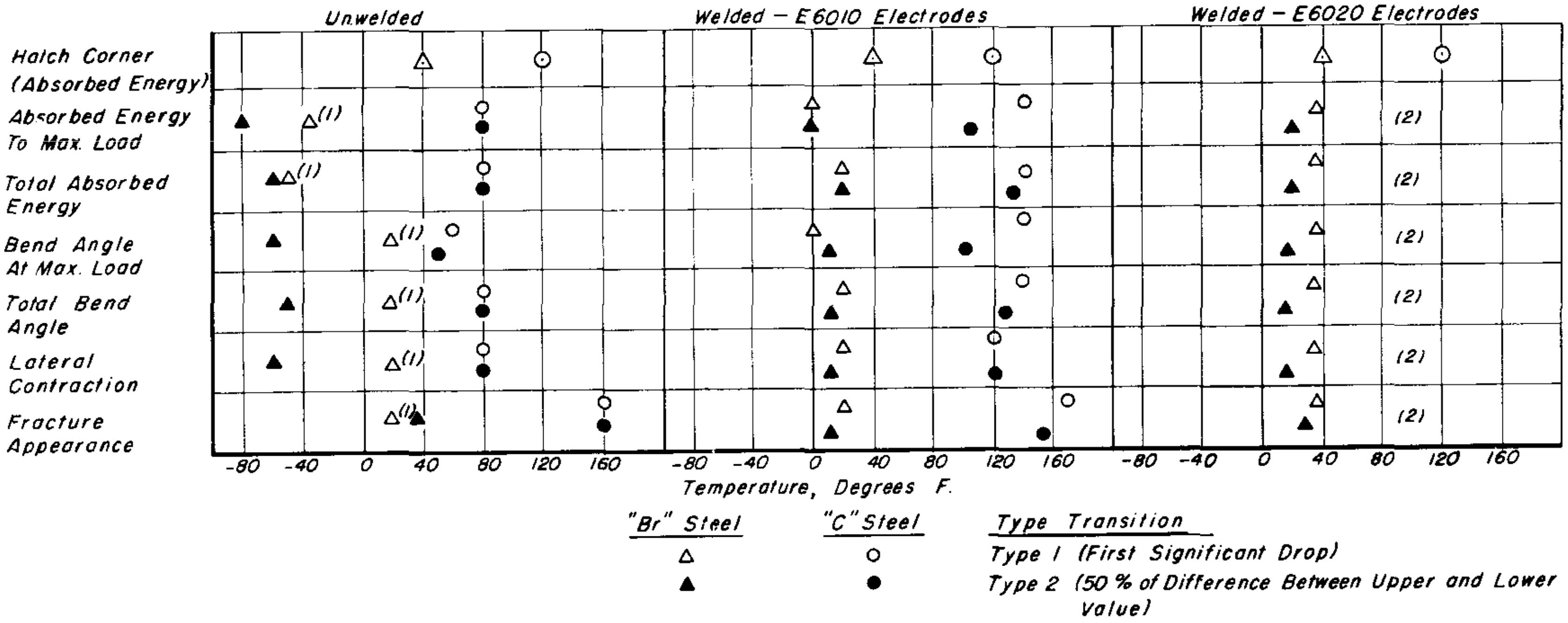


FIGURE 7. TRANSITION TEMPERATURES (TYPES 1 and 2) OF "Br" and "C" STEELS DETERMINED BY STANDARD KINZEL-TYPE SPECIMENS, UNWELDED AND WELDED WITH E6010 AND E6020 ("Br" STEEL ONLY) ELECTRODES, USING VARIOUS CRITERIA. (HATCH-CORNER TRANSITION TEMPERATURES SHOWN FOR COMPARISON)

(1) Type I Transition Is Considered to be not Very Reliable

(2) "C" Steel Was Not Tested

Appendix A, Tables A-1, A-3, and A-5, and are compared in Appendix B, Figures B-1A and B-1B. In general, the transition temperature for "B_r" steel specimens having E6020 weld beads was about 10 to 20 F higher than for specimens having E6010 weld beads. This difference was so small that it was not considered significant.

Tests were not made with "C" steel because only a small influence of E6020 weld metal on the transition temperature of "B_r" steel was noted, and the stock of "C" steel was limited.

From Figure 7 and Appendix B, Figures B-1A and B-1B, it is apparent that the transition temperatures for unwelded "B_r" steel are considerably lower than for the specimens welded with E6010 and E6020 electrodes. Type 1 and Type 2 transitions are shown for unwelded "B_r" specimens, but Type 1 transition is not considered very reliable because the curves show no sharp drop off in absorbed energy. Figures B-1A and B-1B also show that the amount of absorbed energy and the ductility (bend angle and lateral contraction) are considerably higher for the unwelded specimens than for both series of welded specimens. However, the transition temperatures of the unwelded and welded specimens on the basis of fracture appearance were higher than by any other criteria. This further confirms the statement made at the bottom of page 11, that transition temperatures determined by fracture appearance are usually higher.

Influence of Specimen Width on Transition Temperature

Two series of modified Kinzel-type specimens were prepared and tested to determine the influence of variations in specimen width on transition temperature. The specimens of one series were 1-1/2 inches wide and the others were 6 inches wide, as shown by Figure 6, Designs B and C. All of the specimens were made from "B_r" steel and were welded with E6010 electrodes. The welding schedule was the same as used for standard 3-inch Kinzel-type specimens.

The transition temperatures of standard 3-inch-wide Kinzel specimens and the modified specimens 1-1/2 inches and 6 inches wide of "B_r" steel are shown in Figure 8. The detailed data from these tests are given in Appendix A, Tables A-6 and A-7, and the comparison of transition curves is given in Appendix B, Figures B-2A, B-2B, and B-2C. A decrease in width from 3 inches to 1-1/2 inches lowered the transition temperature from +20 F to -20 F for the "B_r" steel with the three criteria*; with other criteria,** the effect was smaller. The transition temperature by fracture appearance, however, was 10 degrees higher than shown by the other criteria. This further substantiates an earlier statement (page11) that transition temperature determined by fracture appearance is usually above that obtained by the other criteria used.

The increase in specimen width from 3 inches to 6 inches had little or no effect on the transition temperature of the "B_r" steel. It was easier to test the 3-inch specimen than the 6-inch specimen, and better uniformity in test results was obtained with it than either 1-1/2 or 6-inch specimens. Therefore, no further tests of the 1-1/2 and 6-inch specimens were planned because no apparent advantage was obtained from their use.

Influence of Notch Depth on Transition Temperature

The third variable considered to have an influence on the behavior of a notched-bead-bend specimen was notch depth. Kinzel-type specimens 3 inches wide of "B_r" and "C" steels having a notch depth of 0.090 inch were prepared, as shown

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* Total absorbed energy, total bend angle, and lateral contraction.

** Absorbed energy to maximum load, absorbed energy after maximum load, bend angle to maximum load, and fracture appearance.

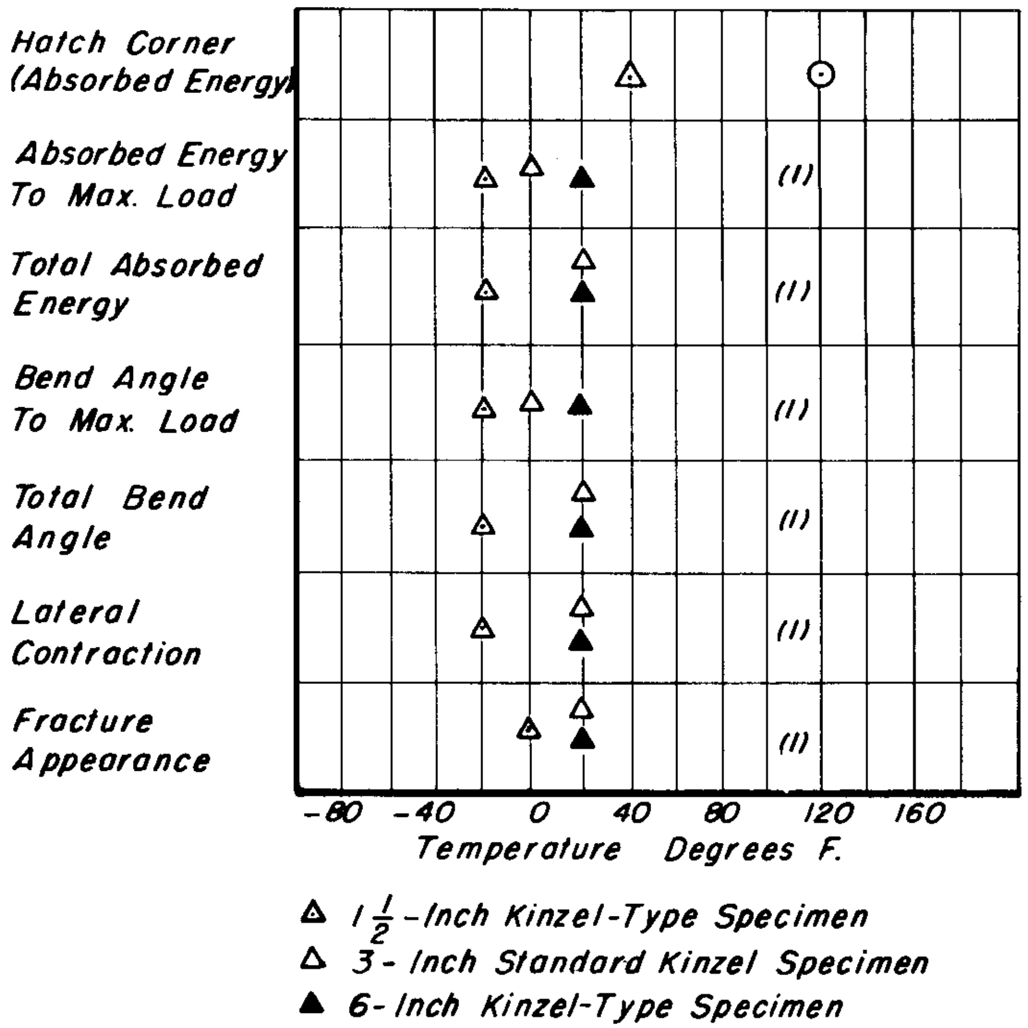


FIGURE 8. TRANSITION TEMPERATURES OF WELDED "Br" STEEL DETERMINED BY STANDARD AND MODIFIED KINZEL-TYPE SPECIMENS USING VARIOUS CRITERIA. (TYPE I TRANSITION)

(1) "C" Steel Was Not Tested

in Figure 6, Design D. These specimens were welded with 3/16-inch E6010 electrodes using the welding schedule shown on page 16. It was desired that these specimens have a notch sufficiently deep to eliminate the weld metal, but not to penetrate below the fusion line and into heat-affected zones at the bottom of the weld. Macrosections of several typical welds indicated that a notch depth of 0.090 inch below the plate surface would be satisfactory for these specimens.

The transition temperatures of the modified Kinzel specimens of "B_r" and "C" steel determined by various criteria are given in Figure 9. The detailed data from these tests are given in Appendix A, Tables A-8 and A-9, and the transition curves are compared with those from standard specimens in Appendix B, Figures B-3A, B-3B, B-4A, and B-4B. A comparison, as in Figure 9, shows that the increase in notch depth raises the transition temperature for both steels. The transition temperature of the "B_r" steel was raised from the 0 F to 40 F range to the 40 F to 100 F range. The "C" steel, however, did not change so much as the "B_r" steel, and the transition temperature was increased only slightly.

The accuracy of the transition temperatures for the "B_r" steel is questioned because of great scatter in the test data, as shown in Appendix B, Figures B-3A and B-3B. The scatter in the plotted data shows that the transition characteristics on this type specimen cover a temperature range which is quite wide. The scatter is greatest for the absorbed energy vs. temperature curves. The transition temperature from these data established by the Type 1 definition is 100 F. A possible explanation for the scatter in absorbed energy measured for this steel and specimen is the normal variation in the location of the root of the 0.090-inch-deep notch with respect to the fusion zone. This might have an influence on the amount of energy to initiate fracture.

On the basis of lateral contraction and fracture appearance, the transition temperature for the "B_r" steel was lower than shown by the other criteria in Figure 9.

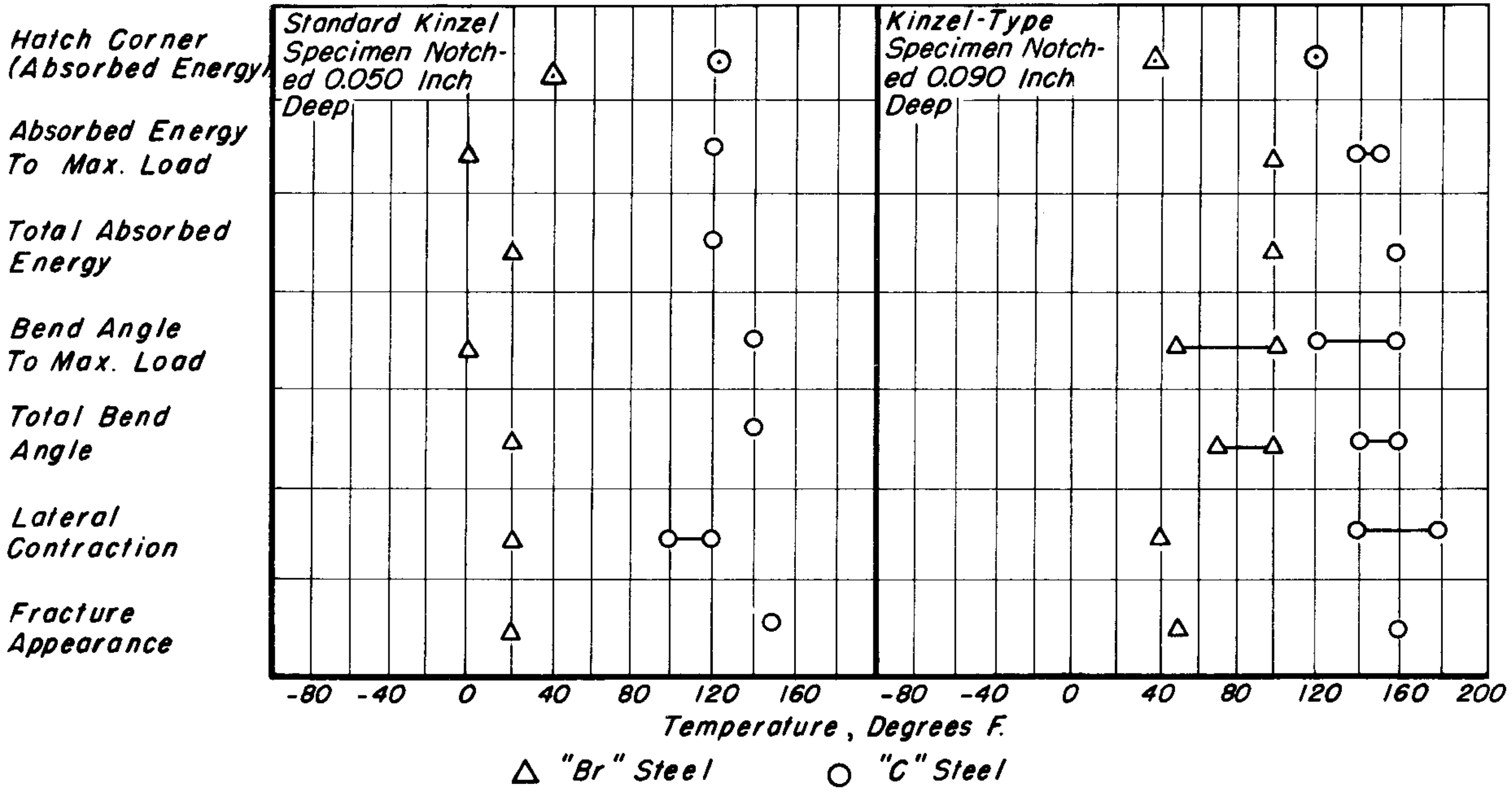


FIGURE 9. TRANSITION TEMPERATURES OF WELDED "Br" AND "C" STEEL DETERMINED BY STANDARD (0.050-INCH NOTCH) AND MODIFIED (0.090-INCH NOTCH) KINZEL-TYPE SPECIMENS USING VARIOUS CRITERIA (TYPE I TRANSITION)

0-12160

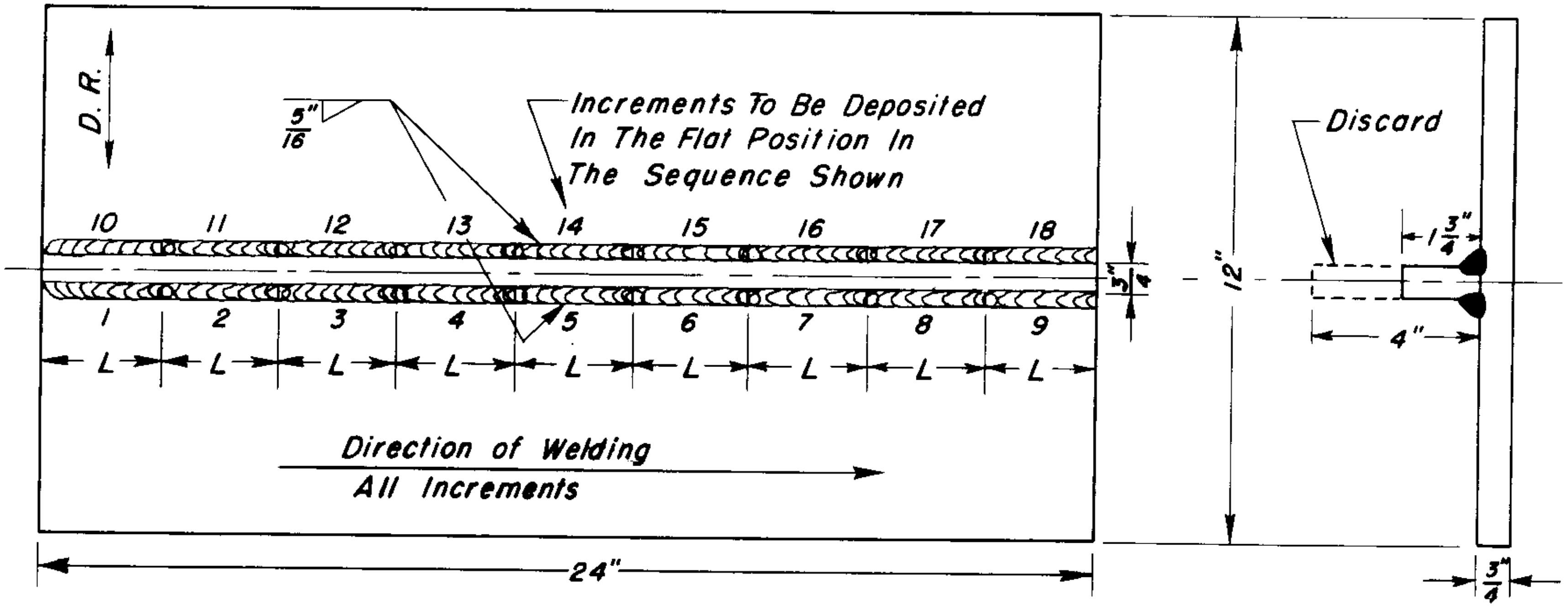
Transition-Temperature Studies With Modified Tee-Bend Specimens

The tee-bend test was used previously during this investigation to determine the transition temperatures of "B_r" and "C" ship steels. The details and data of these tests have been reported(172). The transition temperatures for both the "B_r" and "C" steels determined by the standard tee-bend tests were lower than those of the hatch-corner tests, as shown by Figure 5. The objective of this phase of the investigation, then, was to modify the tee-bend specimen in an attempt to raise the transition temperatures of the steels to those of the hatch-corner tests.

Two types of modifications to accomplish this objective were considered. The first was a modification of the welding procedure and the second was a modification of the width of the specimen. The general procedure used in preparing and testing tee-bend specimens was followed for all of the tests of modified specimens. The plates for the specimens were flame cut to the size shown in Figure 10. The plate surfaces were grit blasted prior to welding to remove mill scale, rust, or other contaminators. All specimens were manually welded and then cooled in air to room temperature. The aging time between welding and testing was eight days.

Influence of Welding Schedule on Transition Temperature

Previous experience on this project has indicated that the greatest disadvantage of the tee-bend test over some other tests was the difficulty in adhering to the welding requirements. It was not easy to produce the size of welds required with the 5/32-inch electrode specified for the test. Consequently, a 3/16-inch-diameter electrode was used instead of a 5/32-inch-diameter electrode, and a welding schedule was set up that would deposit a 3/16-inch fillet with



Increment Length, L

Std. Tee Bend – 2 11/16 Inches
Mod. " " – 4 "

FIGURE 10. WELDING DETAILS FOR TEE-BEND SPECIMEN MADE FROM 3/4" PLATE

slightly less heat input per inch of weld than that deposited by the smaller electrode. It was expected that this change in welding procedure would influence the transition temperatures of the steels being tested. The welding schedule for the standard and modified tee-bend specimens follows:

	Standard Tee-Bend	Modified Tee-Bend
Electrode class	E6010	E6010
Electrode diameter - in.	5/32	3/16
Average welding current - amp	145	180
Average arc volts	25	27
Average welding speed - in./min	2.8	4.0
Arc time - seconds	57	60
Length of weld increment - in.	2.7	4
Heat input - joules/in.	76,500	73,000

A weldment was made from "B_r" steel using the modified welding procedure. It was cut into standard-size specimens, 1-7/8 inches wide, and tested at various temperature levels. The transition temperature for the "B_r" steel obtained with the modified specimens was about 10 degrees lower than for the standard tee-bend specimens, as shown by Figure 11. The detailed data for these tests and those used for comparison are given in Appendix A, Tables A-10 and A-12, and are plotted in Appendix B, Figures B-5A and B-5B.

These tests showed that the change in the welding schedule had only a minor influence on transition temperature. This did not accomplish the desired increase in transition temperature, but it was decided, on the basis of the results, to use the modified welding schedule for tee-bend specimens of different widths.

Influence of Specimen Width on Transition Temperature

Other investigators have shown that an increase in the width of bend specimens usually raises the transition temperature of a steel because of the added constraint. Therefore, tee-bend specimens of "B_r" and "C" steels were made in which the width was increased from 1-7/8 to 3 inches in an attempt to increase the transition temperature. The modified welding schedule was also used for this series of tests rather than the standard schedule. A comparative series of tests using specimens 3 inches wide and welded with the standard schedule might have been desirable to determine the influence of specimen width alone on transition temperature. However, the relatively small influence of the modified welding on the "B_r" steel did not warrant these tests since the supply of "C" steel was very limited.

The transition temperature of the "B_r" steel from the modified tee-bend specimens (3 inches wide) was about +20 F, as shown in Figure 11. This was decidedly higher than the 0 F obtained previously with the standard tee-bend specimens of "B_r" steel, but was still below the transition temperature of the "B_r" steel hatch corner. The "C" steel, however, was influenced more by the modified welding and increased width than the "B_r" steel. The transition temperature was 160 F, which is 40 degrees higher than the transition temperature of the "C" steel hatch corner. These tests indicated that the transition temperature of "C" steel tee-bend specimens is more susceptible to variations in specimen design, and possibly welding procedure, than that of the "B_r" steel specimens. The detailed data from these tests are given in Appendix A, Tables A-10, A-11, A-12, A-13, and A-14, and are compared in Appendix B, Figures B-5A, B-5B, B-6A, and B-6B.

TRANSITION-TEMPERATURE TESTS USING NOTCHED TENSION SPECIMENS

Transversely notched tension specimens ranging in width from 3 to 72 inches have been used by investigators (79, 101, 111, 125) to determine the

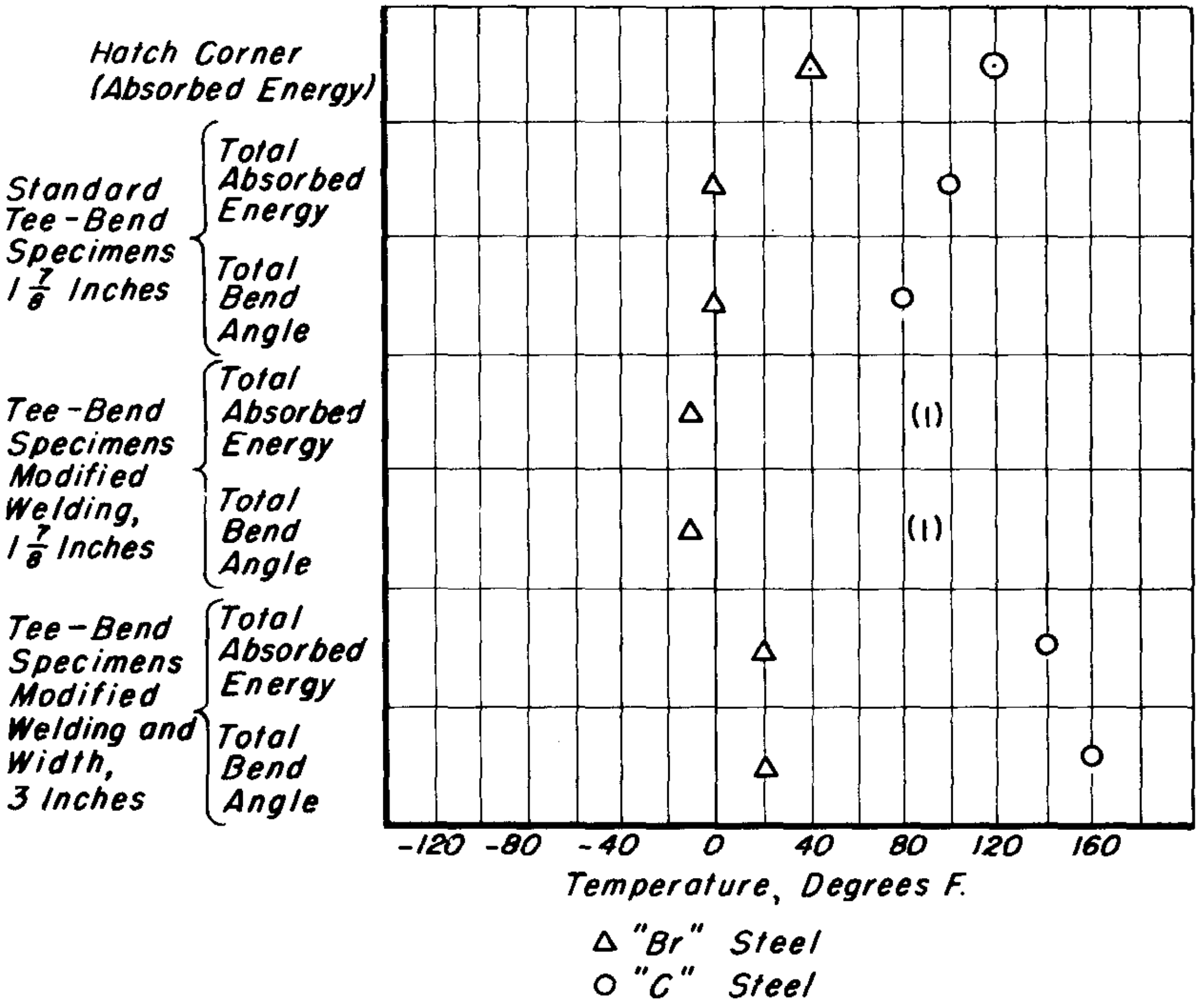


FIGURE 11. TRANSITION TEMPERATURES FOR WELDED "Br" AND "C" STEELS, BASED ON TOTAL ABSORBED ENERGY AND BEND ANGLES OF STANDARD TEE-BEND SPECIMENS, TEE-BEND SPECIMENS MADE BY MODIFIED WELDING SCHEDULE, AND TEE-BEND SPECIMEN 3 INCHES WIDE (TYPE I TRANSITIONS)

(1) "C" Steel Was Not Tested

transition temperatures of various mild-steel ship plates. It has been suggested that the tension test is more representative than the short-radius notched bend test of the conditions that take place when a ship hull, deck, or hatch corner is loaded. Therefore, it was recommended by the Project Advisory Committee that transition temperatures of welded and unwelded "B_r" and "C" ship steels should be determined by using notched tension specimens similar in design to those used for the bend tests, and the results compared with the bend-test results and the hatch-corner test results.

Tension Specimen

A tension specimen, as shown in Figure 12, was used for these tests. Its design was the same as the Kinzel-type notched-bead bend specimens (Kinzel type) except the width was reduced to 2-3/4 inches to accommodate the testing equipment and to prevent the possibility of failure away from the notched section. The electrodes and welding procedure were the same as those used with the standard Kinzel-type bend specimen. Adapter bars were welded to the ends of the project steels to reduce the amount of the "B_r" and "C" steels required. These adapter bars made the tension specimens long enough to reduce the influence of eccentric loading at the notch.

Testing Tension Specimens

The specimens were cooled by means of copper heat-exchanger blocks clamped tightly against the surfaces of the test specimen, as shown in Figure 13. A shallow groove was machined in one block to accomodate the weld bead. Cooling on the edges of the test piece, except where the strain gauges were attached, helped to maintain a constant temperature across the entire specimen. The

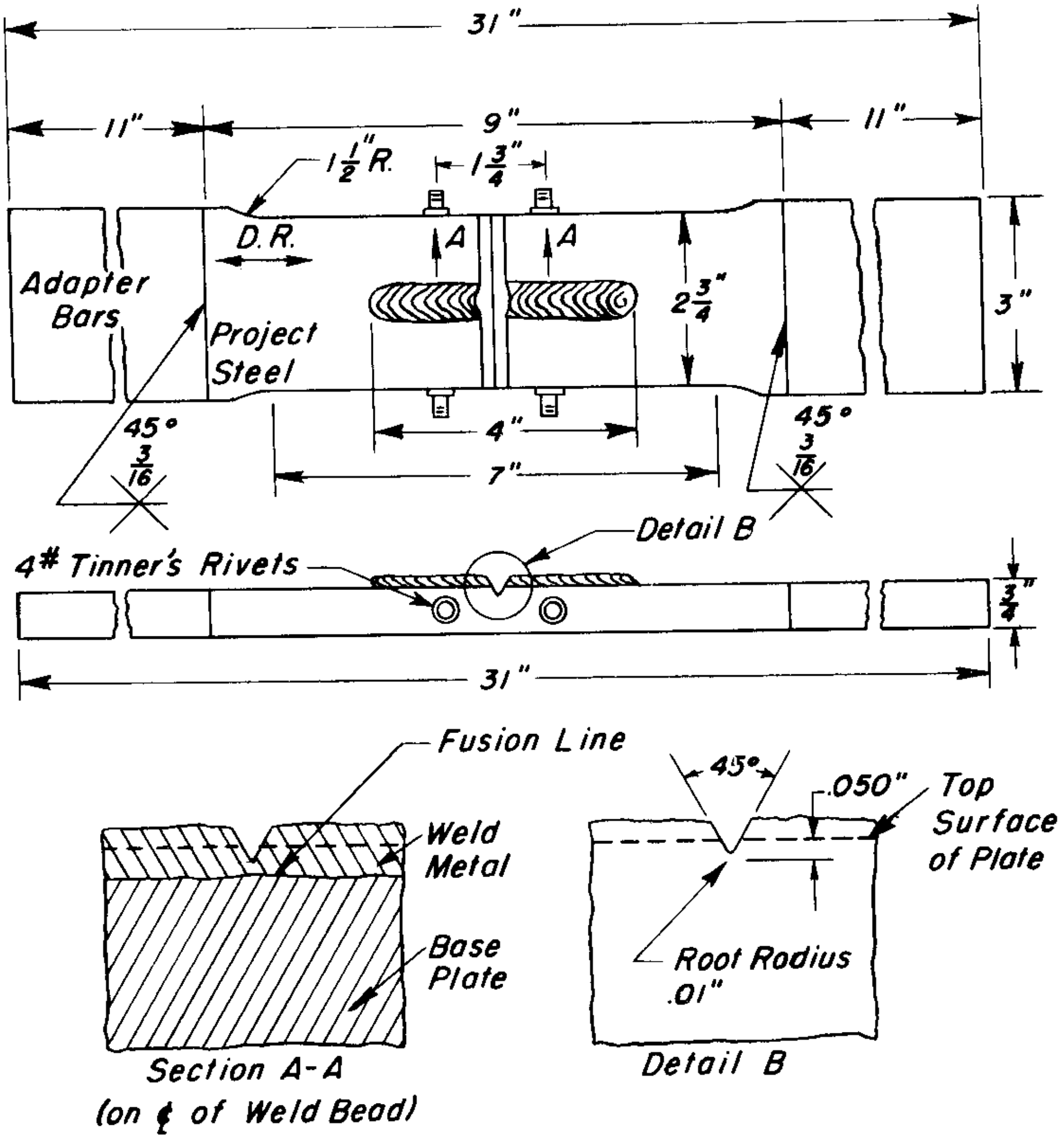


FIGURE 12. TENSION SPECIMEN WITH LONGITUDINAL WELD BEAD AND TRANSVERSE NOTCH

desired temperature was obtained by pumping the coolant or heated solution through the heat exchanger. The specimen temperature was measured by a cooper-constantan thermocouple welded to the specimen 1/8 inch below the surface adjacent to the bead and slightly above the notch, as shown in Figures 13 and 14.

Tests showed that, at a temperature of -80 F, there was only an 8 degree difference in temperature from the center to the outer edge at the notch. This difference became less as the temperature was raised, and, at about 50 F, the specimen temperature was completely uniform.

The tension specimens were pulled in a 200,000-pound Baldwin-Southwark hydraulic testing machine loaded at the rate of 0.02 inch per minute. The amount of energy required to break the specimens was obtained by load-deflection curves plotted from strain-gauge measurements. Details of the clip-type compensating strain gauges are shown in Figure 15. (This method of measuring strain in tension specimens was obtained from the Staff of the Engineering Materials Laboratory at the University of California.) The clips were fastened to tinner's rivets which were soft soldered to each side of the test specimen, as shown in Figures 13 and 14. The leads from SR-4 strain gauges were connected to two Baldwin strain-gauge indicators. The indicator readings were taken at successive load increments until the specimen failed. The load-elongation curves were plotted from these readings.

Results of Tension Tests

The criteria used for determining the transition-temperature curves were: energy absorbed to maximum load, lateral contraction, and fracture appearance.

The transition temperatures of the welded and unwelded notched tension specimens of "B_r" and "C" steels determined by the various criteria are shown in Figure 16. The detailed data and transition-temperature curves for the welded and unwelded notched tension tests are contained in Appendix A, Tables A-15,

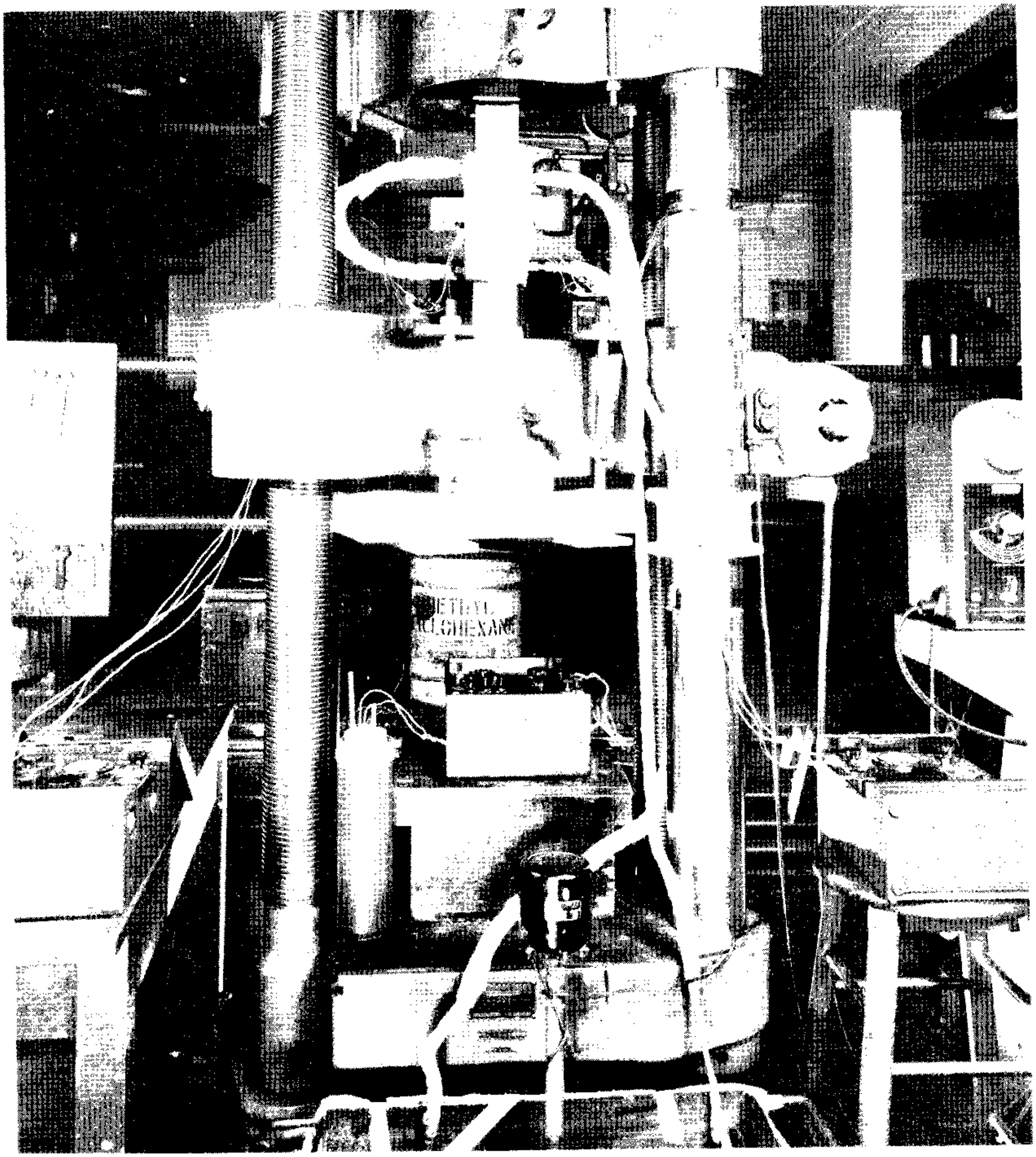


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FIGURE 13. APPARATUS USED FOR TESTING TENSION SPECIMENS

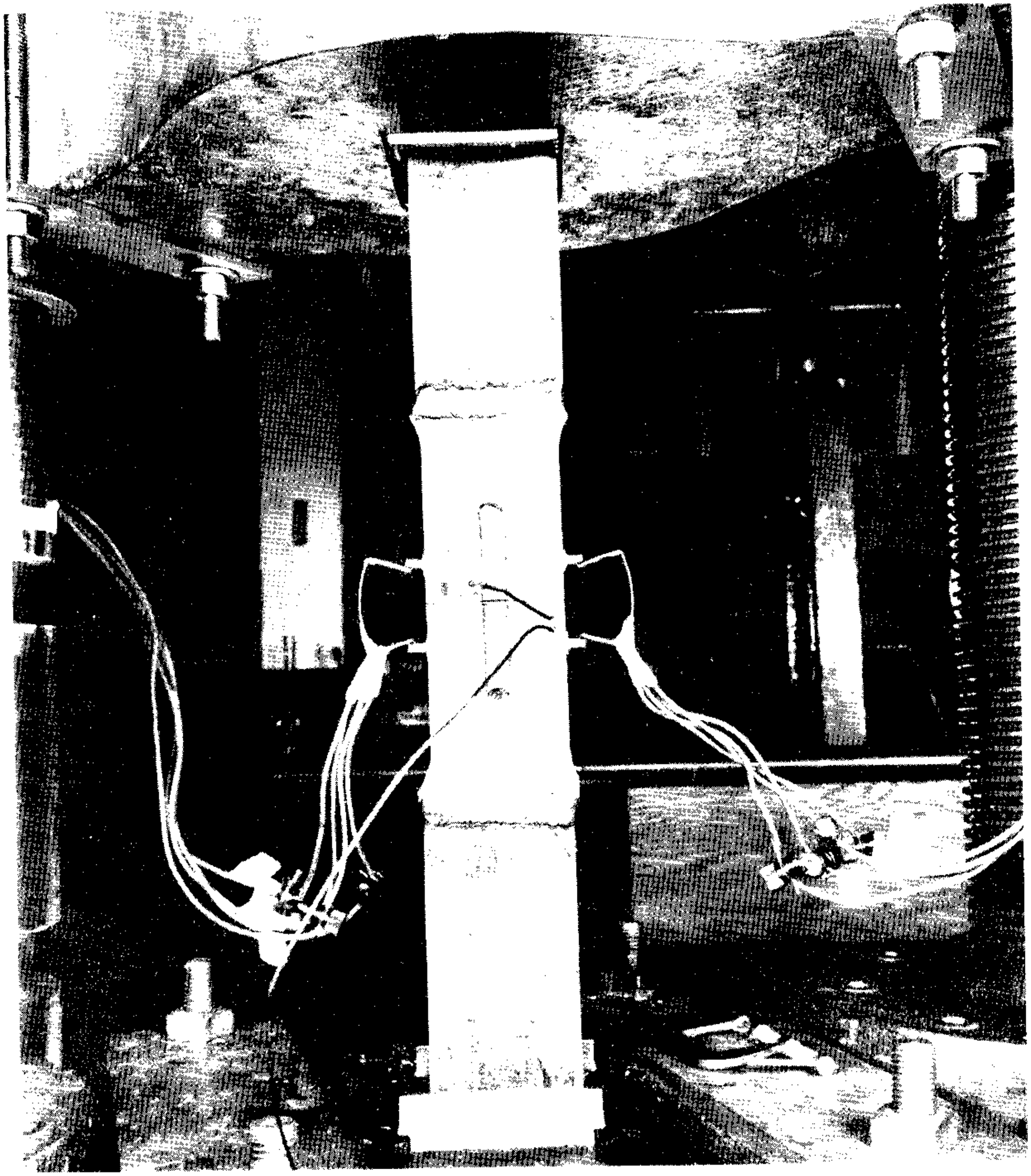

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FIGURE 14. FRONT VIEW OF TENSION SPECIMEN IN TESTING MACHINE WITH STRAIN GAUGES ATTACHED

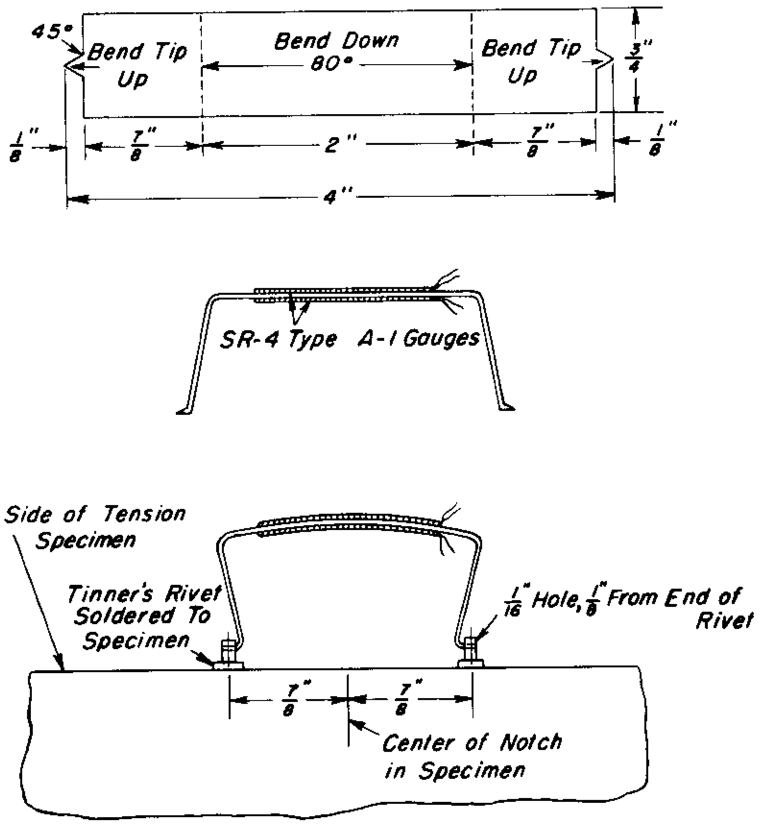


FIGURE 15. DETAILS OF CLIP-TYPE COMPENSATING STRAIN GAUGE SHOWING ATTACHMENT TO TENSION SPECIMEN. (DEVELOPED AT UNIVERSITY OF CALIFORNIA)

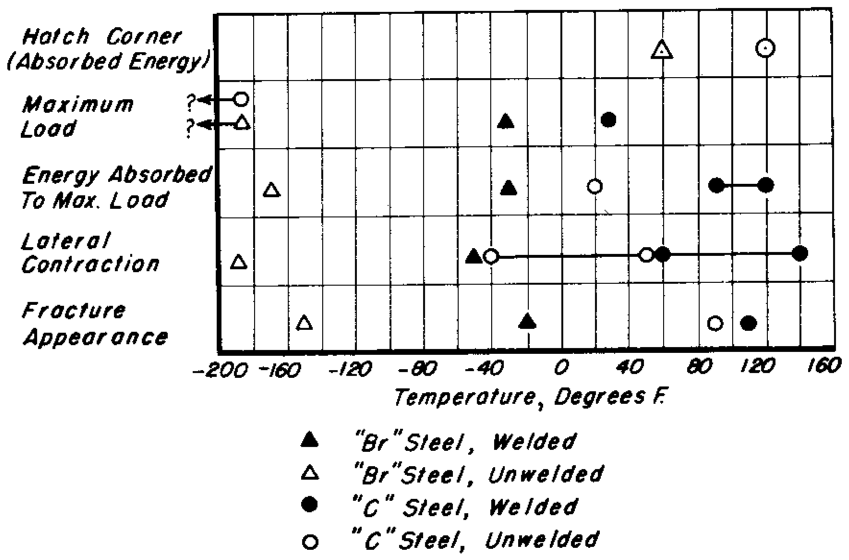


FIGURE 16. TRANSITION TEMPERATURES OF UNWELDED AND WELDED "Br" and "C" STEEL DETERMINED BY NOTCHED TENSION SPECIMENS USING VARIOUS CRITERIA (TYPE I TRANSITIONS)

A-16, A-17, and A-18, and Appendix B, Figures B-7A, B-7B, B-7C, and B-7D. These transition temperatures were considerably lower than those shown by Kinzel-bend, Lehigh-bend, tee-bend, and hatch-corner tests of specimens made from the same steels. The qualitative order of their transition temperatures, however, was the same.

The transition-temperature curves shown in Appendix B, **Figures** B-7A, B-7B, B-7C, and B-7D, are of sufficient interest to warrant some discussion. The "B_r" steel in all tests has shown a more abrupt change in transition properties than the "C" steel. In the tee-bend and notched-bead tension tests, however, this condition was most pronounced. The "C" steel transition was more gradual and was about the same as for the bend tests in general.

The maximum load vs. temperature curve, Appendix B, Figure B-7B, showed a very significiant drop in the strength properties of the welded "B_r" steel at the transition temperature. This property was not so apparent from the bend tests of "B_r" steel, because in bend tests the specimen is loaded in an entirely different manner (Appendix B, Figures B-1A, B-1B, B-2A, B-2B, and B-2C). This also indicates that the over-all properties of the "B_r" steel are better than those of the "C" steel only to a certain temperature, beyond which they abruptly change to about that shown by the more notch-sensitive "C" steel. For the "C" steel notch-bead tension tests, the curve was not well defined and the average curve indicated a more gradual drop in load.

The lateral contraction vs. temperature curves for the tension tests reflected the ductility properties of the steel in the same manner as the bend specimens did, i.e., as the temperature decreased the ductility decreased. As with some of the bend specimens, it was not possible to determine a definite transition temperature for "C" steel, welded or unwelded, by the use of this criterion. The testing temperatures used were not low enough in all cases so that the transition temperature could be determined by the 1 per cent lateral-contraction criterion.

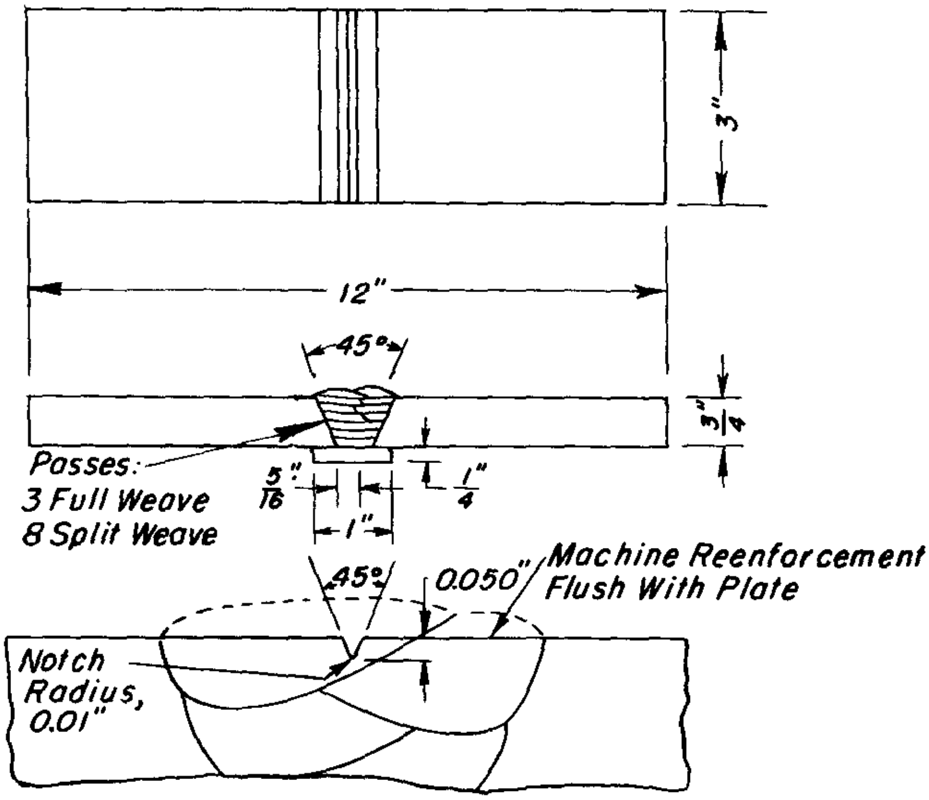
In general, it seems that the notched-bead tension test may have some advantages over its bend-test counterpart. The most apparent disadvantage at present is the low temperatures required for testing, which are well below operating temperatures of ships.

TRANSITION-TEMPERATURE STUDIES OF E6010 AND E6020 WELD METAL

During the earlier phase of this investigation, there were indications that the weld metal and heat-affected zone in the longitudinally welded and transversely notched specimens had a transition temperature independent of that exhibited by the base metal(172). On the basis of these observations, the Project Advisory Committee recommended that further studies be made to determine the transition-temperature properties of mild-steel weld metal and their influence on bead-welded and transversely notched bend specimens.

Preparation and Testing of Specimens

The design of the specimens used for these tests is illustrated in Figure 17. The weld metal was deposited by 3/16-inch-diameter, Class E6010 and E6020 electrodes on "B_r" steel in accordance with the requirements set forth in the Navy Department Bureau of Ships Interim Specification 46E3, dated November 1, 1945. This procedure consisted of heating the tacked joint in boiling water for 5 minutes prior to welding. Within 1 minute after the completion of each layer, including the last layer, the assembly was immersed in boiling water and, within one minute after the boiling had subsided, the specimen was removed from the water and the subsequent layer was started immediately. The first three layers



Specimens Welded According To
Navy Dept. Bureau of Ships Spec.

FIGURE 17. ALL-WELD-METAL BEND SPECIMENS (KINZEL TYPE) HAVING A MULTIPASS SINGLE-VEE BUTT JOINT AND A TRANSVERSE NOTCH.

were weaved the full width of the joint and the next four layers consisted of two split passes each.

After welding, the weld reinforcement was machined flush with the plate surface and a notch (Kinzel design) was cut in the weld metal transverse to the longitudinal direction of the specimen, as shown in Figure 17. In most of the cases, the root of the notch was in columnar grains of weld metal.

The specimens were tested in the same manner as previously described for the notched-bead bend tests. The lower testing temperatures required for these tests, however, were obtained by using liquid nitrogen and a heat exchanger in the cooling bath.

Results of Tests

A comparison of the transition temperatures of the bead-welded and all-weld-metal notched-bend specimens is shown in Figure 18. The detailed data are given in Appendix A, Tables A-19 and A-20, and in Figure 18. The change from ductile to brittle properties for both E6010 and E6020 weld metal occurred at a lower temperature and covered a considerably wider range than the notched-bead bend tests of "B_r" and "C" steel. Both kinds of specimens welded with E6010 electrodes, however, had a lower transition temperature than similar specimens welded with E6020 electrodes.

Before these results could be correlated, it was necessary to determine the cause for the wide transition-temperature range for the all-weld-metal specimens illustrated in Appendix B, Figures B-8A, B-8B, and B-8C. Microsections of a sufficient number of representative specimens, cut through the weld metal transverse to the notch, showed that variations in the grain structure at the root of notch were responsible for the wide transition range. Specimens having the notch cut in a heat-refined grain structure, as shown by Figure 19, showed

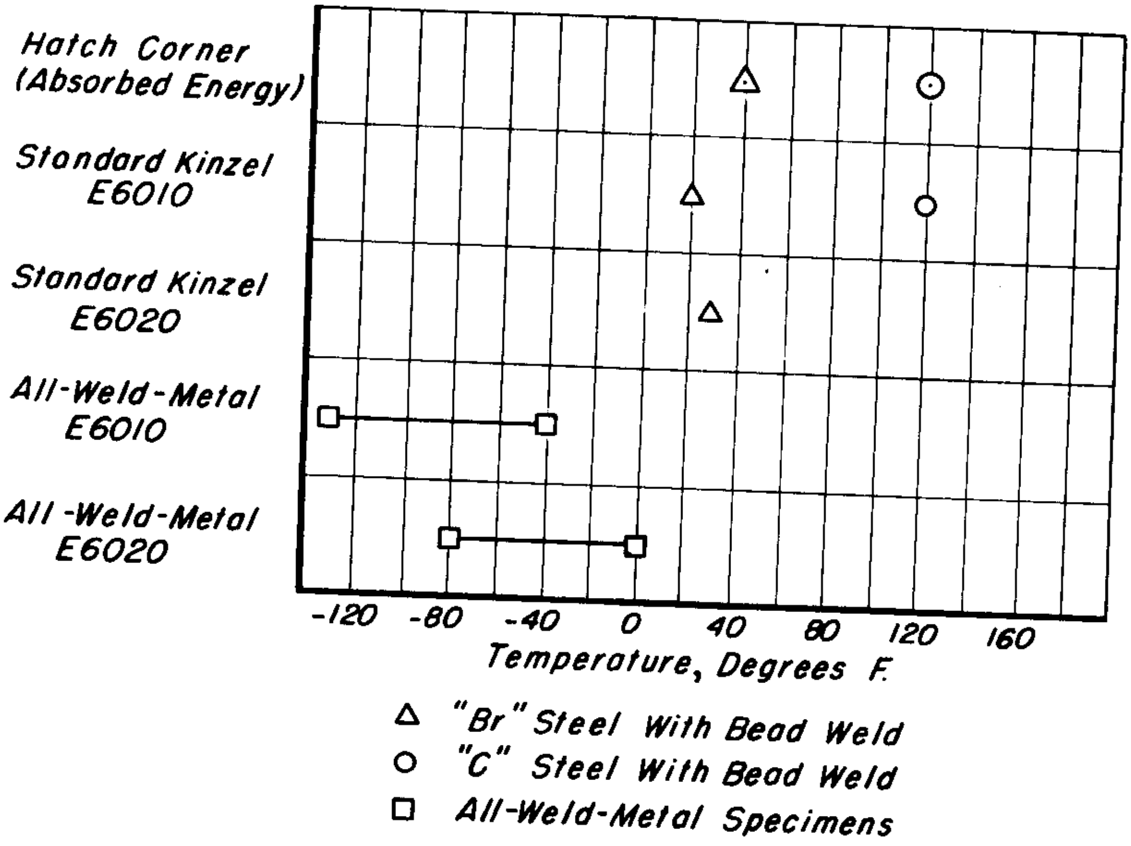


FIGURE 18. TRANSITION TEMPERATURE, BASED ON ABSORBED ENERGY, OF BEAD-WELDED AND ALL-WELD-METAL KINZEL-TYPE SPECIMENS

higher energy absorption and ductility for a given temperature than those having the notch cut in the coarse columnar, as-deposited, weld metal, as shown by Figure 20. The specimens having a fine-grain structure also had a lower transition temperature than the coarse-grain specimens. Figure 21 further illustrates the significant influence that grain structure has on the fracture or behavior of notched-bend specimens. This all-weld-metal bend specimen was notched in the heat-refined grain structure, but failed in the unnotched coarse-columnar weld metal midway between the notch and the base metal.

This suggests that at low temperatures the coarse columnar structure of "as-deposited" weld metal without a notch may be more susceptible to fracture than the heat-refined weld metal containing a notch. In notched-bead bend specimens, initial fracture occurs in the weld bead at the root of the notch. The coarse-grain weld metal (along with other factors), in all probability, contributes to the location of initial fracture and the transition temperature of the specimen. This phase of the work is being investigated further in fracture initiation and propagation studies, along with studies of impurities which may make the columnar structure particularly susceptible to the initiation of a brittle break.

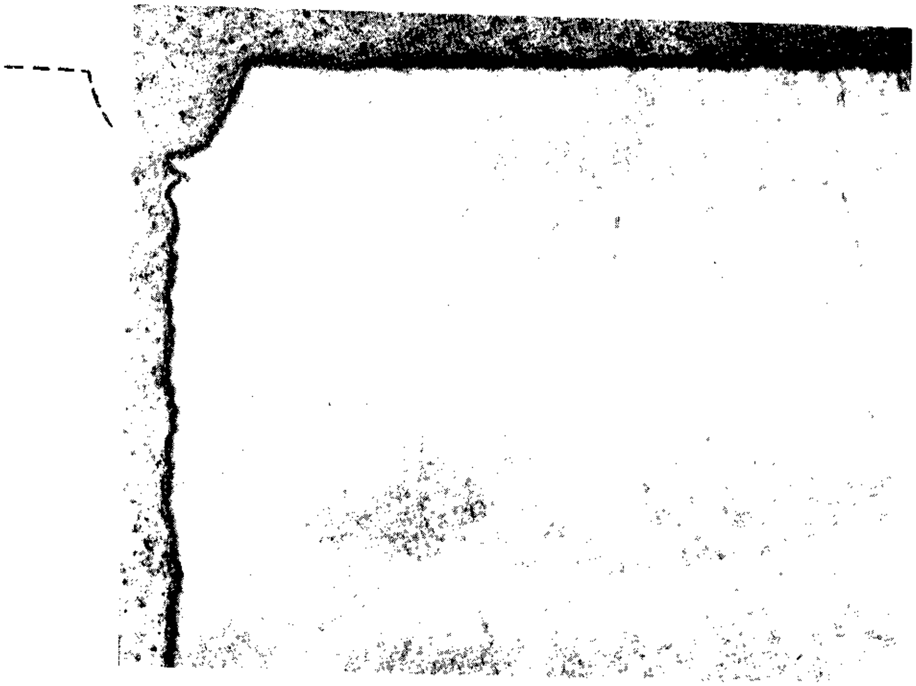
PRELIMINARY FRACTURE INITIATION STUDIES

A considerable amount of effort and time has been expended by many investigators to develop a laboratory-size specimen for predicting the performance of a material used in large welded structures. The criteria generally used for attempting to establish a qualitative relationship between laboratory specimens of different steels and field structures are: fracture appearance, transition temperature, ductility, and the amount of energy required to break the test specimen. Load-deflection curves have been widely used to determine numerical

Mag. 10X 57301

Mag. 100X 57243

FIGURE 19. SECTION OF AN ALL-WELD-METAL NOTCHED BEND SPECIMEN HAVING THE ROOT OF THE NOTCH IN THE REFINED GRAIN STRUCTURE OF THE AS-DEPOSITED E6010 WELD METAL. COMPARE WITH FIGURE 20.



Mag. 10X

57300

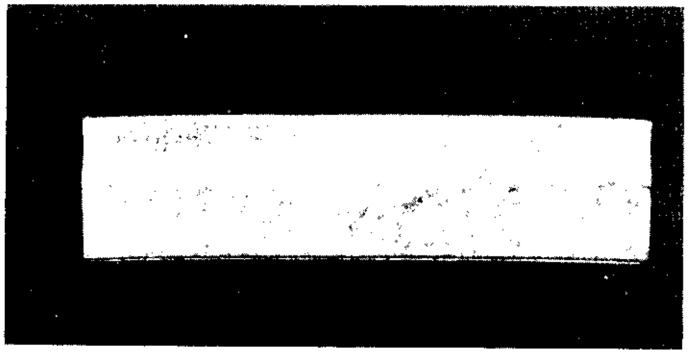
Mag. 100X

57242

FIGURE 20. SECTION OF AN ALL-WELD-METAL NOTCHED BEND SPECIMEN HAVING THE ROOT OF THE NOTCH IN THE COARSE COLUMNAR STRUCTURE OF THE AS-DEPOSITED E6010 WELD METAL. COMPARE WITH FIGURE 19.

56825

56824



56826

FIGURE 21. ALL-WELD-METAL (E6010) BEND SPECIMEN TESTED AT -150 F SHOWING A PREFERENTIAL FRACTURE IN THE COARSE-GRAIN STRUCTURE OF THE WELD METAL ADJACENT TO THE MACHINED NOTCH

values for these criteria so that the behavior of different steels tested at definite temperature levels could be correlated. In analyzing the test results up to now, the maximum load has been used as the point at which the specimen or structure failed. Consequently, the deflection at maximum load and the absorbed energy were used for evaluating the ductility and resistance of the material to initial failure, respectively. Likewise, the energy absorbed by the specimen after maximum load has previously been regarded as the energy required to propagate the fracture to complete failure.

Previous notched-bead bend tests indicated the possibility of the deposited weld metals having a transition temperature independent of that of the heat-affected zone or base metal of the specimen. Furthermore, the geometry of the specimen (location of bead and reinforcement of weld) was thought to be a factor that might influence fracture initiation and propagation. A limited number of bend tests were made, therefore, to obtain a better understanding of the mode of failure of this type of specimen so that a more accurate interpretation could be made of the test data.

The Kinzel-type specimen was selected for these preliminary tests to study fracture initiation and propagation, because this type of specimen has been used most during this investigation, and it was hoped that the information, gained from these studies could be applied to the interpretation of previous test data. Furthermore, the established schedule for depositing the weld bead was normal, while the 0.050-inch-deep notch was sufficient to impose the necessary stress concentration and at the same time leave some weld metal below the notch.

A series of 18 welded Kinzel-type specimens was prepared from "B_r" steel by the standard welding and machining procedures used in precious tests with this specimen. Since the "B_r" steel exhibited ductile properties at 40 F and brittle properties at 0 F, two series of nine specimens were bent various amounts at the two temperatures. The specimens were each bent a predetermined amount ranging from below the observed yield point to the point of maximum load. The load was released and the specimens were removed from the testing jig and examined for cracks.

These tests showed that fracture initiated in the weld metal and heat-affected zone at the root of the notch and at a very low bend angle ranging from 3 to 6 degrees. This occurred at, or slightly above, the yield point of the specimen and far below the maximum load of the specimen. At maximum load, the fracture had propagated through a considerable part of the cross section of the specimen.

On the basis of these results, it was proposed that a thorough study be made of the initiation and propagation of fractures in the various test specimens selected for study on this project. The results of that study will be the subject of a subsequent report.

SUMMARY

A summary plot containing the transition temperatures of all specimens studied is included in Appendix D. The important points of the findings of this investigation are as follows:

1. Generally, modifications of the various specimens shifted the transition temperature of the two steels up or down depending upon the modification. However, the same change in specimen design or procedure of producing the specimens did not produce shifts of similar magnitude in the transition temperature of the "B_r" and "C" steels. Therefore, it appears quite unlikely, on the basis of information available, that any one type or design of small specimen will give the same transition temperature for "B_r" and "C" steels, and other steels that was or might be obtained by large specimens, such as the hatch-corner specimens.

2. The transition temperatures for Kinzel-type unwelded notched specimens of "B_r" and "C" steel, tested in tension, were considerably lower than those for similar

welded specimens. The "B_r" steel had a lower transition than the "C" steel, as in all other tests used. The transition temperatures obtained from the welded "B_r" and "C" steel tension specimens were considerably lower than the transition temperatures of hatch-corner specimens.

3. Transition-temperature studies of E6010 and E6020 weld metals, which were made with all-weld-metal specimens similar in design to Kinzel specimens and tested in bending, showed that the transition temperatures of these weld metals were much lower than those obtained with standard (bead on plate) Kinzel-type specimens. The transition temperature of the E6010 welds ranged from -130 F to -40 F and varied with the location of the notch; i.e., if notch was in columnar structure, the transition was high, and if it was in the normalized structure of the weld metal, it was low. The transition temperature of E6020 weld metal ranged from -70 F to 0 F.

4. Welded Kinzel-type specimens of "B_r" steel welded with E6020 electrodes had a transition temperature about 10 F to 20 F higher than that of similar specimens welded with E6010 electrodes. Tests were not made on "C" steel with the E6020 electrodes because only a small difference was obtained on the "B_r" steel.

5. Welded Kinzel-type specimens of "B_r" steel, 1-1/2 inches wide, had a transition temperature of about -20 F, compared to 20 F obtained with standard 3-inch Kinzel-type specimens. (Hatch-corner transition temperature for "B_r" steel was 40 F.)

6. Welded Kinzel-type specimens of "B_r" steel 6 inches wide had very nearly the same transition temperature (20 F) as the standard 3-inch specimen. (Hatch-corner transition temperature for "B_r" steel was 40 F.)

7. Welded Kinzel-type specimens of "B_r" steel with 0.090-inch-deep notch had a considerably higher transition temperature, 40 F to 100 F, than standard Kinzel-type specimens (transition temperature 0 F to 20 F) of the same steel with a standard 0.050-inch-deep-notch. A similar change in notch for "C" steel specimens had very little influence on transition temperature, which was 140 F to 160 F. (Hatch-corner transition temperature for "C" steel was 120 F.)

8. Tee-bend specimens of standard size (1-7/8 inches wide) made of "B_r" steel with a modified welding procedure had about the same transition temperature as standard tee-bend specimens.

9. Tee-bend specimens, 3 inches wide, of "B_r" and "C" steels had higher transition temperatures than standard 1-7/8-inch-wide specimens. For "B_r" steel, the transition temperature for 3-inch specimens was about 20 F compared to -10 F for standard specimens, but was lower than the 40 F transition temperature of hatch-corner specimens. For the "C" steel, the transition temperature for 3-inch specimens was about 160 F compared to 110 F for standard specimens and 120 F for hatch-corner weldments.

10. A few preliminary tests of fracture initiation and propagation in the Kinzel-type specimen showed that fracture appears to start in the weld metal and heat-affected zone at the root of the notch of the specimen slightly above the yield point of the specimen, and, at maximum load, it has propagated through a part of the cross section of the specimen.

11. The study of published and unpublished literature on the various kinds of tests used to study strength, ductility, and transition temperatures of welded joints in structural steel was continued. Literature on this subject published, or otherwise obtained, and studied since the date of the first report was added to the bibliography, and a complete bibliography is included in this report for convenience.

FUTURE WORK

This report describes work recommended by the Project SR-100 Advisory Committee at its meeting of February 26, 1948, and presented for the committee's approval at its meeting December 7, 1948.

The following program of future work at Battelle Memorial Institute was discussed and approved by the Advisory Committee:

1. Studies are to be made to determine the effect of preheat and postheat on Kinzel-type bend specimens of "B_r" and "C" steel. These studies are to include the following:

    a. Preheats of 10, 70, 150, 250, and 400 F on both "B_r" and "C" steels.

    b. Preheat of 70 F and postheat of 1150 F on "C" and "B_r" steel.

   c. Preheat of 400 F and postheat of 1150 F on "Br" steel.

2. Tests are to be made on unwelded and welded "A" and "W" steels to determine their transition temperatures.

3. Fracture initiation and propagation studies are to be made of Kinzel, Lehigh, and tee-bend specimens of "B_r" and "C" steels. These studies are to determine where and when the fracture starts and how it propagates through the various types of specimens. In addition, tests are to be made to determine the effect of the following factors on fracture:

   a. Type of weld metal
   b. Multipass welds
   c. Power input
   d. Aging after welding
   e. Geometry of specimen

Data given in this report are recorded in Battelle Laboratory Book No. 3856, pp. 1 to 38, and Book No. 3240, pp. 40 to 100.

RWB:RGK:MF:PJR:CBV/vm
September 16, 1949

APPENDIX A

TABLE A-1. RESULTS OF KINZEL-TYPE SLOW-BEND TEST SPECIMENS OF UNWELDED "B_r" STEEL SPECIMENS HAVING A TRANSVERSE NOTCH(1)

Specimen Number	Testing Temp, F	Maximum Load, Lb	Bend Angle, Degrees at Maximum Load	Bend Angle, Degrees at Complete Failure(2)	Absorbed Energy(3): Energy to Maximum Load, Sq In.	Energy to Maximum Load, In. - Lb	Energy After Maximum Load, Sq In.	Energy After Maximum Load, In. - Lb	Total Energy, Sq In.	Total Energy, In. - Lb	Average Lateral Contraction, In.	Average Lateral Contraction, Lb	Fracture Appearance, % Ductile
AC24-1	80	19,100	47	57	7.45	16,790	1.90	4,300	9.35	21,090	0.142	4.75	100
AC24-2	80	19,200	47	57	7.52	16,920	2.00	4,500	9.52	21,420	1.220	4.05	100
AC24-11	40	19,500	51	66	8.46	19,400	2.90	6,500	11.36	25,900	1.390	4.65	100
AC24-12	20	20,000	46	46	8.15	18,330	0	0	8.15	18,330	0.112	3.74	5
AC24-5	0	20,500	43	43	7.51	16,900	0	0	7.51	16,900	0.105	3.50	5
AC24-6	-40	21,300	42	42	7.69	17,300	0	0	7.69	17,300	0.102	3.40	5
AC24-10	-60	21,300	37	37	6.80	15,300	0	0	6.80	15,300	0.085	2.84	5
AC24-7	-80	20,400	27	27	4.87	10,980	0	0	4.87	10,980	0.068	2.27	2
AC24-8	-100	17,400	4	4	0.53	1,190	0	0	0.53	1,190	0.011	0.37	0
AC24-9	-100	20,900	31	31	4.90	11,020	0	0	4.90	11,020	0.059	1.95	0

(1) Data from the First Progress Report recalculated(172).

(2) If specimen did not fail, this measurement was taken at the point on the load-deflection curve where the load had dropped to 13,000 pounds after passing maximum load (6000 pounds was used in first report).

(3) Absorbed energy = measured area under the load-deflection curve times 2,250 inch pounds.

(4) Measurement made at point of maximum contraction (usually 1/32 inch below the notch root) on both sides of fracture with pointed micrometers.

TABLE A-2. RESULTS OF KINZEL-TYPE SLOW-BEND SPECIMENS OF UNWELDED "C" STEEL SPECIMENS HAVING A TRANSVERSE NOTCH(1)

Specimen Number	Testing Temp, F	Maximum Load, Lb	Bend Angle, Degrees at Maximum Load	Bend Angle, Degrees at Complete Failure(2)	Absorbed Energy(3): Energy to Maximum Load, Sq In.	Energy to Maximum Load, In.-Lb	Energy After Maximum Load, Sq In.	Energy After Maximum Load, In.-Lb	Total Energy, Sq In.	Total Energy, In.-Lb	Average Lateral Contraction (4), In.	Average Lateral Contraction (4), %	Fracture Appearance, % Ductile
AC25-10	190	18,800	33	44	5.36	12,080	2.20	5,000	7.56	17,080	-	-	100
AC25-6	160	21,100	33	44	6.12	13,790	2.50	5,600	8.62	19,390	0.100	3.33	50
AC25-11	140	20,600	37	45	6.58	14,800	1.85	4,200	8.43	19,000	0.097	3.23	25
AC25-5	120	21,400	35	41	6.22	14,000	1.60	3,600	7.82	17,600	0.100	3.33	25
AC25-1	80	20,000	31	31	5.16	11,610	0	0	5.16	11,610	0.074	2.47	5
AC25-2	80	20,800	33	33	5.60	12,600	0	0	5.60	12,600	0.081	2.70	5
AC25-9	60	18,800	24	24	3.78	8,500	0	0	3.78	8,500	0.055	1.83	2
AC25-3	40	19,600	25	25	4.38	9,850	0	0	4.38	9,850	0.056	1.87	0
AC25-12	20	19,000	19	19	3.12	7,020	0	0	3.12	7,020	0.045	1.50	0
AC25-4	0	19,200	19	19	3.11	7,000	0	0	3.11	7,000	0.050	1.67	0
AC25-7	-40	19,300	20	20	3.23	7,270	0	0	3.23	7,270	0.042	1.40	0

(1) Data from the First Progress Report recalculated(172).

(2) If specimen did not fail, this measurement was taken at the point on the load-deflection curve where the load had dropped to 13,000 pounds after passing maximum load (6000 pounds was used in first report).

(3) Absorbed energy = measured area under the load-deflection curve times 2,250 inch pounds.

(4) Measurement made at point of maximum contraction (usually 1/32 inch below the notch root) on both sides of fracture with pointed micrometers.

TABLE A-3. RESULTS OF SLOW-BEND TESTS OF KINZEL-TYPE SPECIMENS MADE FROM "B_r" STEEL HAVING A LONGITUDINAL E6010 WELD BEAD AND TRANSVERSE NOTCH(1)

Specimen Number	Testing Temp, F	Maximum Load, Lb	Bend Angle, Degrees at(2)		Absorbed Energy(3)						Average(4) Lateral Contraction(4)		Fracture Appearance, % Ductile
			Maximum Load	Complete Failure	Energy to Maximum Load		Energy After Maximum Load		Total Energy				
					Sq In.	In.·Lb	Sq In.	In. Lb	Sq In.	In. Lb	In.	%	
AC22-1	75	16,100	30	40	4.24	9,540	1.70	3,800	5.94	13,340	0.134	4.6	100
AC22-2	75	16,000	31	41	3.78	8,500	1.70	3,800	5.48	12,300	0.127	4.4	100
AC22-11	50	16,200	24	39	3.42	7,700	2.55	5,700	5.97	13,400	0.111	3.8	100
AC22-5	40	16,300	27	40	3.92	8,830	2.25	5,100	6.17	13,930	0.108	3.7	100
AC22-7	30	16,700	26	40	3.90	8,780	2.45	5,500	6.35	14,280	0.131	4.5	98
AC22-9	25	16,500	23	39	3.38	7,610	2.80	6,300	6.18	13,910	0.102	3.5	100
AC22-10	25	16,300	27	33	4.11	9,260	1.00	2,300	5.11	11,560	0.105	3.6	75
AC22-8	20	16,500	23	23	3.38	7,610	0	0	3.38	7,610	0.065	2.2	5
AC22-15	20	16,400	28	40	4.12	9,280	2.10	4,700	6.22	13,980	0.114	3.9	90
AC22-12	10	15,900	25	38	3.66	8,240	2.15	4,800	5.81	13,040	0.119	4.1	90
AC22-13	10	16,600	24	24	3.58	8,050	0	0	3.58	8,050	0.064	2.2	10
AC22-3	0	15,400	14	14	1.96	4,410	0	0	1.96	4,410	0.034	1.1	2
AC22-14	0	15,000	11	11	1.34	3,020	0	0	1.34	3,020	0.024	0.8	0
AC22-6	-20	13,400	6	6	0.64	1,440	0	0	0.64	1,440	0.068	2.3	25
AC22-4	-40	14,300	8	8	0.91	2,050	0	0	0.91	2,050	0.019	0.6	0

(1) Data from the First Progress Report recalculated(172).

(2) If specimen did not fail, this measurement was taken at the point on the load-deflection curve where the load had dropped to 13,000 pounds after passing maximum load (6000 pounds was used in first report).

(3) Absorbed energy = measured area under the load-deflection curve times 2,250 inch pounds.

(4) Measurement made at point of maximum contraction (usually 1/32 inch below the notch root) on both sides of fracture with pointed micrometers.

TABLE A-4 RESULTS OF KINZEL-TYPE SLOW-BEND SPECIMENS OF WELDED "C" STEEL HAVING A LONGITUDINAL WELD BEAD AND A TRANSVERSE NOTCH(1)

Specimen Number	Testing Temp, F	Maximum Load, Lb	Bend Angle, Degrees at(2)		Absorbed Energy(3)						Average Lateral Contraction(4)		Fracture Appearance, % Ductile
			Maximum Load	Complete Failure	Energy to Maximum Load		Energy After Maximum Load		Total Energy				
					Sq In.	In.-Lb	Sq In.	In.-Lb	Sq In.	In.·Lb	In.	%	
AC23-7	275	18,100	18	26	2.80	6,300	1.50	3,380	4.30	9,680	0.052	1.8	100
AC23-6	230	16,800	23	33	3.20	7,200	1.80	4,050	5.00	11,250	0.067	2.3	100
AC23-5	210	18,000	24	38	3.80	8,550	2.60	5,850	6.40	14,400	0.088	3.0	100
AC23-4	190	17,500	26	39	4.25	9,550	2.20	4,950	6.45	14,500	0.083	2.8	100
AC23-3	170	17,300	27	36	4.20	9,480	1.65	3,720	5.85	13,200	0.076	2.6	90
AC23-2	150	17,800	27	34	4.20	9,420	1.50	3,380	5.70	12,800	0.082	2.8	30
AC23-8	140	18,500	18	18	3.00	6,750	0	0	3.00	6,750	0.074	2.5	10
AC23-9	120	17,000	18	18	2.65	5,960	0	0	2.65	5,960	0.084	2.9	5
AC23-10	120	17,800	18	18	2.70	6,080	0	0	2.70	6,080	0.065	2.2	5
AC23-12	100	15,600	13	13	1.65	3,720	0	0	1.65	3,720	0.049	1.7	5
AC23-1	75	14,700	9	9	1.00	2,250	0	0	1.00	2,250	0.047	1.6	2
AC23-15	70	15,500	12	12	1.45	3,260	0	0	1.45	3,260	0.026	0.9	2
AC23-14	60	14,800	10	10	1.25	2,820	0	0	1.75	2,820	0.022	0.7	2
AC23-13	50	15,400	11	11	1.45	3,260	0	0	1.45	3,260	0.027	0.9	2
AC23-11	20	11,300	3	3	.20	450	0	0	.20	450	0.019	0.6	0

(1) Data from the First Progress Report recalculated(172).

(2) If specimen did not fail, this measurement was taken at the point on the load-deflection curve where the load had dropped to 13,000 pounds after passing maximum load (6000 pounds was used in first report).

(3) Absorbed energy = measured area under the load-deflection curve times 2,250 inch pounds.

(4) Measurement made at point of maximum contraction (usually 1/32 inch below the notch root) on both sides of fracture with pointed micrometers.

TABLE A-5. RESULTS OF SLOW-BEND TESTS OF SPECIMENS MADE FROM "B_r" STEEL AND HAVING A LONGITUDINAL E6020 WELD BEAD AND TRANSVERSE NOTCH (Kinzel Design)

Specimen Number	Testing Temp, F	Maximum Load, Lb	Bend Angle, Degrees at		Absorbed Energy(2)						Average Lateral Contraction(3)		Fracture Appearance, % Ductile
			Maximum Load	Complete Failure(1)	Energy to Maximum Load		Energy After Maximum Load		Total Energy		In.	%	
					Sq In.	In.-Lb	Sq In.	In. Lb	Sq In.	In.-Lb			
AC33-14	120	16,100	27	40	3.95	8,900	2.20	4,900	6.15	13,800	0.149	5.0	100
AC33-1	70	16,800	32	38	4.95	11,000	1.15	2,600	6.10	13,700	0.129	4.3	60
AC33-13	70	16,600	30	41	5.30	11,900	1.10	2,500	6.40	14,400	0.142	4.7	100
AC33-2	40	16,800	31	43	4.75	10,700	2.15	4,800	6.90	15,500	0.122	4.1	90
AC33-11	40	16,500	31	44	4.80	10,800	2.20	4,900	7.00	15,700	0.137	4.6	80
AC33-12	30	17,300	31	44	5.05	11,300	2.25	5,100	7.30	16,400	0.145	4.8	95
AC33-15	30	16,600	19	19	2.73	6,200	0	0	2.73	6,200	0.055	1.8	5
AC33-9	20	16,000	25	25	3.90	8,800	0	0	3.90	8,800	0.094	3.1	40
AC33-10	20	16,000	16	32	2.35	5,300	1.20	2,700	3.55	8,000	0.066	2.2	5
AC33-3	0	14,000	20	20	2.50	5,600	0	0	2.50	5,600	0.068	2.3	5
AC33-8	0	13,400	6	12	0.62	1,400	.85	1,900	1.47	3,300	0.038	1.3	5
AC33-6	-20	14,500	8	8	0.90	2,200	0	0	.90	2,200	0.022	0.7	2
AC33-7	-20	13,500	5	5	0.88	2,000	0	0	.88	2,000	0.016	0.5	0
AC33-4	-40	14,600	6	6	0.70	1,600	0	0	.70	1,600	0.016	0.5	0
AC33-5	-60	14,200	5	5	0.45	1,000	0	0	.45	1,000	0.011	0.4	0

(1) If the specimen did not fracture, this measurement was taken at the point on the load-deflection curve where the load had dropped to 13,000 pounds after passing maximum load.

(2) Absorbed energy = measured area under the load-deflection curve times 2,250 inch pounds.

(3) Measurement made at point of maximum contraction (usually 1/32 inch below the notch root) on both sides of fracture with pointed micrometers.

TABLE A-6. RESULTS OF SLOW-BEND TESTS OF 1-1/2-INCH-WIDE KINZEL-TYPE SPECIMENS MADE FROM "B_r" STEEL HAVING A LONGITUDINAL WELD BEAD AND TRANSVERSE NOTCH (Modified Kinzel Design)

Specimen Number	Testing Temp, F	Maximum Load, Lb	Bend Angle, Degrees at		Absorbed Energy(2)						Average Lateral Contraction(3)		Fracture Appearance, % Ductile
			Maximum Load	Complete Failure(1)	Energy to Maximum Load		Energy After Maximum Load		Total Energy		In.	%	
					Sq In.	In.-Lb	Sq In.	In.-Lb	Sq In.	In.-Lb			
AC32-1	75	8,800	30	37	2.40	5,400	0.70	1,600	3.10	7,000	—	—	100
AC32-2	50	9,300	37	60	3.18	7,200	2.27	5,100	5.45	12,300	—	—	100
AC32-11	40	9,100	28	39	2.33	5,200	1.05	2,400	3.38	7,600	0.111	7.4	100
AC32-10	20	9,500	34	42	2.95	6,600	0.75	1,700	3.70	8,300	0.128	8.5	100
AC32-3	0	10,400	37	37	3.50	7,900	0	0	3.50	7,900	0.099	6.6	8
AC32-9	0	9,100	32	43	2.78	6,200	1.05	2,400	3.83	8,600	0.094	6.3	100
AC32-7	-20	7,500	6	6	0.40	900	0	0	0.40	900	0.019	1.3	0
AC32-8	-20	8,400	12	12	0.80	1,800	0	0	0.80	1,800	0.030	2.0	2
AC32-12	-20	9,900	32	65	3.00	6,800	3.30	7,400	6.30	14,200	—	—	100
AC32-6	-30	9,500	22	22	2.00	4,500	0	0	2.00	4,500	0.062	4.2	5
AC32-4	-40	8,800	14	14	1.15	2,600	0	0	1.15	2,600	0.066	4.4	2
AC32-5	-80	9,700	13	13	1.10	2,500	0	0	1.10	2,500	0.035	2.3	2

(1) If the specimen did not fracture, this measurement was taken at the point on the load-deflection curve where the load had dropped to 13,000 pounds after passing maximum load.

(2) Absorbed energy = measured area under the load-deflection curve times 2,250 inch pounds.

(3) Measurement made at point of maximum contraction (usually 1/32 inch below the notch root) on both sides of fracture with pointed micrometers.

TABLE A-7. RESULTS OF SLOW-BEND TESTS OF 6-INCH-WIDE KINZEL-TYPE SPECIMENS MADE FROM "B_L" STEEL AND HAVING A LONGITUDINAL WELD BEAD AND TRANSVERSE NOTCH (Modified Kinzel Design)

Specimen Number	Testing Temp, F	Maximum Load, Lb	Bend Angle Degrees at Maximum Load	Bend Angle Degrees at Complete Failure(1)	Absorbed Energy(2): Energy to Maximum Load, Sq In.	Energy to Maximum Load, In.-Lb	Energy After Maximum Load, Sq In.	Energy After Maximum Load, In. Lb	Total Energy, Sq In.	Total Energy, In.-Lb	Average Lateral Contraction(3), In.	Average Lateral Contraction(3), %	Fracture Appearance, % Ductile
AC67-3	100	36,100	32	53	5.10	20,100	3.80	15,000	8.90	35,100	-	-	100
AC67-4	60	34,900	29	41	4.55	18,000	2.05	8,100	6.60	26,100	0.107	1.79	50
AC67-7	60	38,000	33	49	5.80	23,000	3.00	11,800	8.80	34,800	0.127	2.11	99
AC67-11	40	39,800	37	63	6.85	27,000	4.55	18,000	11.40	45,000	0.113	1.88	100
AC67-1	20	29,400	9	19	1.25	4,900	1.45	5,700	2.70	10,600	0.058	0.97	2
AC67-13	20	39,000	37	69	6.75	26,700	5.70	22,500	12.45	49,200	0.094	1.57	98
AC67-5	10	30,500	20	20	2.80	11,000	0	0	2.80	11,000	0.051	0.85	2
AC67-6	10	28,500	20	23	2.70	10,600	0	0	2.70	10,600	0.058	0.97	5
AC67-2	0	33,200	16	16	2.30	9,100	0	0	2.30	9,100	0.107	1.79	2
AC67-9	0	35,300	23	23	3.45	13,600	0	0	3.45	13,600	0.055	0.92	5
AC67-8	-20	28,800	3	13	0.35	14,000	1.30	5,100	1.65	6,500	0.041	0.68	2
AC67-10	-40	30,400	3	5	0	700	0.40	1,800	0.65	2,500	0.011	0.18	0
AC67-12	-60	30,500	2	2	0.20	800	0	0	0.20	800	0.008	0.13	0

(1) If the specimen did not fracture, this measurement was taken at the point on the load-deflection curve where the load dropped to 25,000 pounds after passing maximum load.

(2) Absorbed energy = measured area under the load-deflection curve times 3,946 inch pounds.

(3) Measurement made at point of maximum contraction (usually 1/32 inch below the notch root) on both sides of the fracture with pointed micrometers.

TABLE A-8. RESULTS OF SLOW-BEND TESTS OF KINZEL-TYPE SPECIMENS MADE FROM "B_L" STEEL AND HAVING A LONGITUDINAL WELD BEAD AND TRANSVERSE NOTCH 0.090 INCH DEEP (Modified Kinzel Design)

Specimen Number	Testing Temp, F	Maximum Load, Lb	Bend Angle, Degrees at Maximum Load	Bend Angle, Degrees at Complete Failure(1)	Absorbed Energy(2): Energy to Maximum Load, Sq In.	Energy to Maximum Load, In.-Lb	Energy After Maximum Load, Sq In.	Energy After Maximum Load, In.-Lb	Total Energy, Sq In.	Total Energy, In.-Lb	Average Lateral Contraction(3), In.	Average Lateral Contraction(3), %	Fracture Appearance, % Ductile
AC75-7	200	18,500	30	50	5.34	11,900	3.58	8,100	8.92	20,000	0.147	4.90	100
AC75-8	190	17,500	30	44	5.07	11,400	2.50	5,600	7.57	17,000	0.141	4.70	100
AC75-6	160	17,900	29	43	5.04	11,300	2.44	5,500	7.48	16,800	0.117	3.90	100
AC75-4	120	18,800	27	43	4.99	11,200	2.96	6,700	7.95	17,900	0.118	3.93	100
AC75-5	120	18,200	25	42	4.64	10,400	3.06	6,900	7.70	17,300	0.145	4.83	100
AC31-10	100	14,200	18	25	2.39	5,400	1.04	2,300	3.43	7,700	0.106	3.53	100
AC31-1	70	15,000	22	29	3.00	6,800	1.20	2,700	4.20	9,500	—	—	100
AC31-7	60	14,800	22	29	3.02	6,800	1.13	2,500	4.15	9,300	0.103	3.43	100
AC31-9	60	14,800	20	29	2.63	5,900	1.50	3,400	4.13	9,300	—	—	100
AC31-8	50	15,100	16	20	2.13	4,800	0.57	1,300	2.70	6,100	0.078	2.60	50
AC31-14	50	14,900	18	28	2.49	5,600	1.58	3,600	4.07	9,200	—	—	100
AC31-6	40	14,800	11	13	1.28	2,800	0.25	600	1.53	3,400	0.057	1.90	10
AC31-13	40	15,300	20	29	2.85	6,300	1.40	3,200	4.25	9,500	—	—	100
AC31-15	30	16,400	30	42	4.48	10,100	1.95	4,400	6.43	10,500	—	—	100
AC31-2	20	13,900	9	10	1.05	2,400	0.15	300	1.20	2,700	0.073	2.43	15
AC31-11	20	14,800	13	13	1.50	3,400	0	0	1.50	3,400	0.031	1.03	2
AC31-12	20	14,400	10	10	1.23	2,800	0	0	1.23	2,800	0.022	0.73	0
AC31-3	0	14,700	10	10	1.27	2,900	0	0	1.27	2,900	0.026	0.87	2
AC31-4	0	15,500	20	20	2.73	6,100	0	0	2.73	6,100	0.087	2.89	10
AC31-5	-40	16,400	11	11	1.55	3,500	0	0	1.55	3,500	0.009	0.30	0
AC75-1	-40	13,600	1	1	0.15	300	0	0	0.15	300	0.005	0.17	0
AC75-3	-60	14,800	2	2	0.30	700	0	0	0.30	700	0.009	0.30	0
AC75-2	-80	19,100	10	10	1.90	4,300	0	0	1.90	4,300	0.007	0.23	0

(1) If the specimen did not fracture, this measurement was taken at the point on the load-deflection curve where the load had dropped to 13,000 pounds after passing maximum load.

(2) Absorbed energy = measured area under the load-deflection curve times 2,250 inch pounds.

(3) Measurement made at point of maximum contraction (usually 1/32 inch below the notch root) on both sides of fracture with pointed micrometers.

TABLE A-9. RESULTS OF SLOW-BEND TESTS OF KINZEL-TYPE SPECIMENS MADE FROM "C" STEEL HAVING A LONGITUDINAL WELD BEAD AND TRANSVERSE NOTCH 0.090 INCH DEEP (Modified Kinzel Design)

Specimen Number	Testing Temp, F	Maximum Load, Lb	Bend Angle, Degrees at Maximum Load	Bend Angle, Degrees at Complete Failure(1)	Absorbed Energy(2): Energy to Maximum Load, Sq In.	Energy to Maximum Load, In.-Lb	Energy After Maximum Load, Sq In.	Energy After Maximum Load, In.-Lb	Total Energy, Sq In.	Total Energy, In.-Lb	Average Lateral Contraction(3), In.	Average Lateral Contraction(3), %	Fracture Appearance, % Ductile
AC64-9	200	15,900	19	28	2.70	6,100	1.55	3,500	4.25	9,600	0.106	3.53	100
AC64-7	200	16,500	18	29	2.68	6,100	1.75	3,900	4.43	10,000	—	—	100
AC64-6	180	15,900	18	30	2.58	5,800	1.87	4,200	4.45	10,000	0.074	2.96	100
AC64-5	180	15,800	18	28	2.55	5,700	1.60	3,600	4.15	9,300	0.080	2.67	100
AC64-11	160	16,000	18	24	2.57	5,800	0.85	1,900	3.42	7,700	0.072	2.40	80
AC64-10	160	15,700	16	27	2.24	5,100	1.78	4,000	4.02	9,100	0.091	3.03	75
AC64-13	150	15,500	16	16	2.08	4,700	0	0	2.08	4,700	0.085	2.83	50
AC64-12	140	17,000	18	18	2.75	6,200	0	0	2.75	6,200	0.065	2.18	10
AC64-4	140	15,800	15	21	2.00	4,300	1.00	2,300	3.00	6,700	0.067	2.23	10
AC64-14	120	15,500	13	21	1.60	3,600	1.30	2,900	2.90	6,500	0.066	2.20	10
AC64-3	100	16,100	14	14	1.80	4,000	0	0	1.80	4,000	0.039	1.30	2
AC64-2	80	15,800	13	13	1.72	3,900	0	0	1.72	3,900	0.032	1.07	2
AC64-1	60	13,300	7	7	0.63	1,400	0	0	0.63	1,400	0.022	0.73	0
AC64-15	20	14,100	6	6	0.75	1,700	0	0	0.75	1,700	0.015	0.50	0

(1) If the specimen did not fracture, this measurement was taken at the point on the load-deflection curve where the load ha dropped to 13,000 pounds after passing maximum load.

(2) Absorbed energy = measured area under the load-deflection curve times 2,250 inch pounds.

(3) Measurement made at point of maximum contraction (usually 1/32 inch below the notch root) on both sides of fracture with pointed micrometers.

TABLE A-10. RESULTS OF SLOW-BEND TESTS OF TEE-BEND SPECIMENS MADE FROM "B_r" STEEL AND USING STANDARD WELDING SCHEDULE(1)

Specimen Number	Testing Temp, F	Maximum Load, Lb	Bend Angle, Degrees: At Maximum Load	After Maximum Load	At Complete Failure(2)	Absorbed Energy(3): Energy to Maximum Load, Sq In.	Energy to Maximum Load, In. Lb	Energy After Maximum Load, Sq In.	Energy After Maximum Load, In.-Lb	Total Energy, Sq In.	Total Energy, In. Lb
AC20-1	80	12,750	0	0	0	8.30	18,600	6.59	14,900	14.89	33,500
AC21-5	80	13,000	77	43	120	8.05	18,100	6.85	15,500	14.90	33,600
AC20-4	10	12,200	74	46	120	8.39	18,800	6.11	13,900	14.50	32,700
AC20-6	5	12,250	72	48	120	7.70	17,300	7.70	17,300	15.40	34,600
AC21-1	5	12,000	75	45	120	7.85	17,600	7.35	16,700	15.20	34,300
AC20-5	5	12,000	75	20	95	7.90	17,800	3.93	8,900	11.83	26,700
AC20-2	0	12,800	77	31	108	9.83	22,300	4.57	10,100	14.40	32,400
AC21-3	0	12,600	72	22	94	8.20	18,400	3.68	8,400	11.88	26,800
AC21-4	0	12,500	77	23	100	8.27	18,600	4.56	10,400	12.83	29,000
AC21-2	-10	12,250	72	20	92	8.19	18,400	3.43	7,800	11.62	26,200
AC20-3	-20	12,300	74	0	0	8.17	18,400	7.31	16,400	15.48	34,900

(1) Data from the First Progress Report recalculated(172).

(2) If specimen did not fail, this measurement was taken at the point on the load-deflection curve where the load had dropped to 9,000 pounds after passing maximum load (6,000 pounds was used in First Progress Report).

(3) Absorbed energy = measured area under the load-deflection curve times 2,250 inch pounds.

TABLE A-11. RESULTS OF SLOW-BEND TESTS OF TEE-BEND SPECIMENS MADE FROM "C" STEEL AND USING STANDARD WELDING SCHEDULE(1)

Specimen Number	Testing Temp, F	Maximum Load, Lb	Bend Angle, Degrees			Absorbed Energy(3)					
			At Maximum Load	After Maximum Load	At Complete Failure(2)	Energy to Maximum Load		Energy After Maximum Load		Total Energy	
						Sq In.	In.-Lb	Sq In.	In.-Lb	Sq In.	In.-Lb
AC18-4	150	13,400	80	40	120	9.67	21,800	8.96	20,200	18.63	42,000
AC18-3	130	13,350	79	41	120	9.24	20,800	9.69	21,800	18.93	42,600
AC18-2	120	13,200	80	43	120	9.75	22,000	8.03	18,000	17.78	40,000
AC18-5	120	13,500	77	40	120	9.42	21,200	10.20	23,200	19.62	44,400
AC18-6	110	13,000	80	39	119	9.30	20,900	7.56	17,000	16.86	37,900
AC18-1	100	13,400	78	41	119	9.32	21,000	8.68	19,600	18.00	40,600
AC17-6	80	14,300	76	18	94	9.75	22,000	3.15	7,300	12.90	29,300
AC17-1	75	13,300	79	37	116	9.18	20,600	7.50	17,000	16.68	37,600
AC17-5	60	14,100	76	28	104	9.00	20,300	5.95	13,300	14.95	33,600
AC17-4	40	14,000	63	0	63	7.23	16,300	1.22	2,700	8.45	19,000
AC17-2	30	13,650	63	0	63	8.35	18,800	0	0	8.35	18,800
AC17-3	0	13,900	0	0	0	8.65	19,500	2.83	6,300	11.48	25,800

(1) Data from the First Progress Report recalculated(172).

(2) If specimen did not fail, this measurement was taken at the point on the load-deflection curve where the load had dropped to 9,000 pounds after passing maximum load (6,000 pounds was used in First Progress Report).

(3) Absorbed energy = measured area under the load-deflection curve times 2,250 inch pounds.

TABLE A-12. RESULTS OF SLOW-BEND TESTS OF TEE-BEND SPECIMENS MADE FROM "B_r" STEEL AND USING A MODIFIED WELDING SCHEDULE

Specimen Number	Testing Temp, F	Maximum Load, Lb	Bend Angle, Degrees			Absorbed Energy(2)					
			at Maximum Load	after Maximum Load	at Complete Failure(1)	Energy to Maximum Load		Energy After Maximum Load		Total Energy	
						Sq In.	In.-Lb	Sq In.	In.-Lb	Sq In.	In.-Lb
AC70-1	70	13,700	57	43	100	7.2	16,100	6.1	13,800	13.3	29,900
AC70-2	30	14,000	72	28	100	9.8	22,000	4.4	9,900	14.2	31,900
AC70-3	0	14,200	53	47	100	6.8	15,300	6.4	14,400	13.2	29,700
AC70-9	-10	13,600	57	0	57	7.2	16,100	0	0	7.2	16,100
AC70-10	-10	12,300	48	0	48	5.4	12,100	0	0	5.4	12,100
AC70-8	-20	13,800	59	5	64	7.6	17,200	1.0	2,200	8.6	19,400
AC70-4	-40	14,300	48	0	48	5.7	12,800	0	0	5.7	12,800
AC70-5	-60	14,400	60	0	60	8.1	18,100	0	0	8.1	18,100
AC70-7	-60	13,400	42	0	42	5.5	12,300	0	0	5.5	12,300
AC70-6	-80	12,800	28	0	28	3.4	7,700	0	0	3.40	7,700

(1) If specimen did not part, this measurement was taken at the point on the load deflection curve where the load had dropped to 9000 pounds after passing maximum load.

(2) Absorbed energy = measured area under the load-deflection curve times 2,250 inch pounds.

TABLE A-13. RESULTS OF SLOW-BEND TESTS OF 3-INCH-WIDE TEE-BEND SPECIMENS MADE FROM "B_r" STEEL AND USING A MODIFIED SCHEDULE

			Bend Angle, Degrees			Absorbed Energy(2)					
						Energy to Maximum Load		Energy After Maximum Load		Total Energy	
Specimen Number	Testing Temp, F	Maximum Load, Lb	At Maximum Load	After Maximum Load	At Complete Failure(1)	Sq In.	In.-Lb	Sq In.	In.-Lb	Sq In.	In.-Lb
AC95-6	120	21,100	73	42	115	14.80	33,400	11.10	25,000	25.90	58,400
AC94-1	80	21,100	62	53	115	12.50	28,200	12.80	28,800	25.30	57,000
AC94-3	40	22,900	68	47	115	14.80	33,300	13.20	29,700	28.00	63,000
AC95-4	40	22,500	63	52	115	12.80	28,700	14.10	31,800	26.90	60,500
AC95-2	20	22,800	75	0	75	16.30	36,700	0	0	16.30	36,700
AC95-5	20	23,900	65	0	65	14.40	32,400	0	0	14.40	32,400
AC94-2	0	24,000	75	21	96	17.20	38,700	6.50	14,600	23.70	53,300
AC95-3	-0	22,800	61	0	61	12.40	27,900	0	0	12.40	27,900
AC95-1	-20	22,900	54	0	54	10.80	24,300	0	0	10.80	24,300
AC94-4	-40	24,300	61	0	61	13.70	30,800	0	0	13.70	30,800
AC94-5	-70	24,500	51	0	51	11.90	26,800	0	0	11.90	26,800
AC94-6	-80	24,100	46	0	46	10.00	22,500	0	0	10.00	22,500

(1) If specimens did not part, this measurement was taken at the point on the load-deflection curve where the load had dropped to 9000 pounds after passing maximum load.

(2) Absorbed energy = measured area under the load-deflection curve times 2,250 inch pounds.

TABLE A-14. RESULTS OF SLOW-BEND TESTS OF 3 INCH WIDE TEE-BEND SPECIMENS MADE FROM "C" STEEL AND USING A MODIFIED WELDING SCHEDULE

Specimen Number	Testing Temp, F	Maximum Load, Lb	Bend Angle, Degrees			Absorbed Energy(2)					
			At Maximum Load,	After Maximum Load	At Complete Failure(1)	Energy to Maximum Load		Energy After Maximum Load		Total Energy	
						Sq In.	In.-Lb	Sq In.	In.-Lb	Sq In.	In.-Lb
AC96-6	200	21,700	64	51	115	12.40	27,900	11.5	25,900	23.90	53,800
AC97-1	190	21,800	68	47	115	12.90	29,000	11.2	25,200	24.10	54,200
AC97-2	180	21,600	72	43	115	14.20	31,900	10.70	24,100	24.90	56,000
AC96-5	160	21,700	70	15	85	13.70	31,300	4.00	9,000	17.70	40,300
AC97-3	160	20,600	71	44	115	13.60	30,600	9.70	21,800	23.30	52,400
AC97-6	160	20,600	70	45	115	13.10	29,400	10.60	23,800	23.70	53,200
AC97-4	140	20,600	64	34	98	11.70	26,200	7.90	17,800	19.60	44,000
AC97-5	140	20,500	67	48	115	12.60	28,300	11.10	25,000	23,70	53,300
AC96-4	120	21,700	59	10	69	11.20	25,200	2.60	5,800	13.80	31,000
AC96-1	80	21,700	55	0	55	9.90	22,300	0	0	9.90	22,300
AC96-2	40	23,100	56	0	56	11.00	24,700	0	0	11.00	24,700
AC96-3	0	22,500	50	0	50	9.50	21,400	0	0	9.50	21,300

(1) If specimens did not part, this measurement was taken at the point on the load-deflection curve where the load had dropped to 9000 pounds after passing maximum load.

(2) Absorbed energy = measured area under the load-deflection curve times 2,250 inch pounds.

TABLE A-15. RESULTS OF TESTS OF NOTCHED TENSION SPECIMENS OF UNWELDED "B_r" STEEL

Specimen Number	Testing Temp, F	Maximum Load, Lb	Elongation at Max Load,(1) %	Area, Sq In.	Energy Absorbed to Maximum Load,(2) In.-Lb	Lateral Contraction,(3) %	Fracture Appearance, % Ductile
AC118-16	-240	149,200	0.031	10.8	4,300	0.29	0
AC118-14	-220	135,400	0.034	11.60	4,600	0.29	0
AC118-17	-200	127,600	0.061	18.50	7,400	1.38	2
AC118-7	-200	150,000	0.337	116.20	46,500	8.50	3
AC118-9	-180	148,000	0.253	85.30	34,100	11.00	2
AC118-13	-170	142,000	0.280	89.30	35,700	8.05	4
AC118-8	-170	142,000	0.242	77.30	30,900	10.70	11
AC118-12	-160	143,000	0.346	115.60	46,200	10.80	15
AC118-11	-160	141,000	0.403	127.30	51,000	10.50	25
AC118-6	-140	136,600	0.328	97.60	39,000	10.20	100
AC118-3	- 60	135,000	0.340	84.70	33,900	12.20	100
AC118-4	- 40	135,000	0.290	83.50	33,400	11.90	100
AC118-5	- 20	132,000	0.340	97.20	38,800	11.30	100
AC118-2	- 0	129,600	0.305	85.00	34,000	10.40	100
AC118-1	+ 20	128,000	0.324	89.00	35,600	10.80	100

(1) Elongation taken on 1-3/4-inch gauge length.

(2) Absorbed energy = measured area under load-deflection curve in inches times 400 inch pounds.

(3) Measurement made at point of maximum contraction (usually 1/32 inch below the notch root,on both sides of fracture with pointed micrometer.

TABLE A-16. RESULTS OF TESTS OF NOTCHED TENSION SPECIMENS OF WELDED "B_r" STEEL

Specimen Number	Testing Temp, F	Maximum Load, Lb	Elongation at Maximum Load, %(1)	Area, Sq In.	Energy Absorbed to Maximum Load, In.-Lb (2)	Lateral Contraction, %(3)	Fracture Appearance % Ductile
AC111-2	-50	90,400	0.0294	6.05	2,420	0.87	0
AC111-15	-40	102,500	0.0568	11.45	4,580	1.53	0
AC111-11	-40	107,000	0.0678	15.00	6,000	1.74	3
AC111-16	-30	92,300	0.0390	7.50	3,000	0.91	1
AC111-1	-30	130,000	0.165	45.00	18,000	1.46	5
AC111-14	-30	130,800	0.2165	61.00	24,400	9.10	100
AC111-4	-30	131,800	0.230	65.40	26,200	8.76	100
AC111-17	-20	127,200	0.192	52.20	20,800	8.18	100
AC111-10	-20	129,600	0.1945	53.40	21,400	8.84	100
AC111-12	0	126,700	0.1935	52.50	21,000	9.38	100
AC111-8	0	127,000	0.194	52.60	21,000	8.53	100
AC111-13	20	124,500	0.205	55.1	22,000	8.64	100
AC111-20	20	125,000	0.175	46.6	18,600	8.40	100
AC111-3	40	122,500	0.166	43.4	17,400	8.50	100
AC111-9	60	124,200	0.2125	56.7	22,600	9.05	100
AC111-18	75	120,200	0.210	54.7	21,800	8.25	100
AC111-6	72-80	121,600	0.2025	53.0	21,200	8.15	100

(1) Elongation taken on 1-3/4-inch gauge length.

(2) Absorbed energy = measured area under load-deflection curve in inches times 400 inch pounds.

(3) Measurement made at point of maximum contraction (usually 1/32 inch below the notch root) on both sides of fracture with pointed micrometer.

TABLE A-17. RESULTS OF TESTS OF NOTCHED TENSION SPECIMENS OF UNWELDED "C" STEEL

Specimen Number	Testing Temp, F	Maximum Load, Lb	Elongation at Maximum Load, %(1)	Area, Sq In.	Energy Absorbed to Maximum Load, In.-Lb(2)	Lateral Contraction, %(3)	Fracture Appearance % Ductile
AC117-19	-160	134,800	0.130	37.0	14,800	3.82	0
AC117-18	-120	133,400	0.139	38.3	15,300	3.71	0
AC117-17	-100	132,400	0.140	38.0	15,200	3.64	0
AC117-16	- 80	139,500	0.236	70.6	28,200	6.14	0
AC117-15	- 50	132,200	0.177	48.0	19,200	4.47	0
AC117-13	- 40	132,400	0.181	48.6	19,400	4.84	0
AC117-10	0	130,900	0.165	44.2	17,700	8.48	0
AC117-7	20	127,800	0.167	43.3	17,300	8.62	1
AC117-8	40	128,900	0.214	67.5	27,000	6.30	8
AC117-9	60	125,500	0.199	51.3	20,500	5.90	6
AC117-12	60	133,200	0.182	49.6	19,900	4.95	11
AC117-14	70	128,000	0.200	52.5	21,000	6.44	100
AC117-11	80	125,600	0.234	61.8	24,700	6.80	100
AC117-6	80	125,200	0.227	60.6	24,200	6.87	100
AC117-1	100	122,600	0.192	49.6	19,800	6.70	100
AC117-4	120	124,200	0.224	59.3	23,600	7.24	100
AC117-2	140	124,000	0.189	49.0	19,600	6.80	100
AC117-3	160	125,800	0.199	52.1	20,800	6.87	100
AC117-5	180	144,200	0.141	38.9	15,600	Not possible	100

(1) Elongation taken on 1-3/4 inch-gauge length.

(2) Absorbed energy = measured area under load-deflection curve in inches times 400 inch pounds.

(3) Measurement made at point of maximum contraction (usually 1/32 inch below the notch root) on both sides of fracture with pointed micrometer.

TABLE A-18. RESULTS OF TESTS OF NOTCHED TENSION SPECIMENS OF WELDED "C" STEEL

C - NOTCHED TENSION - WELDED

Specimen Number	Testing Temp, F	Maximum Load, Lb	Elongation at Maximum Load, %(1)	Area, Sq In.	Energy Absorbed to Maximum Load, In.-Lb(2)	Lateral Contraction, %(3)	Fracture Appearance, % Ductile
AC104-14	0	104,600	0.0464	10.45	4,180	1.38	1
AC104-16	0	107,400	0.0557	12.85	5,140	1.8	1
AC104-12	20	100,600	0.0446	11.15	4,460	1.42	0
AC104-13	20	110,000	0.0617	14.70	5,880	1.90	2
AC104-10	40	119,400	0.0788	20.60	8,240	1.8	5
AC104-11	40	127,600	0.1037	27.90	11,150	3.1	5
AC104-8	60	107,600	0.587	13.50	5,400	2.0	3
AC104-9	60	120,200	0.0922	23.20	9,280	3.1	5
AC104-2	80	122,400	0.1090	27.90	11,150	3.1	8
AC104-3	80	119,000	0.1021	26.75	10,700	2.0	5
AC104-1	100	121,000	0.1131	29.10	11,600	3.7	15
AC104-5	100	119,600	0.1286	33.50	13,400	—	8
AC104-4	120	120,800	0.1384	34.30	13,700	5.57	100
AC104-6	120	119,400	0.1280	31.90	12,800	5.6	100
AC104-7	140	120,400	0.1213	29.40	11,800	—	100
AC104-20	160	121,000	0.0990	24.20	9,700	3.48	100
AC104-17	180	135,000	0.0780	20.30	8,100	5.23	100

(1) Elongation taken on 1-3/4-inch gauge length.

(2) Absorbed energy = measured area under load-deflection curve in inches times 400 inch-pounds.

(3) Measurement made at point of maximum contraction (usually 1/32 inch below the notch root) on both sides of fracture with pointed micrometer.

TABLE A-19. RESULTS OF TESTS OF ALL-WELD-METAL KINZEL-TYPE SPECIMENS OF E6010 WELD METAL

Specimen Number	Testing Temp, F	Maximum Load, Lb	Bend Angle, Degrees at Maximum Load	Bend Angle, Degrees at Complete Failure(1)	Absorbed Energy(2) Energy to Maximum Load Sq In.	Absorbed Energy(2) Energy to Maximum Load In.-Lb	Absorbed Energy(2) Total Energy Sq In.	Absorbed Energy(2) Total Energy In.-Lb	Average Lateral Contraction(3) In.	Average Lateral Contraction(3) %	Fracture Appearance, % Ductile
AC39	120	18,800	30	36	4.94	11,100	6.03	13,600	0.099	3.30	100
AC34	70	20,500	37	43	6.70	15,100	7.91	17,800	0.111	3.70	100
AC35	0	19,800	32	39	5.60	12,600	6.95	15,600	0.102	3.40	95
AC40	-20	20,600	32	37	5.88	13,200	7.09	16,200	0.095	3.17	30
AC41	-20	20,300	32	36	5.81	13,100	6.66	15,000	0.098	3.27	20
AC42	-30	21,100	33	41	6.52	14,700	8.22	18,500	0.096	3.20	35
AC36	-40	19,000	21	21	3.56	8,000	3.56	8,000	0.052	1.73	5
AC38	-40	21,000	34	39	6.50	14,600	7.60	17,100	0.103	3.43	25
AC43	-60	17,600	12	12	1.82	4,100	1.82	4,100	0.030	1.00	0
AC47	-60	22,000	37	42	7.61	17,100	8.89	20,000	—	—	25
AC48	-60	20,300	30	37	5.58	12,600	7.08	15,900	0.104	3.46	25
AC37	-80	21,100	24	24	4.35	9,700	4.35	9,700	0.060	2.00	0
AC46	-80	22,000	33	40	6.80	15,300	8.33	18,700	0.110	3.66	15
AC44	-105	23,000	33	39	6.46	14,500	8.56	19,300	0.109	3.63	20
AC45	-105	23,200	33	35	7.30	16,400	7.50	16,900	0.100	3.33	15
AC85	-120	25,900	33	40	8.30	18,700	10.20	23,000	0.102	3.40	25
AC86	-120	24,600	28	31	6.51	14,700	7.30	16,400	0.083	2.77	20
AC84	-130	22,200	18	18	3.70	8,300	3.70	8,300	0.050	1.67	0
AC82	-140	22,300	5	5	1.00	2,250	1.00	2,250	0.011	0.37	0
AC87	-150	24,400	17	17	3.57	8,000	3.57	8,000	0.033	1.10	0
AC83	-165	23,800	8	8	1.62	3,600	1.62	3,600	0.024	0.80	0

(1) If the specimen did not fracture, this measurement was taken at the point on the load-deflection curve where the load had dropped to 13,000 pounds after passing maximum load.

(2) Absorbed energy = measured area under the load-deflection curve times 2,250 inch pounds.

(3) Measurement made at point of maximum contraction (usually 1/32 inch below the notch root) on both sides of fracture with pointed micrometers.

TABLE A-20. RESULTS OF TESTS OF ALL-WELD-METAL KINZEL-TYPE SPECIMEN OF

E6020 WELD METAL

Specimen Number	Testing Temp, F	Maximum Load, Lb	Bend Angle, Degrees at Maximum Load	Bend Angle, Degrees at Complete Failure(1)	Absorbed Energy(2) Energy to Maximum Load Sq In.	Absorbed Energy(2) Energy to Maximum Load In.-Lb	Absorbed Energy(2) Total Energy Sq In.	Absorbed Energy(2) Total Energy In.-Lb	Average Lateral Contraction(3) In.	Average Lateral Contraction(3) %	Fracture Appearance, % Ductile
AC51	80	17,300	21	26	3.40	7,700	4.30	9,700	0.059	1.96	100
AC59	40	19,200	25	32	4.50	10,100	5.95	13,400	0.071	2.33	100
AC63	40	18,600	25	32	4.20	9,450	5.60	12.600	0.072	2.40	100
AC49	20	19,400	28	32	4.70	10,600	6.00	13,500	0.069	2.30	100
AC61	20	17,400	19	26	3.10	7,000	4.25	9,600	0.064	2.13	75
AC57	0	16,100	10	18	1.40	3,100	2.55	5,700	0.027	0.90	50
AC60	0	18,000	16	16	2.70	6,100	2.70	6,100	0.038	1.27	0
AC53	-40	19,900	27	34	4.95	11,100	6.30	14,200	0.080	2.66	25
AC52	-40	17,300	10	10	1.80	4,050	1.80	4,050	0.023	0.77	0
AC92	-40	23,300	28	36	5.75	12,900	7.60	17,100	0.077	2.59	0
AC55	-60	17,100	7	7	1.00	2,250	1.00	2,250	0.017	0.57	0
AC58	-60	18,200	9	9	1.40	3,150	1.40	3,150	0.019	0.63	0
AC56	-80	18,100	8	8	1.25	2,800	1.25	2,800	0.020	0.67	0
AC50	-80	20,000	17	17	3.20	7,200	3.20	7,200	0.042	1.40	0
AC54	-105	18.800	7	7	0.95	2,100	0.95	2,100	0.010	0.33	0
AC62	-105	18,800	6	6	0.95	2,100	0.95	2,100	0.012	0.40	0
AC89	-120	20.600	4	4	0.85	1,900	0.85	1,900	0.013	0.43	0
AC90	-130	23,400	12	12	2.60	5,850	2.60	5,850	0.030	1.00	0
AC88	-140	21,000	2	2	0.25	560	0.25	560	0	0	0
AC91	-145	23,800	8	8	1.80	4,050	1,80	4,050	0.018	0.60	0
AC93	-165	23,800	8	8	1.80	4,050	1.80	4,050	0.017	0.57	0

(1) If the specimen did not fracture, this measurement was taken at the point on the load-deflection curve where the load had dropped to 13,000 pounds after passing maximum load.

(2) Absorbed energy = measured area under the load-deflection curve times 2,250 inch pounds.

(3) Measurement made at point of maximum contraction (usually 1/32 inch below the notch root) on both sides of fracture with pointed micrometers.

APPENDIX B

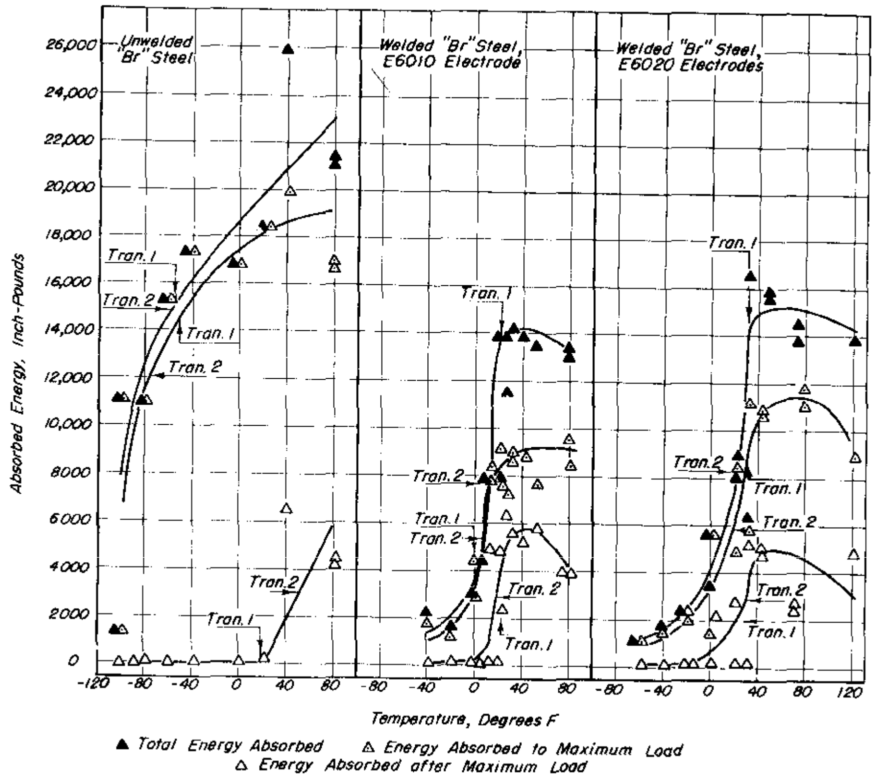


FIGURE B-1A. COMPARISON OF TRANSITION-TEMPERATURE CURVES OF "Br" STEEL, BASED ON ENERGY ABSORBED BY KINZEL-TYPE SPECIMENS, UNWELDED AND WELDED WITH E6010 AND E6020 ELECTRODES

0-11698

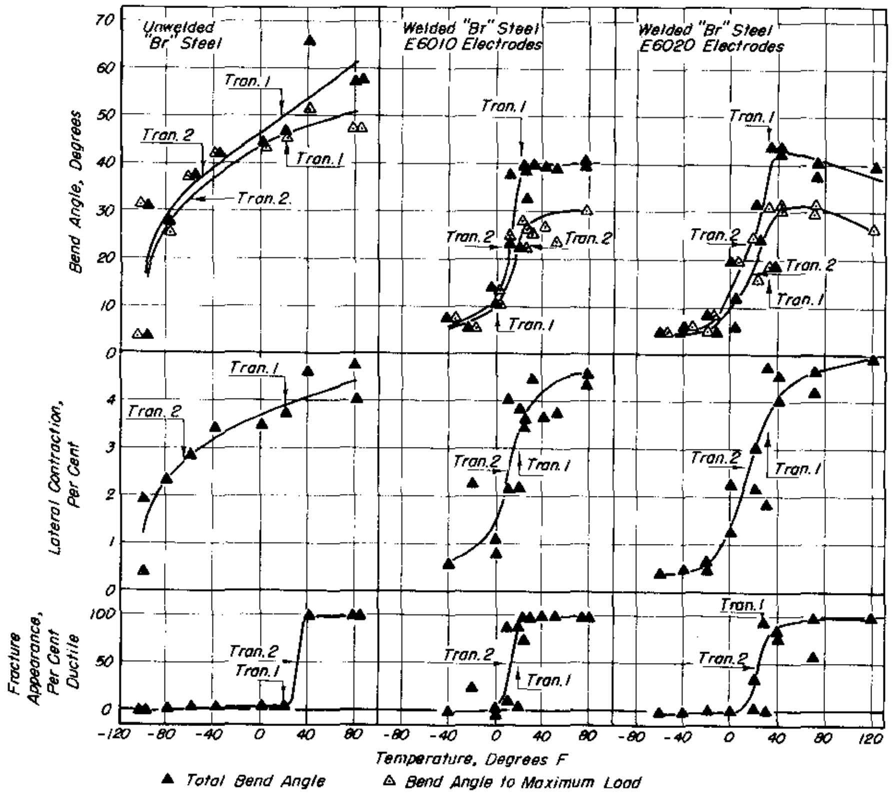


FIGURE B-1B. COMPARISON OF TRANSITION-TEMPERATURE CURVES OF "Br" STEEL, BASED ON BEND ANGLE, LATERAL CONTRACTION, AND FRACTURE APPEARANCE OF KINZEL-TYPE SPECIMENS, UNWELDED AND WELDED WITH E6010 AND E6020 ELECTRODES

0-11699

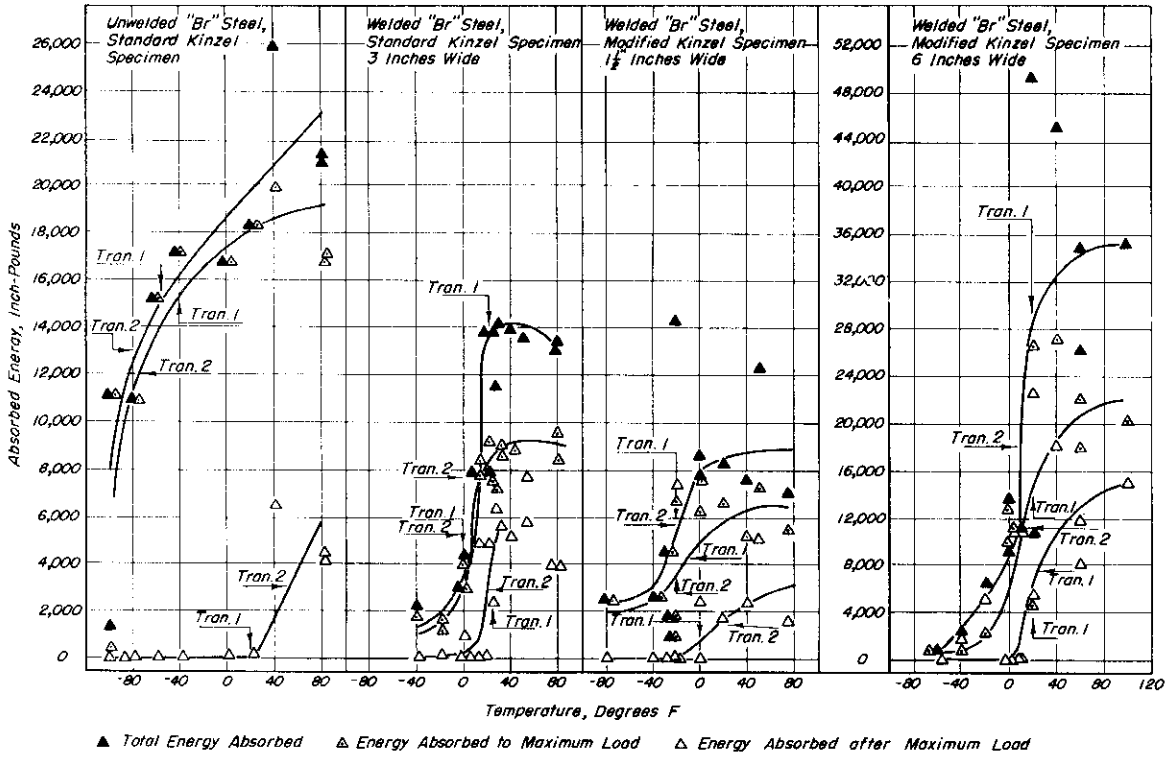


FIGURE B-2A. COMPARISON OF TRANSITION-TEMPERATURE CURVES OF "Br" STEEL BASED ON ENERGY ABSORBED BY STANDARD KINZEL SPECIMENS, 1½ INCHES AND 6 INCHES WIDE, WELDED WITH E6010 ELECTRODES

O-11700

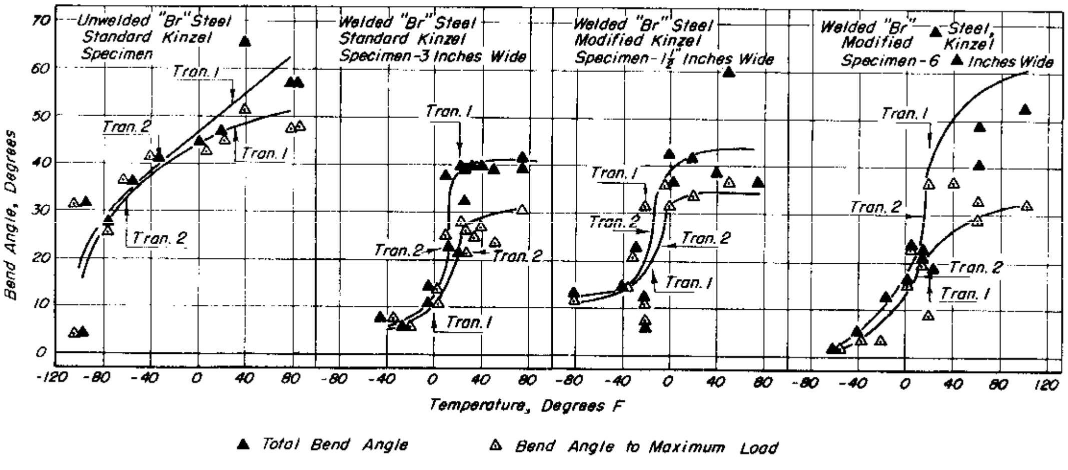


FIGURE B-2B. COMPARISON OF TRANSITION-TEMPERATURE CURVES OF "Br" STEEL, BASED ON BEND ANGLE OF STANDARD KINZEL SPECIMENS AND MODIFIED KINZEL SPECIMENS, 1½ INCHES AND 6 INCHES WIDE, WELDED WITH E6010 ELECTRODES

O-11701

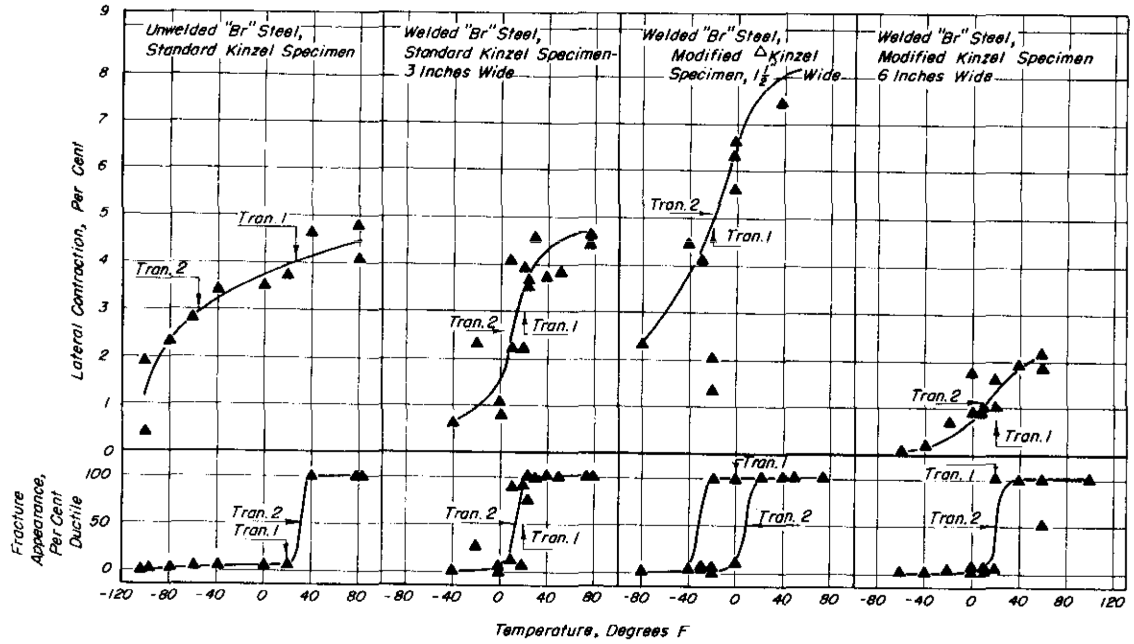


FIGURE B-2C. COMPARISON OF TRANSITION-TEMPERATURE CURVES OF "Br" STEEL BASED ON LATERAL CONTRACTION AND FRACTURE APPEARANCE OF STANDARD KINZEL SPECIMENS AND MODIFIED KINZEL SPECIMENS, 1½ AND 6 INCHES WIDE, WELDED WITH E6010 ELECTRODES

O-11702

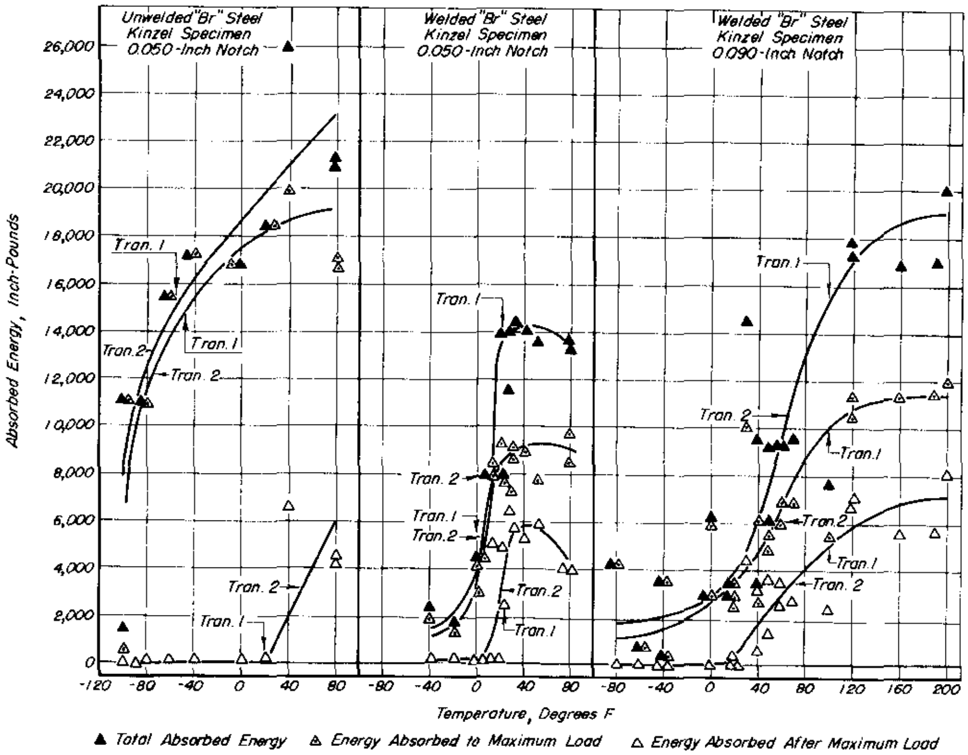


FIGURE B-3A. COMPARISON OF TRANSITION-TEMPERATURE CURVES OF "Br" STEEL, BASED ON ENERGY ABSORBED BY STANDARD KINZEL SPECIMENS AND SPECIMENS NOTCHED 0.090 INCH DEEP. WELDED WITH E6010 ELECTRODES

O-11704

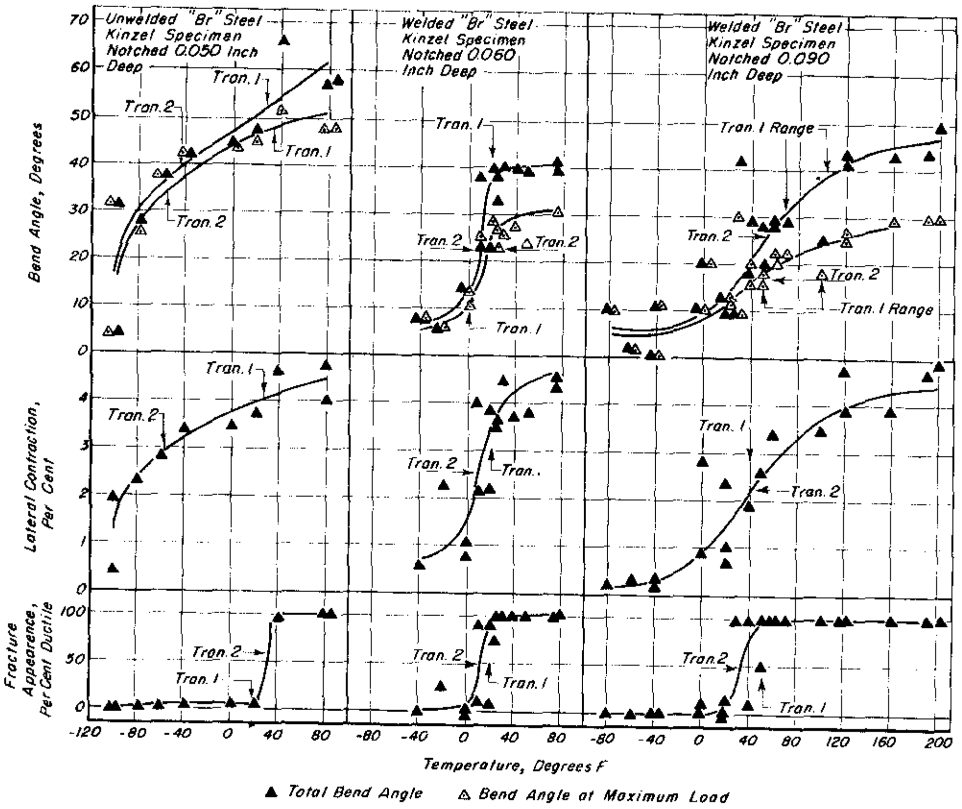


FIGURE B-3B. COMPARISON OF TRANSITION-TEMPERATURE CURVES OF "Br" STEEL BASED ON BEND ANGLE, LATERAL CONTRACTION, AND FRACTURE APPEARANCE OF STANDARD KINZEL SPECIMENS AND KINZEL SPECIMENS, NOTCHED 0.090 INCH DEEP, WELDED WITH E6010 ELECTRODES

0-11703

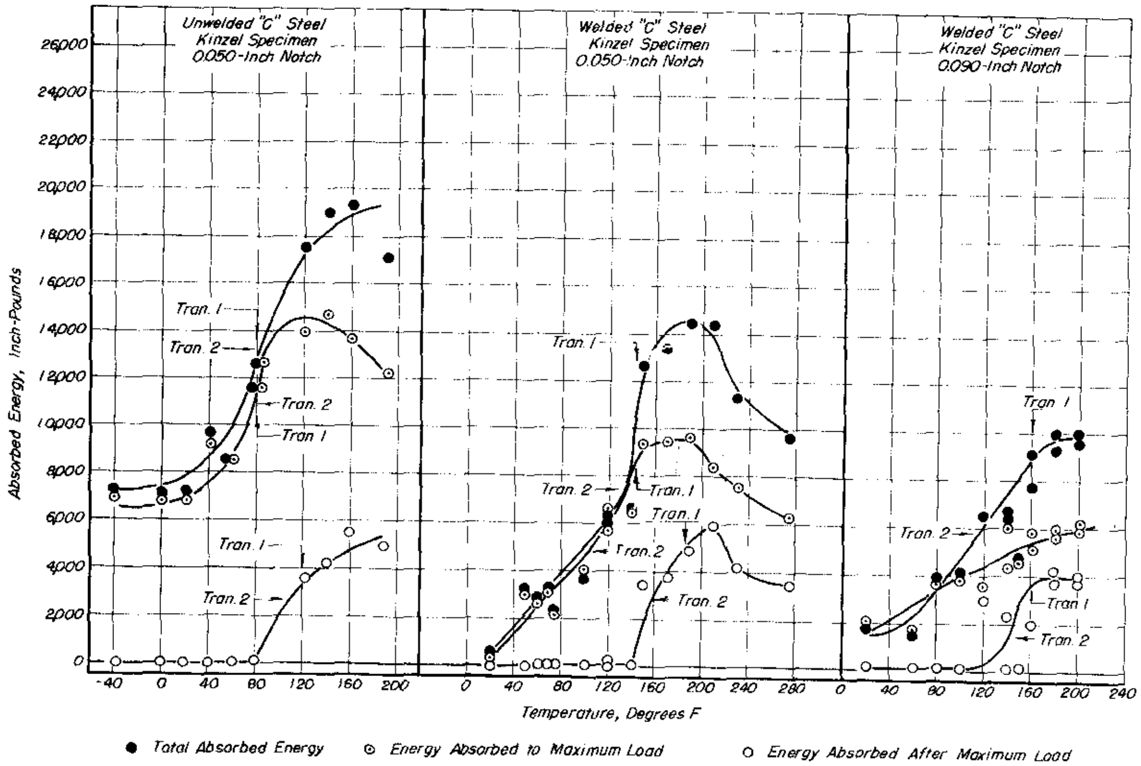


FIGURE B-4A. COMPARISON OF TRANSITION-TEMPERATURE CURVES OF "C" STEEL, BASED ON ENERGY ABSORBED BY STANDARD KINZEL SPECIMENS AND SPECIMENS NOTCHED 0.090 INCH DEEP, WELDED WITH E6010 ELECTRODES

0-11706

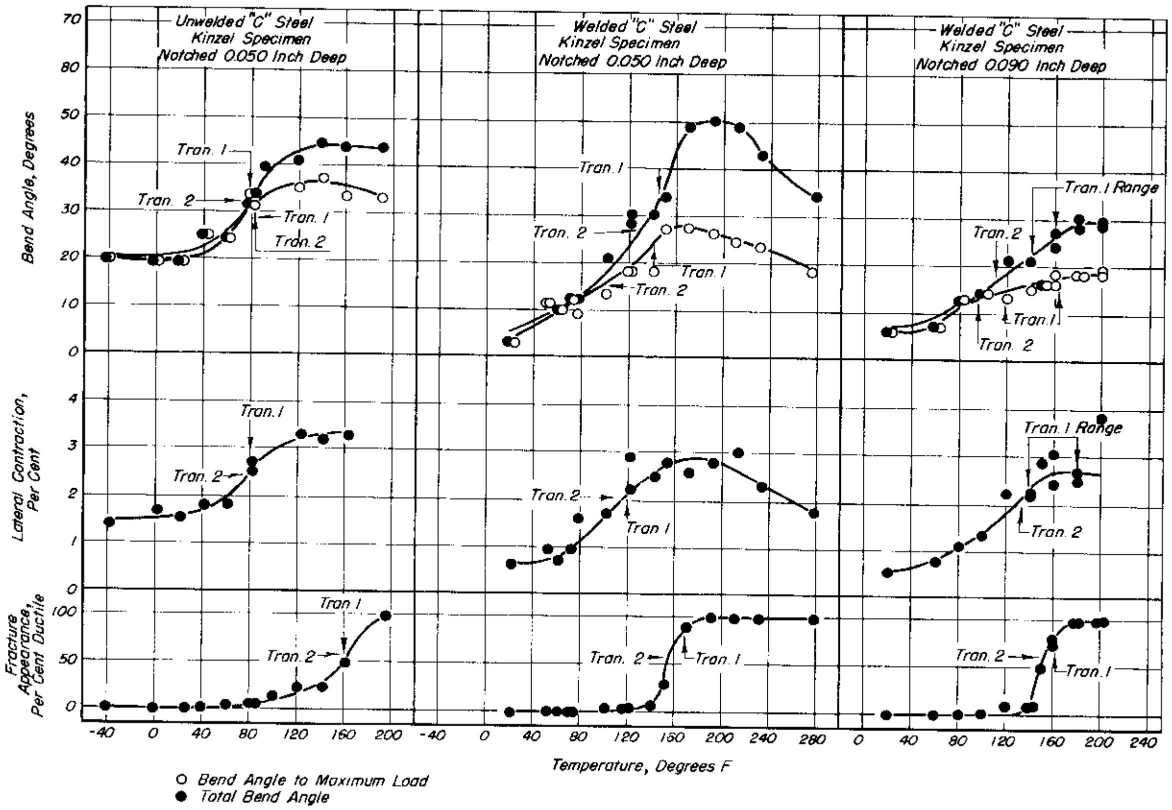


FIGURE B-4B. COMPARISON OF TRANSITION-TEMPERATURE CURVES OF "C" STEEL, BASED ON BEND ANGLE, LATERAL CONTRACTION, AND FRACTURE APPEARANCE OF STANDARD KINZEL SPECIMENS AND SPECIMENS NOTCHED 0.090 INCH DEEP, WELDED WITH E6010 ELECTRODES

O-11705

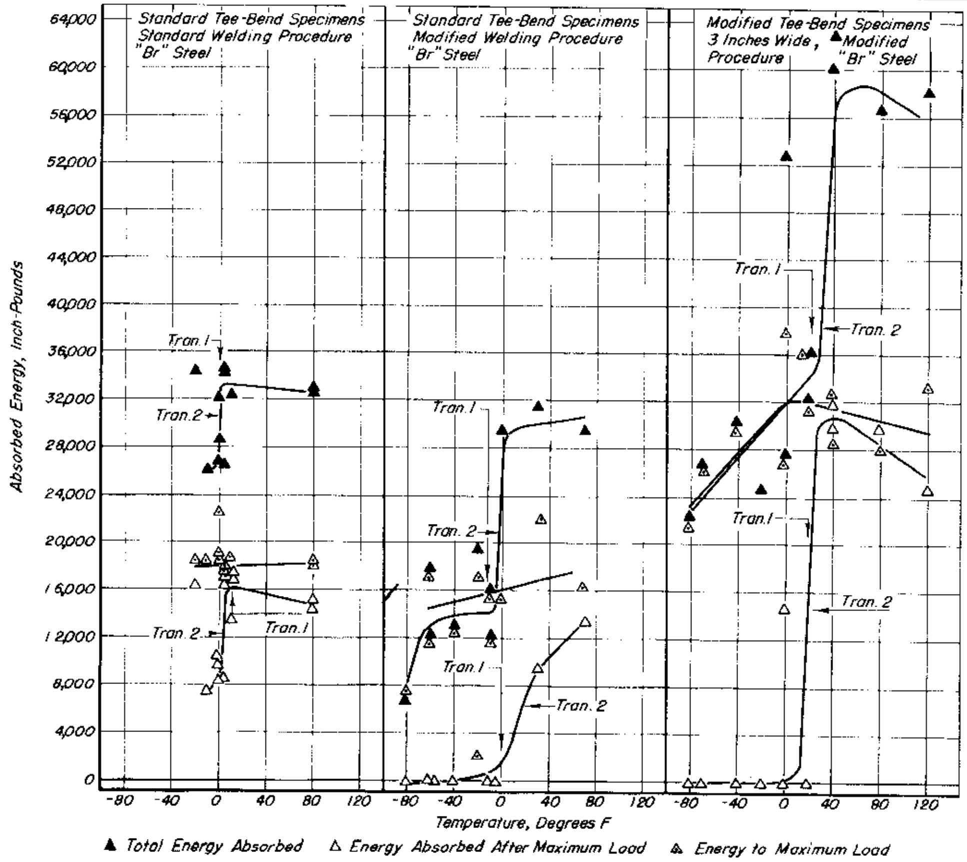


FIGURE B-5A. COMPARISON OF TRANSITION-TEMPERATURE CURVES FOR "Br" STEEL, BASED ON ABSORBED ENERGY OF STANDARD AND MODIFIED TEE-BEND SPECIMENS

O-11708

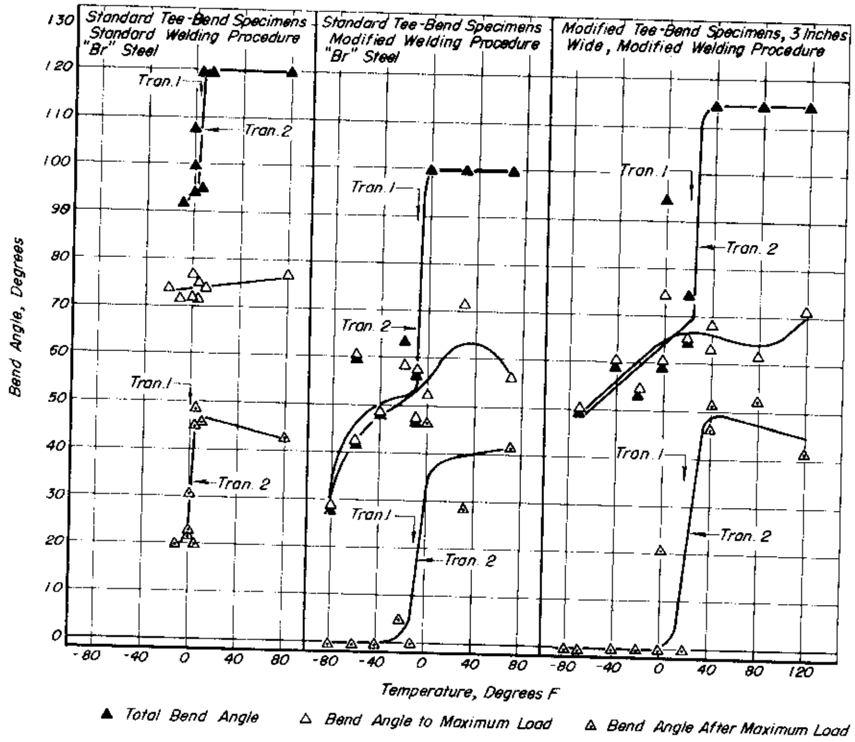


FIGURE B-5B. COMPARISON OF TRANSITION-TEMPERATURE CURVES FOR "Br" STEEL, BASED ON BEND ANGLES OF STANDARD AND MODIFIED TEE-BEND SPECIMENS

0-11707

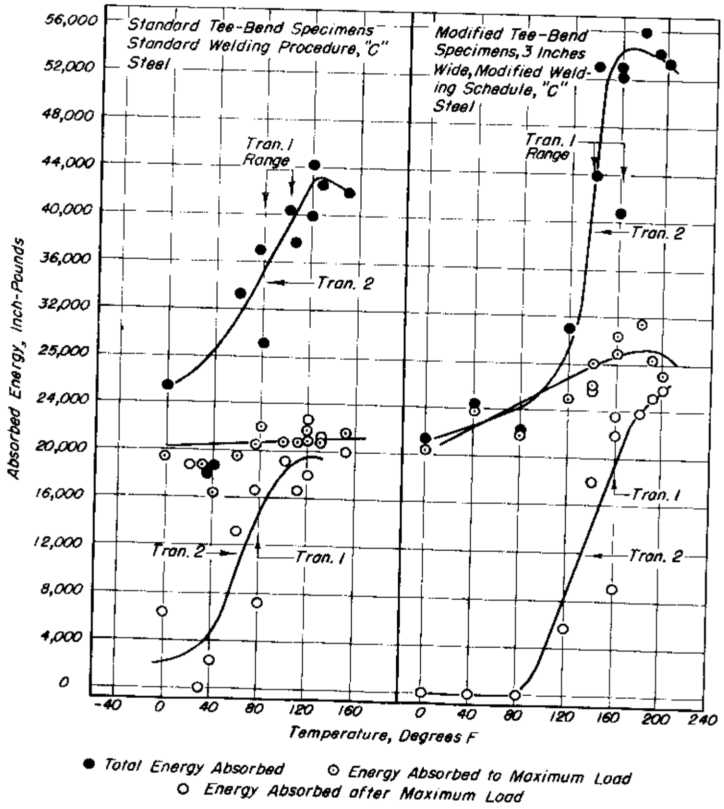


FIGURE B-6A. COMPARISON OF TRANSITION-TEMPERATURE CURVES FOR "C" STEEL, BASED ON ABSORBED ENERGY OF STANDARD AND MODIFIED TEE-BEND SPECIMENS

0-11709

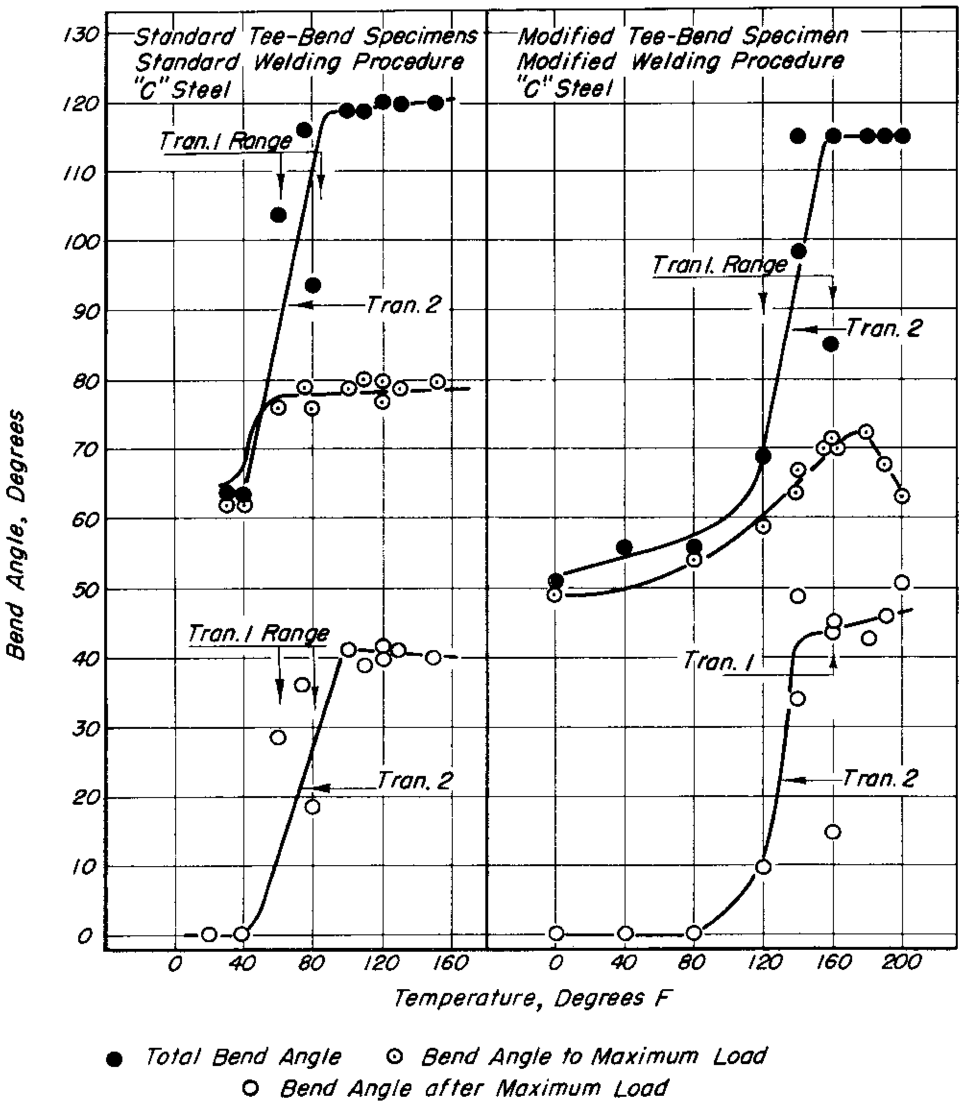


FIGURE B-6B. COMPARISON OF TRANSITION-TEMPERATURE CURVES FOR "C" STEEL BASED ON BEND ANGLE OF STANDARD AND MODIFIED TEE-BEND SPECIMENS

0-11710

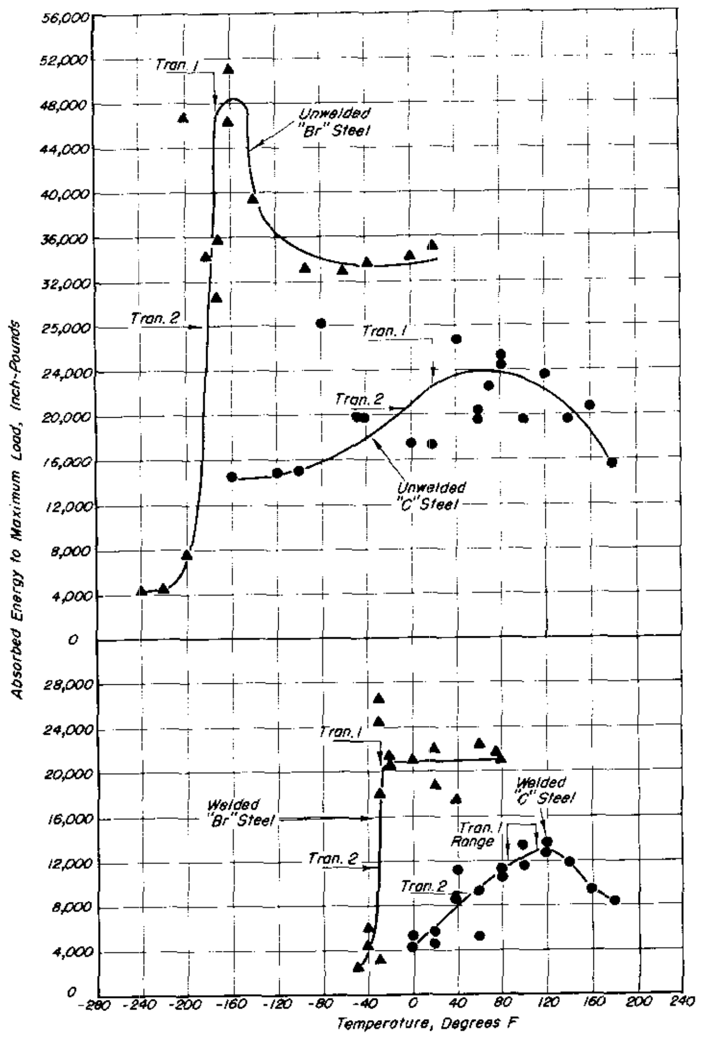


FIGURE B-7A. TRANSITION-TEMPERATURE CURVES FOR UNWELDED AND WELDED "Br" AND "C" STEELS BASED ON ENERGY ABSORBED TO MAXIMUM LOAD BY NOTCHED TENSION SPECIMENS

0-11713

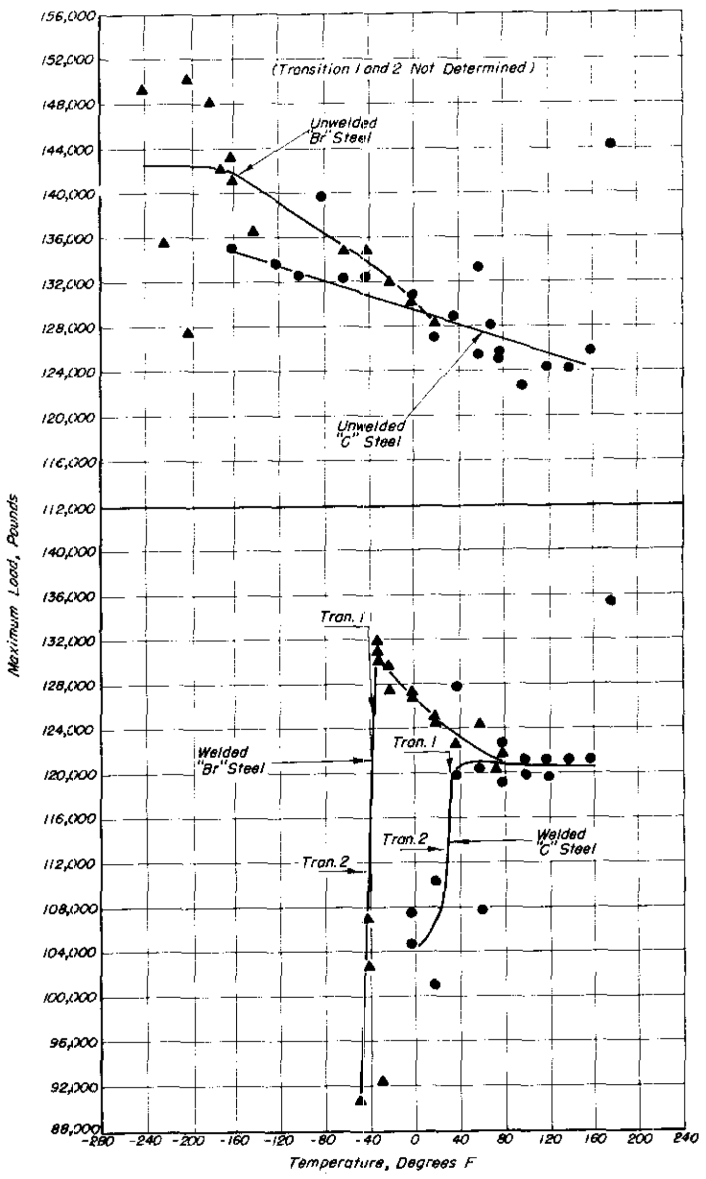


FIGURE B-7B. TRANSITION-TEMPERATURE CURVES FOR UNWELDED AND WELDED "Br" AND "C" STEELS BASED ON MAXIMUM LOAD OF NOTCHED TENSION SPECIMENS

0-11712

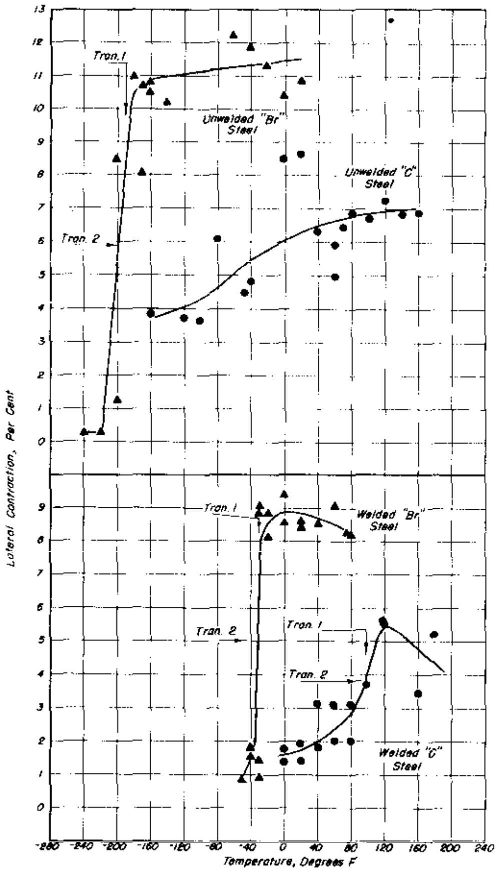


FIGURE B-7C. TRANSITION-TEMPERATURE CURVES FOR UNWELDED AND WELDED "Br" AND "C" STEEL BASED ON LATERAL CONTRACTION OF NOTCHED TENSION SPECIMENS

0-11711

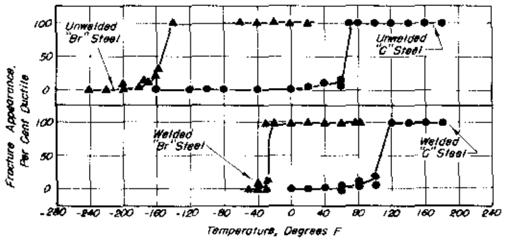


FIGURE B-7D. TRANSITION-TEMPERATURE CURVES FOR UNWELDED AND WELDED "Br" AND "C" STEELS BASED ON FRACTURE APPEARANCE OF NOTCHED TENSION SPECIMENS

0-11714

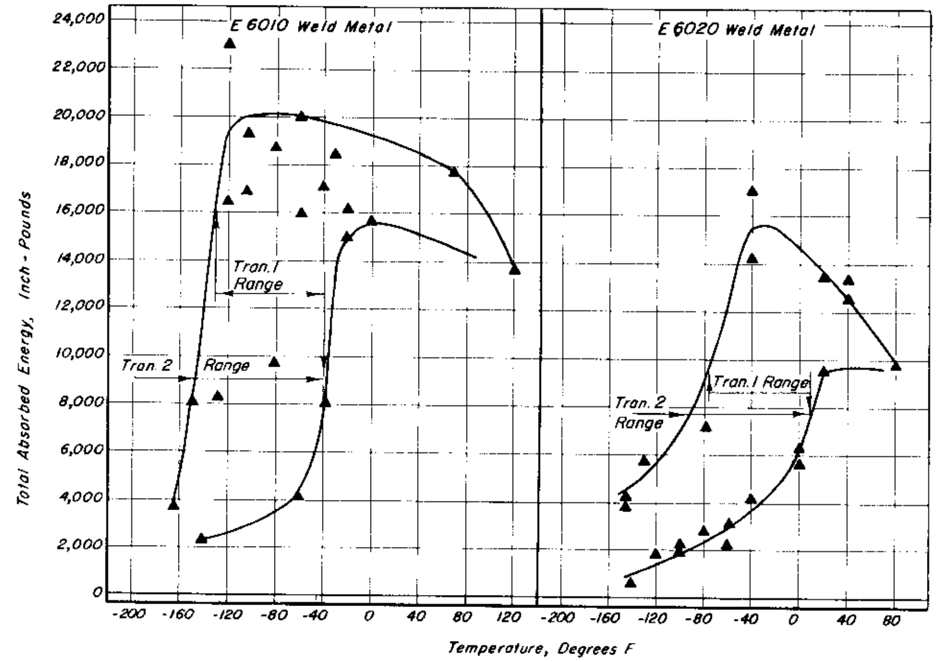


FIGURE B-8A. TRANSITION-TEMPERATURE CURVES BASED ON TOTAL ABSORBED ENERGY OF ALL-WELD-METAL KINZEL-TYPE SPECIMENS MADE FROM E6010 AND E6020 WELD METALS

0-11715

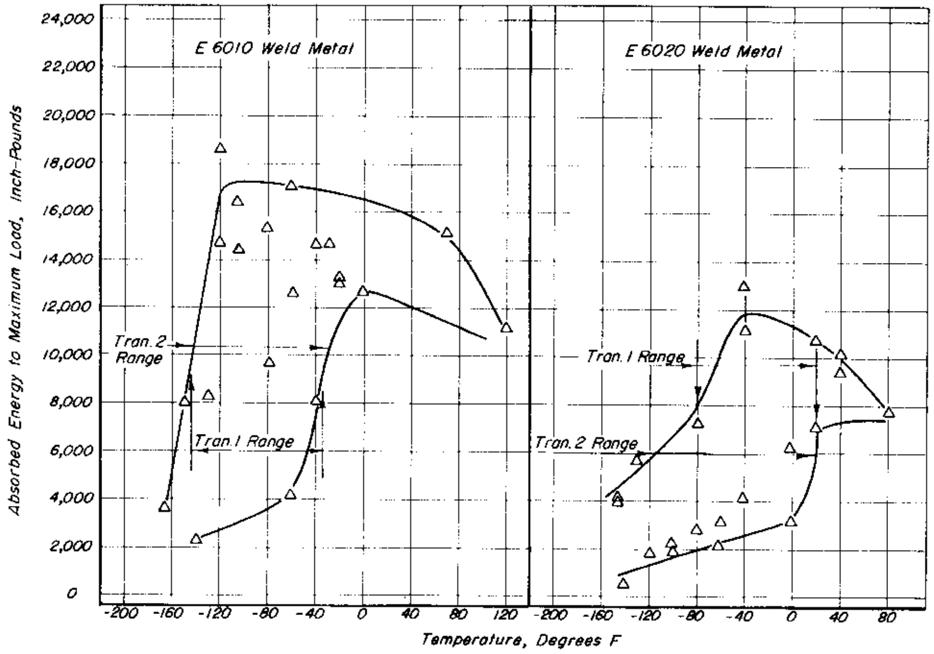


FIGURE B-8B. TRANSITION-TEMPERATURE CURVES BASED ON ABSORBED ENERGY TO MAXIMUM LOAD OF ALL-WELD-METAL KINZEL-TYPE SPECIMENS MADE FROM E6010 AND E6020 WELD METALS

0-11717

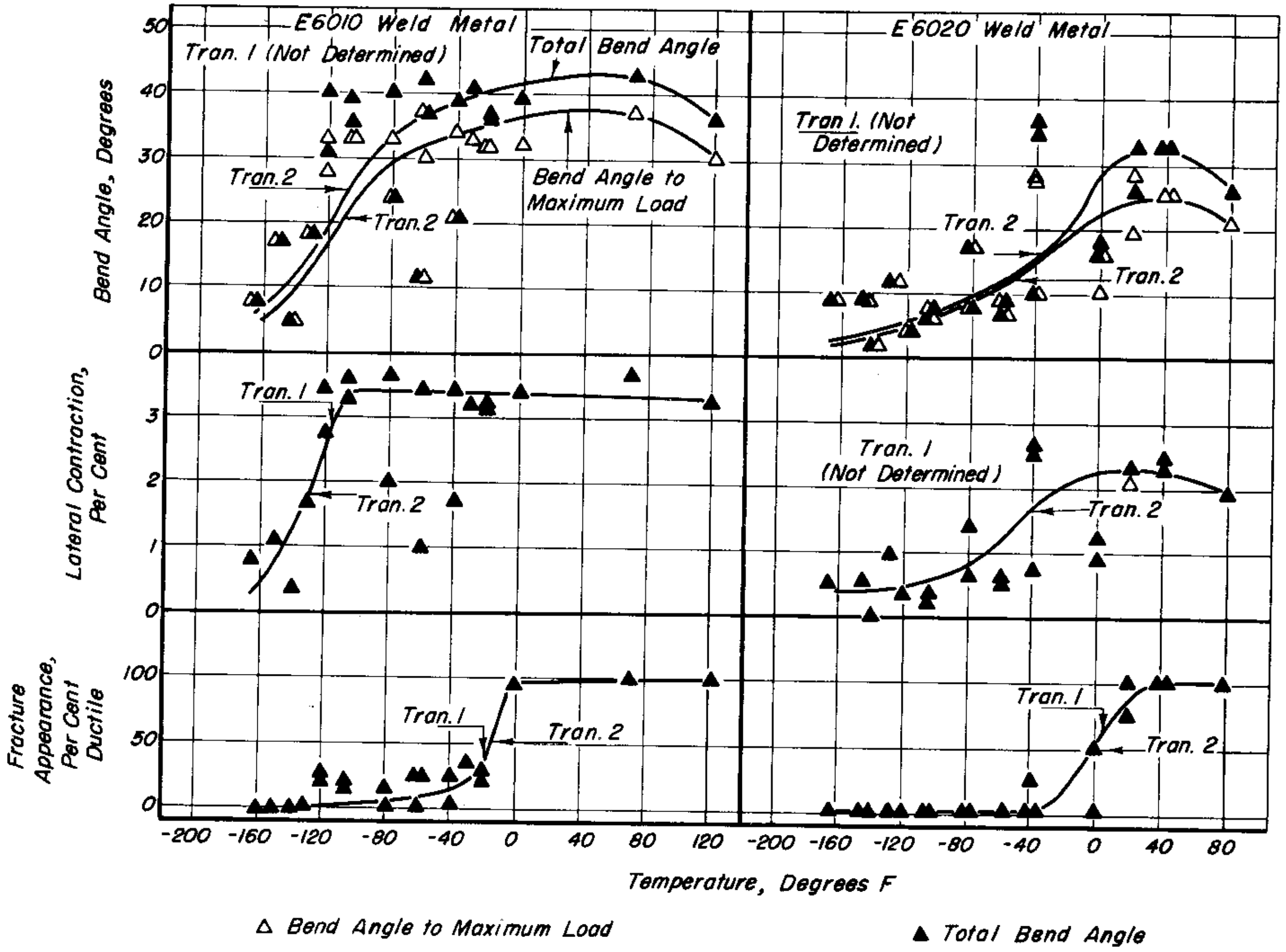


FIGURE B-8C. TRANSITION-TEMPERATURE CURVES BASED ON BEND ANGLE, LATERAL CONTRACTION, AND FRACTURE APPEARANCE OF ALL-WELD-METAL KINZEL-TYPE SPECIMENS MADE FROM E6010 AND E6020 WELD METALS

O-11716

APPENDIX C

APPENDIX C

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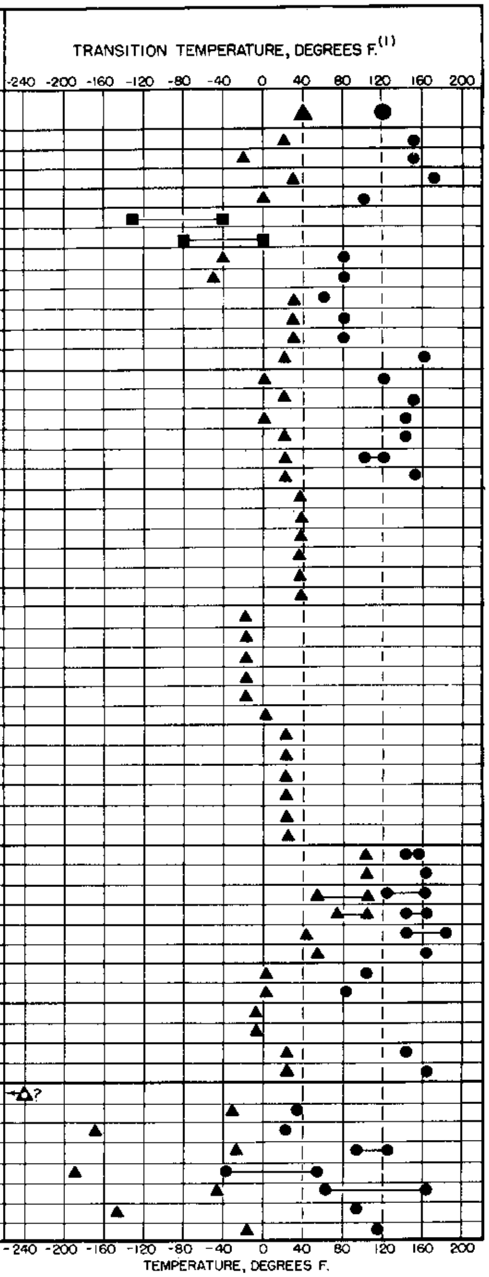
APPENDIX D

SPECIMEN	WIDTH OF SPECIMEN, IN.	WELDED OR UNWELDED	ELECTRODE TYPE	ELECTRODE DIAM IN.	DEPTH OF NOTCH, IN.	CRITERIA FOR DETERMINING TRANSITION TEMPERATURES
HATCH CORNER	—	W	E6020	—	—	TOTAL ABSORBED ENERGY
STANDARD KINZEL	3	W	E6010	3/16	0.050	TOTAL ABSORBED ENERGY
STANDARD LEHIGH	3	W	E6010	3/16	0.080	TOTAL ABSORBED ENERGY
NAVAL RESEARCH LAB.	1 1/2	W	E6010	3/16	0.047	TOTAL ABSORBED ENERGY
STANDARD TEE BEND.	1 7/8	W	E6010	5/32	—	TOTAL ABSORBED ENERGY
KINZEL-TYPE SPECIMEN (ALL-WELD-METAL)	3	W	E6010	3/16	0.050	TOTAL ABSORBED ENERGY
			E6020	3/16	0.050	TOTAL ABSORBED ENERGY
UNWELDED KINZEL-TYPE SPECIMEN	3	U	—	—	0.050	ABSORBED ENERGY TO MAX. LOAD
						TOTAL ABSORBED ENERGY
						BEND ANGLE TO MAX. LOAD
						TOTAL BEND ANGLE
						LATERAL CONTRACTION
						FRACTURE APPEARANCE
STANDARD KINZEL-TYPE SPECIMEN	3	W	E6010	3/16	0.050	ABSORBED ENERGY TO MAX. LOAD
						TOTAL ABSORBED ENERGY
						BEND ANGLE TO MAX. LOAD
						TOTAL BEND ANGLE
						LATERAL CONTRACTION
						FRACTURE APPEARANCE
MODIFIED KINZEL-TYPE SPECIMEN (2)	3	W	E6020	3/16	0.050	ABSORBED ENERGY TO MAX. LOAD
						TOTAL ABSORBED ENERGY
						BEND ANGLE TO MAX LOAD
						TOTAL BEND ANGLE
						LATERAL CONTRACTION
						FRACTURE APPEARANCE
MODIFIED KINZEL-TYPE SPECIMEN (2)	1 1/2	W	E6010	3/16	0.050	ABSORBED ENERGY TO MAX. LOAD
						TOTAL ABSORBED ENERGY
						BEND ANGLE TO MAX. LOAD
						TOTAL BEND ANGLE
						LATERAL CONTRACTION
						FRACTURE APPEARANCE
MODIFIED KINZEL-TYPE SPECIMEN (2)	6	W	E6010	3/16	0.050	ABSORBED ENERGY TO MAX. LOAD
						TOTAL ABSORBED ENERGY
						BEND ANGLE TO MAX. LOAD
						TOTAL BEND ANGLE
						LATERAL CONTRACTION
						FRACTURE APPEARANCE
MODIFIED KINZEL-TYPE SPECIMEN	3	W	E6010	3/16	0.090	ABSORBED ENERGY TO MAX. LOAD
						TOTAL ABSORBED ENERGY
						BEND ANGLE TO MAXIMUM LOAD
						TOTAL BEND ANGLE
						LATERAL CONTRACTION
						FRACTURE APPEARANCE
STANDARD TEE-BEND SPECIMEN	1 7/8	W	E6010	5/32	—	TOTAL ABSORBED ENERGY
						TOTAL BEND ANGLE
TEE-BEND SPECIMEN (MODIFIED WELDING)	1 7/8	W	E6010	3/16	—	TOTAL ABSORBED ENERGY
						TOTAL BEND ANGLE
TEE-BEND SPECIMEN (MODIFIED WELDING)	3	W	E6010	3/16	—	TOTAL ABSORBED ENERGY
						TOTAL BEND ANGLE
NOTCHED TENSION SPECIMEN	2 3/4	U	—	—	0.050	MAXIMUM LOAD
		W	E6010	3/16	0.050	MAXIMUM LOAD
		U	—	—	0.050	ABSORBED ENERGY TO MAX. LOAD
		W	E6010	3/16	0.050	ABSORBED ENERGY TO MAX. LOAD
		U	—	—	0.050	LATERAL CONTRACTION
		W	E6010	3/16	0.050	LATERAL CONTRACTION
		U	—	—	0.050	FRACTURE APPEARANCE
		W	E6010	3/16	0.050	FRACTURE APPEARANCE



(1) TYPE I, HIGHEST TEMPERATURE AT WHICH THE FIRST SIGNIFICANT DECREASE OCCURS IN MEASURED CRITERIA
(2) "C" STEEL WAS NOT TESTED

▲ "Br" STEEL ● "C" STEEL ■ ALL-WELD-METAL

FIGURE D-1. A SUMMARY OF TRANSITION TEMPERATURES OF "Br" AND "C" STEELS DETERMINED BY VARIOUS CRITERIA AND USING VARIOUS SPECIMEN DESIGNS

D-13399