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SERIAL NO. SSC-36

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PROGRESS REPORT

ON

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

BY

F. R. BAYSINGER, R. G. KLINE, I. J. RIEPPEL
and C. B. VOLDRICH

BATTELLE MEMORIAL INSTITUTE
Under Bureau of Ships Contract Nobs-45543

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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.
December 20, 1950

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COMMITTEE ON SHIP STEEL
OF THE
DIVISION OF ENGINEERING AND INDUSTRIAL RESEARCH

December 20, 1950

Chief, Bureau of Ships
Code 343
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Washington 25, D. C.

Dear Sir:

Attached is Report Serial No. SSC-36 entitled "Evalution 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,

Robert F. Mehl

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 represents 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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REPORT

on

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

to

BUREAU OF SHIPS,
NAVY DEPARTMENT

by

F. R. Baysinger, R. G. Kline, P. J. Rieppel, and C. B. Voldrich

Describing Work Completing
CONTRACT NObs-45543

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Contract NObs-45543

ABSTRACT

This report covers the work done during the period January 1, 1949, to June 30, 1949.

On the basis of the discussion of the work reported in the second progress report, SSC-33, the Project Advisory Committee recommended that the behavior of two additional project steels, "A" and "W" should be determined at various temperatures (200 F to -100 F) using the Kinzel-type specimen. It was also decided that a study would be made to determine the effect of preheat and postheat treatments on the behavior of "B_r" and "C" steels when tested at various temperatures (200 F to -100 F) using the Kinzel specimen.

Tests using the Kinzel specimen to determine the transition-temperature range of "A" and "W" steels rate these two steels in the same order that all the other type specimens have done. The four steels which have now been rated with

the welded Kinzel specimen have the following order of increasing transition-temperature range: "B_r", "W", "A", and "C". When tested with Kinzel-type specimens, but without the weld beads, "B_r", "W" and "A" behaved very much alike, while "C" had a considerably higher transition-temperature range.

The studies on the effect of preheat and postheat on welded Kinzel specimens of "B_r" and "C" steels revealed that the "B_r" steel responded more than "C" steel to the use of preheat. As the preheat was raised, the transition-temperature ranges for both steels were lowered. A postheat treatment improved the amount of energy absorbed by both steels at low temperatures.

Vickers hardness surveys of Kinzel specimens of "B_r" and "C" steels welded at various preheats were made. In the specimens of "B_r" steel, the weld metal was harder than the heat-affected zone, while the reverse was true for the "C" steel. Both preheat and a high temperature postheat each reduced hardness in both the weld metal and the heat-affected zone.

INTRODUCTION

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

The second progress report (SSC-33, November 15, 1949)[7*] on this project contained the test results of various modifications of notched bend specimens and of notched tension specimens. It was the object of this investigation to attempt to obtain the same transition temperatures for the project

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* See References, Page 41.

steels, "B_r" and "C", that were obtained from the full-scale hatch-corner test specimens studied at the University of California. Other tests of all-weld-metal specimens, made with E6010 and E6020 electrodes, were included. The second progress report also described some preliminary observations on the initiation of fracture in the bend-test specimens. A bibliography of all literature studied up to December 30, 1948, which pertained to the subject of this investigation, was included in the Appendix.

This report covers tests made with "A" and "W" project steels to determine their transition-temperature ranges using both welded and unwelded Kinzel-type specimens. The results obtained on these steels with the Kinzel-type specimens are compared with those obtained on the same steels by several other specimens. A discussion of methods of determining transition temperatures is included.

This report also covers tests on "B_r" and "C" steels to determine the effect of preheat and postheat treatments on the behavior of welded Kinzel-bend specimens. Hardness surveys were made on welded Kinzel specimens of "B_r" and "C" steels for each preheat and correlated with the test results. Cooling rates on welded Kinzel specimens were recorded for each of the preheat temperatures.

Discussion of Methods of Determining Transition Temperatures

The subject of transition temperatures and methods of determining transition temperatures of various welded and unwelded specimens of ship-grade steel has been discussed at length.[4,7] There has been considerable confusion and difficulty in determining transition temperatures and using them to compare performance of various series of specimens of ship steels tested over a range of temperatures. The data presented in this report, which were obtained from testing several series of specimens at various temperatures, are presented in a different way, with very little reference to transition temperatures. The reasons for presenting the data in this manner are developed in this section of the report.

The term "transition temperature" refers to the temperature at which the mechanical behavior of a material in a given test specimen changes from shear to cleavage or from ductile to brittle. Since this transition usually occurs over a range of temperatures, it is usually not possible to choose a specific transition temperature except by use of an arbitrary definition.

In all previous work on this investigation, four criteria have been used to evaluate the change from shear to cleavage behavior of bend-test specimens tested over a range of temperatures. These are: (a) energy absorbed by a specimen from the beginning of loading to maximum load, (b) the angle through which the specimen is bent from beginning of loading to maximum load; (c) lateral contraction at the root of the notch in the specimen during testing, and (d) fracture appearance. The measured values are plotted as ordinates against temperature as abscissa and an average curve drawn through the plotted data. The transition temperature is then determined from the average curve.

As stated previously, before the transition temperature can be determined from this average curve, an arbitrary definition of the transition temperature must be established. The definitions of transition temperatures which were used are:

1. The temperature coordinate of the point which represents half the maximum value of the average curve.

2. The temperature coordinate of the point which represents the midpoint between the upper and lower limits of the average curve.

3. The highest temperature at which the first significant decrease occurs in the measured property.

The transition from shear to cleavage behavior usually occurs over a range of temperatures and not at a specific temperature. Therefore, a transition temperature chosen by definition might well be 20 or more degrees above or below the temperature at which some test specimens will fail by cleavage. This fact must not be forgotten when the transition temperatures of various series of tests are compared. The main advantage, and the reason for the wide use of an arbitrarily chosen transition temperature, is that voluminous test data for many materials can be readily compared without reference to each individual graph.

There are difficulties which occur in choosing transition temperatures from average curves by any of the definitions listed above. These will be discussed in following sections.

Half of Maximum Value

Using the temperature coordinate of half the maximum value of the average curve as the transition temperature may be misleading. For example, a high maximum value which determines the transition temperature by this method does not insure that the steel will behave well at low temperatures. In Fig. 1, by definition, the steel represented by Curve A has a lower transition temperature than that represented by Curve B, even though the maximum value for the two curves is the same. Steel C, however, which has a lower maximum value, is much better at low temperatures, even though its transition temperature by definition is the same as for B. The transition temperature by itself then might give no indications of great variations in the low-temperature properties of steels being compared by this method.

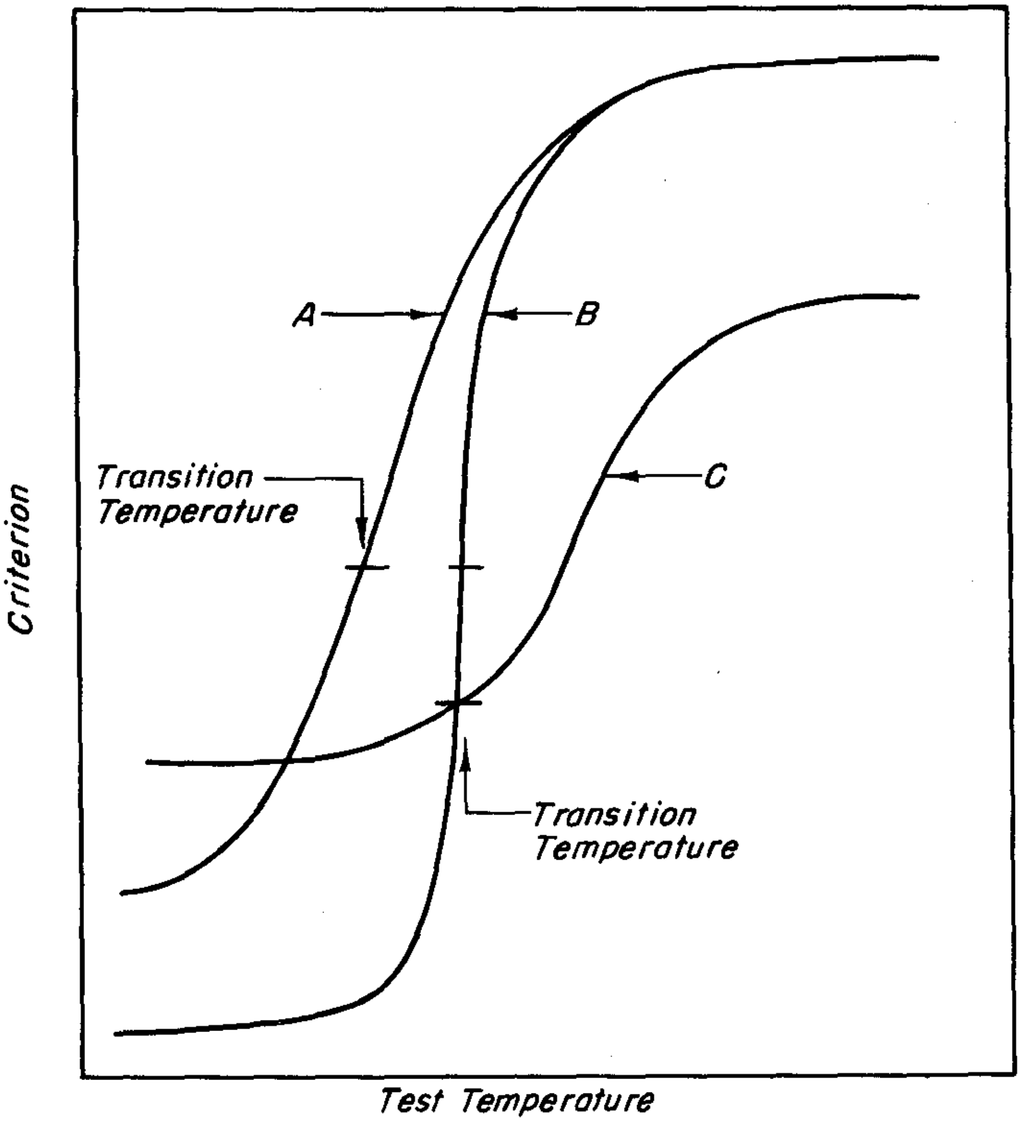

FIGURE 1. SCHEMATIC CURVES ILLUSTRATING TRANSITION TEMPERATURE DEFINED BY HALF OF THE MAXIMUM VALUE OF THE AVERAGE CURVE

0-16694

Midpoint Between Upper and Lower Limits

In picking as transition temperature the midpoint between the upper and lower limits of the average curve, the better low-temperature properties of one material over another may be ignored. Figure 2 is a schematic illustration. In this sketch, materials A, B, and C have the same transition temperature by definition. But to say the materials are, therefore, *similar completely ignores* the better low-temperature values of materials A and B.

First Significant Drop

The definition of transition temperature as the highest temperature at which the first significant decrease occurs was used in previous work at Battelle.[4,7] In a case in which the curve had a sharp drop, the transition temperature was readily located. Figure 3 shows such a curve. In other cases, the curves had no sharp drop, as in Figure 4, and there was no point on the curve to choose as the transition temperature. The choice, in these cases, was influenced by the individual datum points and was located more by these points than by the average curve. The reported transition temperature might be anywhere within the transition range. In many cases, no two persons could agree on the location of the transition temperature.

"Envelope" Method of Presenting Data

To avoid the problems of using average curves and the location of definite transition temperatures, the data in following sections of this report are presented in most cases as envelopes, drawn around the plotted points. These envelopes make it possible to easily compare two sets of data and at the same time see the scatter in each case. It is easy to note whether the transition-temperature range of one series of specimens is generally higher or lower than

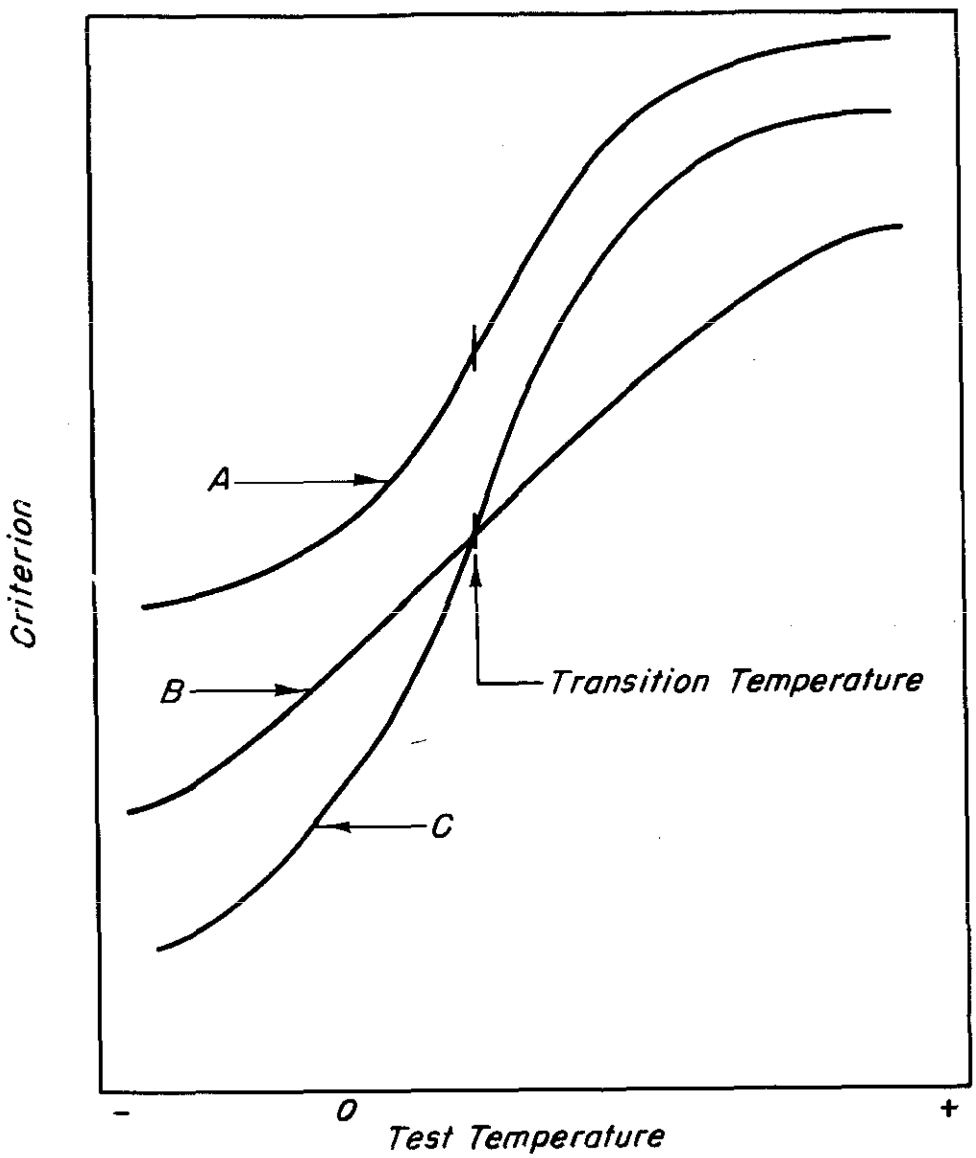

FIGURE 2. SCHEMATIC CURVES ILLUSTRATING TRANSITION TEMPERATURE DEFINED AS MID-POINT BETWEEN UPPER AND LOWER LEVELS OF THE AVERAGE CURVE

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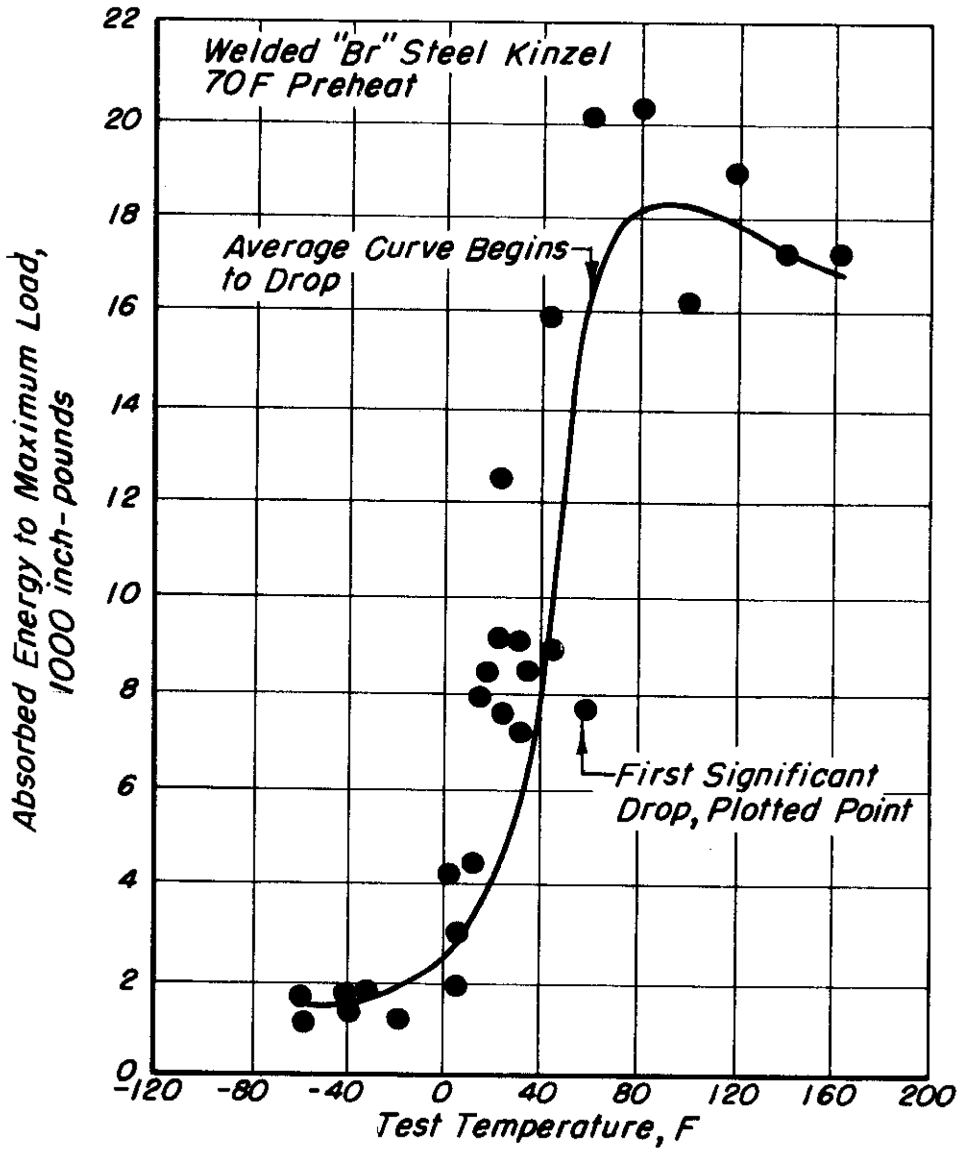

FIGURE 3. CURVE SHOWING HOW THE FIRST SIGNIFICANT DROP OF THE AVERAGE CURVE AND PLOTTED POINTS MAY OCCUR AT THE SAME TEMPERATURE

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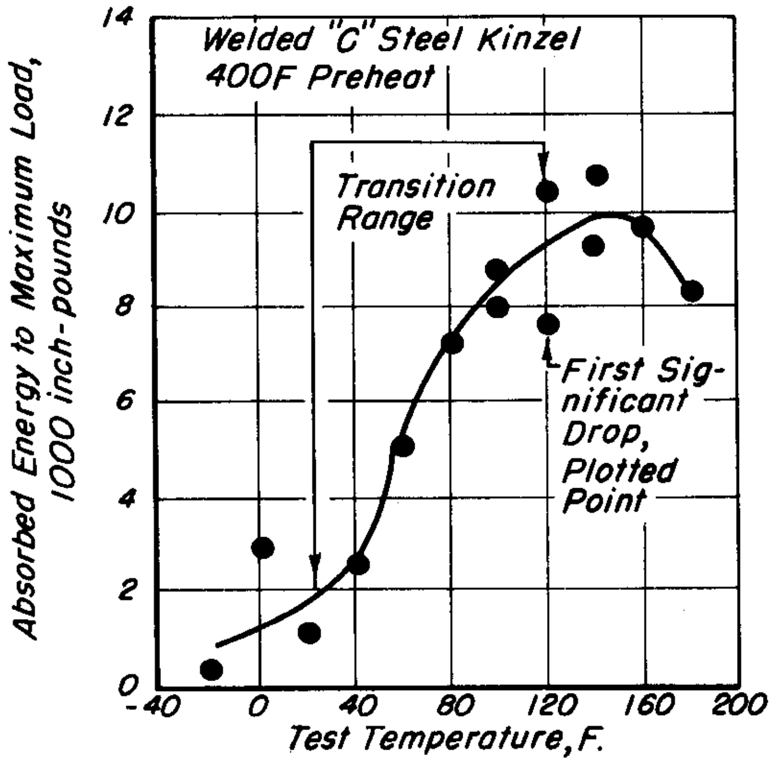


FIGURE 4. CURVE WHICH HAS NO FIRST SIGNIFICANT SHARP DROP

0-16697

that of the other. In Figure 5, the same data are presented by the average curve and envelope methods for comparison. These curves show that there is a definite difference in the behavior of the two series of specimens when tested at various temperatures. It is obvious, when it is attempted to represent these differences by arbitrary transition temperatures, that much is lost. However, if the transition temperatures shown on the average curves (determined by the first significant drop) are compared, and are regarded as representing a range and not a specific point (accurate to about ± 20F), then they show the same trends that are shown by the curves taken as a whole.

Re-evaluation of Data Presented in Previous Reports SSC-23 and SSC-33

The data presented in previous reports SSC-23[4] and SSC-33[7] on this investigation have now been re-evaluated by using the envelope method instead of average curves and transition temperatures. In instances, it was found that no important new conclusions could be drawn from the data when studied by this method. As long as the transition temperatures cited in these previous reports are not considered as precise points, the same overall trends are obtained by their use. However, if the detailed curves are ignored completely, much interesting and important information can be overlooked.

MATERIALS

Steels

Two semi-killed, as-rolled, medium-carbon ship steels, designated as "B_r" and "C", were used in this phase of the investigation for studying the effects of preheat and postheat on the performance of test specimens. In

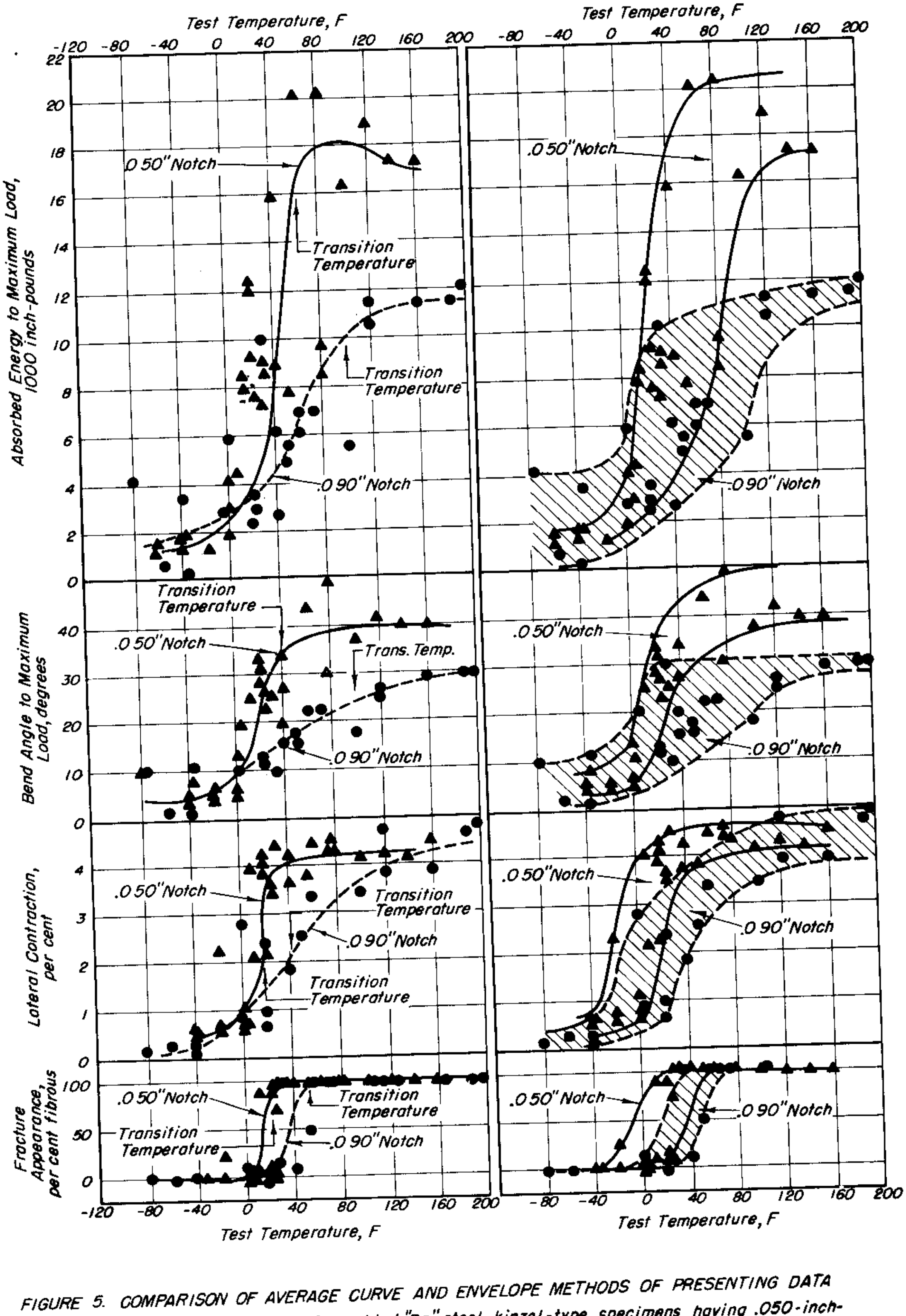


FIGURE 5. COMPARISON OF AVERAGE CURVE AND ENVELOPE METHODS OF PRESENTING DATA

These data are for welded "Br" steel kinzel-type specimens having .050-inch-deep notch. Reference 7.

0-16823

addition, project steels "A" (semi-killed) and "W" (killed) both as-rolled, were proposed by the Advisory Committee for determination of their transition temperatures with the Kinzel-type specimen. The mechanical properties and chemical compositions of the four above-mentioned steels are given in Table 1.

Electrodes

The electrodes used throughout this phase of the investigation were 3/16-inch-diameter Class E6010 electrodes. The welding schedule used for the electrodes will be discussed in a later section of the report.

STUDIES OF TRANSITION RANGES OF "A" AND "W" STEELS WITH KINZEL SPECIMENS

At the December, 1948 meeting of the Project Advisory Committee, it was recommended that "A" and "W" steels be studied with the Kinzel specimen. This was suggested in order to compare such results with results obtained with the Kinzel specimen on "B_r" and "C" steels.

Preparation and Welding of Specimens

Coupons for the test specimens were saw cut from plates of "A" and "W" steels, and the surfaces were cleaned by grit blasting. In order to conserve material, the length of the specimen was reduced from 12 inches to 8 inches. Pilot tests indicated the results were not changed by using the shorter specimen. Figure 6 shows the details of the Kinzel-type specimen as used in these tests.

The weld beads were deposited on the test coupons by automatic welding using 3/16-inch-diameter E6010 electrodes. All of the specimens were welded at room temperature and cooled in air. The aging time for all the specimens between welding and testing was 8 days at room temperature. The welding schedule follows:

TABLE I - MECHANICAL AND CHEMICAL PROPERTIES OF PROJECT STEELS "B_r", "C", "A" AND "W"

Steel Code Letter	Type of Steel	Thickness, In.	Steel Condition	Mechanical Properties: Yield Point, psi	Ultimate Strength, psi	Elongation in 2 In. %	Elongation in 8 In. %	Reduction in Area, %	Hardness Rockwell B
B_r (1)(2)	Semikilled	3/4	As Rolled	32,200-34,600	55,600-58,600	43	33	71-58	58-63
C (1)(2)	Semikilled	3/4	As Rolled	34,500-37,600	61,500-68,500	43-35	32	63-50	66-69
A (1)(2)	Semikilled	3/4	As Rolled	35,400-36,700	57,600-62,900	45	37-32	62-53	58-62
W (3)	Killed	3/4	As Rolled	37,200	62,500	-	30	-	-

Steel Code Letter	Chemical Composition, %: C	Mn	Si	P	S	Cr	Ni	Mo	Cu	Al	Sn	N
B_r (1)	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 (1)	0.24	0.43	0.05	0.012	0.026	0.03	0.02	0.005	0.03	0.016	0.003	0.009
A (1)	0.26	0.50	0.03	0.012	0.039	0.03	0.02	0.006	0.03	0.012	0.003	0.004
W (3)	0.20	0.52	0.23	0.013	0.010	0.07	0.10	0.010	0.17	0.006	0.035	0.005

(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.
(3) Kahn, N. A., and E. A. Imbembo, "Notch Sensitivity of Steel Evaluated by the Tear Test," Welding Journal, April 1949.

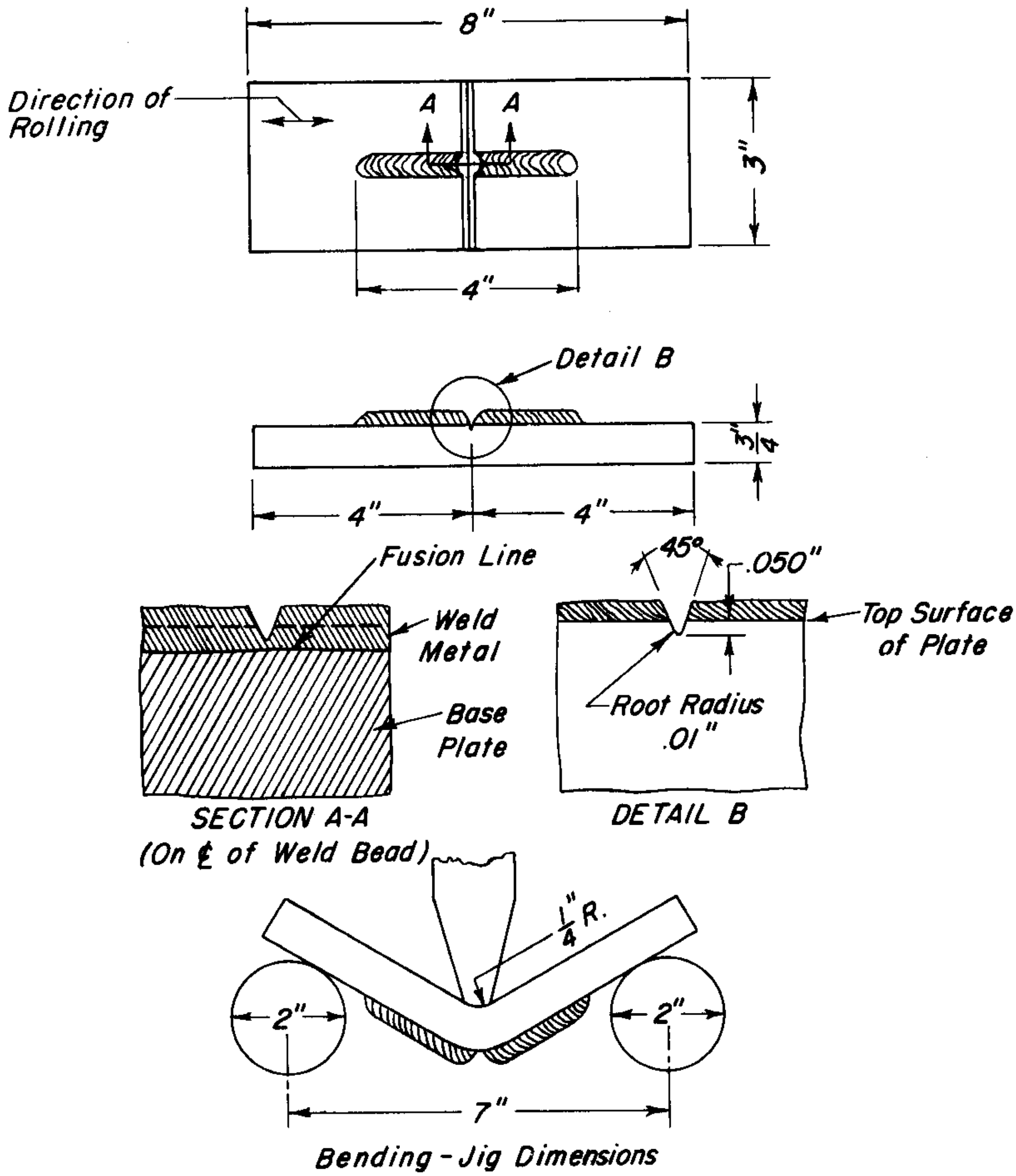


FIGURE 6. BEND SPECIMEN WITH LONGITUDINAL WELD BEAD AND TRANSVERSE NOTCH (KINZEL DESIGN)

O-14388

Average welding current, amps	175
Average arc volts	26
Average welding speed, in./min.	6
Length of weld bead, in.	4
Length of electrode per inch of weld	1.4
Initial plate temperature, F	70
Cooling medium	Air

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

Testing Procedure

A mixture of methyl cyclohexane and dry ice was used to obtain testing temperature down to -100 F. Temperatures above 80 F were obtained by a water bath with resistance-immersion heaters. The bending jig and test specimen were completely immersed in the cooling (or heating) bath during testing.

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.

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

Test Results of Unwelded and Welded Specimens of "A" and "W" Steels

Four series of tests were made to study the behavior of unwelded and welded Kinzel-type specimens of "A" and "W" steels. The detailed data for the welded and unwelded specimens of "A" steel are given in Appendix A, Tables A-1 and A-2 respectively. For comparison, curves based on absorbed energy to maximum load, bend angle to maximum load, lateral contraction, and fracture appearance were plotted, and are shown in Figure 7. The data for the "W" steel are given in Appendix A, Tables A-3 and A-4, and curves are shown in Figure 8.

The temperature ranges for the transition from shear to cleavage behavior based on absorbed energy to maximum load, for both unwelded "A" and "W" steels, are similar. The fully killed "W" steel, however, absorbed more energy than Steel "A", as shown in Figures 7 and 8. In addition, the unwelded "W" steel showed a lower transition-temperature range based on fracture appearance.

When tested in the welded condition, the "W" steel had a lower transition-temperature range with respect to energy absorption, and it also absorbed more energy than the "A" steel. However, when fracture appearances were compared, the "W" steel showed a cleavage-type fracture at higher temperature than the "A" steel.

Comparison of "A" and "W" Steels With "B_r" and "C" Steels

Values of absorbed energy to maximum load of "B_r", "W", "A", and "C" steels are compared in Figure 9. These data rate the "A" and "W" steels between the "B_r" and "C" steels. Unwelded "B_r", "W", and "A" steels have about the same transition-temperature ranges as determined by absorbed energy to maximum load, while that of unwelded "C" steel is higher. The amount of absorbed energy of unwelded "W" and "B_r" steels is similar, but "A" steel absorbe more energy than "C" steel. Welding raised the transition-temperature ranges of "W" and "A" slightly above the "B_r" steel, but less than for "C" steel. The welded "B_r" steel absorbed much more energy than the "W", "A", or "C" steels.

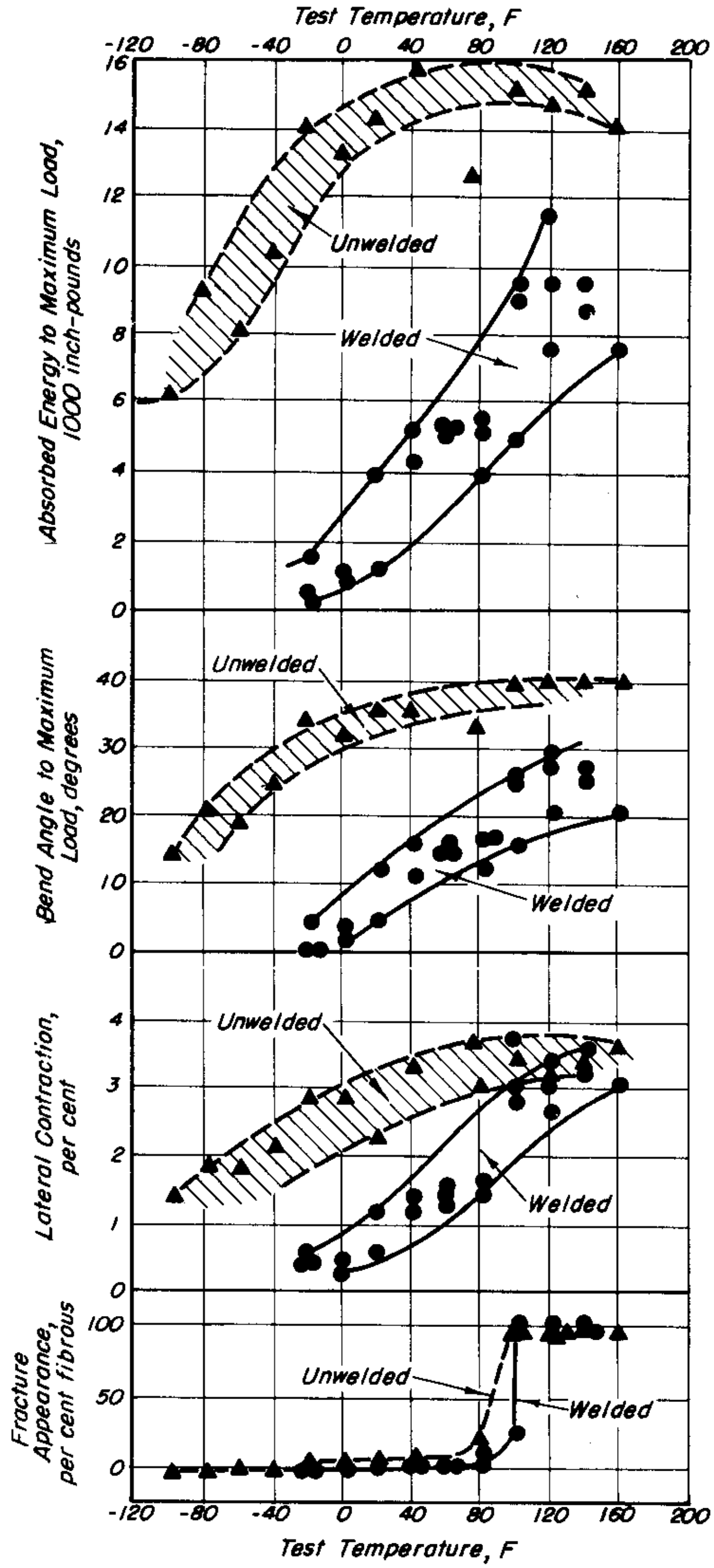


FIGURE 7. COMPARISON OF WELDED AND UNWELDED KINZEL SPECIMENS OF "A" STEEL

O-16619

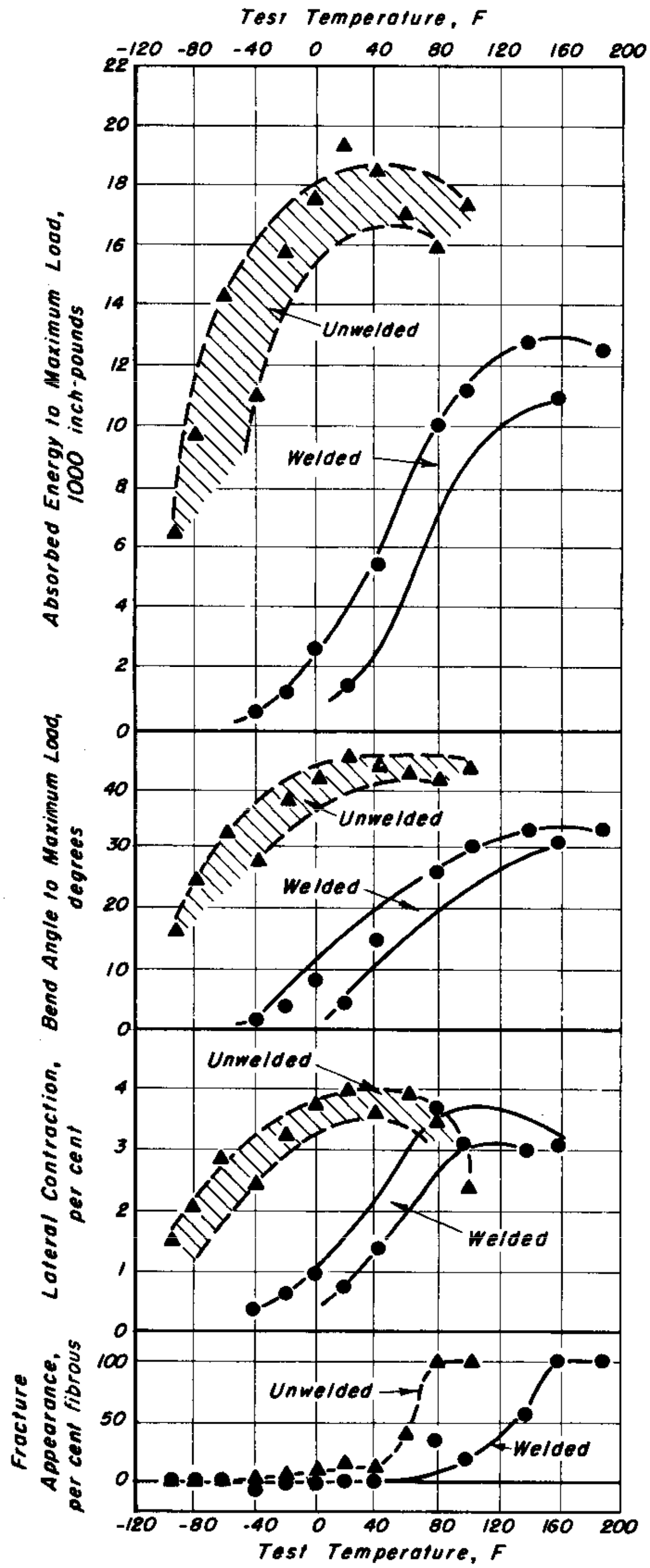


FIGURE 8. COMPARISON OF WELDED AND UNWELDED KINZEL SPECIMENS OF "W" STEEL

O-16620

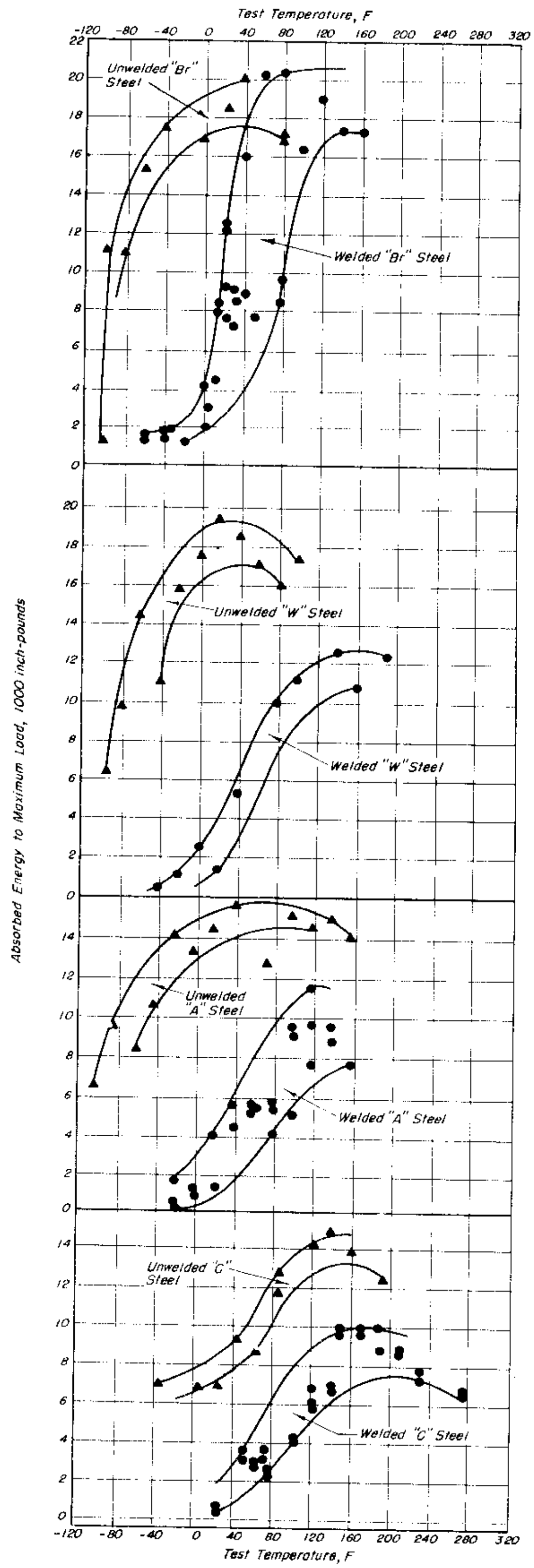


FIGURE 9. COMPARISON OF ABSORBED ENERGY TO MAXIMUM LOAD OF WELDED AND UNWELDED SPECIMENS OF "Br", "A", "W", AND "C" STEEL

O-16624

Comparison of Test Results of Kinzel - Type and Other-Type Specimens

Transition-temperature ranges of the project steels, "B_r", "A", and "C" steels have been determined by other investigators using the Navy tear test, Charpy keyhole, Charpy V-notch, and 72-inch center-notched plate specimens.[1,2,3,6] "W" steel has been tested only with the Navy tear test[5] previous to tests with the Kinzel specimen. These data are shown in Figures 10 through 13, along with "B_r" and "C" steel hatch-corner data for comparison of transition-temperature ranges. Similar curves for unwelded and welded Kinzel specimens are shown in Figures 14 and 15. Additional data for tee-bend and Lehigh specimens of "B_r" and "C" steel are shown in Figures 16 and 17.

All of these tests rate the steels "B_r", "A", and "C" in the same order of increasing transition-temperature range. Both welded and unwelded Kinzel specimens place "W" steel between "B_r" and "A" steel, and the Navy tear test shows a marked similarity between "B_r" and "W" steels.

To compare the specimens in rating steels, the welded and unwelded Kinzel specimens, the Navy tear test specimen, and the Charpy keyhole specimens show markedly the rise in transition-temperature range of "A" steel above "B_r", and "C" steel above "A" steel. All of the tests, including the hatch-corner tests, show that "B_r" steel absorbs more energy and has a lower transition-temperature range than "C" steel. In addition to distinguishing between steels, the welded Kinzel specimen and the Navy tear test specimen of prime plate also match the transition-temperature ranges for "B_r" and "C" steel hatch-corner specimens. The Kinzel specimen, however, appears to show a wider difference in transition-temperature ranges between the steels.

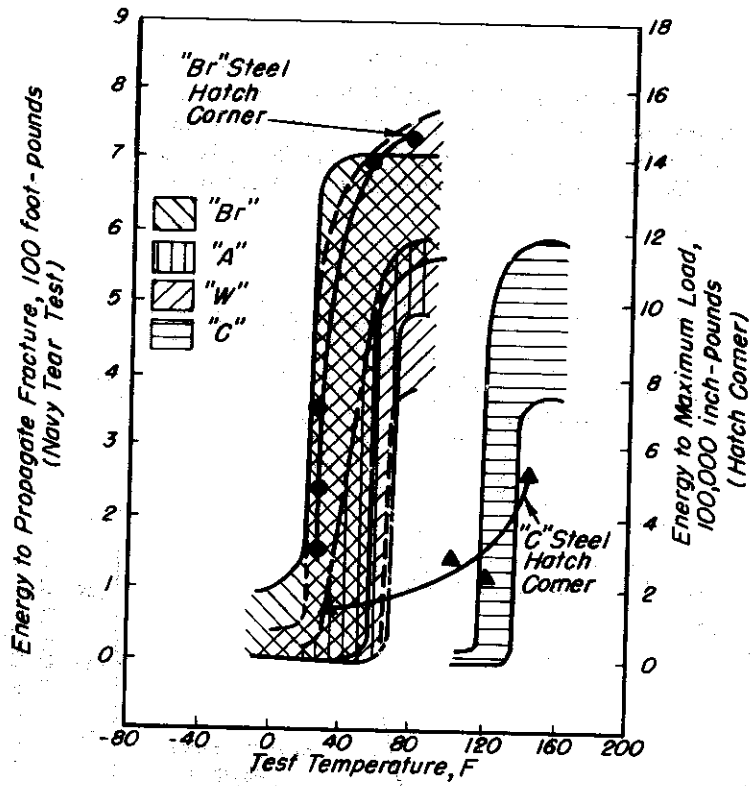


FIGURE 10. COMPARISON OF ENERGY VALUES FOR NAVY TEAR TEST SPECIMENS OF "Br", "W", "A", AND "C" STEELS. HATCH-CORNER DATA ARE INCLUDED FOR COMPARISON OF TRANSITION-TEMPERATURE RANGES. REFERENCES 3,5, AND 6.

0-16698

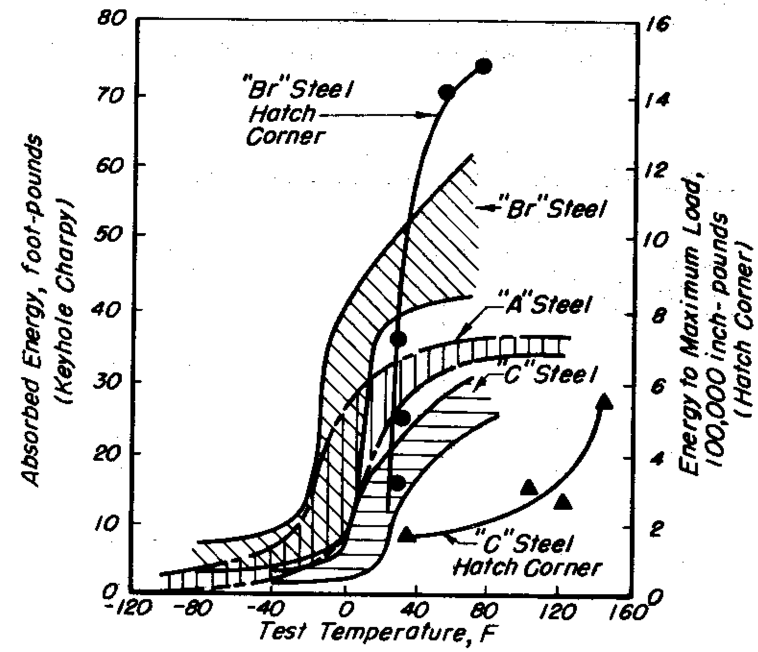


FIGURE 11. COMPARISON OF ENERGY VALUES FOR KEYHOLE CHARPY BARS OF "Br", "A", AND "C" STEELS. HATCH-CORNER DATA ARE INCLUDED FOR COMPARISON OF TRANSITION-TEMPERATURE RANGES. REFERENCES 2 AND 6.

0-16699

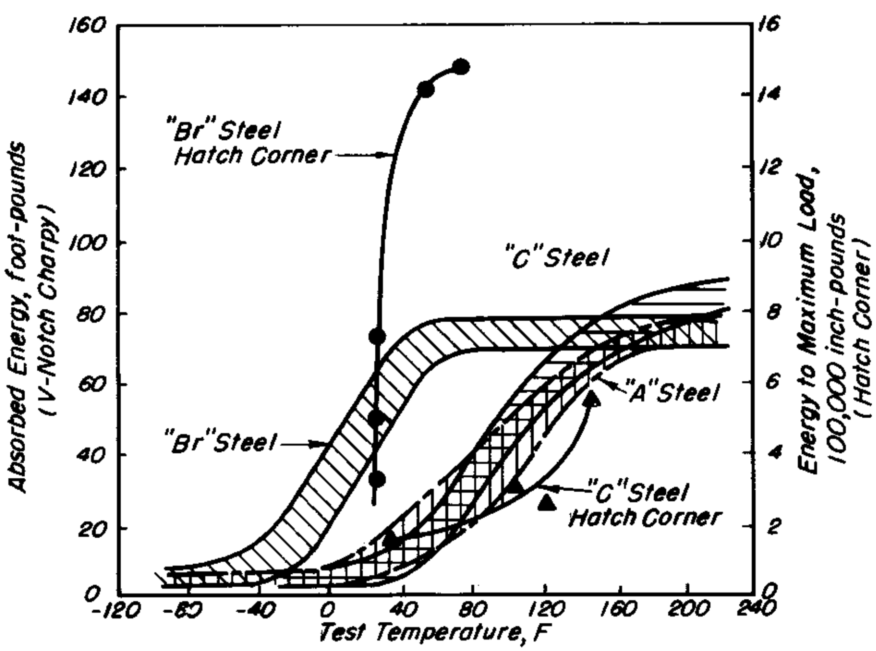


FIGURE 12. COMPARISON OF ENERGY VALUES FOR V-NOTCH CHARPY BARS OF "Br", "A", AND "C" STEELS. HATCH-CORNER DATA ARE INCLUDED FOR COMPARISON OF TRANSITION-TEMPERATURE RANGES. REFERENCES 2 AND 6.

0-16700

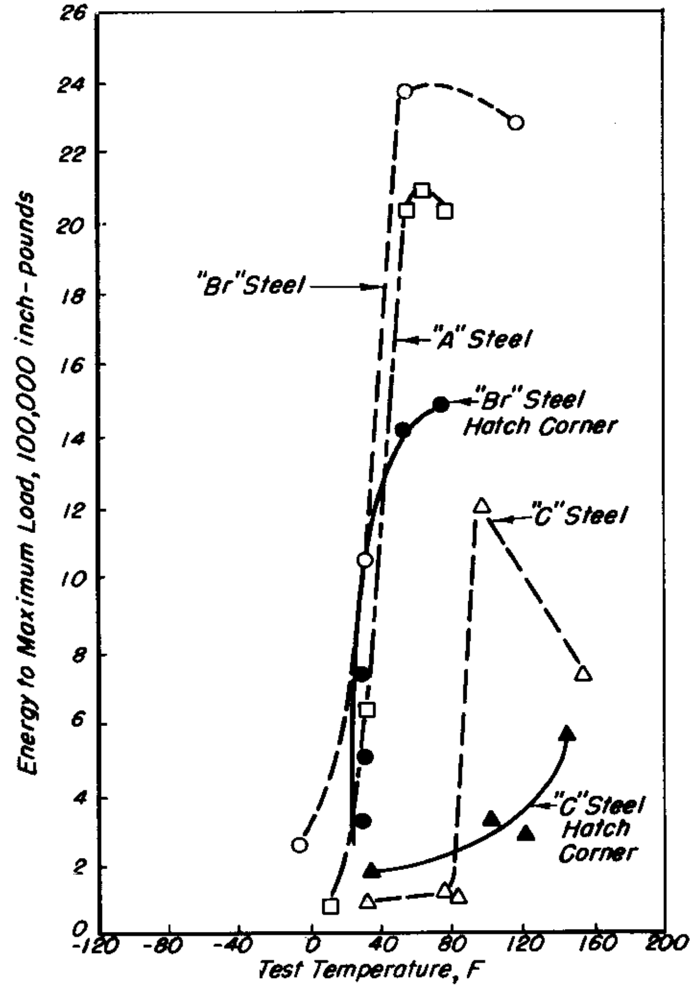


FIGURE 13. COMPARISON OF ENERGY VALUES FOR 72-INCH-WIDE CENTER-NOTCHED PLATE SPECIMENS OF "Br", "A", AND "C" STEELS. HATCH-CORNER DATA ARE INCLUDED FOR COMPARISON OF TRANSITION-TEMPERATURE RANGES. REFERENCES 1 AND 6.

0-16701

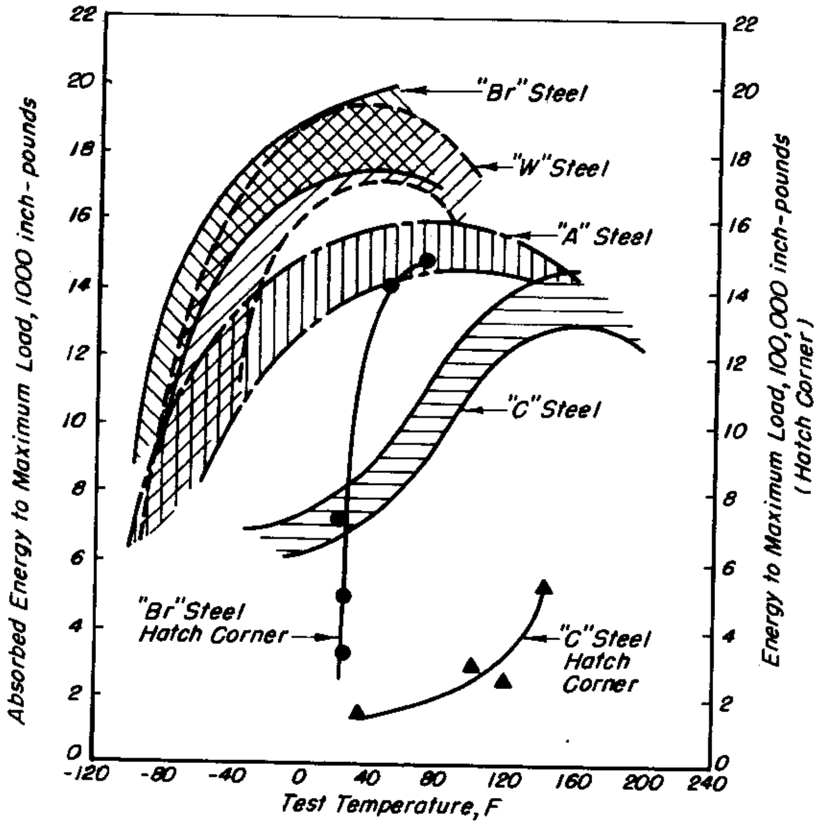


FIGURE 14. COMPARISON OF ENERGY VALUES FOR UNWELDED KINZEL SPECIMENS OF "Br", "W", "A", AND "C" STEELS. HATCH-CORNER DATA ARE INCLUDED FOR COMPARISON OF TRANSITION-TEMPERATURE RANGES. REFERENCE 6.

0-16702

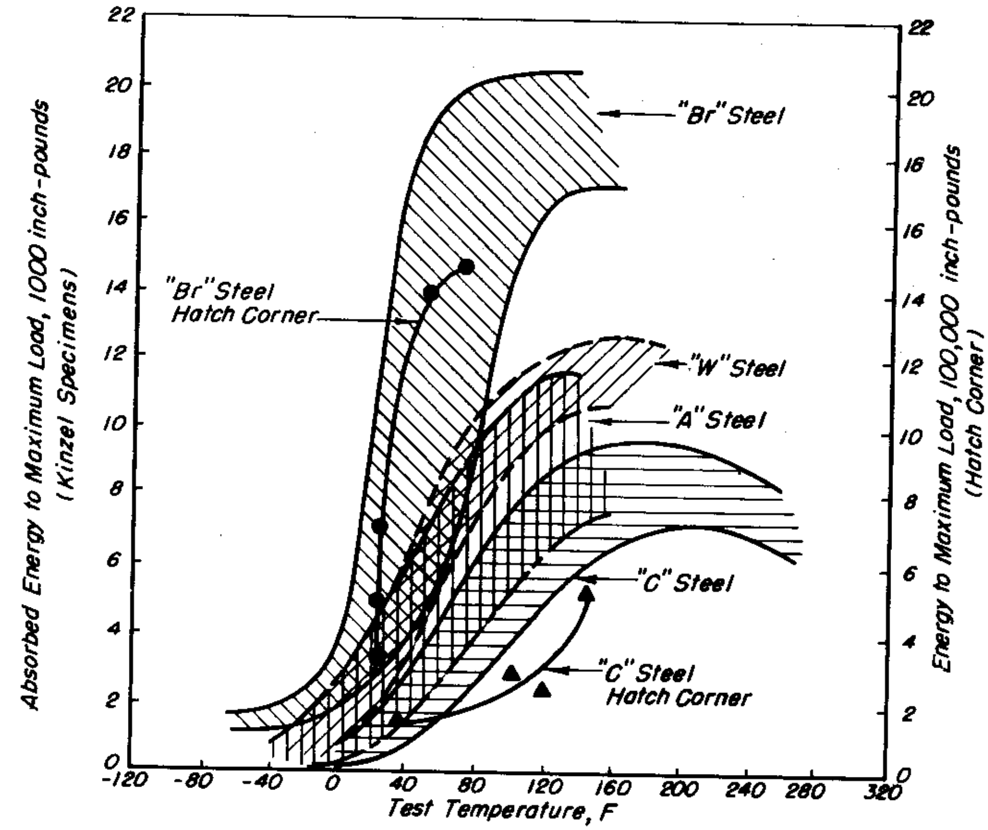


FIGURE 15. COMPARISON OF ENERGY VALUES FOR WELDED KINZEL SPECIMENS OF "Br", "W", "A" AND "C" STEELS. HATCH-CORNER DATA INCLUDED FOR COMPARISON OF TRANSITION-TEMPERATURE RANGES. REFERENCE 6.

0-16703

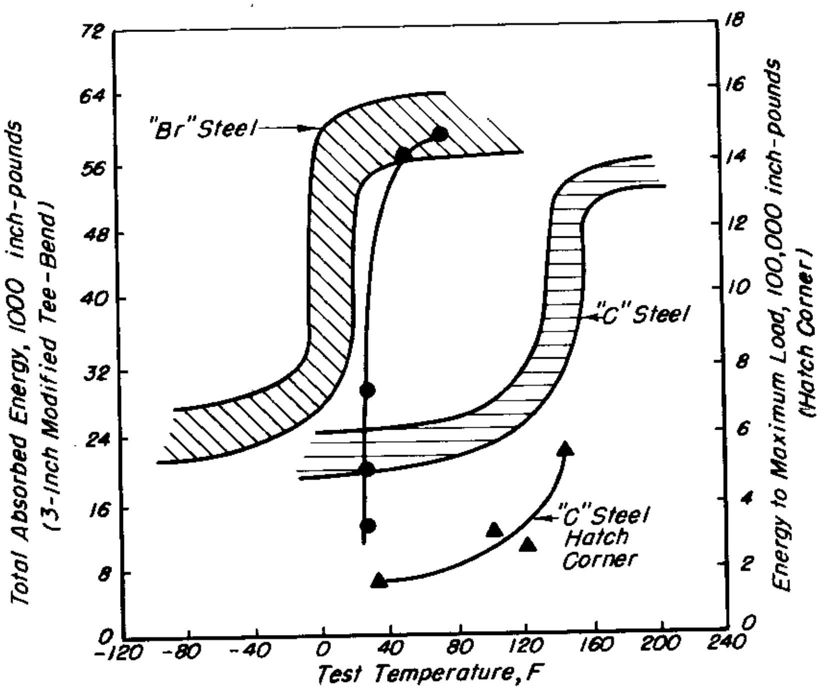


FIGURE 16. COMPARISON OF ENERGY VALUES FOR 3-INCH MODIFIED TEE-BEND SPECIMENS OF "Br" AND "C" STEEL. HATCH-CORNER DATA ARE INCLUDED FOR COMPARISON OF TRANSITION-TEMPERATURE RANGES. REFERENCES 6 AND 7.

0-16704

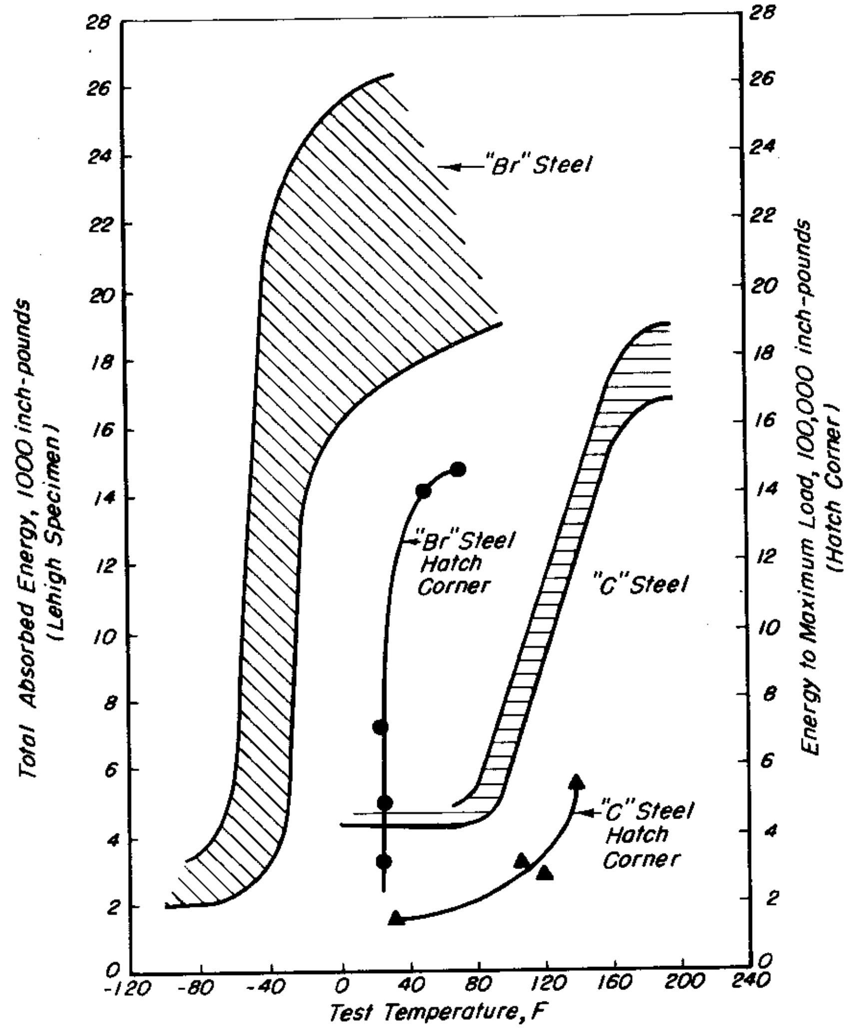


FIGURE 17. COMPARISON OF ENERGY VALUES FOR LEHIGH SPECIMENS OF "Br" AND "C" STEELS. HATCH-CORNER DATA ARE INCLUDED FOR COMPARISON OF TRANSITION-TEMPERATURE RANGES. REFERENCES 4 AND 6.

0-16705

That welded Kinzel specimens, and the Navy tear test specimen containing no weld, match the hatch-corner transition-temperature ranges may be a matter of coincidence, although the probability exists that the small specimens simulate the notch and restraint conditions of the metal in front of the crack in the hatch-corner specimens. Had the transition-temperature range for another steel or another hatch-corner design been determined, it is quite possible that some other specimen, such as the Lehigh specimen, might have matched that transition-temperature range.

With the knowledge that the transition-temperature range of a steel is influenced by the specimen or weldment "design" or condition of restraint, it is reasonable to believe the hatch-corner specimen did not have the same transition-temperature range that it would if tested as incorporated in a ship's hull. But this does not in any way invalidate the usefulness of any or all of the small laboratory specimens such as the Kinzel or Navy tear test in evaluating steels, as long as it is realized that the information relating to transition-temperature ranges is strictly relative rather than actual in relation to some large scale weldment. There must still be correlation between service performance and test predictions in order to set an "acceptance level" for a material as determined by the laboratory specimen.

EFFECT OF THERMAL TREATMENTS ON WELDED KINZEL SPECIMENS OF "B_r" AND "C" STEELS

The effect of certain thermal treatments on the behavior of welded Kinzel specimens of "B_r" and "C" steels has been determined. The thermal treatments were:

a. The use of 10 F, 70 F, 150 F, 250 F, 400 F, and 500 F preheats on "B_r" and "C" steels.

b. The use of 70 F preheat and a postheat of 1150 F for one hour on "B_r" and "C" steels.

c. The use of 400 F preheat and a postheat of 1150F for one hour on "B_r" steel.

Cooling rates were recorded for each condition of preheat. Also, hardness surveys were made of the effects of the various thermal treatments on both steels.

Preparation, Welding, and Testing of Specimens

The test coupons of "B_r" and "C" steels were prepared and welded in the same manner as the coupons of "A" and "W" steels, described previously.

The cooling rates for each preheat were measured by means of a chromel-alumel thermocouple flash welded into a small hole drilled in the bottom side of the specimen, as shown in Figure 18. Cooling curves were recorded on an automatic Speedomax recorder. After preheating and welding, the specimens were permitted to cool in air at 70 F. Average cooling curves for the various preheats are shown in Figure 19.

An examination of these cooling curves shows that the rate of cooling changes with preheat. For a preheat of 10 F, the cooling rate is much faster than the rate for 500 F preheat. Thus, in sixty seconds' cooling time, the end temperatures for 10 F, 70 F, 150 F, 250 F, 400 F, and 500 F preheats are 350 F, 450 F, 500 F, 550 F, 700 F, and 800 F, respectively, illustrating markedly the effect of preheat in slowing the cooling rate.

Effect of Various Preheats on "C" Steel

The test results of the Kinzel specimens of "C" steel using 10 F, 70 F, 150 F, 250 F, 400 F, and 500 F preheats are given in Appendix A, Tables A-5 through A-10. Absorbed energy versus temperature curves are shown in

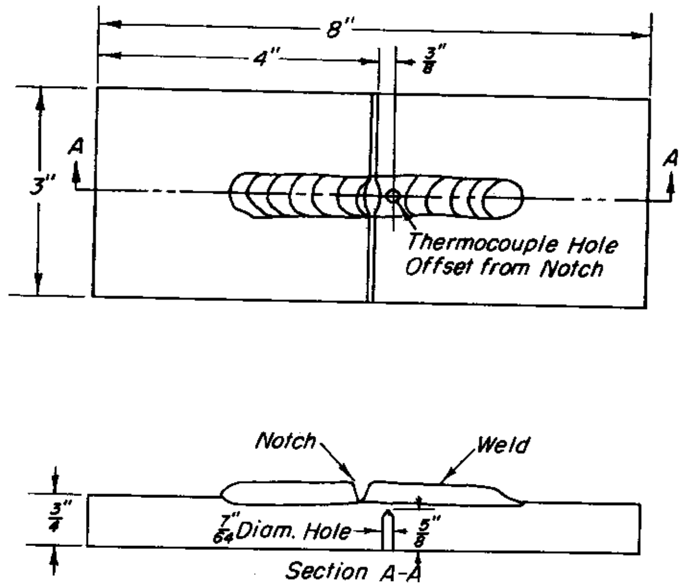


FIGURE 18. SKETCH SHOWING ARRANGEMENT OF THERMOCOUPLE HOLE TO RECORD COOLING RATES ON KINZEL-TYPE SPECIMEN

0-16706

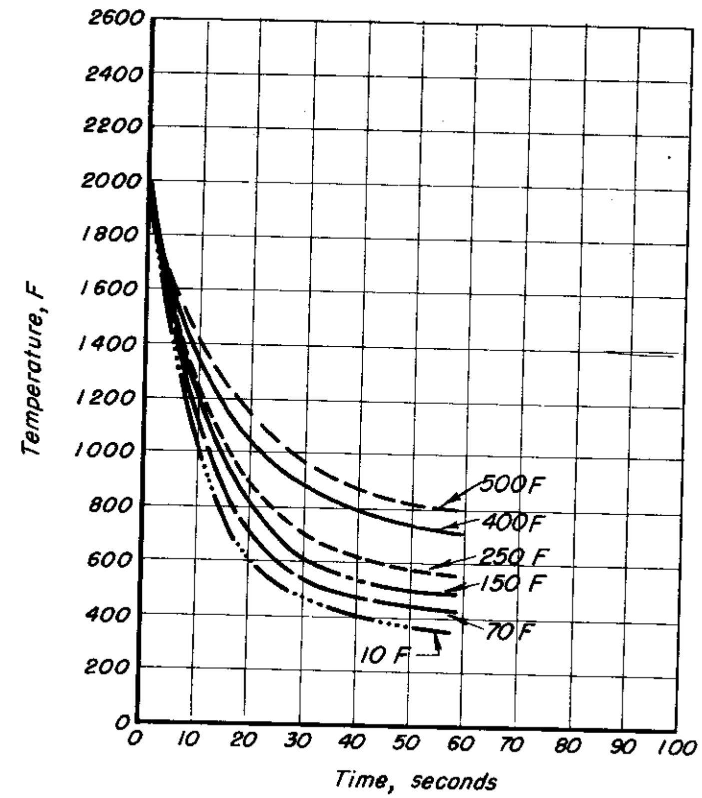


FIGURE 19. AVERAGE COOLING CURVES ON KINZEL-TYPE SPECIMENS USING 10, 70, 150, 250, 400 AND 500F PREHEATS

0-11588

Figure 20, and fracture appearance versus temperature curves are shown in Figure 21. Based on absorbed energy, 10 F and 150 F preheat had little effect on the transition-temperature range or absorbed energy. Preheats of 250F, 400 F, and 500 F, however, each successively lowered the transition range, with the 500 F preheat being most effective. None of the preheats increased absorbed energy at the higher test temperatures. Considering the fracture-appearance curves, a similar trend in lowering the transition-temperature range of "C" steel is observed with the increase in preheat temperatures, except for 500 F preheat. No significance is attached to this deviation, though this is well to keep in mind when using fracture appearance to judge behavior.

Effect of Postheat on "C" Steel

Energy and fracture-appearance curves for Kinzel specimens welded at 70 F preheat, followed by a postheat of 1150 F for 1 hour, are shown in Figures 20 and 21. Complete data are recorded in Appendix A, Table A-11. The postheat treatment did not lower the transition temperature range below that of 500 F preheat, but the maximum absorbed energy was increased about 3000 inch pounds over that obtained with 500 F preheat. The shift in transition temperature range, as measured by fracture appearance, was similar to that of 250 F and 400 F preheats.

Effect of Various Preheats on "B_r" Steel

The test results of the Kinzel specimens of "B_r" steel using 10 F, 70 F, 150 F, 250 F, 400 F, and 500 F preheats are given in Appendix A, Tables A-12 through A-17. Curves of absorbed energy versus temperature are shown in Figure 22, and fracture appearance versus temperature in Figure 23. Considering absorbed energy, 10 F preheat had no effect on the transition temperature range.

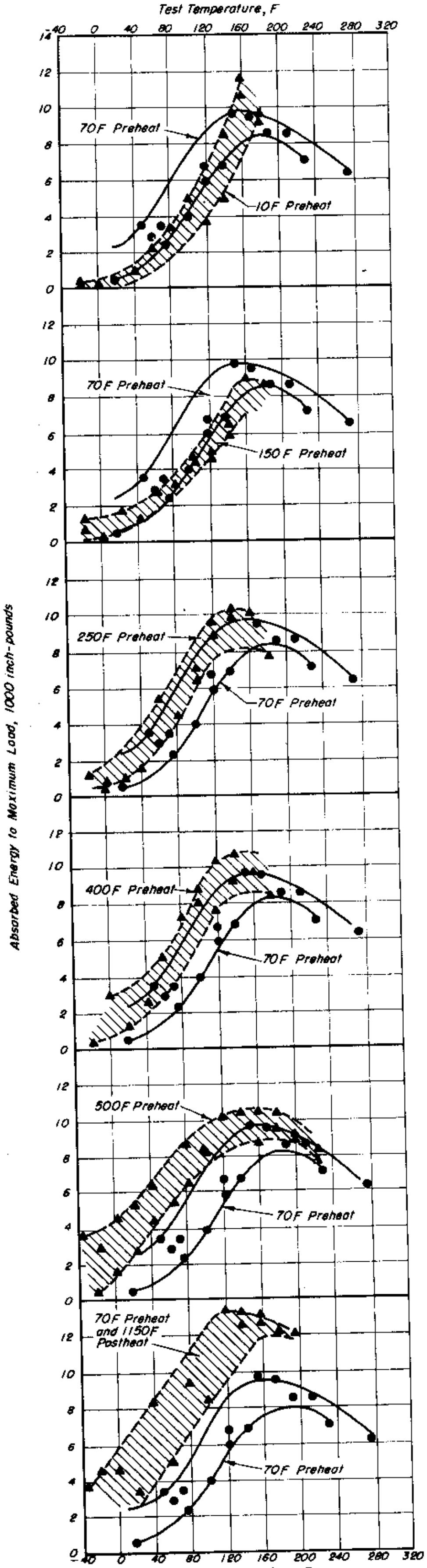


FIGURE 20. EFFECT OF PREHEAT AND POSTHEAT ON WELDED "C" STEEL KINZEL SPECIMENS, USING ABSORBED ENERGY TO MAXIMUM LOAD AS A CRITERION

0-16625

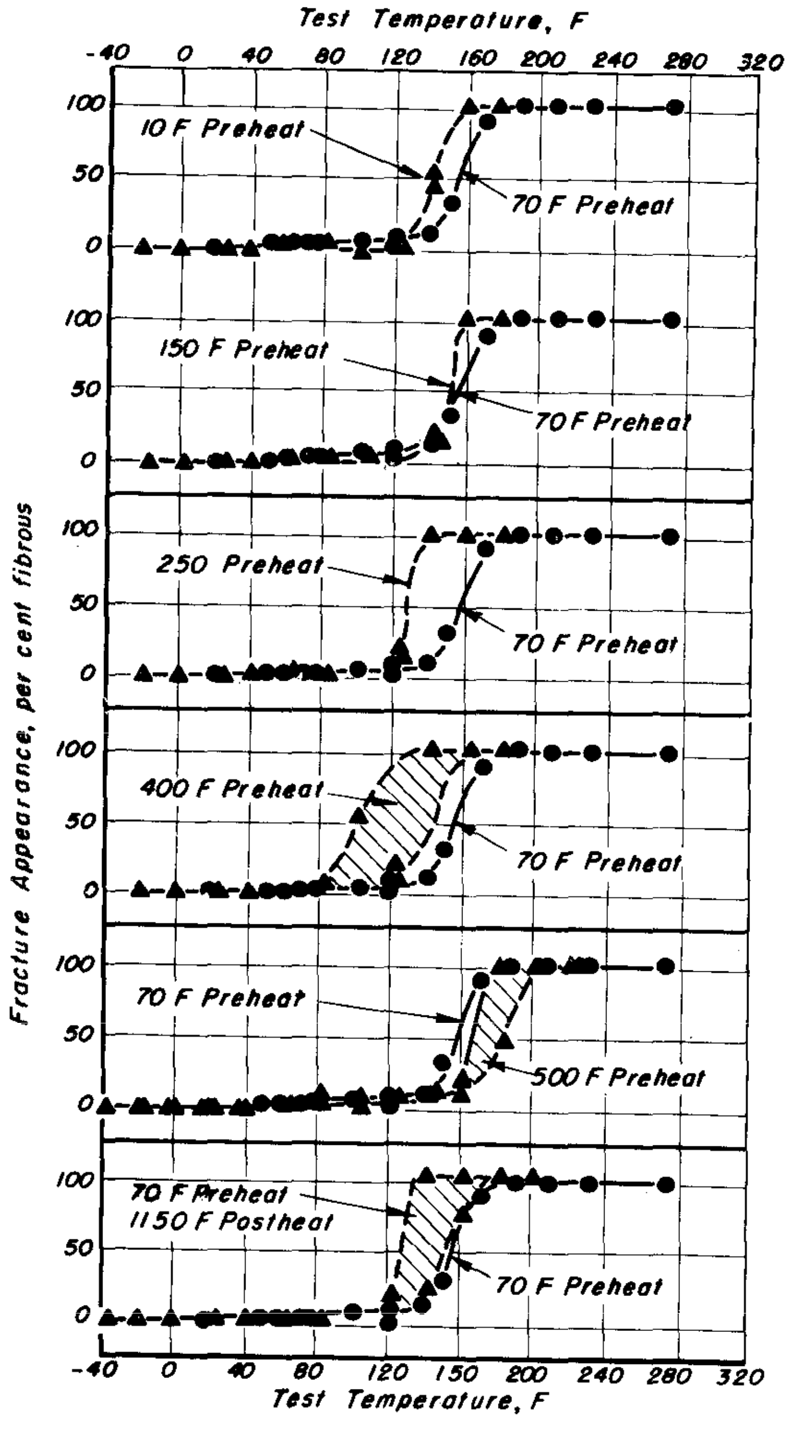


FIGURE 21. EFFECT OF PREHEAT AND POSTHEAT ON WELDED "C" STEEL KINZEL SPECIMENS, USING FRACTURE APPEARANCE AS A CRITERION

O-16622

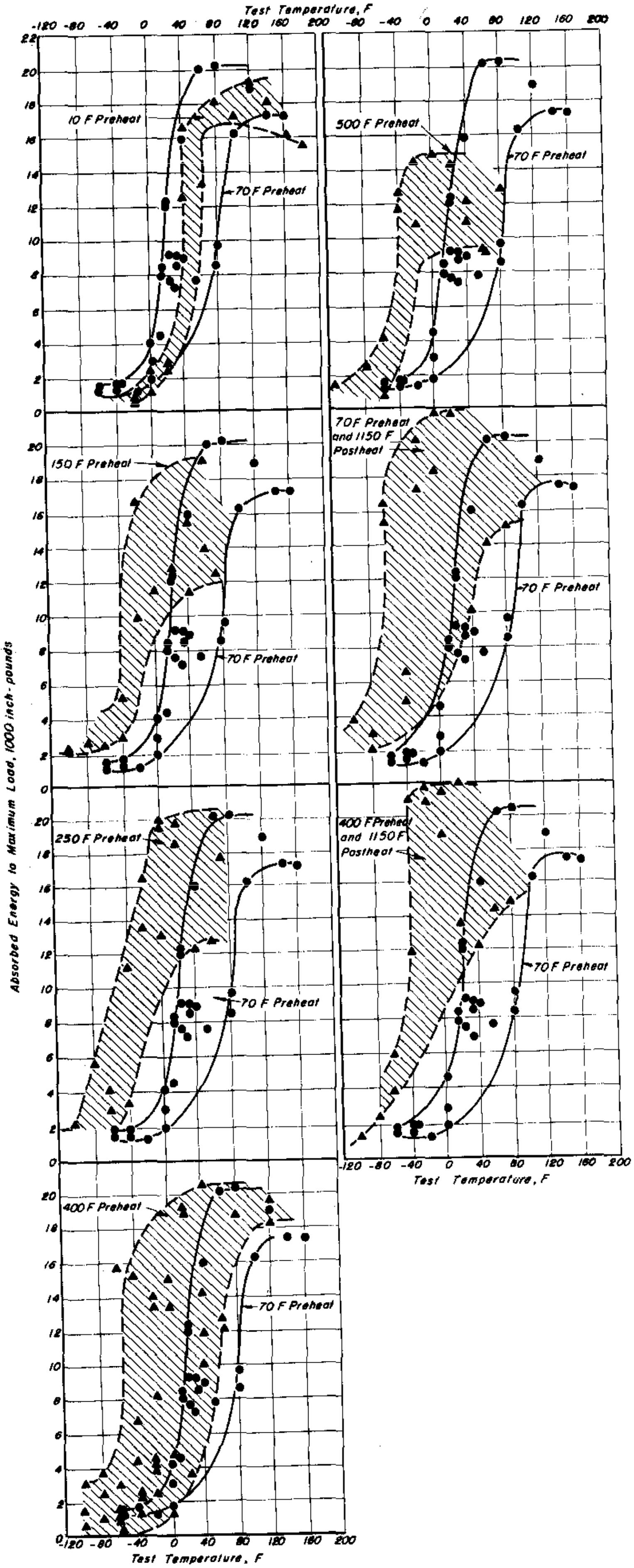


FIGURE 22. EFFECT OF PREHEAT AND POSTHEAT ON WELDED "Br" STEEL KINZEL SPECIMENS, USING ABSORBED ENERGY TO MAXIMUM LOAD AS CRITERION

O-16828

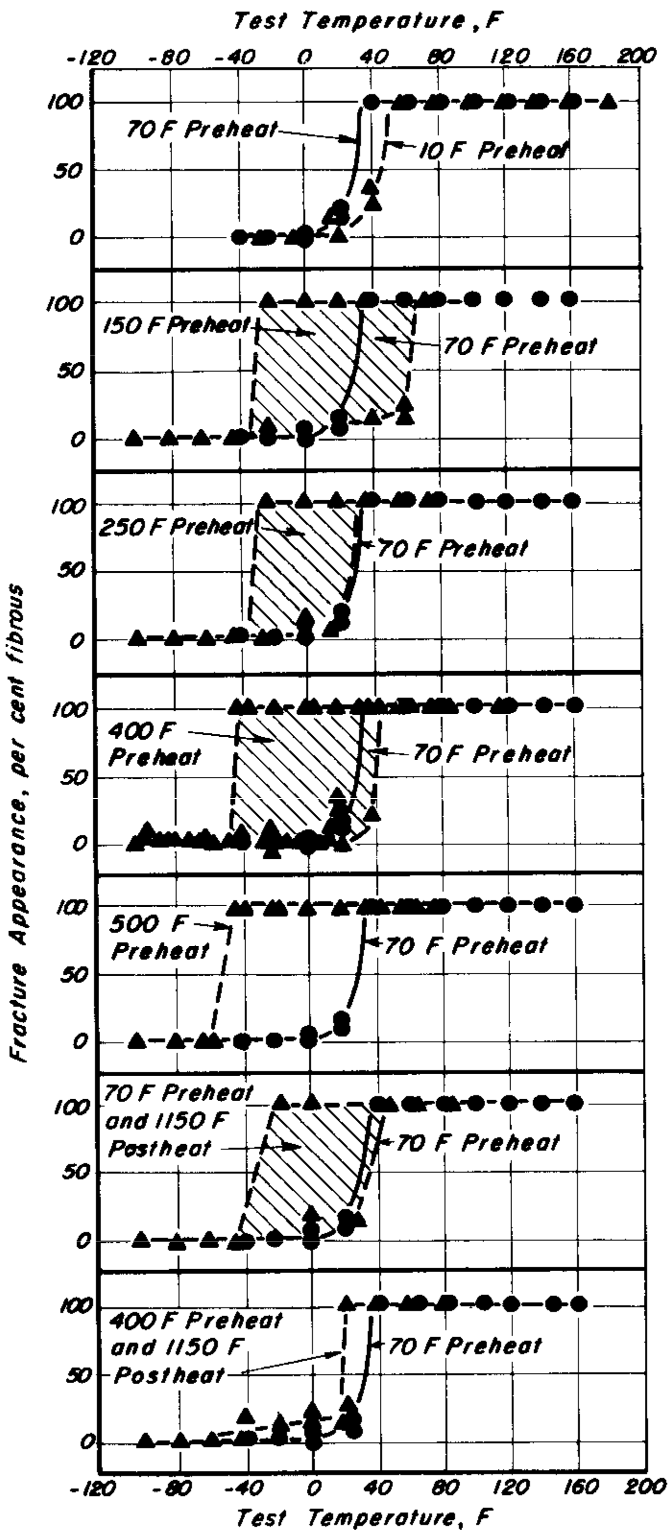


FIGURE 23. EFFECT OF PREHEAT AND POSTHEAT ON WELDED "Br" STEEL KINZEL SPECIMENS USING FRACTURE APPEARANCE AS THE CRITERION

O-16621

Preheats of 150 F, 250 F, 400 F, and 500 F successively lowered the transition temperature range, although less energy was absorbed by the 500 F preheat specimens at higher test temperatures. The lowering of transition temperature with increasing preheat is better illustrated for "B_r" steel by the fracture-appearance curves, as shown in Figure 23.

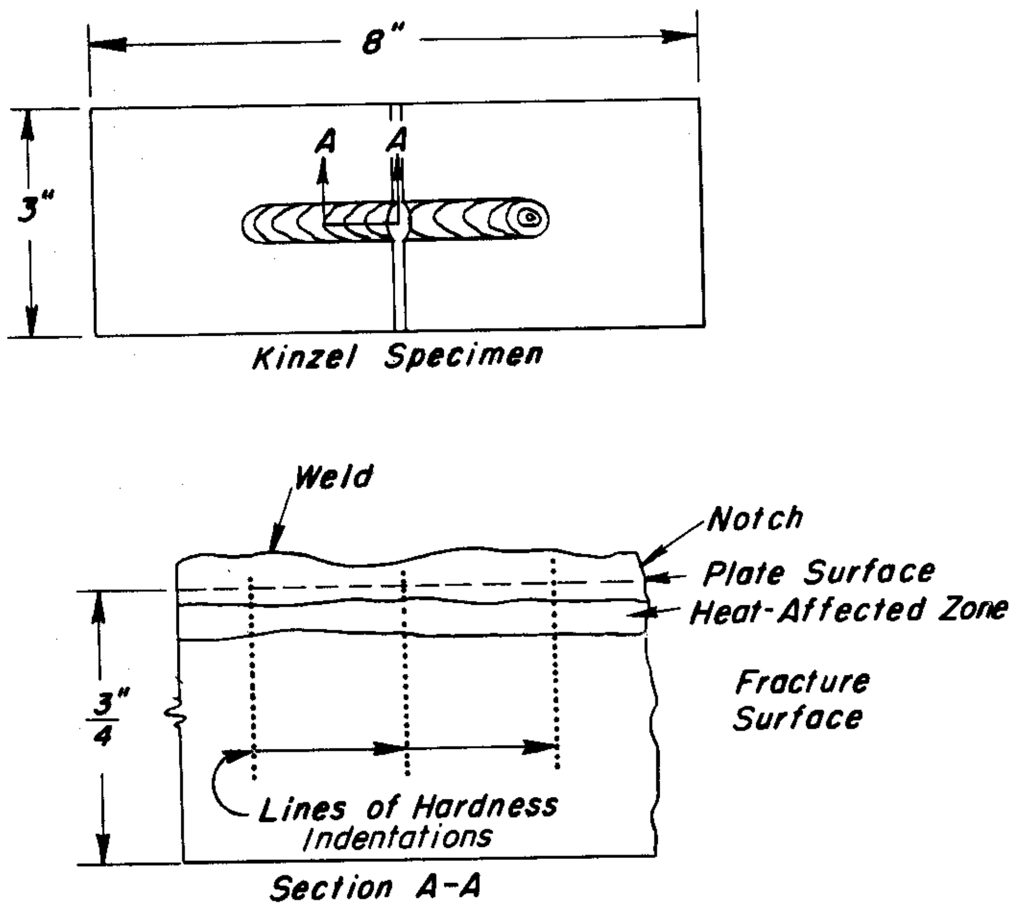
Effect of Postheat on "B_r" Steel

A series of Kinzel specimens of "B_r" steel, welded at 70 F, was postheated at 1150 F for one hour and furnace cooled. Another series was welded at 400 F preheat and given the same postheat treatment. Test results are given in Appendix A, Tables A-18 and A-19. Figure 22 shows that the postheat treatments in both cases resulted in transition-temperature ranges similar to those obtained from specimens welded at 400 F and 500 F preheat. In addition, the amount of absorbed energy was noticeably raised. The envelopes for both series of "B_r" steel which had been postheated are similar. There is apparently little difference between specimens preheated to 400 F and those preheated to 70 F, when the postheat treatment was used.

Results of Hardness Surveys

Hardness surveys were made with a Vickers Hardness Tester, using a 10-kilogram load, on samples of "B_r" and "C" steel welded at the various preheats, and given the postheat treatment described previously. Figure 24 is a sketch showing the manner in which the specimens were prepared. The results of these surveys are shown in Appendix B, Figures B-1 through B-13.

Figure 25 summarizes the results of the hardness surveys made on "C" steel. The heat-affected zone, immediately below the fusion line, had the highest hardness. As higher preheats were used, this zone and the weld metal were softened. As was expected, the 1150 F postheat produced the softest heat-affected



16 Impressions, Spaced 0.025 Inch, Made
Along Each Line

FIGURE 24. SKETCH SHOWING DETAILS OF KINZEL SPECIMENS PREPARED FOR HARDNESS SURVEYS

0-16707

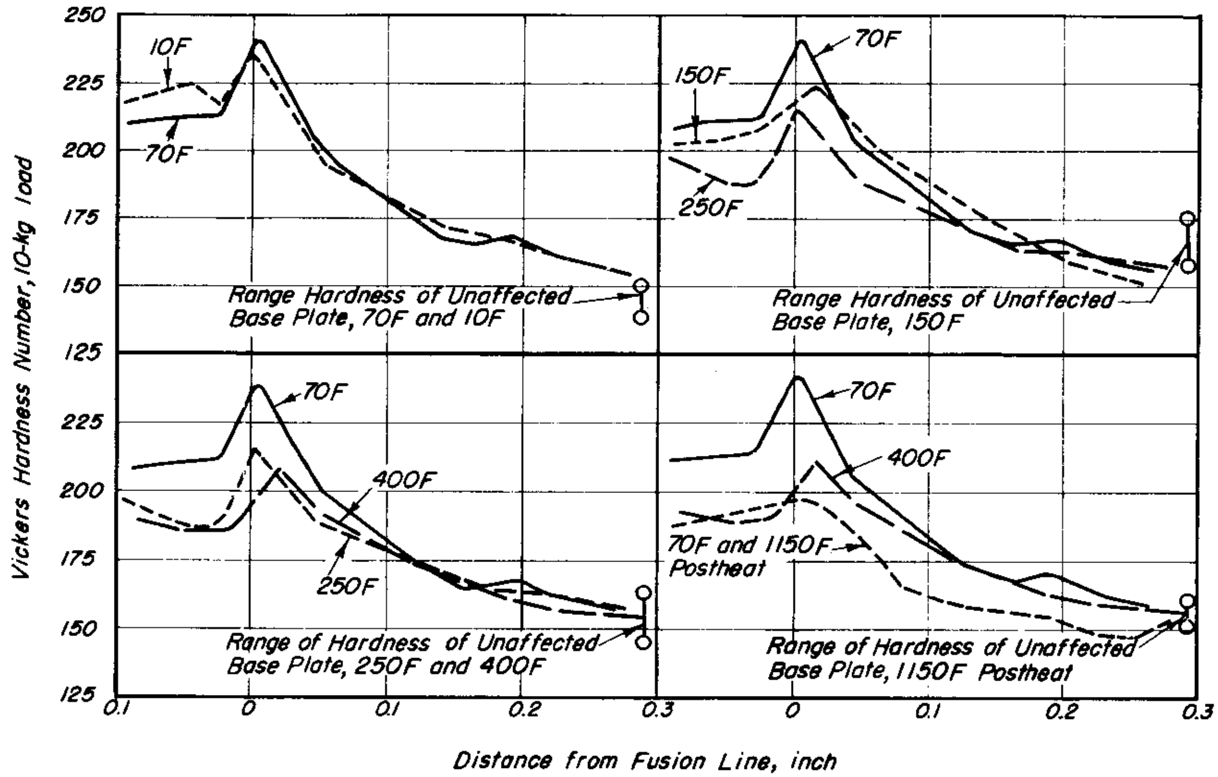


FIGURE 25. COMPARISON OF AVERAGE HARDNESS OF WELDS AND HEAT-AFFECTED ZONES OF KINZEL SPECIMENS OF "C" STEEL WELDED WITH VARIOUS PREHEAT AND POSTHEAT TREATMENTS

0-11590

zone. The weld metal, although softer than this hardened zone, was harder than the rest of the heat-affected zone and the unaffected base plate.

Figure 26 summarizes the hardness surveys on "B_r" steel welded at various preheats, and with preheat and postheat treatments. In the case of "B_r" steel, the heat-affected zone was softer than the weld metal at all the conditions of preheat. As was observed with "C" steel, the application of preheat softened both the weld metal and the heat-affected zone.

In general, the effect of preheat on hardness resulted in an over-all softening of the various zones of the welded specimens of "B_r" and "C" steels. The "C" steel with 0.24 per cent carbon had a heat-affected zone which was harder than the weld metal. However, the "B_r" steel, with 0.18 per cent carbon, produced a heat-affected zone which was softer than the weld metal.

In general, as the preheating temperature was increased, the hardness was decreased in both the weld and the heat-affected zone of both "B_r" and "C" steels. With this decrease in hardness there was a general lowering of the transition-temperature ranges of the specimens made with both steels. It appears then that lowering of the transition range may have been a direct result of lowering of hardness in the weld and heat-affected zone. However, there may have been other changes in the weld metal and heat-affected zone which accompanied the preheating which was responsible for the lowering of the transition ranges of the specimens.

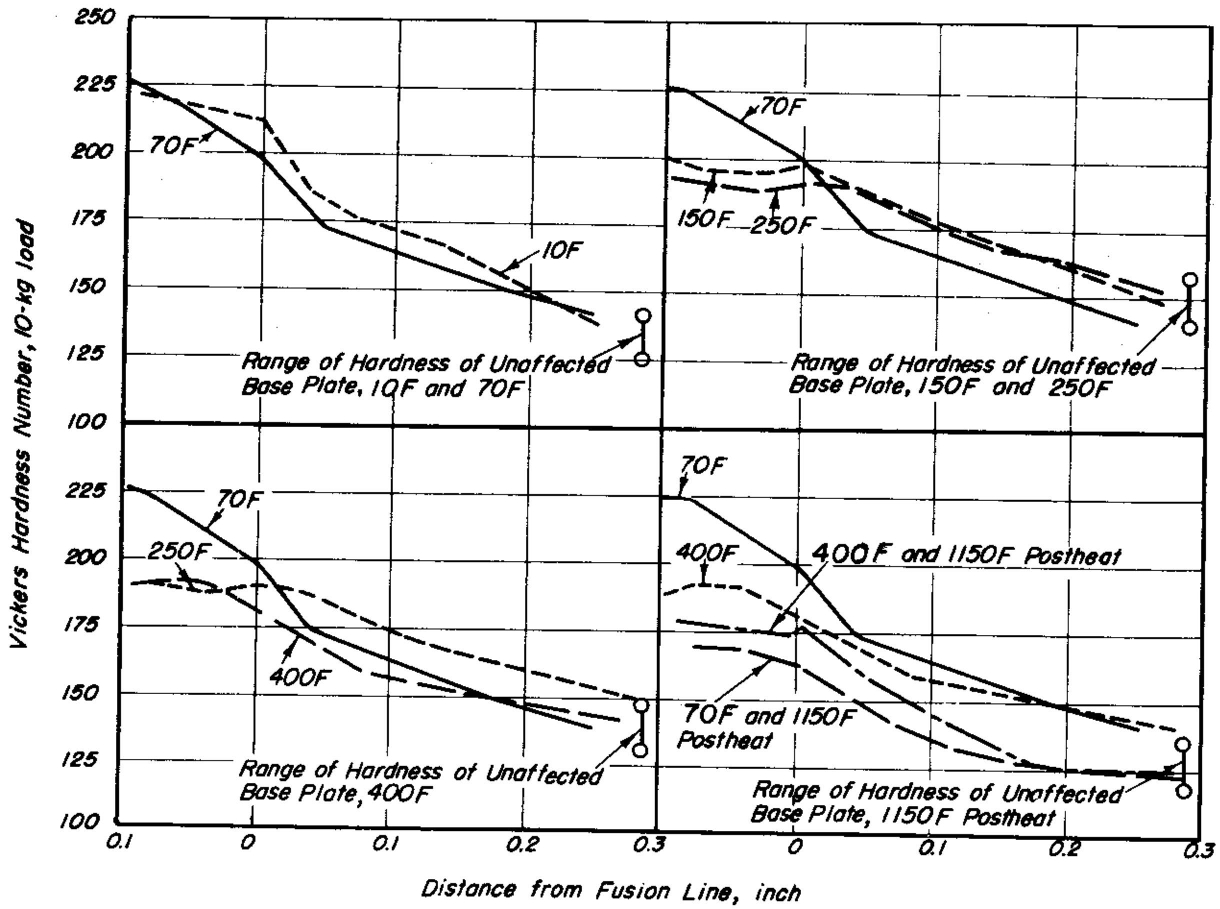


FIGURE 26. COMPARISON OF HARDNESS OF WELDS AND HEAT-AFFECTED ZONES OF KINZEL SPECIMENS OF "Br" STEEL WELDED WITH VARIOUS PRE-HEAT AND POSTHEAT TREATMENTS

0-11591

SUMMARY

1. The transition-temperature ranges for "A" and "W" steels were determined using the Kinzel specimen. The transition-temperature ranges, based on absorbed energy, of the unwelded specimens of both steels were similar, although the "W" steel absorbed more energy.

2. The welded Kinzel specimen rated the "B_r", "W", "A" and "C" steels in that order of increasing transition-temperature range, the same as other tests.

3. Increasing the preheat successively lowered the transition-temperature range of both welded "B_r" and "C" steel Kinzel specimens. "B_r" steel was more responsive than "C" steel to preheat. Both absorbed energy and fracture appearance data indicate these trends.

4. The use of postheat of 1150 F for 1 hour did not lower the transition-temperature range below that accomplished by 400 F preheat for either steel. However, absorbed energy was increased for both "B_r" and "C" steel welded Kinzel specimens.

5. Hardness surveys were made on Kinzel specimens of "B_r" and "C" steels which had been welded at various preheats. The results show that the weld metal of the specimens of "B_r" steel was harder than the heat-affected zone. On the other hand, the heat-affected zone of the specimens of "C" steel was harder than the weld metal. These differences appear to be associated with the carbon content of the "B_r" and "C" steels, which are 0.18 and 0.24 per cent, respectively. In general, the use of preheat or a high temperature postheat tended to soften both the weld metal and the heat-affected zone.

6. Cooling rates were determined for the Kinzel specimen welded at preheats of 10 F, 70 F, 150 F, 250 F, 400 F, and 500 F.

FUTURE WORK

On June 2, 1949, the Advisory Committee for Project SR-100, Contract NObs-45543, "Evaluation of Improved Materials and Methods of Fabrication for Welded Steel Ships," met to review the progress of the work being done at Battelle Memorial Institute. The information contained in this report, describing the work recommended by the committee on December 7, 1948, was presented for the committee's approval.

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

1. Underbead-cracking studies of 42 heats of ABS types of steels will be continued.
2. Studies of fracture initiation and propagation will be made on Kinzel specimens of "B_r" and "C" steels. On the basis of these studies, further recommendations will be made for this aspect of the work.

Data given in this report are recorded in Battelle Laboratory Book No. 3856, pp. 25-33, 40-41, and 54-79; Book No. 4698, pp. 52-59.

FRB:RGK:PJR:CBV/mt
October 25, 1950

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APPENDIX A

TABLE A-1. RESULTS OF SLOW BEND TESTS OF STANDARD KINZEL-TYPE SPECIMENS OF "A" STEEL WELDED AT 70 F

Specimen Number	Testing Temp, F	Maximum Load, Lb	Bend Angle at Maximum Load, Degrees	Absorbed Energy to Maximum Load(1) Sq In.	Absorbed Energy to Maximum Load(1) In.-Lb	Lateral Contraction(2) In.	Lateral Contraction(2) Per Cent	Fracture Appearance, % Fibrous
AC121-3	+160	16,000	21	3.33	7,500	0.092	3.06	100
AC121-2	+140	16,300	25	3.88	8,740	0.096	3.20	100
AC158-4	+140	16,900	27	4.25	9,550	0.108	3.6	100
AC121-1	+120	18,100	29	5.02	11,290	0.080	2.66	100
AC121-15	+120	16,500	21	3.36	7,560	0.093	3.09	100
AC158-3	+120	16,700	27	4.26	9,600	0.102	3.4	100
AC121-4	+100	17,250	26	4.21	9,470	0.091	3.03	100
AC121-14	+100	16,700	25	4.02	9,050	0.085	2.82	100
AC158-2	+100	15,100	15	2.18	4,900	0.112	3.74	25
AC121-5	+ 80	17,000	16	2.34	5,260	0.094	3.13	2.5
AC121-13	+ 80	16,200	12	1.77	3,980	0.044	1.46	2
AC158-10	+ 80	16,000	16	2.44	5,440	0.045	1.50	8
AC121-6	+ 60	16,200	16	2.40	5,400	0.047	1.56	3
AC121-12	+ 60	16,500	15	2.33	5,240	0.046	1.53	2.5
AC158-5	+ 60	16,000	15	2.37	5,330	0.040	1.33	1
AC121-7	+ 40	17,150	11	1.93	4,350	0.037	1.23	1.5
AC158-6	+ 40	16,100	16	2.40	5,400	0.042	1.40	0
AC121-8	+ 20	16,500	12	1.77	3,980	0.037	1.23	2.5
AC158-7	+ 20	13,500	5	0.60	1,350	0.019	0.63	0
AC121-9	0	14,150	2	0.38	855	0.016	0.53	0
AC158-8	0	13,700	4	0.64	1,440	0.013	0.43	0
AC121-10	- 20	12,900	1	0.16	360	0.013	0.43	0
AC121-11	- 20	13,300	1	0.19	428	0.013	0.43	0
AC158-9	- 20	14,300	5	0.73	1,640	0.020	0.66	0

(1) Absorbed Energy = measured area under the load-deflection curve (in column headed "Sq In.") times 2,250 inch-pounds.

(2) 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-2. RESULTS OF SLOW BEND TESTS OF UNWELDED STANDARD KINZEL-TYPE SPECIMENS OF "A" STEEL

Specimen Number	Testing Temp, F	Maximum Load, Lb	Bend Angle at Maximum Load, Degrees	Absorbed Energy to Maximum Load[(1)]		Lateral Contraction[(2)]		Fracture Appearance, % Fibrous
				Sq In.	In.-Lb	In.	Per Cent	
AC136-15	+160	17,500	40	6.28	14,150	0.111	3.70	100
AC136-14	+140	18,000	40	6.70	15,100	0.106	3.53	100
AC136-13	+120	17,750	40	6.51	14,670	0.100	3.33	100
AC136-12	+100	18,300	40	6.75	15,200	0.105	3.50	100
AC136-11	+ 77	18,700	33	5.65	12,700	0.111	3.70	20
AC136-1	+ 40	20,300	36	7.03	15,800	0.103	3.43	10
AC136-2	+ 20	19,500	36	6.44	14,490	0.070	2.33	4
AC136-3	0	19,400	33	5.97	13,430	0.087	2.90	4
AC136-4	- 20	20,300	35	6.32	14,200	0.088	2.93	2
AC136-5	- 40	19,300	25	4.66	10,500	0.067	2.23	0
AC136-6	- 60	18,600	20	3.68	8,290	0.058	1.93	0
AC136-8	- 80	19,400	21	4.20	9,450	0.058	1.93	0
AC136-9	-100	19,250	15	2.9	6,520	0.045	1.50	0

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

(2) 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-3. RESULTS OF SLOW BEND TESTS OF STANDARD KINZEL-TYPE SPECIMENS OF "W" STEEL WELDED AT 70 F

Specimen Number	Testing Temp, F	Maximum Load, Lb	Bend Angle at Maximum Load, Degrees	Absorbed Energy to Maximum Load(1)		Lateral Contraction(2)		Fracture Appearance, % Fibrous
				Sq In.	In.-Lb	In.	Per Cent	
AC140-5	190	17,700	34	5.54	12,500	0.102	3.40	100
AC140-4	160	17,700	32	5.29	11,900	0.094	3.10	100
AC140-3	140	17,900	33	5.66	12,750	0.091	3.00	60
AC140-2	100	18,050	30	4.98	11,200	0.094	3.10	20
AC140-1	80	17,850	26	4.45	10,000	0.108	3.6	35
AC140-6	40	16,600	15	2.39	5,390	0.041	1.36	0
AC140-7	20	13,650	5	0.69	1,550	0.022	0.73	0
AC140-8	0	15,400	8	1.20	2,700	0.027	0.90	0
AC140-9	-20	13,750	4	0.55	1,240	0.017	0.57	0
AC140-10	-40	13,300	2	0.28	630	0.013	0.43	0

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

(2) 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-4. RESULTS OF SLOW BEND TESTS OF UNWELDED STANDARD KINZEL-TYPE SPECIMENS OF "W" STEEL

Specimen Number	Testing Temp, F	Maximum Load, Lb	Bend Angle at Maximum Load, Degrees	Absorbed Energy to Maximum Load(1)		Lateral Contraction(2)		Fracture Appearance, % Fibrous
				Sq In.	In.-Lb	In.	Per Cent	
AC141-11	100	19,100	44	7.77	17,320	0.128	2.35	100
AC141-10	80	18,700	42	7.07	15,900	0.104	3.47	100
AC141-1	60	19,600	43	7.56	17,000	0.115	3.83	40
AC141-2	40	21,500	44	8.17	18,400	0.108	3.60	10
AC141-3	20	20,500	45	8.64	19,420	0.118	3.93	15
AC141-4	0	20,350	42	7.78	17,500	0.112	3.73	10
AC141-5	-20	21,000	38	7.01	15,800	0.093	3.10	1
AC141-7	-40	19,800	28	4.90	11,050	0.072	2.40	0
AC141-6	-60	21,000	33	6.32	14,230	0.084	2.80	0
AC141-8	-80	18,600	25	4.35	9,800	0.061	2.03	0
AC141-9	-95	19,000	16	2.88	6,480	0.044	1.47	0

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

(2) 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-5. RESULTS OF SLOW BEND TESTS OF STANDARD KINZEL-TYPE SPECIMENS OF "C" STEEL WELDED AT 70 F PREHEAT

Specimen Number	Testing Temp, F	Maximum Load, Lb	Bend Angle at Maximum Load, Degrees	Absorbed Energy to Maximum Load(1)		Lateral Contraction(2)		Fracture Appearance, % Fibrous
				Sq In.	In.-Lb	In.	Per Cent	
AC23-7	275	18,100	18	2.78	6,250	0.0520	1.81	100
AC23-6	230	16,800	21-1/2	3.09	6,950	0.0670	2.33	100
AC23-5	210	17,950	24	3.73	8,400	0.0880	3.06	100
AC23-4	190	17,500	24	3.76	8,460	0.0830	2.99	100
AC23-3	170	17,300	28	4.19	9,440	0.0760	2.64	90
AC23-2	150	17,800	27	4.26	9,590	0.0820	2.86	30
AC23-8	140	18,500	18	2.98	6,710	0.0740	2.58	10
AC23-9	120	17,000	18	2.59	5,830	0.0840	2.92	5
AC23-10	120	17,750	18	2.92	6,580	0.0650	2.26	5
AC23-12	100	15,600	13	1.74	3,920	0.0490	1.71	5
AC23-1	75	14,650	8-1/2	1.06	2,390	0.0470	1.64	2
AC23-15	70	15,500	10-1/2	1.51	3,400	0.0260	0.905	2
AC23-14	60	14,800	10-1/2	1.27	2,860	0.0220	0.766	2
AC23-13	50	15,400	11	1.53	3,450	0.0270	0.94	2
AC23-11	220	11,300	4	0.25	560	0.0185	0.644	0

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

(2) 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-6. RESULTS OF SLOW BEND TESTS OF STANDARD KINZEL-TYPE SPECIMENS OF "C" STEEL WELDED AT 10 F PREHEAT

Specimen Number	Testing Temp, F	Maximum Load, Lb	Bend Angle at Maximum Load, Degrees	Absorbed Energy to Maximum Load[1]		Lateral Contraction[2]		Fracture Appearance, % Fibrous
				Sq In.	In.-Lb	In.	Per Cent	
AC134-13	180	18,000	23	4.19	9,200	0.073	2.43	100
AC134-14	180	17,900	25	4.3	9,690	0.089	2.97	100
AC134-10	160	18,550	28	5.19	11,690	0.097	3.24	100
AC134-12	160	18,100	26	4.74	10,680	0.073	2.43	100
AC134-8	140	16,350	23	3.7	8,340	0.081	2.70	50
AC134-15	140	16,200	12	2.18	4,900	0.098	3.26	45
AC134-11	120	15,900	10	1.63	3,670	0.062	2.07	1
AC134-7	100	17,000	14	2.2	4,950	0.039	1.30	1
AC134-9	80	15,750	9	1.5	3,380	0.030	1.00	0
AC134-1	60	15,500	7	1.0	2,250	0.022	0.73	0
AC134-2	40	13,500	4	0.44	990	0.032	1.07	0
AC134-3	20	12,500	2	0.17	380	0.013	0.43	0
AC134-4	0	12,500	1	0.12	270	0.010	0.33	0
AC134-6	-20	13,000	1	0.18	405	0.011	0.37	0
AC134-5	-20	11,400	1	0.11	250	0.009	0.30	0

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

(2) 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-7. RESULTS OF SLOW BEND TESTS OF STANDARD KINZEL-TYPE SPECIMENS OF "C" STEEL WELDED AT 150 F PREHEAT

Specimen Number	Testing Temp, F	Maximum Load, Lb	Bend Angle at Maximum Load, Degrees	Absorbed Energy to Maximum Load(1)		Lateral Contraction(2)		Fracture Appearance, % Fibrous
				Sq In.	In.-Lb	In.	Per Cent	
AC120-4	+180	17,800	23	3.82	8,600	0.082	2.73	100
AC120-3	+160	17,800	23	3.96	8,960	0.079	2.63	100
AC120-2	+140	17,400	18	2.87	6,450	0.088	2.92	18
AC120-10	+140	17,150	16	2.58	5,800	0.076	2.53	17
AC120-1	+120	16,500	14	2.17	4,880	0.069	2.30	8
AC120-5	+120	17,300	13	2.14	4,810	0.069	2.30	2
AC120-6	+100	16,500	12	1.90	4,280	0.075	2.50	7
AC120-15	+100	18,000	12	2.08	4,680	0.042	1.40	3
AC120-7	+ 80	17,100	10	1.40	3,150	0.034	1.13	1
AC120-8	+ 60	16,200	8	1.24	2,800	0.029	0.96	1
AC120-9	+ 40	15,000	9	0.56	1,260	0.020	0.67	0.5
AC120-11	+ 20	16,000	5	0.75	1,690	0.021	0.70	0.5
AC120-12	0	14,000	1	0.14	315	0.013	0.43	0
AC120-13	- 20	15,700	4	0.58	1,305	0.019	0.63	0.25
AC120-14	- 20	15,300	2	0.31	700	0.019	0.63	0

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

(2) 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 STANDARD KINZEL-TYPE SPECIMENS OF "C" STEEL WELDED AT 250 F PREHEAT

Specimen Number	Testing Temp, F	Maximum Load, Lb	Bend Angle at Maximum Load, Degrees	Absorbed Energy to Maximum Load[1]		Lateral Contraction[2]		Fracture Appearance. % Fibrous
				Sq In	In.-Lb	In.	Per Cent	
AC122-6	+180	18,100	20	3.41	7,660	0.076	2.53	100
AC122-3	+160	18,300	26	4.45	10,000	0.085	2.84	100
AC122-11	+140	18,800	28	4.80	10,800	0.076	2.53	100
AC122-2	+140	18,500	25	4.41	9,920	0.095	3.16	100
AC122-5	+120	18,900	24	4.23	9,500	0.067	2.23	15
AC122-1	+120	18,700	21	3.89	8,750	0.101	3.36	20
AC122-15	+100	18,000	18	2.82	6,340	0.052	1.73	4
AC122-4	+100	18,100	19	3.10	6,970	0.059	1.96	5
AC122-7	+ 80	16,900	9	1.95	4,390	0.044	1.47	3
AC122-8	+ 60	17,800	14	2.37	5,330	0.015	0.50	4
AC122-9	+ 40	15,200	4	0.70	1,570	0.025	0.83	4
AC122-10	+ 20	13,200	3	0.36	810	0.013	0.43	0
AC122-12	0	14,200	2	0.32	720	0.015	0.50	0
AC122-14	0	13,400	2	0.28	630	0.014	0.47	0
AC122-13	- 20	14,900	3	0.52	1,170	0.019	0.63	0

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

(2) 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-9. RESULTS OF SLOW BEND TESTS OF STANDARD KINZEL-TYPE SPECIMENS OF "C" STEEL WELDED AT 400 F PREHEAT

Specimen Number	Testing Temp, F	Maximum Load, Lb	Bend Angle at Maximum Load Degrees	Absorbed Energy to Maximum Load(1)		Lateral Contraction(2)		Fracture Appearance, % Fibrous
				Sq In.	In.-Lb	In.	Per Cent	
AC123-6	+180	17,900	21	3.69	8,300	0.081	2.70	100
AC123-3	+160	18,200	26	4.28	9,620	0.084	2.79	100
AC123-13	+140	18,600	27	4.77	10,720	0.089	2.97	100
AC123-2	+140	18,350	25	4.12	9,270	0.091	3.04	100
AC123-1	+120	18,000	19	3.35	7,540	0.060	2.00	5
AC123-5	+120	18,650	26	4.61	10,380	0.091	3.03	20
AC123-4	+100	18,900	22	3.87	8,700	0.064	2.13	5.5
AC123-15	+100	18,400	20	3.54	7,960	0.058	1.93	5
AC123-7	+ 80	18,300	18	3.22	7,250	0.059	1.96	4
AC123-8	+ 60	17,500	13	2.10	5,060	0.041	1.37	0
AC123-9	+ 40	16,000	7	1.13	2,540	0.025	0.83	0
AC123-10	+ 20	14,300	3	0.50	1,170	0.020	0.67	0
AC123-14	0	17,100	8	1.33	2,990	0.028	0.93	0
AC123-11	0	16,750	8	1.32	2,970	0.029	0.97	0
AC123-12	- 20	13,300	2	0.16	360	0.011	0.37	0

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

(2) 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-10. RESULTS OF SLOW BEND TESTS ON STANDARD KINZEL-TYPE SPECIMENS OF "C" STEEL WELDED WITH 500 F PREHEAT

Specimen Number	Testing Temp, F	Maximum Load, Lb	Bend Angle at Maximum Load, Degrees	Absorbed Energy to Maximum Load(1) Sq In.	Absorbed Energy to Maximum Load(1) In.-Lb	Lateral Contraction(2) In.	Lateral Contraction(2) Per Cent	Fracture Appearance, % Fibrous
AC231-6	+225	19,100	18	3.36	7,560	0.097	3.23	100
AC231-5	+225	18,400	20	3.69	8,300	0.088	2.93	100
AC231-4	+200	19,400	22	3.92	8,830	0.082	2.73	100
AC231-10	+200	19,350	23	4.17	9,360	0.087	2.90	100
AC231-2	+180	19,100	25	4.59	10,300	0.079	2.63	50
AC228-3	+180	19,450	22	4.21	9,500	0.075	2.50	100
AC228-16	+160	19,650	25	4.70	10,580	0.074	2.46	22
AC231-1	+160	19,400	20	4.00	9,000	0.081	2.70	10
AC228-17	+140	19,800	24	4.67	10,500	0.067	2.23	5
AC228-8	+120	19,700	24	4.46	10,030	0.038	1.26	5
AC228-11	+100	19,600	20	3.64	8,200	0.054	1.80	0
AC228-12	+100	19,000	21	3.68	8,280	0.062	2.03	5
AC228-14	+ 80	18,200	17	2.98	6,700	0.060	2.00	0
AC228-15	+ 80	19,300	21	3.97	8,930	0.065	2.18	5
AC228-1	+ 60	18,300	13	2.37	5,330	0.043	1.43	0
AC228-4	+ 40	19,150	16	2.93	6,590	0.051	1.70	0
AC228-5	+ 40	17,550	12	2.00	4,500	0.034	1.13	0
AC-228-6	+ 20	16,300	8	1.28	2,880	0.023	0.76	0
AC228-7	+ 20	18,900	14	2.41	5,420	0.039	1.30	0
AC228-9	+ 0	17,100	5	0.85	1,910	0.023	0.76	0
AC231-7	+ 0	19,350	11	2.17	4,880	0.061	2.03	0
AC231-9	- 20	18,350	8	1.55	3,490	0.051	1.70	0
AC228-10	- 20	14,400	1	0.35	787	0.011	0.37	0
AC231-8	- 40	19,350	8	1.77	3,980	0.054	1.80	0
AC228-2	- 60	18,350	13	2.37	5,330	0.043	1.43	0

(1) Absorbed Energy = measured area under the load-deflection curve (in column headed "Sq In.") times 2,250 inch-pounds.

(2) 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-11. RESULTS OF SLOW BEND TESTS OF STANDARD KINZEL-TYPE SPECIMENS OF "C" STEEL WELDED AT 70 F PREHEAT AND POSTHEATED FOR 1 HOUR AT 1150 F

Specimen Number	Testing Temp, F	Maximum Load, Lb	Bend Angle at Maximum Load, Degrees	Absorbed Energy to Maximum Load(1)		Lateral Contraction(2)		Fracture Appearance, % Fibrous
				Sq In.	In.-Lb	In.	Per Cent	
AC126-6	+200	18,500	32	5.35	12,040	0.091	3.03	100
AC126-3	+180	18,700	31	5.40	12,160	0.096	3.20	100
AC126-2	+160	19,500	32	5.65	12,710	0.082	2.73	100
AC126-7	+160	19,150	34	5.74	12,900	0.097	3.23	70
AC126-4	+140	19,300	32	5.56	12,520	0.104	3.46	100
AC126-9	+140	19,400	34	5.87	13,220	0.102	3.40	20
AC126-10	+120	19,500	34	5.89	13,250	0.104	3.46	14
AC126-12	+100	18,300	23	3.71	8,350	0.064	2.10	1
AC126-14	+ 80	18,500	25	4.10	9,220	0.067	2.23	2
AC126-5	+ 60	17,500	17	2.20	4,950	0.045	1.50	0
AC126-15	+ 40	18,650	23	3.65	8,210	0.059	1.97	0
AC126-11	+ 20	15,925	10	1.51	3,400	0.022	0.73	0
AC126-13	0	17,100	14	2.02	4,550	0.037	1.23	0
AC126-1	- 20	18,150	14	2.00	4,500	0.033	1.10	0
AC126-8	- 40	17,250	11	1.65	3,715	0.029	0.97	0

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

(2) 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-12. RESULTS OF SLOW BEND TESTS OF STANDARD KINZEL-TYPE SPECIMENS OF "B_r" STEEL WELDED AT 70 F PREHEAT

Specimen Number	Testing Temp, F	Maximum Load, Lb	Bend Angle at Maximum Load, Degrees	Absorbed Energy to Maximum Load(1) Sq In.	In.-Lb	Lateral Contraction(2) In.	Per Cent	Fracture Appearance, % Fibrous
AC137-14	160	20,700	40	7.69	17,300	0.136	4.50	100
AC137-13	140	20,400	40	7.71	17,360	0.125	4.16	100
AC137-15	120	21,000	42	8.39	18,890	0.128	4.26	100
AC137-9	100	21,000	37	7.27	16,350	0.127	4.23	100
AC137-12	80	21,200	50	10.02	22,550	0.129	4.30	100
AC137-1	60	21,800	44	9.14	20,580	0.134	4.46	100
AC137-2	40	21,000	34	7.01	15,800	0.128	4.26	99
AC137-8	20	16,350	33	5.36	12,080	0.123	4.10	15
AC137-3	20	17,150	32	5.53	12,460	0.128	4.26	15
AC137-4	0	14,900	5	0.85	1,910	0.022	0.73	5
AC137-5	0	15,000	6	0.87	1,960	0.017	0.57	6
AC137-6	-20	15,500	5	0.78	1,755	0.022	0.73	5
AC137-7	-20	15,000	4	0.63	1,420	0.017	0.57	4
AC137-10	-40	15,600	5	0.73	1,642	0.019	0.63	5
AC137-11	-40	15,000	4	0.55	1,240	0.020	0.67	4

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

(2) 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-13. RESULTS OF SLOW-BEND TESTS OF STANDARD KINZEL-TYPE SPECIMENS OF "B_r" STEEL WELDED AT 10 F PREHEAT

Specimen Number	Testing Temp, F	Maximum Load, Lb	Bend Angle at Maximum Load, Degrees	Absorbed Energy to Maximum Load(1)		Lateral Contraction(2)		Fracture Appearance, % Fibrous
				Sq In.	In.-Lb	In.	Per Cent	
AC135-14	180	19,400	36	6.85	15,400	0.126	4.20	100
AC135-12	160	20,250	37	7.18	16,150	0.134	4.46	100
AC135-8	140	20,700	42	8.19	18,410	0.132	4.40	100
AC135-11	120	20,800	41	8.46	19,050	0.167	5.56	100
AC135-6	100	21,300	40	7.7	17,300	0.133	4.43	100
AC135-9	80	21,200	40	8.09	18,200	0.140	4.66	100
AC135-3	60	20,650	31	5.85	13,200	0.121	4.03	100
AC135-15	40	20,800	38	7.4	16,600	0.155	5.26	35
AC135-4	40	17,700	33	5.55	12,500	0.135	4.50	22
AC135-1	20	15,200	7	1.0	2,250	0.034	1.13	15
AC135-5	20	16,100	8	1.22	2,720	0.029	0.97	0
AC135-7	0	14,800	3	0.45	1,010	0.016	0.53	0
AC135-2	0	15,800	6	1.0	2,250	0.024	0.80	0
AC135-10	-20	14,550	2	0.40	900	0.013	0.44	0
AC135-13	-20	14,200	1	0.21	450	0.012	0.40	0

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

(2) 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-14. RESULTS OF SLOW BEND TESTS OF STANDARD KINZEL-TYPE SPECIMENS OF "B_r" STEEL WELDED AT 150 F PREHEAT

Specimen Number	Testing Temp, F	Maximum Load, Lb	Bend Angle at Maximum Load, Degrees	Absorbed Energy to Maximum Load(1)		Lateral Contraction(2)		Fracture Appearance, % Fibrous
				Sq In.	In.-Lb	In.	Per Cent	
AC124-13	+73	19,300	31	5.47	12,300	0.103	3.43	100
AC124-14	+60	21,550	44	8.63	19,200	0.125	4.16	25
AC124-4	+60	21,000	32	6.15	13,830	0.129	4.30	15
AC124-2	+40	21,150	35	6.92	15,600	0.108	3.60	12
AC124-15	+40	18,850	29	5.01	11,300	0.098	3.26	100
AC124-6	+20	19,300	32	5.59	12,600	0.115	3.84	100
AC124-10	0	19,200	28	5.08	11,430	0.115	3.44	100
AC124-1	-20	18,800	25	4.37	9,850	0.069	2.30	6
AC124-5	-20	20,500	39	7.41	16,700	0.117	3.90	100
AC124-8	-40	18,150	14	2.32	5,230	0.038	1.27	0
AC124-9	-40	16,850	8	1.30	2,930	0.028	0.93	0
AC124-7	-60	16,700	7	1.10	2,480	0.027	0.90	0
AC124-11	-60	16,000	7	1.10	2,480	0.023	0.77	0
AC124-3	-80	17,200	7	1.13	2,540	0.023	0.77	0
AC124-12	-100	17,900	6	1.00	2,250	0.021	0.70	0

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

(2) 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-15. RESULTS OF SLOW BEND TESTS OF STANDARD KINZEL-TYPE SPECIMENS OF "B_r" STEEL WELDED AT 250 F PREHEAT

Specimen Number	Testing Temp, F	Maximum Load, Lb	Bend Angle at Maximum Load, Degrees	Absorbed Energy to Maximum Load(1)		Lateral Contraction(2)		Fracture Appearance, % Fibrous
				Sq In.	In.-Lb	In.	Per Cent	
AC125-11	+73	21,150	41	7.90	17,800	0.124	4.14	100
AC125-5	+60	19,600	32	5.69	12,800	0.106	3.54	100
AC125-8	+40	19,100	32	5.51	12,400	0.117	3.90	100
AC125-15	+20	22,000	41	8.22	18,500	0.122	4.06	12
AC125-2	+20	19,700	31	5.65	12,700	0.110	3.68	100
AC125-3	0	19,300	32	5.82	13,100	0.128	4.26	100
AC125-4	0	23,000	42	8.76	19,720	0.131	4.36	15
AC125-13	-20	22,100	35	7.32	16,500	0.098	3.26	6
AC125-7	-20	19,750	33	6.10	13,700	0.111	3.70	100
AC125-10	-40	21,350	25	5.00	11,250	0.069	2.30	1
AC125-1	-40	16,650	9	1.45	3,260	0.029	0.97	0
AC125-12	-60	18,000	10	1.84	4,140	0.035	1.16	0
AC125-6	-60	16,800	9	1.28	2,980	0.027	0.90	0
AC125-9	-80	19,500	14	2.53	5,700	0.039	1.30	1
AC125-14	-100	18,500	5	0.98	2,200	0.026	0.87	0

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

(2) 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-16. RESULTS OF SLOW BEND TESTS ON KINZEL-TYPE SPECIMENS OF "B_r" STEEL WELDED WITH 400 F PREHEAT

Specimen Number	Testing Temp, F	Maximum Load, Lb	Bend Angle at Maximum Load, Degrees	Absorbed Energy TO Maximum Load(1) Sq In.	Absorbed Energy TO Maximum Load(1) In.-Lb	Lateral Contraction(2) In.	Lateral Contraction(2) Per Cent	Fracture Appearance, % Fibrous
AC154-4	120	21,000	42	8.19	18,400	0.141	4.70	100
AC154-3	120	21,000	44	8.70	19,600	0.149	4.95	100
AC154-2	80	21,000	45	9.00	20,200	0.152	5.07	100
AC154-1	80	21,200	42	8.38	18,900	0.131	4.37	100
AC133-1	60	14,000	33	5.73	12,900	0.118	3.93	100
AC133-3	40	18,700	29	5.30	11,920	0.109	3.63	100
AC138-1	40	22,000	45	9.11	20,500	0.126	4.20	17
AC138-9	20	24,100	47	10.62	24,900	0.140	4.66	15
AC138-2	20	23,000	40	8.45	19,000	0.119	3.96	5
AC133-4	20	22,500	41	8.50	19,120	0.132	4.39	25
AC133-8	20	16,850	10	1.64	3,690	0.032	1.07	0
AC133-6	0	17,000	11	1.88	4,230	0.038	1.26	0
AC133-10	0	19,400	32	6.01	13,530	0.103	3.43	97
AC138-4	0	17,400	12	2.14	4,820	0.042	1.40	0
AC138-5	0	14,500	3	0.50	1,125	0.017	0.57	0
AC138-7	-20	16,500	6	1.14	2,565	0.026	0.87	0
AC154-5	-20	17,700	12	2.03	4,570	0.036	1.20	0
AC154-9	-20	18,100	11	2.00	4,500	0.037	1.23	0
AC133-7	-20	16,700	12	1.74	3,920	0.034	1.13	0
AC133-12	-20	20,700	32	6.26	14,100	0.112	3.73	7
AC133-11	-40	15,700	4	0.59	1,330	0.021	0.70	0
AC133-2	-40	19,000	17	3.08	6,940	0.099	3.30	96
AC138-6	-40	16,800	6	1.00	2,250	0.026	0.87	0
AC154-6	-40	16,850	6	1.15	2,590	0.024	0.77	0
AC154-10	-60	15,700	2	0.40	900	0.016	0.54	0
AC133-9	-60	22,900	34	7.05	15,880	0.091	3.03	3
AC133-13	-60	17,000	8	1.35	3,040	0.030	1.00	0
AC138-3	-60	15,250	3	0.48	1,080	0.018	0.60	0
AC138-8	-60	16,000	3	0.73	1,643	0.019	0.63	0

TABLE A-16. (Continued)

Specimen Number	Testing Temp, F	Maximum Load, Lb	Bend Angle at Maximum Load, Degrees	Absorbed Energy to Maximum Load(1)		Lateral Contraction(2)		Fracture Appearance, % Fibrous
				Sq In.	In.-Lb	In.	Per Cent	
AC154-7	- 80	16,400	3	0.50	1,125	0.017	0.57	0
AC133-14	- 80	18,800	9	1.63	3,715	0.031	1.03	0
AC133-15	-100	18,250	8	1.35	3,040	0.026	0.87	0
AC154-8	-100	18,000	1	0.12	562	0.012	0.40	0
AC226-3	+ 60	17,550	30	5.40	12,150	0.107	3.56	100
AC226-1	+ 40	17,700	25	4.46	10,050	0.084	2.80	100
AC226-5	+ 40	19,050	35	6.37	14,300	0.082	2.73	100
AC226-9	+ 20	18,500	29	5.46	12,300	0.077	2.56	100
AC226-8	+ 0	19,300	34	6.57	15,000	0.103	3.43	100
AC226-7	- 20	18,850	31	6.00	13,500	0.111	3.66	100
AC226-6	- 20	18,800	20	3.80	8,550	0.057	1.90	20
AC226-10	- 40	19,500	35	6.69	15,050	0.089	2.96	100
AC226-11	- 40	16,000	7	1.01	4,500	0.012	0.40	0
AC226-16	- 60	15,550	1	0.25	563	0.013	0.43	0
AC226-13	- 60	16,000	4	0.70	1,575	0.019	0.63	0
AC226-15	- 80	17,300	6	1.18	2,660	0.014	0.47	0
AC226-12	-100	17,400	3	0.64	1,440	0.010	0.33	0

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

(2) 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-17. RESULTS OF SLOW BEND TESTS ON STANDARD KINZEL-TYPE SPECIMENS OF "B_r" STEEL WELDED WITH 500 F PREHEAT

Specimen Number	Testing Temp, F	Maximum Load, Lb	Bend Angle at Maximum Load, Degrees	Absorbed Energy to Maximum Load(1) Sq In.	In.-Lb	Lateral Contraction(2) In.	Per Cent	Fracture Appearance, % Fibrous
AC227-14	+ 80	18,000	32	5.60	12,600	0.092	3.06	100
AC227-2	+ 60	17,300	24	4.28	9,650	0.089	2.96	100
AC227-1	+ 60	17,750	24	4.31	9,700	0.107	3.56	100
AC227-3	+ 40	17,750	27	4.89	11,000	0.089	2.96	100
AC227-4	+ 40	18,200	31	5.45	12,270	0.101	3.36	100
AC227-6	+ 20	19,300	33	6.35	14,300	0.109	3.63	100
AC227-9	+ 0	19,800	34	6.44	14,490	0.092	3.06	100
AC227-5	- 20	19,350	25	4.85	10,800	0.098	3.26	100
AC227-7	- 20	19,000	34	6.45	14,500	0.116	3.86	100
AC227-11	- 40	19,100	29	5.68	12,800	0.093	3.10	100
AC227-10	- 40	17,450	28	5.20	11,700	0.088	2.93	100
AC227-15	- 60	17,650	10	1.83	4,120	0.034	1.13	0
AC227-8	- 60	16,750	3	0.66	1,480	0.024	0.80	0
AC227-16	- 80	16,650	5	1.07	2,410	0.022	0.73	0
AC227-13	-100	17,350	3	0.73	1,640	0.016	0.53	0

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

(2) 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-18. RESULTS OF SLOW BEND TESTS OF STANDARD KINZEL-TYPE SPECIMENS OF "B_r" STEEL WELDED AT 70 F PREHEAT AND POSTHEATED AT 1150 F FOR 1 HOUR

Specimen Number	Testing Temp, F	Maximum Load, Lb	Bend Angle at Maximum Load, Degrees	Absorbed Energy to Maximum Load(1) Sq In.	Absorbed Energy to Maximum Load(1) In.-Lb	Lateral Contraction(2) In.	Lateral Contraction(2) Per Cent	Fracture Appearance, % Fibrous
AC127-1	+80	18,350	39	6.63	14,900	0.128	4.26	100
AC127-2	+60	18,850	37	6.16	13,900	0.108	3.60	100
AC127-4	+40	19,700	22	4.40	9,900	0.127	4.23	100
AC127-5	+20	22,250	49	9.64	21,500	0.153	5.09	14
AC127-9	0	20,300	43	8.04	18,100	0.133	4.43	100
AC127-6	0	22,500	48	9.76	22,000	0.165	5.50	20
AC127-13	-20	20,700	48	8.90	20,030	—	—	100
AC127-7	-20	20,500	40	7.51	16,900	—	—	100
AC127-3	-40	18,050	17	2.85	6,420	0.049	1.63	0
AC127-8	-40	16,550	14	2.08	4,690	0.039	1.30	0
AC127-10	-60	22,400	35	7.24	16,300	0.082	2.73	2
AC127-11	-60	22,600	36	6.90	15,520	0.103	3.43	1
AC127-12	-80	16,500	8	1.07	2,410	0.026	0.87	0
AC127-14	-80	17,150	8	1.26	2,835	0.023	0.76	0
AC127-15	-100	18,100	10	1.63	3,670	0.033	1.10	0

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

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

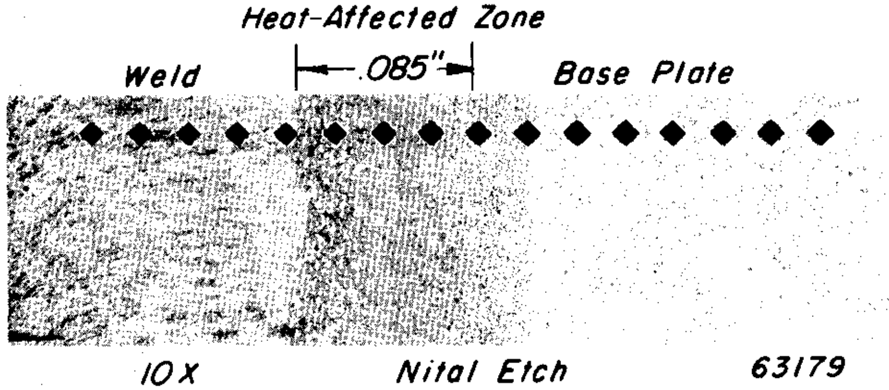
TABLE A-19. RESULTS OF SLOW BEND TESTS OF STANDARD KINZEL TYPE SPECIMENS OF "B_r" STEEL WELDED AT 400 F PREHEAT AND POSTHEATED AT 1150 F FOR 1 HOUR

Specimen Number	Testing Temp, F	Maximum Load, Lb	Bend Angle at Maximum Load, Degrees	Absorbed Energy to Maximum Load(1)		Lateral Contraction(2)		Fracture Appearance, % Fibrous
				Sq In.	In.-Lb	In.	Per Cent	
AC132-15	77	18,300	38	6.64	14,930	0.122	4.06	100
AC132-2	60	18,500	38	6.39	14,390	0.128	4.26	100
AC132-3	40	19,000	33	5.51	12,400	0.120	4.00	100
AC132-5	20	22,500	52	10.21	23,000	0.163	5.43	30
AC132-8	20	19,500	34	6.06	13,650	0.115	3.83	100
AC132-6	0	22,000	42	8.35	18,800	0.153	5.10	15
AC132-10	0	22,700	47	9.49	21,360	0.153	5.10	20
AC132-7	-20	23,200	46	9.58	21,550	0.136	4.52	10
AC132-12	-20	22,700	45	9.23	20,780	0.154	5.12	12
AC132-1	-40	23,300	44	9.27	20,870	0.160	5.33	17
AC132-4	-40	19,200	28	5.27	11,880	0.053	1.76	0
AC132-9	-60	17,350	11	1.76	3,960	0.036	1.20	0
AC132-11	-60	17,700	14	2.66	5,990	0.046	1.53	0
AC132-13	-80	16,300	6	1.02	2,295	0.025	0.83	0
AC132-14	-100	17,350	4	0.59	1,330	0.020	0.67	0

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

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

APPENDIX B



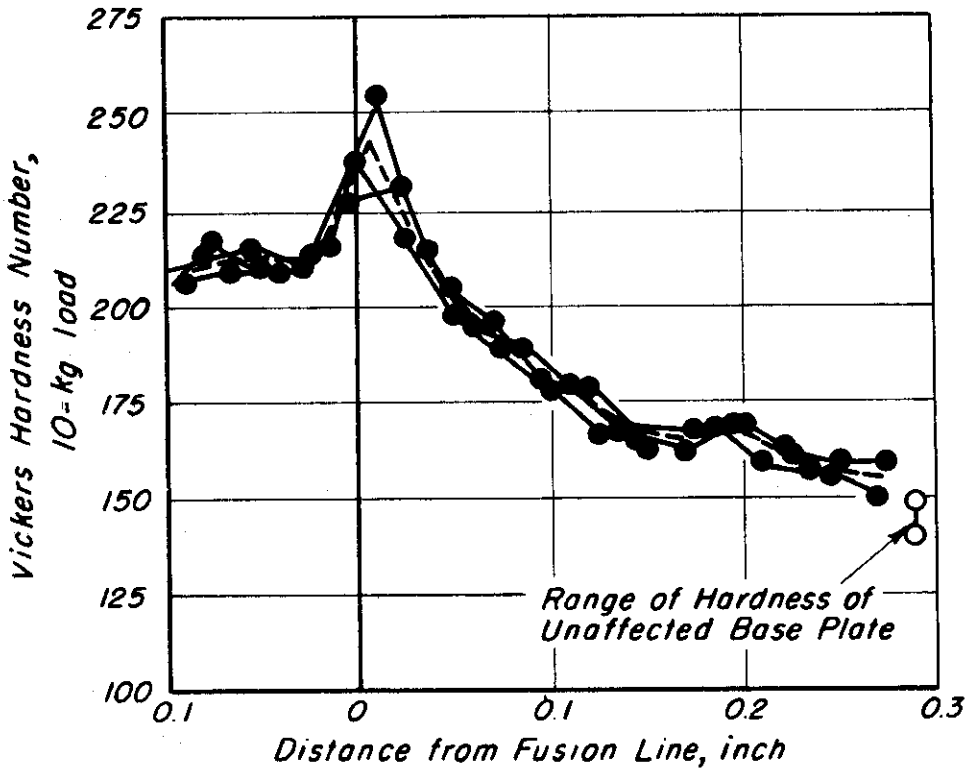
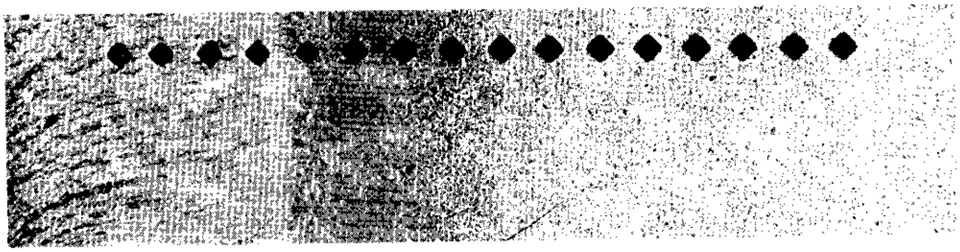


FIGURE B-1. HARDNESS SURVEY OF WELD BEAD AND HEAT-AFFECTED ZONE OF KINZEL SPECIMEN OF "C" STEEL WELDED AT 70F PREHEAT (PHOTO OF HARDNESS TRANSVERSE TYPICAL OF THE THREE MADE)

0-14408



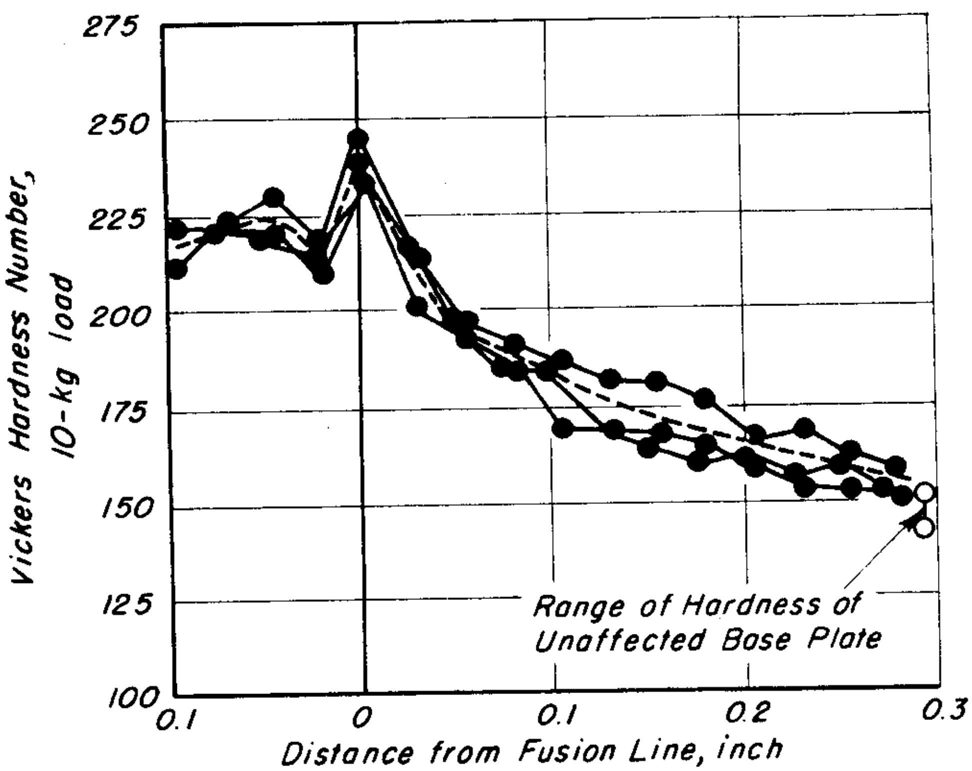


FIGURE B-2. HARDNESS SURVEY OF WELD BEAD AND HEAT-AFFECTED ZONE OF KINZEL SPECIMEN OF "C" STEEL WELDED AT 10F PREHEAT (PHOTO OF HARDNESS TRANSVERSE TYPICAL OF THE THREE MADE)

0 - 14409

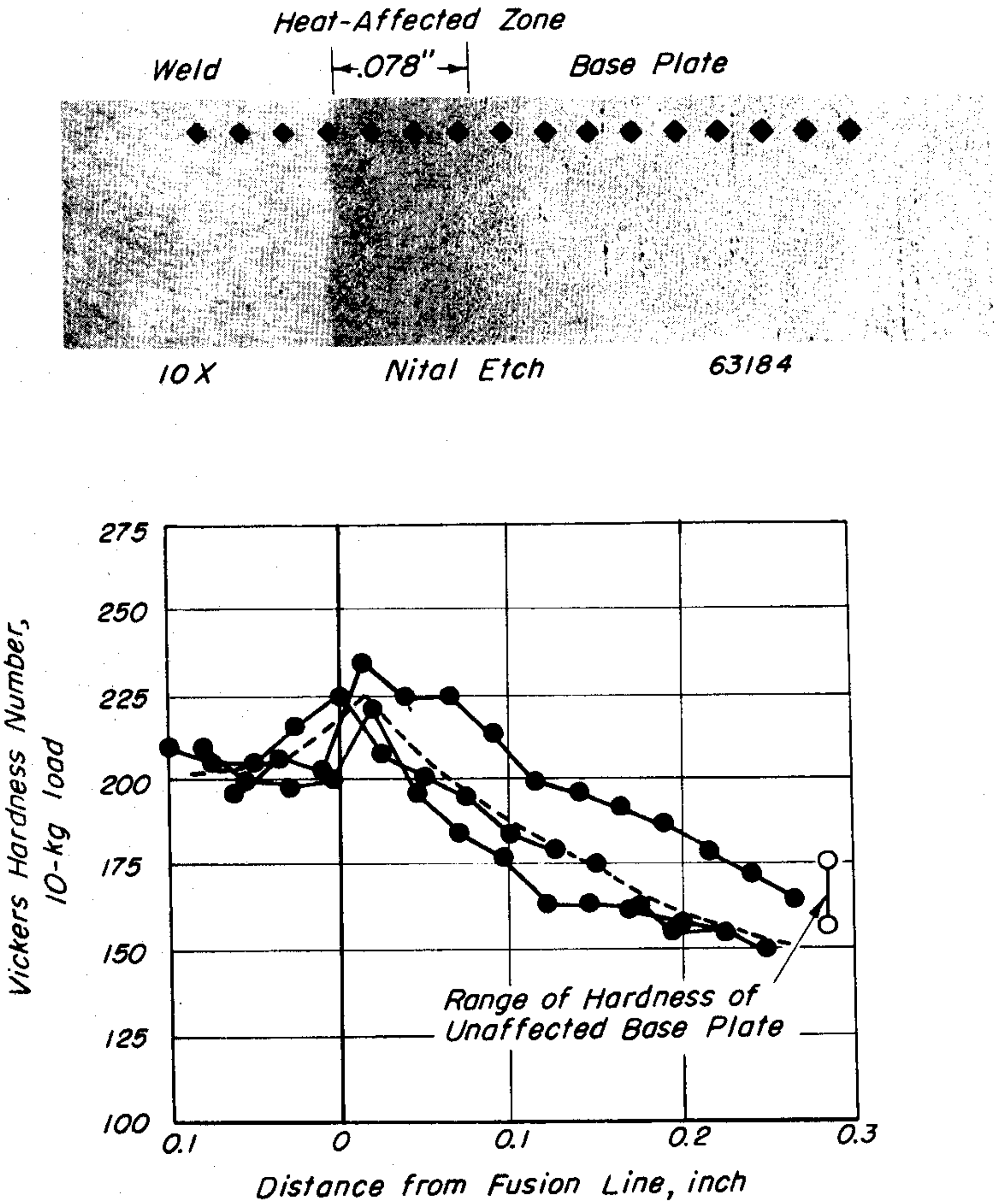
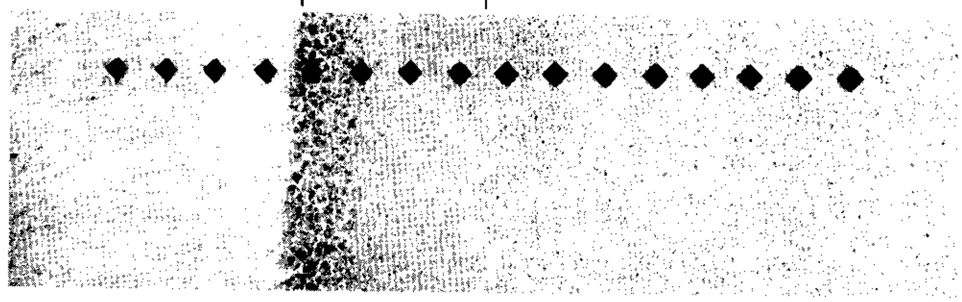


FIGURE B-3. HARDNESS SURVEY OF WELD BEAD AND HEAT-AFFECTED ZONE OF KINZEL SPECIMEN OF "C" STEEL WELDED AT 150F PREHEAT (PHOTO OF HARDNESS TRAVERSE TYPICAL OF THE THREE MADE)

0-14410



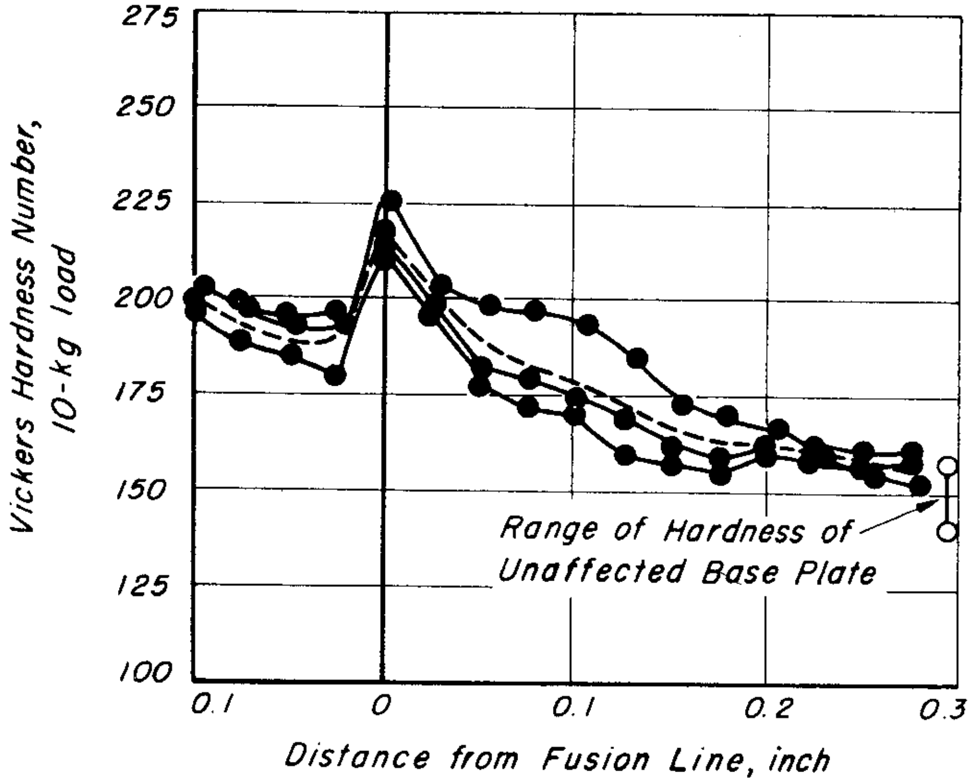
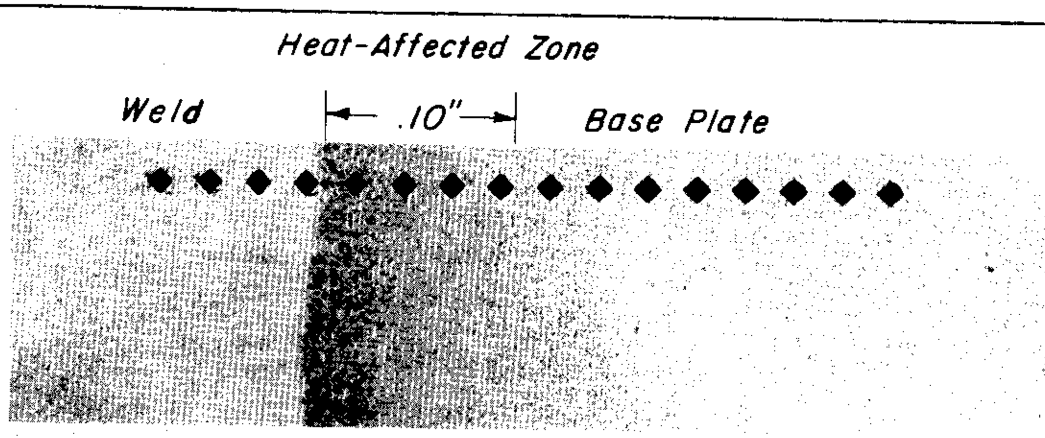


FIGURE B-4. HARDNESS SURVEY OF WELD BEAD AND HEAT-AFFECTED ZONE OF KINZEL SPECIMEN OF "C" STEEL WELDED AT 250F PREHEAT. (PHOTO OF HARDNESS TRAVERSE TYPICAL OF THE THREE MADE)

0-14411



10X Nital Etch 63180

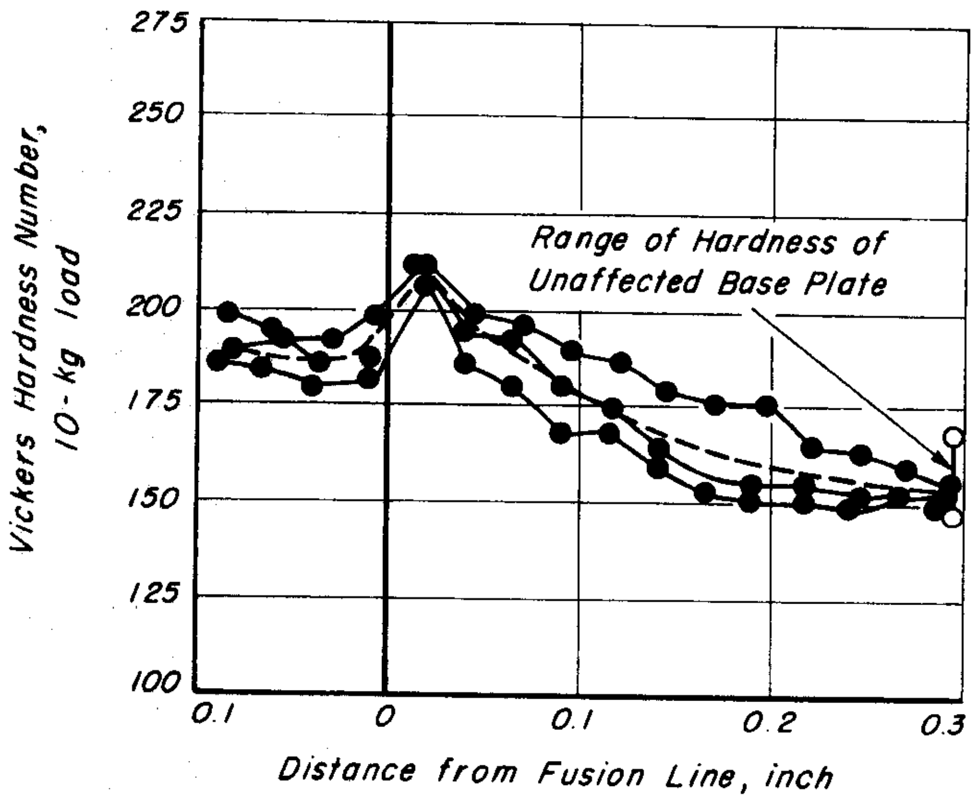
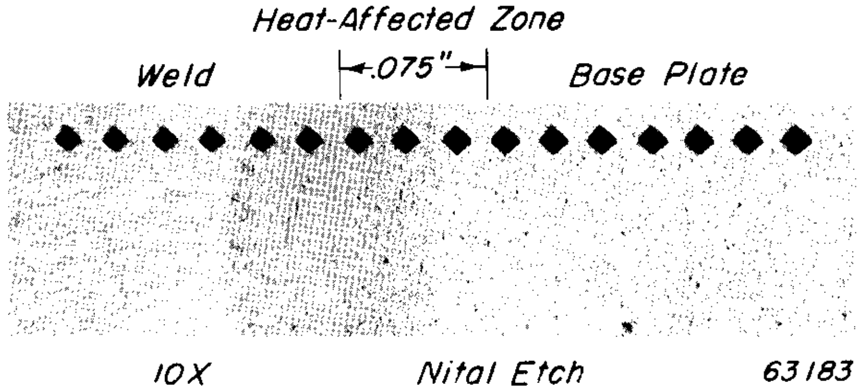


FIGURE B-5. HARDNESS SURVEY OF WELD BEAD AND HEAT-AFFECTED ZONE OF KINZEL SPECIMEN OF "C" STEEL WELDED AT 400F PREHEAT. (PHOTO OF HARDNESS TRAVERSE TYPICAL OF THE THREE MADE)

0-14412



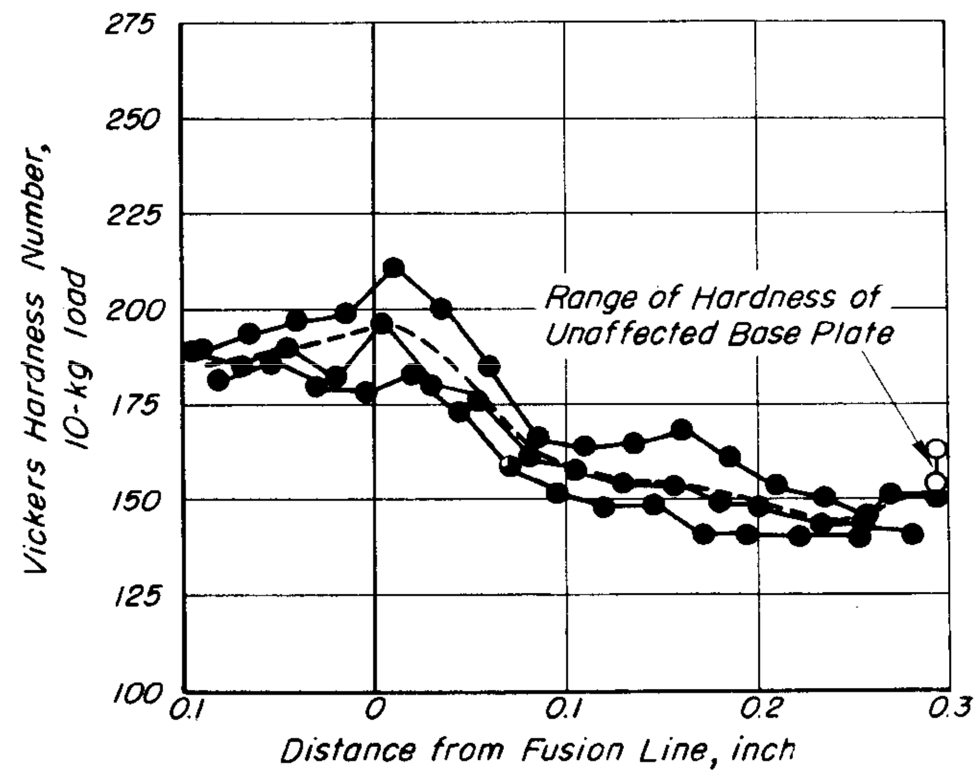
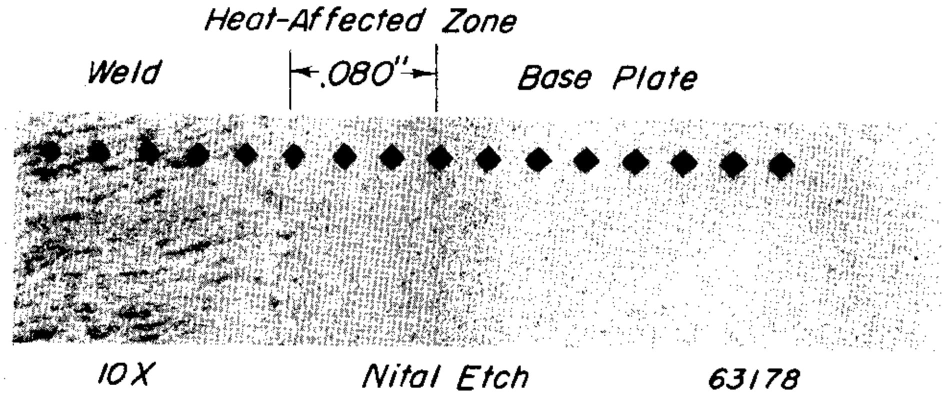


FIGURE B-6. HARDNESS SURVEY OF WELD BEAD AND HEAT-AFFECTED ZONE OF KINZEL SPECIMEN OF "C" STEEL WELDED AT 70F PREHEAT AND POSTHEATED FOR 1 HOUR AT 1150F (PHOTO OF HARDNESS TRAVERSE TYPICAL OF THE THREE MADE)

O-14413



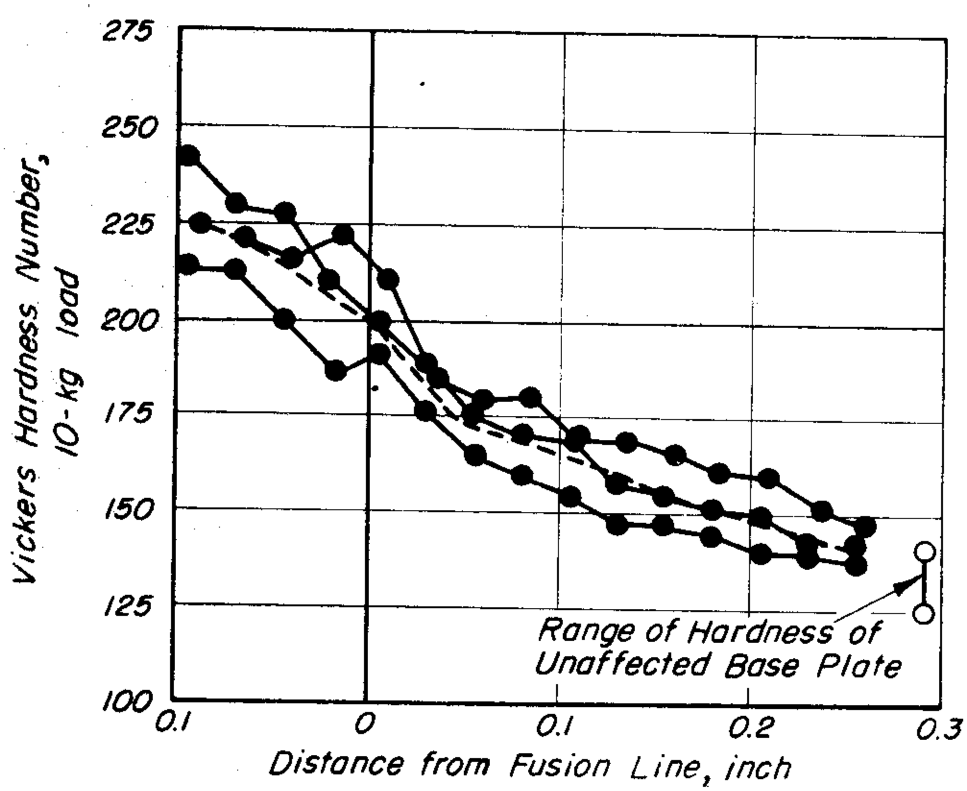


FIGURE B-7. HARDNESS SURVEY OF WELD BEAD AND HEAT-AFFECTED ZONE OF KINZEL SPECIMEN OF "Br" STEEL WELDED AT 70F PREHEAT. (PHOTO OF HARDNESS TRAVERSE TYPICAL OF THE THREE MADE)

O-14414

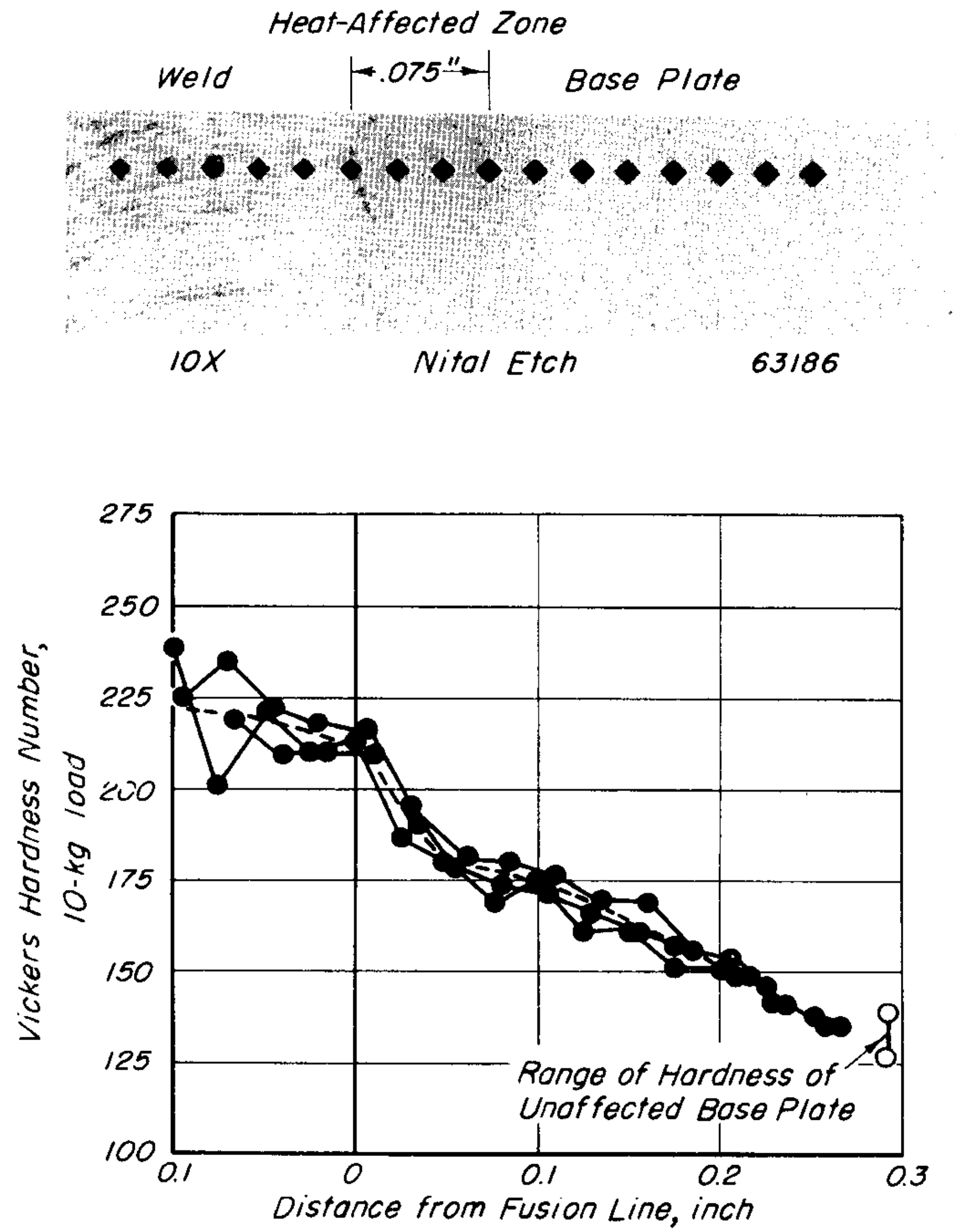
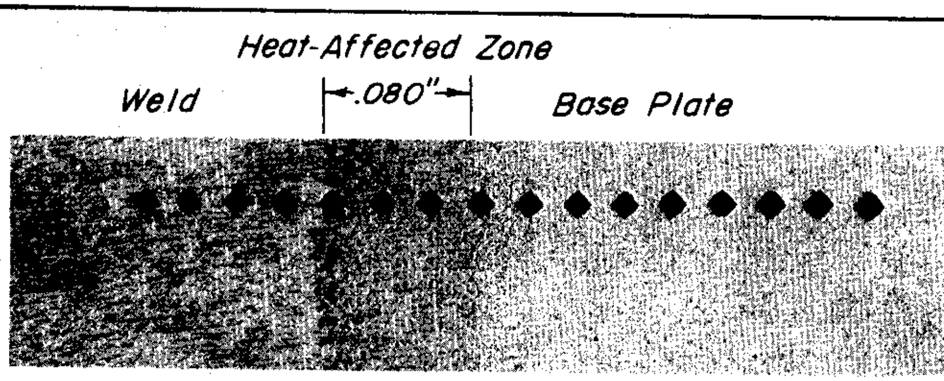


FIGURE B-8. HARDNESS SURVEY OF WELD BEAD AND HEAT-AFFECTED ZONE OF KINZEL SPECIMEN OF "Br" STEEL WELDED AT 10F PREHEAT (PHOTO OF HARDNESS TRANSVERSE TYPICAL OF THE THREE MADE)

0-14415



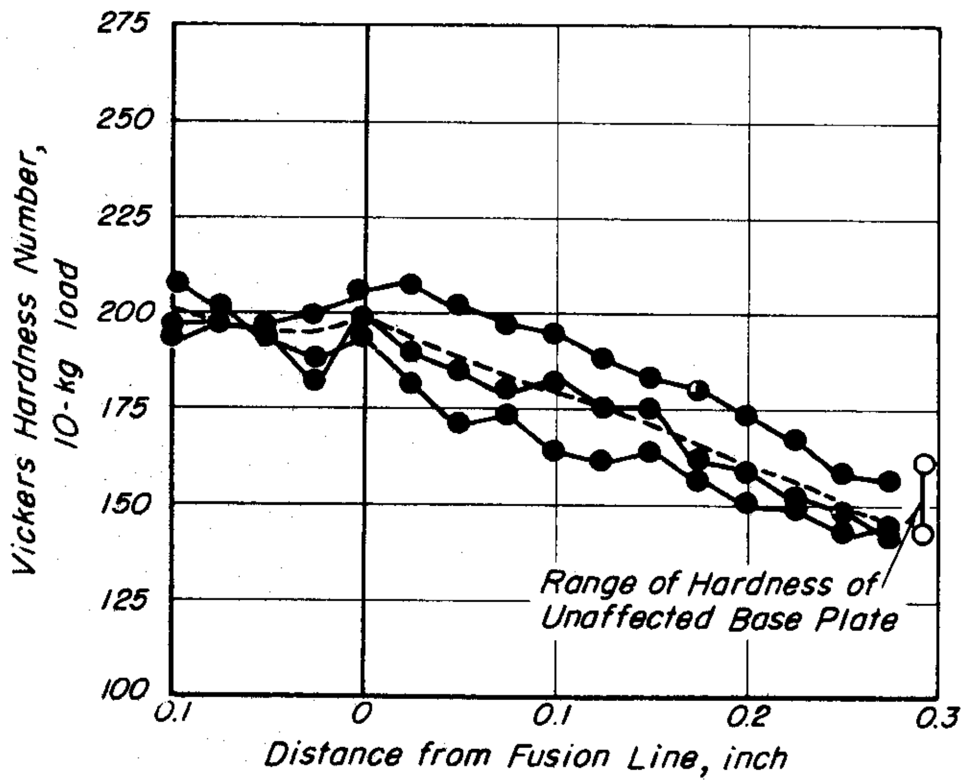
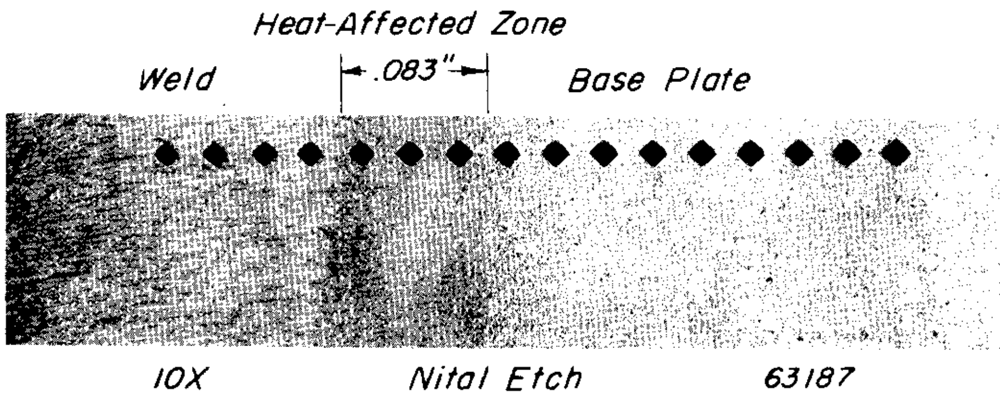


FIGURE B-9. HARDNESS SURVEY OF WELD-HARDENED HEAT-AFFECTED ZONE OF KINZEL SPECIMEN OF "Br" STEEL WELDED AT 150F PREHEAT (PHOTO OF HARDNESS TRAVERSE TYPICAL OF THE THREE MADE)

0-14416



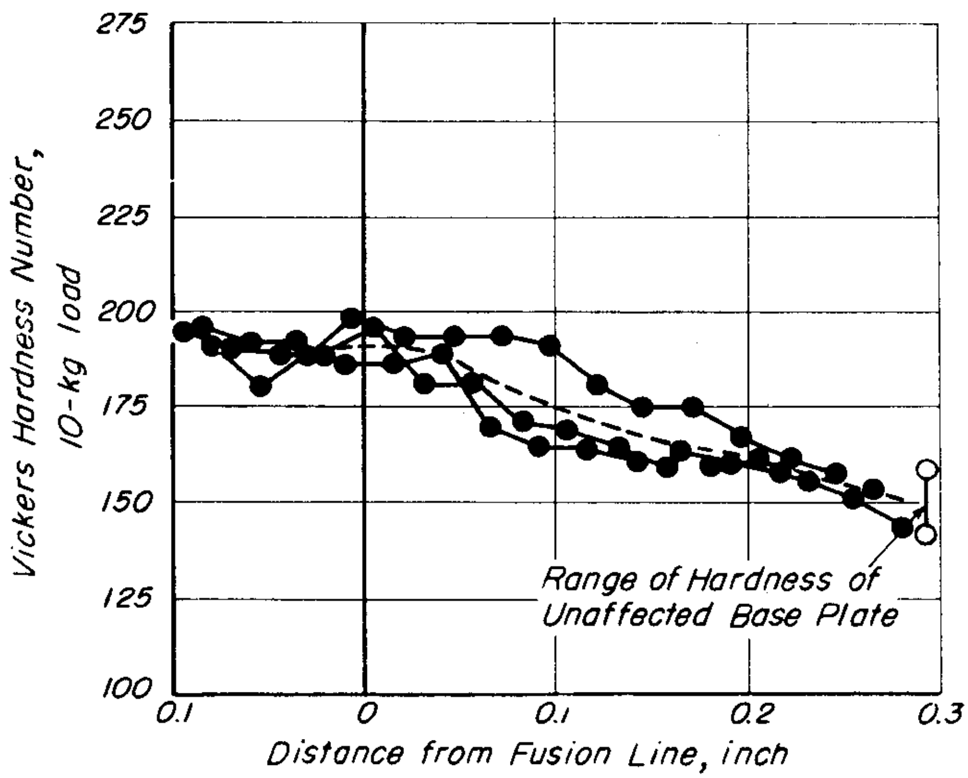
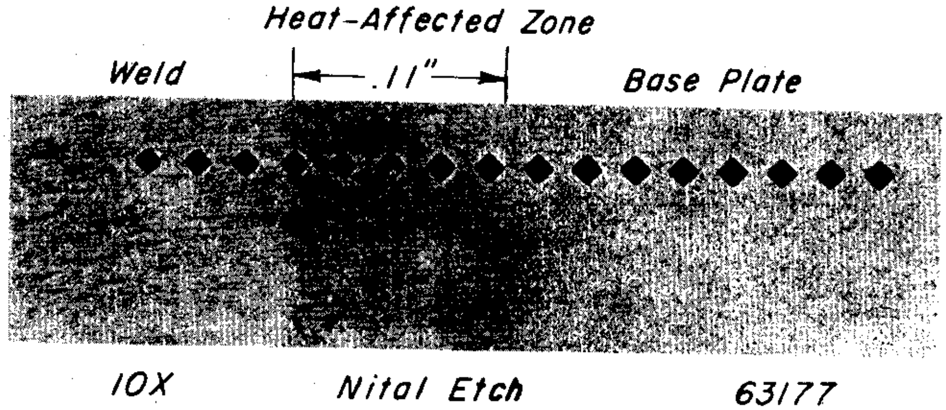


FIGURE B-10. HARDNESS SURVEY OF WELD BEAD AND HEAT-AFFECTED ZONE OF KINZEL SPECIMEN OF "Br" STEEL WELDED AT 250F PREHEAT (PHOTO OF HARDNESS TRAVERSE TYPICAL OF THE THREE MADE)

0-14417



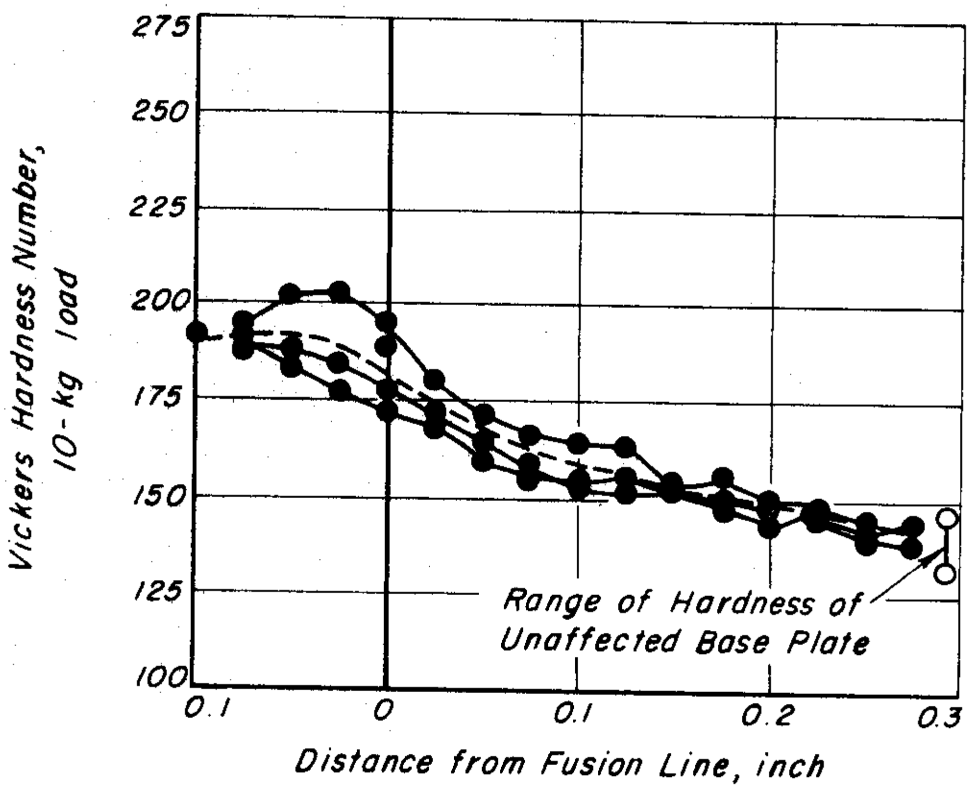


FIGURE B-11. HARDNESS SURVEY OF WELD BEAD AND HEAT-AFFECTED ZONE OF KINZEL SPECIMEN OF "BR" STEEL WELDED AT 400F PREHEAT (PHOTO OF HARDNESS TRAVERSE TYPICAL OF THE THREE MADE)

0-14418

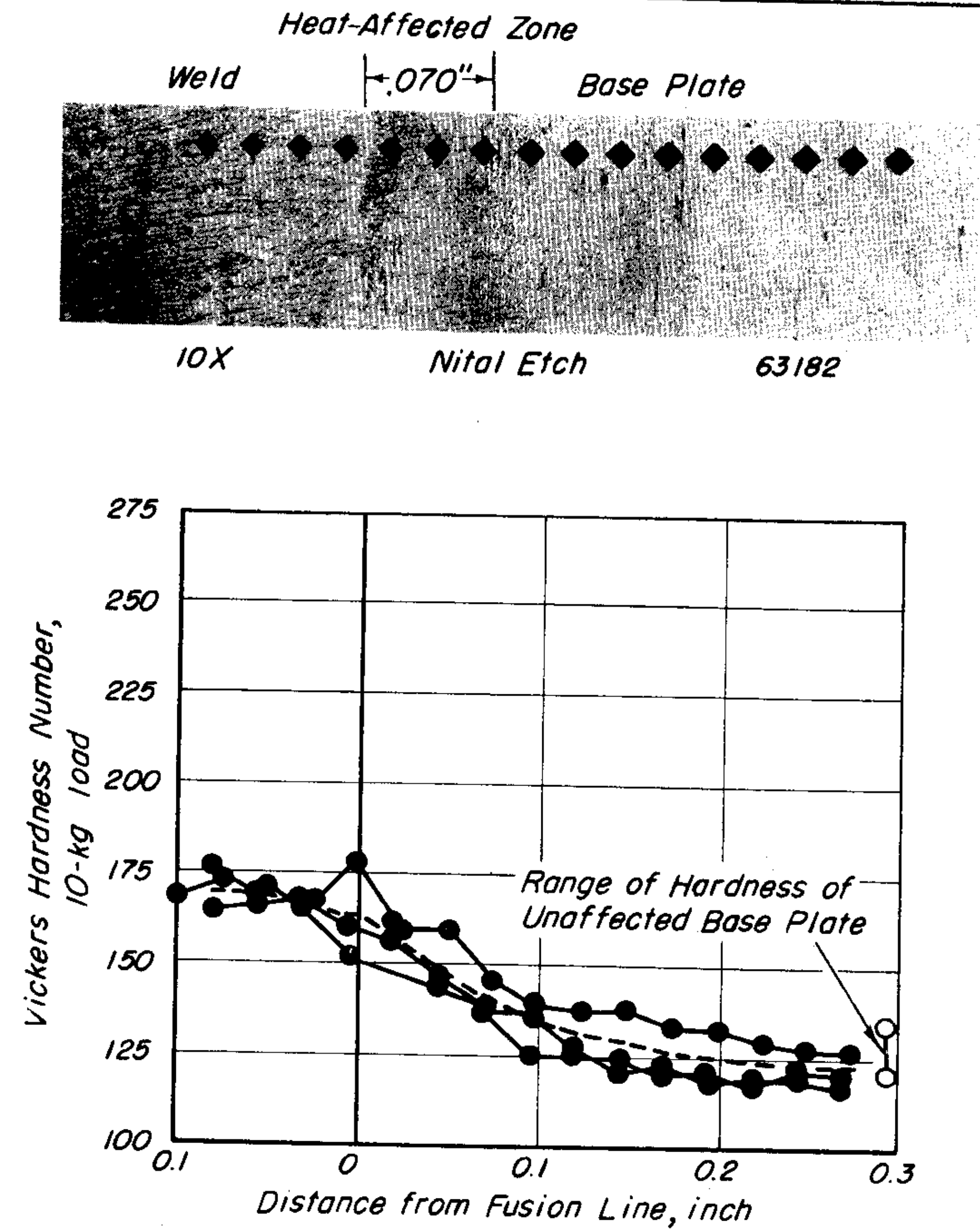


FIGURE B-12. HARDNESS SURVEY OF WELD BEAD, HEAT-AFFECTED ZONE, AND BASE PLATE OF KINZEL SPECIMEN OF "Br" STEEL WELDED AT 70F PREHEAT AND POSTHEATED FOR 1 HOUR AT 1150F. (PHOTO OF TRAVERSE TYPICAL OF THE THREE MADE)

O-14419

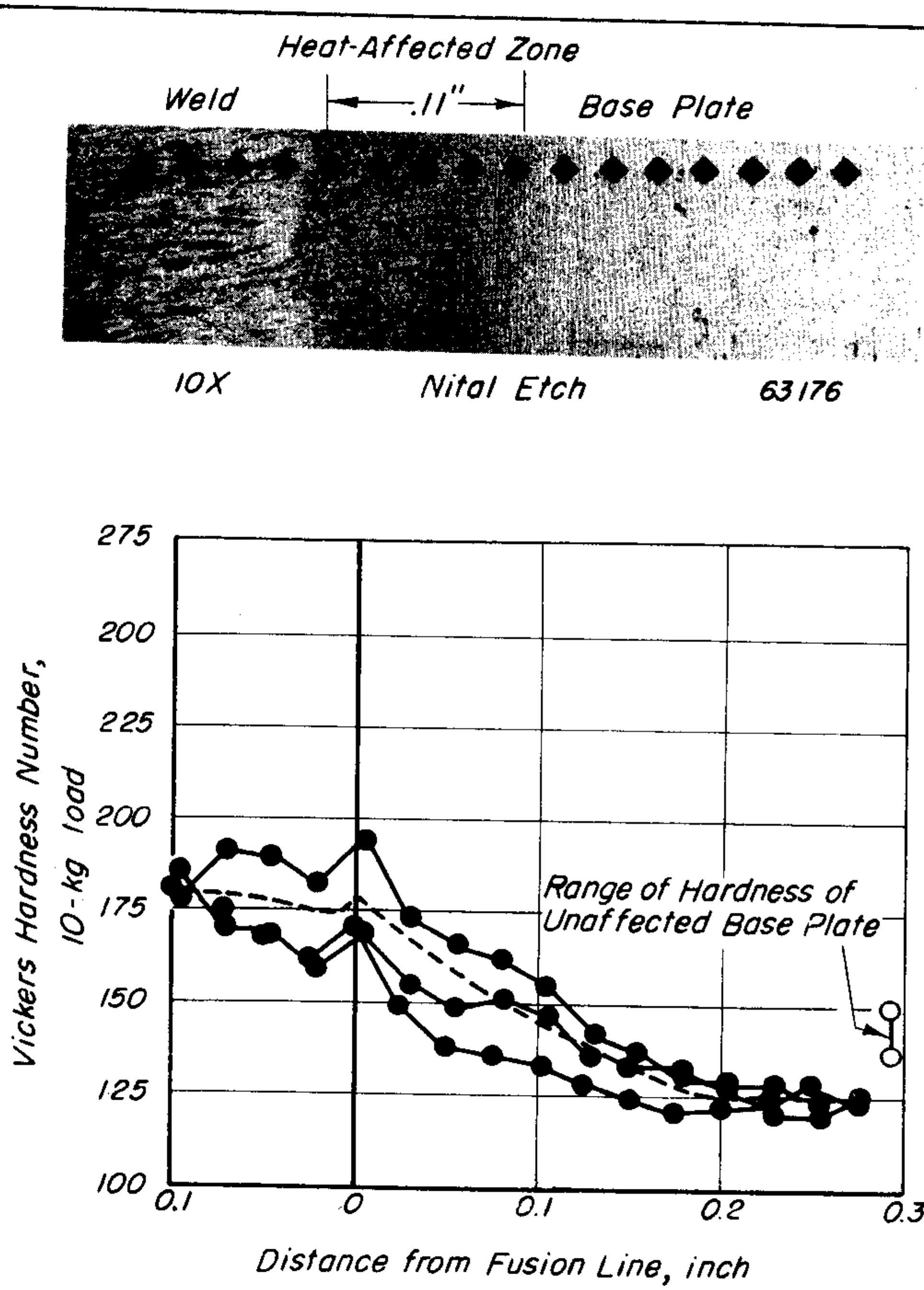


FIGURE B-13. HARDNESS SURVEY OF WELD BEAD AND HEAT-AFFECTED ZONE OF KINZEL SPECIMEN OF "Br" STEEL WELDED AT 400F PREHEAT AND POSTHEATED FOR 1 HOUR AT 1150F. (PHOTO OF HARDNESS TRAVERSE TYPICAL OF THE THREE MADE)

0-14420