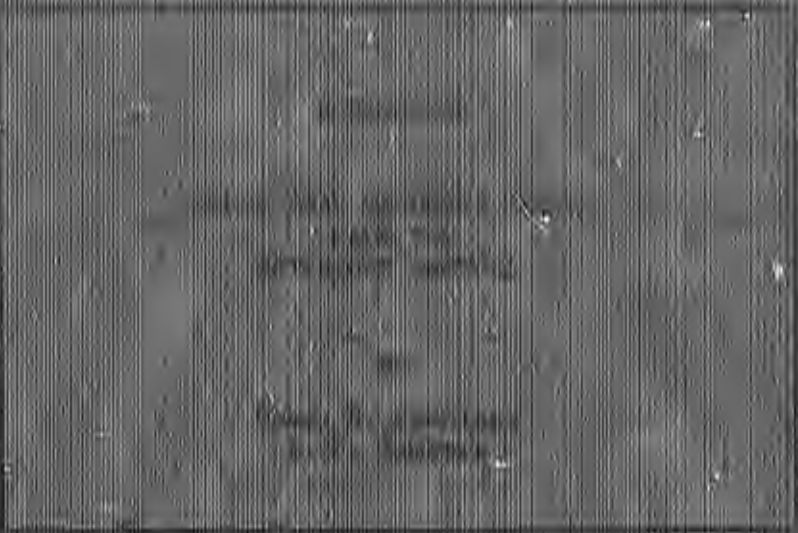




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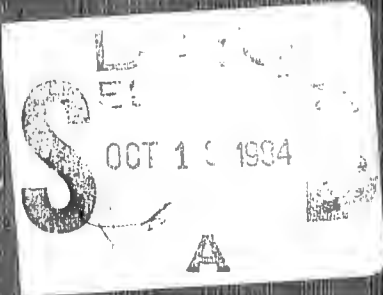
RESEARCH REPORT

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Research Report R-94296-AK

Chas. H. Jennings
E. R. Gamberg
June 14, 1943

WELD BEAD HARDNESS TESTS MADE FOR WATERTOWN ARSENAL

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WELD BEAD HARDNESS TESTS MADE FOR WATERTOWN ARSENAL

Introduction

The following report covers weld bead hardness tests made by the Westinghouse Research Laboratories on a group of nineteen steels for Watertown Arsenal as per government contract W-952-ORD-6272 (Westinghouse order BS-9661-EP). A copy of this contract is included as Appendix I.

Procurement and Preparation of Steels

The steels for this investigation were furnished by the Watertown Arsenal. Inability to obtain all the steels originally specified made it necessary to eliminate four grades and make substitutes for nine grades. A complete list of the steels originally specified for investigation and the steels actually furnished is given in Table I. Only three steels were received in the form of 1/2" thick plates; consequently, it was necessary to forge 16 grades to the proper size, i.e. 5" wide x 1/2" thick bars.

All forging operations were done at the Tool Forging Shop (East Pittsburgh Works). The forging was done within the temperature range of 1800°F. min. and 2300°F. max. by a skilled workman.

After forging, the bars were cut to the specified plate size (6" x 5" x 1/2" thick) and normalized by heating in an electric resistance furnace to 100°F. above their A_{C_3} temperature, holding at those temperatures for 1/2 hour and subsequently cooling in still air. (The normalizing treatment was not followed by an annealing treatment as specified in the contract because the specification, Appendix II, requires that all tests be made on steels in the normalized condition) After cutting and normalizing, all plates were shot blasted to remove the scale and produce a clean surface.

The dimensions of the steels as originally received and the normalizing temperatures used in each case are listed in Table II.

Chemical Analysis and Grain Size

Chemical analyses were made from drillings taken from each steel after forging. Determinations were made for ten elements: Carbon, Manganese, Silicon, Sulphur, Phosphorus, Nickel, Chromium, Molybdenum, Vanadium and Copper.

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Small samples were taken from the unaffected area of each test plate for grain size (McQuaid-Ehn) determination. The samples were pack carburized for 8 hours at 1742°F. (930°C.) and slow cooled. Grain size determinations were made, after polishing and etching these samples, by using a Bausch and Lomb grain size eye piece on a Bausch and Lomb metallographic microscope.

The chemical analysis and grain size determinations for each steel are given in Table III.

Deoxidation Practice

The test record form suggested by the American Welding Society Specification (See appendix II) calls for the deoxidation practice used in making the steel. This information was not furnished by Watertown Arsenal, consequently, it is not included in this report.

Welding Procedure

A. General - The weld bead test specimens were made by depositing beads under the conditions set forth in the American Welding Society Specification "Tentative Tests for Arc Welding Properties of Steel, A. Weld Bead Hardness Test" dated April 1, 1942. (See Appendix II)

A Westinghouse automatic welding head with current supplied by a 600 ampere constant potential generator was used in this investigation. This equipment made it possible to automatically strike the arc and maintain a constant arc voltage and current. An Esterline-Angus recording ammeter and voltmeter was used to record the amperage and voltage of each weld bead. Typical ampere vs. time and voltage vs. time curves are reproduced in Figure 1.

An electric clock was connected into the welding circuit to run while the arc was maintained. This clock was used to accurately and positively control the length of each bead. A three inch long welding bead made at the rate of 5" per minute represents 36 seconds welding time.

All test plates were clamped during welding in a special fixture which was attached to the power driven bed plate traveling at a constant speed of 5" per minute. By using this fixture, it was possible to deposit each weld bead in the proper location with the rapidity required for the preheated and cooled specimens. Figure 2 is a photograph of the welding set-up, showing the automatic head, welding table and clamping fixture.

Pertinent welding data for all weld beads are as follows:

Electrode - 3/16" diam. - A.W.S. E-6010- (Westinghouse A.P.)

Type of Current - Direct Current, Reverse polarity

Amperage 180 amperes

Voltage 24 to 28 volts

Rate of travel 5.0 inches per minute

B. Room temperature tests (60-70°F.) - A three inch weld bead was deposited on one plate of each grade of steel, the initial temperature of the plates being 68°F. After welding, the plates were placed on edge on an asbestos board and allowed to cool in still air to room temperature (68°F.).

C. Preheat tests (300°F.) - Preheat tests were made only on the steels which developed a maximum hardness greater than 350 V.P.N. (Vickers Diamond Pyramid Hardness Number) or produced cracks when welded at room temperature. Fifteen of the nineteen steels were in this category. All fifteen steels developed hardnesses in excess of 350 V.P.N. and eight of the fifteen produced cracks in the heat affected areas adjacent to the welds.

Preheat tests were made by heating the plates in a resistance type electric furnace to 320°F. and holding at that temperature for a minimum of 1/2 hour before welding. After removal from the furnace, each plate was clamped in the welding fixture (Figure 2) and welding started within a period of 20 seconds. The temperature of the plates was checked by means of a 300°F. tempilstik (accuracy $\pm 1\%$), and the arc was struck at the instant the starting end of the plate cooled to a temperature where the tempilstik did not melt. Immediately after a weld bead was deposited, the plate was removed from the welding fixture, placed on edge on an asbestos board and allowed to cool in still air to room temperature (68°F.).

The fifteen steels subjected to the preheat test were: WD 4050, WD 4150, A.I.S.I. 4142, WD 4150, S.A.E. I4340, WD 4640, WD 4815, WD 4820, WD 5150, S.A.E. 8630, S.A.E. 8739, NE 8747, S.A.E. 8949, WD 9130 and WD 9150.

D. Preheat tests (500°F.) - Although the contract did not call for tests made at a preheat temperature of 500°F., two of the steels (S.A.E. I4340 and S.A.E. 8949) produced heat affected area cracks with preheats of 300°F. In order to determine the affect of higher preheat temperatures on the formation of cracks, a test was made on one of these steels by using a preheat of 500°F. The procedure used in making this test was identical to that described for the 300°F. preheat tests except for the preheat temperature used.

E. Cold tests (-20°F.) - Tests at sub-normal temperatures were made only on the steels which did not develop a maximum hardness greater than 350 V.P.N. and did not produce cracks in the 60-70°F. tests. Four grades of steel were in this group; WD 4023, WD 4042, WD 4615 and S.A.E. 8620.

These tests were conducted by submerging the plates in a bath of acetone (in an insulated pan) cooled to -25°F. by the addition of dry ice (solid CO₂). The plates were held at -25°F. for a minimum of twenty minutes before welding. Approximately twenty seconds were required to remove a plate from the bath, wipe it dry, position it on the jig, and strike the arc. After depositing a weld bead, the plate was placed on edge on an asbestos board and allowed to cool in still air to room temperature (68°F.).

Hardness Data and Crack Determination

Specimens 1/2" wide for hardness and crack determinations were removed from the welded test plates in accordance with the American Welding Society Specification (see Appendix II, Figure 1). The removal of these specimens was accomplished with an abrasive disk cut-off wheel operating under water.

The procedure employed to polish the test samples for hardness survey and crack determination was as follows:

1. Rough polish on a belt grinder using a fine belt.
2. Intermediate polish with No. 0 and 00 metallographic paper.
3. Final polish on broadcloth with a solution of alumina and liquid soap.

The polish resulting from the procedure was extremely fine and entirely free from scratches or other blemishes that would affect the hardness readings.

After polishing, the surfaces were examined for cracks and subsequently given a light etch with 1% nital (1 part HNO₃, 99 parts ethyl alcohol) to enable accurate location of the hardness impressions to be made. Following the etching, the specimens were again examined for cracks before the hardness readings were taken.

Hardness readings were taken with a Vickers machine using a load of 10 Kg. and spacing the indentations 0.05" apart as shown in Figure 2 Appendix II. Special care was taken to insure that the hardness readings were within 0.02" of the bottom of the fusion line.

Hardness readings were taken from the center line of the weld to the right and left until it was evident that the hardest zone of the heat affected area of the parent metal had been traversed. Three readings were

also taken of the unaffected parent material in each case. Approximately thirty hardness readings were taken on each specimen.

A typical data sheet for recording hardness data is shown in Appendix III. Data sheets covering all the pertinent information on each weld bead test are also included in Appendix III.

The occurrence of cracks was noted and recorded with information as to type and location on the data sheets in Appendix III. All cracks were classified as root or toe cracks. Figures 3 (a) and 3 (b) show typical cracks of these types.

Test Results

The maximum hardness values obtained at the right and left of each bead, the average hardness of the unaffected plate materials and the presence of cracks are given in Table IV.

Discussion of Test Results

A. General - Examination of Table IV indicates, as to be expected, that preheating lowered the maximum hardness obtained in the heat affected area while cooling to sub-normal temperatures increased the maximum hardness obtained.

Only four of the nineteen steels tested developed hardnesses of less than 350 V.P.N. in the heat affected area when welded at room temperature (60-70°F.). These steels were WD 4023, WD 4042, WD 4615 and S.A.E. 8620. The other fifteen steels produced hardnesses of 390 V.P.N. to 673 V.P.N. in the heat affected areas when welded at room temperatures (60-70°F.)

B. Carbon Equivalent - In an effort to obtain a comparison of the effect of chemical analysis on the maximum heat affected area hardness obtained from the bead hardness tests, the carbon equivalent of each steel was calculated in two ways:

1. If only the carbon and manganese are considered, the carbon equivalent is determined by the formula:

$$\text{Carbon equivalent} = \%C + \% \frac{\text{Mn}}{8} \quad 1$$

2. If all the important alloying elements are taken into consideration, the carbon equivalent is determined by the equation:

$$\begin{aligned} \text{Carbon equivalent} = \%C + \% \frac{\text{Mn}}{6} + \% \frac{\text{Ni}}{15} + \% \frac{\text{Cr}}{5} + \% \frac{\text{Mo}}{4} \\ + \% \frac{\text{V}}{5} + \% \frac{\text{Cu} > .5}{13} * \quad 2 \end{aligned}$$

* Equation taken from "A Guide to the Selection and Welding of Low Alloy Structural Steels" by J. Dearden and H. O. Neill. The Inst. of Welding Quarterly transactions, Vol. 8, No 4 (Oct. 1940, P. 203.)

The carbon equivalent as calculated by equations 1 and 2 are listed for each steel on Table III. For convenience, these values are also listed in Table V which contains the maximum hardness values obtained from each weld sample.

In Figure 4 the maximum hardnesses obtained on plates welded at room temperature are plotted against the carbon equivalents as determined by equations 1 and 2. It is seen from these curves that equation 2 gives the most consistent results. Comparison of these curves indicates that they have about the same slope although equation 2 shifts the curve about .21% to the right.

In Figure 5 maximum hardness values for every test plate are plotted against carbon equivalent as determined by equation 2. All plates that produced cracks in the heat affected area are marked with a + sign. The only significant fact evident from these curves is that the effect of preheating in reducing the hardnesses obtained is not a direct function of the carbon equivalent.

C. Cracks - Eight grades of steels developed cracks in the heat affected areas as a result of welding at room temperature (60-70°F.). In six cases these cracks were located in the heat affected area at the root of the weld bead (Figure 3 a). In two cases the cracks were in the heat affected area at the toe of the weld bead. These cracks progressed almost entirely around the weld bead.

Two grades of steel developed cracks at the 300°F. preheat temperature. The cracks in these cases were "toe" cracks and the steels were the same ones that developed "toe" cracks in the room temperature tests. (S.A.E. X4340 and S.A.E. 8949) A 500°F. preheat test on the S.A.E. X4340 steel did not produce any cracks.

All the steels which produced cracks in the room temperature tests contained heat affected area hardnesses of 498 V.P.N. or greater. However, two Steels (WD 4640 and WD 4050) which developed hardnesses of 554 V.P.N. did not crack. The two steels which produced cracks with the 300°F. preheat developed hardnesses close to 600 V.P.N. on this preheat test.

Conclusions

It is not the intent of this contract that the investigators draw conclusions regarding the weldability of these steels. There are several points, however, that are worthy of note.

(1) When using the carbon equivalent method of comparing the heat affected area hardnesses of steels as obtained by head hardness tests, all the elements which influence hardening should be taken into consideration. Equation 2 as used in this report is not necessarily the

proper equation, but it shows more consistent agreement than equation 1 which considers only Carbon and Manganese.

(2) Cracks were developed in plates welded at room temperature at hardness values as low as 498 V.P.N.

(3) Two types of heat affected area cracks were obtained -- "root" and "toe" cracks.

(4) Preheating to 300°F. before welding reduced the hardness of the heat affected areas and eliminated cracks in all but two steels. The steels which produced cracks at 300°F. preheat developed hardnesses of 592 V.P.N. and 606 V.P.N. and were the same steels that produced "toe" cracks at room temperature. The cracks in the preheated steels were also "toe" cracks.

(5) One 500°F. preheat test made on a steel that produced cracks at 300°F. (S.A.E. X4540) was found to be free from cracks.

(6) Tests on four steels at -20°F. developed heat affected area hardnesses higher than those obtained at room temperatures. No cracks were found in the sub-normal temperature tests.

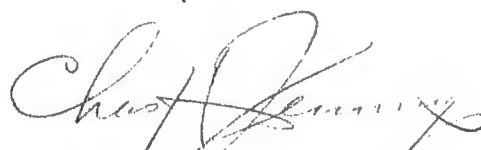
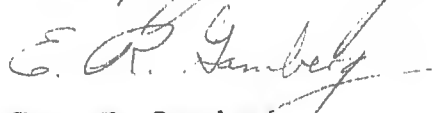


Chas. H. Jennings
E. R. Gamberg

TABLE I
LIST OF STEELS INVESTIGATED

<u>Steels Originally Specified</u>	<u>Steels Furnished For Investigation</u>
WD 4020	WD 4020
S → WD 4050	NAX 9150 (WD 9150) ← S
WD 4055 ←	→ Not Procured
WD 4040	WD 4040
S → WD 4045	NAX 9150 (WD 9150) ← S
WD 4050	WD 4050
WD 4060 ←	→ Not Procured
S → WD X4130	WD 4130 ← S
S → WD 4140	AISI 4142 ← S
WD 4150	WD 4150
S → WD X4540	S.A.E. X4540 ← S
WD 4615	WD 4615
WD 4640	WD 4640
WD 4815	WD 4815
WD 4820	WD 4820
WD 5150	WD 5150
S → WD 8620	S.A.E. 8620 ← S
S → WD 8630	S.A.E. 8630 ← S
WD 8725 ←	→ Not Procured
S → WD 8740	S.A.E. 8759 ← S
WD 8745	NE 8747
WD 8750 ←	→ Not Procured
S → WD 8950	S.A.E. 8949 ← S

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TABLE II

Steel No.	Size, as Received	Forging Temp.		Normalizing Temp. °F.
		Max.	Min.	
WD 4023	1 pc. 2" rd. x 18" long.	2300°F.	1800°F.	1800
WD 4042	1 pc. 2" rd. x 18" long.	"	"	1550
WD 4130	1 pc. 5" square x 11" long.	"	"	1600
AISI 4142	1 pc. 5-3/4" rd. x 4" long.	"	"	1600
WD 4150	1 pc. 2-3/4" rd. x 12" long.	"	"	1550
S.A.E. X4340	1 pc. 3-1/8" rd. x 12" long.	"	"	1550
WD 4615	1 pc. 2" rd. x 18" long.	"	"	1600
WD 4640	1 pc. 2" rd. x 18" long.	"	"	1550
WD 4815	1 pc. 2" rd. x 18" long.	"	"	1550
WD 4820	1 pc. 5" square x 11" long.	"	"	1550
WD 5150	6 pcs. 6" x 6" x 1/2"	Not Forged		1550
S.A.E. 8620	1 pc. 4-3/4" rd. x 12" long.	"	"	1575
S.A.E. 8630	1 pc. 2-3/4" square x 12" long.	"	"	1575
S.A.E. 8738	1 pc. 2-3/4" square x 12" long.	"	"	1575

TABLE II (Continued)

Steel No.	Size, as Received	Forging Temp.		Normalizing Temp. °F.
		Max.	Min.	
NE 8747	1 pc. 2" rd. x 24" long	2300°F.	1800°F.	1550
S.A.E. 8949	1 pc. 2-11/16 rd. x 12" long	"	"	1550
WD 4050	Crucible heat no. 102266 1 pc. 9" square x 6" long.	"	"	1550
WD 9130	5 pcs. 6" x 3" x 1/2"	Not forged		1575
WD 9150	5 pcs. 6" x 3" x 1/2"	Not forged		1550

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TABLE III

Steel No.	Grain Size	C	Mn	P	Chemical Analysis				Mo	V	Cu	C+ Mn 6	Equiv C
					S	Si	Ni	Cr					
WD 4023	7	.19	.69	.010	.011	.225	.18	.04	.24	nil	.14	.51	.59
WD 4042	6	.59	.81	.012	.010	.257	.05	.04	.26	nil	.15	.53	.60
WD 4130	8	.53	.44	.017	.024	.198	.59	.98	.22	nil	.075	.40	.68
AISI 4142	6	.44	.91	.025	.004	.213	.12	.95	.19	nil	.115	.59	.83
WD 4150	7	.48	.59	.015	.023	.245	.10	.86	.22	nil	.12	.58	.81
S.A.E. 14540	7	.41	.66	.017	.007	.283	1.69	.87	.24	nil	.095	.52	.87
WD 4615	5	.08	.53	.015	.011	.056	2.03	.09	.28	.03	.14	.14	.56
WD 4640	7	.59	.70	.014	.007	.229	2.03	.07	.25	.03	.17	.51	.72
WD 4815	6	.19	.56	.017	.010	.224	3.56	.15	.27	nil	.16	.28	.62
WD 4820	6	.19	.61	.015	.005	.241	3.47	.15	.26	nil	.08	.29	.62
WD 5150	8	.48	.68	.014	.013	.173	.16	1.04	.03	.19	.08	.59	.66
S.A.E. 8620	7	.22	.82	.020	.009	.304	.51	.43	.22	nil	.08	.36	.53
S.A.E. 8630	6	.35	.74	.014	.007	.280	.50	.52	.21	nil	.06	.47	.66
S.A.E. 8739	8	.40	.71	.025	.001	.238	.41	.48	.24	nil	.085	.52	.70
NE 8747	8	.45	.71	.010	.018	.262	.45	.51	.25	nil	.13	.57	.76
S.A.E. 8849	8	.46	.93	.015	.011	.257	.52	.56	.32	nil	.06	.62	.84
WD 4050	7	.51	.72	.012	.010	.252	.23	.48	.25	nil	.09	.63	.80
WD 9150	7	.28	.66	.017	.019	.715	.070	.56	.19	nil	.18	.39	.55
WD 9150	6	.49	.69	.023	.034	.841	.04	.65	.02	nil	.08	.61	.74

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TABLE IV
MAXIMUM HARDNESS DATA (V.P.N.) AND CRACKS

Steel No.	-20°F. Tests		60-70°F. Tests		500°F. Tests		500°F. Tests	
	Affected Area Right	Affected Area Left (Ave.)	Affected Area Right	Affected Area Left (Ave.)	Affected Area Right	Affected Area Left (Ave.)	Affected Area Right	Affected Area Left (Ave.)
WD 4023	240	238	227	165	317	192	505	473
WD 4042	387	384	345	229	446	305	505	361
WD 4130			390	213	498	289		
AISI 4142			613	312*	592	351**		
WD 4150			585	294*	592	351**		
S.A.E. 14340			634	568**	592	351**		
WD 4615	212	213	209	145	409	253		
WD 4640			554	266	370	251		
WD 4815			437	254	354	255		
WD 4820			409	244	542	212		
WD 5150			550	222*	542	212		
S.A.E. 8620	333	330	306	206	312	214		
S.A.E. 8630			488	226	376	245		
S.A.E. 8738			498	271*	405	283		
NE 8747			554	295*	606	320**		
S.A.E. 8948			673	316**	339	263		
WD 4050			530	267	342	187		
WD 9130			421	200	542	255		
WD 9150			554	247*	519	255		

* Root crack in heat affected area of parent metal.

** Toe crack in heat affected area of parent metal

TABLE V

MAXIMUM HARDNESS VALUES AND CARBON EQUIVALENT

Steel No	Max. V.P.N. Heat Affected Area		% C + $\frac{\text{Mn}}{8}$	% C. Eq.*
	-20°F.	60-70°F. 300°F.		
WD 4025	240	227	.31	.59
WD 4042	394	345	.53	.60
WD 4150		390	.40	.68
AISI 4142		615	.59	.83
WD 4150		618	.58	.81
S.A.E. X4540		654	.52	.87
WD 4615	215	208	.14	.36
WD 4640		585	.51	.72
WD 4815		487	.28	.62
WD 4820		409	.29	.62
WD 5150		572	.58	.86
S.A.E. 8620	353	506	.36	.53
S.A.E. 8650		488	.47	.66
S.A.E. 8739		498	.52	.70
NE 8747		554	.57	.76
S.A.E. 8948		673	.62	.84
WD 4050		554	.63	.80
WD 9150		421	.39	.55
WD 9150		606	.61	.74

* % Carbon Equivalent is based on the formula No. 2

$$(\% \text{ Carbon Equivalent} = \% \text{C} + \frac{\text{Mn}}{8} + \frac{\text{Ni}}{15} + \frac{\text{Cr}}{5} + \frac{\text{Mo}}{4} + \frac{\text{V}}{5} + \frac{\text{Cu} > .5}{13})$$

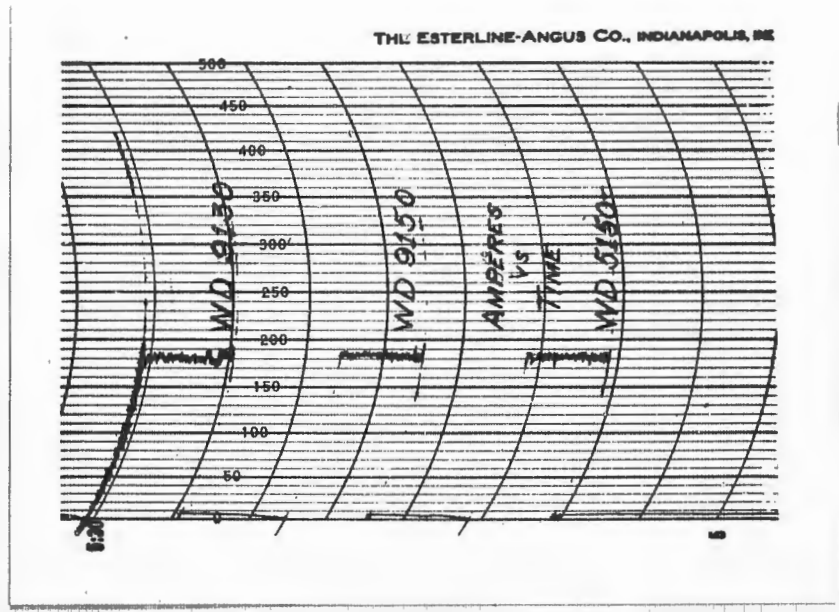


FIG. 1 A

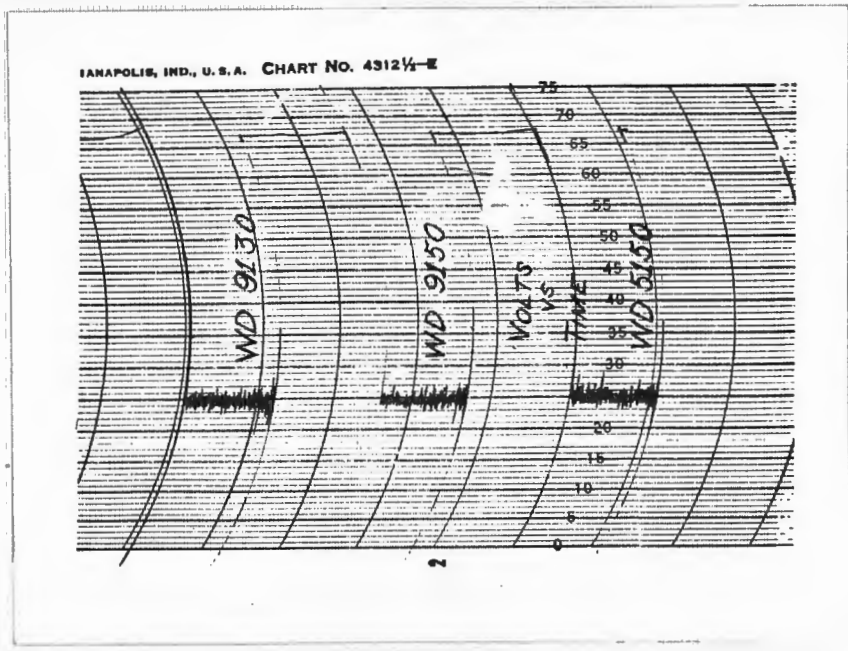


FIG. 1 B



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FIGURE 2

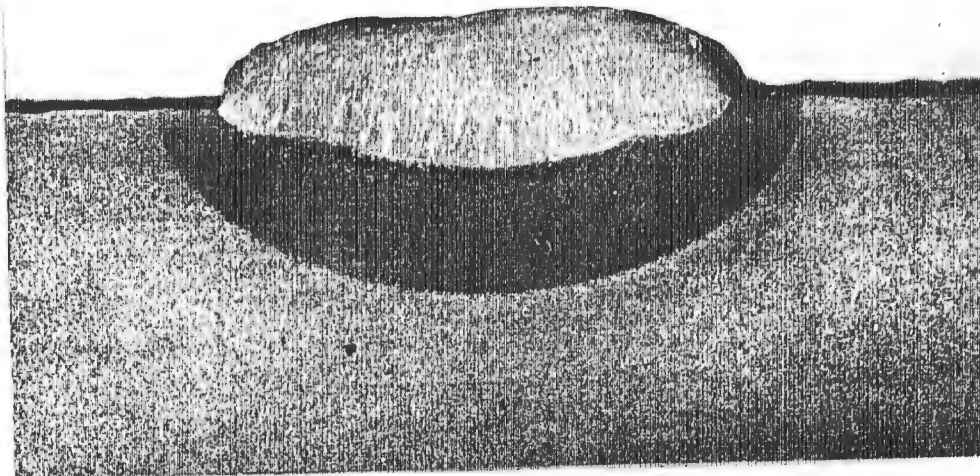


FIG. 3A ROOT CRACK
APPROX. 3X

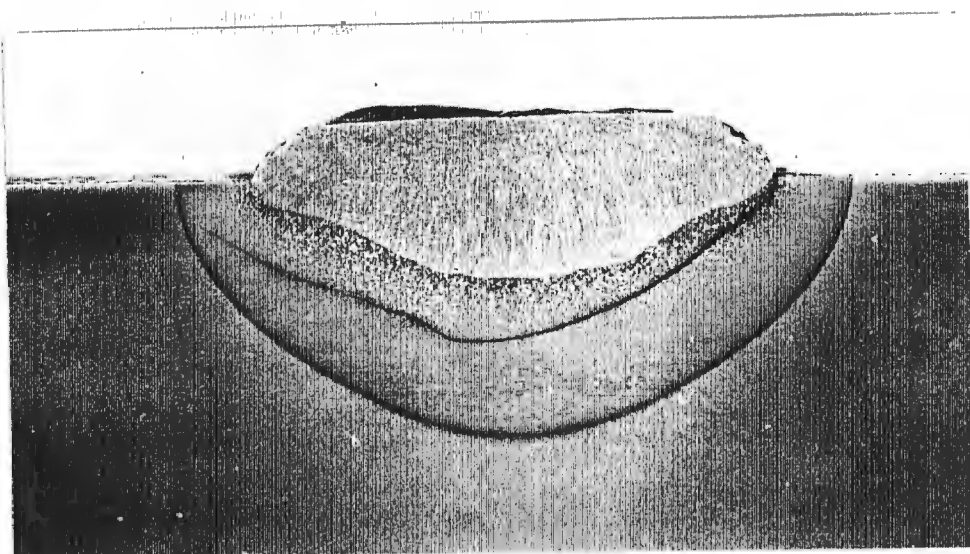


FIG. 3B TOE CRACK
APPROX. 3X

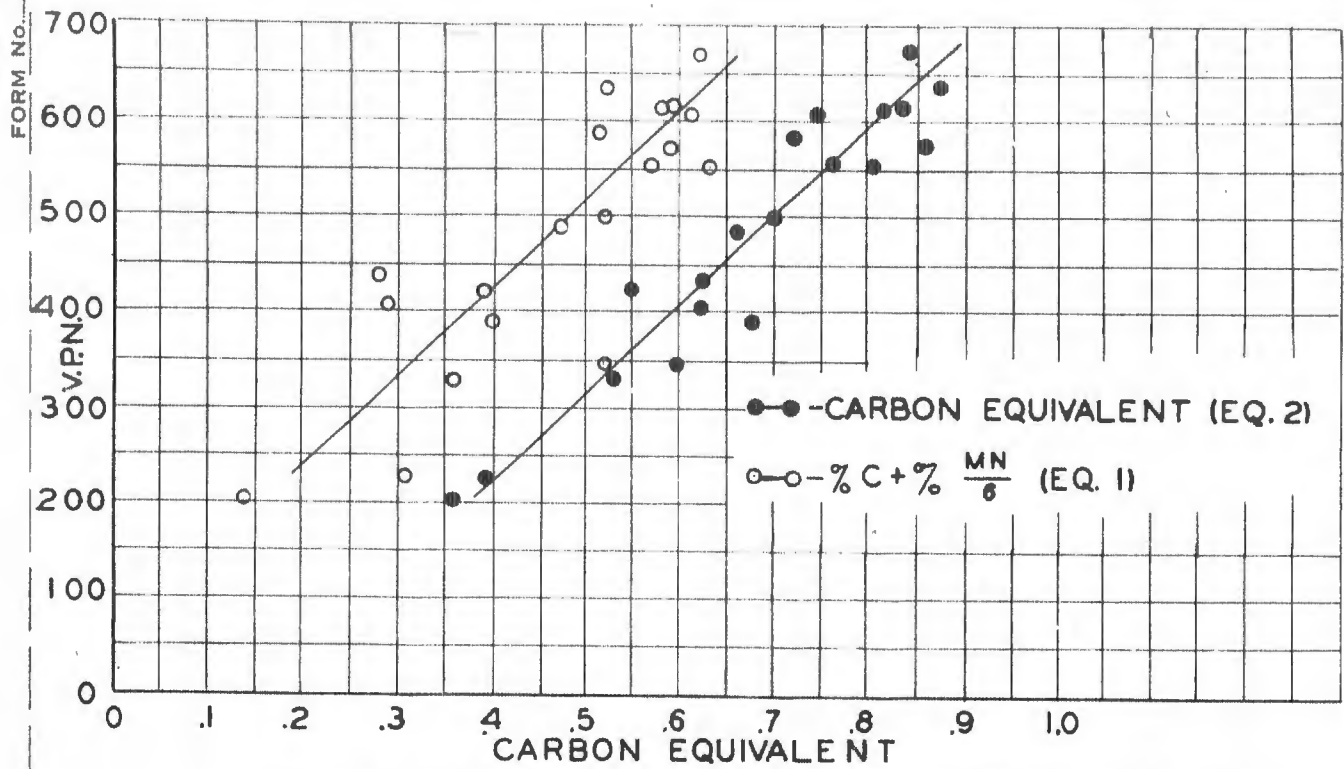


FIG. 4 HARDNESS VS CARBON EQUIVALENTS
ROOM TEMPERATURE (60-70°F)

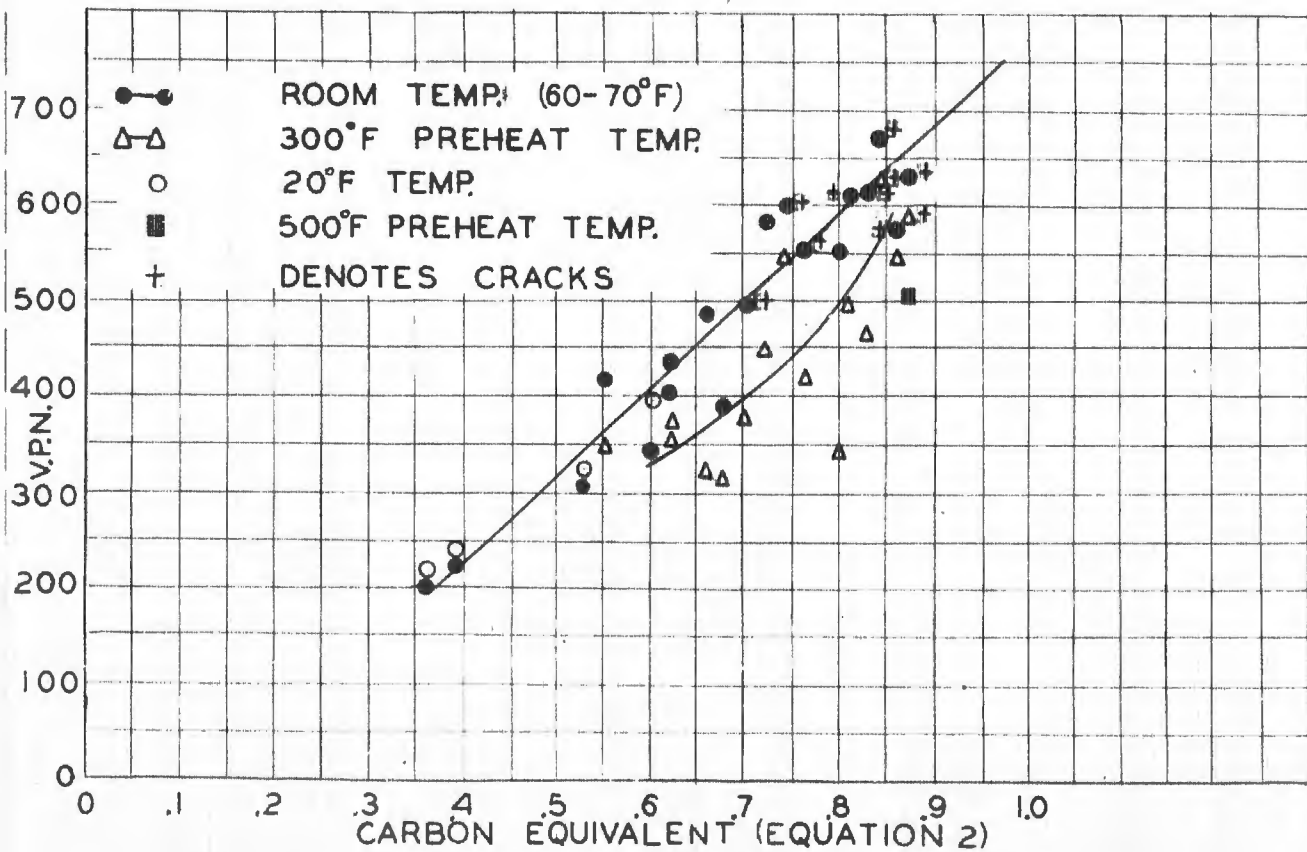


FIG. 5 INFLUENCE OF PREHEAT TEMPERATURE
ON HARDNESS OF HEAT AFFECTED AREA

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APPENDIX I

CONTRACT W-952-ORD-6272

APPENDIX I

Government Order W-592-ORD-6272

Item A

"Make weld bead hardness test on the following W.D. Steels to be supplied by Watertown Arsenal - 4020, 4030, 4035, 4040, 4045, 4050, 4060, X4130, 4140, 4150, X4340, 4615, 4640, 4815, 4820, 5150, 8620, 8630, 8725, 8740, 8745, 8750, 8950."

"In accordance with A. W. S. Tentative Standard Test. Dated April 1, 1942."

"If necessary to make the tests on pieces forged to the proper size from rolled material, such forged pieces to be normalized and annealed before welding."

"If cracks or vickers hardness greater than 350 occur in a test, the test for lower temperatures may be omitted. If vickers hardness is below 350, no test at higher temperatures is required."

"Five copies of the final Report of Tests to be furnished."

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APPENDIX II

AMERICAN WELDING SOCIETY SPECIFICATION

TENTATIVE TESTS FOR ARC WELDING PROPERTIES OF STEEL

Part A

Weld Bead Hardness Test

April 1, 1942

TENTATIVE TESTS FOR ARC WELDING PROPERTIES OF STEEL

A. Weld Bead Hardness Test

1. Preparation of Test Plate

(a) Dimensions of Test Plate

The test plate for the weld bead hardness test shall comply with the requirements of Fig. 1. The surface of the plate on which the weld is deposited shall be ground or shot blasted to remove scale or surface oxide prior to depositing the bead.

(b) Condition of Test Plate

The test plate shall be in the normalized condition.

(c) Temperature of Plate Prior to Welding

The test may be conducted with the test plate at normal temperature or at an elevated or a sub-normal temperature. The following temperatures are standard.

Normal temperature 60 to 70 F

Elevated temperature 300 F

Sub-normal temperature -20 F

(d) Welding Procedure

The weld bead shall be deposited with the following welding procedure:

Electrode Classification No. E6010*

Electrode Size 3/16 in.

Type of Current D.C. reverse polarity

Arc Voltage 24 to 26 volts

Amperage 180 amps.

* This classification number refers to the A.W.S.-A.S.T.M. Tentative Specifications for Iron and Steel Arc Welding Electrodes (A.S.T.M. Serial Designation A235)

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Speed of travel5 inches per minute

Welding Details - Weld beads made on test plate at elevated or sub-normal temperatures shall be started within a period of one minute after the test plate is removed from the heating or cooling medium. The weld shall be deposited without oscillation of the electrode. After welding, the test plate shall be allowed to cool at room temperature. (60 to 70 F).

Note: The welding shall preferably be done with an automatic welding machine. If an automatic welding machine is not available it is recommended that the weld be made in such a way that the operator controls only the feed of the electrode, while a mechanical device is used to move the test plate forward at the prescribed rate.

2. Preparation of Specimen

(a) Removal from Test Plate

The specimen shall be removed from the test plate as shown in Fig. 1. The cross-sectional faces of the specimen shall be ground to produce parallel surfaces.

(b) Polishing

The face to be tested shall be polished to produce a finish sufficiently smooth so that accurate Vickers hardness readings can be obtained with a 10 kg. load.

Note: A recommended procedure for obtaining this finish is as follows: Polish with emery paper down to grade 000; finish polishing on a lap or on metallographic polishing equipment with a fine grade of alumina.

(c) Etching

The face of the specimen to be tested shall be etched in an area at and adjacent to the weld with any reagent which makes the boundary between the weld metal and the base metal visible, without over-etching to the extent that difficulty will be encountered in securing accurate hardness readings on the etched surface.

Note: The etching should be limited to the minimum strength of reagent and time that will show the junction of the weld metal and the heat-affected zone, as over-etching causes difficulty in obtaining accurate hardness readings. Four per cent picric acid or one per cent nital are recommended for carbon and low alloy steels.

3. Testing of Specimen

(a) Hardness of Heat-Affected Zone

Vickers hardness readings shall be made in the heat-affected zone as shown in Fig. 2, using a 10 kg. load for 30 seconds. The first reading shall be taken at a point on the center line of the weld and between 0.00 inches and 0.02 inches from the boundary between the weld metal and the base metal. Subsequent readings shall be taken at 0.050--in. intervals both to the right and to the left, on a line parallel to the surface of the base metal, until there is a substantial decrease in the hardness noted.

(b) Hardness of Unaffected Base Metal

Three Vickers hardness readings shall be made in the unaffected zone in a location on a line with the readings taken in the heat-affected zone and at a distance of approximately one inch from the center line of the weld bead.

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4. Results

(a) Visual Examination

Both cross-sectional faces of the specimen shall be examined for the appearance of cracks, with a 5- to 25-power magnifying glass, before and after etching. Any cracks discovered shall be reported, together with the location thereof.

(b) Hardness of Heat-Affected Zone

The maximum hardness readings obtained in the heat-affected zones to the right and to the left of the bead shall be reported.

(c) Hardness of Unaffected Base Metal

The three hardness values obtained shall be averaged. The resultant average value shall be reported.

5. Recording of Results

The results of the test shall be set forth in a suitable permanent record.

Note: The following form for reporting the results is recommended.

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Record of Weld Bead Hardness Test

1. Type of Steel: _____

2. Chemical Analysis:

C	Mn	P	S	Si	Ni	Cr	Cu	Mo	V	

3. Deoxidation Practice: Killed _____ Semi-Killed _____ Rimmed _____

4. Grain Size (McQuaid-Ehn): _____

5. Normalizing Treatment: _____

6. Welding Data:

(a) Type and size electrode _____

(b) Type of Current _____ Polarity _____

(c) Amperage _____

(d) Voltage _____

(e) Rate of Travel _____

(f) Plate Temperature _____

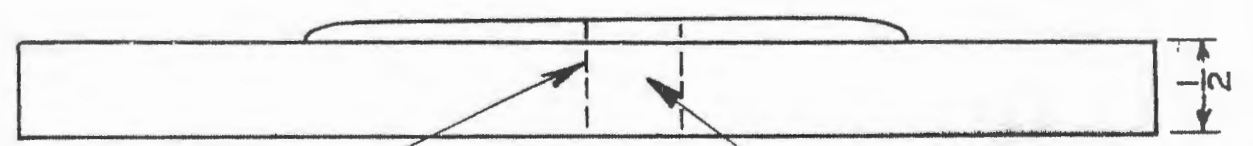
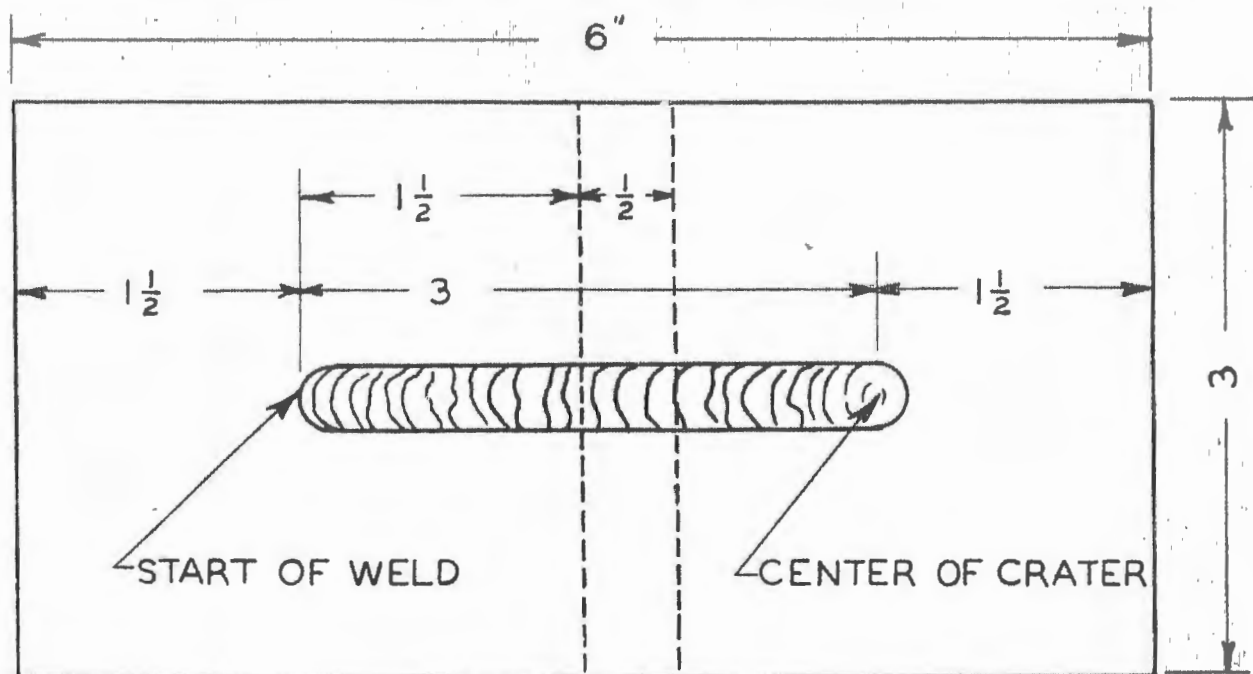
7. Hardness of Heat-Affected Zone (Max.): Right _____ Left _____

8. Hardness of Unaffected Base Metal (Avg.): _____

9. Visual Examination for Cracks: _____

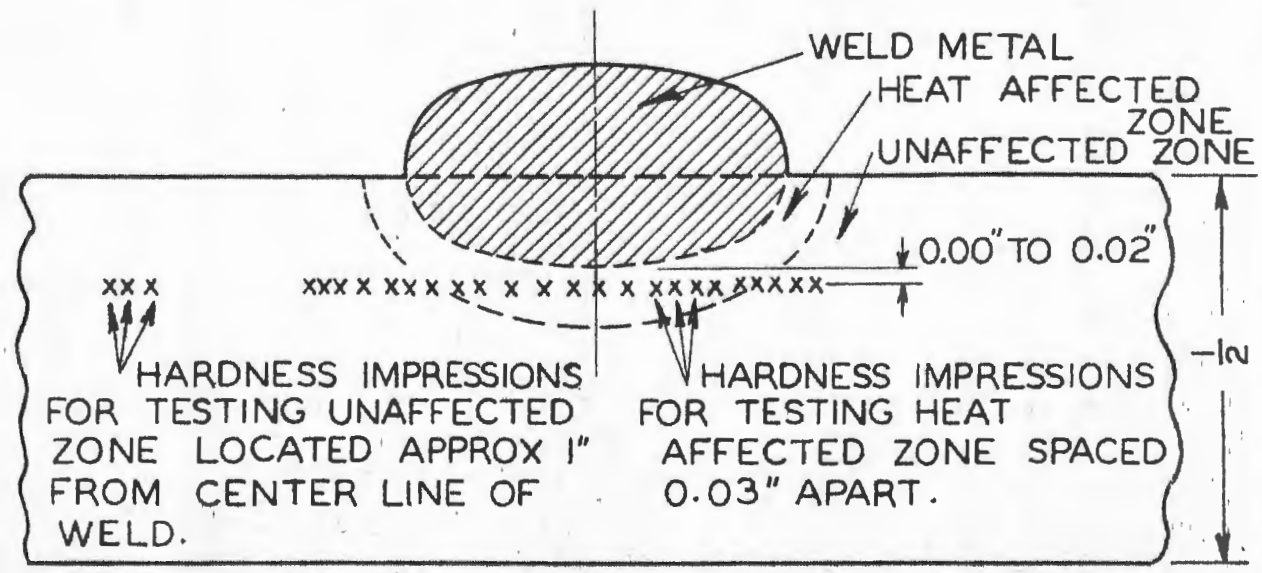
Signature _____

Date _____



THIS FACE OF SPECIMEN TO BE TESTED SPECIMEN

TEST PLATE FOR WELD BEAD HARDNESS TEST
FIG. 1



SPECIMEN FOR WELD BEAD HARDNESS TEST
FIG. 2

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APPENDIX III

DATA SHEETS

TYPICAL HARDNESS DATA SHEET

Steel 4820

68°F. Initial Temp.

<u>Right</u>			<u>Left</u>			<u>Plate</u>		
Ocular Readings	Av.	V.P.N.	Ocular Readings	Av.	V.P.N.	Ocular Readings	Av.	V.P.N.
289-285	287	225	282-282	282	233	275-275	275	245
292-285	288	224	274-274	274	247	275-275	275	245
263-263	263	268	254-254	254	287	278-274	276	243
265-262	264	266	255-255	255	285			
255-255	255	285	250-250	250	297			
255-256	256	283	246-246	246	306			
249-249	249	299	238-238	238	327			
249-245	247	304	226-226	226	363			
242-242	242	317	224-224	224	370			
228-224	226	363	217-217	217	394			
225-223	223	373	217-217	217	394			
220-220	220	383	213-212	213	409			
217-217	217	394	220-223	222	376			
214-212	213	409						

Ave. V.P.N. Plate 244

No Cracks

Max. V.P.N. Right 409

Max. V.P.N. Left 409

Westinghouse Electric & Manufacturing Co.
 Research Laboratories
Record of Weld Bead Hardness Test

1. Type of Steel: WD 4025
2. Chemical Analysis:

C	Mn	P	S	Si	Ni	Cr	Cu	Mo	V		
.19	.69	.010	.011	.225	.18	.04	.14	.24	-		
3. Deoxidation Practice: Killed _____ Semi-Killed _____ Rimmed _____
4. Grain Size (McQuaid-Ehn): 7 ASTM
5. Normalizing Treatment: 1575°F.
6. Welding Data:
- (a) Type and size electrode 3/16" diam. E6010 (Westinghouse AP)
 - (b) Type of Current Direct Polarity Reverse
 - (c) Amperage 180 Amperes
 - (d) Voltage 24 to 26 Volts
 - (e) Rate of Travel 5.0 inches per minute
 - (f) Plate Temperature 68°F.
7. Hardness of Heat-Affected Zone (Max.): Right 227 Left 227
8. Hardness of Unaffected Base Metal (Avg.): 165
9. Visual Examination for Cracks: None

Signature E. R. Gamberg (s)

Date May 26, 1945

Westinghouse Electric & Manufacturing Co.
 Research Laboratories
Record of Weld Bead Hardness Test

1. Type of Steel: WD 4025
2. Chemical Analysis:

C	Mn	P	S	Si	Ni	Cr	Cu	Mo	V
.19	.69	.010	.011	.225	.18	.04	.14	.24	-
3. Deoxidation Practice: Killed _____ Semi-Killed _____ Rimmed _____
4. Grain Size (McQuaid-Ehn): 7 ASTM
5. Normalizing Treatment: 1575°F.
6. Welding Data:
 - (a) Type and size electrode 3/16" diam. E6010 (Westinghouse AP)
 - (b) Type of Current Direct Polarity Reverse
 - (c) Amperage 180 Amperes
 - (d) Voltage 24 to 26 volts
 - (e) Rate of Travel 5.0 inches per minute
 - (f) Plate Temperature -20°F.
7. Hardness of Heat-Affected Zone (Max.): Right 240 Left 238
8. Hardness of Unaffected Base Metal (avg.): 157
9. Visual Examination for Cracks: None

Signature E. R. Ganberg (s)

Date May 26, 1945

Westinghouse Electric & Manufacturing Co.
 Research Laboratories
Record of Weld Bead Hardness Test

1. Type of Steel: WD 4042
2. Chemical Analysis:

C	Mn	P	S	Si	Ni	Cr	Cu	Mo	V
.39	.81	.012	.010	.257	.05	.04	.13	.26	-
3. Deoxidation Practice: Killed Semi-Killed Rimmed
4. Grain Size (McQuaid-Ehn): 6 ASTM
5. Normalizing Treatment: 1550°F.
6. Welding Data:
- (a) Type and size electrode 3/16 " Diam. E6010 (Westinghouse AP)
 - (b) Type of current Direct Polarity Reverse
 - (c) Amperage 180 Amperes
 - (d) Voltage 24 to 26 volts
 - (e) Rate of Travel 5.0 inches per minute
 - (f) Plate Temperature 68°F.
7. Hardness of Heat-Affected Zone (Max.): Right 345 Left 333
8. Hardness of Unaffected Base Metal (Avg.): 229
9. Visual Examination for Cracks None

Signature E. R. Gamberg (s)

Date May 26, 1945

Westinghouse Electric & Manufacturing Co.
 Research Laboratories
Record of Weld Bead Hardness Test

1. Type of Steel: WD 4042
2. Chemical Analysis:
- | C | Mn | P | S | Si | Ni | Cr | Cu | Mo | V |
|-----|-----|------|------|------|-----|-----|-----|-----|---|
| .59 | .81 | .012 | .010 | .257 | .05 | .04 | .13 | .26 | |
3. Deoxidation Practice: Killed _____ Semi-Killed _____ Rimmed _____
4. Grain Size (McQuaid-Ehn): 6 ASTM
5. Normalizing Treatment: 1550°F.
6. Welding Data:
- (a) Type and size electrode 3/16" diam. E6010 (Westinghouse AP)
 - (b) Type of Current Direct Polarity Reverse
 - (c) Amperage 180 amperes
 - (d) Voltage 24 to 26 volts
 - (e) Rate of Travel 5.0 inches per minute
 - (f) Plate Temperature -20°F.
7. Hardness of Heat-Affected Zone (Max.): Right 587 Left 594
8. Hardness of Unaffected Base Metal (Avg.): 207
9. Visual Examination for Cracks: None

Signature E. R. Gamberg (s)

Date May 26, 1943

Westinghouse Electric & Manufacturing Co.
Research Laboratories
Record of Weld Bead Hardness Test

1. Type of Steel: ND 4130
2. Chemical Analysis:

C	Mn	P	S	Si	Ni	Cr	Cu	Mo	V
.33	.44	.017	.024	.196	.39	.98	.075	.22	-
3. Deoxidation Practice: Killed _____ Semi-Killed _____ Rimmed _____
4. Grain Size (McQuaid-Ehn): 8 ASTM
5. Normalizing Treatment: 1600°F.
6. Welding Data:
- (a) Type and size electrode 3/16" diam. E6010 (Westinghouse AP)
 - (b) Type of Current Direct Polarity Reverse
 - (c) Amperage 180 amperes
 - (d) Voltage 24 to 26 volts
 - (e) Rate of Travel 5.0 inches per minute
 - (f) Plate Temperature 68°F.
7. Hardness of Heat-Affected Zone (Max.): Right 390 Left 370
8. Hardness of Unaffected Base Metal (Avg.): 215
9. Visual Examination for Cracks: None

Signature E. R. Gamberg (s)

Date May 26, 1945

Westinghouse Electric & Manufacturing Co.
Research Laboratories
Record of Weld Bead Hardness Test

1. Type of Steel: WD 4130
2. Chemical Analysis:

C	Mn	P	S	Si	Ni	Cr	Cu	Mo	V	
.55	.44	.017	.024	.196	.59	.98	.075	.22	-	
3. Deoxidation Practice: Killed _____ Semi-Killed _____ Rimmed _____
4. Grain Size (McQuaid-Ehn): 8 ASTM
5. Normalizing Treatment: 1600°F.
6. Welding Data:
- (a) Type and size Electrode 5/16" diam. E6010 (Westinghouse AP)
 - (b) Type of Current Direct Polarity Reverse
 - (c) Amperage 180 amperes
 - (d) Voltage 24 to 26 volts
 - (e) Rate of Travel 5.0 inches per minute
 - (f) Plate Temperature 300°F.
7. Hardness of Heat-Affected Zone (Max.): Right 517 Left 512
8. Hardness of Unaffected Base Metal (Avg.): 192
9. Visual Examination for Cracks: None

Signature E. R. Gamberg (s)

Date May 26, 1945

Westinghouse Electric & Manufacturing Co.
 Research Laboratories
Record of Weld Bead Hardness Test

1. Type of Steel: AISI 4142
2. Chemical Analysis:

C	Mn	P	S	Si	Ni	Cr	Cu	Mo	V
.44	.91	.025	.004	.251	.12	.93	.115	.19	-
3. Deoxidation Practice: Killed _____ Semi-Killed _____ Rimmed _____
4. Grain Size (McQuaid-Ehn): 8 ASTM
5. Normalizing Treatment: 1600°F.
6. Welding Data:
 - (a) Type and size electrode 3/16" diam. E6010 (Westinghouse AP)
 - (b) Type of Current Direct Polarity Reverse
 - (c) Amperage 180 amperes
 - (d) Voltage 24 to 26 volts
 - (e) Rate of Travel 5.0 inches per minute
 - (f) Plate Temperature 68°F.
7. Hardness of Heat-Affected Zone (Max.): Right 613 Left 613
8. Hardness of Unaffected Base Metal (Avg.): 512
9. Visual Examination for Cracks: Crack under root of bead

Signature E. R. Gamberg (s)

Date May 28, 1943

Westinghouse Electric & Manufacturing Co.
Research Laboratories
Record of Weld Bead Hardness Test

1. Type of Steel: AISI 4142
2. Chemical Analysis:

C	Mn	P	S	Si	Ni	Cr	Cu	Mo	V	
.44	.91	.025	.004	.251	.12	.93	.115	.19	-	
3. Deoxidation Practice: Killed _____ Semi-Killed _____ Rimmed _____
4. Grain Size (McQuaid-Ehn): 8 ASTM
5. Normalizing Treatment: 1600°F.
6. Welding Data:
- (a) Type and size electrode 3/16" diam. E6010 (Westinghouse AP)
 - (b) Type of Current Direct Polarity Reverse
 - (c) Amperage 180 amperes
 - (d) Voltage 24 to 26 volts
 - (e) Rate of Travel 5.0 inches per minute
 - (f) Plate Temperature 300°F.
7. Hardness of Heat-Affected Zone (Max.): Right 446 Left 464
8. Hardness of Unaffected Base Metal (Avg.): 305
9. Visual Examination for Cracks: None

Signature E. R. Gamberg (s)
Date May 26, 1945

Westinghouse Electric & Manufacturing Co.
Research Laboratories
Record of Weld Bead Hardness Test

1. Type of Steel: WD 4150
2. Chemical Analysis:
- | C | Mn | P | S | Si | Ni | Cr | Cu | Mo | V | |
|-----|-----|------|------|------|-----|-----|-----|-----|---|--|
| .48 | .59 | .015 | .025 | .245 | .10 | .86 | .12 | .22 | - | |
3. Deoxidation Practice: Killed _____ Semi-Killed _____ Rimmed _____
4. Grain Size (McQuaid-Ehn): 7 ASTM
5. Normalizing Treatment: 1550°F.
6. Welding Data:
- (a) Type and size electrode 3/16" diam. E6010 (Westinghouse AP)
 - (b) Type of Current Direct Polarity Reverse
 - (c) Amperage 180 amperes
 - (d) Voltage 24 to 26 volts
 - (e) Rate of Travel 5.0 inches per minute
 - (f) Plate temperature 68°F.
7. Hardness of Heat-Affected Zone (Max.): Right 585 Left 613
8. Hardness of Unaffected Base Metal (Avg.): 294
9. Visual Examination for Cracks: Crack under root of bead

Signature E. R. Gamberg (s)

Date May 26, 1943

Westinghouse Electric & Manufacturing Co.
Research Laboratories
Record of Weld Bead Hardness Test

1. Type of Steel: WD 4150
2. Chemical Analysis:
- | C | Mn | P | S | Si | Ni | Cr | Cu | Mo | V |
|-----|-----|------|------|------|-----|-----|-----|-----|---|
| .48 | .59 | .015 | .025 | .245 | .10 | .86 | .12 | .22 | - |
3. Deoxidation Practice: Killed _____ Semi-Killed _____ Rimmed _____
4. Grain Size (McQuaid-Ehn): 7 ASTM
5. Normalizing Treatment: 1550°F.
6. Welding Data:
- (a) Type and size electrode 3/16" diam. E6010 (Westinghouse AP)
- (b) Type of Current Direct Polarity Reverse
- (c) Amperage 180 amperes
- (d) Voltage 24 to 26 volts
- (e) Rate of Travel 5.0" inches per minute
- (f) Plate Temperature 300°F.
7. Hardness of Heat-Affected Zone (Max.): Right 498 Left 485
8. Hardness of Unaffected Base Metal (Avg.): 289
9. Visual Examination for Cracks: None

Signature E. R. Gamberg (s)

Date May 26, 1943

Westinghouse Electric & Manufacturing Co.
 Research Laboratories
Record of Weld Bead Hardness Test

1. Type of Steel: S.A.E. I4340
2. Chemical Analysis:

C	Mn	P	S	Si	Ni	Cr	Cu	Mo	V
.41	.66	.017	.007	.285	1.69	.87	.085	.24	-
3. Deoxidation Practice: Killed _____ Semi-Killed _____ Rimmed _____
4. Grain Size (McQuaid-Ehn): 7 ASTM
5. Normalizing Treatment: 1550°F.
6. Welding Data:
 - (a) Type and size electrode 3/16" diam. E6010 (Westinghouse AP)
 - (b) Type of Current Direct Polarity Reverse
 - (c) Amperage 180 amperes
 - (d) Voltage 24 to 26 volts
 - (e) Rate of Travel 5.0 inches per minute
 - (f) Plate Temperature 68°F.
7. Hardness of Heat-Affected Zone (Max.): Right 634 Left 620
8. Hardness of Unaffected Base Metal (Avg.): 368
9. Visual Examination for Cracks: Crack extends all way around bead.
Located in heat affected area.

Signature E. R. Gamberg (S)

Date May 26, 1943

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Westinghouse Electric & Manufacturing Co.
Research Laboratories
Record of Weld Bead Hardness Test

1. Type of Steel: S.A.E. X4540
2. Chemical Analysis:

C	Mn	P	S	Si	Ni	Cr	Cu	Mo	V
.41	.66	.017	.007	.285	1.69	.87	.095	.24	-
3. Deoxidation Practice: Killed _____ Semi-Killed _____ Rimmed _____
4. Grain Size (McQuaid-Ehn): 7 ASTM
5. Normalizing Treatment: 1550°F.
6. Welding Data:
- (a) Type and size electrode 5/16" diam. E6010 (Westinghouse AP)
 - (b) Type of Current Direct Polarity Reverse
 - (c) Amperage 180 amperes
 - (d) Voltage 24 to 26 volts
 - (e) Rate of Travel 5.0 inches per minute
 - (f) Plate Temperature 300°F.
7. Hardness of Heat-Affected Zone (Max.): Right 592 Left 592
8. Hardness of Unaffected Base Metal (Avg.): 351
9. Visual Examination for Cracks: Crack from root to toe--not completely around bead.

Signature E. R. Gamberg (s)

Date May 26, 1945

Westinghouse Electric & Manufacturing Co.
Research Laboratories
Record of Weld Bead Hardness Test

1. Type of Steel: S.A.E. X4540
2. Chemical Analysis:

C	Mn	P	S	Si	Ni	Cr	Cu	Mo	V
.41	.66	.017	.007	.283	1.69	.87	.095	.24	-
3. Deoxidation Practice: Killed _____ Semi-Killed _____ Rimmed _____
4. Grain Size (McQuaid-Ehn): 7 ASTM
5. Normalizing Treatment: 1550°F.
6. Welding Data:
- (a) Type and size electrode 3/16" diam. E3010 (Westinghouse AP)
 - (b) Type of Current Direct Polarity Reverse
 - (c) Amperage 180 amperes
 - (d) Voltage 24 to 26 volts
 - (e) Rate of Travel 5.0 inches per minute
 - (f) Plate Temperature 500°F.
7. Hardness of Heat-Affected Zone (Max.): Right 503 Left 493
8. Hardness of Unaffected Base Metal (Avg.): 381
9. Visual Examination for Cracks: None

Signature E. R. Gamberg (s)

Date May 26, 1945

Westinghouse Electric & Manufacturing Co.
 Research Laboratories
Record of Weld Bead Hardness Test

1. Type of Steel: FD 4015
2. Chemical Analysis:

C	Mn	P	S	Si	Ni	Cr	Cu	Mo	V
.08	.35	.015	.011	.058	2.05	.09	.14	.28	.03
3. Deoxidation Practice: Killed _____ Semi-Killed _____ Rimmed _____
4. Grain Size (McQuaid-Ehn): 5 ASTM
5. Normalizing Treatment: 1800°F.
6. Welding Data:
- (a) Type and size electrode 5/16" diam. E6010 (Westinghouse AP)
 - (b) Type of Current Direct Polarity Reverse
 - (c) Amperage 180 amperes
 - (d) Voltage 24 to 26 volts
 - (e) Rate of Travel 5.0 inches per minute
 - (f) Plate Temperature 68°F.
7. Hardness of Heat-Affected Zone (Max.): Right 209 Left 209
8. Hardness of Unaffected Base Metal (Avg.): 145
9. Visual Examination for Cracks: None

Signature E. R. Gamberg (s)
 Date May 26, 1945

Westinghouse Electric & Manufacturing Co.
 Research Laboratories
Record of Weld Bead Hardness Test

1. Type of Steel: WD 4615
2. Chemical Analysis:

C	Mn	P	S	Si	Ni	Cr	Cu	Mo	V
.08	.55	.015	.011	.056	2.05	.09	.14	.28	.05
3. Decoxidation Practice: Killed _____ Semi-Killed _____ Rimmed _____
4. Grain Size (McQuaid-Ehn): 5 ASTM
5. Normalizing Treatment: 1600°F.
6. Welding Data:
- (a) Type and size electrode 3/16" diam. E6010 (Westinghouse AP)
 - (b) Type of Current Direct Polarity Reverse
 - (c) Amperage 180 amperes
 - (d) Voltage 24 to 26 volts
 - (e) Rate of Travel 5.0 inches per minute
 - (f) Plate Temperature -20°F.
7. Hardness of Heat-Affected Zone (Max.): Right 212 Left 215
8. Hardness of Unaffected Base Metal (Avg.): 141
9. Visual Examination for Cracks: None

Signature E. R. Gamberg (s)

Date May 26, 1945

Westinghouse Electric & Manufacturing Co.
Research Laboratories
Record of Weld Bead Hardness Test

1. Type of Steel: WD 4640
2. Chemical Analysis:

C	Mn	P	S	Si	Ni	Cr	Cu	Mo	V	
.59	.70	.014	.007	.229	2.03	.07	.17	.25	.03	
3. Deoxidation Practice: Killed Semi-Killed Rimmed
4. Grain Size (McQuaid-Ehn): 7 ASTM
5. Normalizing Treatment: 1550°F.
6. Welding Data:
- (a) Type and size electrode 3/16" diam. E6010 (Westinghouse AP)
 - (b) Type of Current Direct Polarity Reverse
 - (c) Amperage 180 amperes
 - (d) Voltage 24 to 26 volts
 - (e) Rate of Travel 5.0 inches per minute
 - (f) Plate Temperature 68°F.
7. Hardness of Heat-Affected Zone (Max.): Right 554 Left 585
8. Hardness of Unaffected Base Metal (Avg.): 266
9. Visual Examination for Cracks: None

Signature E. R. Gamberg (s)

Date May 26, 1945

Westinghouse Electric & Manufacturing Co.
 Research Laboratories
Record of Weld Bead Hardness Test

1. Type of Steel: WD 4815
2. Chemical Analysis:

C	Mn	P	S	Si	Ni	Cr	Cu	Mo	V
.19	.56	.017	.010	.224	5.56	.15	.16	.27	-
3. Deoxidation Practice: Killed _____ Semi-Killed _____ Rimmed _____
4. Grain Size (McQuaid-Ehn): 6 ASTM
5. Normalizing Treatment: 1550°F.
6. Welding Data:
- (a) Type and size electrode 5/16" diam. E6010 (Westinghouse AP)
 - (b) Type of Current Direct Polarity Reverse
 - (c) Amperage 180 amperes
 - (d) Voltage 24 to 28 volts
 - (e) Rate of Travel 5.0 inches per minute
 - (f) Plate Temperature 68°F.
7. Hardness of Heat-Affected Zone (Max.): Right 457 Left 455
8. Hardness of Unaffected Base Metal (Avg.): 254
9. Visual Examination for Cracks: None

Signature E. R. Gamberg (s)

Date May 26, 1945

Westinghouse Electric & Manufacturing Co.
Research Laboratories
Record of Weld Bead Hardness Test

1. Type of Steel: WD 4815
2. Chemical Analysis:

C	Mn	P	S	Si	Ni	Cr	Cu	Mo	V	
.19	.56	.017	.010	.224	5.56	.15	.16	.27	-	
3. Deoxidation Practices: Killed _____ Semi-Killed _____ Rimmed _____
4. Grain Size (McQuaid-Ehn): 6 ASTM
5. Normalizing Treatment: 1550°F.
6. Welding Data:
- (a) Type and size electrode 3/16" diam. E6010 (Westinghouse AP)
 - (b) Type of Current Direct Polarity Reverse
 - (c) Amperage 180 amperes
 - (d) Voltage 24 to 26 volts
 - (e) Rate of Travel 5.0 inches per minute
 - (f) Plate Temperature 500°F.
7. Hardness of Heat-Affected Zone (Max.): Right 370 Left 370
8. Hardness of Unaffected Base Metal (Avg.): 251
9. Visual Examination for Cracks: None

Signature E. R. Camberg (s)

Date May 26, 1943

Westinghouse Electric & Manufacturing Co.
Research Laboratories
Record of Weld Bead Hardness Test

1. Type of Steel: WD 4820
2. Chemical Analysis:
- | C | Mn | P | S | Si | Ni | Cr | Cu | Mo | V | |
|-----|-----|------|------|------|------|-----|-----|-----|---|--|
| .19 | .61 | .015 | .005 | .241 | 3.47 | .15 | .08 | .26 | - | |
3. Deoxidation Practice: Killed _____ Semi-Killed _____ Rimmed _____
4. Grain Size (McQuaid-Ehn): 6 ASTM
5. Normalizing Treatment: 1550°F.
6. Welding Data:
- (a) Type and size electrode 3/16" diam. E6010 (Westinghouse AP)
- (b) Type of Current Direct Polarity Reverse
- (c) Amperage 180 amperes
- (d) Voltage 24 to 26 volts
- (e) Rate of Travel 5.0 inches per minute
- (f) Plate Temperature 68°F.
7. Hardness of Heat-Affected Zone (Max.): Right 409 Left 409
8. Hardness of Unaffected Base Metal (Avg.): 244
9. Visual Examination for Cracks: None

Signature E. R. Camberg (s)

Date May 28, 1945

Research Report R-94296-AK

Westinghouse Electric & Manufacturing Co.
Research Laboratories
Record of Weld Bead Hardness Test

1. Type of Steel: WD 4820

2. Chemical Analysis:

C	Mn	P	S	Si	Ni	Cr	Cu	Mo	V
.19	.61	.015	.005	.241	5.47	.15	.08	.26	-

3. Deoxidation Practice: Killed _____ Semi-Killed _____ Rimmed _____

4. Grain Size (McQuaid-Ehn): 6 ASTM

5. Normalizing Treatment: 1550°F.

6. Welding Data:

(a) Type and size electrode 5/16" diam. E6010 (Westinghouse AP)

(b) Type of Current Direct Polarity Reverse

(c) Amperage 180 amperes

(d) Voltage 24 to 26 volts

(e) Rate of Travel 5.0 inches per minute

(f) Plate Temperature 300°F.

7. Hardness of Heat-Affected Zone (Max.): Right 354 Left 354

8. Hardness of Unaffected Base Metal (Avg.) 285

9. Visual Examination for Cracks: None

Signature E. R. Camberg (s)

Date May 26, 1945

Westinghouse Electric & Manufacturing Co.
Research Laboratories
Record of Weld Bead Hardness Test

1. Type of Steel: WD 4640
2. Chemical Analysis:

C	Mn	P	S	Si	Ni	Cr	Cu	Mo	V		
.39	.70	.014	.007	.229	2.03	.07	.17	.25	.05		
3. Deoxidation Practice: Killed Semi-Killed Rimmed
4. Grain Size (McQuaid-Ehn): 7 ASTM
5. Normalizing Treatment: 1550°F.
6. Welding Data:
- (a) Type and size electrode 5/16" diam. E6010 (Westinghouse AP)
 - (b) Type of Current Direct Polarity Reverse
 - (c) Amperage 180 amperes
 - (d) Voltage 24 to 26 volts
 - (e) Rate of Travel 5.0 inches per minute
 - (f) Plate Temperature 300°F.
7. Hardness of Heat-Affected Zone (Max.): Right 409 Left 450
8. Hardness of Unaffected Base Metal (Avg.): 253
9. Visual Examination for Cracks: None

Signature E. R. Camberg (s)

Date May 26, 1945

Westinghouse Electric & Manufacturing Co.
 Research Laboratories
Record of Weld Bead Hardness Test

1. Type of Steel: WD 5150
2. Chemical Analysis:

C	Mn	P	S	Si	Ni	Cr	Cu	Mo	V
.48	.68	.014	.013	.173	.16	1.04	.08	.03	.19
3. Deoxidation Practice: Killed Semi-Killed Rimmed
4. Grain Size (McQuaid-Ehn): 8 ASTM
5. Normalizing Treatment: 1550°F.
6. Welding Data:
- (a) Type and size electrode: 3/16 diam. E6010 (Westinghouse AP)
- (b) Type of Current Direct Polarity Reverse
- (c) Amperage 180 amperes
- (d) Voltage 24 to 26 volts
- (e) Rate of Travel 5.0 inches per minute
- (f) Plate Temperature 68°F.
7. Hardness of Heat-Affected Zone (Max.): Right 580 Left 572
8. Hardness of Unaffected Base Metal (Avg.): 222
9. Visual Examination for Cracks: Crack under root of bead.

Signature E. R. Gamberg (S)

Date May 26, 1945

Research Report R-94296-AK

Westinghouse Electric & Manufacturing Co.
Research Laboratories
Record of Weld Bead Hardness Test

1. Type of Steel: WD 5150
2. Chemical Analysis:
- | C | Mn | P | S | Si | Ni | Cr | Cu | Mo | V |
|-----|-----|------|------|------|-----|------|-----|-----|-----|
| .48 | .68 | .014 | .015 | .173 | .18 | 1.04 | .08 | .03 | .19 |
3. Deoxidation Practice: Killed _____ Semi-Killed _____ Rimmed _____
4. Grain Size (McQuaid-Ehn): 8 ASTM
5. Normalizing Treatment: 1550°F.
6. Welding Data:
- (a) Type and size electrode 5/16" diam. E8010 (Westinghouse AP)
 - (b) Type of Current Direct Polarity Reverse
 - (c) Amperage 180 amperes
 - (d) Voltage 24 to 26 volts
 - (e) Rate of Travel 5.0 inches per minute
 - (f) Plate Temperature 300°F.
7. Hardness of Heat-Affected Zone (Max.): Right 542 Left 519
8. Hardness of Unaffected Base Metal (Avg.): 212
9. Visual Examination for Cracks: None

Signature E. R. Gamberg (s)

Date May 26, 1945

Westinghouse Electric & Manufacturing Co.
Research Laboratories
Record of Weld Bead Hardness Test

1. Type of Steel: S.A.E. 8620
2. Chemical Analysis:

C	Mn	P	S	Si	Ni	Cr	Cu	Mo	V	
.22	.62	.020	.009	.504	.51	.45	.08	.22	-	
3. Deoxidation Practice: Killed _____ Semi-Killed _____ Rimmed _____
4. Grain Size (McQuaid-Ehn): 7 ASTM
5. Normalizing Treatment: 1575°F.
6. Welding Data:
- (a) Type and size electrode 3/16" diam. E6010 (Westinghouse AP)
 - (b) Type of Current Direct Polarity Reverse
 - (c) Amperage 180 amperes
 - (d) Voltage 24 to 26 volts
 - (e) Rate of Travel 5.0 inches per minute
 - (f) Plate Temperature 68°F.
7. Hardness of Heat-Affected Zone (Max.): Right 306 Left 306
8. Hardness of Unaffected Base Metal (Avg.): 206
9. Visual Examination for Cracks: None

Signature E. R. Gamberg (s)

Date May 26, 1945

Westinghouse Electric & Manufacturing Co.
 Research Laboratories
Record of Weld Bead Hardness Test

1. Type of Steel: S.A.E. 8620
2. Chemical Analysis:

C	Mn	P	S	Si	Ni	Cr	Cu	Mo	V
.22	.82	.020	.009	.304	.51	.43	.08	.22	-
3. Deoxidation Practice: Killed _____ Semi-Killed _____ Rimmed _____
4. Grain Size (McQuaid-Ehn): 7 ASTM
5. Normalizing Treatment: 1575°F.
6. Welding Data:
 - (a) Type and size electrode 3/16" diam. E6010 (Westinghouse AP)
 - (b) Type of Current Direct Polarity Reverse
 - (c) Amperage 180 amperes
 - (d) Voltage 24 to 26 volts
 - (e) Rate of Travel 5.0 inches per minute
 - (f) Plate Temperature -20°F.
7. Hardness of Heat-Affected Zone (Max.): Right 355 Left 350
8. Hardness of Unaffected Base Metal (Avg.): 189
9. Visual Examination for Cracks: None

Signature E. R. Gamberg (s)

Date May 26, 1945

Westinghouse Electric & Manufacturing Co.
 Research Laboratories
Record of Weld Bead Hardness Test

1. Type of Steel: S.A.E. 8630
2. Chemical Analysis:

C	Mn	P	S	Si	Ni	Cr	Cu	Mo	V
.35	.74	.014	.007	.280	.50	.52	.06	.27	-
3. Deoxidation Practice: Killed _____ Semi-Killed _____ Rimmed _____
4. Grain Size (McQuaid-Ehn): 6 ASTM
5. Normalizing Treatment: 1575°F.
6. Welding Data:
- (a) Type and size electrode 3/16" diam. E6010 (Westinghouse AP)
 - (b) Type of Current Direct Polarity Reverse
 - (c) Amperage 180 amperes
 - (d) Voltage 24 to 26 volts
 - (e) Rate of Travel 5.0 inches per minute
 - (f) Plate Temperature 68°F.
7. Hardness of Heat-Affected Zone (Max.): Right 488 Left 488
8. Hardness of Unaffected Base Metal (Avg.): 226
9. Visual Examination for Cracks: None

Signature E. R. Gamberg (s)

Date May 26, 1945

Westinghouse Electric & Manufacturing Co.
Research Laboratories
Record of Weld Bead Hardness Test

1. Type of Steel: S.A.E. 8650
2. Chemical Analysis:

C	Mn	P	S	Si	Ni	Cr	Cu	Mo	V
.85	.74	.014	.007	.280	.51	.52	.06	.21	-
3. Deoxidation Practice: Killed _____ Semi-Killed _____ Rimmed _____
4. Grain Size (McQuaid-Ehn): 6 ASTM
5. Normalizing Treatment: 1575°F.
6. Welding Data:
- (a) Type and size electrode 5/16" diam. E8010 (Westinghouse AP)
 - (b) Type of Current Direct Polarity Reverse
 - (c) Amperage 180 amperes
 - (d) Voltage 24 to 26 volts
 - (e) Rate of Travel 5.0 inches per minute
 - (f) Plate Temperature 300°F.
7. Hardness of Heat-Affected Zone (Max.): Right 512 Left 522
8. Hardness of Unaffected Base Metal (Avg.): 214
9. Visual Examination for Cracks: None

Signature E. R. Gamberg (s)

Date May 26, 1945

Westinghouse Electric & Manufacturing Co.
Research Laboratories
Record of Weld Bead Hardness Test

1. Type of Steel: S.A.E. 8759
2. Chemical Analysis:
- | C | Mn | P | S | Si | Ni | Cr | Cu | Mo | V | |
|-----|-----|------|------|------|-----|-----|------|-----|---|--|
| .40 | .71 | .025 | .001 | .238 | .41 | .48 | .085 | .24 | - | |
3. Deoxidation Practice: Killed _____ Semi-Killed _____ Rimmed _____
4. Grain Size (McQuaid-Ehn): 8 ASTM
5. Normalizing Treatment: 1575°F.
6. Welding Data:
- (a) Type and size electrode 3/16" diam. E6010 (Westinghouse AP)
 - (b) Type of Current Direct Polarity Reverse
 - (c) Amperage 180 amperes
 - (d) Voltage 24 to 26 volts
 - (e) Rate of Travel 5.0 inches per minute
 - (f) Plate Temperature 65°F.
7. Hardness of Heat-Affected Zone (Max.): Right 498 Left 498
8. Hardness of Unaffected Base Metal (Avg.): 271
9. Visual Examination for Cracks: Cracks under root of bead, very fine

Signature E. R. Gamberg (s)

Date May 26, 1945

Westinghouse Electric & Manufacturing Co.
Research Laboratories
Record of Weld Bead Hardness Test

1. Type of Steel: S.A.E. 8739
2. Chemical Analysis:
- | C | Mn | P | S | Si | Ni | Cr | Cu | Mo | V |
|-----|-----|------|------|------|-----|-----|------|-----|---|
| .40 | .71 | .025 | .001 | .238 | .41 | .48 | .085 | .24 | - |
3. Deoxidation Practice: Killed _____ Semi-Killed _____ Rimmed _____
4. Grain Size (McQuaid-Ehn): 8 ASTM
5. Normalizing Treatment: 1575°F.
6. Welding Data:
- (a) Type and size electrode 3/16" diam. E6010 (Westinghouse AP)
 - (b) Type of Current Direct Polarity Reverse
 - (c) Amperage 180 amperes
 - (d) Voltage 24 to 26 volts
 - (e) Rate of Travel 5.0 inches per minute
 - (f) Plate Temperature 300°F.
7. Hardness of Heat-Affected Zone (Max.): Right 576 Left 575
8. Hardness of Unaffected Base Metal (Avg.): 245
9. Visual Examination for Cracks: None

Signature E. R. Gamberg (s)

Date May 26, 1945

Westinghouse Electric & Manufacturing Co.
Research Laboratories
Record of Weld Bead Hardness Test

1. Type of Steel: NE 8747
2. Chemical Analysis:
- | C | Mn | P | S | Si | Ni | Cr | Cu | Mo | V | |
|-----|-----|------|------|------|-----|-----|-----|-----|---|--|
| .45 | .71 | .010 | .018 | .282 | .45 | .51 | .13 | .25 | - | |
3. Deoxidation Practice: Killed _____ Semi-Killed _____ Rimmed _____
4. Grain Size (McQuaid-Ehn): 8 ASTM
5. Normalizing Treatment: 1550°F.
6. Welding Data:
- (a) Type and size electrode 3/16" diam. E6010 (Westinghouse AP)
 - (b) Type of Current Direct Polarity Reverse
 - (c) Amperage 180 amperes
 - (d) Voltage 24 to 26 volts
 - (e) Rate of Travel 5.0 inches per minute
 - (f) Plate Temperature 68°F.
7. Hardness of Heat-Affected Zone (Max.): Right 554 Left 548
8. Hardness of Unaffected Base Metal (Avg.): 295
9. Visual Examination for Cracks: Crack under root of bead

Signature E. R. Gamberg (s)

Date May 26, 1945

Westinghouse Electric & Manufacturing Co.
Research Laboratories
Record of Weld Bead Hardness Test

1. Type of Steel: NE 8747
2. Chemical Analysis:

C	Mn	P	S	Si	Ni	Cr	Cu	Mo	V	
.45	.71	.010	.018	.262	.45	.51	.18	.25	-	
3. Deoxidation Practice: Killed _____ Semi-Killed _____ Rimmed _____
4. Grain Size (McQuaid-Ehn): 8 ASTM
5. Normalizing Treatment: 1550°F.
6. Welding Data:
- (a) Type and size electrode 3/16" diam. E6010 (Westinghouse AP)
 - (b) Type of Current Direct Polarity Reverse
 - (c) Amperage 180 amperes
 - (d) Voltage 24 to 26 volts
 - (e) Rate of Travel 5.0 inches per minute
 - (f) Plate Temperature 300°F.
7. Hardness of Heat-Affected Zone (Max.): Right 405 Left 421
8. Hardness of Unaffected Base Metal (Avg.): 285
9. Visual Examination for Cracks: None

Signature E. R. Gamberg (s)

Date May 26, 1945

Research Report R-94296-AK

Westinghouse Electric & Manufacturing Co.
Research Laboratories
Record of Weld Bead Hardness Test

1. Type of Steel: S.A.E. 8949
2. Chemical Analysis:
- | C | Mn | P | S | Si | Ni | Cr | Cu | Mo | V |
|-----|-----|------|------|------|-----|-----|-----|-----|---|
| .46 | .95 | .015 | .011 | .257 | .52 | .56 | .06 | .32 | - |
3. Deoxidation Practice: Killed _____ Semi-Killed _____ Rimmed _____
4. Grain Size (McQuaid-Ehn): 8 ASTM
5. Normalizing Treatment: 1550°F.
6. Welding Data:
- (a) Type and size electrode 5/16" diam. E6010 (Westinghouse AP)
- (b) Type of Current Direct Polarity Reverse
- (c) Amperage 180 amperes
- (d) Voltage 24 to 26 volts
- (e) Rate of Travel 5.0 inches per minute
- (f) Plate Temperature 68°F.
7. Hardness of Heat-Affected Zone (Max.): Right 675 Left 675
8. Hardness of Unaffected Base Metal (Avg.): 318
9. Visual Examination for Cracks: Crack extended nearly from toe to toe of the bead. Located in the heat affected area.

Signature E. R. Gamberg (s)

Date May 26, 1945

Westinghouse Electric & Manufacturing Co.
 Research Laboratories
Record of Weld Bead Hardness Test

1. Type of Steel: S.A.E. 8949
2. Chemical Analysis:

C	Mn	P	S	Si	Ni	Cr	Cu	Mo	V
.46	.95	.015	.011	.257	.52	.56	.06	.32	-
5. Deoxidation Practice: Killed _____ Semi-Killed _____ Rimmed _____
4. Grain Size (McQuaid-Ehn): 8 ASTM
5. Normalizing Treatment: 1550°F.
6. Welding Data:
- (a) Type and size electrode 3/16" diam. E6010 (Westinghouse AP)
- (b) Type of Current Direct Polarity Reverse
- (c) Amperage 180 amperes
- (d) Voltage 24 to 26 volts
- (e) Rate of Travel 5.0 inches per minute
- (f) Plate Temperature 300°F.
7. Hardness of Heat-Affected Zone (Max.): Right 606 Left 627
8. Hardness of Unaffected Base Metal (Avg.): 520
9. Visual Examination for Cracks: Crack in heat affected area by toe of bead.

Signature E. R. Gamberg (s)

Date May 26, 1948

Westinghouse Electric & Manufacturing Co.
Research Laboratories
Record of Weld Bead Hardness Test

1. Type of steel: WD 4050
2. Chemical Analysis:

C	Mn	P	S	Si	Ni	Cr	Cu	Mo	V
.51	.72	.012	.010	.252	.23	.48	.09	.25	-
3. Deoxidation Practice: Killed _____ Semi-Killed _____ Rimmed _____
4. Grain Size (McQuaid-Ehn): 7 ASTM
5. Normalizing Treatment 1550°F.
6. Welding Data:
- (a) Type and size electrode 3/16" diam. E6010 (Westinghouse AP)
 - (b) Type of Current Direct Polarity Reverse
 - (c) Amperage 180 amperes
 - (d) Voltage 24 to 26 volts
 - (e) Rate of Travel 5.0 inches per minute
 - (f) Plate Temperature 68°F.
7. Hardness of Heat-Affected Zone (Max.): Right 554 Left 550
8. Hardness of Unaffected Base Metal (Avg.): 267
9. Visual Examination for Cracks: None

Signature E. R. Gamberg (s)

Date May 28, 1945

Westinghouse Electric & Manufacturing Co.
Research Laboratories
Record of Weld Bead Hardness Test

1. Type of Steel: WD 4050
2. Chemical Analysis:

C	Mn	P	S	Si	Ni	Cr	Cu	Mo	V	
.51	.72	.012	.010	.252	.23	.48	.09	.25	-	
5. Deoxidation Practices: Killed _____ Semi-Killed _____ Rimmed _____
4. Grain Size (McQuaid-Ehn): 7 ASTM
5. Normalizing Treatment: 1550°F.
6. Welding Data:
- (a) Type and size electrode 5/16" diam. E8010 (Westinghouse AP)
 - (b) Type of Current Direct Polarity Reverse
 - (c) Amperage 180 amperes
 - (d) Voltage 24 to 26 volts
 - (e) Rate of Travel 5.0 inches per minute
 - (f) Plate Temperature 500°F.
7. Hardness of Heat-Affected Zone (Max.): Right 359 Left 356
8. Hardness of Unaffected Base Metal (Avg.): 265
9. Visual Examination for Cracks: None

Signature E. R. Gamberg (s)

Date May 26, 1945

Westinghouse Electric & Manufacturing Co.
Research Laboratories
Record of Weld Bead Hardness Test

1. Type of Steel: WD 9150
2. Chemical Analysis:

C	Mn	P	S	Si	Ni	Cr	Cu	Mo	V	
.28	.66	.017	.019	.715	.070	.56	.15	.19	-	
3. Deoxidation Practice: Killed _____ Semi-Killed _____ Rimmed _____
4. Grain Size (McQuaid-Ehn): 7 ASTM
5. Normalizing Treatment: 1575°F.
6. Welding Data:
- (a) Type and size electrode 3/16" diam. E6010 (Westinghouse AP)
 - (b) Type of Current Direct Polarity Reverse
 - (c) Amperage 180 amperes
 - (d) Voltage 24 to 26 volts
 - (e) Rate of Travel 5.0 inches per minute
 - (f) Plate temperature 68°F.
7. Hardness of Heat-Affected Zone (Max.): Right 421 Left 415
8. Hardness of Unaffected Base Metal (Avg.): 200
9. Visual Examination for Cracks: None

Signature E. R. Gamberg (s)

Date May 26, 1945

Westinghouse Electric & Manufacturing Co.
Research Laboratories
Record of Weld Bead Hardness Test

1. Type of Steel: WD 9150
2. Chemical Analysis:
- | C | Mn | P | S | Si | Ni | Cr | Cu | Mo | V |
|-----|-----|------|------|------|------|-----|-----|-----|---|
| .28 | .66 | .017 | .019 | .715 | .070 | .56 | .15 | .19 | - |
3. Deoxidation Practice: Killed _____ Semi-Killed _____ Rimmed _____
4. Grain Size (McQuaid-Ehn): 7 ASTM
5. Normalizing Treatment: 1575°F.
6. Welding Data:
- (a) Type and size electrode 3/16" diam. E6010 (Westinghouse AP)
 - (b) Type of Current Direct Polarity Reverse
 - (c) Amperage 180 amperes
 - (d) Voltage 24 to 26 volts
 - (e) Rate of Travel 5.0 inches per minute
 - (f) Plate Temperature 500°F.
7. Hardness of Heat-Affected Zone (Max.): Right 342 Left 342
8. Hardness of Unaffected Base Metal (Avg.): 187
9. Visual Examination for Cracks: None

Signature E. R. Gamberg (S)

Date May 26, 1945

Westinghouse Electric & Manufacturing Co.
Research Laboratories
Record of Weld Bead Hardness Test

1. Type of Steel: WD 9150
2. Chemical Analysis:

C	Mn	P	S	Si	Ni	Cr	Cu	Mo	V	
.49	.69	.023	.034	.841	.04	.65	.08	.02	-	
3. Decoxidation Practice: Killed _____ Semi-Killed _____ Rimmed _____
4. Grain Size (McQuaid-Ehn): 6 ASTM
5. Normalizing Treatment: 1550°F.
6. Welding Data:
- (a) Type and size electrode 5/16" diam. E6010 (Westinghouse AP)
 - (b) Type of Current Direct Polarity Reverse
 - (c) Amperage 180 amperes
 - (d) Voltage 24 to 26 volts
 - (e) Rate of Travel 5.0 inches per minute
 - (f) Plate Temperature 68°F.
7. Hardness of Heat-Affected Zone (Max.): Right 554 Left 606
8. Hardness of Unaffected Base Metal (Avg.): 247
9. Visual Examination for Cracks: Crack under root of bead

Signature E. R. Gamberg (s)

Date May 26, 1945

UNCLASSIFIED

Westinghouse Electric & Manufacturing Co.
 Research Laboratories
Record of Weld Bead Hardness Test

1. Type of Steel: WD 9150
2. Chemical Analysis:

C	Mn	P	S	Si	Ni	Cr	Cu	Mo	V
.49	.69	.023	.034	.841	.04	.65	.08	.02	-
3. Deoxidation Practice: Killed _____ Semi-Killed _____ Rimmed _____
4. Grain Size (McQuaid-Ehn): 6 ASTM
5. Normalizing Treatment: 1550°F.
6. Welding Data:
 - (a) Type and size electrode 5/16" diam. E6010 (Westinghouse AP)
 - (b) Type of Current Direct Polarity Reverse
 - (c) Amperage 180 amperes
 - (d) Voltage 24 to 26 volts
 - (e) Rate of Travel 5.0 inches per minute
 - (f) Plate Temperature 300°F.
7. Hardness of Heat-Affected Zone (Max.): Right 519 Left 542
8. Hardness of Unaffected Base Metal (Avg.): 255
9. Visual Examination for Cracks: None

Signature E. R. Gamberg (s)

Date May 26, 1945

UNCLASSIFIED