A COMPARISON OF CERTAIN PHYSICAL PROPERTIES OF DOUBLE V-TYPE WELDED JOINTS

by

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INTRODUCTION

There has been considerable controversy concerning the methods of testing welded joints, especially upon qualifying the material and the operator for making joints that are equal or superior to the physical properties of the base metal.

The Navy Department of the United States Bureau of Engineering seeks the following information from their tests on welded joints: the yield point, tensile strength, ductility of weld metal, nature of bond between base metal and deposit, and the density and chemical composition of weld metal (Ronay, 21). To obtain this information they require that a test plate be made which contains coupons for: one all-weld-metal tensile, one root and one face-bend specimen. Representative samples are obtained by milling off a sufficient quantity from the fractured all-weld-metal tensile specimen for the chemical analysis.

The tentative standard tests prepared jointly by the American Welding Society and the American Society for Testing Materials (33) for filler metals require one test coupon for reduced-section tensile, nick-break, free-bend, and density to be taken from the test plate.

The 1938 standard qualification tests of the American

Welding Society (28) for qualifying the welding process in butt joints specify a test plate with two specimens for each of the following tests: reduced-section tensile, root-bend, free-bend, and face-bend. For qualifying the operator they specify for butt joints in plate material: one root-bend and one face-bend. For welded butt joints in pipe two root-bends, two free-bends, and two reduced-section-tensile are required to qualify the welding process. To qualify the operator two root-bend and two face-bends are specified.

The Kansas State Highway Commission (20), to qualify operators, uses a test plate cut to make one nick-break, one free-bend, one reverse-bend, and one fusion line nick-break specimen.

Specifications for fusion welding process of highway and railway bridges of the American Welding Society (27) in their qualification tests call for a test plate having two free-bend, two reduced-section tensile, and two nick-break specimens. The operator to qualify must weld a test plate for the bend and the nick-break tests only.

Tentative rules for welding process in fusion welding steam, oil, and air piping in marine construction (32) require two reduced-section tensile, two free-bend, two root-break, and two side-break specimens to be taken from a welded joint of pipe.

Wilson (35) in qualification tests of marine welding operators, has developed a test procedure intended to show the tensile strength and ductility of the material, the integrity of the bond between the base metal and the weld metal, and to detect such defects as lack of penetration, non-metallic inclusions and porosity. For this purpose the following test specimens are asked for: a full-section-tensile, an all-weld-metal tensile, one nick-break, and one free-bend.

Other tests such as fatigue, impact tensile and notch, and hardness explorations are now being used to a greater extent.

From the various procedures cited it can be readily seen that certain of the tests are included in all the different methods for examining welded joints. Several of the tests are difficult and time consuming to prepare, and expensive testing machines must be available to carry out the recommendations.

This program of research was undertaken for the purpose of comparing the reduced-section tensile, bend, and tensile impact tests and to develop a nick-break so that the energy required to cause rupture could not only be measured, but a study could also be made of the fracture. This was accomplished by combining the notch impact and nick-break tests.

While the primary purpose of this investigation was to compare certain weld tests and to determine satisfactory methods of testing, the nature of this research presented other possibilities for comparison and study.

EXPERIMENTAL PROCEDURE

Materials and Test Plates

The mild steel stock used in making the welded joints consisted of five 3/8-inch bars 16 feet long. Bars 1 and 2 were 6 inches wide and were taken from stock. Their composition was not definitely known but would be classed as ordinary hot rolled mild steel. Bars 3, 4, and 5 were 5 inches wide and were bought under the following specifications: Open Hearth steel, carbon 0.15 - 0.20 per cent, manganese 0.30 - 0.60 per cent, phosphorus 0.045 per cent maximum, sulphur 0.055 per cent maximum. Pieces 5 inches long were sawed from each bar, paired, beveled on a shaper, and welded so that all joints were on a transverse section.

As shown in Plate I, the welded joints were either of the 90- or 60-degree double V-type. Two sizes and various makes of electrodes were used on both alternating and direct-current welding machines. A detailed schedule of the welded joints made is included in Table 1.

All the welding was done by the same person, who was a

Table 1. Schedule of welded plates.

Welding machine used	Width of plate in inches	No. of plates made	Angle of joint in degrees	Welding electrode	
				Size in inches	Make
A-c	6	2	60	1/8	W
A-c	5	7	90	5/32	W
A-c	6	4	60	1/8	C
A-c	6	1	90	5/32	C
A-c	5	6	90	5/32	C
A-c	6	3	60	1/8	T
A-c	6	1	90	5/32	T
A-c	6	1	90	5/32	G
A-c	5	7	90	5/32	G
A-c	6	2	60	1/8	N
A-c	6	2	90	5/32	N
A-c	5	7	90	5/32	N
D-c	6	1	60	1/8	W
D-c	5	7	90	5/32	W
D-c	6	1	60	1/8	C
D-c	6	1	90	5/32	C
D-c	5	6	90	5/32	C
D-c	6	2	60	1/8	G
D-c	6	3	90	5/32	G
D-c	5	5	90	5/32	G
D-c	6	1	60	1/8	N
D-c	6	1	90	5/32	N
D-c	5	7	90	5/32	N
D-c	6	2	60	1/8	E
D-c	6	2	90	5/32	E

Key for welding electrodes:

W = General Electric W 20
C = Hollup Sureweld C
N = Hollup Sureweld N
T = Transweld
G = Lincoln Fleetweld No. 7
E = Lincoln Fleetweld No. 5

qualified and an experienced welder. Test plates having the same number and electrode were welded consecutively, i.e., if the operator welded plate 2 using electrode C on a direct-current machine, he would then weld plate 2 using electrode C on an alternating-current machine. The same welding units were used throughout the welding process.

Each weld was made in the flat position. During the welding operation, the two pieces were held in a fixture designed by the Department of Shop Practice for holding test plates and preventing warpage. The weld was begun at the upper edge of the plate and the electrode moved toward the operator. Layer one was laid in the joint, penetrating through the space between the plates to the V on the under side. In order to reduce the possibility of non-metallic inclusions to a minimum, the reverse side was then chipped and thoroughly cleaned by removing a portion of the filler metal. The depth of this removal varied but in general was about equal to the space between the plates. The plate was again fastened in the fixture and layer two was placed in the joint, as shown in Plate I. After chipping and brushing beads one and two, layers three and four were run in. The plate was always allowed to cool in still air to a temperature that was comfortable to the bare hands before chipping and cleaning for the next layer.

Significant witness markings, shown in Plate I, were then correctly positioned on each plate in order to adequately identify every coupon for the subsequent tests. Identifications were always placed on the surface containing welded layer number four. It was felt that by numbering each plate in the same manner, identical test coupons from different plates would have less variance for comparative results.

The test coupons were milled, according to Plate I, with 1/8 by 5-inch slitting saws, properly spaced and mounted on a cutter arbor in a Hendey milling machine. The plates were held in a specially designed fixture which increased the ease and decreased the time necessary for the cutting. A copious supply of water soluble oil was used as a coolant on the saws in order to prolong their life and to avoid undue heating of the work.

Tensile Tests

The tensile tests were made upon 3/8 by 1-1/4 by 10-inch specimens (Fig. 1). The weld bead on both sides of the specimen was machined off with a shaper. The cross-section was reduced at the weld to a width of 7/8 inch by milling out a segment to a depth of 3/16 inch on each side with a 1-inch diameter cutter. This contour was used be-

EXPLANATION OF PLATE I

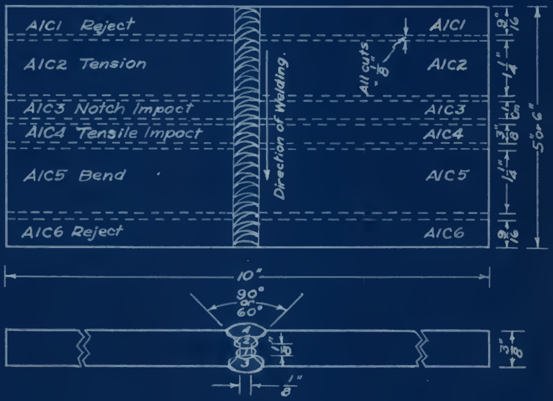
Arc-welded test plate.

A1C1 A = Mach. used. 1 = Plate No. C = Electrode.
1 = Reject.
A1C2 A = Mach. used. 1 = Plate No. C = Electrode.
2 = Static tensile.
A1C3 A = Mach.used. 1 = Plate No. C = Electrode.
3 = Notch impact.
A1C4 A = Mach. used. 1 = Plate No. C = Electrode.
4 = Tensile impact.
A1C5 A = Mach. used. 1 = Plate No. C = Electrode.
5 = Bend.
A1C6 A = Mach. used. 1 = Plate No. C = Electrode.
6 = Reject.

A = Alternating-current welding machine.
D = Direct-current welding machine.

The addition of a third letter (A1C1U) signifies that a 90-degree V and a 5/32-inch welding electrode was used. The absence of the third letter (A1C1) signifies that a 60-degree V and a 1/8-inch electrode was used.

Plate I.


A1C1 Reject
A1C2 Tension
A1C3 Notch Impact
A1C4 Tensile Impact
A1C5 Bend
A1C6 Reject
A1C1
A1C2
A1C3
A1C4
A1C5
A1C6
All cuts 1/8"
Direction of Welding.
9/16"
1 1/4"
1/4"
3/8"
1 1/4"
9/16
5" or 6"
10"
90° or 60°
4
2
1
3
1/8"
3/8"
1/8"

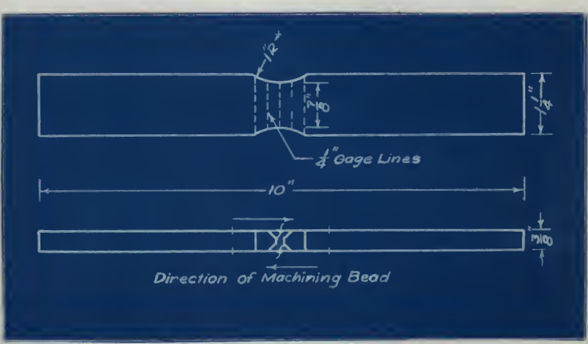


Fig. 1. Tensile test specimen.

cause experience with other tensile specimens had shown that unless the cross sectional area of the weld was greatly reduced, the specimen would break outside the weld and not give a test of the weld metal.

All unit strengths were based upon the thickness of the machined specimen and the minimum width of the reduced section. Measurements were taken with ball micrometers to the nearest thousandth of an inch and the cross-sectional area computed to the nearest ten thousand square inch. This probably did not give the true strength due to the somewhat concentrated stress caused by the abrupt reduced section; however, it was thought by keeping the cross-sectional area constant that uniform comparable results would be obtained. The tests were made on a 50,000-lb. Riehle testing machine and the yield point, ultimate strength, breaking strength, and percentage of elongation were recorded for each specimen.

The gage length used was 1/2 inch. Four gage lines 1/4 inch apart were used on each specimen to insure that the specimen would break within a selected gage length. The final gage length was measured, after fracture, by subtracting the width of the crack from the measured length. It was felt that this correction takes care of certain specimens which could not be properly mated together after breaking.

EXPLANATION OF PLATE II

Fig. 2. Tensile impact test specimen.

Fig. 3. Steps in machining tensile impact specimen.

Plate II

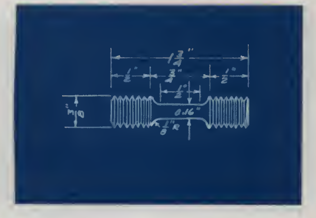


Fig. 2.

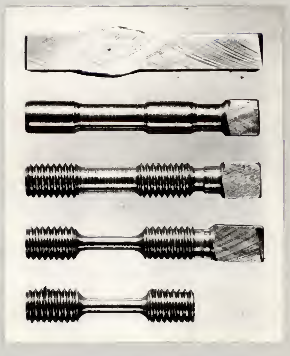


Fig. 3.

Tensile Impact Tests

The tensile impact tests were run on a 120 ft.-lb. Olsen-Izod type of impact testing machine.

The test specimens, shown in Fig. 2, were made by cutting the coupon to 2½ inches in length, then machining to 0.025 inch under size, and reducing the center section below the root of the thread. The next step was cutting the threads by means of a specially designed die holder. The center section was then reduced to 0.175-inch diameter. A 1/8-inch radius tool was then used to round the shoulders and to machine the reduced section to 0.165 inch in diameter. The steps in the machining process are shown in Fig. 3. The final diameter was obtained by polishing to 0.160 inch ± 0.001 inch with emery cloth and metalite-cloth F. The results from this test are considered accurate enough for comparison without making corrections for variations in diameter.

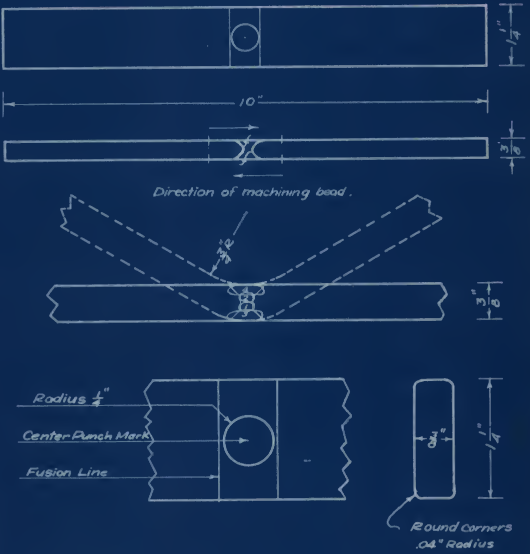
Bend Tests

A measure of the percentage of elongation was obtained by the increase in length over a 1/2-inch diameter circle when a 10 by 1-1/4 by 3/8-inch specimen (Plate III), with the weld across the center, was bent 180 degrees in a

EXPLANATION OF PLATE III

Bend test specimen.

Plate III


1 1/4"
10"
3/8"
Direction of machining bead.
3/4" R
1
2
3
3/8"
Radius 1/4"
Center Punch Mark
Fusion Line
3/8"
1 1/4"
Round Corners
.04" Radius

guided bend tester (Plate IV). The weld bead on both sides of the specimen was machined off and the corners rounded to 0.04-inch radius with a shaper before testing.

The 1/2-inch diameter circle was used as the original gage length. The final gage length was found by flexing a ruler over the outer surface of the bent specimen. The measurement was read, with the aid of a large reading glass, to the nearest 1/128 inch and converted, by the aid of a conversion chart, to the nearest one thousandth inch.

If the specimen fractured within the circle, the width across the fracture was measured and subtracted from the final gage length. This correction took care of certain specimens that checked during the test.

The percentage of elongation was then calculated by the formula: Percentage of elongation =

$$\frac{\text{final gage length} - \text{original gage length} \times 100}{\text{original gage length}}.$$

Notch Impact Tests

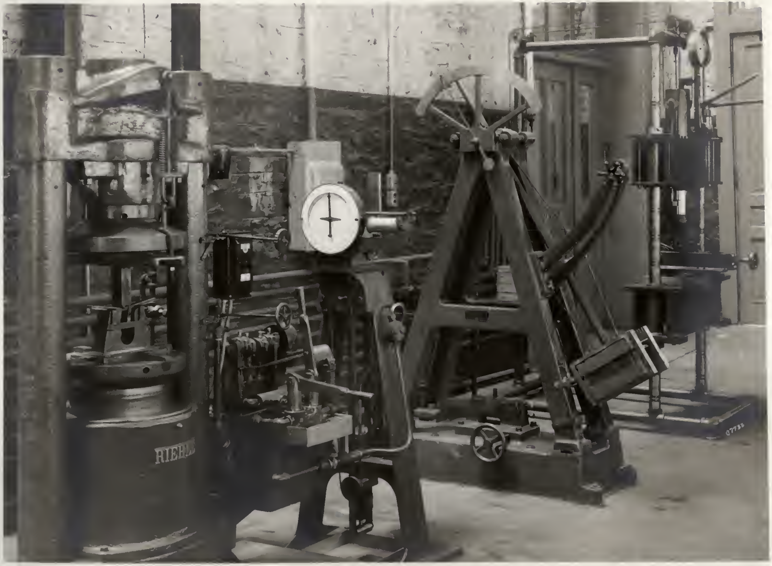
The notch impact tests were run on a 120 ft.-lb. Olsen-Izod type of impact testing machine.

The specimen, Fig. 4, was made by first cutting the coupons to 4-inch lengths with the weld in the center. The specimens were then placed in a jig, Plate VI, and notched

EXPLANATION OF PLATE IV

Guided bend tester.

Plate IV



EXPLANATION OF PLATE V

Fig. 4. Notch impact specimen.

Fig. 5. Notch made with notching apparatus.

Plate V

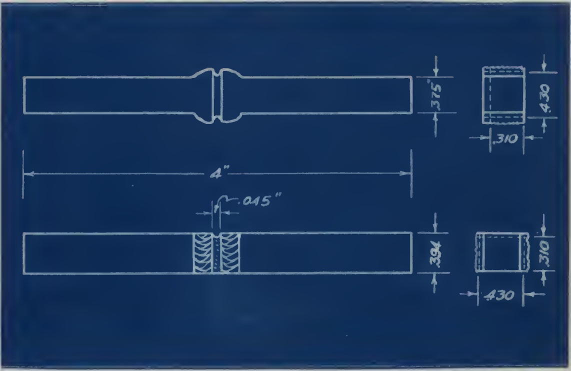


Fig. 4.

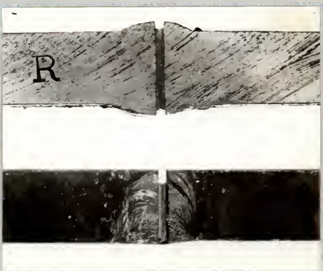
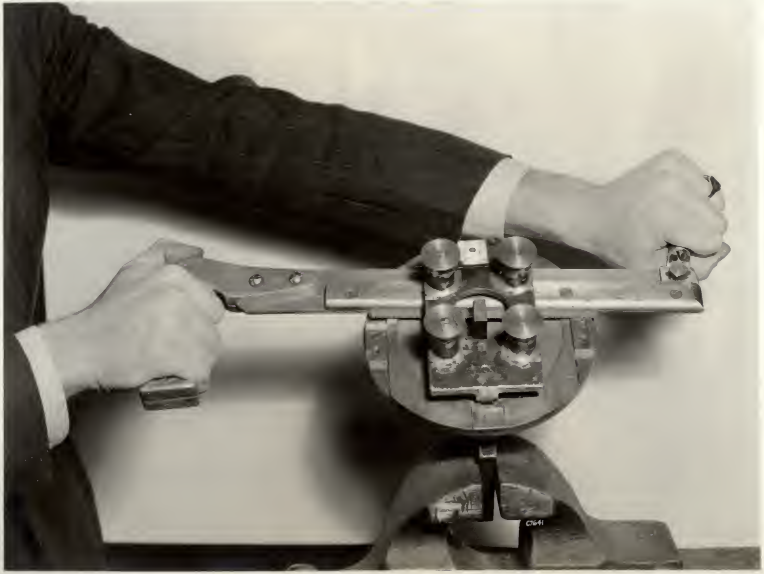


Fig. 5.

EXPLANATION OF PLATE VI

Notching apparatus used for preparing notch impact specimen.

Plate VI



on three sides with a hack saw blade. Two blades were used in making each notch, one for roughing, and the other as a finishing blade. New straight blades were selected and several pieces of mild steel were sawed to eliminate sharp corners and projections on the blades that might cause irregularities in the saw kerf. A stop was fastened to each blade to keep the depth of the notch constant throughout the sawing operation.

The cross-section of each notched specimen was measured with an Ames dial-indicator mounted on a stand, and standardized with Johansen gage-blocks, Plate VII.

The only errors found after the sawing operation were those due to the difference in the width of the coupons and not to the sawing operation. The cross-sectional dimensions were 0.430 inch thick by 0.310 inch wide, (± 0.002 inch).

The notches were studied under the microscope and were found to be somewhat concaved, Fig. 5. This is somewhat different from the square notch sometimes used by others in similar tests.

DATA

Table 2 gives the values of the physical properties for each individual specimen and the average of each series tested.

EXPLANATION OF PLATE VII

Apparatus used for measuring the cross-section of specimen after the notching operation.

Plate VII

Table 2. Physical properties of each plate tested, and the averages of each series.

Specimen Number	Bar No.	Yield Point lb. per sq. in.	Ultimate Strength lb. per sq. in.	Elongation per cent in ½ in.		Impact in ft.-lb.	
				Tensile	Bend	Notch	Tensile
A1C	1	45,550	61,580	26	—(a)	58	10
A2C	1	45,450	62,380	26	17.18	90	17
A3C	1	56,300	62,650	26	15.62	74	18
A4C	2	63,950	83,400	14	18.76	46	13
Av.		52,812	67,502	23	17.19	66	14.5
A1CU	2	59,180	81,400	18	20.32	58	22
A2CU	3	53,750	72,750	17	18.76	53	26
A3CU	3	56,480	75,710	28	20.32	53	22
A4CU	4	55,600	75,650	23	—(b)	44	24
A5CU	4	56,510	74,100	25	20.32	42	—(c)
A6CU	5	59,020	77,810	18	21.88	70	14
A7CU	5	59,000	75,010	18	18.76	47	16
Av.		57,080	76,060	21	20.06	52.5	20.6
A1N	2	57,990	83,820	21	18.76	52	20
A2N	2	56,900	80,600	14	17.18	58	22
Av.		57,445	82,210	17.5	17.97	55	21
A1NU	2	57,460	80,500	22	21.88	66	22
A2NU	3	56,100	74,700	16	18.76	59	8
A3NU	3	54,900	74,400	22	18.76	57	14
A4NU	4	59,420	70,390	8	18.76	66	10
A5NU	4	54,250	74,980	16	17.18	57	10
A6NU	4	59,320	75,000	14	18.76	48	24
A7NU	5	58,780	76,500	20	18.76	47	22
A8NU	5	58,650	75,200	17	18.76	52	24
Av.		57,360	75,384	16.87	18.95	56.5	17

Continued

Table 2. (Cont.)

Specimen Number	Bar No.	Yield Point lb. per sq. in.	Ultimate Strength lb. per sq. in.	Elongation per cent in $\frac{1}{2}$ in.		Impact in ft.-lb.	
				Tensile	Bend	Notch	Tensile
A1W	2	58,800	80,400	8	20.32	58	20
A2W	2	57.100	79,650	18	18.76	44	20
Av.		57,850	80,025	13	19.54	51	20
A1WU	3	57,100	81,800	14	15.62	77	22
A2WU	3	51,750	77,110	19	18.76	50	18
A3WU	3	54,360	67,500	12	18.76	64	18
A4WU	4	56,630	78,900	11	——(e)	56	8
A5WU	4	61,000	81,210	14	18.76	62	26
A6WU	5	57,510	72,100	14	18.76	64	16
A7WU	5	56,290	77,610	16	15.64	47	16
Av.		56,380	76,604	14.29	17.72	60	18
A1GU	2	63,400	90,750	24	14.06	46	21
A2GU	3	55.650	79.120	20	17.18	56	22
A3GU	3	55,250	78,450	18	18.76	58	22
A4GU	4	55,000	79,850	20	15.62	60	22
A5GU	4	58,200	79,400	10	17.18	56	18
A6GU	4	55,410	78,800	15	17.18	48	22
A7GU	5	56,500	78,120	12	17.18	52	——(c)
A8GU	5	59,710	79,180	17	17.18	54	26
Av.		57,390	80,460	17	16.79	54	22
A1T	1	46,820	62,590	26	14.06	90	——(c)
A2T	1	45,650	61,900	49	14.76	62	21
A3T	1	45,050	63,180	15	15.62	62	15
A4T	2	63,910	85,900	15	15.62	41	——(c)
Av.		50,360	68,392	26.25	15.02	64	18

Continued

Table 2. (Cont.)

Specimen Number	Bar No.	Yield Point lb. per sq.in.	Ultimate Strength lb. per sq.in.	Elongation per cent in $\frac{1}{2}$ in.		Impact in ft.-lb.	
				Tensile	Bend	Notch	Tensile
D1C	2	61,100	82,700	18	16.78	70	18
D1CZ	2	58,650	79,200	26.1	20.32	43	16
D2CU	3	57,100	74,000	170	25.00	64	20
D3CU	3	56,800	75,590	26	21.88	48	26
D4CU	4	58,800	75,350	18	23.64	64	20
D5CU	4	58,150	72,510	16	18.76	57	17
D6CU	5	55,350	73,780	15	20.37	68	22
D7CU	5	56,150	70,700	14	20.32	62	22
Av.		57,286	74,600	18.8	20.46	58	20
D1G	1	47,620	67,140	32	15.62	52	16
D2G	1	47,250	64,500	25	14.06	88	16
Av.		47,435	65,820	28.6	14.84	70	16
D1GX	1	45,450	62,300	19	12.50	44	16
D2GZ	2	57,230	83,700	19	20.32	50	20
D3GZ	2	58,610	83,950	23	18.68	24	22
D4GU	4	55,850	77,100	18	17.12	56	30
D5GU	4	58,250	77,410	15	——(b)	48	28
D6GU	4	56,000	76,320	13	16.60	48	16
D7GU	5	56,100	78,410	18	17.18	52	27
D8GU	5	56,910	78,890	19	15.62	44	23
Av.		55,550	77,260	18	17.04	49	23
P1		36,060	51,900	60	23.40	70-71	16-16
P2		44,040	74,220	41	21.88	66-66	38-34
P3		——(f)	67,850	45	21.88	72-74	30-30
P4		55,300	68,610	44	25.00	70-68	30-32
P5		54,760	68,620	46	25.00	76-76	30-31
Av.		47,537	66,240	47.7	21.43	71	29

Continued

Table 2. Concluded

Specimen Number	Bar No.	Yield Point lb. per sq.in.	Ultimate Strength lb.persq.in	Elongation per cent in ½ in.		Impact in ft.-lb.	
				Tensile	Bend	Notch	Tensile
D1W	2	60,900	81,900	14	18.76	38	16
D1WU	3	57,120	77,750	13	2188	51	28
D2WU	3	54,000	73,100	13	1562	34	14
D3WU	3	56,050	76,100	19	1980	48	22
D4WU	4	57,800	76,110	26	1718	24	20
D5WU	4	59,510	78,100	16	1718	33	16
D6WU	5	58,960	77,590	16	1876	55	24
D7WU	5	59,700	79,550	24	1720	21	25
Av.		57,590	76,900	18.1	18.23	36.6	21
D1N	2	60,750	82,920	14	17.18	46	20
D1NU	1-2	44,110	65,100	10		78	16
D2NU	3	55,630	76,590	14	1562	50	26
D3NU	3	53,120	77,090	18	1562	44	30
D4NU	3	57,630	75,390	12	2032	38	27
D5NU	3-4	59,900	76,220	20	1718	43	12
D6NU	5	64,520	81,100	20	1874	32	12
D7NU	5	61,040	73,300	16	1876	54	16
D8NU	5	56,510	77,140	27	2188	22	20
Av.		56,555	75,241	18.14	1830	45	20
D1E	1	52,950	77,680	18	1868	58	22
D2E	1	45,560	62,890	32	1718	80	18
Av.		49,255	70,285	25	17.93	69	20
D1EZ		61,350	79,750	22	2032	57	14
D3EU		56,670	80,100	24	2032	53	17
Av.		59,010	79,225	23	2032	55	16

(a) Bent out of weld.
(b) Broke in fusion line.
(c) Ruined machining.

(e) Broke (slag).
(f) Not detected.

Table 3 gives a comparison of the average physical properties of joints made from bars 3, 4, and 5. Data for making a comparison of the welding machines and electrodes are also included.

Table 4 gives the average value of each series welded from bars 3, 4, and 5. These data were used in plotting the graphs shown in Figures 9, 10, 11, 12, 13, and 14.

DISCUSSION OF DATA

Parent Metal

Considerable variation in the physical properties of the welded plates was found after the tests were performed. Microscopic and physical property studies were made of the different bars in an attempt to find the cause of this variation.

The metal in bar 1, Fig. 6, was found to have large grain structure, traces of impurities, and to be of low carbon content. The physical properties were found to be below those of the other plates for yield point, ultimate tensile strength, and tensile impact values. The bend per cent elongation and the notch impact values were about equal to the other bars, while the tensile per cent elongation was about one-third higher. The welds made from this

EXPLANATION OF PLATE VIII

Fig. 6. Parent metal taken from bar 1. Magnification 150 diameters.

Fig. 7. Parent metal taken from bar 2. Magnification 150 diameters.

Fig. 8. Parent metal taken as a representative sample of bars 3, 4, and 5. Magnification 150 diameters.

Plate VIII

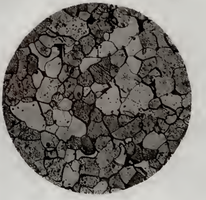


Fig. 6.

Fig. 7.

Fig. 8.

Table 3. Comparison of average physical properties of bars 3, 4 and 5.

Properties Compared	From Highest to Lowest Values RANK NUMBER 1	 2	 3	 4
	ELECTRODES			
Tensile Strength lb. per sq. in.	G AC 78,990 (7)* DC 77,630 (5) Av. 78,310	W DC 76,900 (7) AC 76,600 (7) Av. 76,750	N DC 76,690 (7) AC 75,170 (7) Av. 75,930	C AC 75,170 (6) DC 73,660 (6) Av. 74,420
Yield Point lb. per sq. in.	N DC 58,330 (7) AC 57,350 (7) Av. 57,840	W DC 57,590 (7) AC 56,380 (7) Av. 56,990	C DC 57,060 (6) AC 56,730 (6) Av. 56,900	G DC 56,620 (5) AC 56,530 (6) Av. 56,580
Elongation per cent in ½ in.	C AC 21.5 (6) DC 17.7 (6) Av. 19.6	N DC 18.1 (7) AC 17.5 (6) Av. 17.8	G DC 16.6 (5) AC 16.0 (6) Av. 16.3	W DC 18.1 (7) AC 14.3 (7) Av. 16.2
	WELDING MACHINES			
Tensile Strength lb. per sq. in.	AC. 76,280 (27)	DC 76,220 (25)		
Yield Point lb. per sq. in.	DC. 57,400 (25)	AC 56,750 (27)		
Elongation per cent in ½ in.	DC 17.6 (25)	AC 17.3 (26)	* Shows no. tested. Continued	

Table 3. (Cont.)

	PARENT METAL		
Tensile Strength lb. per sq. in.	Bar 5 68,620 (1)	Bar 4 68,610 (1)	Bar 3 67,900 (1)
Yield Point lb. per sq. in.	Bar 4 55,300 (1)	Bar 5 54,750 (1)	Bar 3 Not detected.
Elongation per cent in $\frac{1}{2}$ in.	Bar 5 (1) 46.0	Bar 3 45.0 (1)	Bar 4 44.0 (1)
	WELDED PLATES		
Tensile Strength lb. per sq. in.	Bar 5 (17) AC 76,720 (9) DC 76,440 (8) Av. 76,580	Bar 4 (17) AC 76,830 (10) DC 76,130 (7) Av. 76,480	Bar 3 (17) AC 75,870 (9) DC 75,760 (8) Av. 75,870
Yield Point lb. per sq. in.	Bar 5 (17) DC 58,360 (9) AC 58,190 (8) Av. 58,280	Bar 4 (17) DC 57,770 (10) AC 57,140 (7) Av. 57,460	Bar 3 (17) DC 56,380 (8) AC 55,040 (9) Av. 55,210
Elongation per cent in $\frac{1}{2}$ in.	Bar 3 (17) AC 18.4 (9) DC 17.0 (8) Av. 17.7	Bar 5 (17) DC 18.8 (9) AC 16.5 (8) Av 17.6	Bar 4 (16) DC 17.4 (7) AC 15.6 (9) Av. 16.5
			Continued

Table 3. (Cont.)

Tensile Impact in ft.-lb.	ELECTRODES			
	G DC 24.8 (5) AC 22.0 (6) Av. 23.4	C DC 21.0 (6) AC 21.0 (5) Av. 21.0	W DC 21.3 (7) AC 19.3 (6) Av. 20.3	N DC 20.0 (7) AC 18.6 (6) Av. 18.6
	WELDING MACHINES			
	DC 21.8 (25)	AC 19.9 (23)		
	PARENT METAL			
	Bar 4 31.0 (2)	Bar 5 30.5 (2)	Bar 3 30.0 (2)	
	WELDED PLATES			
	Bar 3 DC 22.7 (8) AC 19.0 (8) Av. 20.8	Bar 5 DC 22.0 (9) AC 16.8 (7) Av. 19.4	Bar 4 DC 21.0 (7) AC 16.4 (8) Av. 18.7	
Bend Elongation per cent in ½ in.	ELECTRODES			
	C DC 21.7 (6) AC 20.0 (5) Av. 20.8	N AC 18.5 (7) DC 18.3 (7) Av. 18.4	W DC 18.2 (7) AC 17.7 (6) Av. 18.0	G AC 17.6 (7) DC 16.6 (4) Av. 16.9
	WELDED MACHINES			
	DC 18.7 (24)	AC 18.3 (25)		
	PARENT METAL			
	Bars 4 & 5 25.0 (1)	Bar 3 22.0 (1)	Continued	

Table 3. (Concluded)

Bend Elongation per cent in ½ in.	WELDED PLATES			
	Bar 3 DC 19.2 (8) AC 19.1 (9) 19.1	Bar 5 DC 18.8 (9) AC 18.4 (8) 18.6	Bar 4 DC 18.4 (7) AC 18.0 (8) 18.2	
Notch Impact in ft-lb.	ELECTRODES			
	C DC 61.0 (6) AC 52.0 (6) Av. 57.0	G AC 55.0 (7) DC 50.0 (5) Av. 53.0	W AC 60.0 (7) DC 38.0 (7) Av. 49.0	N AC 55.0 (7) DC 40.0 (7) Av. 48.0
	WELDING MACHINES			
	DC 56.0 (25)	AC 47.0 (27)		
	PARENT METAL			
	Bar 5 76.0 (2)	Bar 3 73.0 (2)	Bar 4 69.0 (2)	
	WELDED PLATES			
	Bar 3 AC 59.0 (9) DC 47.0 (8) Av. 53.0	Bar 4 AC 54.0 (10) DC 47.0 (8) Av. 51.0	Bar 5 AC 54.0 (8) DC 46.0 (9) Av. 50.0	

bar averaged about 65,000 pounds per square inch in tensile strength.

The metal in bar 2 (Fig. 7) was found to have a much smaller grain structure, free from impurities, and to contain enough carbon to place it high in the mild steel range. The tensile strength of this bar was over 74,000 pounds per square inch, which was well above that of the other bars. The average tensile strength of all the welded plates made from this bar was slightly over 82,000 pounds per square inch.

Figure 8 shows a sample chosen to represent the microstructure of bars 3, 4, and 5. The grain size and carbon content is typical of that found in steel of this carbon range. The tensile strength of the three bars varied less than 1000 pounds per square inch. The average tensile strength for all plates tested from each bar also varied less than 1000 pounds per square inch.

After a study was made of the test data and the metallographic comparison of the different bars of parent metal considered, it was decided to disregard discussions and comparisons of the data taken from bars 1 and 2.

Tensile Test

The specimens, with the exception of those taken from bar 1, broke in the weld due to the greatly reduced welded section. In most cases the fracture occurred abruptly and straight across the joint. However, in a few instances the edges of the fracture were jagged and could not be fitted together for measuring the final gage length. In order to give more uniform results, the width of the check was subtracted from the final measured gage length. Since the tensile specimens were greatly reduced in the region of the weld, it was assumed that the drop of the beam of the testing machine indicated the yield point of the weld metal rather than the yield point of the parent metal.

The breaking strength was recorded for all specimens but was found to be of little or no value in this problem. In several instances the break occurred as the ultimate strength was reached, or so quickly after that it was practically impossible to balance the machine before the break.

Forty-nine specimens were examined under a low-power binocular microscope and all were found to contain traces of slag. In this examination 46 were found to have slag at the junction of the first and second and 21 between the second and third layers of the weld. Slag was found in the number three layer of 24 and in the fourth layer in nine specimens, while four contained slag in all layers. The examination revealed the test pieces to be free from voids and gas inclusions and in only a very few instances was it considered that the non-metallic inclusions made any noticeable difference in the results obtained from the test.

In a comparison of the electrodes, the average of all plates welded, G was slightly higher in tensile strength, C for average per cent elongation. with N ranking first in yield point. Ranks and values for the different welding machines and electrodes are found in Table 3.

In comparing the different welding machines, Table 3, the a-c was slightly higher in tensile strength and lower in yield point and per cent elongation than the d-c machine.

Tests were made on the different parent metals with bar 5 ranking highest in tensile strength and per cent elongation while bar 4 was highest in yield point. In an average of all the plates made from each bar, the bars retained the same rank in tensile strength that they had before welding. The changes in the yield point and per cent elongation in rankings and values are shown in Table 3. The d-c welding machine in this series of averages outranked the a-c in tensile strength and yield point. but was only 1.4 per cent lower in per cent elongation than the a-c.

While the tensile test is rapidly going out of usage in the testing of welded joints, it is still used as a basis of comparison for other tests, and it is for that purpose that it was used in this research. However, after studying this group of specimens it was concluded that there is a possibility of its use to detect non-metallic inclusions that otherwise might not be found by other methods of destructive testing.

Tensile Impact Test

The tensile impact test gives primarily a measure of the ability of the welded joint to withstand sudden application of loadings in tension.

The test specimen used was a standard size Izod specimen 0.160 inch in diameter. It was realized that this diameter is quite small to represent a welded section made on 3/8-inch plate because the slightest defect will greatly weaken a specimen of this size. Nevertheless, most of the joints proved to be free from the common defects found in welded joints and the results obtained were considered satisfactory for comparative purposes.

In this series of tests, electrode G ranked highest with electrodes C, W, and N ranking as shown in Table 3. The d-c welds had higher values for each electrode and a higher total average for all plates welded.

In the parent metal test, Table 3, bar 4 ranked first and bar 5 ranked slightly higher than bar 3. The averages of all the plates welded from each bar changed their rankings, giving bar 3 first, bar 5 second, and bar 4 last. The d-c welds tested highest for all three bars.

From the 50 specimens tested, 15 broke outside the weld for an average value of 24 foot-pounds. Five out of the 35 were found to have slag inclusions and averaged 12.5 foot-pounds. Fifteen had no showing of slag for an average of 19 foot-pounds, while the remaining 15 broke through the fusion line and had a 20 foot-pound average. The tensile impact fractures showed no appreciable difference between the welding machines in the manner in which the specimens failed.

This is one of the newer tests for welded joints and considerable work is now being done in the Department of Shop Practice with larger specimens. It was decided that a larger cross-section would give a more representative test of a welded joint made on 3/8-inch plates.

Bend Test

According to Henry and Claussen (8), the primary purpose of the bend test for welded joints is to determine ductility, that is, to determine whether or not the weld cracks during bending. They also state that cracks may originate at inclusions, improperly fused areas, or porosity, or may arise from an inherent lack of capacity for deformation.

In this series of determinations the guided-bend test was used. Henry and Claussen (8) believe this type of bend test has advantages over the free-bend as it more nearly assures that the specimen will bend in the weld and that all specimens will have the same angle when bent. Ordinarily the cracks will appear in tension and when a crack exceeding 1/8 inch on either side appears, the specimen is considered to have failed.

In the tests performed in this research little difficulty was encountered from the use of this type of bend test, all specimens bent through the weld.

Electrode C was found to have the highest average of per cent elongation, with electrodes N, W, and G ranking as shown in Table 3.

The d-c machine had a slightly higher average for all plates welded than the a-c, Table 3.

A specimen was taken from each bar of parent metal, prepared, and tested in the same manner as the weld specimens. Bars 4 and 5 each had a percentage of elongation of 25 per cent while the value of bar 3 was 22 per cent.

The average of welds made from each bar gave bar 3 the highest value with bar 5 second and bar 4 last. The d-c welds had a slightly higher average for each bar.

Only three specimens failed to make the complete bend, one d-c weld and two a-c. One a-c weld failed through the center of the weld and was found to have a large amount of slag running through the center of the joint. The other two failed in the fusion line due to improper fusion between the weld metal and the parent metal.

Eight d-c and two a-c welds were found to have cracks in the tension surface after completing the bend. These cracks occurred in the fusion line and with the exception of one, were greater than one-eighth inch in length, so the welds would be disqualified in practice. However, the width of the crack was subtracted from the final gage length and the percentage of elongation computed and was included with the other specimens for the final average of each series with apparently satisfactory results.

The same gage length, one-half inch, was used for finding the percentage of elongation in the tensile and bend tests. The average for all tests made shows the percentage of elongation, as found in the bend tests, to be 18.5 per cent, while the average for the tensile tests was 17.5 per cent. This was found to be true for both a-c and d-c welds and for all electrodes with the exception of the a-c series using electrode C where the tensile percentage of elongation was 1.5 per cent higher than the bend elongation.

The bend test is used in preference to the tensile test by some in qualifying operators and welding processes, because it is felt that if a specimen passes the bend test it has sufficient ductility for practical usage.

Notch Impact Test

Notch impacting testing as applied to welded joints is one of the more recent tests. This test does not measure the resistance of the weld to sudden application of force, but it does measure the ability of the material to distribute highly concentrated stress at a given point. If the welded joint will distribute stress well, the impact value is high (22).

Several different sizes of specimens and different types of notches were found to be used in this test. At the present time some attempt is being made to standardize the procedure, but so far no agreement seems possible.

A study was made of the different types of test specimens and their comparative results. The Republic Steel Corporation (22) has made a study of different notches used in impact testing and has found the larger size radius notch to give higher values and the wide square notch to give equal values to the standard Izod notch. As a result of this study the test specimen and the method of preparing the test pieces used in this research were developed.

The notch used in this research was a combination of the square and radius notch as shown in Fig. 5 in the discussion of test methods. The apparatus for preparing the specimen was developed and made by the staff members of the Department of Shop Practice.

The type of specimen used in this research proved to be very satisfactory as was shown by the results obtained from the tests. It was easily and rapidly prepared and not only gives an impact value but breaks the test piece across the weld for visual inspection thus eliminating the need of a nick-break test where values are not obtained.

The average results as shown in Table 3, rank electrode C highest, with electrode G second, W third, and N fourth. The a-c welds have higher values for all the electrodes, with the exception of electrode C where the d-c was higher. In the average of all plates welded the a-c welding machine had higher values than the d-c.

In the parent metal test, bar 5 had the highest average value with bar 3 ranking second, and bar 4 third. The average for the welded joints made from each bar was lower than the corresponding parent metal average and it gave the bars a different ranking. Bar 3 ranked first, bar 4 second, and bar 5 third, with the a-c welds ranking higher than the d-c for each bar.

A visual inspection was made of each joint after fracture. Five out of the 52 tested contained voids or gas pockets and averaged 46 foot-pounds. Ten were found to contain slag and averaged 54 foot-pounds, while 37 were found to have no visual defects and averaged 51 foot-pounds. This seems to show that specimens having voids or gas pockets give lower impact values than those free from defects.

Comparison of Physical Tests

In some instances an attempt has been made to draw a line of "best fit" to show a correlation between the tests shown on each graph. The reader may not wholly agree with the drawing of this line; nevertheless, it was felt the general direction of all lines that might be drawn would have the same trend.

Averages for each series made with the d-c welding machine are plotted as small circles and those made with the a-c machine are plotted as x's. The series made with each electrode is designated by a letter given each electrode as shown in Table 1 in the discussion of experimental procedure.

Figure 9 disclosed a definite relation between tensile and bend per cent elongation. The trend of the line reveals that as the bend elongation increased the tensile elongation also increased in about the same proportion, with the a-c series falling nearer the line than the d-c.

In Fig. 10 in the relation between notch and tensile impact there seemed to be a slight trend of the line which might show that as the tensile impact increased the notch impact decreased. The spread of the data shows that for a great variation in notch impact values only a slight variation in tensile impact can be expected. There seemed to be but little difference in the way the series from each machine fell in regard to nearness to the line. However, electrodes C and W fell nearer the line for both a-c and d-c welds than any of the other electrodes.

There appeared to be but little relation between bend elongation and tensile impact; however, as the line was drawn in, Fig. 11, it followed a trend showing that as the bend elongation increased the tensile impact values decreased. The spread of points displays no advantage for either welding machine, while electrodes W and N for each machine fell nearest the line.

In the relation between bend elongation and notch impact manifested in the same figure, there appeared a more definite trend showing that as the bend elongation increased, the notch impact values likewise increased. The spread reveals both welding machines about equal with elec-

Table 4. Average data used in plotting graphs.

Specimen Number	No. Spec. Tested	Yield Point lb. per sq.in.	Ultimate Strength lb. per sq.in.	Elongation per cent in ½ in.		Impact in ft.-lb.	
				Tensile	Bend	Notch	Tensile
AWU	7	56,380	76,600	14.3	17.7	60.0	19.3
ACU	6	56,730	75,170	21.5	20.0	52.0	21.0
AGU	7	56,530	78,990	16.0	17.2	55.0	22.0
ANU	7	57,350	74,370	17.5	18.5	55.0	17.3
Av.		56,750	76,280	17.3	18.35	55.5	19.9
DWU	7	57,590	76,900	18.1	18.2	38.0	21.3
DCU	6	57,060	73,660	17.7	17.0	60.5	21.0
DGU	5	56,620	77,630	16.6	16.6	50.0	24.8
DNU	7	58,330	76,690	18.1	18.3	40.0	20.0
Av.		57,400	76,220	17.6	18.7	47.0	21.8

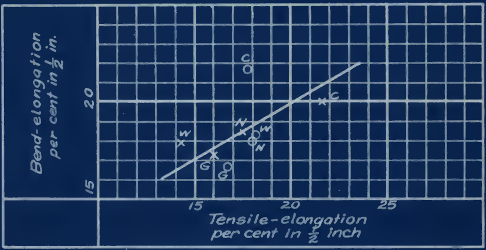


Fig.9 Relation between bend-elongation and tensile-elongation.

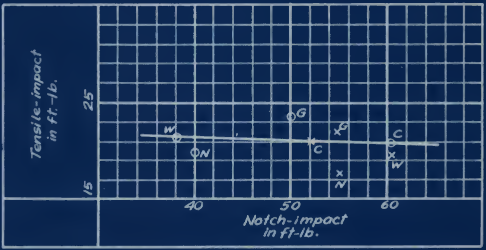


Fig.10. Relation between notch-impact and tensile-impact.

trode N falling nearest the line for both machines.

In the relation between tensile elongation and tensile and notch impact, Fig. 12, no attempt was made to draw a line. However, the points show that the variation in tensile elongation had but little effect on the notch impact values, and that those of the d-c machine were affected more with the variation in tensile elongation than the tensile impact and tend to decrease as the elongation increased. The d-c welds have a greater spread than the a-c and electrode N falls nearest the line for both machines.

A trend toward a definite relationship between ultimate tensile strength and tensile and bend elongation was found in Fig. 13. In both instances as the ultimate strength increases, the elongation values decrease. The bend elongation values were nearer a straight line than the tensile elongation and the d-c welds fell nearest the lines in both instances. Electrode G was nearer the line for both a-c and d-c welds in tensile elongation and electrode C fell on the line in the bend elongation.

The increase in ultimate tensile strength appeared to have but little effect on the tensile impact values, but seemed to affect the notch impact values to a great extent (Fig. 14). No attempt was made to draw a line showing the relation between the tensile strength and the tensile impact

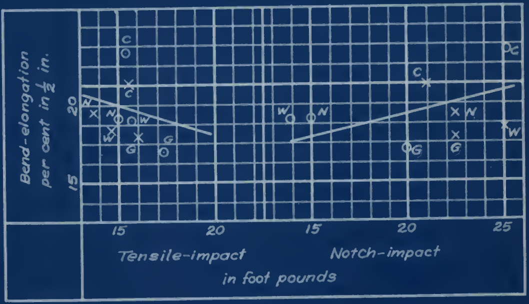


Fig 11. Relation between bend-elongation and tensile and notch-impact.

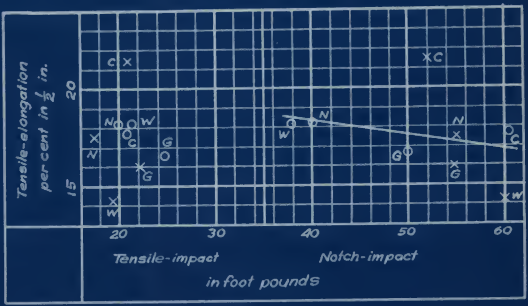


Fig.12. Relation between tensile-elongation and tensile and notch-impact.

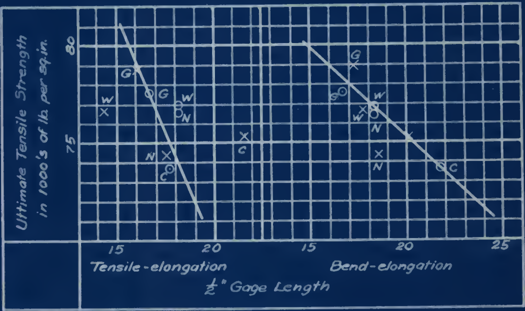


Fig.13. Relation between tensile strength and tensile and bend-elongation.

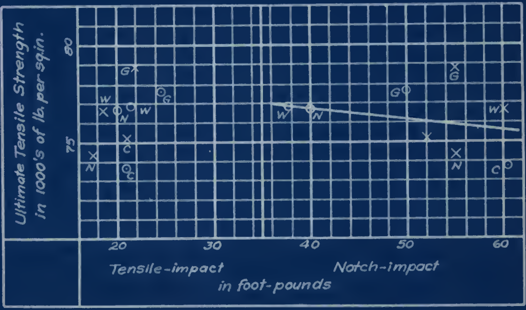


Fig.14. Relation between tensile strength and tensile and notch-impact.

values. The spread of the points for each welding machine appeared about equal. The line drawn in relation to the notch impact values had a trend revealing that as the tensile strength increases the notch impact values decrease. The a-c welds had less spread than the d-c for impact values and were farther away from the line. Electrodes W and N had a slight advantage over the other electrodes in nearness to the line for both machines.

Metallographic Comparison

The photomicrographs of the joints, Figures 15 and 20, are selected as samples representative of the joints found in this research. These joints are identical in respect to welding procedure, operator, size of V, size and make of electrode, and parent metal. The only variable was the welding machines. The joint in Fig. 15 was welded with a d-c machine, and the joint in Fig. 20 with an a-c machine.

In the microscopic study of the a-c and d-c joints, no appreciable difference was found in the structure in similar sections of the welds. The grain sizes are practically the same with the exception of that found at the center of the weld. The size grains found in the d-c joint (Fig. 18) seem to be smaller than those found in the a-c joint (Fig. 24).

EXPLANATION OF PLATE IX

Fig. 15. Photomicrograph of d-c welded joint. Magnification 4 diameters.

Fig. 16. Junction of parent metal and heat affected zone. Larger grains of parent metal merging into finer grain of heat affected zone. Magnification 150 diameters.

Fig. 17. Fusion line showing smaller grain of parent metal and a coarser structure, due to the effect of the welding heat near the filler metal. Magnification 150 diameters.

Fig. 18. Fine grain at center of weld metal. The heats from layers three and four have raised the temperature of this section above the critical range refining the grain. Magnification 150 diameters.

Fig. 19. Typical columar grains which grow at right angles from the scarfed surface of the plate metal into the weld metal of all non-heat treated welded joints. Magnification 150 diameters.

Plate IX

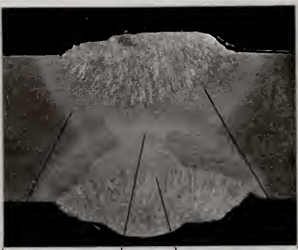


Fig. 15.

Fig. 16.

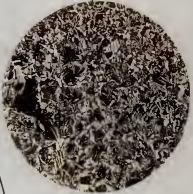


Fig. 17.

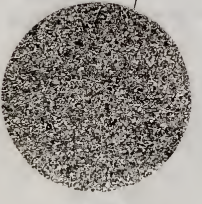


Fig. 18.

Fig. 19.

EXPLANATION OF PLATE X

Fig. 20. Photomicrograph of a-c welded joint. Magnification 4 diameters.

Fig. 21. Parent metal used in making welded joints shown in Fig. 20 and Fig. 15. Magnification 150 diameters.

Fig. 22. Large size grains typical of structure found between the columar, Fig. 19, and the smaller grain structure, Fig. 17. Magnification 150 diameters.

Fig. 23. Smaller grain than the columar structure, Fig. 19, probably due to faster cooling, being nearer the surface. Magnification 150 diameters.

Fig. 24. Grain size in center of joint. Magnification 150 diameters.

Plate X

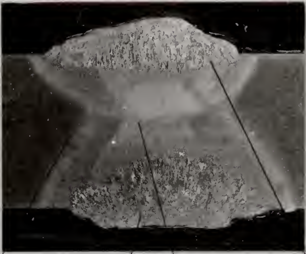


Fig. 20.

Fig. 21.

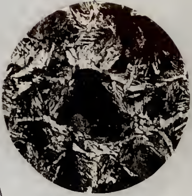


Fig. 22.

Fig. 23.

Fig. 24.

No attempt was made to explain these findings as the writer felt that a greater number of tests should be studied before a definite conclusion could be reached.

SUMMARY

The results of the tests recorded in the previous pages may be summarized as follows:

1. No appreciable difference between the a-c and d-c welds was apparent in such physical properties as tensile strength, tensile and bend per cent elongation.

2. Alternating-current welds were slightly higher in yield point and notch-impact values.

3. Direct-current welds had higher averages for tensile impact.

4. Electrode G was found to have the highest averages when used with both welding machines for tensile and tensile-impact strength, and lowest averages for bend elongation and yield point.

5. As the tensile strength increased, the ductility, as measured by tensile and bend per cent elongation, decreased.

6. As the tensile strength decreased, the notch-impact strength increased.

7. With an increase in bend elongation and notch-

impact, a decrease in tensile-impact values was apparent.

8. Increased tensile per cent elongation resulted in a decrease of notch-impact strength.

9. Tensile-impact strength was not noticeably affected by the change in tensile strength or tensile per cent elongation and only slightly affected by variations in notch-impact strength.

10. As the tensile per cent elongation increased, the bend per cent elongation increased.

11. The parent metal showed lower values for yield point and ultimate tensile strength and higher values for bend elongation, tensile elongation, notch and tensile-impact than the welded metal.

12. The average ductility as measured from the bend elongation was slightly higher than that measured from the elongation of the tensile test.

13. Electrodes W and N had a slightly higher average, with the exception of the notch-impact test when used on the d-c welding machine.

14. It is quite desirable to have certified parent metal or metal of approximately equal physical properties before uniform results can be obtained in weld testing.

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REFERENCES

(1) Boehm, Robert C.
Physical and metallographical investigation of low-carbon low-alloy welded steel. Amer. Welding Soc., Jour. 17:34-36. Sept. 1938.

(2) Conley, William J.
A quick shop test for quality of weld and its correlation with the standard tests. Amer. Welding Soc., Jour. 17:31-34. Oct. 1938.

(3) Davies, H. E.
Jigs and fixtures for welding. Amer. Welding Soc., Jour. 17:16-19. Apr. 1938.

(4) Emerson, R. W.
Weldability of medium carbon steel. Amer. Welding Soc., Jour. 17:7-17. Oct. 1938.

(5) French specifications for qualifying welders. Amer. Welding Soc., Jour. 18:86-87. Feb. 1939.

(6) Gipson, J. F.
Visual inspection of welds. Amer. Welding Soc., Jour. 17:21-22. Mar. 1938.

(7) Grandinetti, John R.
An investigation of the tensile and torsional strength of weld-metal and welded joints. Amer. Welding Soc., Jour. Supplement. 17:27-29. Aug. 1938.

(8) Henry, O. H. and Claussen, G. E.
Testing the physical properties of welds. Amer. Welding Soc., Jour. 18:288-294. May, 1939.

(9) Henry, O. H.
Relation of low temperature on the tensile impact resistance of iron, steel and welded joints. Amer. Welding Soc., Jour. Supplement. 15:2-8. Oct. 1936.

(10) Henry, O. H.
Impact tests of welds. Amer. Welding Soc., Jour. 17:9-12. Feb. 1938.

(11) Henry, O. H.
The metallography of welds. Amer. Welding Soc., Jour. 17:8-14. Apr. 1938.

(12) Henry, O. H.
Tensile impact tests on welds at low temperatures. Amer. Welding Soc., Jour. 17:23-27. Aug. 1938.

(13) Hodge, J. C. and Sadler, C. R.
Weldability and properties of materials for casing strings. Amer. Welding Soc., Jour. 17:26-27. May, 1938.

(14) Lohman, Welhelm.
Progress in welding during the last six months of 1937. Amer. Welding Soc., Jour. Supplement. 17:9-13. June, 1938.

(15) Matting, A. and Klein, H.
Types of specimens for tension and bend test on light metal welds. Amer. Welding Soc., Jour. Supplement. 17:42-44. Nov. 1938.

(16) Newby, Howard L.
Field practice in welding oil well casing. Amer. Welding Soc., Jour. 17:17-19. Sept. 1938.

(17) Petrenko, S. N.
Comparative slow bend and impact notched bar tests of some materials. Dept. of Comm. Tech. papers of the Bur. of Standards. 19(289):318-346. June 27, 1925.

(18) Procedure Handbook of Arc Welding Design and Practice. ed. 4. Cleveland. Lincoln Electric Co. 819 p. c. 1936.

(19) Qualifying operators for important work. Amer. Welding Soc., Jour. 16:30-32. Aug. 1937.

(20) Qualification tests for arc welding operators. Kans. State Highway Comm. 7 p. Oct. 28, 1936. (Blue Print).

(21) Republic Alloy Steels. Cleveland. Republic Steel Corporation. 255 p. c. 1938.

(22) Ronay, Bela.
Some navy testing practices. ...In Welding Handbook, 1938. New York. Amer. Welding Soc. 1211 p. 1938.

(23) Sandelin, R. W.
Metallurgical aspects of a particular type of defect in welded material. Amer. Welding Soc., Jour. 17:29-30. Aug. 1938.

(24) Sandelin, R. W.
The simple steel analysis and its relation to quality in steel. Amer. Welding Soc., Jour. 17:9-14. Sept. 1938.

(25) Sparagen, W. and Claussen, G. E.
Impact tests of welded joints-II, a review of the literature from Jan. 1, 1936 to Jan. 1, 1938. Amer. Welding Soc., Jour. Supplement. 17:8-27. Sept. 1938.

(26) Sparagen, W. and Claussen, G. E.
Impact tests of welded joints. Amer. Welding Soc., Jour. 15:2-11. Apr. 1936.

(27) Specifications for design, construction, alternation and repair of highway and railway bridges by fusion welding. New York. Amer. Welding Soc. 66 p. 1936.

(28) Standard qualification procedure. ...In Welding Handbook, 1938. New York. Amer. Welding Soc. 1211 p. 1938.

(29) Symposium on impact testing. Forty-first annual meeting of the Amer. Soc. for Testing Materials. Atlantic City, N.J. June 28, 1938. Philadelphia. Amer. Soc. for Testing Materials, Proc. 38(pt. II):1-177. 1938.

(30) Tentative specifications for iron and steel filler metal. Amer. Welding Soc., Jour. 16:21-26. Aug. 1937.

(31) Tentative rules for the qualification of welding processes and testing of welding operators. Amer. Welding Soc., Jour. 15:2-12. Oct. 1936.

(32) Tentative rules for fusion welding steam, oil, or air piping in marine construction. Amer. Welding Soc., Jour. 17:38-41. Apr. 1938.

(33) Tentative specifications for iron and steel filler metal. ...In Welding Handbook, 1938. New York. Amer. Welding Soc. 1211 p. 1938.

(34) The testing and qualifications of welding operators. New York. Linde Air Products. 23 p. 1935.

(35) Wilson, James W.
Results achieved by qualification tests of marine welding operators. Amer. Welding Soc., Jour. 17:16-18. Nov. 1938.