COMPARISON OF ALTERNATING-CURRENT AND DIRECT-CURRENT METALLIC ARC-WELDED JOINTS

by

LEO ALBERT MOORE

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INTRODUCTION

Metals have long been joined together by riveting, soldering, and welding according to Fassler (5) who stated that the natives of India, two thousand years B.C., were able to melt, forge and weld iron. Little improvement was made in these methods until the nineteenth century. That it was possible to melt metals by means of the electric current was demonstrated in 1865 by Wild's English Patent No. 1412. Bernardo, in 1880, performed the first electric arc weld by means of a carbon arc. (Fassler, 5).

Elihu Thompson, contemporary of the late Thomas A. Edison, is given credit for the most important revolution in regard to welding. In the year 1886, he demonstrated that practically all of the metals could be welded by means of his electrical resistance method.

In metallic arc welding a supply of electrical current sufficient in amount of the right voltage, and arranged to keep the arc stable, is necessary according to Hubert (17). This author further states that voltage across the metal arc should be from 15 to 26 volts with ordinary bare and coated electrodes, and up to 45 volts with some special electrodes. The usual range of current is from 50 to 500 amperes for hand welding. The heat of the arc melts a small pool of metal on the work piece which is to be welded or built up. Any additional metal required is obtained from a metal wire rod or electrode, which is melted by heat of the arc and deposited in the pool in a molten state. When the heat of the arc melts a small pool in the work piece, it melts the tip of the electrode at the same time. A small portion of this molten tip is then carried across the arc and deposited in the pool. There it fuses with the base metal.

Two types of metallic arc-welding machine are in general use at the present time, classified according to the characteristics of the electrical current used to produce the arc, namely, alternating-current and direct-current welders. The alternating type can be further divided into the generator type and the transformer type.

In all types it is usually necessary to have some kind of current control in order to secure the proper current for the electrode used and the material to be welded.

Direct-current welding gained popularity before alternating-current, due to the fact that direct-current was the standard current used until quite recently. It may be recalled that here at Kansas State College the change over from d-c to a-c was made only a few years ago.

About 1904 the first a-c arc welder was built for use with covered electrodes. Thousands of these machines were used in shipbuilding during the World War.

Nearly all the arc welder manufacturers build both a-c and d-c machines at the present time. Many authorities believe that the a-c machines produce the best welds, while others claim that d-c welders give the best results.

Holslag (9) stated that it is now generally accepted that the combination of a-c welding, heavy current, and covered electrodes is best for good work, and that the Writ-Jones tests made in 1918 in which all test pieces broke outside the weld in 60,000-lb. boiler plate, still stands unassailed as good a job as has ever been done with arc welding. These were done with a-c.

Notvest (22) found that over 98 percent of commercial arc welding is done with d-c. The experiences of a pressure vessel manufacturer, according to Tilton (34), were that a-c automatic gave somewhat greater welding speeds than did d-c; and fewer defects to be chipped out; that hand welding, except with low current values, operators liked the a-c arc to handle. These same men were originally trained on d-c and without exception expressed preference for a-c because of the ease with which it could be handled.

From the preceding statements, it can be seen that the relative quality of welds produced with a-c and d-c machines is generally debatable. Due to the fact that the merits of these two types of welders are questioned, this program of research was attempted. The purpose of the investigation was to obtain indications of the qualities of welds made on each type of arc-welding machines and to compare the results.

TEST METHODS

Materials and Test Plates

The stock used in making the comparative tests consisted of ordinary hot rolled mild steel bars, 1/2 inch thick, 5 inches wide, and 16 feet long. Pieces 7½ inches long were sawed from these bars, then beveled and welded.

The coupons for the various tests as shown in Plate I were cut by means of five slitting saws, 3 inches in diameter by 1/8 inch thick, mounted on a special arbor with the proper spacings. The welded plates were placed in a fixture (Plate IV) built for this purpose to speed up the cutting operation and insure duplicate size coupons.

All coupons were taken from plates made by arc welding two 7½ by 5-inch strips of ½-inch flat stock along their 7½-inch side (Plate III). All joints were of the double V-butt type. A fixture was designed and built to hold two sections at an angle of 60 degrees from the vertical. This allowed the planer to travel in the horizontal plane and produce a 30-degree angle on each piece. On completion of this operation, the sections were reversed and another cut was taken from the opposite side producing uniform angles on all sections (Plate II).

The welded test plates used in this research were welded by the writer; the D-series with a Westinghouse Flex Arc, 200-ampere, direct-current, generator type machine, using the setting best adapted for ½-inch mild steel, and the A-series with an alternating-current, transformer type welder, designed and built in the Department of Shop Practice, using the best voltage and current setting for the mild steel used.

Lincoln Fleetweld No. 7, 5/32-inch heavy flux-coated electrode was used for both types of welds and machine settings were recorded for each test plate. The two 5-inch strips of flat stock were placed in a fixture (Plate III) and clamped in position allowing a 9/64-inch gap, and tacked at both ends of the double V. Two passes on each side were made on some plates and three passes on each side on others. The last pass or bead was made on the identification side of the plate.

At the present time a number of test methods are used. Many are similar but most of them vary according to the type of job to be tested. No accepted standard specifications have been adopted by the A.S.M.E., A.W.S., or A.S.T.M. Tentative specifications are used by these three organiza-

EXPLANATION OF PLATE I

Arc-welded test plate.

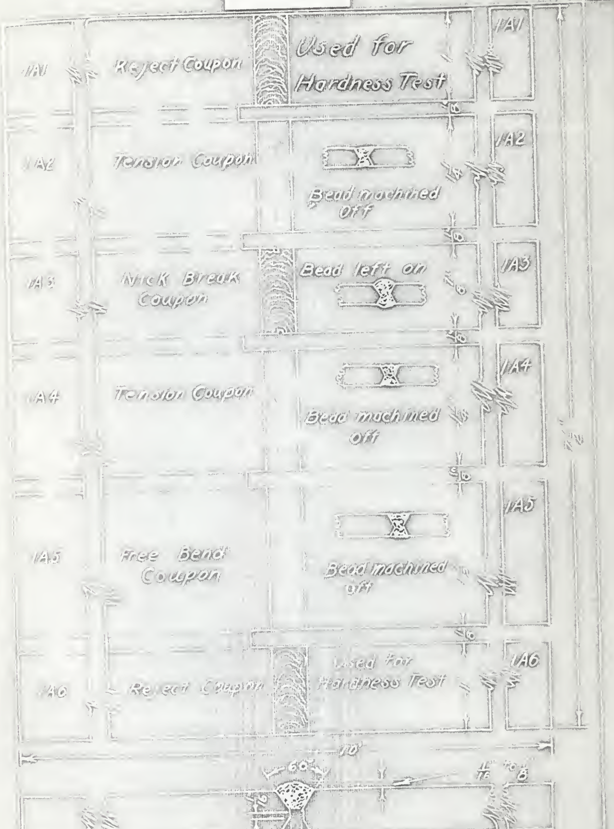
1A1	1 = Plate No.	A = Mach. used.	1 = Reject.
1A2	1 = Plate No.	A = Mach. used.	2 = Tension.
1A3	1 = Plate No.	A = Mach. used.	3 = Nick-Break.
1A4	1 = Plate No.	A = Mach. used.	4 = Tension.
1A5	1 = Plate No.	A = Mach. used.	5 = Free-Bend.
1A6	1 = Plate No.	A = Mach. used.	6 = Reject.

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

When D appears in place of A it designates direct-current arc-welding machine was used.

Reject coupons 1 and 6 were used for hardness tests.

Plate I



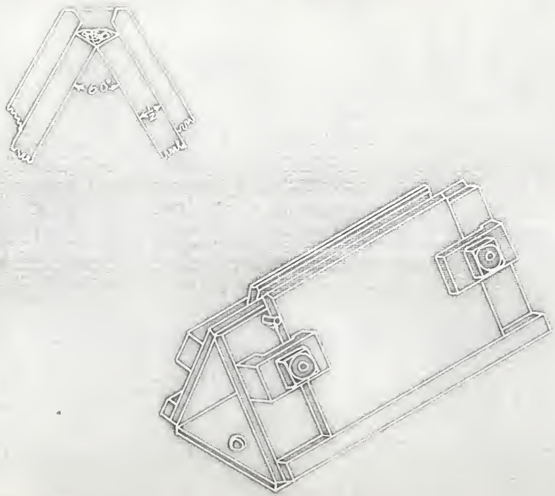
1A1
Reject Coupon
Used for Hardness Test
1A2
Tension Coupon
Bead machined off
1A3
Nick Break Coupon
Bead left on
1A4
Tension Coupon
Bead machined off
1A5
Free Bend Coupon
Bead machined off
1A6
Reject Coupon
Used for Hardness Test
60°

EXPLANATION OF PLATE II

Fixture to hold two plates at an angle of 60 degrees so the planer would produce a 30-degree bevel, then the plates were turned around and the next bevel made; thereby a double V-joint was produced.

Plate II

Plate II

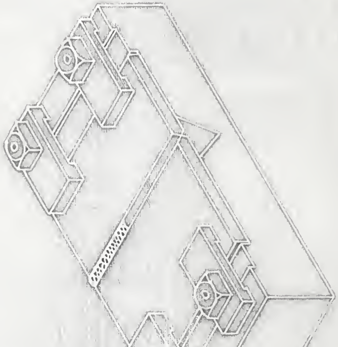


EXPLANATION OF PLATE III

Fixture for holding plates to insure a minimum of warpage while being fabricated.

Plate III

Plate III

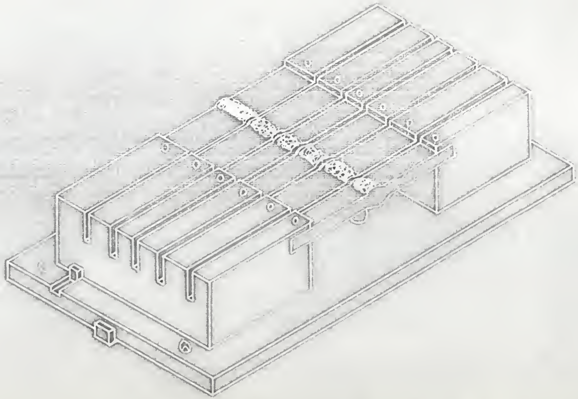


EXPLANATION OF PLATE IV

Fixture for holding welded plates to speed cutting operation and insure duplicate size coupons.

Plate IV

Plate IV



EXPLANATION OF PLATE V

Fixture designed to hold the tension coupons for milling operation.

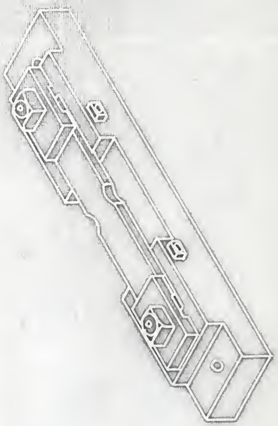


Plate V

EXPLANATION OF PLATE VI

Fig. 1. Tension coupon milled to a width of 1 inch.

Fig. 2. Tension coupon further reduced to 0.8 inch.

Fig. 3. Reduction in weld only.

nch.

Plate VI

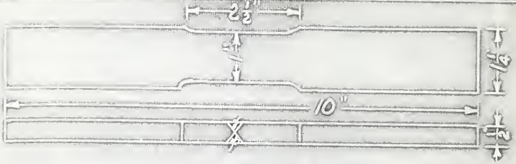


Fig. 1.

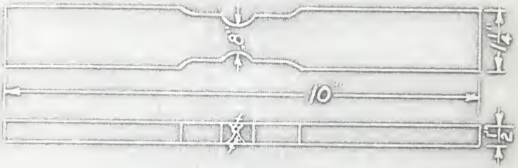


Fig. 2.

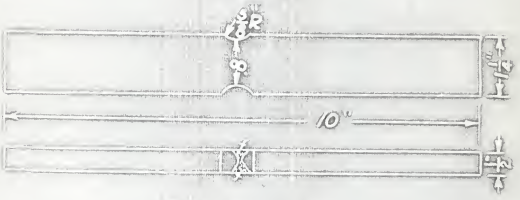
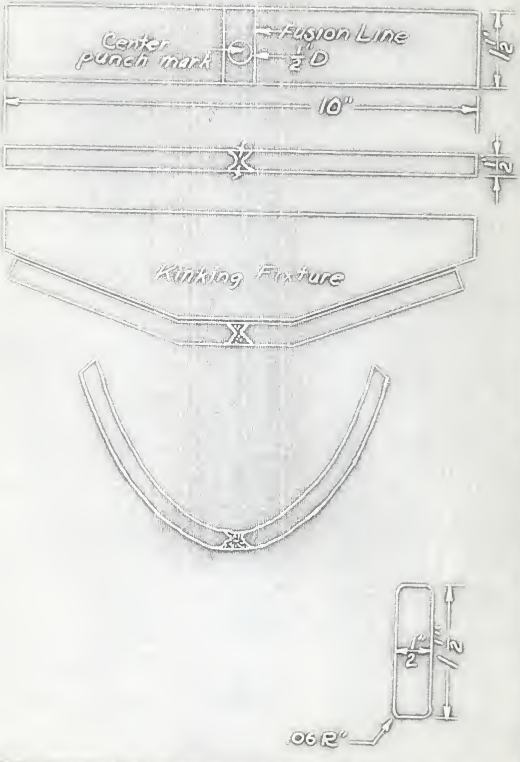


Fig. 3.

EXPLANATION OF PLATE VII

Free-bend coupon with kinking fixture for starting the bend.

Plate VII


Center punch mark
Fusion Line
1/2" D
1 1/2"
10"
1/2"
Kinking Fixture
1 1/2"
1/2"
.06 R"

tions but changes from time to time, as new testing information presents itself, are incorporated in the tentative plans. With the A.S.M.E. specifications as a guide, the following tests were selected to make the comparison of a-c. and d-c welds.

Tensile Test

Two tensile coupons ½ inch thick, 1-1/4 inches wide, and 10 inches long were taken from each of the welded plates, the cross-sections of which were reduced at the weld to a width of 1 inch (Fig. 1). This was done by machining out a segment to a depth of 1/8 inch and 2½ inches long on both sides, with a 1-1/4-inch diameter milling cutter, as shown in Plate V.

The tests were made on a 100,000-lb. Riehle testing machine and the yield point, ultimate strength, and breaking strength were recorded for each coupon. Since the cross-sectional area was kept constant, comparisons between the concomitant properties were simplified.

Twelve coupons as shown in Fig. 1 were tested and eleven broke outside the weld. Since this procedure would not give a true test of the welded joint it was decided to further reduce the coupon in the weld to 0.8-inch cross-section and to machine off the reinforcement, thus forcing the break to take place in the weld or fusion line. (Figures 2 and 3).

Free-Bend Test

The free-bend test was selected because it has gained wide recognition with the A.S.M.E. Boiler Construction Code (26), and has been proposed as a standard test for weld metal ductility by the A.S.T.M.

One free-bend test coupon, 1/2 inch thick, 1½ inches wide, and 10 inches long was taken from each welded plate. The reinforcement was machined flush with the base metal, having the tool marks running lengthwise of the coupon.

To permit measuring the stretch in the surface of the weld after completing the bend, light lines were scribed near the fusion line. These light lines or gage points were spaced 1/2 inch apart.

The machined coupon was prepared for bending by kinking each end, approximately one-third the length, by sledging it, while the other end was held in a heavy vise and fixture. (Plate VII). Each end was kinked to between 15 and 20 degrees. It was then placed in a testing press, built by the Department of Shop Practice, and squeezed until the first signs of failure appeared. Then the increased distance between the gage points was measured and the percentage of elongation calculated. Percentage of elongation

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

Nick-Break Test

One coupon from each welded plate ½ inch thick, 7/8 inch wide, and 10 inches long was taken for the nick-break test. The center of the weld was nicked by sawing a slot 1/16 to 1/8 inch deep across the thickness on both sides. These coupons were placed in a fixture and broken by a sudden blow from a steam hammer and the condition of the fractures noted.

Plate VIII shows a-c, and Plate IX shows d-c fractures.

Hardness Test

A Rockwell hardness testing machine, with the B scale and 100-kilogram load and a 1/16-inch ball, was used for the hardness test. Plate X shows a fixture designed and built by the Department of Shop Practice to hold the coupons so that five main rows of hardness data were taken lengthwise through the weld and into the parent metal on both sides of the weld (Figs. 7 and 8). This fixture had two threaded rods, one at right angle to the other, and both in the same horizontal plane. One complete turn of one

EXPLANATION OF PLATE VIII

A-c nick-break sections of broken coupons.

Plate VIII

Plate VIII

EXPLANATION OF PLATE IX

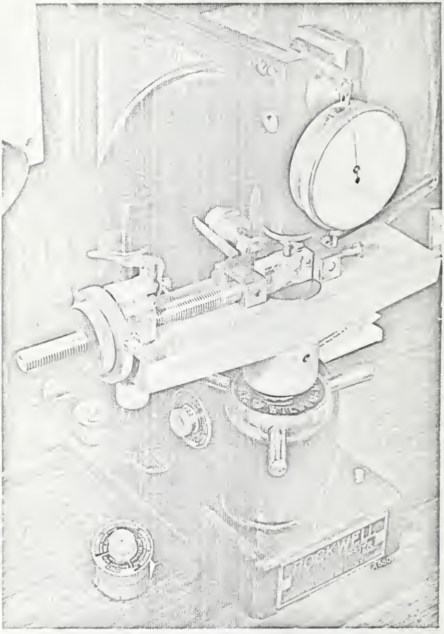
D-c nick-break sections of broken coupons.

Plate IX

EXPLANATION OF PLATE X

Rockwell hardness tester with the B-scale using 100-kilogram load and a 1/16-inch ball. The fixture holding the segment of hardness coupon made it possible to take 109 readings 1/12 inch apart measured from the center of the weld.

Plate X



threaded rod caused the hardness marks to be spaced 1/12 inch apart in the lengthwise direction, and one complete turn of the other screw moved the coupon 1/12 inch in the crosswise direction (Plate X). These segments were etched to determine the center of the weld with meticulous care; the first hardness reading was taken at this point. All other hardness marks were carefully located with respect to the first readirg. At the end of the first row of hardness marks an extra penetration was made with the tester to designate the side having the identification marks.

Hardness measurements were made over the cross-section of the number 1 and 6 coupons from welded plates 2, 4, 8, 10, 18, and 20. Since approximately 109 hardness readings were made per plate it was felt that selecting representative plates from the total group would give fair averages for comparative purposes.

DATA

The schedule of welded plates with the number of passes on each side and machine setting information are given in Table 1.

In Table 2 the yield point, ultimate tensile strength and breaking strength are given.

The ductility as indicated by the percentage of elongation is given in Table 3.

Table 4 gives the results of averaging the yield point, tensile, and elongation tests.

The various group ductility and tensile strength averages are shown in Table 5.

Table 6 shows a sample of Rockwell B hardness data of coupons 18A1 and 18D1.

Table 7 gives the Rockwell B hardness averages for the representative plates selected.

ANALYSIS OF DATA

Tensile Tests

The ultimate tensile strength of the first 12 coupons tested was approximately 10,000 lbs. per square inch less than all the others. This was due to the small reduction in cross-sectional area at the weld (Plate VI). All coupons except one broke outside the weld so a further reduction in the width of the welded metal was made, forcing the break to take place in the weld. This accounts for the low reading shown in Fig. 4 for coupons 1, 2, and 3. Figure 4 shows a graph of the results of a-c and d-c tensile tests.

In comparing the welds made by the two types of welding machines the yield point and ultimate strength were slightly greater for the a-c.

The breaking point was recorded when possible, but in

Table 1. Schedule of welded plates.

Plate No.	Pass No. and machine setting*						Remarks
	1	2	3	4	5	6	
1 A	B4	B4	B4	B4			
1 D	100	100	100	100			
2 A	B4	B4	B4	B4			Plates 1 to 4 inc. not chipped.
2 D	100	100	100	100			
3 A	B4	B4	B4	B4			
3 D	100	100	100	100			
4 A	B4	B4	B4	B4			
4 D	100	100	100	100			
5 A	B4	B5	B4	B4			
5 D	100	105	100	100			
6 A	B4	B5	B5	B5			
6 D	100	105	105	105			
7 A	B4	B5	B5	B5	B5	B5	Plates 5 to 16 inc. started chipping under side of No. 1 pass.
7 D	105	110	110	110	110	110	
8 A	B4	B5	B5	B5	B5	B5	
8 D	105	110	110	110	110	110	
9 A	B4	B5	B5	B5	B5	B5	
9 D	105	120	120	120	120	120	
10 A	B4	B5	B5	B5	B5	B5	
10 D	105	120	120	120	120	120	
11 A	B4	B5	B5	B5	B5	B5	
11 D	105	120	120	120	120	120	
12 A	B4	B5	B5	B5	B5	B5	
12 D	105	120	120	120	120	120	
13 A	B4	B5	B5	B5	B5	B5	
13 D	105	125	125	125	125	125	

Table 1 (concluded).

Plate No.	Pass No. and machine setting* 1	2	3	4	5	6	Remarks
14 A	B4	B5	B5	B5	B5	B5	
14 D	105	125	125	125	125	125	
15 A	B4	B5	B5	B5	B5	B5	
15 D	105	125	125	125	125	125	Plates 17 to 22
16 A	B4	B5	B5	B5	B5	B5	inc. were not
16 D	105	125	125	125	125	125	chipped.
17 A	B4	B5	B5	B5	B4	B4	
17 D	105	125	125	125	105	105	Plates 21 to 22
18 A	B4	B5	B5	B5	B4	B4	grain of metal
18 D	105	125	125	125	105	105	run at right
19 A	B4	B5	B5	B5	B4	B4	angles to weld.
19 D	105	125	125	125	105	105	There were no
20 A	B4	B5	B5	B5	B4	B4	nick-break cou-
20 D	105	125	125	125	105	105	pons taken from
21 A	B4	B5	B4	B4			these plates.
21 D	105	125	105	105			
22 A	B4	B5	B4	B4			
22 D	105	125	105	105			

*Machine setting information:

A-c

Setting	Voltage	Current
B4	87	146
B5	67	168

D-c

Setting	Voltage	Current
100	41.5	112
105	40.9	118
110	40.3	124
115	39.7	130
120	39.0	136
125	38.3	142

Table 2. Tensile tests.

Coupon No.	Yield point lb./sq.in.	Ultimate strength lb./sq.in.	Breaking point lb./sq.in.	Remarks
1A2	40,460	62,240	47,200	(2)
1A4	42,640	63,060	54,080	(2)
1D2	40,980	59,220	53,140	(2)
1D4	41,900	60.560	(1)	(3)
2A2	39,200	60,300	50,240	(2)
2A4	41,160	60,260	51,400	(2)
2D2	43,400	61,340	51,460	(2)
2D4	43,200	61,220	51,400	(2)
3A2	40,780	59,900	50,220	(2)
3A4	41,080	61,600	51,920	(2)
3D2	42,140	60,860	50,000	(2)
3D4	40,000	60,800	51,860	(2)
4A2	48,375	71,500	(1)	(3)
4A4	52,237	73,394	(1)	(3)
4D2	48,583	75,911	(1)	(3)
4D4	50,421	70,105	(1)	(3)
5A2	50,875	72,875	(1)	(3)
5A4	49,324	77,339	66,788	(3)
5D2	50,275	73,200	67,975	(3)
5D4	50,203	75,508	71,519	(3)
6A2	49,600	75,875	(1)	(3)
6A4	51,386	78,452	(1)	(3)
6D2	49,797	72,914	(1)	(3)
6D4	50,411	76,234	(1)	(3)
7A2	52,167	75,497	53,276	(3)
7A4	50,676	77,885	73,051	(3)
7D2	50,592	75,257	55,540	(3)
7D4	48,712	73,510	(1)	(3)
8A2	52,016	76,613	(1)	(3)
8A4	51,411	70,713	(1)	(3)
8D2	49,056	75,611	64,642	(3)
8D4	50,713	77,295	(1)	(3)
9A2	51,417	76,262	(1)	(3)
9A4	49,798	76,613	62,298	(2)
9D2	51,658	75,637	(1)	(3)
9D4	49,314	76,899	68,912	(2)
10A2	48,386	75,559	68,318	(3)
10A4	48,665	74,117	(1)	(3)
10D2	48,679	74,923	(1)	(3)
10D4	48,156	77,222	42,752	(3)
11A2	52,434	75,827	22,089	(3)
11A4	49,059	77,063	63,901	(2)

Table 2 (continued).

Coupon No.	Yield point lb./sq.in.	Ultimate strength lb./sq.in.	Breaking point lb./sq.in.	Remarks
11D2	46,573	75,893	64,262	(3)
11D4	51,804	76,339	65,360	(3)
12A2	51,884	76,161	65,650	(3)
12A4	47,508	75,827	57,820	(3)
12D2	48,992	77,943	(1)	(3)
12D4	49,463	70,254	61,377	(3)
13A2	48,622	77,091	64,591	(3)
13A4	54,779	77,631	51,405	(3)
13D2	53,025	74,825	(1)	(3)
13D4	53,430	76,855	32,825	(3)
14A2	51,810	75,696	(1)	(3)
14A4	50,802	76,304	(1)	(3)
14D2	53,750	76,607	(1)	(3)
14D4	50,252	76,187	(1)	(3)
15A2	51,429	77,057	60,365	(2)
15A4	51,361	77,910	47,090	15 to 22
15D2	51,789	77,299	66,256	inc.
15D4	53,947	77,267	62,145	failed in
16A2	52,134	76,778	(1)	the weld.
16A4	54,283	77,406	(1)	
16D2	49,291	75,565	46,060	
16D4	53,387	76,806	60,642	
17A2	54,608	74,390	(1)	X
17A4	57,951	79,521	(1)	X
17D2	49,651	74,775	(1)	
17D4	51,189	74,850	(1)	
18A2	54,605	78,264	(1)	X
18A4	50,928	79,746	(1)	X
18D2	53,917	76,330	(1)	
18D4	51,616	71,869	53,258	
19A2	54,825	77,011	(1)	
19A4	52,083	77,998	(1)	
19D2	53,289	80,491	(1)	X
19D4	51,862	73,826	(1)	X
20A2	56,190	76,213	(1)	X
20A4	53,568	78,204	(1)	X
20D2	54,038	80,443	(1)	X
20D4	54,743	79,040	(1)	X
21A2	51,763	79,654	(1)	X (4)
21A4	54,958	75,938	(1)	X (4)

Table 2 (concluded).

Coupon No.	Yield point lb./sq.in.	Ultimate strength lb./sq.in.	Breaking point lb./sq.in.	Remarks
21D2	55,019	79,316	(1)	X (4)
21D4	51,404	79,165	(1)	X (4)
22A2	63,989	85,617	(1)	X (4)
22A4	53,800	76,425	(1)	X (4)
22D2	53,573	80,854	(1)	X (4)
22D4	53,011	74,873	(1)	X (4)

X indicates relieved from full section coupon to 1-1/4-inch diameter arc in weld only.

(1) Ultimate strength and breaking strength so close together reading could not be taken.

(2) Failed outside of weld.

(3) Failed in weld.

(4) 21 and 22 series plates were at right angles to rolling process.

Table 3. Ductility.

Coupon No.	Percent elongation in 1/2 inch	Coupon No.	Percent elongation in 1/2 inch
1A5	28	11A5	20
1D5	30	11D5	22
2A5	42	12A5	18
2D5	30	12D5	30
3A5	26	13A5	22
3D5	24	13D5	20
4A5	24	14A5	24
4D5	26	14D5	16
5A5	18	15A5	30
5D5	30	15D5	22
6A5	26	16A5	18
6D5	32	16D5	22
7A5	20	17A5	26
7D5	40	17D5	32
8A5	24	18A5	28
8D5	26	18D5	16
9A5	30	19A5	20
9D5	26	19D5	22
10A5	18	20A5	22
10D5	32	20D5	24

Table 4. Yield point, tensile and elongation results.

	Av. yield point lb./sq.in.	Av. ultimate strength lb./sq.in.	Av. percent elongation
A	50,614	74,541	24.2
D	49,936	73,907	26.1

Table 5. Group ductility and tensile strength averages.

Plates inclusive	Machine setting change	Passes	Chipped	Av. percent elongation in 1/2 inch	Av. U. T. strength lb./sq.in.
1 to 4	(See Table 1)	2	No	A 30.50 D 27.50	A 64,031 D 63,752
5 to 16			Yes	A 22.33 D 26.33	A 76,189 D 75,668
1 to 7		2		A 27.33 D 28.66	A 68,899 D 67,322
7 to 20		3		A 22.85 D 25.00	A 76,619 D 76,064
21 to 22		2	No	?	A 79,408 D 78,552
17 to 22			No		A 78,248 D 77,152
7 to 12	(See Table 1)	3	Yes	A 21.66 D 29.33	A 75,678 D 75,565
13 to 20	(See Table 1)	3		A 23.75 D 21.75	A 77,326 D 76,439

EXPLANATION

In Table 6, hardness data of coupons 18A1 and 18D1 were taken on the edge of the weld; column 3 and No. 10 hardness numbers are inclosed in parenthesis which indicate the first mark taken in the center of the weld.

Figures 7 and 8 illustrate how this information was taken from the coupon. The extra hardness mark taken at the bottom of each indicates the identification side. Magnification 2 diameters.

Table 6. Rockwell B hardness test.

	18A1							18D1						
No.	Bead	1	2	3	4	5	Bead	Bead	1	2	3	4	5	Bead
1		69	69	68	69	72			76	76	74	73	74	
2		70	71	66	70	73			76	78	74	76	77	
3		72	71	71	70	75			77	79	76	76	77	
4		74	74	72	74	75			77	77	77	79	78	
5		76	75	74	75	75			80	79	78	79	78	
6		82	74	74	75	79			83	74	79	79	81	
7	87	83	76	73	76	80	77	82	90	81	78	79	83	90
8	89	83	76	74	77	80	86	92	94	87	79	81	89	91
9	91	90	85	81	86	83	92	95	96	91	82	93	90	93
10	91	89	87	(87)	86	84	93	95	97	93	(89)	92	87	95
11	91	90	88	83	86	85	92	95	94	90	89	94	87	97
12	89	85	82	81	77	73	92	94	92	83	83	83	87	95
13	90	83	76	77	76	78	93		88	81	83	80	79	
14		81	74	77	76	77			82	83	82	80	77	
15		79	74	78	75	74			82	82	81	79	74	
16		75	74	77	73	72			80	80	80	78	77	
17		73	73	73	71	71			80	79	78	77	76	
18		71	70	71	70	69			77	76	76	74	73	
19		67 (68)	69	71	70	68			75	75	73	74	75	

Fig. 7.

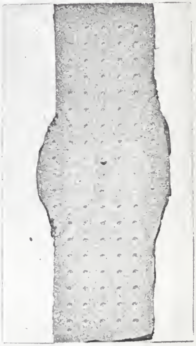


Fig. 8.

Table 7. Rockwell B hardness averages.

Coupon No.	V.Av.	H.Av.	V.Av.	H.Av.	Coupon No.	V.Av.	H.Av.	V.Av.	H.Av.
2A1	76.47	90.70			2D1	73.21	86.86		
2A6			72.55	86.83	2D6			71.47	84.33
4A1	73.42	84.57			4D1	74.00	90.66		
4A6			73.39	87.33	4D6			77.42	92.00
8A1	76.61	91.33			8D1	73.61	83.57		
8A6			76.00	87.70	8D6			73.64	85.50
10A1	68.84	86.57			10D1	73.50	88.83		
10A6			77.32	86.57	10D6			76.42	88.42
18A1	75.16	88.10			18D1	79.53	92.57		
18A6			88.83	89.50	18D6			74.79	86.50
20A1	82.70	94.85			20D1	73.00	87.70		
20A6			76.53	88.40	20D6			79.84	93.40
Grand total av.	75.53	89.35	77.44	87.72		74.48	88.37	75.60	88.36

EXPLANATION OF PLATE XI

Fig. 9. Annealed metal. Magnification 125 diameters.

Fig. 10. Parent metal slightly affected by heat treatment. Magnification 125 diameters.

Fig. 11. Photomicrograph of a-c welded joint. Magnification 3 diameters.

Fig. 12. Columar structure merging into coarser grain metal. Magnification 125 diameters.

Fig. 13. Parent metal. Magnification 125 diameters.

Plate XI

Fig. 9.

Fig. 10.

Fig. 11.

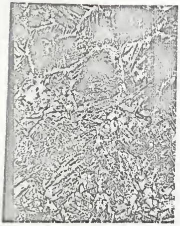


Fig. 12.

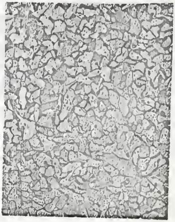


Fig. 13.

EXPLANATION OF PLATE XII

Fig. 14. Columar structure. Magnification 125 diameters.

Fig. 15. Columar structure merging into coarser grain zone. Magnification 125 diameters.

Fig. 16. Photomicrograph of d-c welded joint. Magnification 3 diameters.

Fig. 17. Parent metal. Magnification 125 diameters.

Fig. 18. Annealed metal. Magnification 125 diameters.

Plate XII

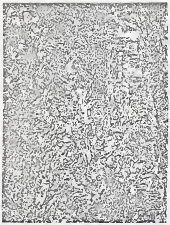


Fig. 14.

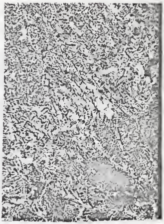


Fig. 15.

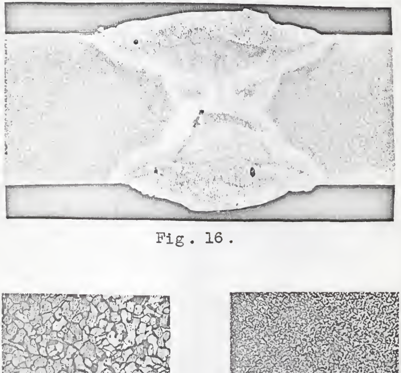


Fig. 16.

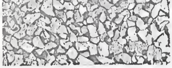


Fig. 17.

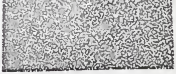


Fig. 18.

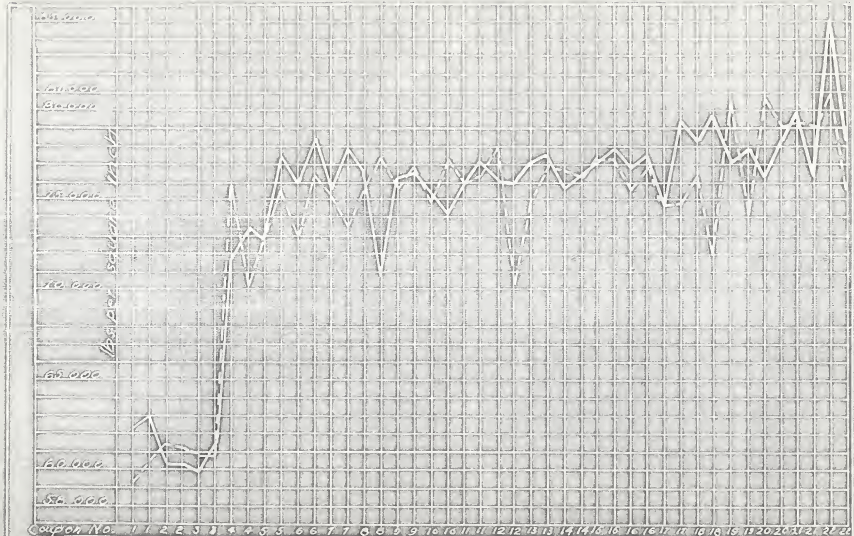


Fig. 4. Tensile comparison. 1st. 1 = 1A2 and 1D2, 2nd. 1 = 1A4 and 1D4.
1st. 2 = 2A2 and 2D2, 2nd. 2 = 2A4 and 2D4.
——— a-c, - - - - - - - - - d-c.

several cases it was so close to the ultimate strength that a reliable reading could not be taken. Because of this difficulty it was decided that such data had very little comparative value.

Ductility

The average percent elongation for a-c was 24.2 and for d-c 26.1 percent. This gives a slight increase in ductility to the welds made by the d-c machine. The range of elongation for a-c was from 18 percent to 42 percent and for d-c 16 percent to 40 percent, as shown by Table 3. The highest elongation was for a-c while the d-c elongation was the lowest. Figure 5 gives a graphic picture of comparison of the ductility test. This test gives a slight increase in ductility to the welds made by the d-c machine.

Group Ductility and Tensile Strength Averages

Plates 1 to 4 inclusive were welded with two passes on each side, with the first current selections and without chipping. The a-c had a slightly higher ductility and tensile strength.

Plates 5 to 16 inclusive were chipped. The d-c group had a higher ductility, but a lower tensile strength.

Plates 1 to 7 inclusive were welded with two passes on each side, the d-c group having a slightly higher ductility but lower tensile strength.

Plates 7 to 20 inclusive were welded with three passes on each side. The a-c group shows a lower ductility but a higher tensile strength.

Plates 21 and 22 were welded with two passes on each side and were not chipped. There were no ductility coupons but the tensile strength for this group is higher for a-c.

Plates 17 to 22 inclusive give the a-c group higher tensile strength.

Plates 7 to 12 inclusive were welded with a higher current setting, had three passes on each side, and were chipped. The d-c group had higher ductility, but the a-c group had a higher tensile strength.

Plates 13 to 20 inclusive were welded with a still higher current setting and with three passes on each side. The a-c group was higher in both ductility and tensile strength.

In all of these group comparisons the a-c groups had a higher tensile strength, and the d-c groups had a higher ductility with the exception of two cases.

Rockwell B Hardness Averages

In Table 7 each coupon tested had 19 vertical and seven horizontal hardness readings. In seven of the eight grand

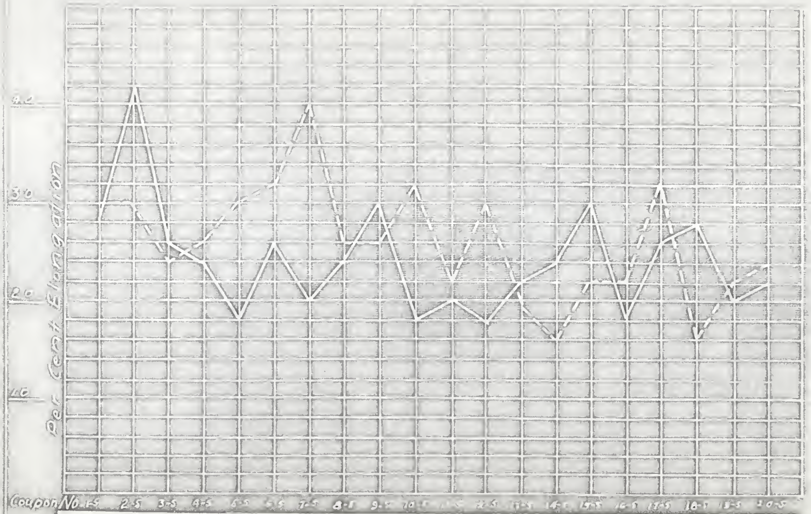


Fig. 5. Ductility comparison. ———————— = a-c.
- - - - - - - - = d-c.

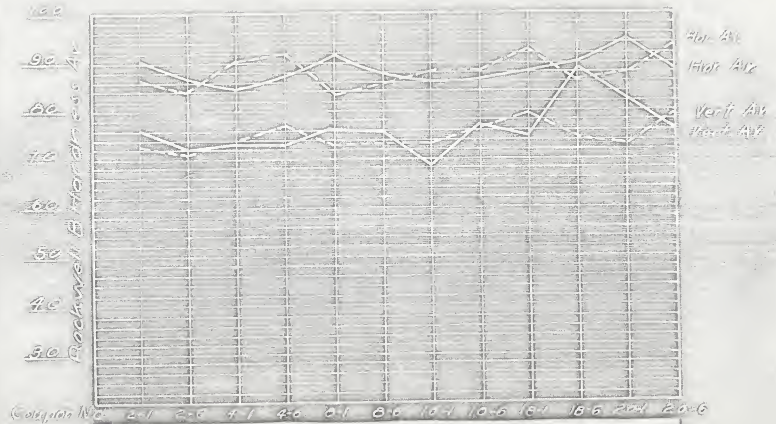


Fig. 6. Rockwell B-hardness average.
———————— = a-c.
- - - - - - - - = d-c.

total averages, the a-c series had a higher grand total reading than the d-c series. The average for the vertical hardness readings was greater on the No. 6 coupon as compared to the No. 1 coupon, which indicates that the metal had a higher temperature at the end of the pass in both a-c and d-c.

The horizontal hardness averages were lower on the No. 6 coupon than on the No. 1 coupon, which indicates the annealing effect of the last bead on the preceding beads. This is illustrated by Figs. 9 and 18 and shows the fine grained metal structure. The last bead is of much coarser structure as shown by Figs. 12 and 15.

SUMMARY

The results of the a-c and d-c welding tests may be summarized as follows:

1. In tensile strength, the a-c had a higher average than the d-c.

2. In percent elongation, the d-c outranked the a-c.

3. Of eight grand-total-hardness averages seven were higher for a-c and one higher for d-c.

4. In both a-c and d-c as the tensile strength increased, the ductility decreased.

5. In general, the results of this research on welding show no appreciable difference between alternating-current and direct-current welds.

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