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PRODUCTION ENGINEERING MEASURES PROGRAM
MANUFACTURING METHODS AND TECHNOLOGY

PARALLEL AND INTERSECTING WELDS IN HIGH-STRENGTH STEEL SHEET

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Final Report

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ABSTRACT

The objective of this project was to determine interaction effects of parallel and intersecting welds in high-strength steel sheet as well as to determine the need for excessive buildup of the welded area. Included are the effects of minor variables in welding upon the weldments. The alloys used in the project were 4130, 4340, and 18% Ni maraging steel sheet. The joining process was gas tungsten arc welding.

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INTRODUCTION

In the manufacture of missile and rocket cases, the fabrication of component parts into the end item quite often requires parallel weldments in close proximity and weldments that intersect those parallel welds. Because the weld deposit is an as-cast structure and because the temperatures of welding affect the microstructure of the parent metal in the vicinity of the weld, the overall properties of a welded component can be detrimentally affected by such weldments. Normally, the deleterious effects are compensated for by additional filler metal in the weldment. This safety step increases the cost, fabrication time, material, and weight of the end item. The present program investigated the joint geometries mentioned above to determine the extent to which additional filler metal buildup was required.

This project was funded as part of the U.S. Army Missile Command Manufacturing Methods and Technology Program.

Guidance in the selection of materials, the spacing between parallel weldments, and geometry of test specimens were received from the Missile Command which sponsored the program.

OBJECTIVE

The objective of this program is to determine the minimum buildup required on adjacent and intersecting weldments and to determine the effects, if any, of the spacing between the parallel welds upon the properties of the weldments.

MATERIALS AND PROCEDURES

The materials used in this program include sheets of AISI 4130, AISI 4340, and 18% nickel maraging steel and filler wires designated as Linde 140, Airco AX-140, Linde 71, and 18% nickel maraging steel. The composition and thicknesses of the sheet material used are given in Table 1. The composition and diameters of the filler wire used are given in Table 2.

Table 1. THICKNESS AND COMPOSITION OF BASE MATERIALS

Designation	Thickness (in.)	Weight Percent														
		C	Mn	P	S	Ni	Cr	Mo	Cu	Al	Co	B	Zr	Ca	Ti	Si
4130	0.032	0.28	0.45	0.009	0.024	0.06	0.92	0.17	0.11	-	-	-	-	-	-	0.23
4130	.050	.30	.51	.009	.024	.06	.93	.20	.12	-	-	-	-	-	-	.34
4130	.063	.29	.54	.008	.025	.07	.94	.18	.13	-	-	-	-	-	-	.26
4340	.063	.39	.63	.009	.023	1.81	.81	.24	.14	-	-	-	-	-	-	.30
18% Ni Maraging	.030	.007	.04	.005	.006	18.15	-	4.93	-	0.10	7.32	0.003	0.02	0.06	0.43	.02
18% Ni Maraging	.055	.007	.04	.005	.006	18.15	-	4.93	-	.10	7.32	.003	.02	.06	.43	.02

The objective in determining the heat treatments was to develop a treatment that would produce a tensile strength of approximately 250,000 psi. After some initial investigations, the following heat treatments were used throughout the program.

For the 4130 and the 4340 materials in all thicknesses, the heat treatment consisted of heating to 1550 F (842 C) for 1 hour, oil quenching to room temperature, and tempering at 450 F (232 C) for 1 hour, and air cooling. Although the tensile strengths for the different thicknesses of the 4130 steel decreased with decrease in thickness of the sheet, the sponsor agreed to keep the heat treatment constant for this material.

For the 18% Ni maraging steels in both thicknesses, the heat treatment consisted of heating to 1500 F (815 C) for 1 hour, air cooling to room temperature, aging at 900 F (482 C) for 3 hours, and air cooling to room temperature.

The tensile properties produced in the various sized sheets by the above heat treatments are given in Table 3.

In preparation for welding, the sheet materials were machined into sections of appropriate size. The edges to be welded were ground parallel and square. The entire surface of the section was sand-blasted to remove oxidization and provide uniformity. This was followed by wire brushing with a clean, stainless steel wire brush. Next, the sections were washed in a biodegradable detergent solution and the faying surfaces cleaned with acetone. Just before welding, the faying surfaces were draw-filed and wiped with a clean dry cloth.

Table 2. DIAMETER AND COMPOSITION OF FILLER WIRE

Designation	Diameter (in.)	Weight Percent											
		C	Mn	Si	Ni	Cr	Mo	P	S	Al	Ti	Co	V
Linde 140	0.045	0.11	1.65	0.35	2.90	0.70	0.90	0.008	0.007	-	-	-	-
Airco AX-140*	0.045	0.07-0.11	1.75-2.0	0.25-0.45	2.0-2.5	0.85-1.10	0.5-0.6	-	-	-	-	-	-
Linde 71	0.030	0.31	0.55	0.65	-	1.25	0.5	-	-	-	-	-	0.25
18% Ni Maraging	0.030	0.033	0.036	0.10	18.88	-	5.12	0.003	0.011	0.106	0.66	9.04	-

*Nominal analysis

Table 3. TENSILE PROPERTIES* OF HEAT-TREATED SHEET

Alloy	Thickness (in.)	Yield Strength 0.2% (ksi)	Tensile Strength (ksi)	Elongation (%)
4130	0.032	191	215	2.8
4130	.050	199	238	5.0
4130	.063	216	253	5.3
4340	.063	213	263	6.7
18% Ni	.030	239	246	4.2
18% Ni	.055	238	245	4.7

*Average of three tests

The welding program was planned to include welds with no filler and welds with filler. Further, the heat treatments listed above would be given as pre-welding heat treatments, post-welding heat treatments and both. The spacing between the parallel welds would be 1/2, 3/4, 1, and 1-1/4 inches. The gas tungsten arc welding process was used throughout. For backing of the weldments, a copper plate was machined with grooves 1/16" deep and 3/16" wide with appropriate separation between the grooves to match the spacers used in making the parallel welds. The welding setup is shown in Figure 1. During the early stages of the project it was necessary to change and modify the backup plate. Because the new backup plate was a less efficient heat sink it was necessary to change the welding variables to obtain satisfactory weldments. Throughout the project, it was noted that on the materials used, especially the thinner materials, relatively small changes in variables could produce a wide range of effects upon the weldments, varying from lack of penetration to burn-through. These variations will be discussed later in the report. In the initial development of settings for the welding variables, four variables were altered. These were the amperage, the voltage, the travel speed, and the filler wire rate of feed for those welds where filler wire was used. Experience showed that a wide range of settings for these variables could be used with satisfactory results. However, for simplicity and more consistent results, the travel speed and filler wire feeding rate were held constant and only the amperage and voltage were varied. Table 4 lists the welding variables finally selected. Since some variations had to be used in these settings, they should be used as a guide rather than rigid numbers to produce satisfactory weldments. It will also be noted that the travel speed for the 4340 material welded with filler wire is slower than that for the other materials. This was required because the diameter of the filler wire was greater than that used on the other materials.

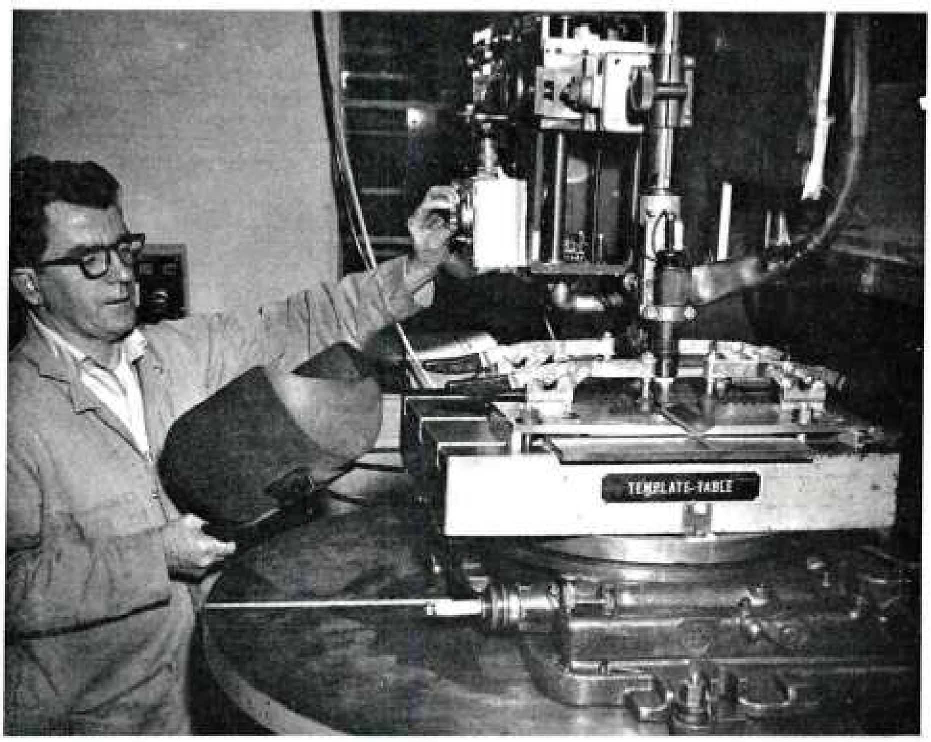

Figure 1. GTA welding setup for parallel and intersecting welds

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All welds were made in the same direction using run-on tabs. When used, the filler wire was fed into the arc at an angle of 75° from the tungsten electrode. The height of the wire feed guide was adjusted so that the wire would make contact with the sheet to be welded at a distance in front of the electrode equal to the diameter of the filler wire.

RESULTS AND DISCUSSION

The experimental data were obtained by testing flat tension specimens, Figure 2, and notched flat tension specimens, Figure 3. As requested by the sponsor, to obtain results that would simulate actual production conditions, the weldments were tested in their as-welded configuration without having the reinforcement of the weld ground flat. This produced an inaccuracy in the testing of the intersecting welds. The longitudinal weld would increase the cross-sectional area by

Table 4. WELDING VARIABLES

Base Material	Thickness (in.)	Filler Material	Diam. (in.)	Wire Feed (in./min)	Amperage	Voltage
4130	0.032	None	-	-	70-75	10-20
4130	.050	None	-	-	100-105	11-13
4130	.063	None	-	-	130-135	11-13
4340	.063	None	-	-	125-130	8.5-11.5
18% Ni	.030	None	-	-	70	10.5-12
18% Ni	.055	None	-	-	110-120	12
4130	.032	Linde 71	0.030	33	70	11
4130	.050	Linde 71	.030	33	96-102	11-12
4130	.063	Linde 71	.030	33	120-130	11.5-13
4340	.063	Airco AX-140	.045	14.5	114	13
18% Ni	.030	18% Ni	.030	33	67.5-70	11-13
18% Ni	.055	18% Ni	.030	33	120	11-12.5

Note:

Electrode: W-2Th, 0.062 in. diam., 30° incl. tip angle
Travel speed: 13 in./min
Argon shielding gas: 50 cfh flow

Type	A	B	C	E	F	G	T	W
TF 4	8	2.0	2-1/2	1/2R	2-1/4	3/4	0.030-0.063	0.500

Dimensions in inches

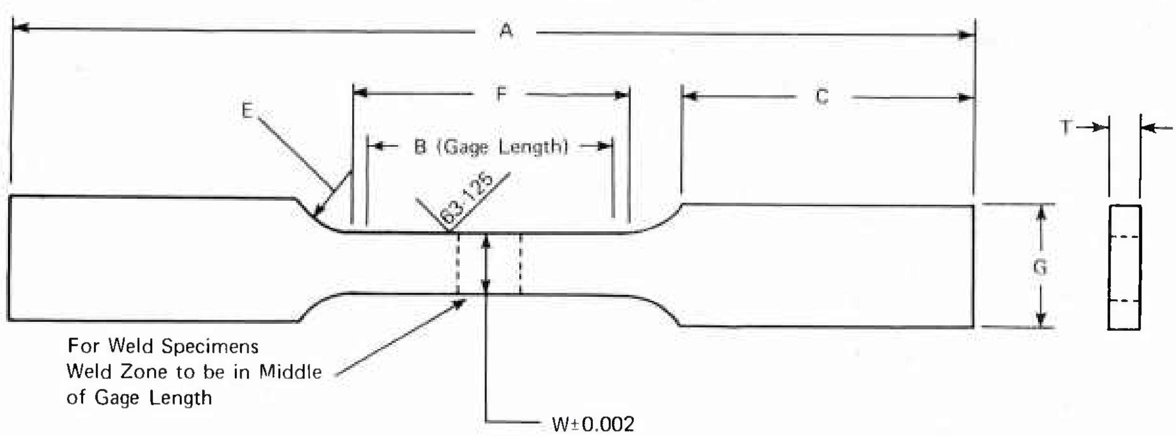


Figure 2. Flat tension specimens

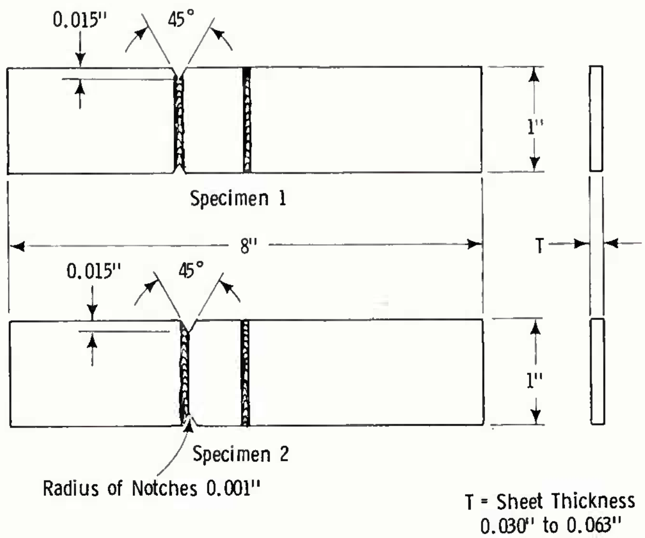


Figure 3. Notched flat tension specimen

an amount of buildup. This could not be measured, therefore the cross-sectional area was based on the width and thickness of the sheet. The results obtained will tend to be higher than they actually are. Three specimens were tested in each condition and the average of these results are listed in the Appendix, Tables A-1 to A-3.

With the large number of variables used in obtaining the data in this report, there is no clear and concise method by which the data can be presented graphically. Therefore, the data has been tabulated in the Appendix thereby enabling the reader to use it as he will.

In Table A-1, the data on single weldments without spacing are presented.

In Table A-2, the data on the parallel weldments with spacings of 1/2, 3/4, 1, and 1-1/4 inches are presented.

In Table A-3, the data on intersecting weldments are presented. In this case, a single weld intersects two parallel welds at right angles.

In Table A-4, the sharp notch tension test data are reported.

In all tables, the conditions for the specimens are listed as A, B, C, etc. These are defined as follows:

Condition	Description
A	As-received material welded without filler and then fully heat treated with the heat treatment designated in the text for that material.
B	As-received material welded with filler metal and given the appropriate heat treatment.
C	Heat-treated material welded without filler and post-weld heat treated.

D Heat-treated material welded with filler; no post-weld heat treatment.

E Heat-treated material welded with filler and post-weld heat treated.

Data are grouped according to the spacing between parallel welds. In various groups all conditions are not covered because the data obtained under certain conditions were so low as to be of no interest on this project.

Toward the end of the program, the sponsor indicated a desire to obtain some notch toughness data. It was determined that a modification of the Double-Edge-Notch Tension Specimen described in ASTM publication E-338-7 would be used, see Figure 3. Since we are interested in weld strength, the notches were originally placed on the centerline of one of the weldments (Figure 3, Specimen 1). The notch was changed to the heat-affected zone (HAZ) of one of the weldments (Figure 3, Specimen 2). The data are listed in Table A-4 of the Appendix. Because the request for notch toughness data was made late in the program and material for all conditions was no longer available, the data obtained are relatively spotty.

The notch concentration factor for the notched tension specimens is calculated with the equation

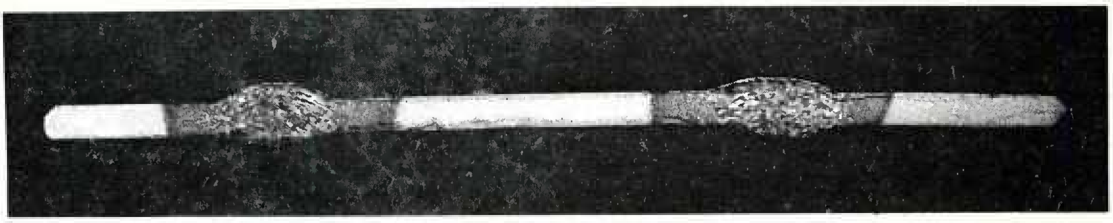
$$K = \sqrt{1/2W/r}$$

W = distance between notches in inches
r = radius of notches in inches
For the specimen used, K = 18.71.

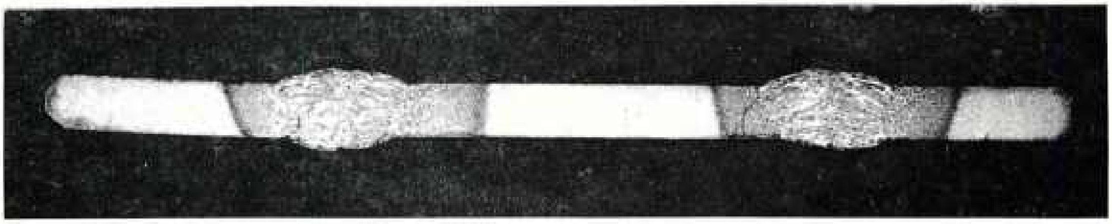
Random specimens were selected for metallographic examination. Representative photomicrographs of parallel weldments with 1/2" spacing are shown in Figure 4.

Before discussing the effects of weld spacing on the properties of the weldment, it is believed to be of value to discuss the minor variables that occurred during the performance of this project. These so-called minor variables had large effects upon the actual welding performed.

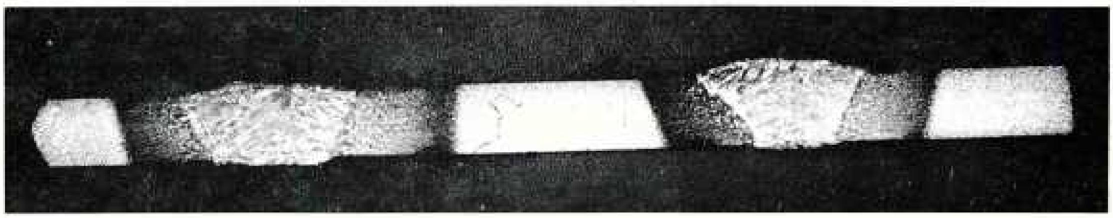
The initial work was done using an existing backup plate which was grooved for the parallel welds. While this was being used, a second backup plate was being made that could be used for both parallel and intersecting welds. When the second plate was put into the welding setup, it was observed that the welding variables determined while using the first plate no longer applied. The thickness of the two plates was not the same, therefore their function as a heat sink was different and the welding variables had to be adjusted to accommodate this difference. It was also observed that the thinnest sheet quite often cracked on welding. Although, preheat would overcome this deficiency, it was not desirable to introduce this variable into the welding process. It was thought that decreasing the heat-withdrawing property of the heat sink would correct the situation. This was accomplished by placing a one-inch-wide piece of glass tape on the backup plate 3/16" back from the centerline of the groove. This slight alteration eliminated the cracking.



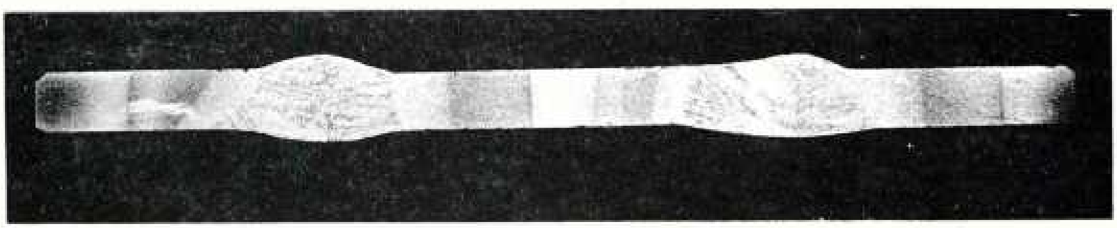
4130 Steel, 0.032" Thick, Condition B



4130 Steel, 0.050" Thick, Condition B



4130 Steel, 0.063" Thick, Condition B



18% Ni Maraging Steel, 0.055" Thick, Condition D

Figure 4. Representative photomicrographs of parallel welds - 1/2" spacing. Mag. 5X

On one occasion a new coil of filler wire was introduced into the welding process, followed by a deterioration of the welds produced. Microscopic examination of the filler wire surface revealed that it was contaminated to a far greater degree than the previous coil used. By replacing the contaminated coil than an uncontaminated coil of the same wire, the troubles were eliminated.

When making welds with 1/2" spacing, it was observed that at the end of the weld a high degree of mismatch and lack of penetration was produced. It was finally observed that the stress produced during welding lifted the 1/2-inch strip. By improving the hold-down fixturing for the 1/2-inch strip, this problem was corrected.

At one time a series of welds were produced in which the last third to quarter of the weldment lacked penetration. This was overcome by changing the ground from being attached to a corner of the backup plate to being attached to both ends of the backup plate at a point near to the centerline of the weld.

When intersecting welds were introduced into the program, it was noted that a lack of penetration developed in the area of the intersections. This was initially blamed on the slow response of the welding equipment to the change in height of the base metal where the buildup of the parallel welds occurred. The motor driven control was replaced with a solid state electronic device. This reduced the amount of lack of penetration but did not eliminate it. The next step was to grind off the weld bead buildup of the parallel welds at the faying surfaces to a 45° angle. This completely eliminated the lack of penetration in this area.

A series of welds were made that varied from lack of penetration to complete burn-through. After an extensive investigation, it was observed that the faying surface of the sheets being welded were contaminated. The contamination was of two types. The first was in the form of dark glassy spots that occurred intermittently along the ground edge of the plate. This was believed to be caused during the grinding of the edge in material preparation. The second contamination was in the form of very small bits of paper attached to the ground surface. These came from the paper towel used to wipe the ground edge prior to welding. By draw filing the ground surfaces and wiping this surface with a cloth, this problem was eliminated.

At times the wire feed mechanism produced trouble in the weldments. To summarize, the angle at which the wire is introduced must be kept close to 75° from vertical. The height at which it is fed or the spot at which it is introduced to the weld puddle must be constant. Also, it must be adjusted with the tip of the tungsten in the position it will be during welding. Finally, the coil of wire should be mounted in the same plane as that of arc travel to reduce its sideward motion during welding. Having the tip of the wire guide as close as possible to the nozzle of the torch will also aid in reducing the side-to-side motion of the wire.

Although it is not critical, the flow of the shielding gas must be adjusted to the conditions under which the weld is made. At first a minimum flow rate was used to reduce cost but it was found that the break in the hold-down plates, in the vicinity of the parallel welds, caused lack of protection at these points. Randomly increasing the flow rate caused irregularities due to arc blow. By making adjustments in the flow rate, both troubles were eliminated.

Inconsistent results obtained in the initial phases of the project were traced to variations in the geometry of the tip of the tungsten electrode. The literature* indicates the extent to which electrode geometry can affect the welding operation. By grinding the vertex angle of the electrode to 30° and maintaining this angle, the inconsistencies were drastically reduced.

*SAVAGE, W. F., STRUNEK, S. S., and ISHIKAWA, Y. *The Effect of Electrode Geometry in Gas Tungsten-Arc Welding.* Welding Journal, v. 44, November 1965, p. 489s-496s.

On the thin sheet weldments that were heat treated prior to welding, the lack of flatness in the sheet plus the distortion developed by the heat and stress of welding caused the sheet to buckle slightly and separate from the backup plate, thereby reducing the heat flow characteristics. This would result in burn-through. By improving the hold-down clamping device, this problem was eliminated.

Once the voltage, current, travel speed, and wire feed speed were established, relatively small changes in these variables had no appreciable effect upon the weldments produced.

One of the studies made on the project was the path which the fracture took in the breaking of the flat tension specimens. The following determinations were made for parallel weldments.

1. Weldments made with filler metal and post-weld heat treatment broke predominantly in the base metal.

2. Weldments welded without filler metal and with or without post-weld heat treatment broke either in the heat-affected zone or in the weld.

3. Weldments made with filler metal and without post-weld heat treatment broke about half in the parent metal and half in the HAZ.

For those weldments with parallel and intersecting welds:

1. Weldments made with filler and with post-weld heat treatment again broke predominantly in the parent metal.

2. Weldments made without filler but with post-weld heat treatment broke in the HAZ.

In reviewing the mechanical test data, it must be taken into consideration that the strengths reported are based on the cross-sectional area of the base metal not of the weld area. As a result, those values for specimens that broke through the weld may have an actual strength lower than that reported. For the intersecting welds, all actual values should be lower than those reported. No practical method could be devised in which the actual cross-sectional area could be measured accurately. It should be further noted that the cross-sectional area will vary with the amount of buildup on the weldment.

In general, all weldments without filler broke at strengths lower than that of the base material. As a result, these weldments were sometimes omitted in the parallel weld series and all were omitted from the intersecting weld series.

All weldments welded with filler but without post-weld heat treatment gave tensile values quite a bit below that of the base metal.

Weldments made with filler and given a post-weld heat treatment had values close to that of the parent metal with half being above and half below. All but four had tensile strength above a value equal to 90% of the tensile strength of the parent metal.

In all tests, these values did not vary with the different materials used.

It is further noted that those specimens with two parallel weldments generally have lower tensile strengths than the comparable specimens with a single weldment. This may be related to the possibility that when making the second weldment the material being welded did not seat as well on the backup plate. This would be caused by buildup on the underside of the first weldment. Any void between the material being welded and the copper backup plate would cause a variation in heat flow which could be detrimental to the weld being made. Unfortunately, no records were taken that would indicate the sequence in which the parallel welds were made.

Since the path for fracture for those specimens that broke in the weldment was predominantly through the heat-affected zone, the amount of buildup in the weldment is not critical. In other words, no matter how much buildup is used, the weakest area of the weldment will be at the edge of the built-up zone. To add an excess of filler metal will only move the weakened area a little further from the centerline of the weld. It was also noted that for the welding conditions used in this project, the heat-affected zone was relatively narrow and would not affect the adjacent weld.

In the case of intersecting welds, the main fault to avoid is lack of penetration in the area of intersection. Although weld buildup at the intersection could be used to compensate for this weakness in the flaw, this would increase costs by requiring more filler metal and labor to provide the buildup. A sound welding procedure that would prevent the development of the flaw would be the better solution. Also, attempts to repair the lack of penetration flaws by manual repair welding produced more problems rather than correcting the situation.

To obtain an indication of the notch toughness of the weldments, it was decided to make sharp notch tension tests and compare the data obtained with that for standard tension specimens. Originally, two notches were placed at the centerline of one of the welds, one notch at each end of the weld. A study of the path of fracture showed that the fracture started in the weld at the notch and usually propagated to the heat-affected zone. This meant that the cross-sectional area varied for each specimen and accurate notched specimen tensile strengths could not be determined. Later, the notches were placed with their centers in the heat-affected zone of the weldment and more reproducible results were obtained.

Because of the items noted above, it is not possible to draw definite conclusions from the sharp notch tension test data of the welded specimens. However, it can be concluded that the sharp notch tensile strength of the material was not drastically affected by welding.

Selected parallel weldments were examined metallographically to determine whether or not the heat-affected zones of the weldments overlapped. Figure 4 shows representative photomicrographs. It will be noted that as the thickness of the parent metal increased, the width of the weld-affected area increased. Although no photomicrographs of the 4340 material are shown, they were comparable to those of the 4130. It will also be noted that the width of the weld-affected area for the 18% Ni maraging steel was greater than that for the other materials. However, in no case was there an overlap of the two areas. This again would indicate that there were no interrelated effects of the parallel welds.

CONCLUSIONS

1. In welding high-strength steel alloys in relatively thin cross sections, it is mandatory that welding procedures be determined and maintained for producing sound welds.

2. Excessive buildup of weldments will not necessarily improve the strength of the joint.

3. Minor variations in electrode configuration, wire feeding geometry, joint preparation and fixturing of the joint to be welded can have a large effect on the soundness of the welded joint.

4. Manual repair of lack of penetration faults in intersecting welds is not a feasible solution.

5. Minor changes in welding variables of voltage, amperage, travel speed, and wire feeding rate did not affect the mechanical properties of the weldment.

6. There are no interrelated effects between parallel welds down to 1/2-inch spacing between weldments.

ACKNOWLEDGMENT

The author wishes to commend Mr. Daniel NcNaught for his patience, diligence, and keen observation of anomalies in the weldments developed during welding. Without his full cooperation, many of the so-called minor problems would have been overlooked and the successful completion of the project would have been severely hampered.

APPENDIX. COMPILATION OF TEST DATA

Condition	Description
A	As-received material welded without filler and then fully heat treated with the heat treatment designated for that matrial.
B	As-received material welded with filler metal and given the appropriate heat treatment.
C	Heat-treated material welded without filler and post-weld heat treated.
D	Heat-treated material welded with filler; no post-weld heat treatment.
E	Heat-treated material welded with filler and post-weld heat treated.

Table A-1. TEN5ION TE5T OATA ON 5HEET5 WITH 5INGLE WELOMENT5

5pacing	Condi-tion	Y.5. 0.2% (ksi)	T.5. (ksi)	Elon. (%)	Y.5. 0.2% (ksi)	T.5. (ksi)	Elon. (%)	Y.5. 0.2% (ksi)	T.5. (ksi)	Elon. (%)	Y.5. 0.2% (ksi)	T.5. (ksi)	Elon. (%)	Y.5. 0.2% (ksi)	T.5. (ksi)	Elon. (%)	Y.5. 0.2% (ksi)	T.5. (ksi)	Elon. (%)
		4130 - 0.032" T			4130 - 0.050" T			4130 - 0.063" T			4340 - 0.063" T			18% Ni - 0.030" T			18% Ni - 0.055" T		
5ingle Weld	A	206	244	2.7	201	244	4.0		cracked			cracked		231	234	1.2	234	236	2.0
	8	210	257	3.4	198	239	4.8	222	258	3.8	239	281	5.0	223	227	2.7	241	245	4.5
	C	209	242	1.8	197	238	5.0		omitted			omitted		236	238	2.0	242	243	2.8
	0	196	197	0.5	181	181	1.0	215	217	1.5	207	209	1.0	151	153	2.0	155	159	2.5
	E	208	245	2.8	199	240	5.0	230	268	3.5	242	287	3.3	243	250	3.0	253	257	3.5

Table A-2. TEN5ION TE5T OATA ON 5HEET5 WITH PARALLEL WELOMENT5

5pacing	Condi-tion	Y.5. 0.2% (ksi)	T.5. (ksi)	Elon. (%)	Y.5. 0.2% (ksi)	T.5. (ksi)	Elon. (%)	Y.5. 0.2% (ksi)	T.5. (ksi)	Elon. (%)	Y.5. 0.2% (ksi)	T.5. (ksi)	Elon. (%)	Y.5. 0.2% (ksi)	T.5. (ksi)	Elon. (%)	Y.5. 0.2% (ksi)	T.5. (ksi)	Elon. (%)
		4130 - 0.032" T			4130 - 0.050" T			4130 - 0.063" T			4340 - 0.063" T			18% Ni - 0.030" T			18% Ni - 0.055" T		
1/2 in.	A	148	169	2.3	179	210	3.7		omitted		205	242	3.7	214	218	1.7	220	228	4.4
	8	198	228	2.0	210	251	3.8	215	251	5.0	244	291	3.7	238	242	2.0	235	241	2.8
	C	161	185	1.7	189	216	2.7	184	218	5.7	206	255	1.5	222	230	0.8	217	226	2.5
	0	171	174	0.7	158	168	1.0	157	166	2.5	183	188	1.5	128	148	2.0	125	146	2.5
	E	197	236	3.0	183	218	4.5	197	231	5.0	225	269	4.8	226	233	1.8	226	232	2.8
3/4 in.	A	153	182	2.2	-	-	-	-	-	-	214	252	3.5	214	220	2.7	211	214	3.0
	8	204	240	1.8	216	254	4.3	216	252	4.8	226	263	4.0	226	241	2.0	231	237	3.2
	C	149	172	3.3	170	190	2.8	185	213	4.2	214	256	4.2	233	238	2.5	215	229	2.8
	0	113	127	1.8	167	178	2.5	159	172	2.0	183	193	1.0	131	146	1.8	138	146	3.2
	E	157	182	3.5	183	216	3.9	198	228	4.5	217	257	4.7	234	242	2.2	227	235	3.5
1 in.	A	-	-	-	-	-	-	211	255	3.8	-	-	-	-	-	-	-	-	-
	8	177	213	4.2	186	223	3.8	203	237	4.7	215	226	2.5	234	240	3.2	239	248	3.8
	C	139	152	0.3	191	232	4.2	193	224	1.6	211	255	3.8	205	211	3.2	220	225	3.7
	E	197	227	2.7	183	217	3.5	203	237	4.5	216	255	2.8	251	257	1.2	251	258	2.7
1-1/4 in.	8	172	227	3.8	190	222	3.2	203	240	5.5	223	263	3.0	238	247	3.3	233	241	3.0
	C	160	168	1.5	184	205	2.7	193	231	1.1	215	256	3.8	208	213	2.5	212	220	5.3
	E	166	191	3.0	198	234	4.8	207	255	2.8	216	263	3.7	233	244	2.5	243	249	2.7

Table A-3. TEN5ION TE5T OATA ON SHEET5 WITH PARALLEL ANO INTER5ECTING WELOMENTS

5pacing	Condi-tion	Y.5. 0.2% (ksi)	T.5. (ksi)	Elon. (%)	Y.5. 0.2% (ksi)	T.5. (ksi)	Elon. (%)	Y.5. 0.2% (ksi)	T.5. (ksi)	Elon. (%)	Y.5. 0.2% (ksi)	T.5. (ksi)	Elon. (%)	Y.S. 0.2% (ksi)	T.5. (ksi)	Elon. (%)	Y.5. 0.2% (ksi)	T.5. (ksi)	Elon. (%)
		4130 - 0.032" T			4130 - 0.050" T			4130 - 0.063" T			4340 - 0.063" T			18% Ni - 0.030" T			18% Ni - 0.055" T		
1/2 in.	8	190	210	1.3	210	226	2.3	206	231	2.3	121	144	4.3	251	257	2.0	247	251	2.0
	C		cracked			cracked		174	183	2.2	194	197	1.2	219	229	2.0	231	242	3.3
	E	203	210	1.3	210	226	3.0	175	182	1.2	203	244	1.7	245	250	1.7	251	257	3.0
3/4 in.	8	187	207	1.2		omitted		196	206	2.0	100	149	2.5	251	255	1.8	250	255	3.0
	C		cracked		180	194	2.2	199	204	2.0	-	176	1.2	237	239	3.0	211	223	1.5
	E		burn-through		184	202	3.0	209	227	2.5	237	273	4.3	222	229	3.0	252	256	2.3
1 in.	8	192	206	1.8	206	238	1.0	208	225	3.7	232	283	4.9	247	258	3.0	234	243	4.2
	C	168	178	1.7	190	218	2.7	198	207	1.7	230	255	2.0	217	226	3.0	220	229	4.2
	E	191	197	2.0	199	215	2.7	199	225	3.3	226	275	5.0	262	275	2.0	253	264	3.0
1-1/4 in.	8	192	202	0.7	200	221	2.3	210	228	1.6	227	274	5.0	254	260	2.3	234	243	4.8
	E	192	202	4.0	206	219	1.8	194	205	1.5	229	277	4.8	250	259	3.2	231	240	4.3

Table A-4. 5HARP NOTCH TEN5ION TE5T OATA*

5pacing	Condi-tion	Std. T.5. (ksi)	Notch T.5.† (ksi)	Ratio	5td. T.5. (ksi)	Notch T.5.† (ksi)	Ratio	5td. T.5. (ksi)	Notch T.5.† (ksi)	Ratio	5td. T.5. (ksi)	Notch T.5.† (ksi)	Ratio	5td. T.5. (ksi)	Notch T.5.† (ksi)	Ratio	5td. T.5. (ksi)	Notch T.5.† (ksi)	Ratio
		4130 - 0.032" T			4130 - 0.050" T			4130 - 0.063" T			4340 - 0.063" T			18% Ni - 0.030" T			18% Ni - 0.055" T		
5ingle Weld	A	244	171 171	0.70 0.70	242	134 139	0.55 0.57	-	-	-	-	-	-	234	182 198	0.78 0.85	236	222 226	0.94 0.96
	B	257	159 215	0.62 0.84	239	146 195	0.61 0.82	258	134 134	0.52 0.52	281	181 220	0.64 0.78	-	-	-	-	-	-
	C	242	150 150	0.62 0.62	238	154 154	0.65 0.65	-	-	-	-	-	-	-	-	-	-	-	-
	0	-	-	-	-	-	-	217	72 95	0.33 0.44	-	-	-	-	-	-	-	-	-
	E	245	159 206	0.65 0.84	240	164 183	0.68 0.76	268	118 154	0.44 0.57	287	188 217	0.66 0.76	227	167 255	0.74 1.12	245	196 241	0.80 0.98
	8ase Material	215	209	0.97	253	148	0.58	238	192	0.81	263	171	0.65	245	243	0.99	246	251	1.02
1/2 in.	8	228	150 275	0.66 1.21	251	147 217	0.59 0.86	251	153 207	0.61 0.82	-	-	-	242	161 294	0.67 1.21	241	171 277	0.71 1.15
	C	-	-	-	212	187 187	0.88 0.88	-	-	-	-	-	-	-	-	-	226	217 237	0.81 0.96
	0	174	65 90	0.37 0.52	168	100 162	0.60 0.96	-	-	-	-	-	-	148	100 178	0.68 1.20	146	123 179	0.69 1.23
	E	236	135 247	0.57 1.05	223	140 227	0.63 1.02	231	157 242	0.68 1.05	-	-	-	233	150 172	0.64 1.21	232	192 284	0.68 1.22
3/4 in.	8	240	147 246	0.61 1.03	254	160 246	0.63 0.97	252	168 234	0.67 0.93	263	164 263	0.62 0.98	241	162 283	0.67 1.17	237	186 267	0.78 1.13
	C	174	161 163	0.93 0.94	190	111 111	0.58 0.58	-	-	-	-	-	-	238	171 302	0.72 1.27	229	185 217	0.81 0.95
	0	127	106 189	0.83 1.49	178	96 146	0.54 0.82	-	-	-	-	-	-	146	102 171	0.70 1.17	146	120 148	0.82 1.01
	E	182	86 195	0.47 1.07	216	149 245	0.69 1.13	228	166 222	0.73 0.97	257	137 252	0.54 0.99	235	201 283	0.86 1.20	235	201 283	0.86 1.20
1 in.	8	213	202	0.95	233	197	0.88	255	202	0.79	226	177	0.78	240	246	1.03	248	243	0.99
	E	-	-	-	-	-	-	-	-	-	-	-	-	257	205	0.80	251	237	0.94
1-1/4 in.	8	227	200	0.88	222	205	0.92	240	189	0.79	-	-	-	247	244	0.99	241	236	0.98
	E	-	-	-	-	-	-	-	-	-	-	-	-	244	209	0.86	249	227	0.90

*Notches in weld (spacings - single weld, 1/2 in., and 3/4 in.)
Notches in heat-affected zone (spacings - 1 in. and 1-1/4 in.)
†Top value calculated on cross-sectional area at weld, bottom on area of sheet

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