APPLICABILITY OF FIRECRACKER WELDING TO SHIP PRODUCTION

BETHLEHEM STEEL CORPORATION/
MARITIME ADMINISTRATION

July 31, 1975

by

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PRBFACE

This report presents the results of a research program for the Bethleha Steel corporation and under the support of the U. S. Maritime Administration. Mr. W. C. Brayton, Bethlehm Steel Corporation was the Program Manager. The objective was to develop the procedures, facility requirements, consumables and general specifications for the application of firecracker welding to shipyard fabrication.

The program was carried out by the Battelle-Columbus Laboratories under the broad direction of Mr. D. C. Martin. Mr. R. P. Meister was the Project Manager, Mr. R. M. Evans was the Project Engineer and Mr. John F. Dethloff the Principal Technician. Dr. R. L. Rdthman, formerly of the Battelle-Columbus Laboratories, was Technical Consultant to the program.

Special welding electrodes were fabricated by the Hobart Brothers Company, Troy, Ohio, under the supervision of Mr. H. B. Cary, and Mr. W. A. Wiehe. Experimental adhesive tapes for holding electrodes in place were furnished by the 3M company, Industrial Specialties Division, St. Paul, Minnesota, through Mr. Roger H. Keith. The assistance of these organizations is gratefully acknowledged.

Experimental data for the program are recorded in Battelle-Columbus Laboratory Record Books, Nos. 31305 and 31810.

SUMMARY

Firecracker welding is a particular version of the shielded metal-arc welding process. In this technique standard electrodes are used to automatically produce welds by placing them in the groove, starting the arc, and allowing it to travel along the joint. An investigation of firecracker welding was conducted to establish the procedures, specify the operating parameters and define the consumables for its use in shipyards.

During the program, a number of standard electrodes in the AWS Classes E6XXX and E7XXX were evaluated for the production of firecracker welds in the horizontal position. Electrodes having both circular and modified cross sections were studied to provide information for choosing those most applicable for fillet and groove welds. Those with the normal circular cross section produced welds equal to or better than the others. Two standard electrodes E6027 and E7024 were shown capable of producing better welds more consistently than all the others considered. These were then used in all further studies. Long electrodes (72 inches) specially produced for the program and commercially available 28-inch-long electrodes were used to successfully make both fillet and groove welds. The electrodes chosen and the AC welding techniques defined permitted the use of several passes to produce large fillet welds and make multipass groove welds. The E6027 electrode was the most preferred because of the consistency obtained.

Significant progress was made in the development of methods of holding the electrode in the joint as welding progressed. This work covered the use of adhesive tapes, copper hold-down blocks, mechanical clamps and permanent magnets. Tapes were the preferred holding system in this program. Other hold-down methods were equally effective, the choice would depend on factors such as costs fixture maintenance? space available and tolerance to spatter. Electrodes up to about 18 inches long can be held in place with the electrode holder only.

Many tapes lose their holding capability due to resistance heating of the long electrode. Commercial reinforced strapping tape was suitable for welds up to 25 inches long. An evaluation of special tapes

produced for the program revealed one composite tape having much promise. This tape was capable of holding 72-inch-long electrodes without deterioration caused by the hot electrode.

The firecracker welding parameters developed show that lower power inputs than used during manual shielded metal-arc welding must be used. This is especially true when fillet welding where arc stability and spatter may be excessive. The coatings on the electrodes used in this program were the same as used for the standard shielded metal arc process. It is expected that an improved firecracke welding electrode coating could be found which would produce better weld surfaces.

Weld-through protective coatings on the plate have the same effect on firecracker welding that they have on other processes. They cause unstable arcs and spatter.

Vertical welds made by holding all-pxition type electrodes in the joint with a grooved copper bar were also made. The weld bead obtained when using one and two-pass techniques had undesirable features such as poor shape and inadequate base metal fusion.

FINAL REPORT

on

FIRECRACKERWELDING FOR
SHIPYARD APPLICATIONS

to

BETHLBHEN STEEL CORPORATION/
MARITIME ADMINISTRATION

from

BATTELLE
Columbus Laboratories

July 31, 1975

INTRODUCTION

Firecracker welding is an automatic welding process using shielded metal-arc (SMA) electrodes and equipment. An SMA electrode is placed lengthwise in the joint as shown in Figure 1. It is fixed in place by a suitable hold-down method, and the butt end placed in an electrode holder connected to a suitable power supply. The arc is then initiated, and it runs the length of the electrode automatically completing the weld without further operator involvement.

There are several inherent differences between firecracker welding and conventional SMA welding:

(a) The size of the firecracker weld is determined solely by the type and diameter of the electrode since no electrode manipulation occurs during firecracker welding. The expected fillet sizes for a given size and type electrode are shown in Table 1 for the types in which all weld metal comes from the electrode core and for those in which thirty percent of the weld metal comes from iron powder in the coating.

(b) The welding speed is determined by the operating current. Higher currents produce higher speeds.

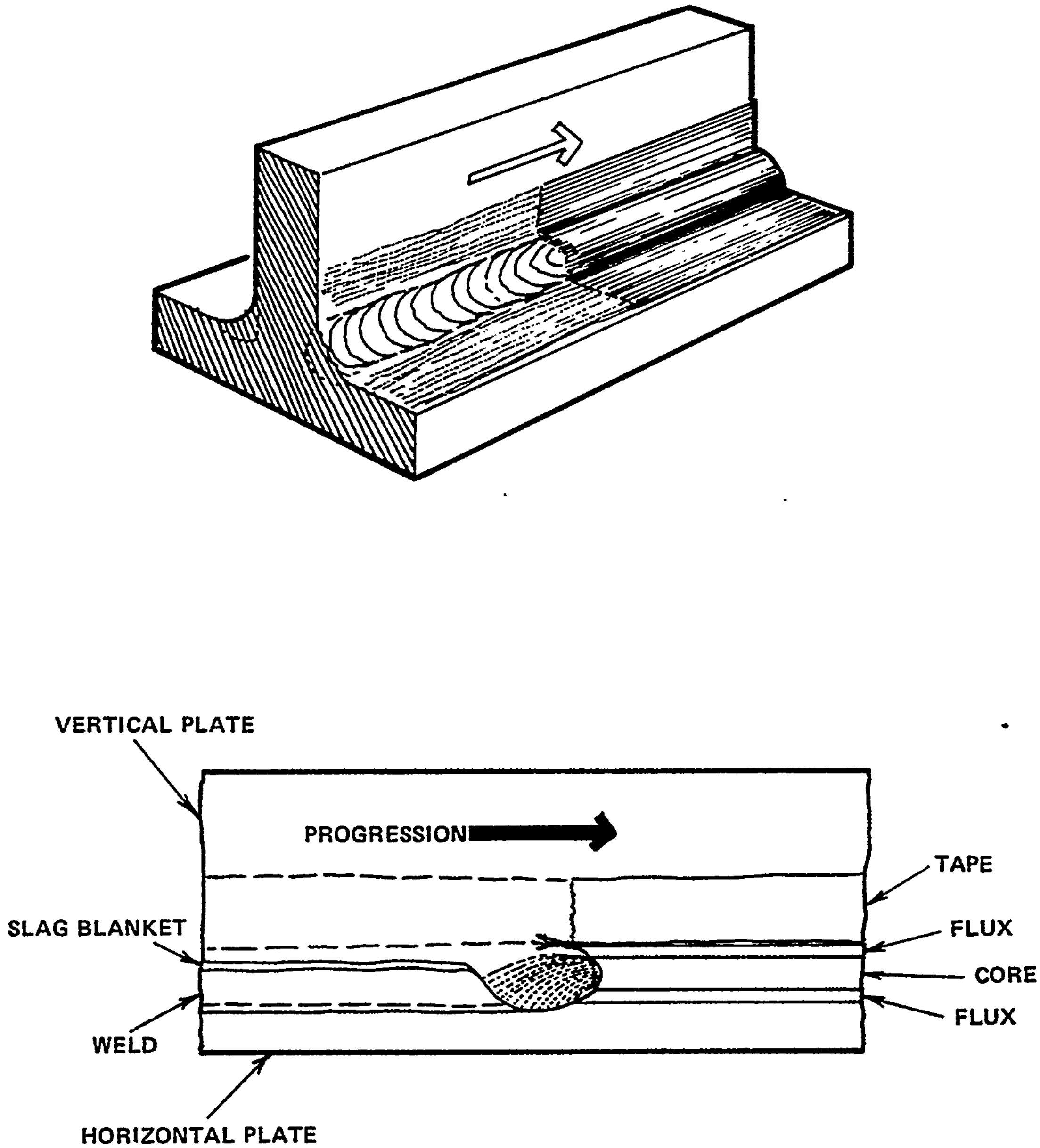


FIGURE 1. SCHEMATIC OF FIRECRACKER WELDING

TABLE 1. CALCULATED RELATIONSHIP OF ELECTRODE DIAMETER TO FIRECRACKER WELD FILLET SIZE

Electrode Diameter, inch	Fillet Size Without contribution From Coating, inch	Fillet Size if Coating Contributes 30% of Weld Metal, inch
l/8	5/32	3/16
3/16	1/4	9/32
1/4	5/16	11/32
5/16	3/8	7/16

However, for any given type and size of electrode, the usable current range for satisfactory weld is limited.

(c) In general, the currents used in firecracker welding are different from those recommended for conventional SMA. This is necessary to reduce spatter and to produce an acceptable weld profile. A major component of the firecracker arc force is directed parallel to the joint directly toward the liquid weld metal rather than directly into the joint as with conventional SMA. If the current is too high, this component can spread spatter along the joint and agitate the weld puddle, thus disturbing solidification patterns. Optimum firecracker welding currents will produce good shaped welds with adequate penetration and little spatter, but this optinnm current is always less than that recommended for the conventional procedures. A further effect of the force parallel to the joint is to cause instability at initiation until a good weld pool is established.

(d) The electrode length, hence the length of continuous weld, can be much greater than for manual or gravity SMA welding.[a] The electrodes do not have to be of standard lengths to fit a device such as a gravity welder; rather, the length can be chosen to fit fabrication requirements for a particular application.

(e) Firecracker welding is an automatic process and does not require that the welder be involved during welding- He only has to place the electrode and start the arc to initiate welding and to chip the slag after welding is completed.

(a) Gravity welding is a shielded metal arc welding process in which a mechanical device holds the electrode and permits feeding the arc by the force of gravity.

(f) Firecracker welding can be used to make limited access welds which are difficult or impossible for a welder to make with conventional SMA techniques.

(g) The arc length cannot be manually lengthened or shortened during welding. Voltage is determined by the electrode shape, size, and fit to the joint.

me advantages of firecracker welding to ship construction are in the areas of limited access welding, long fillets, and perhaps vertical fillet welding. In the case of horizontal fillet welds, the firecracker method compebes with gravity welding, but is capable of much longer continuous welds; no widely accepted welding process exists which can be operated in an automatic mode for limited access and vertical fillet welding.

The long fillet weld features of firecracker welding are applicable throughout the shipyard - in panel, subassembly, and final erection stages. No complex equipment is required - only a conventional shielded metal-arc power source - so that it can be performed at any physical location within the yard. The operator skill required is less than that needed in conventional shielded metal-arc weldings and the use of long electrodes will permit one welder to conduct more simultaneous welding than possible with gravity welding. Grillage construction is an example of an effective use of firecracker welding.

Limited access welds are a problem in many phases of ship construction. They normally require more labr input per unit of weld than accessible welds and can be of lower quality due to limited visibility and generally poor working conditions. Rudder construction is one example where such problems are encountered. Firecracker welding does not require welder visiblity of accessibility.

Recognizing these applications and advantages, a program was established at Battelle-Columbus by Bethlehem Steel, Sparrows Point Shipyard and the Maritime Administration to develop firecracker welding for shipyard application. This program was organized in four phases as follows.

Phase I - Electrode Screening and Procedure Development

The objective of this phase was to establish a laboratory procedure for firecracker welding and select the most promising electrode(s) to produce fillet welds of adequate size in one pass, for subsequent development and for eventual production use. Electrode type, length, coating, coating shape and thickness, core diameter, electrical parameters including current, voltage, and type of power, and hold-down methods were all to be studied and their effects on firecracker welding determined. The results of this phase would be applicable to all subsequent work.

Phase II - Evaluation of Long Electrodes

The electrodes performing best in the firecracker welding experiments of Phase I were procured in six-foot lengths from Hobart Brothers Company. Electrodes as long as 28-inch gravity rods were examined in Phase I, and lengths from three to six feet studied in Phase II. Securing all electrodes in six-foot lengths, permitted preparation of three-, four-, and five-foot electrodes in-house by cutting the long ones to the desired length. The objective of this phase was to determine if a limiting length exists for practical firecracker welding and, if so, what that limit is.

Phase III - Production Welding in the Horizontal Position

The objective of this phase was to solve production-related problmes associated with firecracker welding. Included in this catagory were start and stop procedures, further hold-down works effect of tack welds, and effect of primer. simultaneous two-sided firecracker welding, multiple-pass welds, and groove welds were also to be examined.

Phase IV - Vertical Firecracker Welding

The objective of Phase IV was to develop procedures for vertical firecracker welding.

PHASE I - ELECTRODE SCREENING AND PROCEDURE DEVELOPMENT

3/16-Inch-Diameter Electrodes

The initial experimental effort of Phase I was directed to screening studies on 3/16-inch electrodes to determine the best electrodes for the more intensive program effort to follow and to assess the importance of several key variables including electrode shape and electrical variables. The electrodes included in this phase along with their dimensions are shown in Table 2.

All welds made in this phase were horizontal fillets 12 inches long. Mild steel plate was used with the surface in the as-received condition. The specimen used is shown in Figure 2. The electrode was placed in the joint and held in place by either tape or a copper bar contoured to fit the electrode. (Hold down procedures are discussed in another section of this report.) An AC/DC power Supply [a] was used and a conventional electrode holder attached to the butt end of the electrode. current and voltage were monitored continually by strip chart recorders. The desired current level was set on the machine and the arc started. In some welds the current was changed midway through the weld to examine two current levels in one experiment, and in some the machine setting was not changed. Normal current and voltage decreases during welding were of the order of 10 percent. A carbon rod was normally used to initiate the arc in the 3/16-inch electrode welds.

The three principal electrode geometries used are shown in Figure 3. These geometries are the round (as received) and the one-flat and two-flat shapes shown in the figure. The flat shapes were made by removing coating on an abrasive belt. The rationale involved in expertienting with the shapes was to get the core of the electrode closer to the joint, thereby creating an arc which would be shorter, stiffer, and directed into the corner. The one flat geometry was used to observe arc behavior, but it was recognized that it was impractical for production use because of alignment difficulties. The two flat geometry was easily aligned, and it

(a) Model TG301, 300 amp., Hobart Bros. Co., Troy, Ohio.

TABLE 2. SIZES OF 3/16-INCH ELECTRODES[a]

Electrode	Length, Inches	Coating Thickness, Inch	Total Electrode Diameter, Inch
E6010	14	0.025	0.236
E6013	14	0.033	0.253
E6027	18	0.103	0.391
E7018	14	0.055	0.297
E7024	18	0.102	0.391
E7028	18	0.099	0.385
E7016	14	0.048	0.284

(a) All core diameters were 0.187 $\pm$ 0.001 miles.

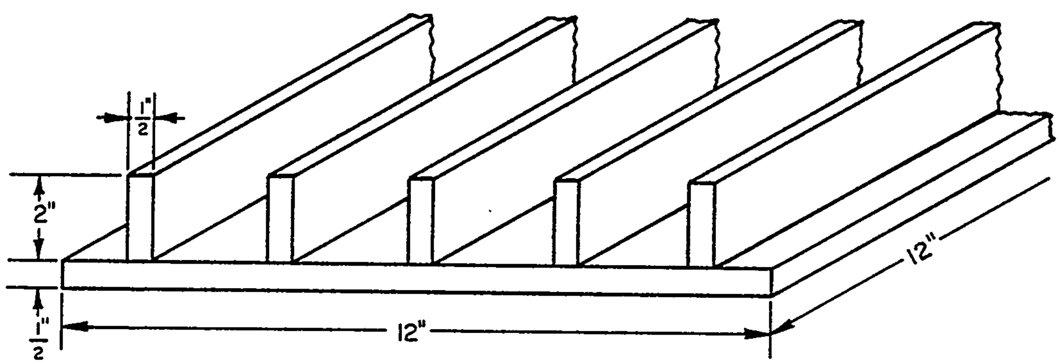
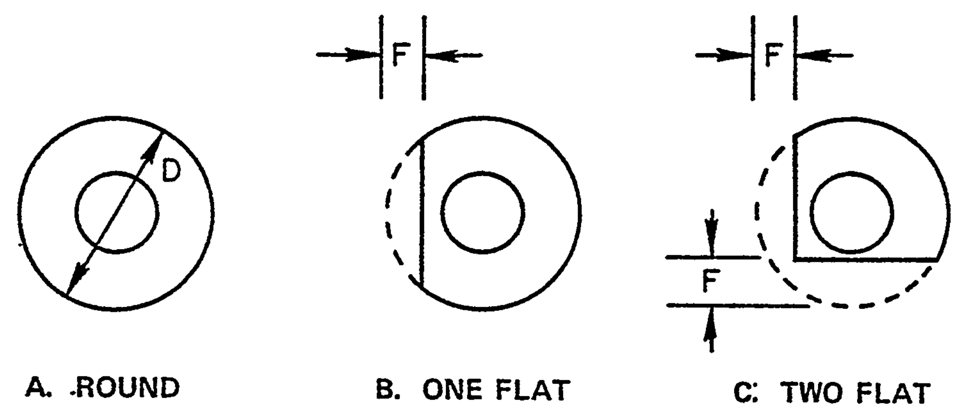


FIGURE 2. SPECIMEN USED FOR FIRECRACKER WELDING STUDIES

Note: As the program progressed ribs were placed on both faces of the plate. This minimized warping while conserving steel.



ELECTRODE	D (IN.)	F (IN.)	PERCENT FLUX REMOVED, BY WEIGHT	
			ONE FLAT	TWO FLAT
7016	0.284	.020	8	15
7024	0.391	.049	12	24
7028	0.385	.053	12	23

FIGURE 3. TYPICAL DIMENSIONS FOR ELECTRODE GEOMETRIES USED IN 3/16 INCH STUDY

was successful in lowering the operating voltage over that of the round electrode, thereby causing a shorter arc. The effects of two-flat and round geometries are discussed as part of the results of each electrode in the following pages; however, it can be noted here that although the two-flat lowered operating voltage, it did not produce consistently better welds in many cases than the round electrode. A three-flat geometry was experimented with briefly and abandoned when no advantages were observed over the simpler two-flat electrodes. The three-flat geometry was obtained by grinding off the point at the juncture of the flat sides of the two-flat electrode.

Results of Screening Tests With 3/16 Inch Electrodes

E6010 Electrodes

Sample No.	I (amps)	V (volts)	Power Type	Electrode Shape	Hold-down
102	110-125	23-28	DCRP	Round	Tape
103	145-155	32-34	DCRP	Round	Tape
101	180-190	34-37	DCRP	Round	Tape
104	185-190	30-32	DCRP	Round	Cu

The above series of welds represent a wide range of operating conditions, yet none produced a satisfactory weld. The weld tended to be discontinuous, to lie more in the flat (flange) than the vertical (web) part of the joint and to short out during running. The 6010 electrode was abandoned to concentrate on more promising electrodes.

E6012 Electrodes

Sample No.	I (amps)	V (volts)	Power Type	Electrode Shape	Hold-down
122	165-170	21-26	DCSP	Round	Cu
124	165-175	22-25	DCSP	Round	Cu
123	185-190	26-30	DCSP	Round	Cu
121	205-225	28-32	DCSP	Round	Cu
125	195-220	--	DCRP	Round	Cu
126	185-max	20-25	DCRP	Round	CU
127	260-275	27-30	Ac	Round	Cu
128	255-260	29-30	AC	Round	Cu
129	270-275	27-28	AC	Round	Cu
1210	270-280	27-28	AC	Round	Cu

The welds made with the E6012 electrode were erratic. The DCSP welds tended to be discontinuous at the higher currents and produce rough surfaces when a bead was obtained. The lower current welds had a better surface appearance, but the beads were convex with small legs, and significant undercut occurred. The DCRP welds both shorted out. The AC welds were also quite convex and at the currents used showed significant undercut.

E6013 Electrodes

Sample No.	I (amps)	v (volts)	Power Type	Electrode Shape	Hold-down
131	190-200	27-32	DCRP	Round	Cu
132	190-205	28-30	DCRP	Round	Cu
134	225-230	25-30	DCRP	Round	Cu
133	Would not	start	DCSP	Round	Cu
135	265-270	29-31	A C	Round	Cu
136	255-260	27-29	AC	Round	Cu
137	245-250	27-30	AC	Round	Cu
138	220-225	26-27	AC	Round	Cu

The E6013 welds at lower current showed some promise although the beads were convex. The high current DCRP weld showed poor wetting, and the majority of the weld metal was on the flange. The DCSP weld could not be started. Welds made with AC current were similar to the DCRP welds. They were quite convex and showed serious undercut when the current was over 225 amperes. At lower currents only minor undercut was encountered.

E7016 Electrodes

Sample No.	I (amps)	v (volts)	Power Type	Electrode Shape	Hold-down
169	190-200	22-28	AC	Round	Cu
1610	180-220	20-22	AC	Flat	Cu
16R	190-200	20-28	AC	Round	Cu
	190-200	24-26	AC	Round	Cu
16FF	200-210	22-24	AC	2 Flat	Cu
	190-200	22-24	AC	2 Flat	Cu
162	145-155	20-27	DCRP	Round	Cu
163	160-180	22-30	DCRP	Round	Cu
164	165-190	21-30	DCRP	1 Flat	Cu
168	165-180	20-27	DCRP	1 Flat	Cu
165	180-195	21-25	DCRP	2 Flat	Cu
161	170-195	22-30	DCRP	Round	Cu

(E7016 Electrodes Continued)

Sample No.	I (amps)	V (volts)	Power Type	Electrode Shape	Hold-down
167	165-185	21-30	DCRP	Round	Cu
166	235-250	24-28	DCRP	2 Flat	Cu
D16R	170-180	28-30	DCRP	Round	Cu
	175-185	32-34	DCRP	Round	Cu
D16FF	195-20S	22-26	DCRP	2 Flat	Cu
	190-200	21-24	DCRP	2 Flat	Cu

The E7016 electrode produced good firecracker welds with both AC and DCRP power. An electrdde with one or two flats tended to give a better weld profile (less convexity) than a round electrode, although acceptable welds occured with both geometries. Also0, DCRP tended to give a smoother weld surface than AC. The best operating current was around 200 amps; higher currents gave undercut, and lower currents reduced the vertical leg size.

Reproducibly good firecracker welds were obtained with E7016 electrodes. However, the fillet size (approximately 3/16 inch) was less than that obtained with electrodes containing iron powder which produce firecracker welds of comparable or better quality, and for this reason the program emphasis on E7016 electrodes was reduced.

E7028 Electrodes

Sample No.	I (amps)	(Volts)	Power Type	Electrode Shape	Hold-down
288	230-250	30-34	AC	Round	Cu
2814	240-250	32-34	AC	Round	Cu
2815	250-260	26-28	AC	2 Flat	Cu
2816	240-250	26-28	AC	2 Flat	Cu
289	250-270	28-32	AC	1 Flat	Cu
2810	250-270	26-28	AC	2 Flat	Cu
2811	300	32-34	AC	2 Flat	Cu
28R	240-250	32-36	AC	Round	Cu
	240-250	32-36	AC	Round	Cu
28FF	250-260	28-32	AC	2 Flat	Cu
	250-260	28-32	AC	2 Flat	Cu
283	140-155	22-30	DCRP	Round	Cu
281	185-250	25-35	DCRP	Round	Cu
282	160-200	25-35	DCRP	Round	Cu
284	150-190	27-38	DCRP	Round	Cu

(E7028 Electrodes Continued)

Sample No.	I (amps)	V' (volts)	Power Type	Electrode Shape	Hold-down
286	190-225	30-37	DCRP	1 Flat	Cu
285	215-235	34-37	DCRP	Round	Cu
2812	260-280	30-34	DCRP	2 Flat	Cu
2813	255-275	29-34	DCRP	2 Flat	Cu
287	220-240	25-30	DCRP	2 Flat	Cu
D28R	210-220	34-36	DCRP	Round	Cu
	220-230	31-33	DCRP	Round	Cu
D28FF	215-240	28-35	DCRP	2 Flat	Cu
	240-250	27-30	DCRP	2 Flat	Cu

The principal problem encountered with E7028 electrodes was surface porosity. It occurred in practically all firecracker welds made with this electrode. Changes in electrode handling did not eliminate porosity; it occurred when electrodes were removed from the hermetically sealed container, and it occurred when electrodes were baked at 600 F overnight and held at 300 F until use. Porosity occurred for both AC and DCRP welds and irrespective of the electrode geometry.

With respect to aspects of the weld other than porosity, E7028 electrodes generally produced good firecracker welds. The best current range was found to be 220 to 260 amps with both AC and DCRP power. Undercut occurred occasionally, but the bead contour was otherwise good. Fillet sizes of 5/16 inch were obtained with round electrodes and 1/4 inch with two flats. Lower currents tended to make the weld metal ball up and give poor fusion. The two-flat electrodes gave better bead shape in general than the round electrode. The porosity probla was unique to E7028 electrodes among all those examined in the program, and the program emphasis was reduced for E7028 electrodes for this reason.

E7018 Electrodes

Sample No.	I (amps)	(voyts)	Power Type	Electrode Shape	Hold-down
1815	170-180	20-26	AC	Round	Cu
1816	190-200	18-22	AC	1 Flat	Cu
1819	210	25	AC	2 Flat	Cu

the entire weld was maintained. Fillet size with round electrodes was 1/4 inch vertical leg and 5/16 horizontal and with 2 flat electrodes it was 1/4 inch plus for both legs.

E7024 Electrodes

Sample No.	I (aPs)	V (volts)	Power Type	Electrode Shape	Hold-down
247	210-220	34-38	AC	Round	Cu
248	240-250	32-34	AC	2 Flat	Cu
249	24Q-250	20-32	AC	2 Flat	Cu
2410	330	44	AC	Round	Cu
2411	300	38-40	AC	1 Flat	Cu
2412	300	34-36	AC	2 Flat	Cu
2413	300	38-40	AC	2 Flat	Cu
24R	240-250	34-38	AC	Round	Cu
	240-250	34-38	AC	Round	Cu
24FF	250-260	30-32	Ac	2 Flat	Cu
	250-260	30-32	AC	2 Flat	Cu
241	160-210	31-41	DCRP	Round	Cu
243	165-195	36-40	DCRP	Round	Cu
244	190-200	35-37	DCRP	1 Flat	Cu
242	225-250	36-46	DCRP	Round	Cu
245	205-240	34-41	DCRP	1 Flat	Cu
246	225-250	33-38	DCRP	2 Flat	Cu
2414	250-275	35-40	DCRP	2 Flat	Cu
D24R	225-235	32-37	DCRP	Round	Cu
	225-235	32-37	DCRP	Round	Cu
D24FF	245-255	32-34	DCRP	2 Flat	Cu
	245-255	32-34	DCRP	2 Flat	Cu
2415	260-285	35-39	DCSP	2 Flat	Cu

The E7024 electrode continually gave the best welds of all electrodes studied during the screening tests. It performed equally well with AC or DCRP power, and the arc was smooth and stable. Bead shape was good with fillet legs being approximately equal, with little undercut, and good blending at the toes. Fillet sizes were typically 1/4 inch vertical leg and 5/16 inch plus horizontal leg with round electrodes and both legs 5/16 inch with the two-flat electrode shape. The bead showed some excess convexity with a bump in the center of the bead, but this appears to be characteristic of the electrode as it occurs for E7024 deposits in conventional and gravity welding as well as firecracker. Good welds were made with both round and two-flat geometries with no clear preference indicated. Optimal operating currents were in the 220 to 250 amp range; higher currents produced a harsher arc, more spatter, and less favorable bead appearance and shape. The E7024 was considered the best 3/16 inch diameter electrodes tested for firecracker welding.

Summation of Electrode Screening Results

Based on welds made with 3/16 electrodes 14 inches long only. Both copper and tape holddowns were used.

E6010

No satisfactory welds made. Welds discontinuous or to one leg of T joint. Shortouts common.

E6012

Poor welds produced regardless of current type and polaritY. Beads were too convex, rough, and often discontinuous.

E6013

DCRP welds very convex. DCSP welds could not be started. Ac welds had excessively high crown and bad undercut at tolerable current levels.

E6027

Produces firecracker welds with good profile with each current type. AC current preferred. Higher currents possible than with other electrodes because of minimal undercut. Slag flows away from weld bead. Best electrode of the E6XXX group evaluated. Second choice in screening tests.

E7016

Good firecracker welds produced on AC and DCRP currents. Fillets are small and convex.

E7018

Like E7016; good welds with short fillet legs and convex profile.

E7024

Firecracker welds produced were the best made during the screening tests. Good reproducible welds obtained on both AC and DCRP currents. Weld beads convex. Higher currents possible without undercut or spatter than with most other electrodes.

The electrodes chosen for continued study in Phase II and III of the program were E6027 and E7024. These electrodes produce weld beads of desirable shape which are readily reproducible. They are also chosen for another reason important to the success of firecracker welding. It will be desirable in many firecracker welding applications to make a complete weld in a single pass due to space limitation. The heavy coating containing as much as 50 percent iron powder on these electrodes provides weld fillet sizes not obtainable with other electrodes. Thus they provide more assurance that weld beads of adequate size can be made in a single pass.

PHASE II - EVALUATION OF LONG ELECTRODES

As a resultof the conclusions drawn during Phase I and the concurrent results from Phase III when using 28-inch electrodes specially made 72-inch-long electrodes were ordered for evaluation for firecracker welding. These were standard E6027 and E7024 electrodes with the normal circular cross section. The diameters of the E6027 were 7/32 and 1/4 inch. The E7024 electrode was secured in three diameters, 3/16, 7/32, and 1/4 inch, because the early results indicated this electrode would be preferred. Approximately 50 lbs. of each size of electrode were ordered.

when received, the long electrodes appeared normal except for straightness and 3 deformation marks on the coating of each electrode which were caused by the racks in the baking oven. The straightness caused no problems during the program. The coating deformation marks contained cracks as shown in Figure 4. These defects were all oriented on one side of the electrode and therefore could be located in the weld joint to avoid any influence on the test results. All electrodes ware tipped with a self-starting compound.

The coating thickness on the long electrodes were approximately the same as on electrodes used in other parts of the program. They are given in Table 3.

The long electrodes were evaluated initially by cutting into shorter lengths and comparing welding results with those obtained in Phase III work with 28-inch electrodes. Even though there were differences in coating thicknesses and the defect spots were present, the welds produced duplicated previous results.

The initial long electrode welds were made as a fillet on common hot-rolled angle iron in order to get data on the operating conditions rewired. These fillets were made at the same welding parameters used for 28-inch electrodes. These parameters proved satisfactory for the long electrodes. In these tests there was some concern for changing power input conditions as the arc progressed, for the resistance heating that sould occur, the suitability of the strapping tape holddown, and for the welding speed. The data recorded in Table 4 show that the power input variations were not a serious factor for concern. The data are very similar to records for 28-inch electrodes. The input power as measured by the parameter EI/1000 continuously decreased, but did not go below the level known to be satisfactory from other tests. The total lapsed time to make the 66.5-inch weld bead was 8.4 minutes or an average of 7.9 in./min. This welding speed is essentially the same as recorded for other electrodes of this diameter. The taperature rise of the electrode during welding was measured by heat-sensitive crayon marks on the stub end coating. When 66.5 inches of the electrode had burned off the surface of the electrode at the stub end was between 700 and 800 F. This increase in electrode surface temperature is very important to any holddown method involving adhesive tape because of

FIGURE 4. TYPICAL DEFECT IN COATING OF 72 INCH ELECTRODES

TABLE 3. COATING THICKNESS ON 72-INCH ELECTRODES

Electrode Type	Electrode Diameter, in.	Coating thickness, in.
E6027	7/32	0.100
E6027	1/4	0.096
E7024	3/16	0.076
E7024	7/32	0.084
E7024	1/4	0.100

TABLE 4. POWER INPUTS DURING WELDING WITH A 72 INCH E6027, 7/32 INCH DIAMETER ELECTRODE

Distance from Arc Start, in.	Current, A	Voltage, V	ExI/1000
0	190	41	7.8
16	200	37	7.4
33	205	35	7.4
49	205	34	7.0
66	210	33	6.9

possible burning and loosening of the tape. In these tests strapping tape holddown failure did occur. The problem and the efforts undertaken to overcome it are discussed in detail in another section of this report.

Subsequently, T joints were produced with each of the long electrodes. The results verified the test discussed above and the expectations developed from welds made with shorter lengths of those electrodes: 1. Satisfactory fillet welds up to at least 60 inches long can be made consistently with E6027 electrodes. 2. Completely satisfactory fillet welds over about 30 inches long are difficult to produce with E7024 electrodes, and duplication was not often possible. A tendency for the bead to favor one side of the joint and for entrapment of slag in the bead are deterrents for the use of E7024 electrodes. 3. The method of holding the electrode in the joint and the need for welding over tack welds are critical to the success of firecracker welding long joints. Sections of this report on experimental hold-down adhesive tapes, on two-side welds and on welding over tacks cover the work conducted on these subjects with both 72-inch and other lengths of electrodes.

PHASE II AND III - EVALUATION OF LONG ELECTRODES AND PRODUCTION WELDING

Optimization of Welding with 28-Inch E6027 and E7024 Electrodes

During the electrode screening work of Phase I, two electrodes were chosen as most apt to consistently produce good firecracker welds of the desired size. These were the AWS E6027 and E7024. It was determined that these electrodes would be obtained in 6-foot lengths and 3 diameters for study in Phase II of this program, which had the objective of finding any limiting electrodes lengths that may exist for firecracker welding. At the same time, it was concluded that much information on firecracker welding could be developed with the commercially available 28-inch long electrodes, thus eliminating possible time loss before delivery of the 6-foot long electrodes. This meant that much of the work proposed originally as Phase III, Production Welding in The Flat Position was accomplished before the longer electrodes were delivered.

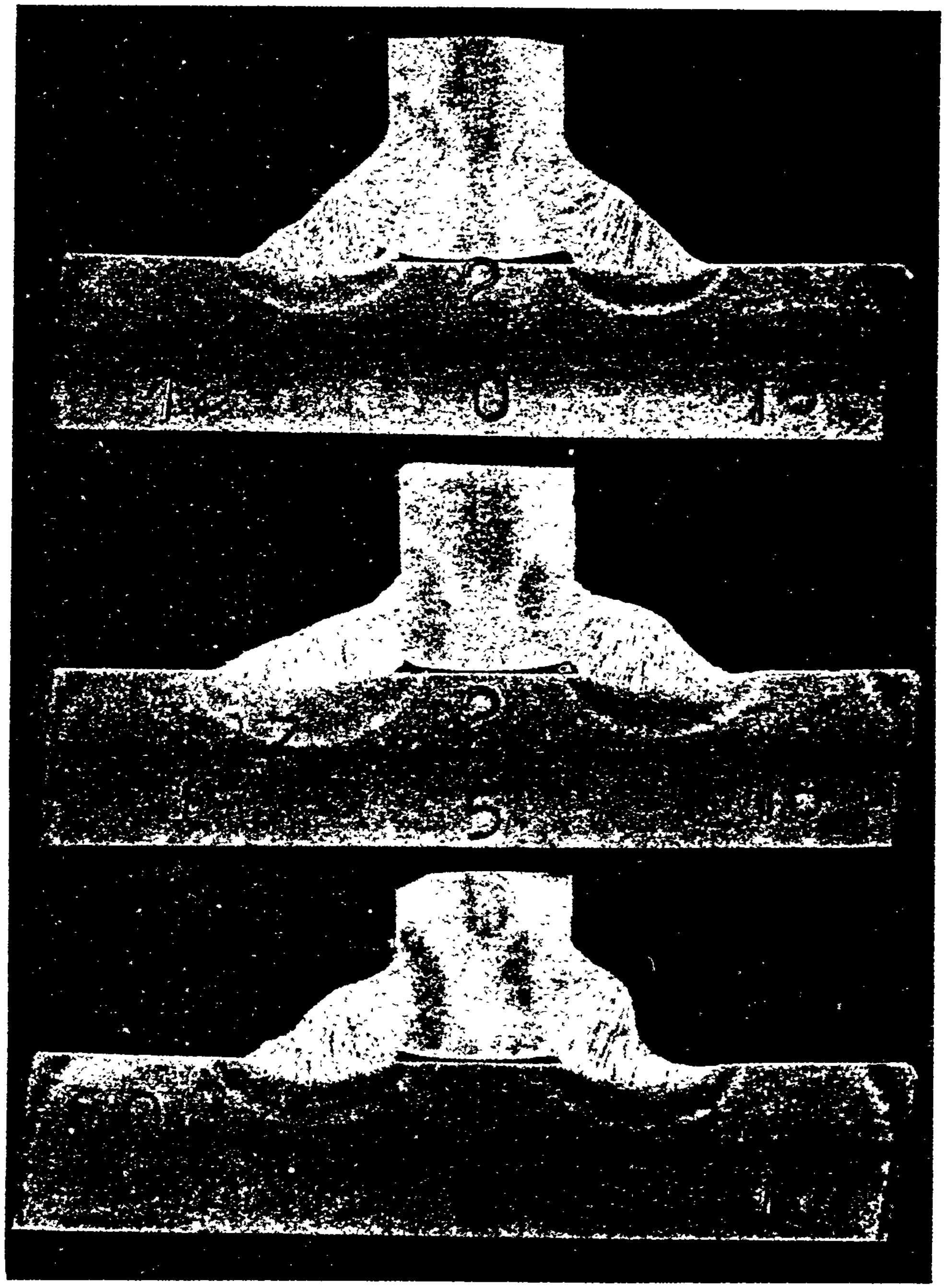
Selection of Welding Parameters

Numerous welds were made to develop those welding parameters for welding with 1/4 and 7/32-inch diameter electrodes that would consistently produce the best fillet shape with a minimum of undesirable features. These tests were run using either a mechanical device, or "strapping tape" to hold the electrode in the joint. The initial recorded data for welds made to develop welding parameters indicated that the best welds were obtained when the operating conditions, given in Table 5, were met.

The results with DC current welding were never as satisfactory as those with AC current. Consequently, it was concluded that subsequent development efforts would be limited to AC welding. The maximum values cited in Table 5 were of concern because the welding currents were much lower and the voltage was higher than commonly used with these electrodes for gravity welding. A study was therefore initiated to verify these values. The results are illustrated in Figure 5, which shows profiles of welds made with 1/4 inch electrodes at varying current levels. The top welds were made at 230 amperes and the lower ones at 300 amperes. The improved fillet profile obtained at lower currents is quite evident. In addition, other factors were recorded which justified limiting the maximum welding current for fillet welds. At higher currents, spatter was much greater, slag removal was difficult, undercut was less controllable and in the case of E7024, the convex profile of the fillet became more pronounced. The maximum welding parameters given in Table 5, therefore, served as the basis for all subsequent studies. They were altered as experience was gained, but were never increased above these maximums for fillet welding. For example, in preparation for the consistency tests reported in the next section the technician was instructed to determine initially the current and voltage settings which gave the most desirable operating conditions consistently.

TABLE 5. SUMMARIZATION OF INITIAL WELDING PARAMETER STUDIES

Electrode	Diameter, in.	Voltage, V.	Amperes, A	Polarity	Notes
E6027	1/4	35-39	235-240	AC	Maximum values
E6027	7/32	37-39	225-235	AC	Maximum values
E6027	3/16				
E6027	1/4	33-40	230-250	DCRP	Not good welds, arc blow
E6027	1/4	30-35	195-210	DCSP	Ditto
E7024	1/4	27-32	235-250	AC	Maximum values
E7024	7/32	27-32	210-220	AC	Maximum values
E7024	3/16				
E7024	1/4	32-36	245-260	DCRP	Much spatter, arc blow
E7024	1/4	34-36	235-250	DCSP	Ditto



Electrode Specimen No.	Current	Electrode Specimen No.

Consistency of Firecracker Welding Results

In order to establish further the validity of the welding parameters developed and to measure the uniformity of welds made by firecracker welding a “consistency run" was conducted. The E6027 and E7024 electrodes used were 28 inches long and 7/32 inch in diameter. This run utilized 10 electrodes of each class and 10 of each coating condition (not slotted and slotted) operated under identical preset welding parameters. All welds were run using AC current at a voltage between 35 and 40 volts and a welding current from 190 to 210 amperes for E6027; 30-36 volts and 200-220 amperes for E7024. Slotted electrodes coating studies are also discussed later in this report. In this way it was expected that the true value of slotting the electrode coating would also be found. The 40 weld joints were the T type and the steel was used as received from the supplier. Electrodes-were held in place by strapping tape.

The data collected during and after the production of the consistency run welds are given in Tables 6 and 7. The general conclusions drawn from these data follow.

E6027 Electrodes

(1) Under the conditions selected for standard coated E6027 electrodes good welds can be consistently produced regardless of whether or not the coating is slotted.

(2) Slotting the coating does not lead to better welds or electrode operation. (The data in Table 6 show 3 samples had poor penetration when 2 sections were examined macroscopically. Actually penetration along the length of all welds varied. This is shown in Figure 6 where sample 132 shows satisfactory penetration after repreparation for the macrograph.)

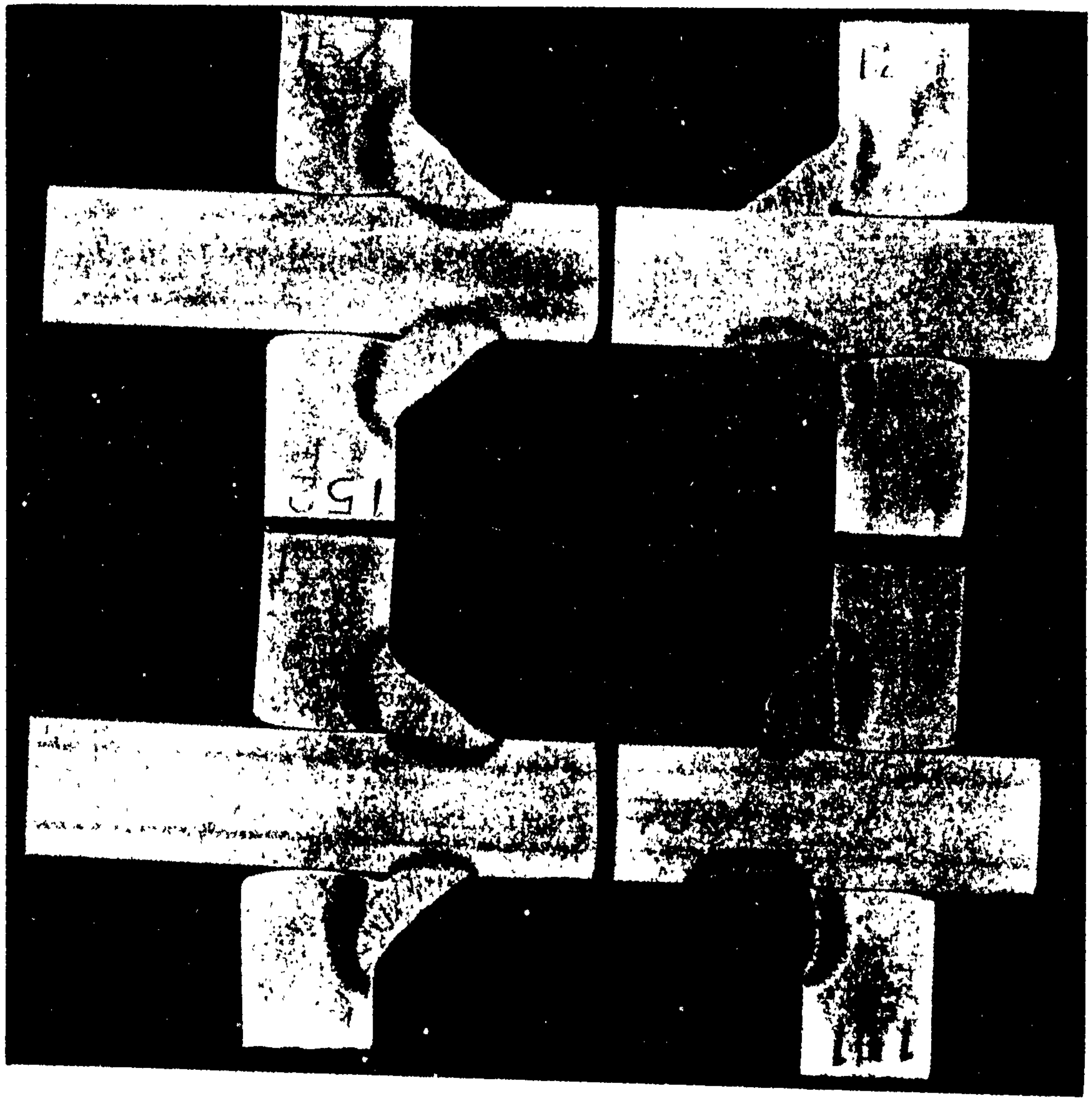
(3) Lower voltages lead to inferior welds and slag pockets in the weld bead; higher currents lead to undercutting.

TABLE 6 – ANALYSIS OF CONSISTENCY RUN WELDS MADE WITH 7/32 IN. DIAMETER E-6027 ELECTRODES

			WELD BEAD DATA - VISUAL										WELDING CURRENT, AVE. AMPS.				WELDING VOLTAGE, AVE. VOLTS				MACROSCOPIC - (2 SECTIONS)						
SAMPLE No.	COATING CONDITION	WELD LENGTH, IN.	NUMBER SLAG POCKETS	POCKETS 1ST THIRD	POCKETS 2ND THIRD	POCKETS 3RD THIRD	UNDERCUT - YES/NO/SLIGHT	SPATTER RATING	FILLET SHAPE	FILLET SURFACE	FILLET SIZE - HOR. IN.	FILLET SIZE - VERT. IN.	FIRST QUARTER BEAD	SECOND QUARTER BEAD	THIRD QUARTER BEAD	FOURTH QUARTER BEAD	FIRST QUARTER BEAD	SECOND QUARTER BEAD	THIRD QUARTER BEAD	FOURTH QUARTER BEAD	WETTING AT FILLET TOES	ROOT PENETRATED - YES/NO	UNDERCUT - YES/NO				Remarks
132	STD.	21.5	0	—	—	—	SLIGHT	GOOD	CONCAVE	NORM.	0.31	0.25+	205	205	205	200	36	36	35	37	GOOD	No	No				
133	STD.	21.5	0	—	—	—	DITTO	GOOD	DITTO	DITTO	0.31	0.25+	200	200	200	195	37	36	37	39 R	DITTO	No	No				R INDICATES ERRATIC CURVE
134	STD.	21.0	0	—	—	—	"	MED.	"	"	0.31	0.25	200	200	200	195	37 R	37	36	38 R	"	YES	YES				
135	STD.	20.5	0	—	—	—	No	MED.	"	"	0.31	0.25+	200	200	200	200	37 C	36	37 C	38 R	"	No	No				C INDICATES CLIMBING CURVE
136	STD.	15.5	0	—	—	—	No	MED.	"	"	0.31	0.25+	205	205	200	—	35 C	36	36	—	"	YES	No				ARC LOST TACK BROKE
137	STD.	21.5	0	—	—	—	No	MED.	"	"	0.31	0.25+	195 B	200	200	200	39 B	37	36	35	"	YES	YES				B INDICATES A CUSP ON CURVE
138	STD.	21.0	1	0	0	1	No	GOOD	"	"	0.31	0.31	190	195	200	205	40 R	39 R	36 S	39	"	YES	No				S INDICATES A SINKING CURVE
139	STD.	21.0	0	—	—	—	No	MED.	"	"	0.31	0.31	190	195	200	205	41 R	37 S	35 S	34 C	"	YES	No				
140	STD.	21.0	0	—	—	—	No	GOOD	"	"	0.31	0.31	190	195	200	200 B	40 R	38 S	36 S	36 B	"	YES	No				
141	STD.	21.0	0	—	—	—	No	GOOD	"	"	0.25+	0.31	200 B	200	210 C	210 S	40 R	38 S	35 S	35 S	"	YES	No				
152	SLOT	21.5	0	—	—	—	SLIGHT	GOOD	CONCAVE	NORM.	0.31	0.25+	210	205	205	205	35 C	35	35	36 B	GOOD	YES	YES				
153	SLOT	21.0	0	—	—	—	SLIGHT	DITTO	DITTO	DITTO	0.31	0.31	200	205	205 B	200	34 R	34 R	—	—	FAIR	YES	No				VOLT RECORDER LOST INK
154	SLOT	21.5	0	—	—	—	No	"	"	"	0.31	0.25+	205	205	205	205	36 R	35 R	35 R	35 R	GOOD	YES	No				
155	SLOT	21.5	0	—	—	—	SLIGHT	"	"	"	0.31	0.31	205	205 B	200	200	34 C	35 B	37 C	36	FAIR	YES	No				
156	SLOT	21.0	0	—	—	—	No	"	"	"	0.31	0.25+	200	205	205	200	37 R	36	36 R	36	FAIR	YES	No				
157	SLOT	21.0	0	—	—	—	YES	MED.	"	"	0.31	0.25	195	200	205	210	40 R	38 S	35 S	35	GOOD	YES	No				
158	SLOT	21.0	0	—	—	—	YES	MED.	"	"	0.31	0.25	190 B	200	205	200	41 B	38 S	36	37	DITTO	YES	No				
159	SLOT	21.0	0	—	—	—	SLIGHT	MED.	"	"	0.31	0.31	200	200	200	200	40 R	37	38	39	"	YES	YES				
160	SLOT	21.5	0	—	—	—	No	GOOD	"	"	0.31	0.25	190	200	200	200	39 R	38 R	37 R	36 R	"	YES	No				
161	SLOT			TEST LOST WHEN TACKS FAILED																							REPLACED BY No. 162
162	SLOT	21.0	0	—	—	—	No	GOOD	"	"	0.31	0.25+	205	205	205	205	34 R	35 R	36	36	"	YES	No				

TABLE 7 – ANALYSIS OF CONSISTENCY RUN WELDS MADE WITH 7/32 IN. DIAMETER E-7024 ELECTRODES

		WELD BEAD DATA – VISUAL											WELDING CURRENT, AVE. AMPS				WELDING VOLTAGE AVE. VOLTS					MACROSCOPIC (2 SECTIONS)					
SAMPLE No.	COATING CONDITION	WELD LENGTH, IN.	NUMBER SLAG POCKETS	POCKETS IN 1ST THIRD	POCKETS IN 2ND THIRD	POCKETS IN 3RD THIRD	UNDERCUT YES/NO/SLIGHT	SPATTER RATING	FILLET SHAPE	FILLET SURFACE	FILLET SIZE HORIZ., IN.	FILLET SIZE VERT., IN.	FIRST QUARTER BEAD	SECOND QUARTER BEAD	THIRD QUARTER BEAD	FOURTH QUARTER BEAD	FIRST QUARTER BEAD	SECOND QUARTER BEAD	THIRD QUARTER BEAD	FOURTH QUARTER BEAD	WETTING AT FILLET TOES	ROOT PENETRATED YES/NO	UNDERCUT YES/NO				Remarks
122	STD.	21.0	2	2	—	—	No	MED.	CONVEX	SMOOTH	0.35	0.25	210	220	220	220 S	29	31	31	31	GOOD	YES	No				S INDICATES A SINKING CURVE
123	STD.	21.0	0	—	—	—	No	DITTO	DITTO	DITTO	0.35	0.25	215	215	210	205 S	30	30	31	34	DITTO	YES	YES				W INDICATES A CYCLIC CURVE
124	STD.	21.0	1	1	—	—	No	"	"	"	0.35	0.25	220	215	210 S	205	31	30	33 C	36 W	"	YES	YES				C INDICATES A CLIMBING CURVE
125	STD.	21.0	0	—	—	—	No	"	"	"	0.35	0.25	210	210	210	205 S	33	34	34	36 C	"	YES	YES				
126	STD.	21.0	2	2	—	—	No	"	"	"	0.35	0.25	220 W	215	210	210	29 C	31	31	31	"	YES	YES				
127	STD	20.5	0	—	—	—	SLIGHT	"	"	"	0.35	0.25	215 S	210	210	210 W	33 C	32	32	34 R	"	YES	YES				R INDICATES AN ERRATIC CURVE
128	STD.	21.0	1	1	—	—	SLIGHT	"	"	"	0.35	0.25	215 S	205	210	215	33 C	34	31 S	30	"	YES	No				
129	STD.	21.0	0	—	—	—	No	"	"	"	0.35	0.25	205 S	205	210 C	215	35 C	35	32 S	31	"	YES	YES				
130	STD.	21.0	0	—	—	—	No	"	"	"	0.35	0.25	200	205	210	215	36 R	32 S	30 S	29	FAIR	YES	YES				CRACK AT START
131	STD.	21.0	15	6	7	2	No	"	"	"	0.35	0.25	220	220	226	220	31 C	30 S	27	28 W	POOR	YES	No				CRACK AT END
142	SLOT	—			TEST DISCARDED MACHINE SETTING IN ERROR																						REPLACED BY No. 165
143	SLOT	22.0	2	0	0	2	SLIGHT	GOOD	CONVEX	ROUGH	0.20	0.35	245	245	245	245	28	27	27	27 R	GOOD	YES	YES				
144	SLOT	21.0	0	—	—	—	YES	MED.	DITTO	ROUGH	0.32	0.25	235 S	225	220	220	32 C	34	35	35	GOOD	YES	YES				
145	SLOT	21.0	0	—	—	—	YES	MED.	"	SMOOTH	0.32	0.25	235	235 S	225 S	220	31 C	33 C	35 C	35 S	GOOD	YES	YES				
146	SLOT	21.0	7	1	3	3	No	GOOD	"	ROUGH	0.25	0.35	245	240	245	245	28 C	29	28	27	POOR	YES	No				
147	SLOT	21.0	0	—	—	—	SLIGHT	MED.	"	SMOOTH	0.32	0.25	230 S	230	230	225	36 S	33	33	34	GOOD	No	YES				
148	SLOT	21.0	0	—	—	—	YES	BAD	"	DITTO	0.32	0.25	230 S	225	225	225	36	35	34	35	DITTO	YES	YES				
149	SLOT	21.0	0	—	—	—	YES	BAD	"	"	0.32	0.25	230 S	225	225	225	36	35	35	35	"	YES	YES				
150	SLOT	21.0	0	—	—	—	SLIGHT	MED.	"	"	0.32	0.25	225 S	230 C	225 S	220	36 W	33 S	35 C	37 S	"	YES	YES				
151	SLOT	21.0	0	—	—	—	No	MED.	"	"	0.32	0.25	230	230	230	230	35 W	33	32 S	33	"	YES	YES				
165	SLOT	20.0	0	—	—	—	SLIGHT	MED.	"	"	0.32	0.25	230	230 S	220	225 R	34 C	35	33 S	33	"	YES	YES				



No. 157S

E6027

No. 152F

No. 132S

E6027

No. 137F

No. 126S

E7024

No. 131S

No. 146F

E7024

No. 151S

FIGURE 6. TYPICAL CROSS SECTIONS OF WELDS MADE DURING CONSISTENCY STUDY
F = Section taken 5 inches from end of weld
S = Section taken 5 inches from start of weld

(4) The fillet sizes are as expected with the electrode diameter chosen (> 1/4 inch) and the fillets have legs which are slightly longer on the horizontal than on the vertical leg.

(5) Wetting of the mill scale coated base metal was uniform and good.

(6) Weld spatter from the taped-in-place electrode was not a problem.

(7) In comparison with E7024 electrodes, the E6027 electrodes have greater tolerance for most of the variables encountered.

<u>E7024 Electrodes</u>

(1) Under the conditions used, satisfactorily complete welds can be produced with E7024 electrodes if welding parameters are closely controlled.

(2) Welding parameter control is more important for E7024 than for E6027 electrodes.

(3) Slotting the E7024 coating does not improve welding results. (See note under conclusion 2 for E6027 electrodes regarding penetration on macroscopic examinations,)

(4) AC welding voltages below about 32 volts lead to slag pockets and the weld bead concentration on one leg of the joint. The increase in current which results from lower voltages does not improve results.

(5) Undercut and spatter are not significant when proper weld parameters are used.

(6) Fillet sizes on properly made welds are slightly larger (> 1/4 inch). than with E6027 electrodes; the horizontal legs are also slightly longer.

(7) Wetting of the mill scaled base plate was good.

As a futher evaluation of the welds made during the consistency run each weld was cross sectioned in two typical places. Figure 6 shows cross sections of a few of these welds including some of the best and worst obtained during the entire run. Nothing was found to alter the conclusions made. No porosity was found in any of the joints. There were variations in penetration as measured by whether or not the corner of the joint was fused. In Tables 6 and 7 this is noted but the degree of penetration is not. Often fusion of the root was minimal, especially on welds made with E7024 electrodes. This variation in penetration was presumed to be at least partially due to the rounded edge of the hot-rolled steel bar stock used for the leg of the T. This is shown in Figure 6. The cavity at the root of the weld nearly always contained slag.

M adjunct experiment was undertaken at the conclusion of the consistency run to check the premise that the shape of the steel T joint member significantly influenced joint root penetration. Specimens were prepared on which the leg of the T was square and butted closely to the base. The welds were made under the standardized conditions with both 1/4 and 7/32-inch diameter electrodes. Figure 7 shows typical cross sections of the joint obtained. The slag persisted at the root of the joint although the size of the cavity was significantly reduced. The presence of slag in joints made by firecracker welding is also discussed in other places in this report.

Welding Over Tack Welds

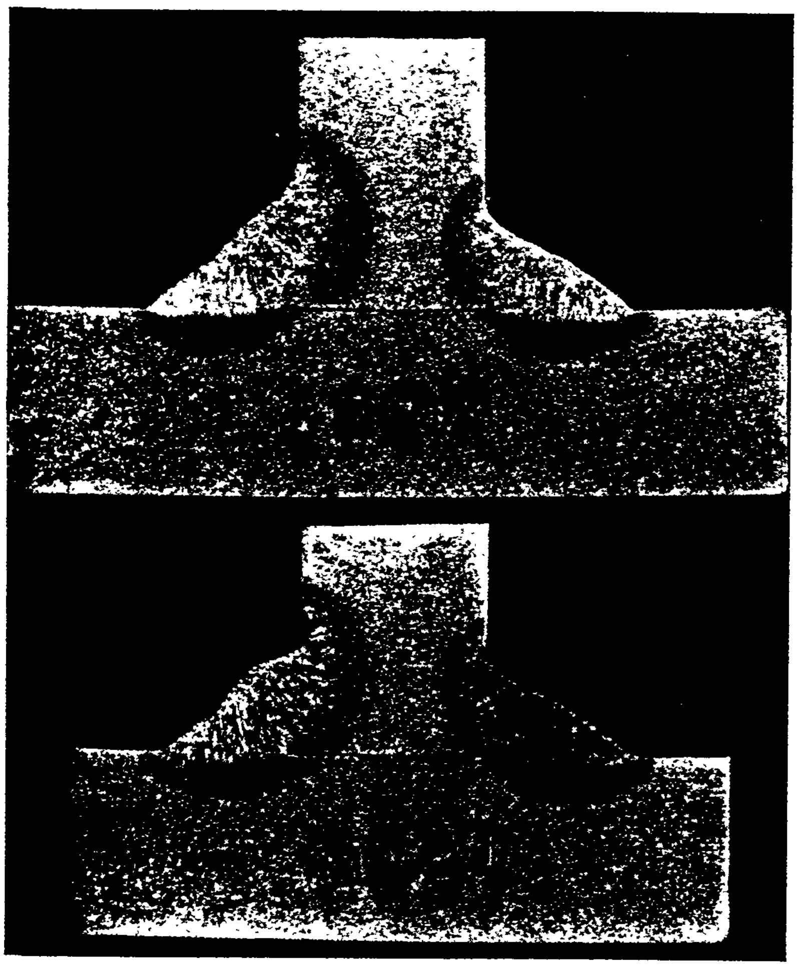
In most construction welding it is desirable to position joint components and to hold them in position with tack welds until the final weld is made. During final welding the preferred procedure is to weld over tack welds without concern for their removal. When firecracker welding the same procedure would be preferred. Consequently, a study was made to determine how the presence of tack welds influence firecracker welds.

Simulated Tack Welds

The method used to determine the influence of tack welds on firecracker welding was to simulate tack welds of various sizes with triangular wedges placed beneath 72-inch-long electrodes. E6027 or E7024 electrodes were placed in the joint and the wedge located near its midpoint

4 inch electrode

3/16 inch electrode

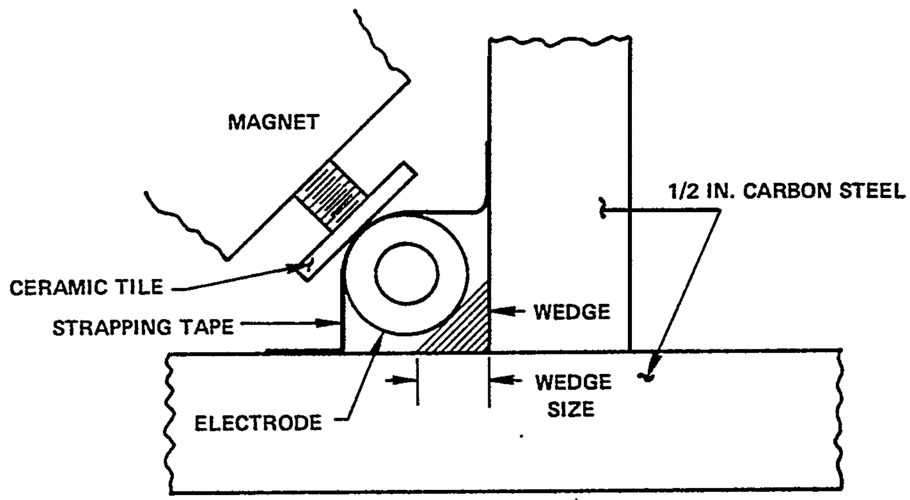


4 inch electrode

3/16 inch.electrode

FIGURE 7. CROSS SECTIONS OF TEE JOINTS HAVING SQUARED CONTACT AREAS

as shown in the sketch. The end of the electrode to be burned was then covered and held in place by carefully rolled strapping tape as demonstrated in Figure 14. The wedge sizes used were 3/16, 1/4, 5/16, and 3/8 inch. The standardized welding parameters were then used in the collection of the data given in Table 8.



AS noted in Table 8, in every case, whether welding was interrupted due to an arc outage or whether the weld was completed to the wedge location the maximum voltage at the time the arc extinguished was about 50 volts. It appears that for the electrode types, sizes and the welding parameters used this is a maximum voltage capable of sustaining the arc. As the space between the electrode and the base metal increases and the arc voltage increases. The arc will be sustained until that arc length is reachea where the voltage is about 50 volts. This does not necessarily mean the weld bead is satisfactory to that point.

Also as noted in Table 8, the voltage remains relatively stable at the original voltage i.e., approximately 34 volts for the first 20 inches (approximately) of arc travel. At which point it starts to increase either gradually as in weld W3 (Figure 8) or abruptly, Weld W15 (Figure 8). Since

TABLE 8. DATA FOR WELDING-OVER-TACK STUDY

Sample Number	ELECTRODE TYPE	ELECTRODE DIAM., IN.	WEDGE SIZE, IN.	LENGTH OF WELD TO WEDGE, IN.	VOLTAGE RANGE V (A)	CURRENT RANGE A (A)	ARC TRAVEL TO VOLTAGE JUMP, IN.	VOLTAGE AT ARC STOP, V	WELD COMPETE YES OR NO	TOTAL ARC TRAVEL, IN.	Remarks
W-1	6027	7/32	0.19	33	37/40	180/200	19	42	Y	32	Good weld bead, slightly to vertical leg
W-2	6027	7/32	0.25	32	36/50	160/200	19	48	Y	31	Two arc outs after 25 in., fair weld slag pockets after 29 in.
W-3	6027	7/32	0.31	31	36/49	165/200	19	49	N	29	Unstable arc after 15 in., arc stopped itself, good weld
W-4	6027	7/32	0.38	33	35/47	170/200	18	47	N	25	Good weld until arc stopped
W-9	6027	1/4	0.19	35	32/35	230/250	32	38	Y	34	Good bead full length
W-10	6027	1/4	0.25	34	34/39	215/235	25	44	Y	33	Good bead full length, slightly to horizontal
W-11	6027	1/4	0.31	34	34/40	215/235	21	48	Y	33	Arc rough after 16 in., poor bead from 22 in. to end
W-12	6027	1/4	0.38	34	33/40	210/240	22	48	Y	33	Two arc outs (27 and 29 in.), 24 in. good weld
W-5	7024	7/32	0.19	32	34/42	195/210	31	42	Y	31	Good weld for 30 in., then slag pockets
W-6	7024	7/32	0.25	32	35/45	190/220	20	45	Y	31	Fair weld for 20 in., then went to horizontal leg
W-7	7024	7/32	0.31	31	33/53	170/220	22	53	Y	30	Arc unstable after 24 in., good weld full length
W-8	7024	7/32	0.38	33	33/42	190/220	15	48	N	26	Not a good weld, scattered slag pockets full length
W-13	7024	1/4	0.19	34	32/39	245/265	31	44	Y	33	Poor weld after 5 in., slag pockets and to vertical leg
W-14	7024	1/4	0.25	34	32/37	245/260	25	47	N	31	Weld bead similar to W-13
W-15	7024	1/4	0.31	34	32/35	245/255	19	50	N	22	Arc unstable after 20 in., arc stopped at 22 in., poor weld
W-16	7024	1/4	0.38	34	30/37	230/260	20	49	N	26	Arc unstable after 18 in., arc stopped at 26 in., poor weld

(A) EXCLUDING FINAL SURGE

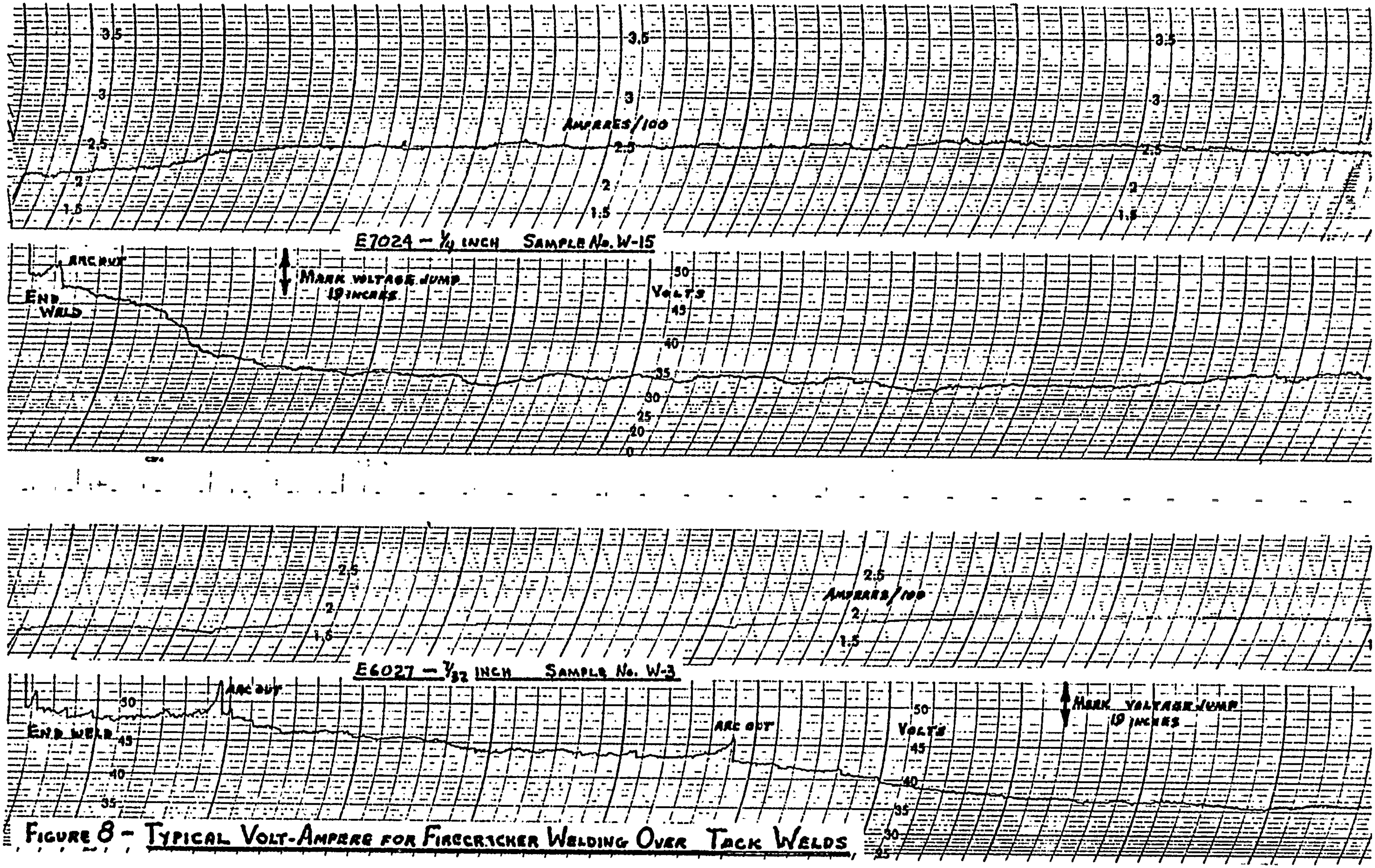


Figure 8 – Typical Volt-Ampere for Firecracker Welding Over Tack Welds

in these tests the electrodes were held firmly in place with tape and hold-down clamps, this probably indicates the point at which the space between the electrode and the base plate starts to significantly increase. This point, of course, is a function of the stiffness of the electrode and the strength of the tape and how well it was applied. We presume it represents a maximum in closeness of fit of electrode to the joint.

As indicated in Table 8, with both the 7/32 and 114-inch diameter E6027 electrode, good welds could be deposited with wedge spacers up to 1/4 inch. That is, if electrodes exceeding 18 inches length are used with one end on the base metal surface and the other end or some point on the electrode 20 inches distant lying on a 1/4 inch high tack weld, a satisfactory weld can be made.

As might be expected the results obtained with E7024 electrodes are not as clear. The E7024 electrodes are subject to slag pockets under the best welding conditions, and attempting to weld over tacks aggravates the situation. Slag pockets were obtained even when welding over the smallest wedge, 0.19 inches. high. It appears that E7024 is unsuitable for welding over any but the smallest tack welds and any tack weld must be ground down to less than 3/16 inch before firecracker welding that area.

In summary, results of these tests indicate satisfactory fire-cracker welds may be made over 1/4 inch tack welds with E6027 electrode. Of course, the start end of the electrode must be in contact with the base metal at the root of the groove to satisfactorily start the arc. Then the acceptable tack spacing is dependent on electrode length. If 18 inch long electrodes are used the tack spacing must be at least 18 inches if the full electrode length is to be consumed. Similarly a 28-inch space could be used for a 28 inch long electrode. If you want to weld over a tack weld with the tack at the midpoint of the electrode you must have at least a 36 inch long electrode. These examples illustrate the many possibilities in tack spacing and effectively point out there is no real limitation on tack weld spacing.

Actual Tack Welds

As a check on the conclusion drawn when wedges were used to simulate tack welds, actual long welds were made in which a 3-inch tack was placed near the center. These welds were made with bcth E6027 and E7024 electrodes, 7/32 and 1/4 inch in diameter and 72 inches long. The tack weld size varied from 1/8 to 1/4 inch. The results of these tests verified the conclusions of the simulated tack tests in so far as tack size was concerned. They also demonstrated the need for careful control of procedures when welding over tacks. For example, the electrode must be centered longitudinally on the tack weld or the bead may go to one or the other leg of the joint. Also the hold-down system must be capable of maintaining the electrode location as the arc approaches and progresses over the tack. When these criteria are met the weld bead is uniform over the tack end it can be located only by the increased size of the fillet. In every case the E6027 electrode was more capable of producing a good weld fillet over a tack weld than E7024.

Two-Side Welds

In some situations it is desirable to weld both sides of T joints at one time. Such situations might often be encountered in confined places where firecracker welding is most applicable. Therefore, a few tests were made to determine whether or not difficulties would arise when making two-side firecracker welds.

These welds were made with 1/4 inch diameter, 72 inch long E6027 and E7024 electrodes. The limitations of the available welding power sources prevented making welds with electrodes of other diameters. Two power sources were used; one the 300 amp AC/DC transformer-rectifier combination used in all our firecracker welding studies, the other a 300 amp AC variable transformer welding machine. The test specimen was the standard T used in this program. The electrodes were held in place by strapping tape aided by the permanet magnets as previously described. The welding parameters for each electrode were set as nearly the same as possible on the two machines and were 240-260 amperes and 30-38 volts. The arcs were caused to travel together by making slight adjustments on the AC/DC power source. No difficulties were met in keeping the arcs together. The travel speed was between 7.0 and 7.5 in/min. It was found necessary to tack the joint components with about l/8-inch tacks to avoid lateral movement of the leg as the weld progressed.

The weld beads produced with E6027 were uniform and contained no important defects. The E7024 weld beads contained the same slag pocket type of defect that is usually found when using this long electrode.

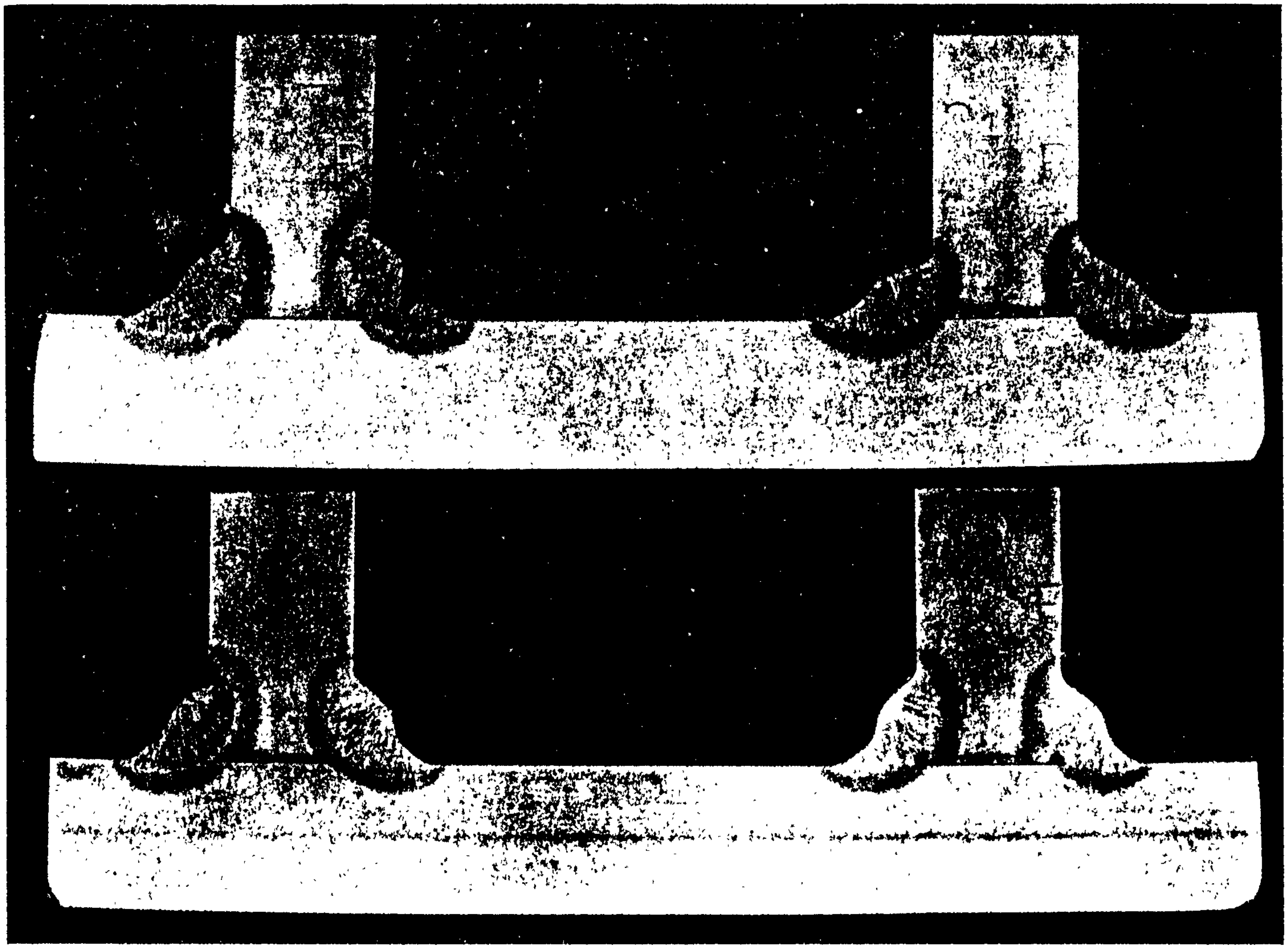
One item of interest relative to the hold-down technique was recorded during the two-side welds. When welding with the magnets in place the arc voltage raised 3-5 volts as the arc neared and passed beneath the magnets. Also the arc became slicghtly unstable. The quality of the weld bead in the area of the magnets did not appear to be adversely affected. The need for study of the influence of magnetic hold-down systems on firecracker welding is mentioned later in this report.

Directing the Arc During Firecracker Welding

In the screening studies conducted in Phase I of the program, an effort was made to cause the arc to consistently remain in the root of the joint being welded. This was deemed necessary to assure satisfactory joint penetration and to control the fillet shape. It was concluded that shaping the electrode coating to cause the core to be near the root of the joint offered little promise for this purpose. This conclusion is verified in Figure 9. It can be seen that welds made with normal round electrodes are as well placed as those made with electrodes having two flat sides, (see Figure 3). The defects in the E6027 welds are the result of using excessive current.

The work reviewed was based on the use of 3/16-inch diameter electrodes. It was found that when welding with larger diameter electrodes, 7/32 and 1/4 inch, the need for a method of positioning the arc was increased. A few attempts to produce fillet welds when using one flat on l/4-inch diameter electrodes showed no promise. The one flat was actually considered detrimental because it made initiation of the arc difficult.

Round E6027 Round E7024



Flat E6027 Flat E7024

FIGURE 9. FILLETS RESULTING FROM ROUND AND FROM ELECTRODES WITHIN FLAT ON SIDE NEAR JOINT ROOT

Work on altering the electrode coating was continued using techniques other than flats on the coating. TWO additional techniques were evaluated, thinner electrode coatings and slotted electrode coatings.

Effect of Reducing Electrode Coating Thickness

To examine the influence of reduced coating thicknesses, the coatings on standard 14 x 1/4 inch E6027 and E7024 electrodes were ground off . The coating thicknesses evaluated were 0.095 (as received), O.O75 and 0.060 inch. The welds were made by using a combination hold-down procedure, tape on one half of the electrode and a copper block on the other half. The copper used had a close-fitting circular groove. The data for these welds are shown in Table 9. In general, the welds produced were slightly better in the area of the copper hold down. AISO, the voltage and current was usually less erratic in the section held down by the copper block.

The data show that reducing the coating thickness may reduce the arc voltage, but this does not improve the weld bead configuration or reduce spatter. By observation, it was noted that the arc maintained a horizontal length along the joint which was approximately the same regardless of the coating thickness. There was also an indication that too thin coatings can be detrimental.

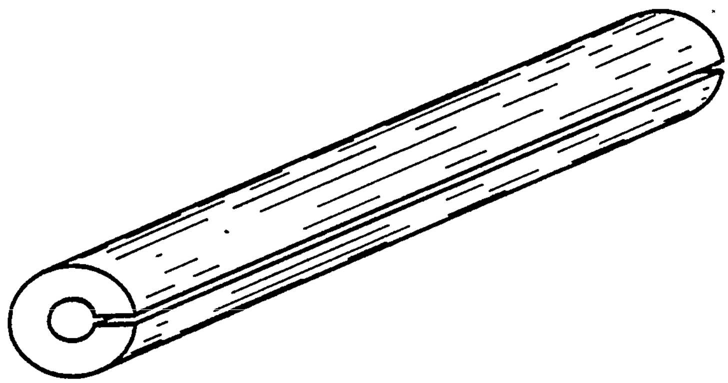
It was concluded that no advantage was gained by reducing the electrode coating thickness.

Effect of Slotting the Electrode Coating

Based on the knowledge that when using coated electrodes which contain longitudinal cracks in the coating, the arc tends to be directed by the crack, narrow slots were cut in the coating to determine if the firecracker welding arc would be so directed. The slots were ground in the coating by hand, using dental separating discs. The slots were about 0.03-inch wide and are cut through the coating, as shown in the sketch.

TABLE 9. AC WELDS MADE WITH VARYING COATING THICKNESS ON l/4-INCH Electrodes

Electrode Type	Coating Thickness, in.	Voltage, V	Current, A	Notes Taped Section	Notes Cu Held Section
E6027	0.095	34-36	240-250	Equal legs, long arc	Equal legs, looked like 2 passes
E6027	0.075	25-35	240-255	Unequal legs, long arc	Equal legs, good weld bead
E6027	0.060	25-26	250-260	Unstable arc, poor weld	Poor weld, arc out
E7024	0.095	29-40	235-255	Long arc, much spatter	Poor weld, arc out
E7024	0.075	28-34	250-270	Long arc, much spatter	Unequal legs, undercutting
E7024	0.060	29-30	250-265	Unstable arc, poor weld	Poor weld, better than taped



The initial results when using slotted electrodes were quite encouraging. The arc was more steady and remained in the groove of the joint better than when the slot was absent. The arc was shorter, but the expected value of this effect was reduced, because when the arc became too short and the resulting voltage too low, the welding slag appeared to flood the arc. As a result, it was concluded that much more experimental work was needed. It was important to determine whether or not the slot was useful to improve the weld, and if it was, was it a feasible technique in view of the possible arc flooding. Many test runs using three different diameter electrodes 3/16, 7/32, 1/4-inch diameter) were made which verified the ability to direct the arc and also the arc flooding condition. None of the tests showed that the resultant weld was improved over that obtained with an unslotted electrode. The data in Table 10 show the results of cross-sectional examination as well as the welding parameters for a number of these welds. It is noted that many of the weld beads have unbalanced legs this also occurs consistently with electrodes which are not slotted.

The welds Number 120 and 121 in Table 10 were made with electrodes which were intermittently slotted along their length, as shown in the sketch. This was done so that a comparison could be made under identical welding conditions and to see if any change in operation could be observed

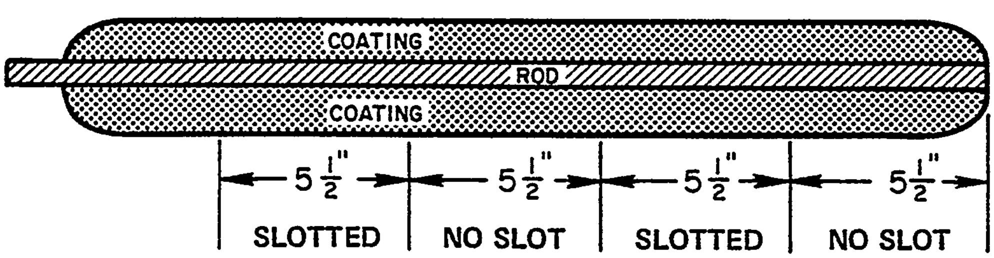


TABLE 10. SLOTTED ELECTRODE WELDING DATA
(All welds AC except No. 99 which
was DCSP - all held down by tape)

Sample No.	Electrode Type	Electrode Diameter, Inch	Coating Condition	Voltage V	Current A	Fillet size, in. Horiz.	Fillet size, in. Vert.	Penetration	Undercut
96	6027	1/4	Slotted	30-35	240-260	3/8	5/16	Good	None
97	7024	1/4	Ditto	25-27	260-280	1/4	5/16	Good	None
98	7024	1/4	Ditto	28	270-280	5/16	5/16	Fair	None
99	6027	1/4	Ditto	--	--	3/8	1/4	Good	None
108	7024	3/16	Ditto	30-33	200	5/16	1/4	Good	Slight
109	7024	3/16	Ditto	33-34	200	1/4	5/16	Good	None
112	7024	3/16	Ditto	27-35	185-200	3/8	3/16	Fair	None
120	6027	7/32	No slot	37-41	190-215	5/16	5/16	Good	None
120	6027	7/32	Slotted	37-41	190-215	3/8	5/16	Good	None
121	7024	7/32	No slot	31-34	215-225	3/8	1/4	Good	Slight
121	7024	7/32	Slotted	31-34	215-225	5/16	1/4	Good	None

when the arc proceeded from a slotted section to an unslotted section of the electrode. It is evident that even though welding parameters were unchanged that the random variation in bead shape persisted. The arc was observed closely during the time it passed through a transition from slotted to unslotted coating. No significant or abrupt change in operating feature occurred. The arc did appear more stable in the slotted sections. The weld beads produced were equal in either area of both electrodes. The transition from section to section could not be located on the weld bead.

It was concluded that the only advantage for using slotted electrodes was a possible increase in arc stability. Consequently, slotted electrodes were included in a “consistency run” which was made to determine reliability of the chosen firecracker welding procedure. This series of tests have been covered elsewhere in a previous section of the report. As noted in that section, the consistency run failed to confirm any substantial improvement in weld quality or consistency. In view of the difficulty and expense of producing the slot and the directionality of the slotted electrode it was decided to discontinue further work on slot evaluation.

Welding in a Circular Groove

As indicated in the previous sections on methods of directing the firecracker welding arc no reasonable technique appears to alter the results obtained with standard round electrodes. As a result of these experiences it was reasoned that it should not be concluded that placing the electrode core as close as possible to the joint root would cause the weld bead to be properly located. Thus, an experiment designed to show if the weld bead clearly would locate itself according to the location of the electrode core was made. Circular bottom grooves of three sizes (1/2, 3/4, and 1 inch diameter) were machined in a low-carbon steel bar. All grooves were 1/2 inch deep. Then, 7/32-inch-diameter electrodes were carefully centered in these grooves and taped in place. Since the contact line of the electrode was centered in the groove and was also the nearest location of the electrode core to the base of the groove the resulting weld bead should be centerd in the groove if the nearness premise was valid.

Figure 10 shows the results of this experiment. In all but one case the weld bead is displaced from the centerline of the groove. It was concluded that the activity of the welding arc is too great to assure that it will remain on any consistent line in the joint area. This conclusion was verified by observation and by movies taken of the arc during welding.

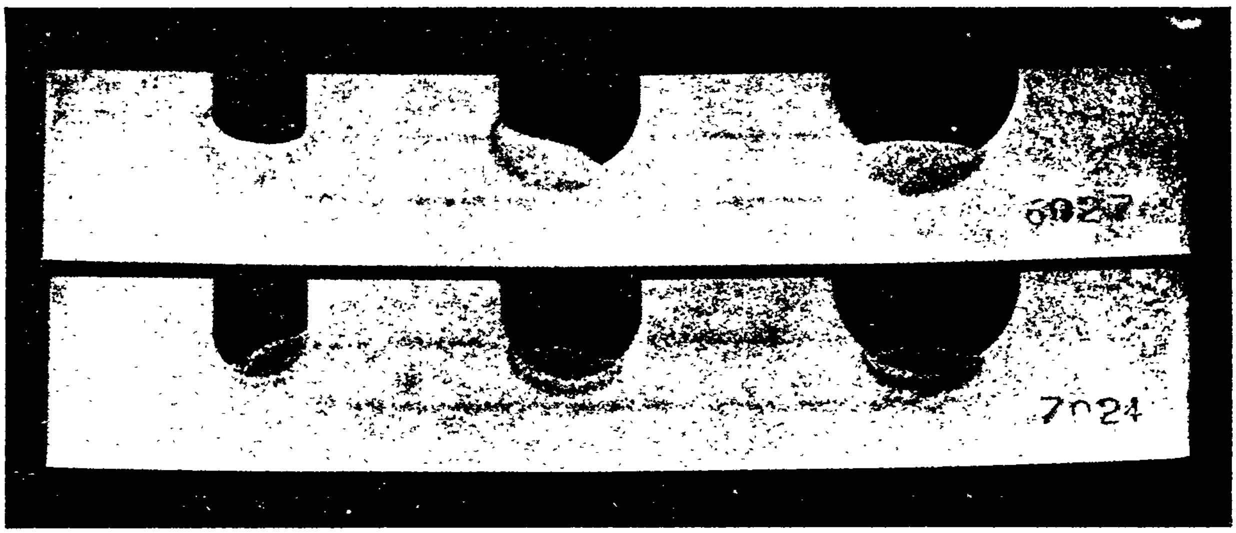


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FIGURE 10. CROSS SECTIONS OF FIRECRACKER WELDS IN CIRCULAR GROOVES

Effect of placing an Easily Ionizable Material in the Joint Area

Another method evaluated for causing the firecracker welding arc to concentrate in the corner of a T joint was the placement of easily ionized materials in this area. It was felt that causing such a concentration of the arc would improve penetration and bead configuration by more evenly balancing the fillet legs. Carkon and cesium carbonate were used for this purpose because they are known to be readily ionized in the arc .

TWO methods of placement were used for the ionizable material.
1. Masking all of the T joint area but a 1/8 inch stripe at the root of the joint followed by coating the unmasked area with either carbon or

cesium carbonate in a carrier. 2. Masking the electrode and producing a l/8-inch wide stripe of the ionizable coating along its length. The electrode was then placed with the stripe directed toward the root of the joint. The carbon coating was produced by utilizing a commercial carbon aerosol lubricant spray. The cesium carbonate was used as a water solution, 5 g per ml, painted in the stripe area and dried. The electrodes used were l/4-inch E6027 and E7024, 28 inches long. Welds were made under standardized AC conditions and are recorded in Table 11.

The carbon failed to produce any measurable effect on the weld bead shape, arc action or joint penetration when compared to welds made without carbon.

The cesium carbonate produced a marked effect on the operation of the firecracker welding arc especially when the E6027 electrode was used. It caused a long “wild” arc rather than a shortened arc as expected. This long arc did not stay in the weld groove, the weld fillet had a long horizontal leg very similar to fillets made without the cesium carbonate.

No advantage was recorded which suggested any further study of the use of an ionizable material in the joint area when using an AC power supply. The effect when using a DC power supply was not studied.

Other A&c Control Studies

Numerous additional firecracker welding experiments were undertaken on the premise that better arc control was needed to assure proper weld bead configuration and location.

Power Source Machine Settings. At the beginning of this program it was a concensus among engineers that the most appropriate type of welding machine for firecracker welding was a constant current type with a drooping voltage characteristic. Consequently, all the major work was done on **a** 300 ampere AC/DC transformer rectifier machine of that the. In using this machine current range settings were used which gave the most desirable results. The voltages were fixed by the arc length obtained during the weld in progress because in firecracker welding the electrode position is fixed and cannot be moved to change arc length at will.

TABLE 11. WELDS MADE WITH IONIZABLE MATERIAL IN JOINT AREA

Sample No.	Electrode Type	Ionizing Material and location	Current amps.	Voltage volts	Holddown	Effects
30	E6027	Carbon in groove	235-245	35-36	Tape	None recorded
31	E7024	Ditto	250-265	34-40	Tape	Spatter bad
32	E6027	Carbon on rod	240-245	33-36	Tape	None recorded
33	E7024	Ditto	250-265	30-36	Tape	None recorded
76	E7024	Cs_2CO_3 in groove	245-250	33	Tape	Spatter finer than usual
77	E6027	Ditto	215-230	38-43	Tape	Spatter bad, long arc
80	E7024	Ditto	245-250	33-35	Tape	Ditto
81	E6027	Ditto	210-230	35-40	Tape	Ditto
94	E6027	Cs_2CO_3 on rod	215-220	36-40	Tape	Ditto
95	E7024	Ditto	220-230	34-37	Tape	Ditto

An eamimination of the effect of machine setting on the firecracker welding parameters when using the constant current power source was made. It was shown that when AC welding with 1/4 Inch electrodes at a current of 250 amperes, the mean voltage was 2 to 5 volts lower if the "Max" setting was used instead of the "60-290 amps" setting. It was concluded from this result that the "Max" setting should be used whenever possible in order to reduce the arc length and thus spatter. Subsequent tests, however, showed that the effort to minimize arc voltage could lead to inferior weld beads. It was found that when voltages below approximately 30 volts were used particularly when using E7024 electrodes, the welds obtained have a greater tendency to contain pockets of slag and areas of poor base metal wetting.

<u>Power Source Open Circuit Voltage</u>. A constant current DC motor generator welding machine having an adjustable open circuit voltage was used to eamine the effect of altering this parameter. Welds were made on DC straight polarity at open circuit voltages of 50 and 82 volts. The welds produced were satisfactory but no improvement was noted. Welds made at 82 open circuit voltage on the motor generator duplicated those obtained during normal practice with the constant current power source in every respect. It was concluded that DC motor generator power sources are suitable for firecarcker welding, but offer no advantages.

<u>Constant Potential Welding Power Source</u>. A gas metal-arc constant potential welding power source was also evaluated for firecracker welding. This machine provided a low open-circuit DC voltage, a variable inductance control and also a slope control. The results with the constant potential welding power source were negative. Many combinations of welding parameters were evaluated, none of them approached duplicating the welds made when using a constant potential power source on either AC or DC current.

<u>Arc Action Studies - High Speed Movies</u>. During the course of the arc control and other studies of the firecracker welding arc a number of short reels of high-speed motion pictures of the arc action were taken.

They were taken at either 50 or 128 frames per second expecting that some characteristic of the arc action would be found which would suggest means for improving the consistency and quality of the weld beads produced. Movies were taken using two different electrode sizes, E6027 and E7024 electrodes, and both AC and DC straight polarity power. The electrodes were held down with tape and a mechanical device in combination. Data for these welds are given in Table 12. Exposures were varied in order to permit observation of either the arc action or the weld pool action. The resulting motion pictures were examined using a movie analyzer capable of projecting at speed from 2 to 28 frames per second.

lCll arcs oscillate nonuniformly between the legs of the joint. The 3/16 inch electrode arc was rod-like while the arc of the 1/4 inch electrode was fan-like. Significantly, the molten slag on the weld pool appeared to build up, then flow away, build up again and flow away again in a nonorderly manner. This action and minor arc-outages seemed to coincide with defects in-the weld. For example, careful study of the film permitted orientation of such phenomena with the defect in weld No. 68 as shown in Figure 11. The orientation was not sufficiently definitive to be conclusive evidence of the formation of such defects.

Electrode Hold-Down Methods Development

One of the most important objectives of every phase of this research program was the development of methods to hold the electrode in place during firecracker welding. A practical approach to this development was taken because it was also an objective of the program to make fire-cracker welding a simple procedure especially useful for welding in close quarters. Thus, the hold-down developed should be simple to use and require a minimum of space and skill for its use. It was at the same time realized that the best hold down method for a particular situation would vary. It is possible, for example, to produce firecracker welds with short electrodes (12 or perhaps 18 inches) and depend only on the force caused by properly holding them with a common electrode holder. The choice of hold down method depends on costs, location of the weld, the production numbers, space available, acceptability of spatter near the weld, etc.

TABLE 12. DATA FOR WELDS USED FOR MOTION PICTURE STUDY

Sample No.	Electrode Type	Electrode diam. in.	Voltage v	Current A	Frames per sec.	Length of film ft.	Estimated length of weld covered in.	Polarity
50	7024	1/4	35	240	128	100	6	AC
51	7024	1/4	34	240-250	128	100	6	AC!
65	6027	3/16	39	190-200	128	100	6	DCSP
66	7024	3/16	36	200-210	128	100	6	DCSP
67	6027	1/4	33-36	185-215	128	100	6	DCSP
68	7024	1/4	34-38	220-240	128	100	6	DCSp
69	6027	3/16	35	240-250	128	100	6	AC
70	7024	3/16	35	245-250	128	100	6	AC
71	6027	1/4	38-40	235-240	128	100	6	AC
P-1	6027	7/32	36-38	190-200	50	400	48	AC
P-2	6027	7/32	32-36	210-220	50	400	36	AC

FIGURE 11. SLAG POCKETS IN FIRECRACKER FILLET WELDS

Four methods of holding long electrodes (i.e., those that could not be held down only at the end by the current constant clamp) in place were evaluated; copper bars, adhesive tapes, mechanical clamps and permanent magnets.

Copper Bars

Nassive square copper bars having their corner shaped to accept the electrode had been proven for use in holding firecracker welding electrodes in previous work at Battelle-Columbus. They, therefore, were used especially in the early electrode screening part of the present program for flat position welding and during all vertical welding studies. TWO basic configurations of the copper block corners were used as shown in cross section in Figure 12. In each case the dimensions of the corner area were varied as required to hold electrodes of different outside diameter snuggly in the joint area.

Experimental welds made in the flat position with copper bars holding the electrode in the joint show the following advantages over the other methods studied.

- Better weld bead surface
- Less spatter on base metal
- EaSier slag removal
- Higher currents permissible.

Shape 1 provides the advantage noted-to a greater degree than Shape 2 and therefore was preferred.

There are also disadvantages to the use of copper hold-down bars for firecracker welds in any position. Some of them are:

- High cost
- High service damage factor
- Heavy to handle in significant lengths
- Need for several sizes and/or shapes.

Because of these factors the use of copper bars for holding electrodes in place in the present study was minimized for horizontal position welding after the completion of the screening phase. They were used for all vertical welding experiments.

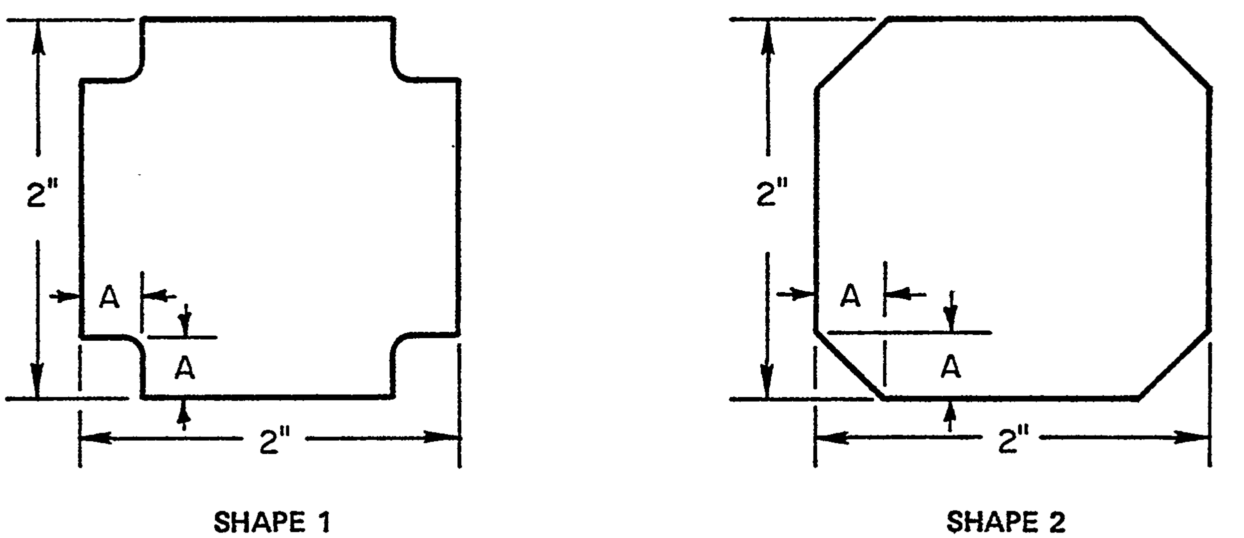


FIGURE 12. CROSS SECTIONS OF COPPER HOLD-DOWN BARS (Dimension A veried to fit outside diemeter of electrodes)

An example of a copper hold-down bar in place ready for horizontal welding to begin is shown in Figure 13. Typical welding data for 1/4 inch electrodes held down with copper bars having Shape 1 are given in Table 13. The effect of CUrrent is evident, the preferred welding parameters show welding currents that are slightly higher than those indicated in Table 6. The inbalance of fillet legs is not great in any case.

<u>Adhesive Tapes</u>

A material for holding the electrode in the joint area which showed several advantages for use where firecracker welding is expected to have application was adhesive tape. The usefulness of adhesive tapes for holding the electrode in place was examined in some detail. Six types of widely used tapes chosen because they are inexpensive and representative of several readily available types were evaluated:

(1) Paper masking
(2) Filament binding
(3) Furnace sealing
(4) Glass cloth electrical
(5) Vinyl electrical
(6) Cloth book repair.

The tapes were Used to hold the electrode for its full length and also intermittently by banding across the electrode axis. The results with each tape were distinctive. Fune, smoke, and odor varied widely. Some tapes caused weld porosity; others did not. The residue was tar-like with some tapes while others left little residue. Two tapes, glass cloth electrical and filament binding, were much more suitable than all others. They adhered well until the arc passed, produced a minimum of fume, etc., left no harmful residue and did not appear to affect the weld. No advantage was noted for taping the full length of the electrode except that the tape confined the spatter to some extent. This was considered important and most subsequent studies used tape over the full length of the electrode.

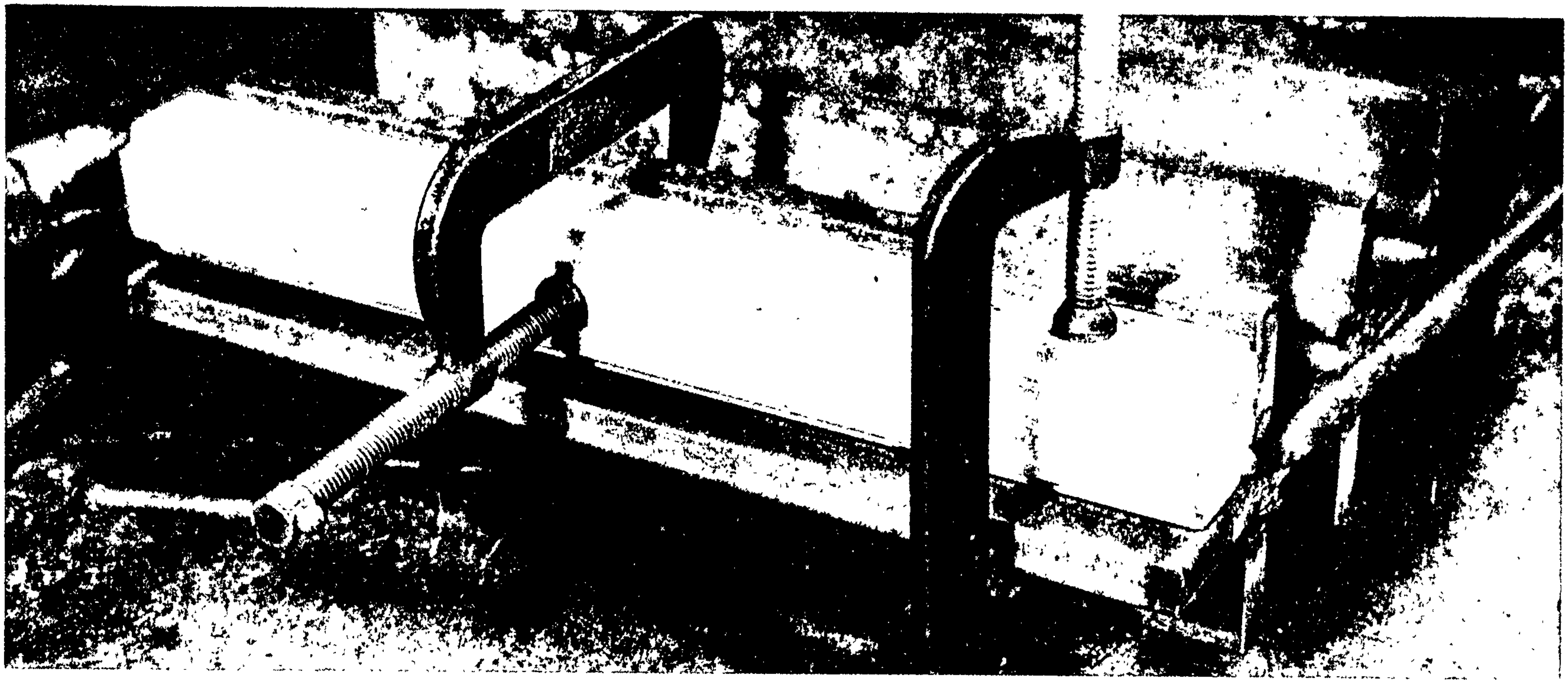


FIGURE 13. HOLDDOWN BAR IN PLACE FOR FILLET WELDING

TABLE 13. TYPICAL WELDING DATA FOR 1/4 IN. DIAMETER ELECTRODE HOLD DOWN WITH A COPPER BAR

Sample No.	Electrode	Ave. Voltage v	Ave. Current A	Fillet Size Vert. leg. in.	Fillet Size Horiz. leg. in.	Shape	Undercut Vert. leg.	Undercut Horiz. leg.	Penetration*
42	E7024	33	300	3/8	1/4	Poor	Yes	No	Poor
42		29	285	3/8	5/16	Poor	Yes	No	poor
**42		29	260	7/16	3/8	Excellent	No	No	poor
42		27	250	3/8	1/4	Too Convex	No	No	Poor
43	E7024	34	305	3/8	5/16	Convex	No	No	Poor
43		30	295	5/16	3/8	Convex	No	No	Poor
43		28	260	3/8	7/16	Convex	No	No	Poor
43		27	250	5/16	5/16	Too Convex	No	No	Poor
44	E6027	41	310	3/8	3/8	Flat	No	No	Some
44		37	285	1/4	5/16	Poor	Yes	No	Some
44		35	265	3/8	3/8	Rough	No	No	Poor
**44		32	240	3/8	5/16	Excellent	No	No	Poor
45	E6027	35	310	5/16	3/8	Good	No	No	Poor
45		34	285	3/8	3/8	Convex	No	No	Poor
45		31	265	3/8	3/8	Good	No	No	Poor
45		30	250	5/16	5/16	Flat	No	No	Poor

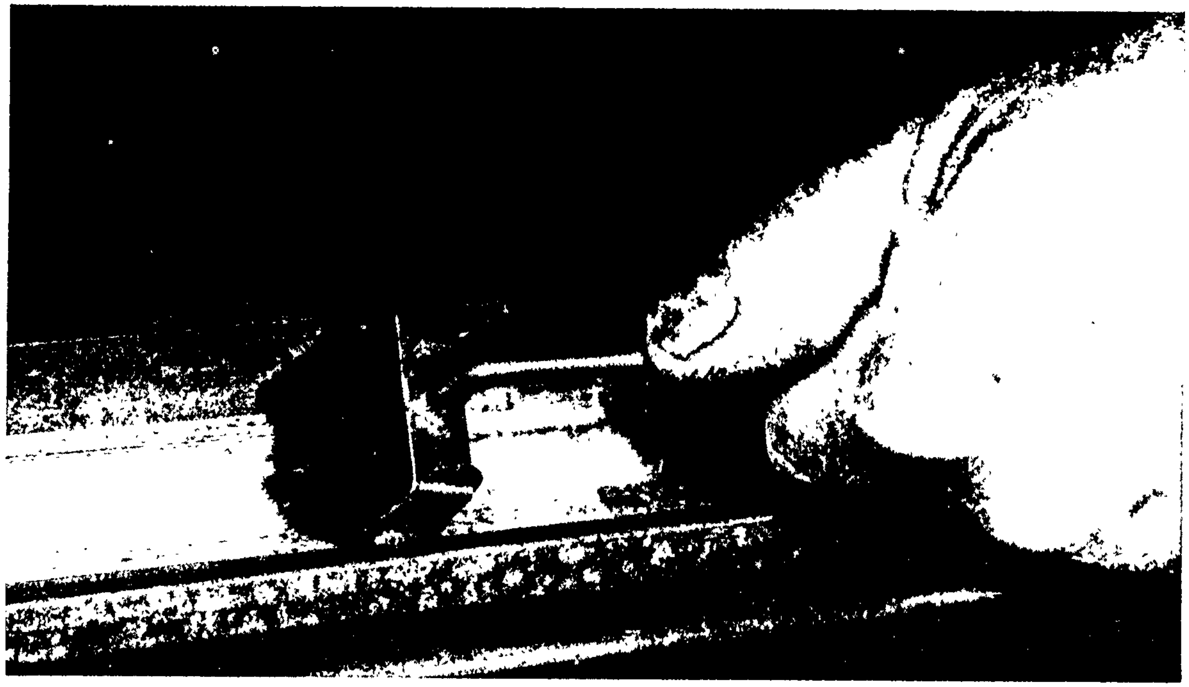
* Penetration here is a note on whether or not the corner of the T leg. was fused. This may have been influenced by the rounded shaped of the hot rolled bar edge.

** Preferred parameters.

The glass cloth tape was preferred because it was woven and thus had significant strength in two directions. But, since it was not readily available in the widths desired most experimental work was conducted using the binding or strapping tape. NO overlapped strips of l-inch-wide tape were used to hold the electrode; this gave a double layer of tape over the electrode. It was found that rolling the tape in place aided in overcoming minor crookedness of the electrode. Figure 14 shows the **rolling** operation being performed with a rubber roller made fOr use on T joints. Figure 15 shows a 28-inch-long electrode taped in place ready for welding. Table 14 presents typical welding parameters occuring when the electrodes are held down with strapping tape.

During the early tape hold-down studies commercial welding backup tapes were also evaluated. There were two types of these tapes, a simple woven asbestos tape and a composite tape made from heat-resistant granules backed with an aluminum metal foil backing bearing the adhesive. The asbestos tape proved completely unsatisfactory for firecracker welding. The composite tape as produced was also unsatisfactory but this was because the bulk of the granular material prevented forming the tape into the joint as demonstrated in Figure 14.

The commercial composite tape was altered by removing varying amounts of the granular material and testing further. It was necessary to remove nearly all of the granules before the tape could be suitably formed into the joint. When this was done the tape resisted the heat generated in the electrode and held it in place until the arc passed. However, as the arc proceeded the metal foil of the tape was melted into the weld Pol. This caused excessive spatter and boiling of the weld pool, the result of which was a quite porous and unsatisfactory weld bead. This work permitted the formulation of ideas of how a tape could be made that might be suitable. As a result of this effort, suggestions were conveyed to the manufacturer on the premise that when the experimental work proceeded to the 72-inch-long electrodes, a tape having heat resistance greater than that of the strapping tape would be needed. Our presumption was well founded. The tape maker responded quickly and furnished several tape samples for our evaluation when using the extra long electrodes. These



14. ROLLING HOLD-DOWN TAPE IN PLAC] %

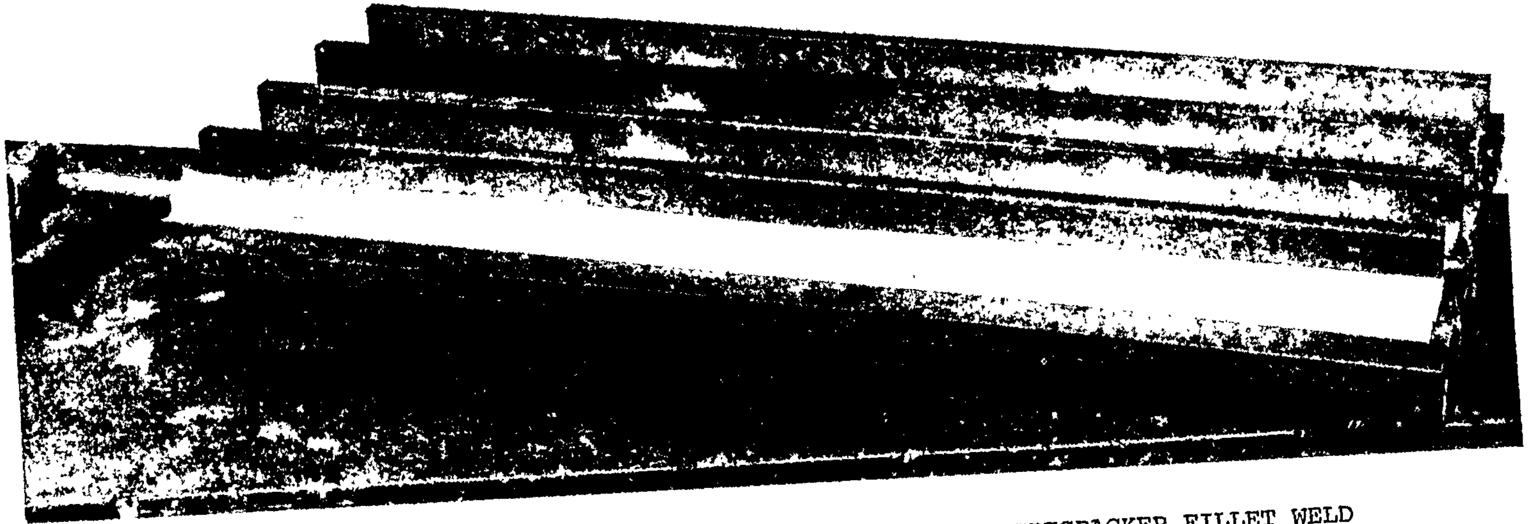


FIGURE 15. ELECTRODE (28 INCH) TAPED IN PLACE FOR FIRECRACKER FILLET WELD

TABLE 14. TYPICAL WELDING DATA FOR 1/4 INCH DIANETER ELECTRODES HELD BY GLASS FIBER STRAPPING TAPE

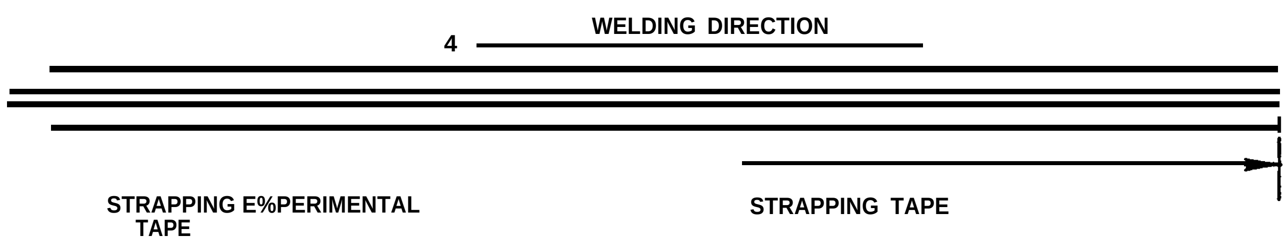
Sample No.	Electrode	Ave. Voltage v	Current amps.	Fillet Size Vext. Leg. in.	Fillet Size Horiz. Leg. in.	Shape	Undercut Vert. Leg.	Undercut Horiz. Leg.	Spatter	Slag Removal
19	E6027	34	230	5/16	3/8	Excellent	No	Yes	Normal	Easy
**19	E6027	37	2 4 0	3/8	3/8	Excellent	No	No	Heavy	Easy
19	E6027	36	250	5/16	7/16	Excellent	No	Yes	Heavy	Easy
19	E6027	36	265	5/16	3/8	Flat	No	No	Heavy	Difficult
18	E6027	34	265	1/4	1/2	Convex	No	No	Bad	Difficult
18	E6027	37	280	5/16	3/8	Flat	No	No	Bad	Difficult
18	E6027	38	300	1/4	3/8	Convex	No	No	Bad	Difficult
18	E6027	40	315	1/4	3/8	Poor	No	No	Bad	Difficult
18	E6027	42	320	5/16	5/16	Poor	No	Yes	Bad	Difficult
16	E7024	29	230	5/16	3/8	Convex	No	No	Normal	Easy
16	E7024	32	240	5/16	7/16	Convex	Yes	No	Normal	Easy
**16	E7024	32	250	5/16	3/8	Convex	Yes	No	NOrMal	Easy
16	E7024	33	265	5/16	3/8	Too convex	Yes	No	Heavy	Difficult
17	E7024	33	265	1/4	3/8	Too convex	Yes	No	Heavy	Difficult
17	E7024	33	280	5/16	3/8	Too convex	No	No	Bad	Difficult
17	E7024	37	300	5/16	1/4	Too convex	No	Yes	Bad	Difficult
17	E7024	38	315	5/16	5/16	Poor	Yes	Yes	Bad	Difficult
17	E7024	33	320	5/16	5/16	Poor	Yes	Yes	Bad	Difficult

** preferred parameters.

are described in Table 15, their evaluation is covered in the following paragraphs.

Experimental Tape Evaluation. When firecracker welding with 72-inch-long electrodes the resistance heating of the electrode becomes significant. For example, when a 3/16-inch-diameter electrode is used measured temperatures on the coating surface at the electrode holder always exceeds 800 F before the end of the weld is reached. Some temperatures were measured at 1100 F. The strapping tape fails long before the weld is completed under these conditions. Failure is by fusion of the tape base and splitting between the glass fibers. The early stage of such a failure is shown in Figure 16. It is seen from the photo that an improved tape must be well insulated in the area that contacts the electrode. This was the basis for the design of the tapes supplied. A general description of the experimental results when using these tapes follows, identification numbers are the supplier’s followed by the program specimen number in brackets.

Because of the short lengths of tape received it was necessary to evaluate them in short sections as part of a 72-inch electrode hold-down. This was done as shown in the sketch of how the electrode was



secured in the joint area. When set up as shown an experimental tape was exposed to ample temperature rise for its evaluation. The electrode used in all tests was 7/32-inch-diameter E7024. The preferred welding parameters for this electrode were also followed. The events occurring during the test of each tape follow.

Tape ISD-619-(L-11). Strapping tape sinking after 20 inches of arc travel, badly burned after 30 inches and clear off of rod after 36 inches of arc travel. After 40 inches, tape-619

TABLE 15. GENERAL DESCRIPTION OF EXPERIMENTAL TAPES FOR FIRECRACKER WELDING

Identification No.	General Characteristics	Length received inches
ISD-617	Glass-like beads, backed by woven glass-like fiber tape about 1 inch wide, backed by a woven black fiber cloth about l-1/2 inch wide, backed by 3 inch wide aluminum foil with adhesive.	62
ISD-618	A black woven cloth (graphite?) about 1-1/4 inch wide backed by a heavy "Scotch taPe" 2-1/4 inch wide which contains fibers longitudinally (not like strapping tape) .	+30
ISD-619	A white "blotter like" material 1 inch wide backed by a heavy tape like that on ISD-618.	530
ISD-620	Cream colored brittle paper like tape 1 inch wide and ca. 1/16 inch thick backed by same tape used on ISD-618.	16
ISD-621	Same as ISD-620 except paper like tape may be thicker.	15

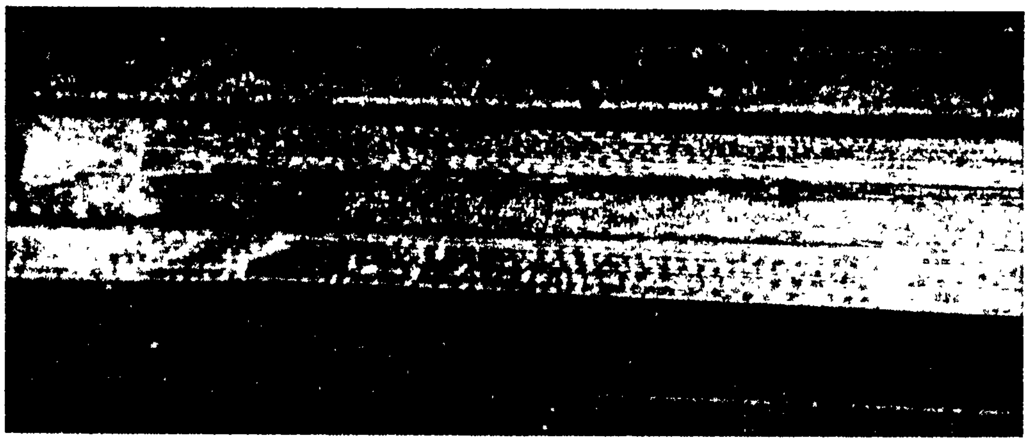


FIGURE 16. FAILURE INITIATION OF STRAPPING TAPE ON 72 INCH ELECTRODE

was charred and the remaining strapping tape was aflame. After 50 inches the tape on -619 was aflame. The -619 burns off evenly as the arc proceeds under it; the arc may be slightly smoother also. This tape did not show much promise.

Tape ISD-618-(L-12). Black portion of tape was cut down from 1-1/4 inch to 3/4 inch and this was placed on 2-inch-wide strapping tape that was on hand. The strapping tape (not -618) began smoking after the arc had traveled 20 inches and was completely split and off the electrode at 30 inches. At this ttie the tape on -618 began to split. This was complete after the arc had traveled 42 inches. All tapes was aflame after 48 inches. The arc proceeded satisfactorily under the woven black tape but it was difficult to observe. This tape does not show promise as a hold-down material.

Tape ISD-617-(L-13). The foil backing and other layers were preformed to the T joint shape. The built-up portion was much too wide. Smoking started after about 20 inches of arc travel, the strapping tape was badly split after 28 inches, at this point the voltage trace was erratic because the tape did not hold, the electrode was held in place manually. The -617 tape appeared intact after 46 inches of arc travel, the voltage was down as the arc went under the experimental tape, an indication of good hold down and confined arc. The arc cut the foil but the molten foil does not seem to get in the arc, the cut did not go the full length of -617. Much smoke and flame evolved from the ends of -617 while the arc was und~ it. The weld bead in the experimental tape section was not as good as with other tapes. The adhesive on the foil seemed to hold well when hot. This tape may have promise. A concern was shown for the difficulty of shaping, the smoke and its possible effect on welding and the quality of the weld produced.

Tape IsD-620-(L-15). Tape very hard to shape to the electrode and joint, it was too wide and brittle or friable. Strapping tape started to smoke after 24 inches of arc travel and was split badly after 36 inches. Experimental tape intact after 42 inches. No tape was holding anything after 44 inches except the -620. The -620 tape was ballooned out away from the rod and flaming after 52 inches of arc travel. The -620 tape melted into the arc. Not a fair test because of the fit of the tape, however, little promise would be expected from this tape.

Tape ISD-621-(L-16). This tape was more difficult than -620 to shape into the joint. The results of the welding test were for practical purposes identical with those for ISD-620. ISD-621 shows little premise.

Tape ISD-617-(L-17). This test was a repeat of L-13. The results duplicated L-13. The strapping tape was all consumed when the arc had traveled 50 inches and the -617 was intact. Only 2 inches of the foil on -617 was consumed. The bead beneath the -617 was not good, but there was no indication that the -617 caused this. Other comments on L-13 apply to this test.

Tape ISD-617-(L-18). This test was intended to be like L-13 and L-17 except that for this test the foil was perforated every 1/4 inch with an awl after it was placed on the joint. It was supposed that the perforations would vent the fume and gases from under the tape. The test was aborted before complete by a short at the electrode holder. Much was learned from the nearly 4 inches of -617 which did see the arc. The perforations did vent smoke and flame but not visibly until the arc was within 1 inch. The layers of -617 were not seriously burned until the arc passed. The adhesive on the foil remained tight until the arc passed and was sticky when cold after the test.

Some general comments on the use of all the tapes can also be made.

(1) In all cases the built-up portion of the tape was too wide. This prevented close fitting the tape to the electrode and minimized the effectiveness of the adhesive area. The resultant poor fit to the electrode may have caused some of the experimental tapes to appear more resistant to heat than actually was the **case.** The built-up portion should have a maximum width of 3/4 inch for the electrodes used in this study.

(2) The built-up portion of tapes ISD-619, -620, and -621 was too friable for satisfactory handling.

(3) The built-up portion of tapes ISD-619, -620, and -621 was made narrower by carefully cutting about 1/4 inch off one edge. This had an adverse effect on the adharing surface but permitted,closer conformance to the electrode.

(4) Preforming the tape for the T joint as was done with ISD-617 had a distinct advantage in reducing the time to place the tape.

It is apparent that the only one of the tapes evaluated which showed enough promise for further study was ISD-617. This tape is quite similar in construction to available commercial welding backed tapes and therefore its development for firecracker welding should not be difficult. Work on its future development should include; narrower built-up area, more ductile foil backing, dimensional adjustments to fit T joints and v grooves, and preforming. A study of how the confined vapors that occur during welding influence the weld quality and the need for perforating the foil should also be made.

Mechanical Holddown

The device used during this program to hold electrodes in place for firecracker welding is shown in Figure 17. The toggle clamps were spaced to give hold-down contacts varying from 8 to 24 inches depending on

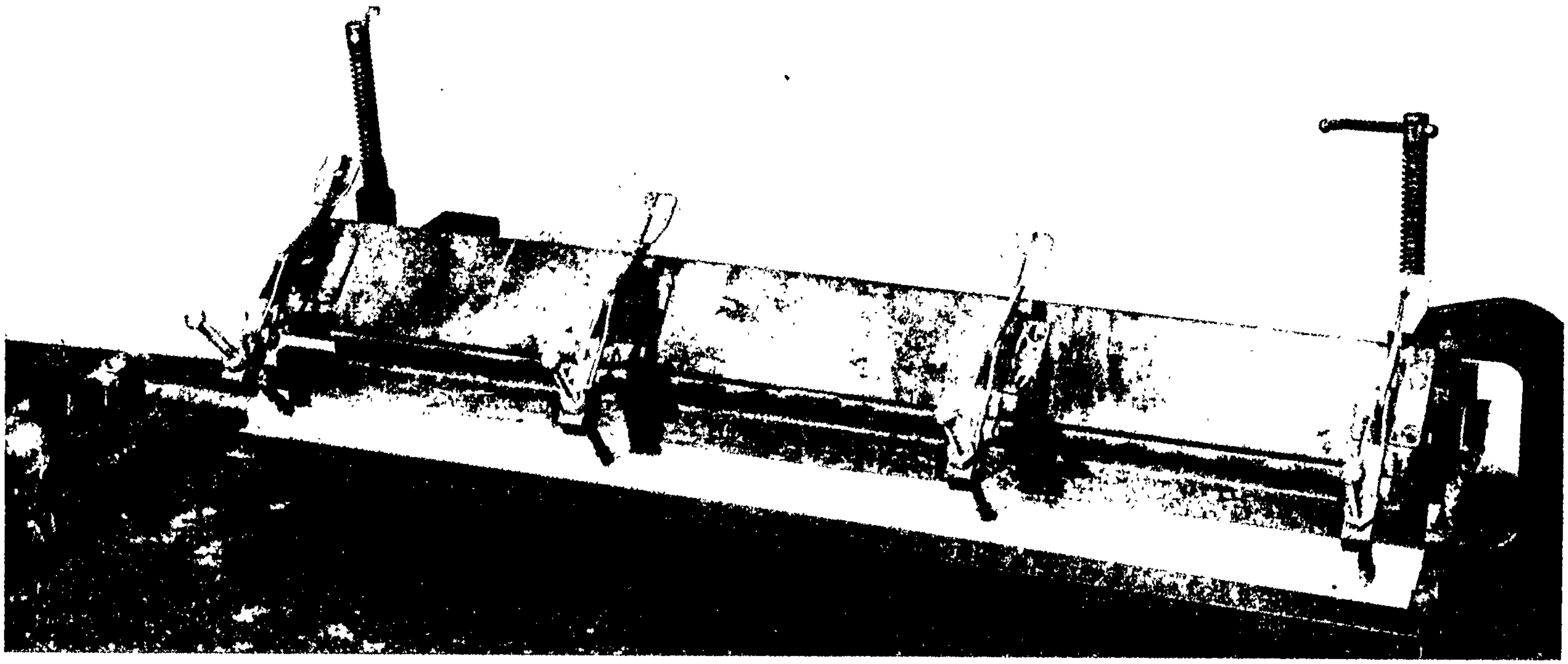


FIGURE 17. MECHANICAL DEVICE FOR HOLDING IN
PLACE DURING RE RA KE

the length of electrode being tested. The contact screws permitted adjustment to allow for different diameter electrodes and also some latitude in location of the device which was held in place by c clamps. This latitude can be used when making multipass welds. The ends of the contact screws w=e protected from the arc by wrapping with glass electricians tape. Ceramic tips were tried and required replacement after each weld; the glass tape lasted for several welds. In Figure 17 the hold-down device is shown with the electrode also taped in place. This was done to give contrast in the photo. The device was used both with and without the tape in place. When kdzh were used it was mainly to permit the use of tuned or bent electrodes.

The mechanical hold-down device was adequate for experimental purposes. In actual practice it is expected that a similar device could be designed which permitted quick location and would be held in place with electromagnets. Its usefulness would depend on the ease of handling and placement in the small places where firecracker welding would have the greatest application.

Magnetic Holddown

A logical method for holding the electrodes for firecracker welding in place involves the use of magnets. Either permanent magnets or electromagnets could be used. In this program permanent magnets *were* used in order to avoid the need for constructing electromagnets to suit the intended purpose. In actual practice electromagnets would be better suited because they could be carefully positioned before being energized. Positioning the permanent magnets could be difficult especially in the confined spaces where firecracker welding is most apt to be used.

A 72-inch-long electrode is shown held in place by magnets in Figure 18. The magnets used were the standard weld positioning type having a stainless steel bolt positioned such that it would provide a contact point on the electrode. A ceramic pad protected the bolt end from the arc. The bolt threads and magnet faces were protected with strapping tape. A closeup of one of the magnets with an electrode in place is shown in Figure 19.

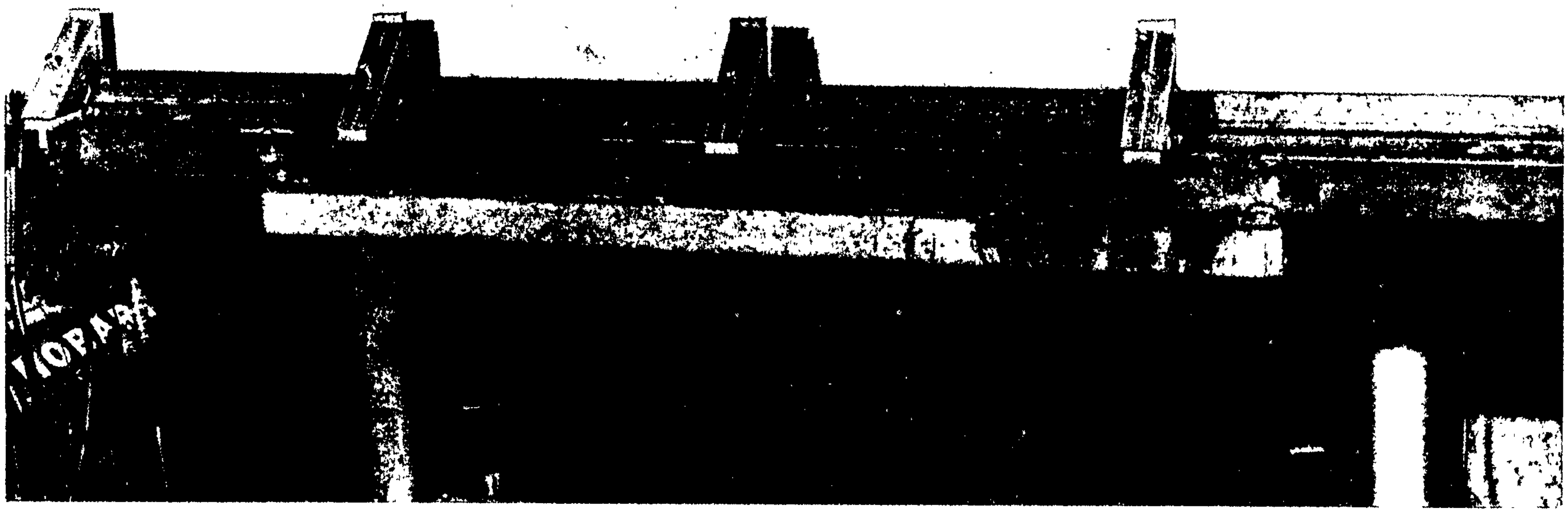


FIGURE 18. 72 INCH FIRECRACKER WELDING ELECTRODE HELD IN PLACE WITH PERMANENT MAGNETS

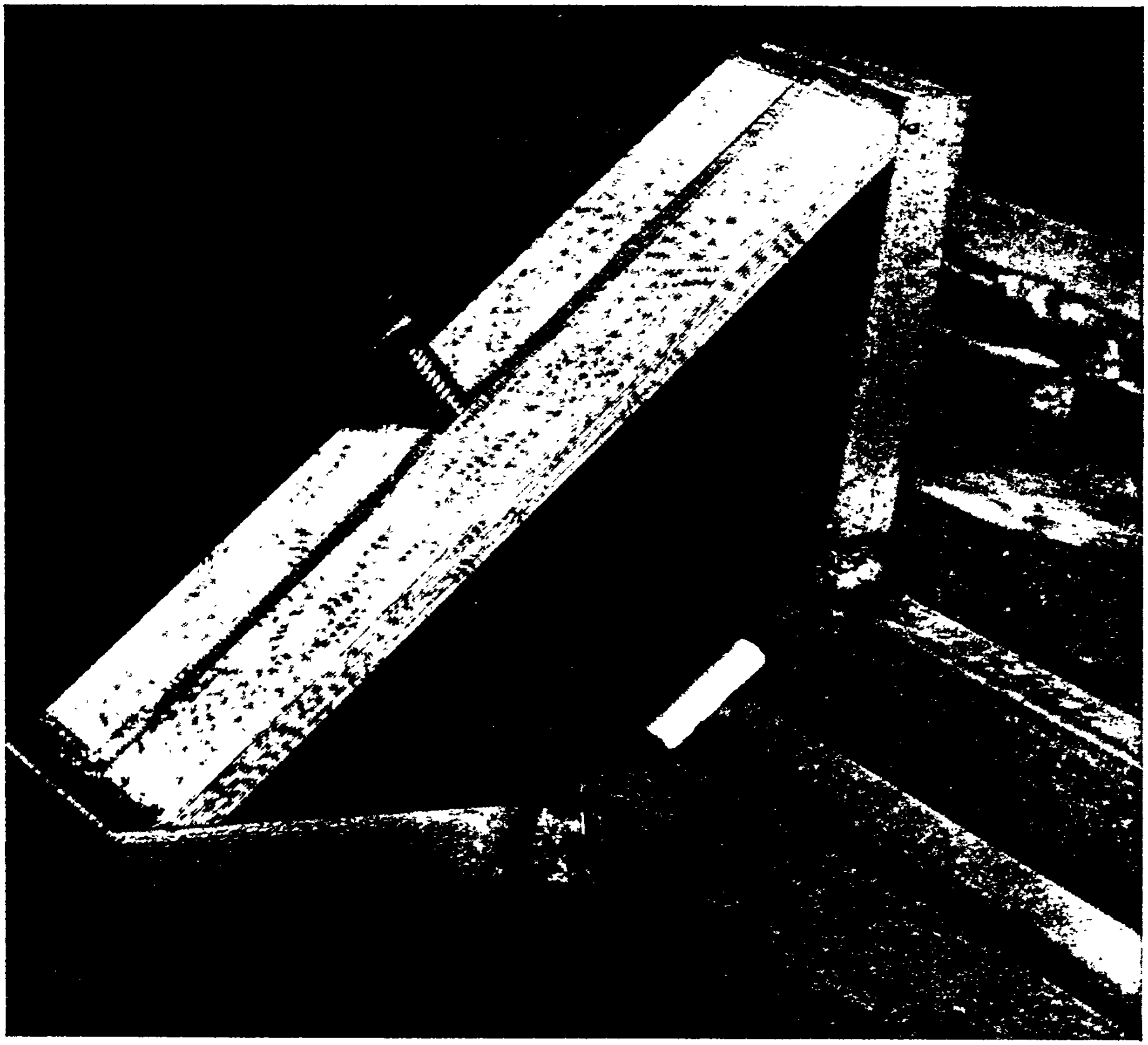


FIGURE 19. CLOSE-UP OF MAGNET HOLDING ELECTRODE IN PLACE
(Note tabs welded to specimen to serve as pads for magnet faces)

The magnetic hold-down system shown and described was capable of holding the electrodes used in this program without difficulty. A concern for the possible effect of the magnetic field appeared to be unfounded when welding with a single electrode. No visible or other effect was noted as the arc proceeded along the joint. This was not the case when the electrodes on both sides of the T joint were held with magnets set face to face on each side of the T and two fillets were produced simultaneously.

In the case of the two-side welds the strapping tape holddown was augmented with permanent reagents to overcome any deterioration of the tape on 72-inch electrodes. When welding with the magnets in place the arc voltage on the one arc covered by a recorder raised 3-5 volts as the arc neared and passed beneath the magnets. The quality of the weld bead in the area of the magnets was not adversely affected. Further study of the influence of magnetic hold-down systems on welding results is needed.

Multipass Fillet Welds

In order to study the feasibility of making multipass fillet welds several previously made welds were built up with two additional passes. Either E6024 or E7024 electrodes 28 inches long and 7/32 or 1/4 inch in diameter were used for these joints. The second pass was placed at the intersection of passes 1 and 2. Standardized welding conditions ware used with the electrode held in place with strapping tape aided in some cases by the mechanical hold-down device. Data for these welds are given in Table 16. Typical cross sections of five of the welds are given in Figure 20.

As indicated by the data collected little difficulty was encountered in producing three pass T joint welds. The welding parameters were essentially the same as for single pass welds for both of the test electrodes. The often encountered characteristics of each electrode did not change either. Using the combination of electrode sizes given in Table 16. Specimen Nos. 114, 115, 116, 172, 173, and 174, the fillet

TABLE 16. MULTIPASS FILLET WELD DATA

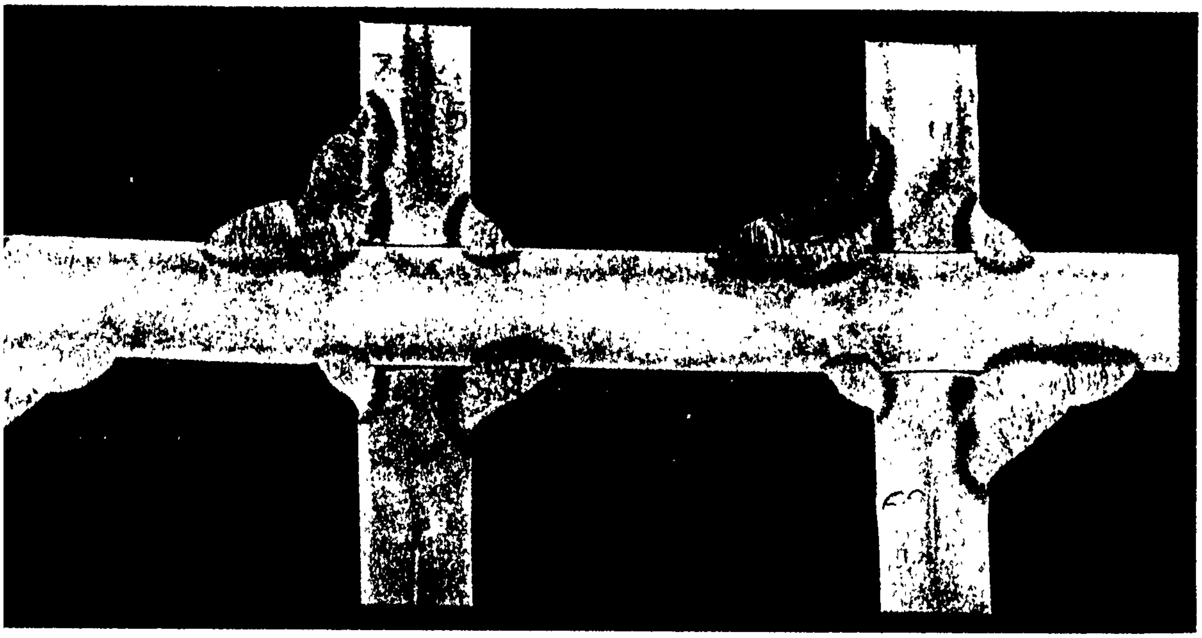
Specimen No.	Pass No.	Electrode Type	Electrode diem., in.	Voltage v	Current A	Polarity	Pass No. Fillet size, inches Horiz.	Vert.	Comments
114	1	6027	7/32	35-39	205-215	AC	5/16	1/4	
	2	6027	1/4	32-35	225-235	AC	- -	- -	Spatter heavy; bead to base plate too much
	3	6027	1/4	33-39	2257235	AC	13/16	5/8	Spatter heavy; slag sags; small slag packets at vertical toe
173	1	6027	1/4	29-36	225-265	DCSP	3/8	l/4	
	2	6027	7/32	33-37	180	AC	- -	- -	Spatter heavy; good weld, well placed
	3	6027	7/32	32-38	180	AC	13/16	1/2	Spatter medium; slag pockets at vertical toe and on bead
174	1	6027	1/4	29-38	210-260	DCSP	3/8	1/4	
	2	6027	7/32	34-37	195-200	AC	- -	- -	Spatter medium; very good weld, well placed
	3	6027	7/32	34-39	195-205	AC	3/4	5/8	Spatter medium; arc stable; slag sags; pockets at vertical toe
i72	1	6027	1/4	30-35	240-270	DCSP	3/8	1/4	
	2	6027	1/4	32-38	210-225	AC	5/8	- -	Spatter heavy; covers first pass well; no pocket or slag sag
	3	6027	1/4	32-34	210-220	AC		- -	Spatter medium; slag sags; small slag pockets top edge
115	1	7024	7/32	29-32	235-245	AC	5/16	1/4	
	2	7024	1/4	30-35	260-280	AC		- -	Spatter heavy; good, well placed bead; horizontal leg long

TABLE 16. (Continued)

Specimen No.	Pass No.	Electrode Type	Electrode diem., in.	Voltage v	Current A	Polarity	Pass No. Fillet size, inches Horiz.	Vert.	Comments
	3	7024	1/4	28-32	260-280	AC	3/4	11/16	Spatter medium; bead went to vertical causing poor contour
116	1	7024	7/32	30-32	235-245	AC	3/16	1/4	
	2	7024	7/32	30-31	215	AC			Spatter fair; good well placed bead; current low, unexplained
	3	7024	7/32	30-37	205-240	AC	3/4	1/2	Spatter fair; arc nearly snuffed out; good, well placed bead
192	1	7024	3/16	32-35	180-185	AC		--	
	2	7024	3/16	30-33	185-190	AC	--	--	
	3	7024	7/32	30-32	235-240	AC	1/2	3/8	Good well placed bead; 6 inches of poor wetting
195	1	6027	3/16	37-40	170-175	AC	--	--	
	2	6027	3/16	35-38	175-180	AC	--	--	
	3	6027	7/32	34-36	200-205	AC	5/8	1/2	Good head, good contour, slag sags? slag pockets at top configuration not too good

E7024
No. 115

E7024
No. 116



No. 174

IGURE 20. CROSS SECTIONS OF MULTIPASS FILLET WELDS size had significantly unbalanced leg lengths as shown. This is evident too in Figure 20. A effort was made to produce welds with balanced fillet legs by making the final pass with a slightly larger electrode. The success of this technique is shown in the data for Specimens 192 and 195 in Table 16. Further experimentation with the production of multipass fillet welds showed that welds with legs up to about 7/16 inch can be made with the three pass procedure. When making these welds it is necessary to use electrodes of different sizes to minimize a tendency to produce fillets which have long horizontal legs. In general, this means that the second pass at the horizontal toe of the fillet should be made with a smaller electrode than the third pass at the vertical toe.

The weld bead surface of a typical three pass weld made with E6027 is shown in Figure 21. Figure 22 shows a similar E7024 weld. Some poor wetting defects were noted with the E7024 welds in addition to the slag pockets often encountered when using this electrode. Both types of defects in E7024 welds are attributed to the quick freezing character of the slag. Defects were encountered at the vertical toe of the third pass of some welds made with E6027. This surface porosity varied from fine pinholes to slag pockets like those visible in Figure 23 and apparently results from the high fluidity of the slag. Much of the slag produced by the third pass flows away from the upper edge of the weld as shown in Figure 24. The siag flows away from the molten metal nonuniformly, thus creating the pockets of tightly adhering slag when the weld metal has frozen.

The characteristics of the slags encountered and a discussion of the subject are discussed in a later section of this report.

Welding Through Primer Coatings

Often steel plate which is to be welded in the shipyard or other heavy construction projects is coated with a primer paint before welding. It therefore was desirable to examine the effect of these primers on firecracker welding procedure and also on the character of

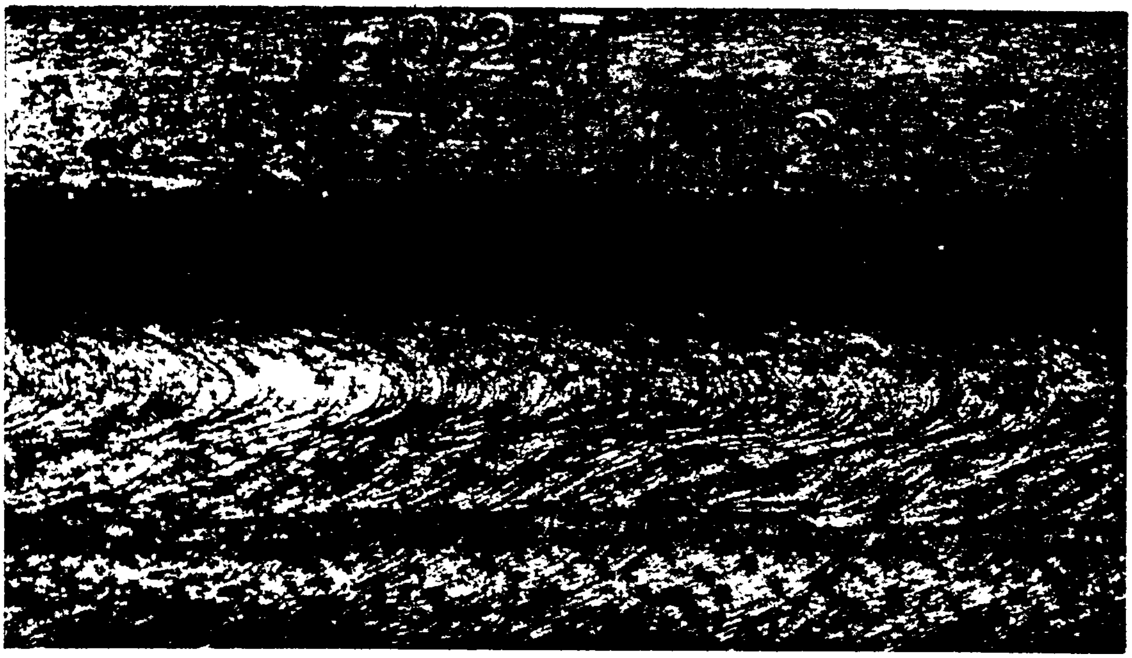


FIGURE 21. TYPICAL THREE-PASS E6207 FIILET WELD

FIGURE 22. TYPICAL THREE-PASS E7024 FILLET WELD

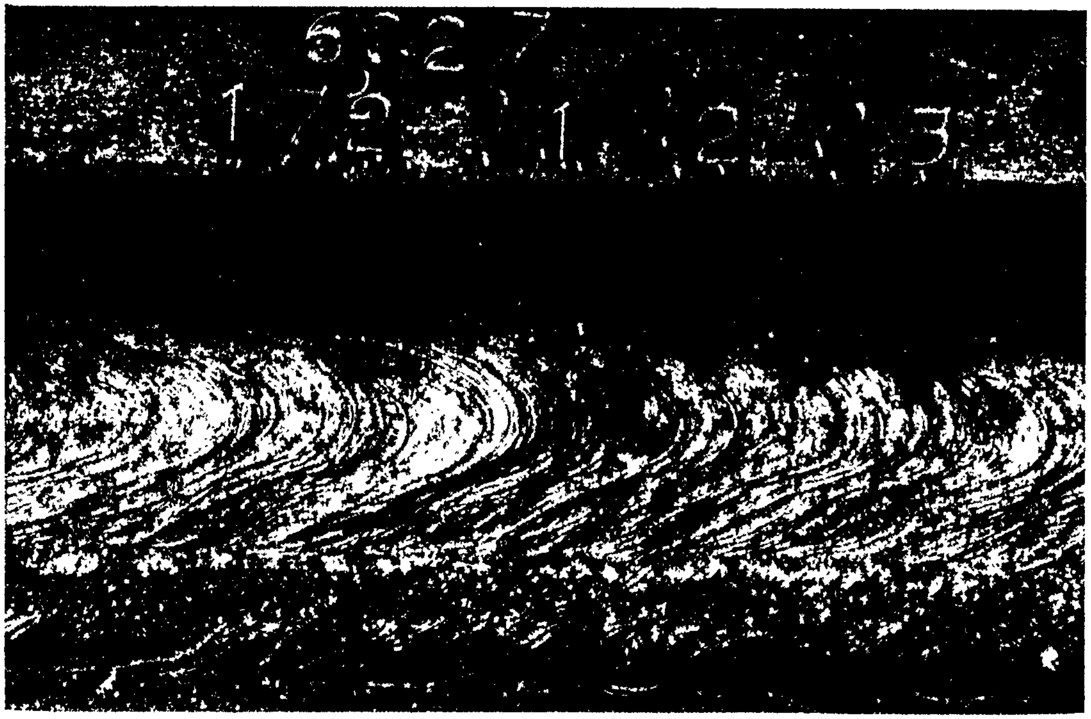


FIGURE 23. DEFECTS IN THE UPPER TOE OF A THREE-PASS E6027 FILLET WELD

FIGURE 24. THIRD PASS SLAG WHICH HAS FLOWED AWAY FROM THE UPPER TOE OF THE E6027 WELD

the weld produced. The welding literature[a] indicates that generally the presence of a protective coating on the base metal has significant influences on the behavior of the welding arc but little effect on the mechanical properties of the weld. Consequently, the influence of these coatings on firecracker welding were limited to obsemation of the arc activity, deviation in the visual quality of the weld from coating -free welds, and radiographs of the weld for porosity.

TWO different coatings were chosen for evaluation. One was a water base material; the other an organic, alkyl, base material. They were chosen as representative of the two types of primer coatings widely used in industry. Both were supplied in kits consisting of fluids and powder and were mixed as the instructions indicated before use. The primers were sprayed on the specimens for welding after they were grit blasted, solvent cleaned and dried. The coating thickness for each material was 0.0008 inch. The coatings were dried in air for 72 hours before considered ready for the welding tests.

The weld specimen was a corner joint made for convenience in radiographing. Welds were made with 7/32-inch diameter, 28-inch long E6027 and E7024 electrodes under the standardized AC welding conditions. Two welds were made through each coating with each electrode; in addition a bare specimen was welded with each electrode. The welding parameters and test observations are recorded in Table 17. Figure 25 shows the welded specimens after grit blasting.

It is apparent from Table 17 that the major effect when fire-cracker welding through paint primers is essentially the same as when welding with other processes, arc instability and spatter are greatly increased. The increased arc instability and the excessively long arc are detrimental to firecracker welding. They cause the weld bead to wander to one leg or the other of the T joint much more than when the primer is not present. This effect is visible in Figure 25; it was encountered relatively often when using E7024 electrodes without a primer coating but very seldom with E6027 electrodes. Consequently, it was

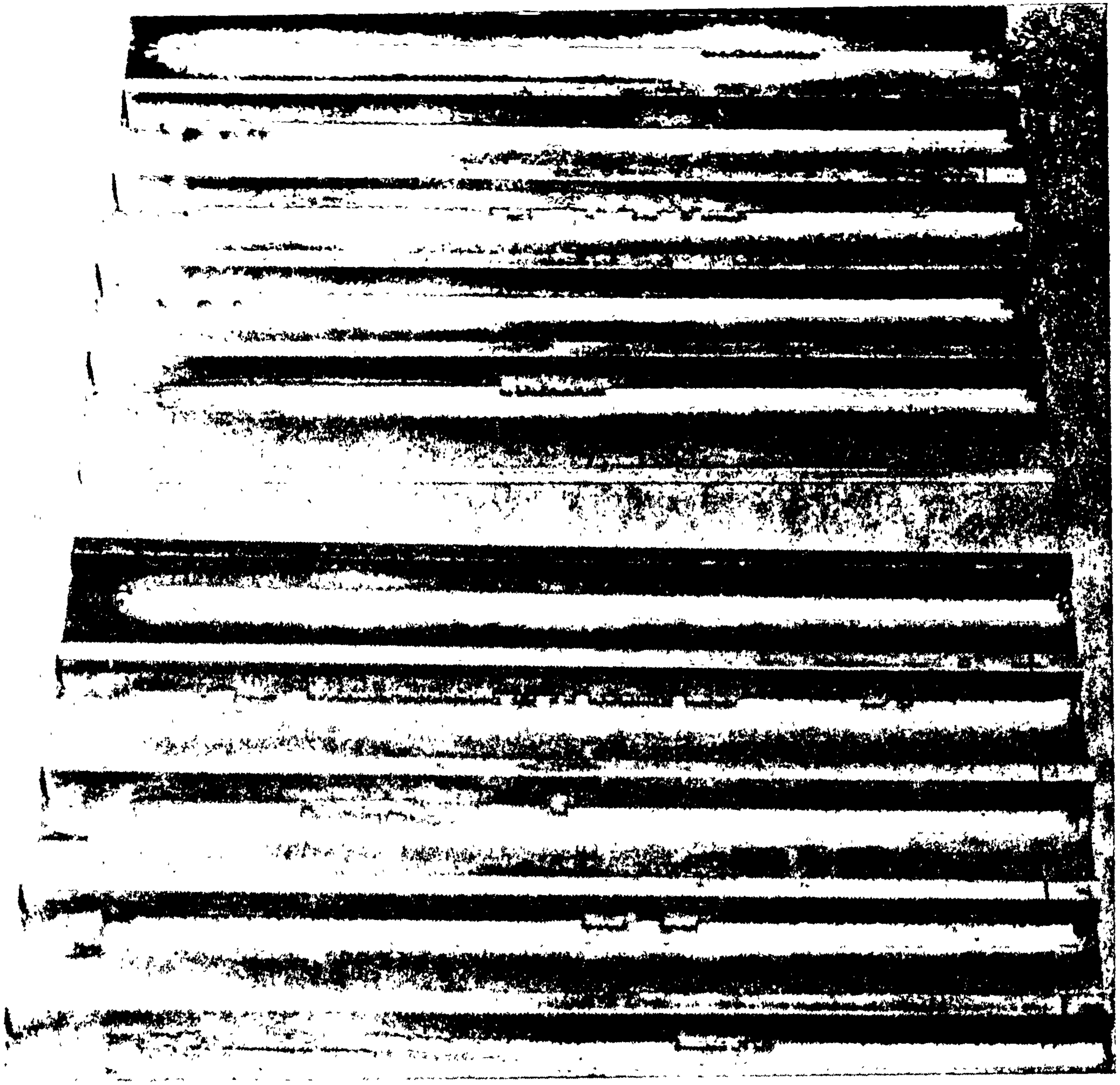
[a] Pattee, H. E. and Monroe, R. E., “Effect of Protective Coatings on the Weldability of Selected Steels”, Welding Journal, 48(6), pp 221S-230s, (1969)

TABLE 17. RESULTS AND OBSERVATIONS OF FIRECRACKER WELDS MADE THROUGH PRIMER COATING

Specimen No.	Coating* No.	Electrode Type	Voltage V	Current A	Arc Stability	Spatter	Weld Surface	
P-1	11	E6027	37-44	**190-200**	Bad	Heavy	Good	Bead not uniformly in joint; slag pockets which are uncommon for E6027; arc flame very long**
P-3	11	E6027	33-38	**185-195**	Bad	Heavy	Fair	Generally a better weld than previous one; slag pockets in weld; arc flame long
P-2	11	E7024	30-35	**215-220**	Fair	Heavy	Good	Bead in and out of joint root; slag pockets in weld; long arc flame
P-4	11	E7024	28-34	**215-230**	Fair	Heavy	Good	Good weld except for slag pockets in last 4 inches; arc flame quite long
P-5	2	E6027	33-40	**190-200**	Bad	Heavy	Fair	Long arc flame; non uniform bead; slag pockets
P-7	2	E6027	30-35	**190-200**	Bad	Heavy	Fair	Poor weld mostly on base plate; long arc flame
P-6	2	E7024	30-38	**200-230**	Bad	Heavy	Good	Long arc; good weld each end; slag pockets near center
P-8	2	E7024	30-34	**215-230**	Bad	Heavy	Good	Arc flame long; good weld except near the end; slag pockets
P-9	None	E6027	30-35	**190-200**	Fair	Medium	Good	Uniform bead; normal for E6027
P-lo	None	E-7024	30-33	**215-220**	Fair	Medium	Good	One large slag pocket; about average for E7024

* Number 11 is **organic** base? Number 2 is water base.

** Length of arc as compared to usual arc for these electrodes



E7024 Control Weld
NO coating

E7024 Coating No. 2

E7024 Coating No. 2

E7024 Coating No. 11

E7024 Coating No. 11

E6027 Control Weld
No coating

E6027 Coating No. 2

E6027 Coating No. 2

E6027 Coating No. 11

E6027 Coating No. 11

FIGURE 25. FIRECRACKER FILLET WELDS MADE THROUGH PRIMER cOATINGS

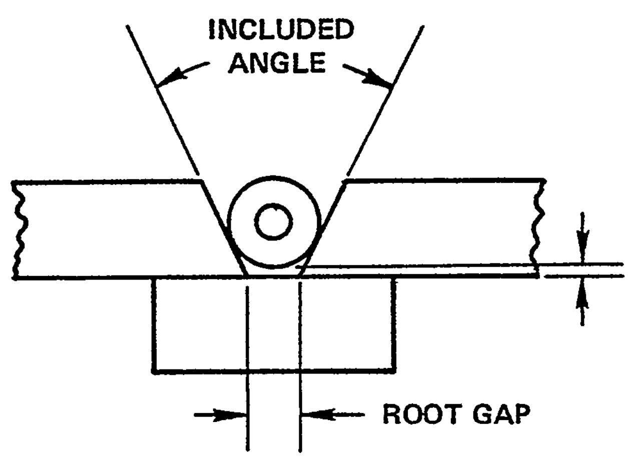
concluded that the E6027 electrode had less tolerance for primer coatings during firecracker welding because Figure 25 shows much evidence of arc wander on the E6027 specimens. There is also some indication from the data in Table 17 that arc stability may be better when using the E7024 electrode. In either case the presence of primer coatings is detrimental to firecracker welding.

Each of the specimens in Table 17 was radiographed to determine if weld porosity was caused by welding through primers. No porosity was found in any specimen.

There was no evidence that one type of primer had a different influence on welding than the other.

Groove Welds

A study of the suitability of firecracker welding for producing groove welds was made using a vee joint design in l/2-inch plate and a l/2=inch backing plate. Welds were made in grooves having either a 60- or a 45-degree included angle and four different root gaps; 1/8, 3/161 l/4~ and 5/16-inch. The electrodes used were either 7/32 or 1/4 inch in diameter. The hold-down was strapping tape. The essential details of the joint used with an electrode in place are shown in the sketch.



Data collected for the initial pass of all the groove welds produced are recorded in Table 18.

E6027 ELECTRODES

Sample Number	INCLUDED ANGLE	ROOT GAP, IN.	STANDOFF, IN.	VOLTAGE, AVE., E	CURRENT, AVE., I	ELECTRODE, DIAM., IN.	ExI/10^3	PENETRATION, VISUAL	PENETRATION, ACTUAL	VISIBLE SLAG POCKETS YES OR NO
G-2	45	0.25	0.07	33	215	7/32	7.1	Poor	--	Y
G-4	45	0.19	0.15	34	205	7/32	7.0	Good	Inc.	N
G-6	45	0.13	0.22	34	205	7/32	7.0	Good	Inc.	N
G-7	60	0.25	0.01	34	205	7/32	7.0	Good	Full	N
G-8	60	0.19	0.07	33	205	7/32	6.8	Good	Inc.	N
G-9	60	0.13	0.12	33	200	7/32	6.6	Fair	Inc.	N
G-13	60	0.13	0.10	35	170	3/16	6.0	Good	Inc.	N
G-14	60	0.19	0.04	32	175	3/16	5.6	Good	Inc.	N
G-15	60	0.25	0.00	34	175	3/16	6.0	Good	Inc.	N
G-16	45	0.13	0.21	35	175	3/16	6.1	Fair	Inc.	N
G-17	45	0.19	0.14	35	180	3/16	6.3	Poor	--	Y
G-18	45	0.25	0.05	34	175	3/16	6.1	Poor	--	Y
G-25	45	0.19	0.15	33	245	1/4	8.1	Fair	Inc.	N
G-26	45	0.25	0.07	33	240	1/4	7.9	Fair	Inc.	N
G-27	45	0.31	0.00	30	250	1/4	7.5	Poor	--	Y
G-28	60	0.19	0.07	30	250	1/4	7.5	Fair	Inc.	N
G-29	60	0.25	0.01	30	245	1/4	7.4	Fair	Inc.	Y
G-30	60	0.31	0.00	32	245	1/4	7.9	Fair	Inc.	Y
G-39	60	0.19	0.07	35	195	7/32	6.8	Good	Inc.	N
G-40	60	0.25	0.00	33	200	7/32	6.6	Good	Inc.	N
G-43	60	0.31	0.07	39	260	7/32	10.3	Fair	--	Y
G-44	60	0.25	0.01	38	240	7/32	9.1	Good	Full	N
G-47	45	0.25	0.07	38	235	7/32	8.9	Good	Inc.	N
G-48	45	0.31	0.00	37	240	7/32	8.9	Good	Full	N
G-49	45	0.31	0.00	30	205	7/32	6.2	Poor	--	Y
G-53	60	0.25	0.00	37	240	7/32	8.9	Good	Full	N
G-54	60	0.25	0.01	36	245	7/32	9.0	Good	Full	N

-- = Weld Not Sectioned

Inc— = Backup Plate Fusion

E7024 ELECTRODES

SAMPLE NUMBER	INCLUDED ANGLE	ROOT GAP, IN.	STANDOFF, IN.	VOLTAGE, AVE., E	CURRENT, AVE., I	ELECTRODE, DIAM., IN.	ExI/10^3	PENETRATION, VISUAL	PENETRATION, ACTUAL	VISIBLE SLAG POCKETS YES OR NO
G-1	60	0.25	0.00	27	225	7/32	6.1	Poor	--	Y
G-3	60	0.19	0.04	27	220	7/32	6.0	Poor	Inc.	Y
G-5	60	0.13	0.10	27	220	7/32	6.0	Fair	Inc.	N
G-10	45	0.25	0.03	27	215	7/32	8.0	Poor	--	Y
G-11	45	0.19	0.10	26	210	7/32	5.5	Poor	--	Y
G-12	45	0.13	0.17	29	215	7/32	6.2	Fair	Inc.	N
G-19	45	0.13	0.21	36	185	3/16	6.7	Good	Inc.	N
G-20	45	0.19	0.14	30	200	3/16	6.0	Fair	Inc.	N
G-21	45	0.25	0.05	30	200	3/16	6.0	Good	Inc.	N
G-22	60	0.13	0.10	32	200	3/16	6.4	Poor	--	Y
G-23	60	0.19	0.04	29	200	3/16	5.8	Fair	Inc.	Y
G-24	60	0.25	0.00	29	195	3/16	5.7	Fair	Full	Y
G-31	45	0.19	0.10	27	270	1/4	7.3	Poor	--	Y
G-32	45	0.25	0.03	25	275	1/4	6.9	Fair	Full	Y
G-33	45	0.31	0.00	26	275	1/4	7.2	Poor	--	Y
G-34	60	0.19	0.04	27	285	1/4	7.7	Fair	Inc.	Y
G-35	60	0.25	0.00	27	275	1/4	7.9	Poor	--	Y
G-36	60	0.31	0.00	30	270	1/4	8.1	Poor	--	Y
G-37	45	0.25	0.03	31	345	1/4	10.7	Good	Inc.	N
G-38	60	0.25	0.00	33	335	1/4	10.7	Fair	Full	Y
G-41	60	0.19	0.04	29	220	7/32	6.4	Poor	--	Y
G-42	60	0.25	0.00	28	225	7/32	6.3	Fair	--	Y
G-45	60	0.19	0.04	37	235	7/32	8.7	Good	Inc.	N
G-46	60	0.25	0.00	32	250	7/32	8.0	Good	Inc.	N
G-50	45	0.25	0.03	30	260	7/32	7.8	Fair	Inc.	Y
G-51	45	0.31	0.00	31	265	7/32	8.2	Fair	Full	Y
G-52	45	0.31	0.00	29	230	7/32	6.7	Poor	--	Y
G-55	60	0.25	0.00	32	255	7/32	8.2	Good	Full	N
G-56	00	0.25	0.00	34	255	7/32	8.7	Good	Full	N

The cross sections of all of the single pass welds having root gaps less than 1/4 inch had incomplete penetration. In these welds the degree of penetration appeared to be a direct function of the stand-off distance regardless of electrode diameter or included angle. This is shown in Figure 26. It was found that to assure ccmplete penetration of the root gap the standoff distance should be essentially zero. Also, the electrode should not be loose in the groove, i.e., free to roll on its axis in the groove. The preferred joint preparation was a 60-degree included angle with a l/4-inch root gap.

The power input required during groove welding was found to be higher than that required for fillet welds as shown in Table 19. The use of slightly higher power inputs aided in assuring complete penetration and in the formation of a more desirable weld contour. Excess spatter was not a deterrent to raising the welding power input as was the case when making fillet welds by the firecracker welding process. The preferred welding parameters for groove welding are compared with standardized fillet welding parameters in Table 19.

Multipass Groove Welds

Utilizing certain of the single pass specimens recorded in *Table* 18 a number of multipass groove welds were made. All of these specimens had a 60-degree included angle and a 1/4 inch root gap. In each, three additional passes were required to fill the groove sufficiently for study purposes. All passes utilized 7/32 inch electrodes with strapping tape holddown. The welding parameters were as given in Table 19.

During production of the multipass groove welds no problems arose. Each weld pass with either electrode was complete and properly placed. Slag removal was not difficult. Its removal was carefully completed to assure absence of inclusions. The resultant welds were radiographed and sectioned for metallographic study. The results are shown clearly in Figure 27. Specimens G7 and GX show typical first pass cross sections for welds made under the preferred conditions. Specimens G44 and G46 were made several days prior to G53, G54, G55, and G56. They were also examined first.

E7024

Angle	Gap	Electrode Diam.	Standoff
45	1/8	7/32	0.17
45	1/4	1/4	0.03
60	1/8	7/32	0.10

E6027

Angle	Gap	Electrode Diam.	Stand-off
45	1/8	7/32	0.22
45	1/4	1/4	0.07
60	1/8	7/32	0.12

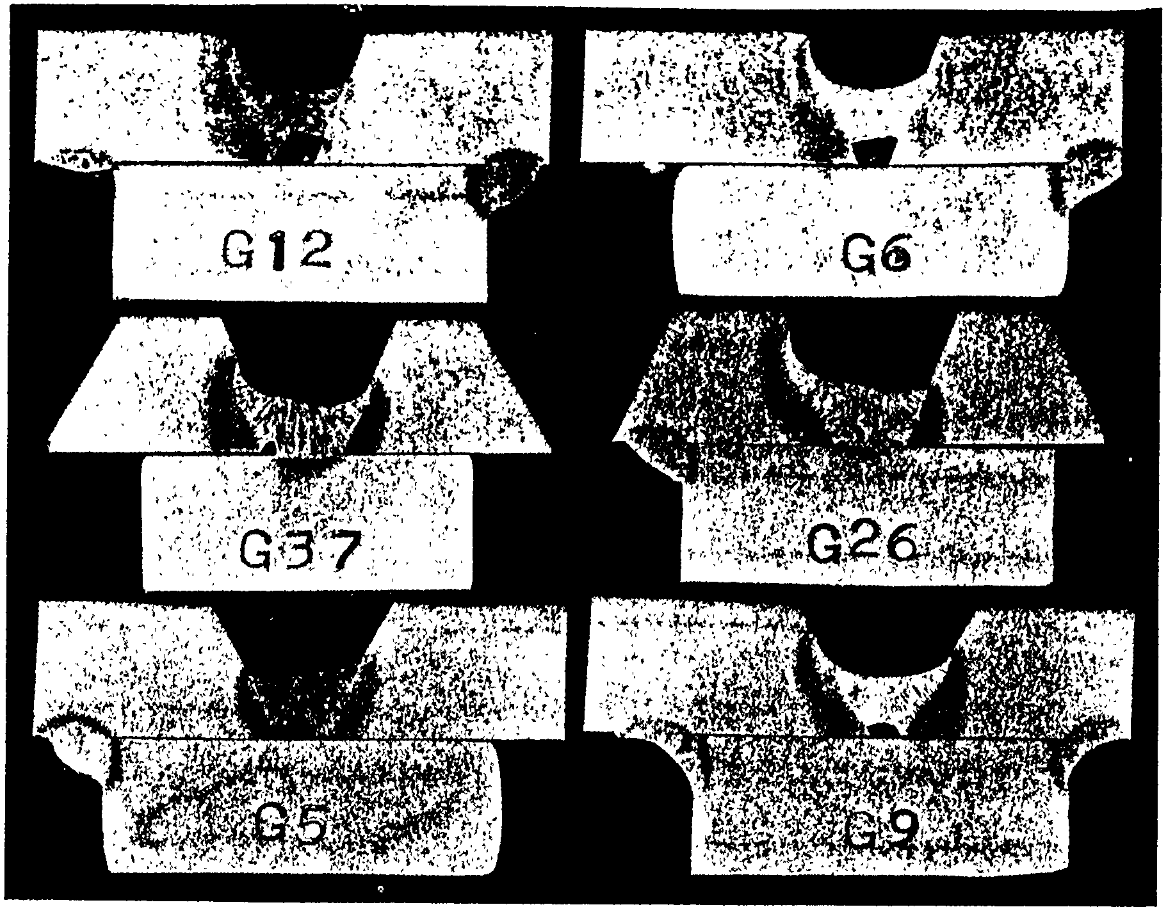


FIGURE 26. EFFECT OF STANDOFF DISTANCE ON PENETRATION IN GROOVE WELD

TABLE 19. COMPARISON OF GROOVE AND FILLET PREFERRED WELDING PARAMETERS

Electrode Type	Diameter in.	Groove Welding			Groove Welding		
		Voltage E	Current I	Power $\frac{E \cdot I}{10^3}$ Ave.	Voltage E	Current I	Power $\frac{E \cdot I}{10^3}$ Ave.
6027	7/32	35-40	235-245	9.0	36-38	195-200	7.3
6027	1/4	30-34	245-250	8.8	35-38	235-240	8.7
7024	7/32	30-34	245-255	8.0	33-36	205-210	7.2
7024	1/4	27-30	270-280	8.8	27-32	235-250	7.2

E6027 E7024

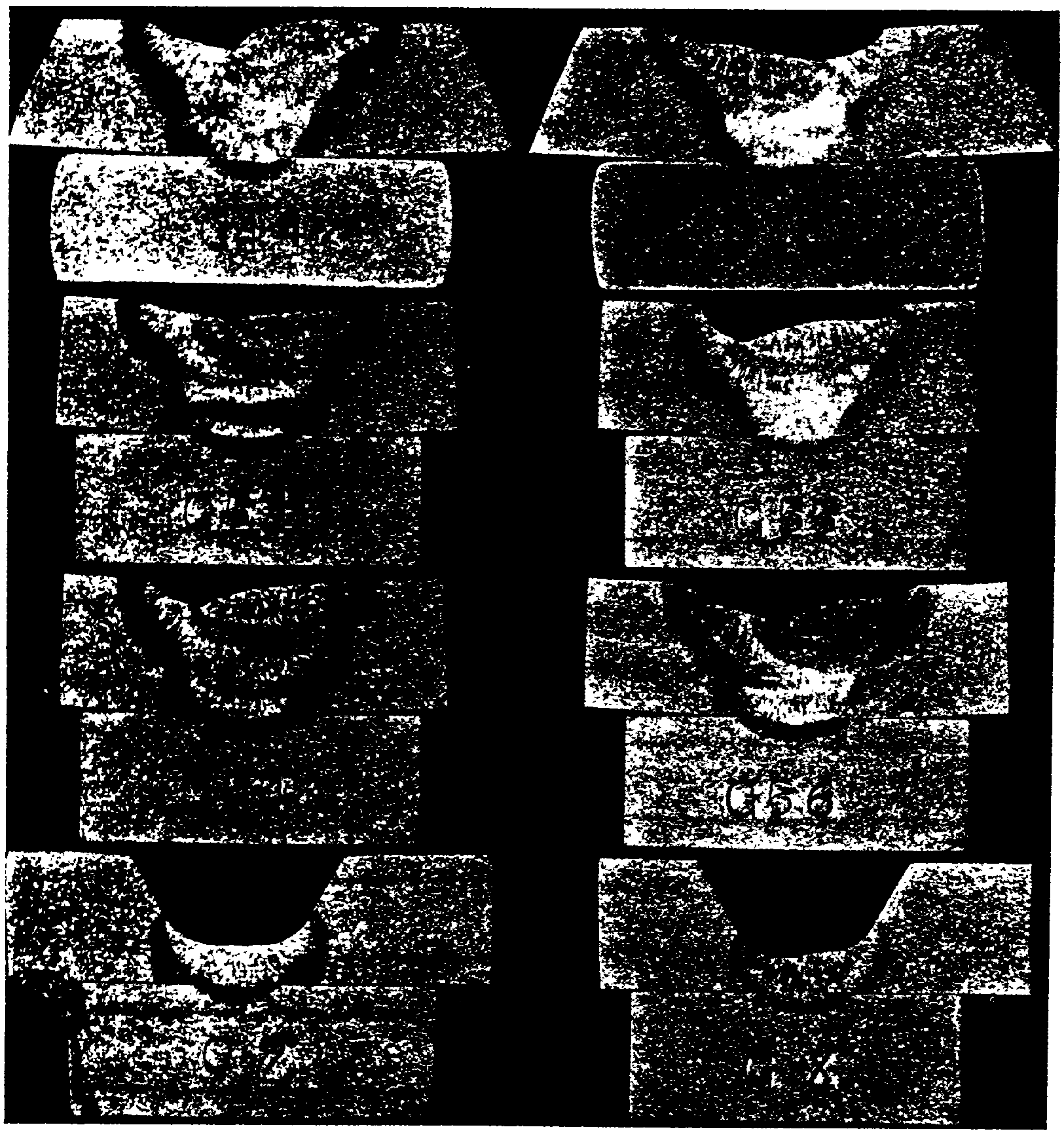
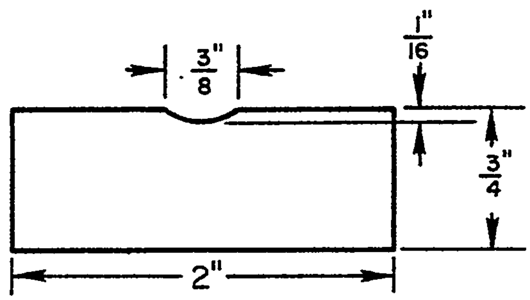


FIGURE 27. MULTIPASS FIRECRACKER GROOVE WELDS

The examination revealed the slag inclusion in G44 and questionable penetration in G46. The radiograph showed the inclusion in G44 was continuous in the weld, the lack of penetration was not. The remaining specimens were then made using special precautions during cleaning between passes. Radiographic and metallographic study of these welds showed the same slag inclusion site in all E6027 welds. The problem of slag inclusions beneath the third pass of these groove welds is related to the characteristics of the slag. These same characteristics influence the properties of multipass fillet welds and the surface appearance of firecracker welds made with all the E6027 electrodes used on this program. Because of this apparent deficiency in the E6027 electrodes it was concluded that E7024 electrodes were best when making groove welds.

Copper-Backed Groove Welds

In welding butt joints it is a coxmon practice to use rmovable copper backup bars rather than steel as done in the groove welding tests discussed in the previous paragraphs. Consequently, the feasibility of making firecracker welds in a groove backed with a copper bar was examined. The copper bar used had the cross section shown in the sketch. The welding



parameters used were those shown in Table 19. The root gap was varied from O to 1/4 inch and both E6027 and E7024 electrodes were used. No satisfactory welds were obtained. It appeared that a situation similar to that of electrode standoff as discussed in the steel-backed groove weld section also existed in these tests. The arc tended to go to the sides of the groove rather than to the root of the joint because the standoff was too great. The chilling effect of the copper bar also caused the slag to freeze in the groove and inhibit the arc’s ability to sweep it out of the joint root. Welds made with a flat copper backing bar were no better than those made with the grooved bar.

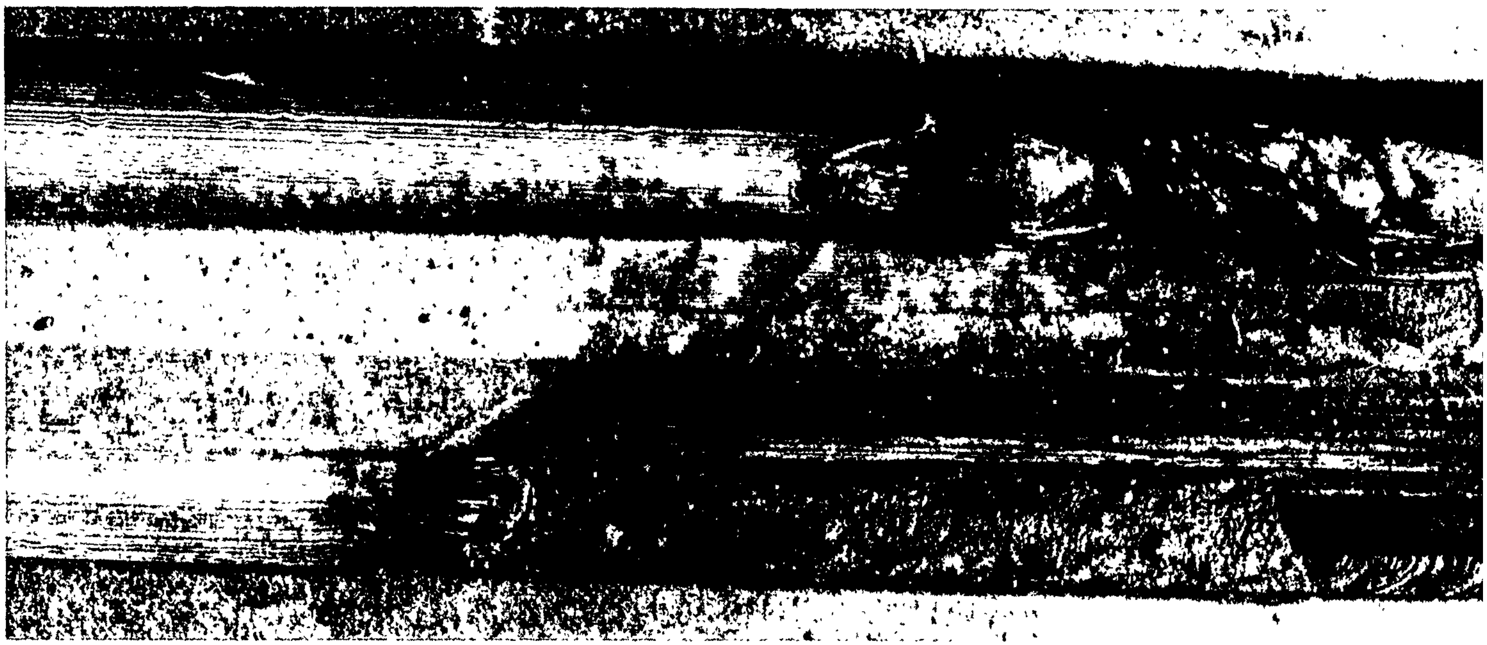
Slag Characteristics

In several places in this report comments have been made o-n how the characteristics of the molten slag influence results when firecracker welding. The subject of this section is an expansion of those comments.

In general, the most noticeable difference between the slags which result from welding with E6027 and E7024 electrodes is their flow characteristics. This, in turn, is probably related to the freezing temperature. The slag from E6027 freezes more slowly than that from E7024. The result of this is that the slag from E6c027 often leaves the weld bead uncovered. Figure 24 shows the slag from a multipass E6027 weld flowed away from the upper toe of the Weld. Figure 28 shows a comparison of how the slag flows when the arc is stopped with each of the two electrodes. The flow pattern on the slag of the E7024 electrode shows the crater in the pool and the fingernail of the burned electrode clearly. Thus, the slag has frozen before it had time to backflow into the area of the electrode end. The slag at the end of the E6027 electrode does not show a crater nor a fingernail indicating that the slag has flowed toward the electrode end before freezing. This difference in characteristics of the two slags is important because of the resultant arc action. The high freezing temperature of the E7024 is considered the cause of intermittent entrapment of the slag and slag pockets such as those shown in Figure 11. The fluidity and low freezing temperature of the slag from E6027 electrodes is responsible for the pronounced ebb and flow of slag as mentioned in the section on movies of the arc action. This also causes slag pockets but in addition it leads to periodically significant increases in spatter and to arc outages when the current is held low in order to minimize spatter and undercutting. The implication is that an electrode coating which is best for firecracker welding would

Electrode
E6027

Electrode
E7024

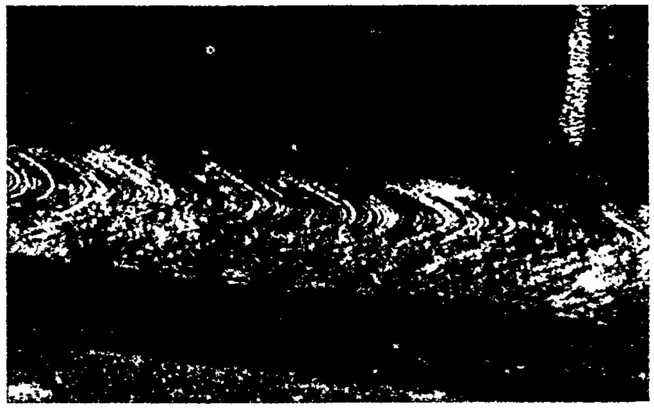


SURFACE OF FROZEN SLAG AT POINT OF ARC EXTINGUISHME have freezing and flow characteristics which are a compromise of those of both E6027 and E7024 electrodes.

As indicated another aspect of the difference in freezing characteristics is that of flowing off of the molten metal as shown in Figure 24. The result of this event, especially when making multipass fillet we<ds, is slag inclusions and shallow pits near the weld toe. This was shown in Figure 23. The conclusion here also is that the slag should freeze before the molten metal. Also, it should not flow off the metal **as it freezes.**

Probably less important to the properties of the firecracker weld but important for ease of cleaning between passes and also finished surface appear&ce is the smoothness of the weld bead. The E7024 electrode produces an easily remved slag and a weld bead which is smooth. The weld bead produced by E6027 electrodes is rough and on a comparative basis **the slag is not always easily removed.** The difference in these surfaces is shown in Figure 29. Note that the E6027 bead is well covered with small particles of slag or other material while the E7024 bead shows a minimum of this type of material. In addition, the metal flow pattern is significantly different. It is not known whether or not this difference can be contributed to the freezing properties of the respective slags. It is apparent that a preferred slag would result in **a** surface like that produced by E7024 electrodes. Again it can be stated that the best coating for firecracker welding would be a compromise between that from the two electrodes under study; because E6027 consistently produces a more complete weld bead than E7024.

The consistent presence of underbead slag inclusions in multipass groove welds made with E6027 electrodes provides another reason to be concerned about slag characteristics when firecracker welding. The phenomena cannot, however, be attributed directly to the freezing temperature differences. If this were true the E6027 slag should have a better chance of avoiding entrapment. It is felt that the inclusion problem derives from some complex peculiarities of the two slags such as fluidity and surface tension at welding temperatures. The development of a preferred electrode coating for use when firecracker welding would require consideration of such properties.



Electrode E7024 - 3/16 inch diam.

Electrode E6027 - 3/16 inch diam.

FIGURE 29. SURFACE APPEARANCE OF WELD BEAD AFTER SLAG REMOVAL

4949
4947

A very large amount of proprietary laboratory and field work has gone into the development of welding electrodes, yet very little definitive published data are available. Even knowing this, it appears that the suggestion that a better coating for firecracker welding might be one which bears some of the properties of E6027 and E7024 coatings is feasible. For examplel if the vagaries of synergism are neglected, direct mixture of the components of the two compositions should produce the desired results. This can be *presumed* because the physical properties of the known major constituents of each; Fe_2O_3 in E6027 and TiO_2 in E7024 are compatible with such an approach. TiO_2 fuses at about 1900 C while Fe_2O_3 fuses at 1545 C; thus, a small addition of TiO_2 **to the** E6027 coating composition should raise the melting and improve flow characteristics of the E6027 coating for firecracker welding. The addition of TiO_2 would probably raise the surface tension in the molten slag/molten metal system and produce a more convex weld bead. This is because published data[a] for the two systems in a nitrogen atmosphere show the Fe_2O_3/mild steel surface tension value to be about 700 dynes/cm and TiO_2/mild steel 900 dynes/cm. However, an addition of a small amount of another common electrode coating constituent may overcome the surface tension increase if this is required. The surface tension of the molten SiO_2/molten steel system in nitrogen, for example, is about 550 dynes/cm.

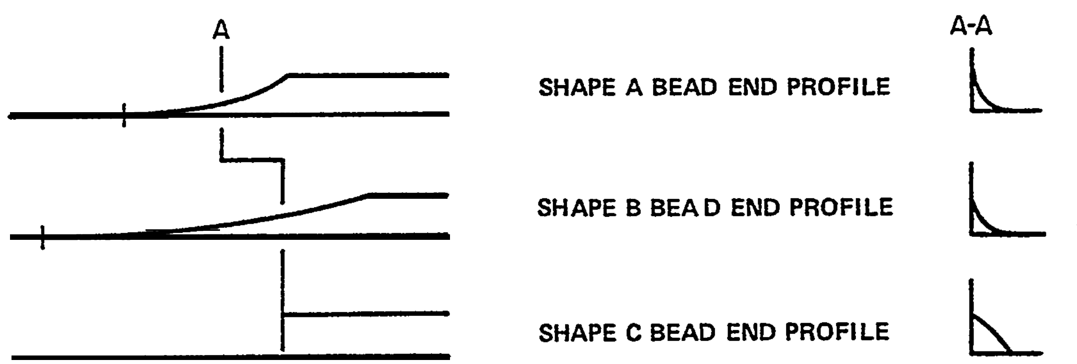
The above discussion serves mainly to show that it is reasonable to predict that an electtode coating which is better than those now known can be developed for firecracker welding. The success of the development would depend on the actual happenings when reasonable components for the coating alterations are combined and subjected to the environment and conditions of firecracker welding.

[a] Hazlett, T. A., "Coating Ingredients' Influence on Surface Tension, Arc Stability and Bead Shape", Welding Journal, 36(l), pp 18s-22s, (1957)

Start and Stop Procedures

Production firecracker welding of lengthy joints would require that a reproducible method of weld termination which provides the weld quality necessary for the end of a weld or for continuation of the weld. This means that techniques be available for both stopping and starting firecracker welds which will provide the most desirable weld bead profiles for either or both situations. A brief experimental study was therefore undertaken to indicate the magnitude of the problem and give an indication of how the needed techniques might be developed.

The specimens used were short sections of T joints on which firecracker weld beads were run with 7/32 and 1/4 inch E6027 and E7024 electrodes and stopped by cutting the power. This formed a crater such as shown in Figure 30. These craters were then prepared to feather the joint root profile and to give different starting area shapes. The general shapes prepared are shown in the sketch.



Shape A had the normal crater length and cross section with only the feathering operation. It was 1 inch long. Shape B was the same as A except length of taper was extended to 2 inches long. The Shape C was prepared by cutting the end perpendicular to its axis.

FIGURE 30. CRATER FORMED WHEN POWER IS CUT OFF DURING FIRECRACKER WELDING

FIGURE 31. CRATER FORMED WHEN CURRENT IS REDUCED BEFORE POWER CUT-OFF DURING FIRECRACKER WELDING

The continuing weld bead was then started from the prepared area with the end of the new electrode located as given in Table 20. Standardized welding parameters were used *in* all cases. Electrodes were held in place with magnets, no tape was used.

It is apparent from the data presented that some preparation of the *area* where firecracker weld bead is to be restarted is needed. From a visual viewpoint this preparation for 7/32-inch electrodes would involve a simple grinding-out of the bead end to give a feathered profile (Shape A). A square bead end preparation (Shape C) would also give the desired bead appearance, but this may not be a practical shape for production. The restarting of E7024 electrodes and all l/4-inch electrodes presents a greater problem. It is more difficult to obtain the desirable restart weld bead blending in these cases. This was not unexpected; reproducibility is more difficult with E7024 than with E6027. In all of the program work, welds made with l/4-inch electrodes are less easy to control? to obtain consistently good bead shape and uniformity than when smaller diameter electrodes are used.

Several experiments were also conducted to evaluate methods of producing the most suitable weld end configuration. In the tests recorded in Table 20 the welding current *was* reduced immediately before power cut-off in an effort to fill the weld crater. This accomplished the desired effect but produced a cavity at the root of the fillet as shown in Figure 31. This cavity is evident at the end of all firecracker welds, but it is increased in size by the fillet buildup. It is probebly the result of a lack of arc force in this area large enough to move the slag from the root. Because of the enlarged cavity at the weld end caused by crater filling techniques, welds which are to be continued with another electrode should not be subjected to the crater fill before preparation to continue.

Two other methods of ending the firecracker weld bead were evaluated. First, it was found that lifting the electrode to increase voltage and thus root penetration and crater filling cause a spreading of the fillet end without changing the crater and root cavity significantly. Second, by pushing the electrode into the weld pool, the bead is swollen slightly but the crater and root cavity remain.

TABLE 20. FIRECRACKER WBLD RESTART DATA

Sample No.	Electrode Type	Electrode Diam. in.	End Profile Shape	Location of Electrode end	Visual Results
Ss-1	7024	1/4	A	Middle of crater	Large hump at restart, crater not filled
SS-2	6027	1/4	A	Ditto	Poor shape, bead to vertical leg, lump at end, crater not filled
SS-3	6027	7/32	A	Ditto	Slight humps at restart, crater not all filled, passable profile
SS-4	6027	7/32	c	1/16 inch from cut face	Slight hump at restart, passableprofile
SS-5	6027	7/32	c	1/4 inch from cut face	No hump, slight cavity in toe at cut face, passable profile
sS-6	6027	7/32	B	3/8 inch from high end	Slight hump, profile fair, 1/4 inch crater not filled
SS-7	7024	7/32	A	Middle of crater	Hump at restart, bead to vertical leg
SS-8	6027	1/4	A	3/8 inch from high end	Hump at restart, crater not filled, fusion questionable

It is evident from the information gathered that additional research will be required to define the procedures for stopping firecracker weld beads to produce cavity-free end contour. The techniques required to produce visually satisfactory starts from prior weld beads have been demonstrated. These should be evaluated further to find the specific parameters needed to assure freedom from lack-of-fusion and other defects.

PHASE IV - VERTICAL FIRECRACKER WELDING

Vertical Welding

An important possible application for a perfected firecracker **welding** procedure is in the welding of vertical joints where a minimum of work space is available. A typical shipyard application area is the egg-crate structure common to double bottoms. Consequently, a significant effort was expended during Phase IV of the present program on examining the feasibility of firecracker welding for vertical joints.

Electrode Screening and Initial Weld Evaluation

The approach taken during the vertical welding studies was to physically contain the molten weld metal and slag in proper relation to the joint axea as welding progressed. To do this the copper hold-down technique was used in conjunction with standard round electrodes. shaped electrodes were not used because experience during flat welding failed to show that their use was necessary. An electrode set up beneath a copper block and ready for initiation of the arc at the top with a carbon rod is shown in Figure 32. The holding groove in the copper block was the same as those shown in Figure 12, Shape 1. when vertical down welding it was found that best results were obtained when the electrode was free to slide in the groove but not free to move laterally significantly.

Utilizing the setup described each of the available 3/16-inch-diameter all-position electrodes (E601O, E6012, E6013, and E7016, and

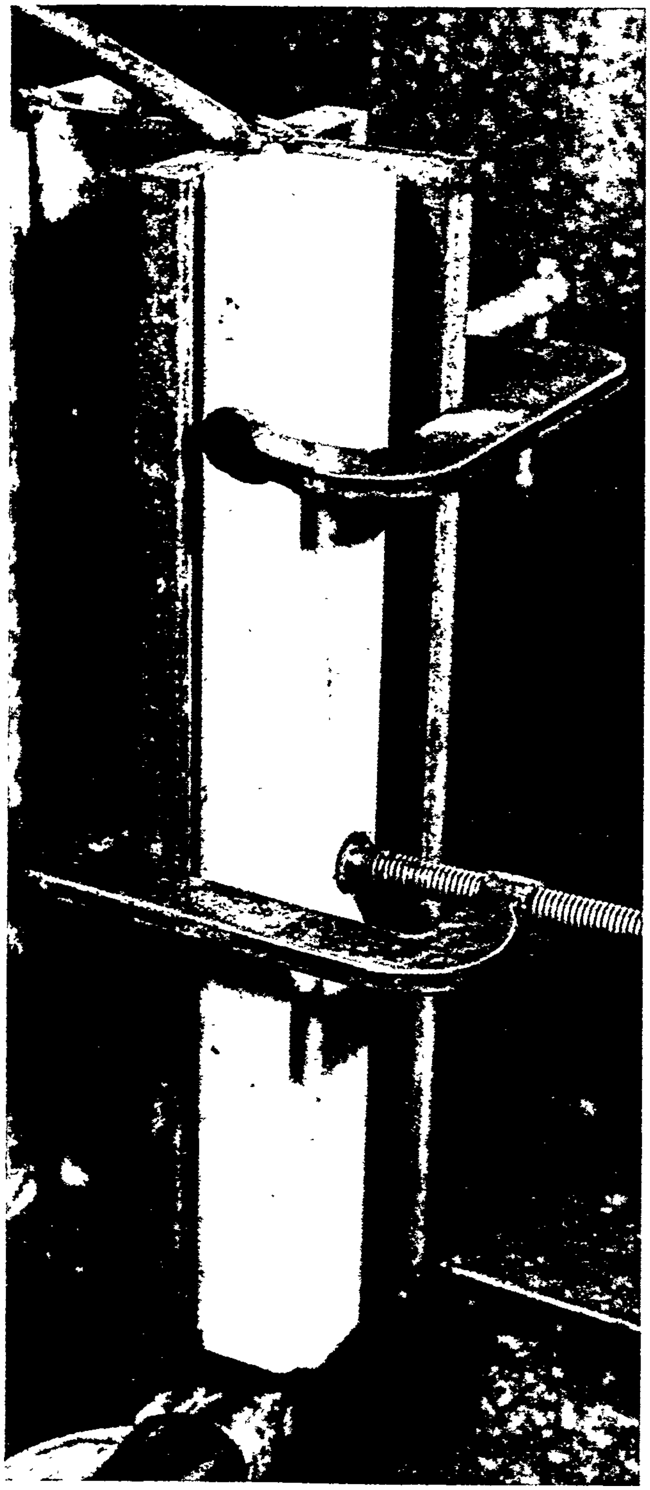


FIGURE 32. ELECTRODE IN PLACE FOR VERTICAL-DOWN FIRECRACKER WELDING

E7018) were evaluated to choose the most promising one or two for additional study. The results of these initial vertical-down welds served to show the magnitude and kinds of problems that were to be encountered. Initiating and maintaining the arc was always difficult. AC current appeared best for arc initiation and continuation. The most successful welds were made with AC current and E6013 or E6012 electrodes. The molten slag and metal are not always properly oriented in the joint. The slag can also flow in the joint to snuff out the *arc. This* was especially evident with the E7016 and E7018 electrodes which have a very fluid slag. The molten metal often caused a short-out of the arc after welding had progressed far enough for it to flow downward into the arc. The results of a micrographic evaluation of these welds and the appropriate welding parameters are given in Table 21. Not all of the welds recorded in Table 21 were complete; most were not considered good weld beads but their evaluation was useful to making the following general observations.

(1) **Satisfactory arc initiation was obtained more consistently** when AC current-was used.

(2) Neither DCSP nor DCRP **CUrrentS** maintain the arc as well after initiation as AC current.

(3) The most promising electrodes in the group wece E6012 and E6013.

(4) The **least** premising electrodes in the group were E7016 and E7018.

(5) At currents above 250 amperes all electrodes are resistance heated to a red color before the n-inch weld is complete.

(6) High-frequency starting of the arc is desirable.

(7) Welding machine settings (volt/amp curve characteristics) may be important. Arc initiation problems when DC welding vary with the machine settings.

(8) Duplication of results is difficult because of the lack of control of the molten metal and slag flow.

TABLE 21. WELDING AND MACROGRAPHIC DATA ON INITIAL VERTICAL WELDS

Sample Number (a)	ELECTRODE TYPE	WELDING CURRENT AMPS. AVE.	WELDING VOLTAGE VOLTS AVE.	POLARITY	FILLET SHAPE	SURFACE	FILLET SIZE, IN.	PENETRATION (b)	COMMENTS (c)
V-3	6012	330	27	AC	Concave	Smooth	3/16	Little	Too hot but good bead
V-4	6012	340	26	AC	Concave	Smooth	1/8	None	Hot, good bead
V-5	6013	335	28	AC	Concave	Smooth	1/8	None	Hot, fair bead, pinholes
V-6	6013	270	22	AC	Concave	Smooth	3/16	None	Nearly a snuff out, fair bead
V-7	6013	240	22	AC	Straight	Smooth	1/4	Little	← Good bead
V-15	6012	245	24	DCSP	Concave Cracked	Smooth	1/8	None	← Good bead, one bad spot
V-17	6012	315	24	DCSP	Concave	Smooth	1/8	None	Poor bead
V-18	6012	250	24	DCSP	Concave	Smooth	3/16	Little	Last half good, first poor
V-20	6012	250	24	DCSP	Concave	Smooth	3/16	None	Fair bead until last quarter
V-22	6012	265	23	DCSP	Concave	Smooth	3/16	None	← Uniformly good bead
V-26	6013	255	22	DCSP	Concave Cracked	Smooth	1/8	None	Pores in weld, slag trapped
V-27	6013	260	23	DCSP	Concave Pores	Smooth	1/8	Little	Like V-26
V-28	6010	225	30	DCRP	Concave	Smooth	1/8	None	Nearly a snuff out, toe not fused
V-29	6010	225	28	DCRP	Concave	Smooth	1/8	None	Like V-28
V-30	6010	215	29	DCRP	Concave	Smooth	3/16	Little	Like V-28 and V-29
V-31	6010	230	30	DCRP	Concave	Smooth	3/16	Little	Snuffed out, unfused toe
V-32	7016	250	25	DCRP	Concave	Smooth	1/8	None	Snuffed out at middle of joint
V-33	7016	240	23	DCRP	Concave	Uneven	1/8	Little	Snuffed out at one third point
V-34	7016	265	26	DCRP	Concave	Uneven	1/8	Little	Same as V-33
V-35	7016	245	26	DCRP	Concave	Smooth	1/8	None	Nearly snuffed out, mostly metal balls
V-36	7016	235	25	DCRP	Concave	Smooth	1/8	Little	Much like V-25, worse
V-37	6010	220	31	DCRP	Concave	Smooth	1/8	Some	Poor weld, mostly metal balls
V-38	6010	225	29	DCRP	Concave Cracked	Rough	3/16	Some	Poor weld, porous, very convex
V-39	6013	255	24	AC	Concave	Smooth	3/16	Little	Attempt to repeat V-7, no check
V-40	6013	255	24	AC	Concave	Smooth	1/8	None	Attempt to repeat V-7, no check

(a) Missing samples not suitable for evaluation
(b) Some penetration is more than little
(c) ← Indicates most acceptible welds

Typical cross sections of several of the better portions of welds recorded in Table 21 are shown in Figure 33. They verify the observations made and indicate why some of the fillets cracked, the throat of the welds were too thin. Fusion and penetration is practically zero with none at the toe of some welds. Indications are that the fillet is formed more *or* **less by a casting action stiilar to arc spraying.**

Welding With E6011, E6012, and E6013

Vertical welding studies were continued with verification tests using electrodes E6012 and E6013. E6011 electrodes were added because of their characteristics and are preferred in shipyard operations. As experienced during the earlier tests repeatability was difficult. The parameters for welding vertical down with 3/16-inch E6012 and E6013 were verified and the same values were found suitable for 3/16-inch E6011. Each of these electrodes can be used to make visually satisfactory welds using **AC current.** The most satisfactory welds were made with E6012 and E6011. Welds made with DC current are not *as* satisfactory as AC welds. A significant difference between the initial welds and those made during
No explanation for this was found.
subsequent studies *was* shown. The latter welds were much less concave. NO

A major problem with each electrode was arc initiation. No technique for assuring positive initiation has been found. Only a minor difference was noticed between electrodes in this respect. It appeared the best way to produce satisfactory welds vertically would be to use a two-pass technique in which the concave first pass is built up by a second pass.

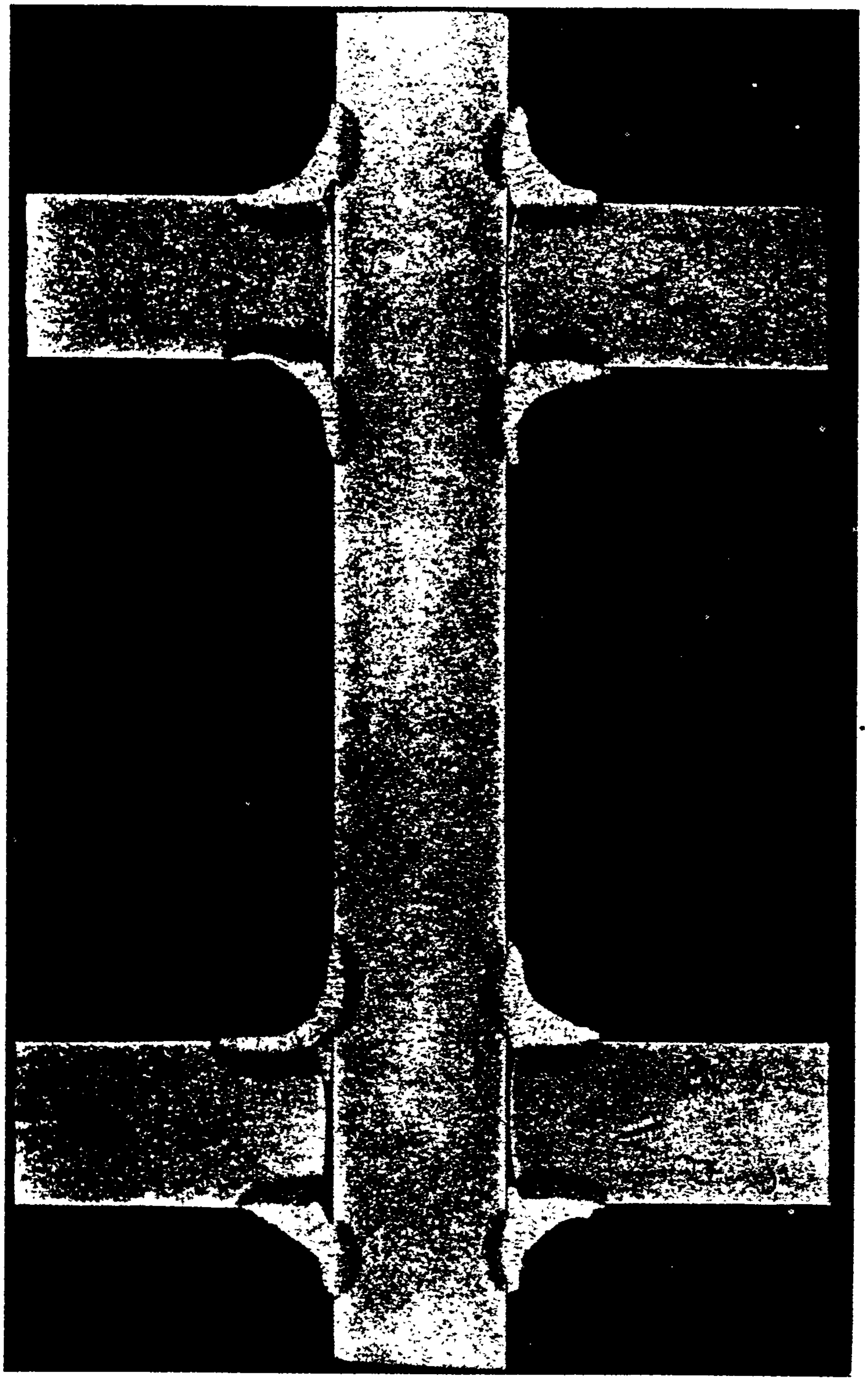
Two-pass vertical-down welds were produced using the preferred parameters given in Table 22 and a copper holddown with a groove deepened to accommodate the buildup from the first pass. The resulting welds were not ideal; the molten metal was cast against the previous weld fillet where little fusion occurred and the fillet was too confined by the copPer backup block. Typical cross sections of the joints produced are shown in Figure 34. The first pass shows poor penetration and some porosity. The second pass fills the joint and elminates the convexity of the first pass

No. V-34
E7016

No. V-35
E7016

No. v-31
E601O

No. V-30
E601O



NO. V-36
E7016

No. V-37
E601O

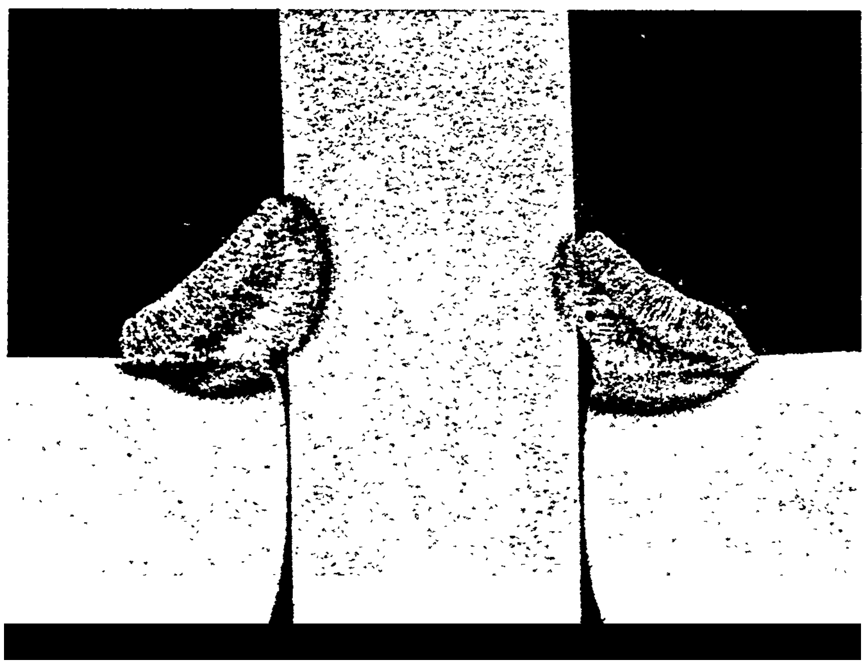
NO. V-28
E601O

FIGURE 33. CROSS SECTIONS OF SINGLE PASS VERTICAL-DOWN WELDS

TABLE 22. PREFERRED WELDING PARAMETERS FOR MAKING VERTICAL-DOWN WELDS WITH 3/16 INCH. DIAMETER ELECTRODES

Electrode Type	Starting Current, Amps.	Running Current, Amps.	Voltage volts	Polarity
E6011	220	210	33-34	AC
E6012	310	300	27-28	AC

No. V-103
E6011



No. V-105
E6012

FIGURE 34. CROSS SECTIONS OF TWO-PASS VERTICAL-DOWN WELDS

fillet. The *poorly* shaped fillet toes are attributed to the shape of the copper backup slot. It may be-possible to eltiinate this by further development of the slot shape.

Welding With Electrodes Larger and Smaller Than 3/16-Inch Diameter

TO examine the feasibility of making vertical-down welds with electrodes larger than 3/16 inch, a short study using l/4-inch E6012 electrodes was made. The variables studied were: AC, DCSP and DCRP power, machine current settings to alter the voltage/current characteristics; and the fit of the copper hold-down groove. No combination of welding parameters was found which resulted in a weld. It was concluded that the volume of molten metal and high fluidity of the slag were such that they could not be kept in the joint. The result of this was that the arc was quickly either snuffed out by the slag *or* shorted out by the molten metal.

5/32-inch diameter electrodes were also used for vertical welds. E6012 and E6013 were used in this work. **Good fillet welds were** obtained at welding currents commensurate with the electrode size (190-200 aIQS, 26-30 volts). With the smaller electrodes arc starting and other problems encountered with 3/16-inch electrodes were minimized. But, some shorting out of the arc and slag pockets in the weld were encountered. It was concluded that without extended developmental effort firecracker welding is unlikely to become a viable procedure for producing vertical welds. This effort would necessarily include study of every facet of the procedure and also electrode development.

Vertical-Up Welding

Because it would be desirable in some situations to make firecracker welds vertically upward, several attempts were made to accomplish this objective. The procedure used was the same as that used for vertical-down welding except for the starting technique and a provision made to hold the weld metal in place at the start of the weld. Starting of the 3/16-inch E6012 electrode was accomplished by using steel wool in the groove at the electrode tip. Leakage of molten metal and slag was prevented by setting the specimen on a steel plate. No real difficulties were encountered in initiating the arc and the weld ran for its full length. The resulting weld beads were very poor. They were cast to the groove shape in the copper backup bar and consisted of irregular masses of metal and slag which had the appearance of a sponge. It did not appear that firecracker welds in the vertical position can be made by causing the arc to proceed upward.

CONCLUSIONS

Based on the statements which follow regarding the results of this study, firecracker welding is considered a workable procedure for use in shipyards.

(1) An evaluation of the standard electrodes normally used showed that AWS E6027 and E7024 electrodes can produce single pass 5/16 inch fillet welds.

(2) AWS E6027 is preferred because more consistent bead formation is obtained.

(3) Other electrodes in the E7XXX class can be used for firecracker welding if smaller fillets are acceptable. They are E7016 and E7018. Other E6XXX class electrodes give beads that are too convex.

(4) Fillet welding parameters were established for 3 diameters of the preferred electrode; 3/16, 7/32, and 1/4 inch. AC welding current is preferred. Welding currents for firecracker welding are significantly lower than would be required when using these electrodes for the usual shielded metal-arc application. The voltage consequently is higher. Voltages above 40 lead to excessive spatter, below 30 to poor weld bead shape.

(5) The length of the electrode poses no serious problems up to 60 inches of weld with E6027 and 30 inches of weld with E7024 electrodes. The major concern with long electrodes is the fieans of holding than in the joint.

(6) Commercial glass-filament adhesive strapping tape is a feasible hold-down mataial for welds up to at least 24 inches long. A noncommercial tape was found which appeared suitable for welds up to 60 inches long. Mechanical hold-down systems and grooved copper blocks

also can be used. The magnetic hold-down systems also appear feasible.

(7) Firecracker welds can be made over tack welds if the tack fillet size is less than 1/4 inch. TO make satisfactory welds over tacks the electrode must be centered longitudinally on the tack and the hold-down must be capable of maintaining this location.

(8) Electrodes having cross sections with 1, 2, or 3 flat sides or with longitudinal slots do not improve a lack of imbalance of the fillet legs. Easily ionized materials on the electrode or in the weld groove also failed to improve fillet configuration. Standard electrodes with concentric circuler cross sections were preferred.

(9) Multipass fillet welds can be produced by firecracker welding. Electrodes having different diemeters should be chosen for each pass to produce fillets with equal legs. The flow characteristics of the welding slag are important during multipass welding. The slag from E6027 flows off the bead and this contributes to the presence of small shallow slag pockets in the weld bead surface. The E7024 electrode slag presents the opposite condition. It apparently freezes quickly thus contributing to the presence of large deep slag pockets and also minimal wetting of the base metal by the weld metal.

(10) The effect of paint primers on the steel when firecracker welding is essentially the same as for other welding processes. Arc instability and spatter are greatly increased when a primer is present regardless of its type. The E6027 electrode had less tolerance for primers on the base metal than the E7024. Primers do not cause porosity in firecracker welds.

(1.1) Groove welds are readily made by firecracker welding. The preferred groove has a 60-degree included angle and a l/4-inch root gap and is backed with a flat steel bar. It was desirable for the electrode to touch, or nearly touch both sides of the groove and the backing bar. This eliminated slag inclusions. Also the preferred welding parameters involved slightly higher welding currents, lower voltage and higher power inputs than fillet welds. Multipass groove welds were built up using one diameter electrode. Slag inclusions were a recurring probla when *using E6027* electrodes.

(12) Satisfactory groove firecracker welds were not made when copper backup bars (grooved and flat) were used. The chilling effect of the copper on the slag plus the standoff distance in case of the grooved backup prevented full penetration of the joint.

(13) The practical problems involved when starting or stopping and reinitiating a firecracker fillet weld bead are similar to those encountered when shielded metal=zuc welding. TO produce a satisfactory restart some preparation of the crater at the end of the weld bead is required. Also all 1/4 inch electrodes and the E7024 electrodes are less easy to restart than the E6027.

(14) Satisfactory crater filling at the end of a weld is obtained by gradually reducing the welding current. A cavity is produced at the root by this procedure; its effect on mechanical properties of the weld was not determined.

(15) During the program vertical firecracker fillet welds were made using standard all-position electrodes which were held in place with a grooved copper block. Fillets, when produced, were small and too concave even where more than one pass was used.

RECOMMENDATIONS

The program on the development of firecracker welding has shown that the procedure is practical for producing single or multipass fillet weld and butt groove joints. It has also shown that if additional effort is expended, the application areasi consistency, and quality of the firecracker welds produced can be increased. Therefore. the following recommendations are made for continued development of firecracker welding. It is felt that successful conclusion of the studies suggested will make the process more *viable* in many application areas.

(1) Examine the flux compositions used on E6027 and E7024 to learn their specific melting and flow characteristics. Use the knowledge gained to compound a new coating composition. This coating would have the good characteristics of each without either undesirable property.

(2) In conjunction with commercial adhesive tape makers, devise and evaluate a new holddown tape for firecracker welding. The background for this effort was laid during the present program, and at least one promising tape was found.

(3) Examine the value of shaping the core of electrodes used in firecracker welding. A possible advantage of a shaped electrode core is the improvement of root penetration in fillet welds. They may also be useful for vertical welding. During the present program it was shown that shaping the electrode coating alone would not accomplish these objectives.

(4) Develop refined methods of stopping and restarting firecracker weld beads. The end configuration of firecracker welds made so far is undesirable from a mechanical property standpoint. Techniques for starting a new electrode from an exisitng weld bead need refinement.

(5) Experimental work has shown that firecracker welds can be made much more reproducibly with 3/16 or 7/32-inch-diameter electrodes than with l/4-inch electrodes. It is desirable that the process be useful with electrodes of larger diameters. Consequently, a study of the cause of this size factor and methods of overcoming it is recommended.

(6) Tack welds present two problems where firecracker welding. The size which can be welded over even with care is limited to less than 1/4 inch and ground out tacks cause lack-of-wetting defects in the toe of the weld. A study of methods of increasing the size of tack that can be covered and how to improve weld quality in the area of groundout tacks may be needed.