"HIGH METAL DEPOSITION PER AMPERE"

WELDING MATERIALS & PROCESS EVALUATION .

MARAD PROJECT SP-1-7-1

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FOREWORD

The purpose of this report is to present the results of one of the research and development programs which was initiated by the members of the Ship Production Committee of The Society of Naval Architects and Marine Engineers and financed largely by government funds through a cost sharing contract between the U.S. Maritime Administration and Bethlehem Steel Corporation. The effort of this project was directed to the development of improved methods and hardware applicable. to shipyard welding in the U.S. shipyards.

Mr. W. C. Brayton, Bethlehem Steel Corporation was the Program Manager, Mr. G. D. Uttrachi, Linde Division of Union Carbide Corporation, was the Senior Project Engineer who provided the technical direction. The work was performed at the Union Carbide Research Facility at Ashtabula, Ohio.

Special acknowledgement is made to the members of Welding Panel SP-7 of the SNAME Ship Production Committee who served as technical advisors in the preparation of inquiries and evaluation of sub-contract proposals.

EXECUTIVE SUMMARY

BACKGROUND AND OBJECTIVES

Many welding process and material developments have been introduced to provide increased weld metal deposition per ampere. The intent is usually to provide higher weld metal deposition rates per hour so Welding might progress more rapidly. Other advantages occur when weld heat input must be restricted to provide acceptable base plate heat-affected-zone mechanical properties. Increased weld metal without added arc power can also be used to reduce weld burn-through on poorly fit weld joints or where thin root welds are employed.

The utilization of the high deposition rate per ampere welding system, not just its development must be considered. High metal deposition rates must be consistent with good bead shape, weld deposit soundness and satisfactory weld mechanical properties.

PLANNED APPROACH

The Linde Division of the Union Carbide Corporation has undertaken an evaluation of a number of commercially available "high metal deposition per ampere" welding materials and processes as a sub-contractor to the Bethlehem Steel Corporation, Sparrows Point, Maryland under MARAD Project SP-1-7-1. In addition to the evaluation of commercially available processes, several experimental high deposition efficiency electrodes were evaluated. All materials and processes are being considered for their potential use in shipyards.

Effective utilization of these systems/materials is the key to their successful application for specific weld joints.

SUMMARY

Evaluation of the processes and materials investigated for this project pointed out areas which should be investigated in greater depth with improved backing. and supplemental filling techniques which will permit the use of higher currents and travel speeds in an effort to achieve optimum performance for various shipyard applications.

INTRODUCTION:

Many welding process and material developments have been introduced to provide increased weld metal deposition per ampere. The intent is usually to provide higher weld metal deposition rates per hour so welding might progress more rapidly. Other advantages occur when weld heat input must be restricted to provide acceptable base plate heat-affected-zone mechanical properties. Increased weld metal without added arc power can also be used to reduce weld burn-through on poorly fit weld joints or where thin root welds are employed.

The utilization of the high deposition rate per ampere welding system, not just its development must be considered. High metal deposition rates must be consistent with good bead shape, weld deposit soundness and satisfactory weld mechanical properties.

CONCLUSIONS:

1. Increased deposition rate, although a worthwhile goal, has practical limitations. When welding plate of the thickness used in this project, 1-in. (25 mm) or less, it is difficult to realize appreciably increased operating efficiency from only deposition rates. The first weld passes must be deposited at lower currents so that there is no burn-through. The next passes can be increased in deposition rate, but the actual number of passes remaining to complete the joint will be limited so that the total savings in time may not be of major significance. If thicker plates were to be welded, the initial passes

would be made as in 25 mm plate, but now more groove area would remain to be filled so that increased deposition rate could be used to decrease the time to complete the weld.

2. Of the processes investigated for this project, two were superior for the applications evaluated. These processes were: “Unionfil”, metered iron powder additions to a submerged arc weld, and “hot wire” where an externally heated second wire is added to a submerged arc weld puddle. Both processes allow controlled additions of extra metal without increasing the total power density on the main electrode making each a more versatile process.
3. The experimental fabricated electrodes developed to provide increased deposition rate per ampere performed as designed. However, the increase was not sufficient to reduce the number of weld passes in some cases by even one pass. Simple process changes such as straight polarity were at least equally effective.
4. One process variation, evaluated to complete the one side root welds in one fill pass, was successful. This was a two wire Scott system with iron powder added to the joint. It could be useful for weldments where weld and HAZ impact requirements are not critical.
5. Keeping in mind the intended shipyard uses of these processes and considering mechanical properties, ease of operation, equipment required, and cost, the Unionfil process would be the "best" choice for increasing deposition rate and efficiency.

EXPERIMENTAL PROGRAM:

Processes Selected For Evaluation

For this project, two series of welds were made. The first series was made from one side in 25 mm thick ABS Grade B plate. Root welds were made with semi-automatic Linde FC-707 flux cored wire using backing tape. From the many fill. processes and materials available for evaluation, the following were selected. for this study. At least one weld was made with each material/process with-no restriction on allowable heat input:

1. Submerged Arc DC Reverse Polarity as a base for comparison.
2. Submerged Arc DC Straight Polarity to provide increased metal deposition rate and document possible problem areas.
3. Submerged Arc DC Reverse Polarity with Linde MC-70 iron powder electrode - l/8-in. (3.2 mm) diameter.
4. Submerged Arc DC Reverse Polarity with Linde MC-70 iron powder electrode - 3/32-in. (2.4 mm) diameter.
5. Submerged Arc DC Reverse Polarity with special high iron powder Linde MC-70 iron powder electrode.
6. Submerged Arc DC Reverse Polarity with Linde 997-39B iron powder flux and solid wire.
7. Submerged Arc DC Straight Polarity with Linde 997-39B iron powder containing flux and MC-70 iron powder electrode.
8. Submerged Arc “hot wire” with solid wires.
9. Submerged Arc DC Reverse Polarity with iron powder added to the weld by a metered process, commercially sold by Union Carbide Canada, known as Unionfil.

10. Semi-automatic flux cored wire with Linde FC-72 as base for comparison.
11. Semi-automatic flux cored wire with Linde FC-70 high deposition efficiency iron powder electrode.
12. Semi-automatic flux cored wire with special high iron powder Linde HFC-70 iron powder electrode.

After this initial series, two additional process variations were evaluated in order to further reduce the completion time required for the 25 mm joint. The first variation consisted of a two wire Scott connected welding system with electrodes spaced six inches (152 mm) apart. The joint was filled completely with iron powder; the two wire system 'was then used to fuse this powder and complete the weld in one pass. A second process variation involved one attempt to increase deposition rate using the Unionfil process. Deposition rate was increased by 36 percent over the original weld made in the first series of tests.

The second series of welds was made in higher toughness, ABS Grade AH-36 plate, 7/8-in. (22 mm) thick. This series was made using a maximum of 70 kJ/in. (276 kJ/m) heat input with the following processes:

1. Semi-automatic flux cored wire with special high iron powder Linde FC-70 electrode.
2. Semi-automatic fine wire - high current "Hi-Dep" Mig welding.
3. Submerged Arc with special high iron powder Linde MC-70.
4. Submerged Arc with metered additions of iron powder; Unionfil.

Procedure Details - **Plate Preparation and Conditions Similar to All Welds**

The first series of welds was made using ABS Grade B plate. The plates were 18-in. (457 mm) long, 1-in. (25 mm) thick, and 6-in. (152mm) wide: All welds were made with a 60° included angle and 3/32-in. (2.4 mm) root gap. For all plates, two semi-automatic root" passes were made using Linde FC-707 operating at 320 amps, 28 volts, 12 ipm (5 mm/sec.). 3M brand adhesive backing tape was used to achieve a good underbead for the root pass. The total number of passes listed-in the following descriptions includes these two passes. See Figure A for illustration of the first joint configuration.

The second series of welds was performed with a maximum heat input of 70 kJ/in. (276 kJ/m). This heat input was selected to simulate a practical maximum level to ensure satisfactory HAZ properties in low temperature toughness plates. The plate used was ABS Grade AH-36. Dimensions were 7/8-in. (22 mm) thick, 6-in. (152 mm) wide, and 18-in. (457 mm) long. For this series of welds, the joint configuration was an asymmetrical double bevel with 60° included angles. See Figure B. The first or backing pass was made in the smaller groove. Then the plates were turned over and the weld completed. This joint configuration is more efficient than the large single "V" of series one, but requires plate turnover.

No preheat was used for any of the welds. Interpass temperature was kept at 300 F ± 25 F (149 C ± 14 C). In Figures 1-16, a schematic of each process is shown together with a list of the number of passes to complete the weld, parameters used for each pass, the resulting deposition rate and the heat input for each pass. A photomacrograph and comments relative to the weldability, efficiency, and applicability of the process for shipyard use are also included. The figure number corresponds to the weld/process number and is used for identification in this report.

Process Descriptions

Weldments 1 through 7 are made using the typical submerged arc process with material variations only. Weldments 3 and 4 use the same materials, but wire diameter is changed to evaluate the affect on deposition efficiency of different wire diameters. Weldments 4 and 5 use identical wire diameters, however, the amount of core material in the wire is increased for weldment 5. (Three cored wire material variations were used in this project. The materials are designated FC indicating a flux cored wire, MC indicating a metal cored wire and H indicating a higher than normal core content, e.g., HMC implies a high metal cored wire.) By increasing the core content for a given wire diameter, the metal jacket thickness is reduced which leads to an increased deposition rate.

Weldment 8 is the first significantly different process. In addition to the main electrode, a second smaller diameter wire is added to the weld puddle. This wire is operated with a long extension and I^2R heating is allowed to heat the wire so it is almost molten when entering the puddle. This technique is known as "hot wire" welding.

Weldments 9, 9A, and 14 use a technique called the Unionfil system. In this process, a metered amount of metal powder is added to the weld. For these welds, the powder was a low alloy steel. The powder, delivered to the area of the electrode by a tube, is drawn around the wire by its magnetic field and carried into the weld puddle.

Weldments 10 and 11 were semi-automatic processes using conventional electrodes.

Weldment 12 used an experimental electrode with greater than normal core percent.

Weldment 13 was made using a process called "Hi-Dep". This. is a semi-automatic Mig process utilizing a longer than normal tip-to-work distance to get a rotating spray arc transfer of metal. Deposition rates per ampere are three to four times greater using this process as compared to conventional techniques.

Weldment 15 was another weld made using the increased core percent electrode, but in conjunction with a conventional submerged arc welding system.

Weldment 16 involves the use of two AC submerged arc wires with the goal"to complete the weld in one pass in addition to the two initial root passes. For this joint, iron powder was added directly to the groove prior to welding. The groove was filled completely and over-fill was scraped even to the plate surface.

RESULTS AND DISCUSSION:

Joint Completion Efficiency

As the goal of this project was to gain information about high deposition per ampere welding processes, the first criteria for evaluation was the number of passes required to fill the groove. This criteria is somewhat subjective as differences in reinforcement can account for variations in weld pass count by plus or minus one pass. This must be considered when comparing processes.

First Series Joint Completion Times

The first weld series consisted of nine submerged arc and three semi-automatic cored wire process/material variations. Within the submerged arc group, four passes . separated the minimum from the maximum; the submerged arc "hot-wire" process used

8 passes while the metal-cored wire welds used eleven passes each. Another way of ranking the efficiency of these various techniques is to compare them on a "time to complete one unit of weld length" basis. Using the idealized condition of continuous welding operation, the various submerged arc processes were ranked using this method. The evaluation is made by multiplying travel speed (a constant) by the variable number of passes to obtain "minutes per length of joint". Table 1 contains a summary of these calculations.

From the table it may be seen that the "hot wire" process can complete (assuming 100 percent arc time) an idealized joint 1.3 times faster than the slowest processes, i.e., two of the submerged arc metal cored wire welds (nos. 4 & 5).

The "hot wire" process may be chosen as the "best" process as it fills a given joint the fastest. But for the total picture, this is a simplistic 'approach. "Hot wire" is a more complicated process considering equipment requirements and operation. Thus, the gain in theoretical joint completion time may not offset the added complexities.

Comparing the three semi-automatic processes in the same manner, but using 12 ipm (5 mm/see.) rather than 15 ipm (6.3 mm/see.) as the travel speed constant, the "minutes per length of weld" calculation can again be made. A summary is presented in Table 2. Again, there is not much difference between welding processes, 9 min./ft. (. 0295 min./mm) for the conventional cored wire FC-72 versus 8 min ./ft. (.0262 min./mm] for the conventional high deposition rate cored wire FC-70 and the experimental high iron powder HFC-70.

First Series Variations

After performing all of the welds in the first series, it was decided to repeat one of the processes with parameters changed to increase deposition rate. The one selected was the Unionfil process. Several reasons made this process a good choice for further experimentation. The Unionfil process requires a minimum of extra equipment and that which is required is easy and convenient to operate. The process proved a good method for depositing large amounts of metal per unit of power and the likelihood of producing good quality welds was high. (See Figure 9A for process details). The deposition rate employed for the maximum rate was 39 lbs./hr. (17.7 kg/hr.), 25 percent more than the previous rate obtained in series 1.

Using the previous weld length/time ranking, this process would complete one foot (304mm) of joint in 5.2 minutes (.0171mm/min.). This is 38 percent faster than the previous “best”.

A second process variation was also evaluated. This was an attempt to. complete the weld in one fill pass (in addition to the two root passes). Process variables are described in Figure 16. This weld was completed in one pass at a travel speed of 12 ipm (5.1 mm/see.). If the sole objective of this project was to rapidly weld, this process would be the “best”. However, several problems exist. Good root passes are essential as the power density is high creating the possibility of burning through the plates. With the high current employed, arc stability is somewhat less than optimum. This causes an uneven bead surface and some difficulty in flux peeling. With an awareness of the possible problem areas, this process may be useful in a shipyard for selected welds.

Second Series

The second series of welds, those where heat input was kept below 276 kJ/m and welding done from both sides of plate, again demonstrated the trade-off between addition of large amounts of metal per unit power and acceptable bead contour - reinforcement. Four processes were studied. Three were discussed previously as weldments 13, 14, and 15. The fourth was a semi-automatic HFC-70 process with $C0_2$ shielding.. It was tried with two different joint configurations.

Weldment 13, the Mig "Hi-Dep" process, was eliminated from consideration after making three less than optimum welds. The "Hi-Dep" process allows a high deposition rate per amp, but it does not provide penetration proportional to the current level used so joint geometry would require redesign. Since this was not desirable at present, it was decided that no further work would be done using this technique. Figure 13 illustrates our best attempt using "Hi-Dep".

Weldment 14, using the Unionfil process, allowed increased flexibility in filling the joint compared with conventional single wire. In a conventional weld, once conditions are established, a certain wire feed rate is also established with no variability. Thus, for a given heat input, a certain amperage, voltage and travel speed are selected. The deposition rate is fixed within a narrow range. This may lead to the problems encountered in the HFC-70 weld described below where a balance between optimum fill and penetration caused problems. When using the Unionfil process, a new variable is available i.e., powder addition rate. Thus, optimum fill efficiency may achieved. This is visible in Figure 14.

Weldment 15 (HMC-70) also demonstrates the filling problem, but to a lesser degree than with the semi-automatic HFC-70. As may be seen in Figure 15, some extra re-inforcement is apparent, but it is not excessive.

Using the 22 mm plate with the HFC-70 wire, it was difficult to balance the filling of the groove. Keeping parameters set to maximize deposition rate; two passes were not sufficient as incomplete penetration resulted, but three passes were too many as excess reinforcement was present. Obviously, this process could have been used to produce an excellent weld, but keeping the goal of maximum deposition rate, it was decided this would not be a suitable choice. As no satisfactory welds were produced, no data is presented.

Thus, trying to reach two goals, one, high deposition rate and the other limited heat input, necessitated balancing one against the other. Of the processes evaluated, the Unionfil performed best and the HMC-70 submerged arc was next best.

Mechanical Properties

The second criteria for evaluating the welding processes was weld mechanical property performance. The data for all welds is summarized in Table 3. The two welds that were made using iron powder flux, weldments 6 and 7, were found by x-ray to contain cracks. Since these were a result of basic material deficiencies, no retests were made and no mechanical data is reported for the two welds completed.

For this project, welding wire/flux combinations were chosen which had a high probability of producing mechanical properties within the limits specified by ABS. As seen from the summary of mechanical properties in Table 3, properties for some of the processes are sufficiently good now to show that less costly materials could be used and still meet the specified ranges.

Direct comparisons of mechanical properties are limited because the materials used for the various processes were not identical. It is felt that those welds which are too high in strength can be corrected by making some change in the wire/flux combination used. This should not adversely affect the deposition rates obtained.

The single pass two wire AC weld, number 16, had adequate strength and toughness. This process would only be useful where high heat input and. subsequent deterioration of the heat-affected-zone properties could be tolerated. Weldments 1, 2, 5, 8, 9A, 14, and 15 deviated from specified mechanical values. The UTS was higher than specified for weldments 1, 2, 8, 9A, 14, and 15 and one value of the three Charpy values was less than 25 ft.-lbs. (34 J) for weld number 5. Additionally for weldment 2, weld cleanliness was felt to be a possible problem area. The chemistry of these welds would require adjustment to meet the required minimum properties. Semi-automatic welds .11 & 12 had poor notch toughness properties. Again, it is felt that by slightly modifying electrode chemistry, properties could be improved.

Weldment 9, the Unionfil process, was not appreciably different than the other processes in the number of passes required or mechanical properties. This process did show that it was a good choice when it was optimized to increase deposition rate (weld 9A). The mechanical properties are more than adequate and the number of passes-required was the least of the evaluata one-side processes with the exception of the two wire AC weld, number 16. It seems that the best combination of higher deposition rate along with ease of welding, relatively little additional cost above that paid for initial equipment, and good mechanical properties are all found in the Unionfil process. This is true for both the first and second series of welds. By comparison, none OF the other welds seemed to-distinguish themselves.

Further experimentation would provide further refinement of high deposition per amp materials/processes. It is felt that for many areas of ship construction, time and money could be saved by utilization of optimized processes.

TABLE 1

WELD NO.	PROCESS TYPE	TIME PER UNIT OF JOINT LENGTH MIN./FT.	(MIN./mm]
1	DCRP 44 Wire	10.0	.0328
2	DGSP 44 Wire	9.2	.0302
3	MC-70 l/8-in. (3 MM)	10.0	.0328
4	MC-70 3/32-in. (2.4 mm)	10.8	.0354
5	HMC-70	10.8	.0354
6	DCRP Iron Powder Flux	9.2	.0302
7	DCSP Iron Powder Flux	9.2	.0302
8	Hot Wire	8.4	.0275
9	Unionfil	9.2	.0302

TABLE 2

10.	FC-72	9	.0295
11	FC-70	8	.0262
12	WC-70	8	.0262

TABLE 3

Weld Number - Process	Total No. of Passes	of High Dep. Passes[1]	Plato Dist. Deg.	UTS	2% Y.S. Psi (MPa)	% EL. in 2" (50 mm)	% R.A.	Charpy V-Notch Impacts - Ft.-Lbs. (J) +32°F (0°C)	-4°F (-20°C)	-22°F (-30°C)	-40°F (-40°C)
SERIES I - SUB ARC, 15 ipm (6,3 mm/s)											
1, DCRP w/4 mm L44/124	10	5	3.5	94,480 (651)	75,580 (521)	25	58.2	70 (95)	62 (84)	--	--
2. DCSP w/4 mm L44/124	9	5	2	94,200 (649)	77,640 (535)	18.5	37		45 (61)		
3, DCRP w/3,2mmMC-70/124	10	5	3	72,040 (497)	64,180 (442)	30.5	67.2	101 (137)	&		
4, DCRP w/2.4mmMC-70/124	11	6	2	73,450 (506)	60,310 (415)	29	64.9	(104)	(75)		
5, DCRP w/2.4 mmHMC-70/124	11	6	3	69,250 (477)	55,570 (383)	29	67.2	(99)	54a (73)		
6. DCRPw/4mm L44/997-39B	9	4	1	WELD DEPOSIT CRACKED							
7, DCSP W/3.2 minMC-70/997-39B	9	4	2	WELD DEPOSIT Cracked							
8, DCRP w/4mm L44/124 Hot Wire	8	4	4	90,995 (627)	75,090 (517)	26.5	61.2	67 (91)	56 (76)	--	--
9, DCRP w/4 mm L44/124 + Fe	9	4	2	79,380 (547)	64,690 (446)	26.5	62.3	(73)	42 (57)		
9A, DCRP w/41 mm L44/124 + Fe	7	4	2	81,390 (561)	66,010 (455)	26.5	56.8	52 (70)	35 (47)	--	--

1. Total number of passes minus initial gap fill passes made at lower deposition rates.
2. 16 ipm (6.7mm/s)

a. High 77 (104), Low 23 (31)
b. High 37 (50), Low 24 (32)
c. High 16 (22), Low 14 (19)
d. High 12 (16), Low10 (14)

TABLE 3

-2- (con't.)

Weld Number - Process	Total No. of Passes	No. of High Dep. Passes[1]	Plate Dist. Deg.	UTS Psi (MPa)	.2% Y.S. Psi (MPa)	% EL. in 2" (50 mm)	% R.A.	[illegible] +32°F (0°C)	 -4°F (-20°C)	 -22°F (-30°C)	 -40°F (-40°C)
SEMI-AUTOMATIC, 12 ipm (5.1 mm/s)											
10. DCRP w/2.4 mm FC-72	9	6	2	80,600 (556)	71,100 (490)	30	62.5	66 (89)	56 (76)		
11. DCRP w/2.4 mm FC-70	8	5	2.5	69,250 (477)	60,160 (415)	29	64.3	29[b] (39)	15[c] (20)		
12. DCRP w/2.4 mm HFC-70	8	5	2	69,020 (476)	59,050 (407)	27	65.2	35 (47)	11[d] (15)		
SERIES II, (6.3 mm/s)											
13. DCRP w/0.9 mm L82 "Hi-Dep"	3	3	2	NO TESTS TAKEN - SEE TEXT							
14. DCRP w/4 mm L44/124 + Fe[2]	3	3	2	96,480 (665)	89,810 (619)	25	58	63 (85)	51 (69)	47 (64)	
15. DCRP w/2.4 mm HMC-70/124	4	4	3	82,200 (567)	71,910 (496)	28.5	62.8	52 (70)	43 (58)	34 (46)	
SINGLE PASS TWO WIRE, (5.1 mm/s)											
16. AC w/6 mm 36, 4 mm L44/166P	3	1	3	69,700 (481)	45,500 (314)	25	61.6	48 (65)	9 (12)	--	
ABS PROPERTY REQUIREMENTS											
Ordinary Strength (Series I)				58,300/ 81,100 (402-559)	44,100 min. (304)	22	----	25* (34) 35**(47)	25* (34) 35**(47)		
Higher Strength (Series II)				71,000/ 95,000 (489-654)	55,500 min. (383)	20	----	30* (41) 40**(54)	30* (41) 40**(54)		

Total number of passes minus initial gap fill passes made at lower deposition rates.

2. 16 ipm (6.7 mm/s)

a. High 77 (104) Low 23 (31) Automatic
b. High 37 (50) Low 24 (32) Semi-automatic
c. High 16 (22) Low 14 (19)
d. High 12 (16) Low 10 (14)

FIGURE A

SERIES I - JOINT CONFIGURATION

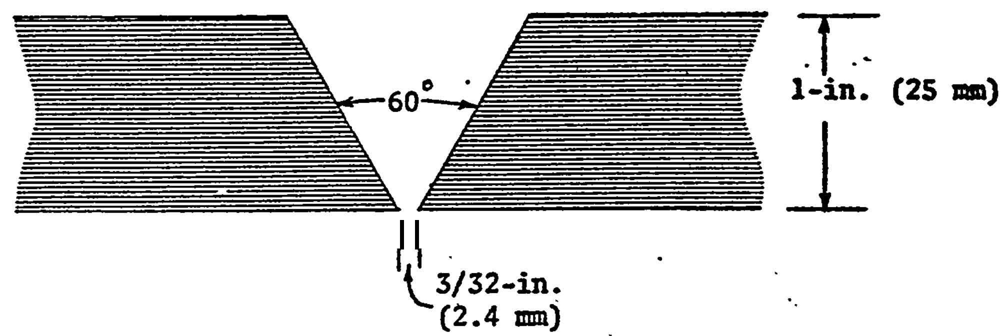


FIGURE B

SERIES II - JOINT CONFIGURATION

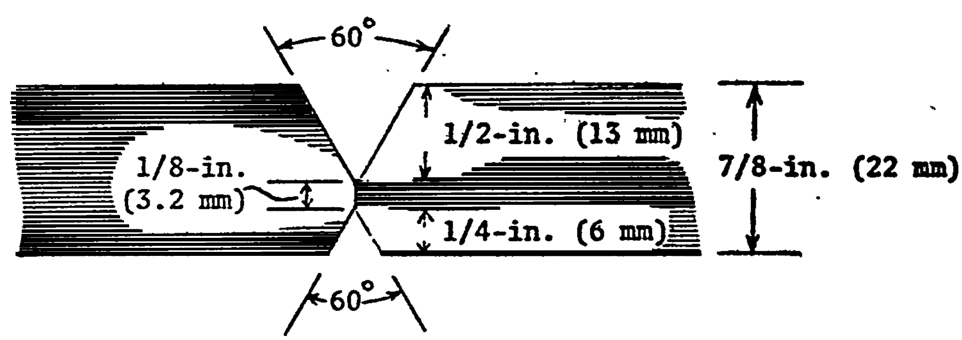
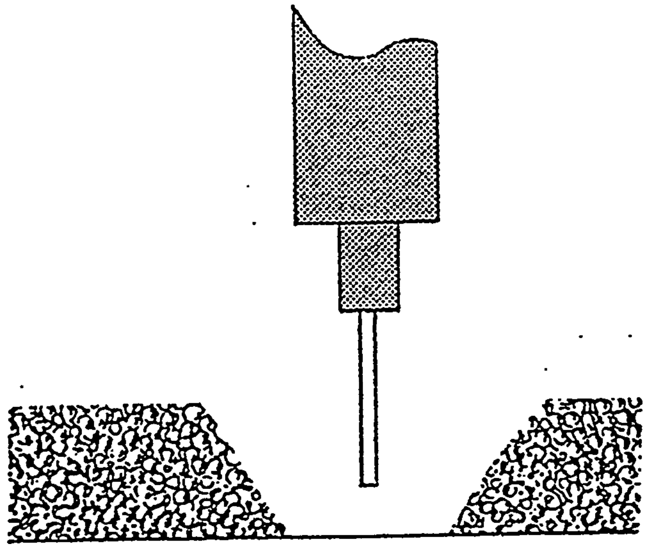


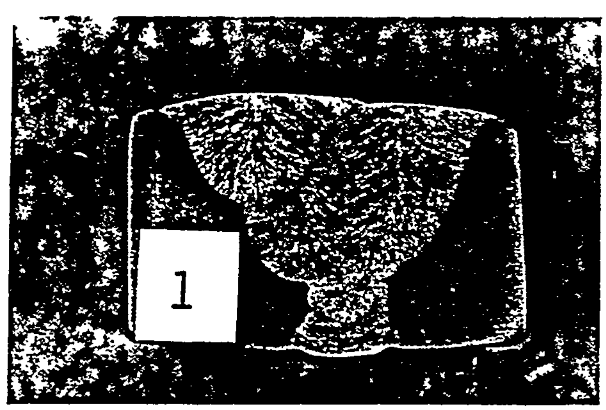
FIGURE 1



DCRP, 5/32″ (4 mm)
L-44 with 124 flux
15 ipm (6.3 mm/s)

Passes	Parameters Amp	Volt	Deposition Rate Lbs./Hr.	kg/Hr.	Heat Input kJ/in.	kJ/mm
1*	320	28	11	4.95	44.8	176
2*	"	"	"	"	"	"
3	400	31	"	"	49.6	195
4	"	"	"	"	"	"
5	500	32	13	5.85	64.0	252
6	700	33	19.5	8.78	92.4	364
7	"	"	"	"	"	"
8	"	"	"	"	"	"
9	"	"	"	"	"	"
10	"	"	"	"	"	"

*Semi-automatic FC-707 root passes

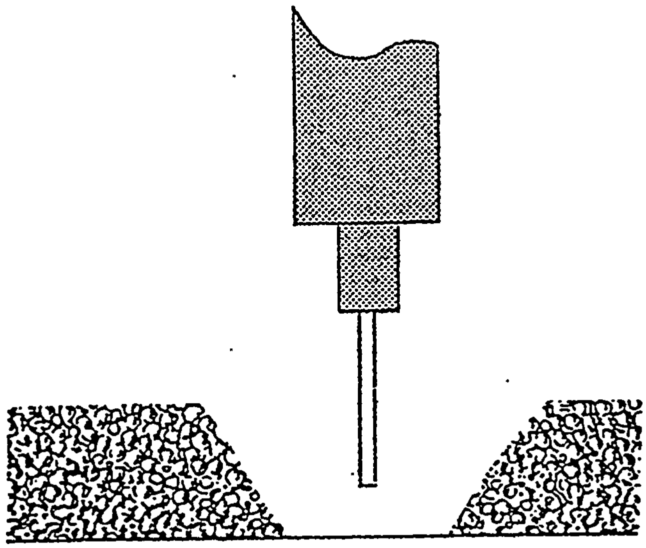


Comments:

Conventional process for comparison

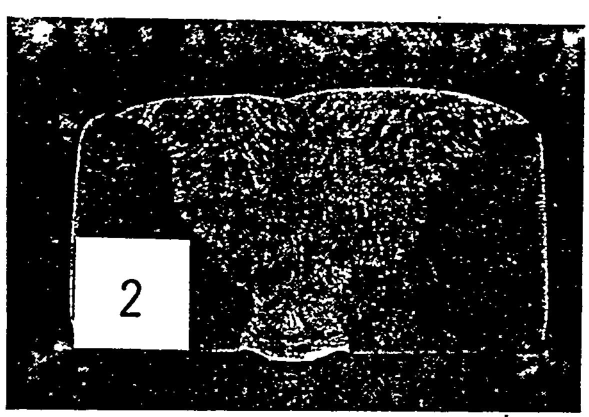
FIGURE 2

DCSP, 5/32″ (4 mm)
. L-44 with 124 flux
1S ipm [6.3 mm/s]



Passes	Parameters Amp	volt	Deposition Rate Lbs./Hr.	kg/Hr.	Heat input kJ/in.	kJ/mm
1*	320	28	11	4.95	44.8	176
2*	"	28	"	"	"	"
3	450	33	12	5.45	59.4	234
4	500	34	19	8.64	68.0	268
5	700	"	29	13.2	95.2	375
6	"	36	"	"	"	"
7	"	"	"	"	"	"
8	"	"	"	"	"	"
9	"	"	"	"	"	"

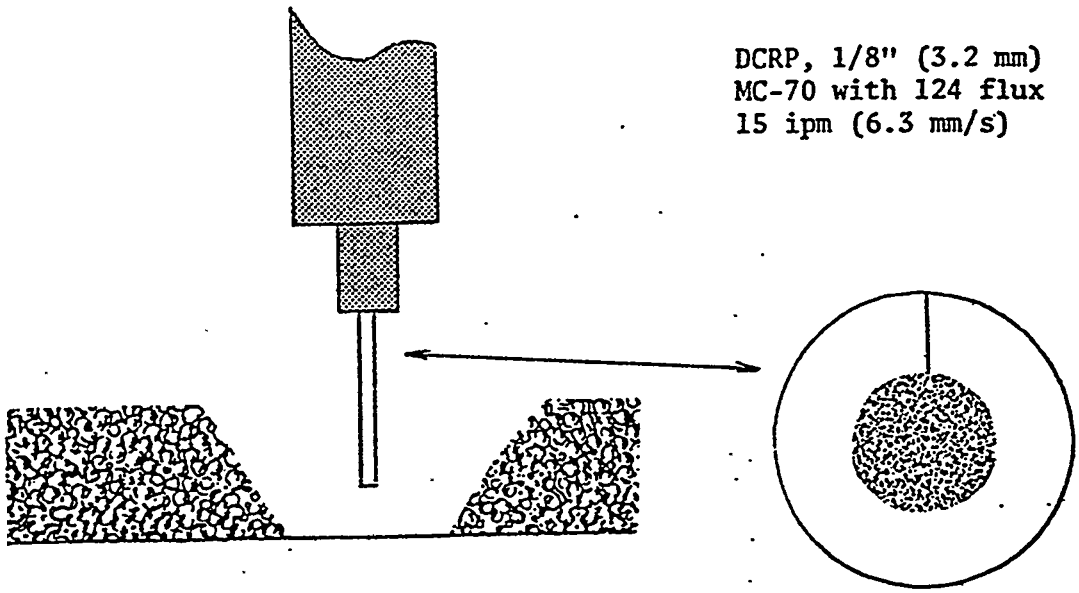
* Semi-automatic FC-707 root passes



Comments:

Less penetration than DCRP (#1)
Slightly increased deposition
rate. Note inclusion in photo.

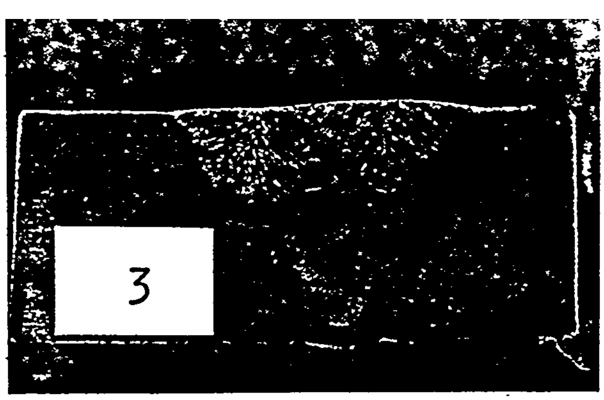
FIGURE 3



DCRP, 1/8" (3.2 mm)
MC-70 with 124 flux
15 ipm (6.3 mm/s)

Passes	Parameters		Deposition Rate		Heat Input	
	Amp	Volt	Lbs./Hr.	kg/Hr.	kJ/in.	kJ/mm
1*	320	28	11	4.95	44.8	176
2*	"	"	"	"	"	"
3	400	32	10.7	4.86	51.2	201
4	500	33	13.3	6.05	66.0	259
5	"	"	"	"	"	"
6	600	34	16.2	7.36	81.6	321
7	"	"	"	"	"	"
8	"	"	"	"	"	"
9	"	"	"	"	"	"
10	"	"	"	"	"	"

*Semi-automatic FC-707 root passes

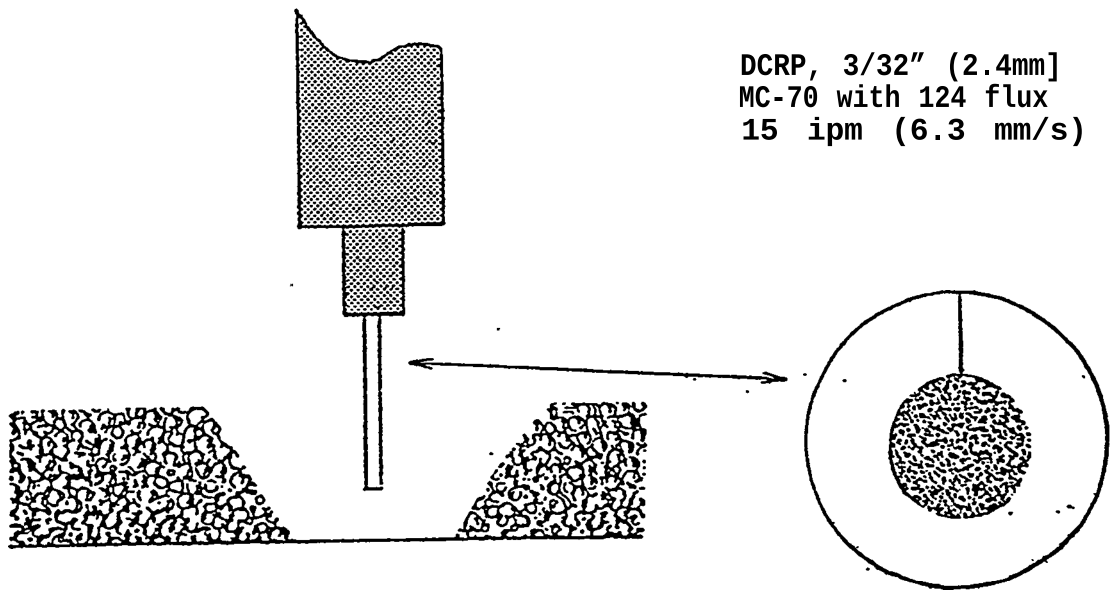


Comments:

This weld is similar to that of Figure 4 except for wire diameter. This was to see the change in deposition rate.

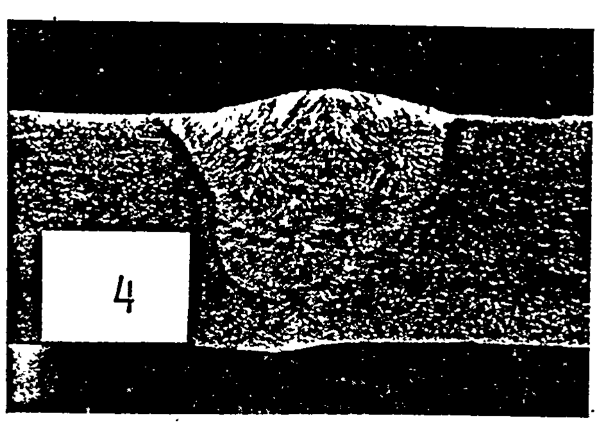
FIGURE 4

DCRP, 3/32″ (2.4mm]
MC-70 with 124 flux
15 ipm (6.3 mm/s)



Passes	Parameters Amp	Parameters volt	Deposition Rate Lbs./Hr.	Deposition Rate kg/Hr.	Heat Input kJ/in.	Heat Input kJ/mm
1*	320	28	11	4.95	44.8	176
2*	"	"	"	"		"
3	400	32	11.6	5.27	51.2	201
4	500	33	15.8	7.18	66.0	259.
5	"	"	"	"	"	"
6	550	34	18	8.18	74.8	294
7	"	"	"	"	"	"
8	"	"	"	"	"	"
9	"	"	"	"	"	"
10	"	"	"	"		"
11	"	"	"	"	"	"

*Semi-automatic FC-707 root passes

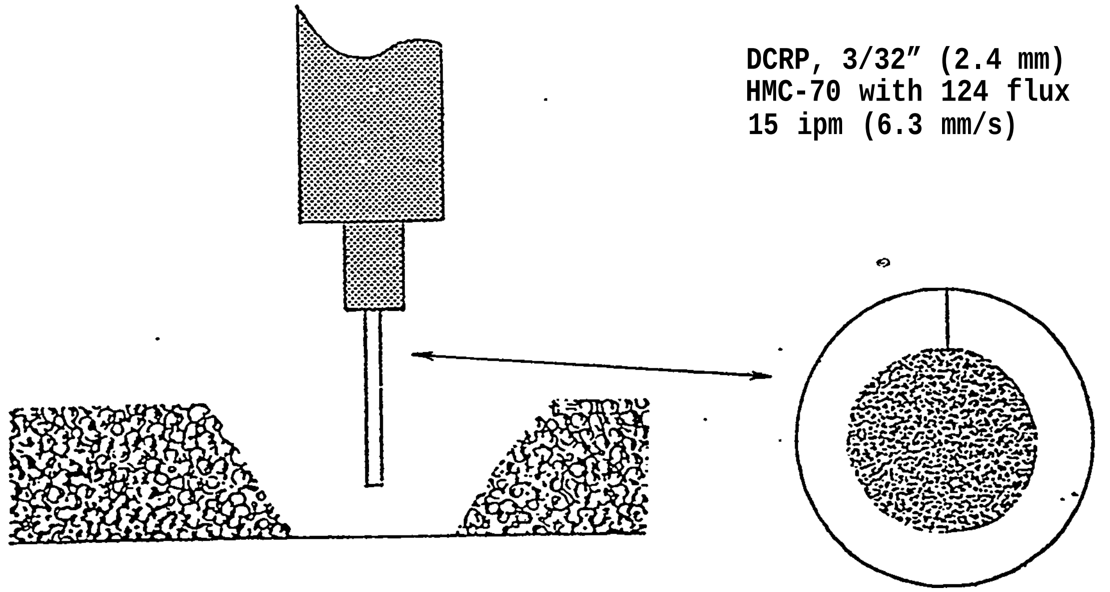


Comments:

This weld is similar to Figure 3 except for wire diameter. The smaller diameter yields greater deposition. Differences in bead placement accounted for the difference in number of passes required.

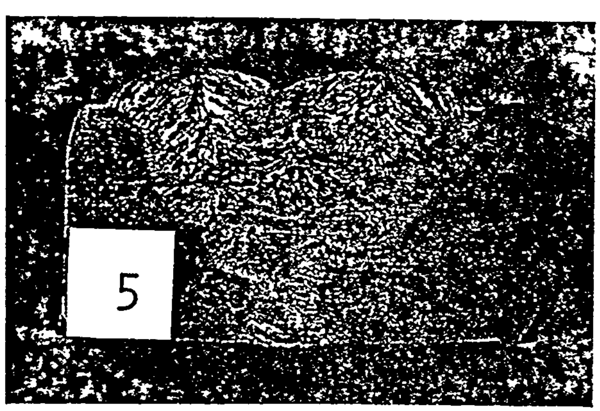
FIGURE 5

DCRP, 3/32" (2.4 mm)
HMC-70 with 124 flux
15 ipm (6.3 mm/s)



Passes	Parameters		Deposition Rate		Heat Input	
	Amp	Volt	Lbs./Hr.	kg/Hr.	kJ/in.	kJ/mm
1*	320	28	11	4.95	44.8	176
2*	"	"	"	"	"	"
3	400	32.5			52.0	204
4	500	33.5		-	67.0	264
5	"	"		"	"	"
6	550	35	-	-	77.0	303
7	"	"	"	"	"	"
8	"	"	"	"	"	"
9	"	"	"	"	"	"
10	"	"	"	"	"	"
11	"	"			"	"

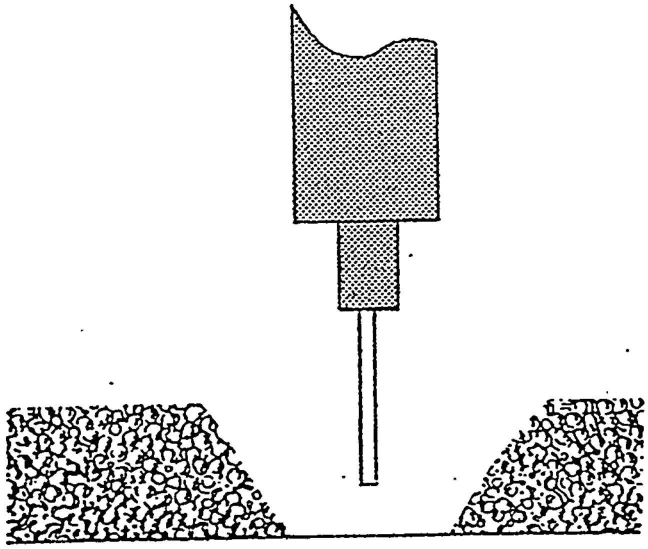
*Semi-automatic FC-707 root passes



Comments:

HMC-70 is identical to MC-70 except there is a larger amount of metal power in the core material. This should have increased deposition rate. Again, bead placemen: affects the total number of passes..

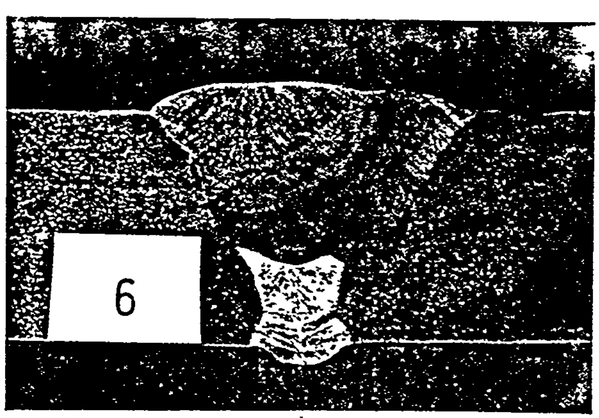
FIGURE 6



DCRP, 5/32" (4 mm)
L-44 with 997-39B **iron**
power flux
15 ipm (6.3 mm/s)

Passes	Parameters		Deposition Rate		Heat Input	
	Amp	volt	Lbs./Hr.	kg/Hr.	kj/in.	kJ/mm
1*	320	28	11	4.95	44.8	176
2*	"	"	"	"	"	"
3	400	33	12.7	5.77	52.8	208
4	500	36	19.3	8.77	72.0	.283
5	"	"	"	"	"	"
6	700	37	24.8	11.27	103.6	408
7	"	"	"	"	"	"
8	"	"	"	"	"	
9	"	"	"	"	"	"

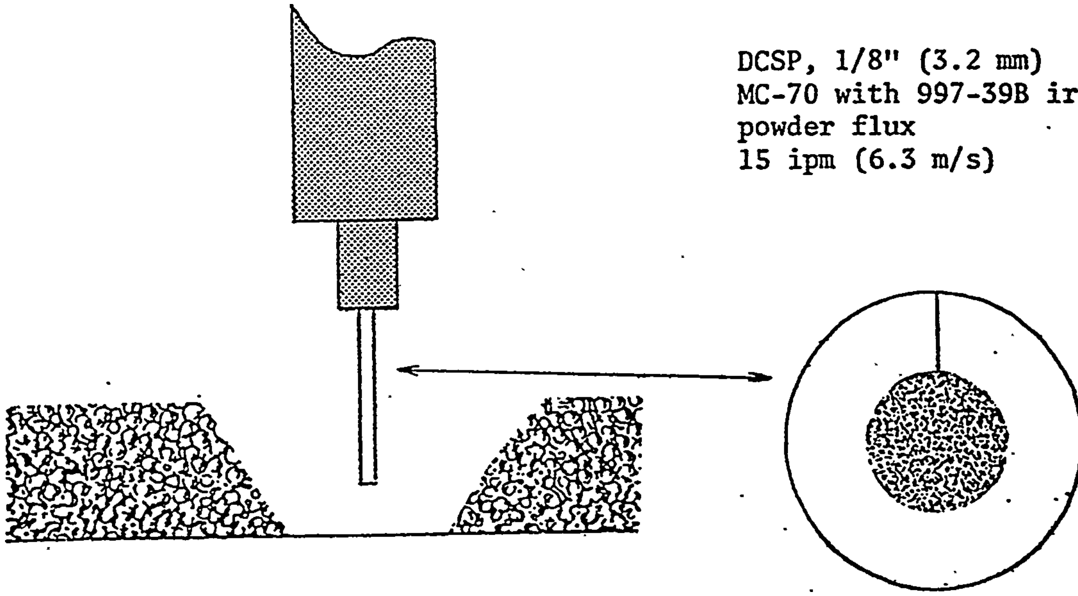
*Semi -automatic FC-707 root passes



Comments:

The addition of the iron powder flux decreased the number of required passes compared to weld #l. Weld cracked, see text.

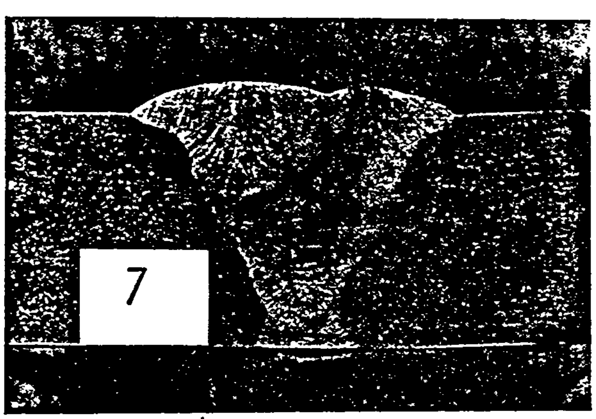
FIGURE 7



DCSP, 1/8" (3.2 mm)
MC-70 with 997-39B iron
powder flux
15 ipm (6.3 m/s)

Passes	Parameters Amp	Parameters volt	Deposition Rate LbS./Hr.	Deposition Rate kg/Hr.	Heat Input kJ/in.	Heat Input kJ/mm
1 *	320	28	11	4.95	44.8	176
2 *	"	"	"	"	"	"
3	400	34	14	6.36	54.4	214
4	500	36	19.6	8.91	72.0	283
5	"	"	"	"	"	"
6	600	38	24	10.91	91.2	359
7	"	"	"	"	"	"
8	..	"	"	"	"	"
9	"	"	"	"	"	"

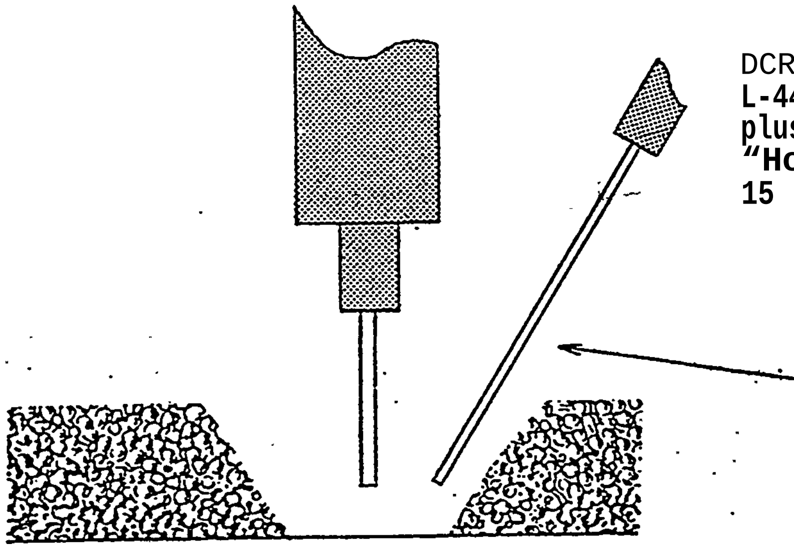
*Semi-automatic FC-707 root passes



Comments:

This weld was to be an optimization using both the iron powder flux and metal cored electrode. Compared to Figure 6, the number of passes required did not decrease. Weld cracked, see text.

FIGURE 8

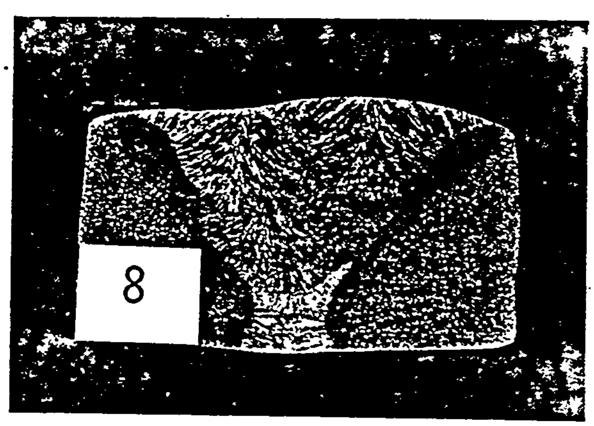


DCRP 5/32″ (4 mm)
L-44 with 124 flux
plus L-44 1/16″ (1.6 mm)
"Hot Wire"
15 ipm (6.3 mm/s)

Hot
Wire

Passes	Parameters Amp	volt	Deposition Rate Lbs./Hr~	kg/Hr.	HeaT Input kJ/in.	kJ/mm
1	320	28	11	4.95	.44.8	176
2	"	"	"	"	"	"
3	400	32	15	6.82.	53.2	209
4	500	33	21	9.55	68.4	269
5	700	33	28.5	12.95	96.4.	379
6	700	34	"	"	99.2	391
7	"	"	"	"	"	"
8	700	35	"	"	102.0	401

*Semi-automatic FC-707 root passes.



Comments:

The heat input figures have the **"Hot** Wire″ included. This process had one of the highest deposition rates.

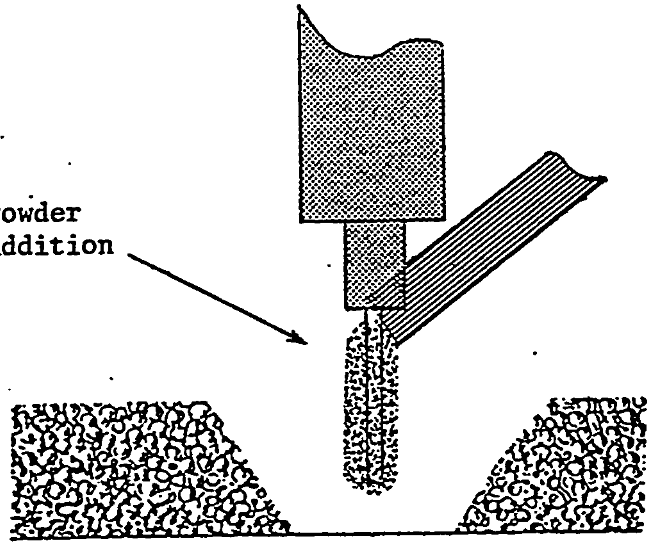
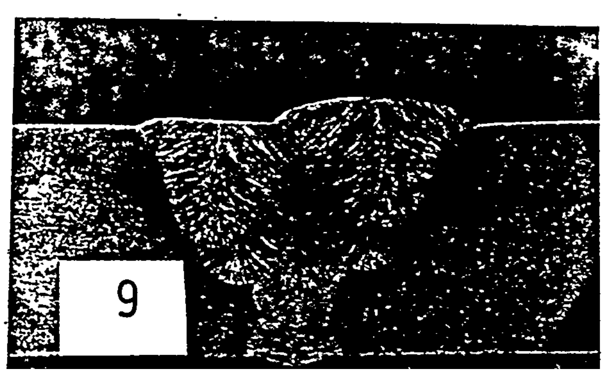


FIGURE 9

DCRP, 5/32″ (4 mm)
L-44 with 124 flux and alloy steel powder addition by the Unionfil process.
15 ipm (6.3mm/s)

Passes	Parameters Amp	Volt	Deposition Rate lbs./Hr	kg/Hr	Heat Input kJ/in.	kJ/mm
1*	320	28	11	4.95	44.8	176
2*	"	"	"	"	"	"
3	400	32.5	13.2	6.00	52.0	205
4	490	35	17.7	8.04	68.6	270
5	"	"	"	"	"	"
6	700	36.5	25	11.36	102.2	402
7	"	"	"	"	"	"
8	"	"	"	"	"	"
9	"	"	"	"	"	"

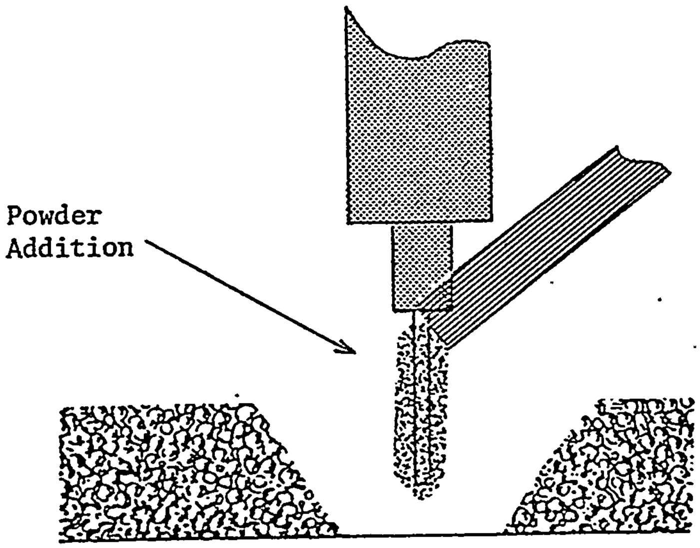
*Semi-automatic FC-707 root passes



Comments:

This process showel promise. Better bead placement and optimization of parameters would improve this process (see #9A). Deposition totals include powder additions.

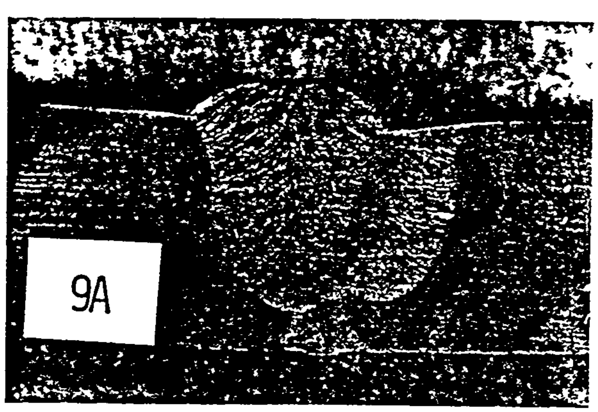
FIGURE 9A



DCRP, S/32" (4 mm)
L-44 with 124 flux and alloy steel powder addition by the Unionfil process.
15 ipm (6.3 mm/s)

Passes	Parameters		Deposition Rate		Heat. Input	
	Amp	volt	Lbs./Hr.	kg/Hr	kJ/in.	kJ/mm
1 *	320	28	11	4.95	44.8	176
2*	"	"	"	"	"	"
3	480	34	18.9	8.59	65.3	257
4	875	41.5	39	17.73	145.3	572
5	"	"	"	"	"	"
6	"	"	"	"	"	
7.	"	"	"	"	"	"

*Semi-automatic FC-707 root passes



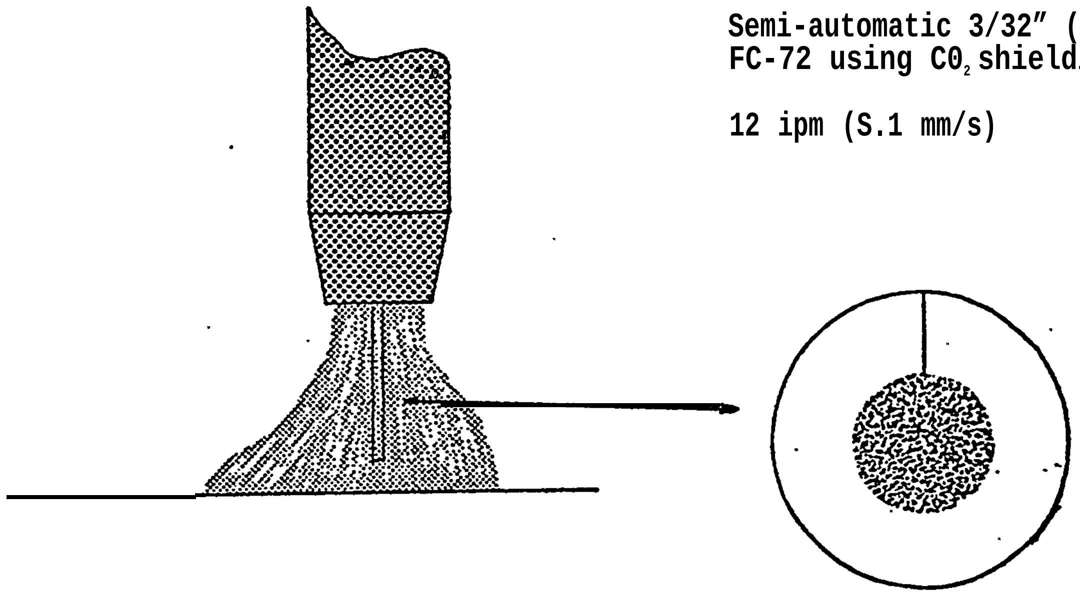
Comments:

This was an **optimization attempt of weld #9. Further work would provide** a **better weld contour.**

FIGURE 10

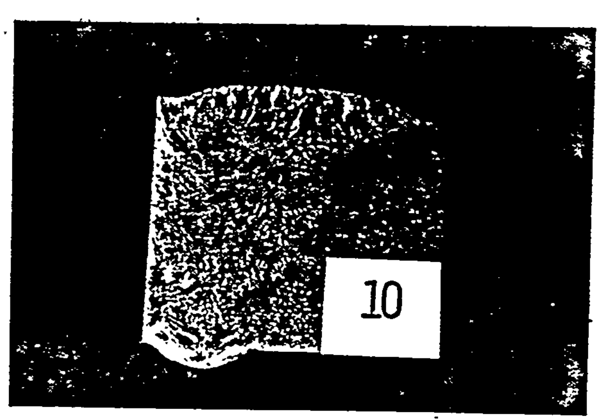
Semi-automatic 3/32″ (2.4 mm) FC-72 using CO_2 shielding at

12 ipm (S.1 mm/s)



Passes	Parameters Amp	volt	Deposition Rate Lbs./Hr.	kg/Hr.	Heat Input kJ/in.	kj/mm
1*	320	28	11	4.95	44.8	176
2*	"	"	"	"	"	"
3	390	30	10.5	4.77	46.8	184
4	475	32	15	6.82	60.8	239
5	"	"	"		"	"
6	"	"	"	"	"	"
7	"	"	"	"	"	"
8	"	"	"	"	"	"
9	"	"	"		"	"

*Semi-automatic FC-707 root passes

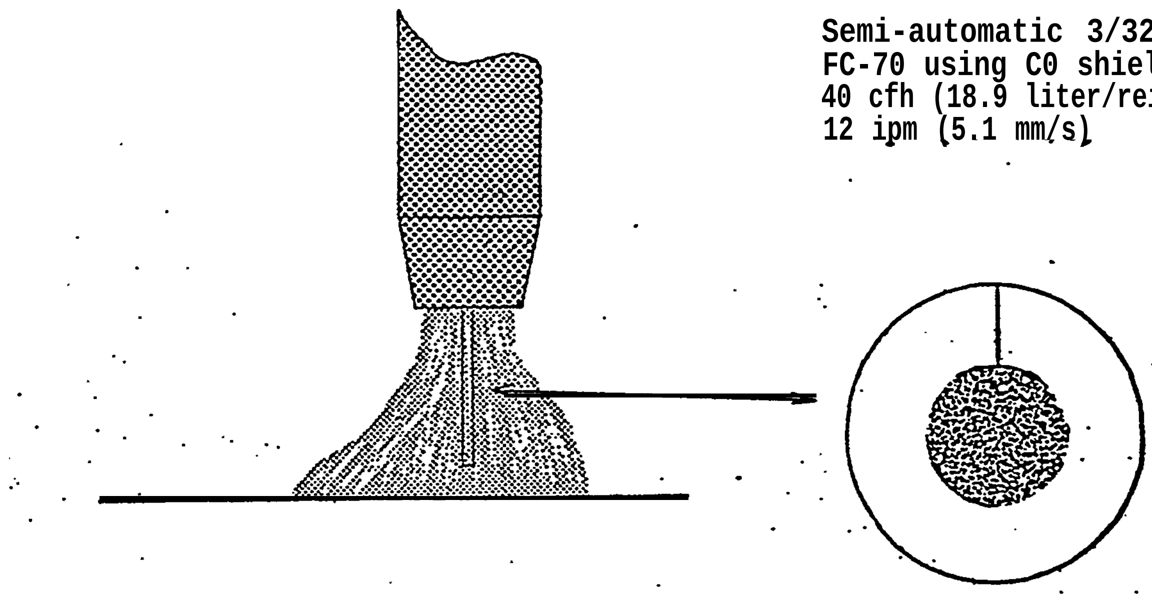


Comments:

Standard cored wire. Good overall bead shape. Lower deposition rate allowed an easier balance between number of passes and amount of fill.

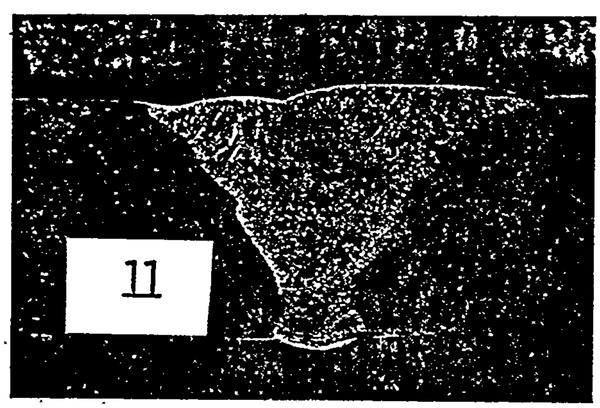
FIGURE 11

Semi-automatic 3/32" (2.4 mm) FC-70 using C0 shielding at 40 cfh (18.9 liter/rein.). 12 ipm (5.1 mm/s)



.Passes	Parameters		Deposition Rate		Heat Input	
	Amp	volt	Lbs./Hr.	kj/Hr.	kJ/in.	kJ/mm
1 *	320	28	11	4.95	44.8	176
2*	"	"	"		"	"
3	400	30	13	5.91	48.0	189
4	475	32	15.6-	7.09	60.8	239
5	"	"	"	"	"	"
6	"	"	"	"	"	"
7	"	"	"	"	"	"
8	"	"	"	"		"

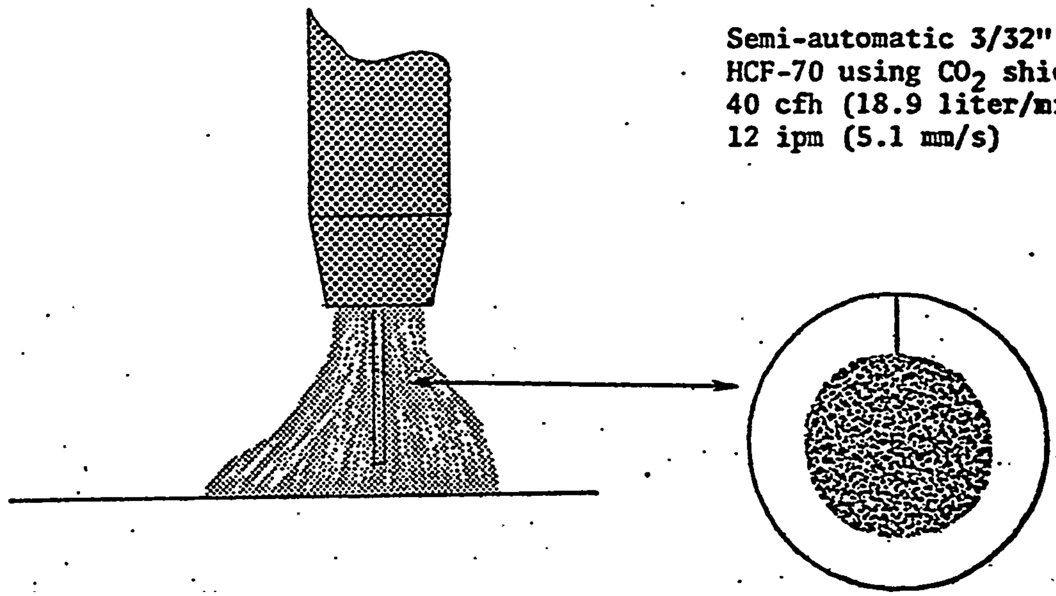
*Semi-automatic FC-707 root passes



Comments:

Standard cored wire. Slight undercut along. one edge; performance similar to FC-72, Figure 10.

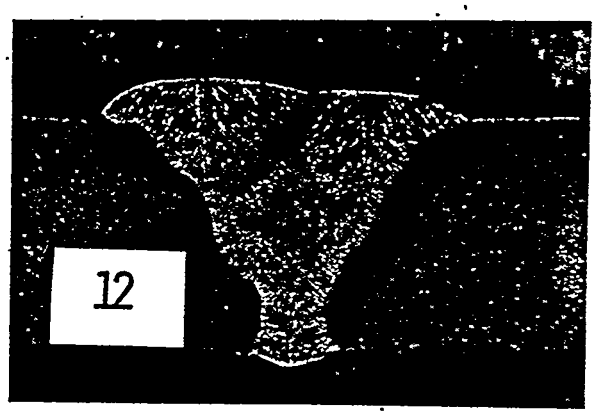
FIGURE 12



Semi-automatic 3/32" (2.4 mm) HCF-70 using CO_2 shielding at 40 cfh (18.9 liter/min.). 12 ipm (5.1 mm/s)

Passes	Parameters Amp	Parameters volt	Deposition Rate: Lbs./Hr.	Deposition Rate: kg/Hr.	Heat Input kJ/in.	Heat Input kJ/mm
1*	320	28	11	4.95	44.8	176
2*	"	"	"	"	"	"
3	400	30	13.2	6.00.	48.0	189
4	475 "	32	17.8	8.09	60.8	239
5			"	"	"	"
6	"		"	11	"	"
7	"	"	"!	"	"	"
8	"	"	"	"	"	"

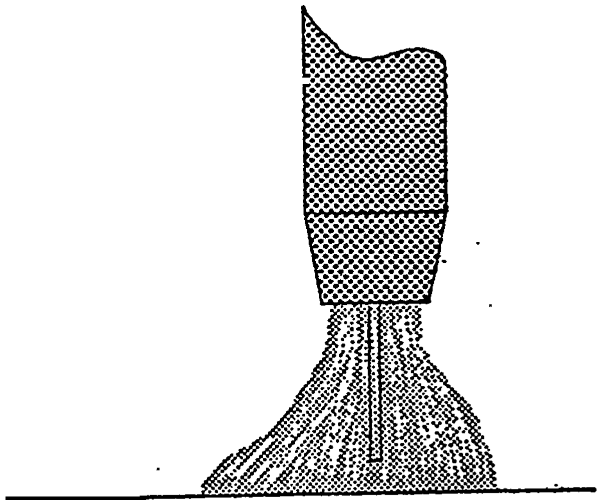
*Semi-automatic FC-707 root passes



Comment5:

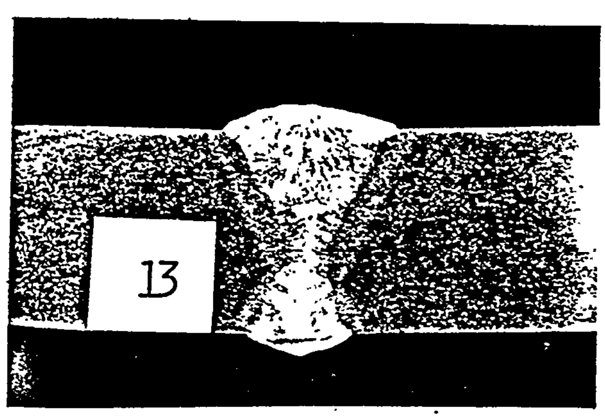
This weld was made using the higher core percent.FC-70 wire. This increased deposition rate compared to the previous two welds, .Figures 10 & 11.

FIGURE 13



Semi-automatic .035″ (0.9mm) L-82 using 5% 02-95% Ar gas. Hi-Dep" prOCess.
15 ipm (6.3mm/s).
TWO side weld.

Passes	Parameters		Deposition Rate		Heat Input	
	Amp	volt	Lbs./Hr.	kg/Hr.	KJ/in.	KJ/mm
1	340	39	24	10.9	53.0	208
2	"	"	"	"	"	"
3	"	"	"	"	"	"



Comments:

Note minimal penetration in the root area; joint redesign would be necessary to adequately utilize process.

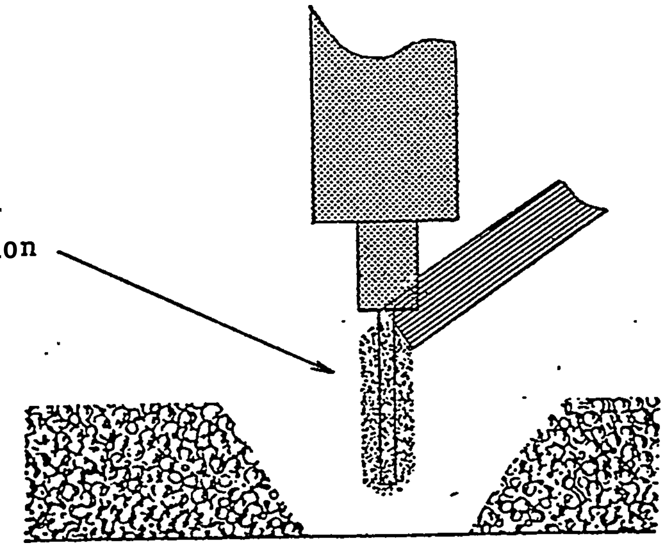
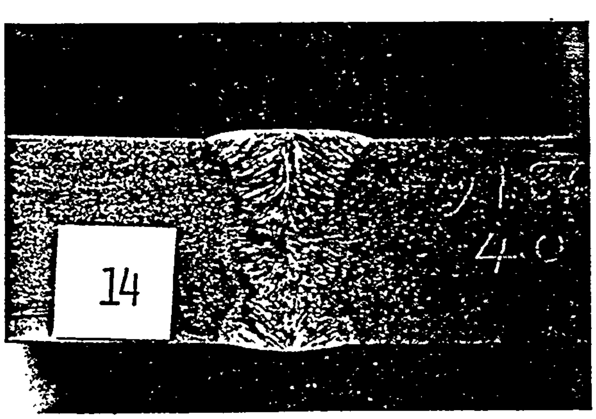


FIGURE 14

DCRP, 5/32" (4 mm)
L-44-with 124 flux and alloy steel powder Unionfil process.
Pass 1 24 ipm (6.8 mm/s),
2 and 3 at 16 ipm (6.8 mm/s).
Two side weld.

Passes	Parameters AmP	volt	Deposition Rate Lbs./Hr.	kg/Hr.	Heat Input kJ/in.	kJ/mm
1	566	28	- -	- -	.39.2.	154
2	665	"	25	11.36	69.8	275
3	600	31	26.3	11.95	"	"

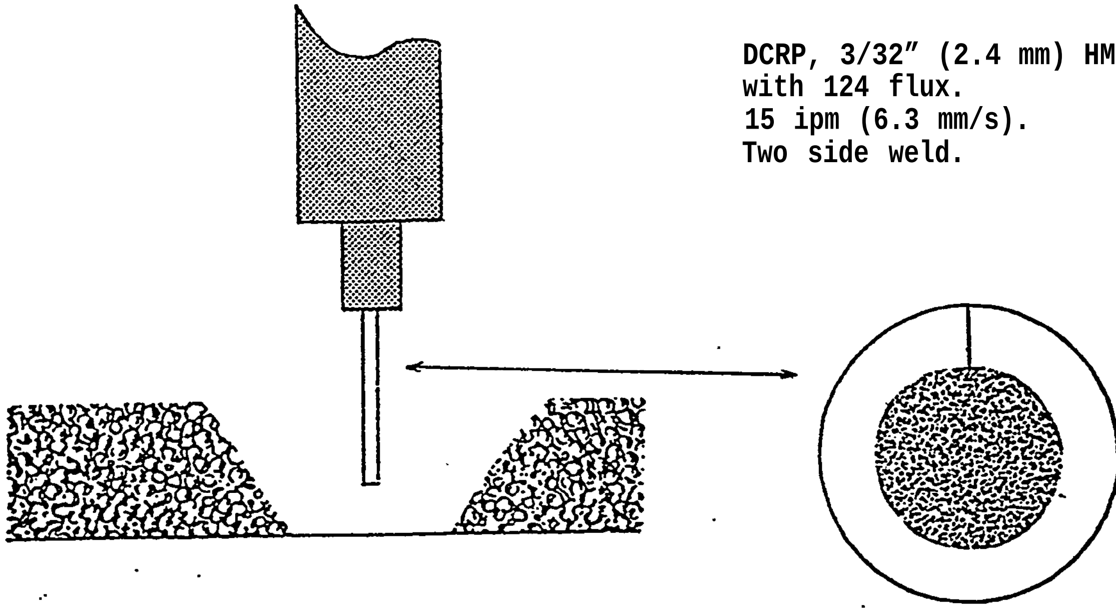


Comments

Weld contour was good. This is the process that seemed optimum.

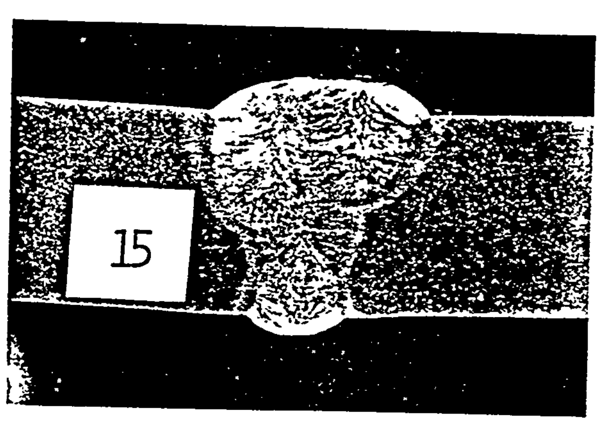
FIGURE 15

DCRP, 3/32″ (2.4 mm) HMC-70
with 124 flux.
15 ipm (6.3 mm/s).
Two side weld.



Passes	Parameters Amp	Parameters volt	Deposition Rate Lbs./Hr.	Deposition Rate kg/Hr.	Heat Input kJ/in.	Heat Input kJ/mm
1 *	440	29	13.7	6.2	30.3	119
2*	510	34	19.4	8.8	69.4	273
3	520	"	"	"	"	"
4	500	"	"	"	"	"

*Semi-automatic FC-707 root passes



Comments:

Problems were encountered balancing heat input and fill rate. See text.

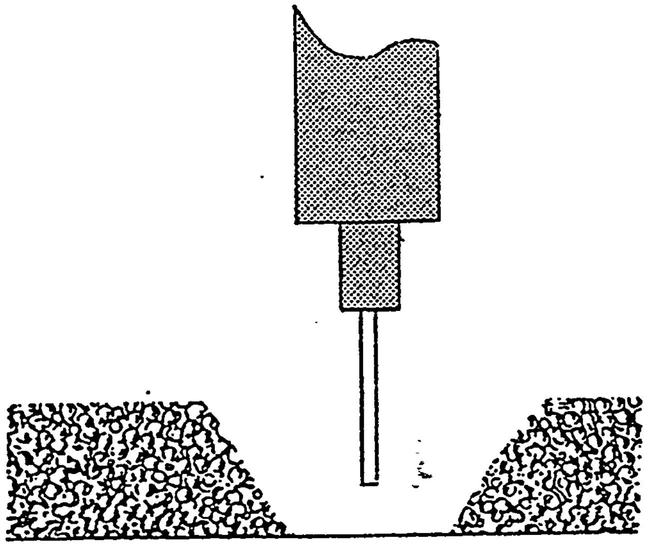
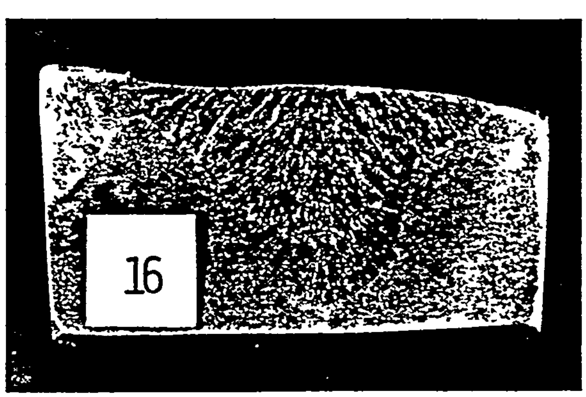


FIGURE 16

Two wire AC. Lead electrode 1/4" (6 mm) L-36, trail . electrode
5/32" (4 mm) L-44, 166P flux. Groove filled completely with alloy steel powder 'prior to welding.

Passes	Parameters		Deposition Rate		Heat Input	
	Amp	volt	Lbs ./Hr.	kg/Hr .	kj/in.	kJ/mm
1 *	320	28	11	4.95	44.8	176
2 *	"	"	"	"	"	"
3 Lead	1050	45	- -	- -	399	1590
Trail	775	42	- -	- -		



Comments:

No deposition rate was *measured.* It was estimated at-about 55 lbs./hr. (25 Kg/hr.) . Bead at left edge is not relevant.