The Effects of Process Variables on the Weld Deposit Area of Submerged Arc Welds

Variables that have the strongest influence on the volume of the weld deposit are determined

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ABSTRACT. The results of bead-on-plate submerged arc welding experiments are presented to determine the effects of process variables on the weld deposit area at a constant heat input of 3 kJ/mm. It is found that the deposit area is a function of the welding current, welding voltage, welding speed, electrode polarity, electrode diameter and electrode extension. In general, welds made using direct current electrode negative (DCEN) polarity, a small-diameter electrode, long electrode extension, high welding current, low welding voltage and a high welding speed have large deposit areas. The weld deposit area is, however, not affected significantly by the power source or the flux type used in this investigation.

Introduction

The relationship between arc welding parameters and weld bead geometry is complex since a number of factors are involved. Yet there is a need to have this information for procedure development and for understanding the mechanism of weld bead formation. A means of anticipating the weld bead geometry is also necessary because all welding parameters have to be selected before a weld can be specified to meet the requirements for a particular situation, especially when using automated welding equipment such as with the submerged arc welding (SAW) process. As a result, several researchers have attempted to investigate the effects of various process variables on the weld bead geometry. Such work published prior to 1978 has been summarized by Shinoda and Doherty (Ref. 1).

Subsequent to the above publication, McGlone (Ref. 2), and McGlone and Chadwick (Ref. 3) carried out further work on submerged arc welding. The variables included in these studies were welding current, voltage, speed, bevel angle and electrode diameter. Chandel, *et al.* (Refs. 4–6), extended the study to include the effects of electrode polarity and extension on the weld joint penetration, melting rate and bead size. It was found that both electrode extension and polarity were important variables.

Among the weld features, the weld deposit area is one of the most important ones because it not only affects the number of passes required to fill a joint, but also constitutes a major portion of the bead size and hence determines the dilution from the base plate (Refs. 7, 8). Therefore, in this investigation, an attempt is made to study the influence of welding parameters on the weld deposit area, which has not yet been studied independently. A schematic of the weld deposit area is illustrated in Fig. 1. The effects of electrode polarity, extension, diameter, welding current, voltage, travel speed, power source setting (constant current or constant voltage) and flux basicity on the weld deposit area are presented. In addition, the data is reduced with regression techniques (both linear and curvilinear) to permit the calculation of weld deposit area as a function of these variables. An effort is also made to compare the calculated deposit area from existing melting rate equations (Refs. 5, 9, 10) with the measured weld deposit areas.

Key Words:

Bead-on-plate Welds
Deposit Area
Electrode Polarity
Electrode Extension
Electrode Diameter
Welding Current
Welding Voltage
Welding Speed
Flux
Regression Equations

Experimental Procedure

The base material used for this investigation was a 19-mm-thick (0.75-in.) ASTM A36 plate. This plate was cut into 600 X 150 mm (24 X 6 in.) pieces and both surfaces were sand blasted to remove dirt and oxides. Lincoln L60 welding wires were used along with Linde 124 and OP121 fluxes.

A Miller DC 1500 power source, which could be switched to either constant current or constant voltage mode, was used to deposit experimental bead-on-plate welds. A total of 115 and 138 welds were successfully made using direct current electrode negative (DCEN) and direct current electrode positive

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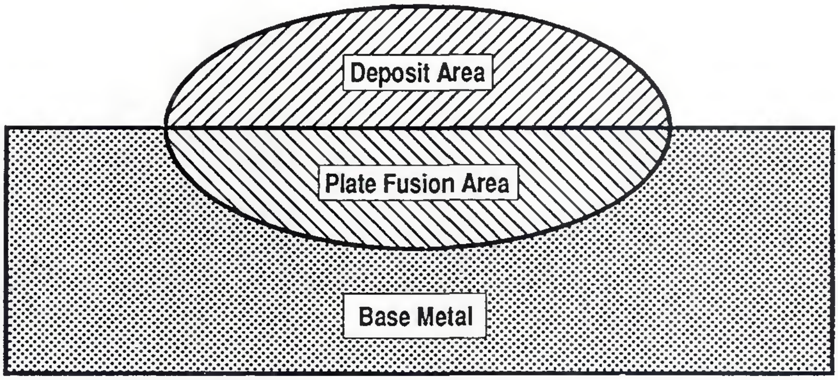

Fig. 1 — Schematic of test plate.

(DCEP) polarities, respectively. For each weld, the process variables were preselected and preset; however, minor adjustments to the welding currents and voltages had to be made at the beginning of the weld to achieve the preset levels, and the actual current and voltage values were recorded continuously using a strip chart recorder. In this investigation, both electrode polarities (DCEN and DCEP), two levels of electrode extensions (25.4 and 76.2 mm) (1 and 3 in.), three electrode diameters (2.4, 3.2 and 4.0 mm) (0.09, 0.125 and 0.16 in.), four levels of current for each electrode diameter (300–1000 A) and three levels of welding voltages (32, 35, and 38 V) were used. The travel speed was adjusted between 3.22 to 12.66 mm/s (7.6 to 29.9 in./min) to give a heat input of 3 kJ/mm (76 kJ/in.). The effect of flux type and power source setting was studied for one electrode diameter (3.2 mm) using the same variables and their levels. These conditions were selected because they are the most representative values of shop floor welding. Each weld was cross-sectioned at midlength, polished and etched with 2% nital, and the weld deposit area was measured using a planimeter.

Results

The results of present investigation in terms of process variables (current, voltage, welding speed, electrode diameter, electrode polarity, electrode extension, power source and flux type) and weld deposit area are given in Table 1. In the subsections below, some observations are apparent from the data in Table 1.

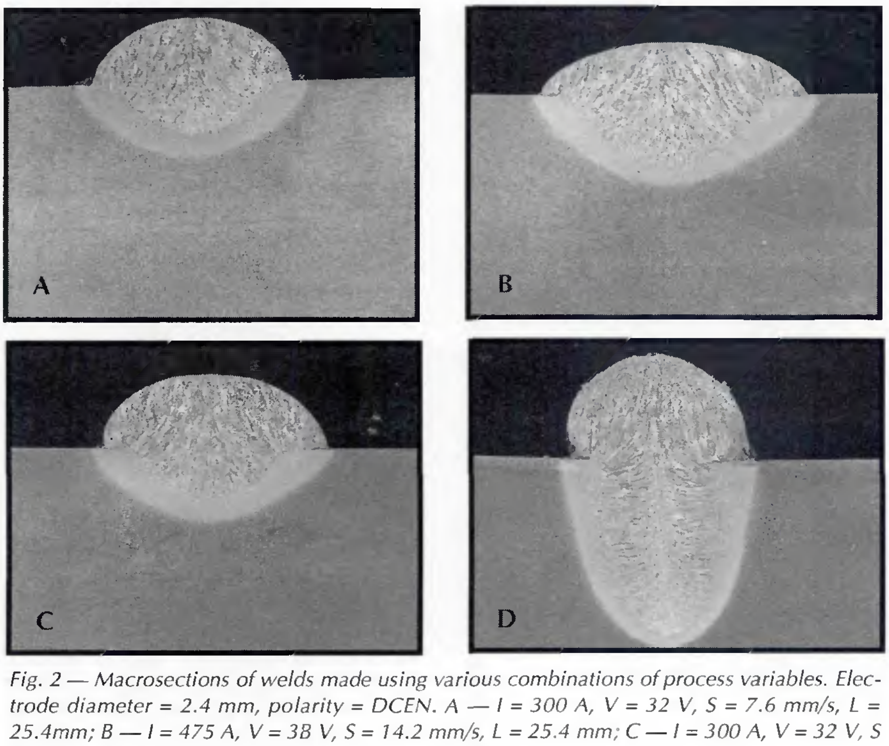

Fig. 2 — Macrosections of welds made using various combinations of process variables. Electrode diameter = 2.4 mm, polarity = DCEN. A — I = 300 A, V = 32 V, S = 7.6 mm/s, L = 25.4mm; B — I = 475 A, V = 38 V, S = 14.2 mm/s, L = 25.4 mm; C — I = 300 A, V = 32 V, S = 7.6 mm/s, L = 76.2 mm; D — I = 550 A, V = 38 V, S = 16.5 mm/s, L = 76.2 mm.

In other cases, observations are better made by presenting averaged values with some variables held constant. Such representations are contained in Tables 2 to 7. Macrosections of four welds made using various process parameters are shown in Fig. 2.

The Effect of Electrode Polarity

It is apparent from Table 1 that considerably higher deposit area values are obtained when the electrode is negative as compared to when electrode is positive. The importance of polarity is very significant, and it must be included in regression expressions for computing deposit area. Since the polarity cannot be assigned a numerical value, the strategy to be adopted in this presentation is to offer separate relationships for DCEN and DCEP.

The Effect of Electrode Extension

Electrode extension is the distance between the end of the electrical contact tube and the end of the unmelted electrode. Table 1 shows that all other factors being equal, a longer electrode extension of 76.2 mm gives higher deposit area values. Once again it is apparent that this is a relatively strong effect and must be considered in the regression analysis for computing deposit area.

The Effect of Welding Current

To establish a relationship between welding current and deposit area, Table 2 was constructed. The average deposit areas were obtained by taking the average of all measured values with the same welding current, for a particular electrode diameter and extension, but without taking into account the effects of voltage and speed. Such a representation of data is valid in the sense that the heat input is always 3 kJ/mm. It is apparent from Table 2A that higher deposit areas are obtained with negative electrode polarity. However, the effect of welding current on the deposit area seems to have little significance.

Unlike the above (electrode extension of 25.4 mm, 1 in.), Table 2B shows that, for both positive and negative polarities, current has a considerable effect on deposit area. The combined effects of welding current and electrode diameter on the average deposit area is shown in Fig. 3 and Table 2B. The deposit area decreases considerably with electrode diameter.

In summary, it is apparent from these results that current and electrode diameter are important where the electrode extension is large but not nearly so important when electrode extension is short.

The Effect of Welding Voltage

Tables 3A and 3B show the effect of welding voltage on the average deposit area. The average deposit areas in these tables were obtained by taking the average of all measured areas of welds deposited with the same voltage for a given electrode diameter and extension, but without taking into account the effects of current and speed. It can be seen here that, for all conditions, there is a decrease in deposit area when voltage is increased.

Figure 4 shows the effect of welding voltage on the average deposit area, for both electrode negative and electrode positive polarities and for an electrode extension of 76.2 mm.

The Effect of Electrode Diameter

For an electrode extension of 25.4 mm, it can be seen from Table 3A that the effect of electrode diameter on deposit area is minimal. However, for an electrode extension of 76.2 mm, it is apparent from Table 3B and Figs. 3 and 4 that the average deposit area for a smaller electrode is higher for both polarities.

The Effect of Welding Speed

Table 4 shows the average deposit area against welding speed, for an electrode diameter of 3.2 mm. The average deposit areas in this case were obtained by taking the average of all the values for welds with the same welding speed and electrode extension, but without taking into account the effects of machine setting (constant current or constant voltage) or flux type (acidic or basic) used. In a majority of cases, it is apparent that there is an increase in deposit area as the welding speed increases. Figure 5 shows this effect for an electrode diameter of 3.2 mm.

The data available for 2.4 and 4.0 mm (0.09 and 0.16 in.) electrode diameters were rather limited. Only one measured deposit area value is available for each welding speed for any given electrode diameter and extension. Table 4B and 4C show the average deposit area against average welding speed for electrode diameters of 2.4 and 4.0 mm, respectively. It can still be seen here that the deposit area increases as the average welding speed or current is increased.

The Effect of Machine Setting and Flux

Table 5 shows the average deposit area against flux (acidic or basic) and

Table 1 — Welding Parameters and Measured Deposit Area

Electrode Diameter (mm)	Voltage (V)	Welding Current (A)	Welding Speed (mm/s)	Electrode Extension (mm)	Deposit Area (mm^2)		Remarks
					DCEN	DCEP	
2.4	32	300	3.22	25.4	47.83	—	CVFL
	35	300	3.51		51.56	30.44	
	38	300	3.81		44.59	28.14	
	32	400	4.28		54.68	36.90	
	35	400	4.66		48.03	32.36	
	38	400	5.08		40.98	33.07	
	32	475	5.08		59.00	46.52	
	35	475	5.55		54.14	—	
	38	475	6.01		47.77	34.42	
	32	550	5.88		53.33	52.31	
	35	550	6.43		52.51	—	
	38	550	6.99		42.34	31.08	
	32	300	3.22	76.2	62.25	50.45	
	35	300	3.51		93.10	45.81	
	38	300	3.81		59.40	38.90	
	32	400	4.28		86.92	60.60	
	35	400	4.66		66.80	60.73	
	38	400	5.08		62.81	54.51	
	32	475	5.08		75.92	62.89	
	35	475	5.55		77.87	74.48	
	38	475	6.01		80.35	60.47	
	32	550	5.88		130.2	106.2	
	35	550	6.43		62.22	62.22	
	38	550	6.99		75.35	73.78	
3.2	32	300	3.22	25.4	—	46.15	CVFL
	35	300	3.51		68.67	32.52	
	38	300	3.81		44.72	33.82	
	32	450	4.78		—	39.30	
	35	450	5.25		—	37.55	
	38	450	5.72		—	64.30	
	32	600	6.39		—	40.14	
	35	600	6.99		—	33.80	
	38	600	7.62		—	30.82	
	32	750	8.00		—	53.10	
	35	750	8.76		—	35.37	
	38	750	9.48		—	29.83	
	32	300	3.22	76.2	—	51.47	CVFL
	35	300	3.51		53.39	49.26	
	38	300	3.81		52.69	36.30	
	32	450	4.78		70.71	50.93	
	35	450	5.25		—	44.80	
	38	450	5.72		64.30	41.38	
	32	600	6.39		78.85	68.00	
	35	600	6.99		73.46	60.33	
	38	600	7.62		64.27	57.43	
	32	750	8.00		101.9	95.51	
	35	750	8.76		—	62.89	
	38	750	9.48		80.40	55.75	
3.2	32	300	3.22	25.4	53.45	38.71	CCFL
	35	300	3.51		44.35	35.92	
	38	300	3.81		53.62	35.30	
	32	450	4.78		52.97	35.40	
	35	450	5.25		50.40	32.61	
	38	450	5.72		50.06	34.69	
	32	600	6.39		57.01	41.67	
	35	600	6.99		55.56	37.39	
	38	600	7.62		40.80	33.86	
	32	750	8.00		44.95	37.23	
	35	750	8.76		61.63	36.63	
	38	750	9.48		41.76	45.60	
	32	300	3.22	76.2	59.79	35.30	CCFL
	35	300	3.51		53.00	40.37	
	38	300	3.81		49.79	46.66	
	32	450	4.78		64.00	52.45	
	35	450	5.25		66.67	49.32	
	38	450	5.72		53.45	40.86	
	32	600	6.39		102.1	61.18	
	35	600	6.99		74.27	58.11	
	38	600	7.62		56.54	48.51	

Table 1—Welding Parameters and Measured Deposit Area — continued

Electrode Diameter (mm)	Voltage (V)	Welding Current (A)	Welding Speed (mm/s)	Electrode Extension (mm)	Deposit Area (mm^2) DCEN	Deposit Area (mm^2) DCEP	Remarks
	32	750	8.00		102.4	93.29	
	35	750	8.76		66.76	73.20	
	38	750	9.48		68.42	59.58	
3.2	32	300	3.22	25.4	—	66.46	CV,FO
	35	300	3.51		—	35.91	
	38	300	3.81		—	33.87	
	32	450	4.78		—	38.29	
	35	450	5.25		—	35.01	
	38	450	5.72		—	—	
	32	600	6.39		—	30.61	
	35	600	6.99		—	32.08	
	38	600	7.62	—	32.08		
	32	750	8.00		—	46.01	
	35	750	8.76		—	—	
	38	750	9.48		—	36.77	
	32	300	3.22	76.2	77.80	14.25	CVFO
	35	300	3.51		44.08	38.31	
	38	300	3.81		65.49	41.91	
	32	450	4.78		73.89	55.45	
	35	450	5.25		63.91	54.63	
	38	450	5.72		54.80	—	
	32	600	6.39		74.70	60.72	
	35	600	6.99		67.23	51.00	
	38	600	7.62		59.50	57.04	
	32	750	8.00		71.88	74.21	
	35	750	8.76		84.33	96.09	
	38	750	9.48		72.25	68.70	
3.2	32	300	3.22	25.4	54.66	33.65	CCFO
	35	300	3.51		52.57	38.63	
	38	300	3.81		57.73	29.96	
	32	450	4.78		55.13	37.22	
	35	450	5.25		54.46	38.65	
	38	450	5.72		51.38	34.49	
	32	600	6.39		—	41.61	
	35	600	6.99		52.85	36.33	
	38	600	7.62		49.00	34.32	
	32	750	8.00		59.74	56.26	
	35	750	8.76		54.61	45.41	
	38	750	9.48		51.64	39.63	
	32	300	3.22	76.2	—	39.89	CCFO
	35	300	3.51		61.13	40.27	
	38	300	3.81		51.49	38.55	
	32	450	4.78		73.04	54.99	
	35	450	5.25		69.00	50.29	
	38	450	5.72		83.95	45.21	
	32	600	6.39		67.93	67.21	
	35	600	6.99		69.04	57.94	
	38	600	7.62		61.64	50.80	
	32	750	8.00		98.55	87.14	
	35	750	8.76		74.08	65.17	
	38	750	9.48		—	65.80	
4.0	32	400	4.28	25.4	41.48	39.57	CV FL
	35	400	4.66		41.75	30.91	
	38	400	5.08		—	32.72	
	32	600	6.39		56.39	37.00	
	35	600	6.99		48.75	38.91	
	38	600	7.62		39.74	28.32	
	32	800	8.55		38.71	41.45	
	35	800	9.31		63.10	43.74	
	38	800	10.12		28.58	46.19	
	32	1000	10.67		59.14	58.64	
	35	1000	11.68		67.13	30.25	
	38	1000	12.66		65.25	36.13	
	32	400	4.28	76.2	50.29	51.97	
	35	400	4.66		38.91	36.51	
	38	400	5.08		40.80	31.11	
	32	600	6.39		71.24	49.01	
	35	600	6.99		49.03	46.44	
	38	600	7.62		47.89	39.92	

welding machine setting (constant current or constant voltage) for an electrode diameter of 3.2 mm. The average deposit areas were obtained by taking the average of all measured values with the same machine setting, the same flux type and the same electrode extension, but without taking into account the effects of current, voltage and speed. It can be seen from this table that there are no significant changes on the average deposit area by switching from one machine setting to another, or by changing from one flux to another.

Regression Equations

The following linear and curvilinear equations correlating welding parameters and weld deposit area were obtained from the data (Refs. 3, 11):

For electrode negative (DCEN),

$$A_d(\text{lin}) = 95.52 + 0.36*L - 1.03*V - 11.39*D + 0.10*I - 5.88*S \quad (1)$$

$$A_d(\text{log}) = 3010.46*L^{0.27}*S^{0.25}*V^{-1.36}*D^{-0.48} \quad (2)$$

Note that current (I) does not appear in Equation 2.

For electrode positive (DCEP),

$$A_d(\text{lin}) = 45.87 + 0.35*L + 0.12*I - 0.27*V - 9.15*D - 6.95*S \quad (3)$$

$$A_d(\text{log}) = 59.31*L^{0.33}*I^{0.42}*V^{-1.0}*D^{-0.47} \quad (4)$$

where A_d = deposit area, mm^2; D = electrode diameter, mm; I = welding current, A; L = electrode extension, mm; S = welding speed, mm/s; V = welding voltage, V; lin = equation obtained by using linear regression analysis; log = equation obtained by using curvilinear regression analysis.

Note that welding speed (S) does not appear in Equation 4

It should be noted that, due to low tolerance of some of the process variables, only four variables could be included in Equations 2 and 4. Because of the insensitivity of deposit area to current in Equation 2 and to welding speed in Equation 4, unrealistic equations are generated by forcing the analysis to include these variables.

The statistical data for correlation Equations 1 to 4 are given in Table 6. The correlation coefficients, R, of these equations are 0.76, 0.77, 0.78 and 0.81, respectively. It is noted that the correlation coefficients for curvilinear Equations 2 and 4 are higher than those for linear Equations 1 and 3. However, since differences are small, both curvilinear and linear equations are equally useful for use in estimating the deposit area.

Discussion

Interpretation of the Regression Equations

Equation 1 indicates that an increase of L (electrode extension) and I (welding current) increases the deposit area while an increase of D (electrode diameter), S (welding speed) and V (welding voltage) decreases the deposit area. Equation 2 indicates that an increase in L (electrode extension) and S (welding speed) increases the deposit area while an increase of D (electrode diameter) and V (welding voltage) decreases the weld deposit area.

These observations are in general agreement except that the variable S (welding speed) seems to behave differently in each equation by virtue of the fact that it carries a different sign. It seems that the log relationship, Equation 2, tends to support the results that indicate the general trend is the weld deposit area increases with welding speed or welding current, at a constant heat input of 3 kJ/mm. On the other hand, the linear relationship, Equation 1, tends to support the results that indicate for a particular current setting, there is generally a decrease in deposit area when the speed or voltage is increased, again at a constant heat input of 3 kJ/mm.

Linear Equations 1 and 3 are similar. However, Equation 4 includes I (welding current) as a variable instead of S (welding speed). It seems that the influence of current is stronger than welding speed when the positive electrode polarity is used, as evidenced by the expo-

Table 1—Welding Parameters and Measured Deposit Area — continued

Electrode Diameter (mm)	Voltage (V)	Welding Current (A)	Welding Speed (mm/s)	Electrode Extension (mm)	Deposit Area (mm^2)		Remarks
					DCEN	DCEP	
	32	800	8.55		84.80	84.06	
	35	800	9.31		54.81	69.29	
	38	800	10.12		54.28	49.83	
	32	1000	10.67		81.95	58.81	
	35	1000	11.68		92.86	64.07	
	38	1000	12.66		73.40	77.64	

Remarks: CC = constant current power source setting, CV = constant voltage power source setting; FL = Linde 124 (acidic) flux; FO = OP121 (basic) flux

Table 2A — Relationship between Welding Current and Deposit Area(a)

Electrode Diameter (mm)	Welding Current (A)	Average Deposit Area (mm^2)	
		DCEN	DCEP
2.4	300	47.99	29.29
	400	47.90	34.11
	475	53.64	40.47
	550	49.39	41.70
	Average	49.73	36.39
3.2	300	52.73	38.40
	450	52.42	38.68
	600	51.02	35.47
	750	51.39	41.94
	Average	51.89	38.62
4.0	400	41.62	34.40
	600	48.29	34.74
	800	43.46	43.79
	1000	63.84	41.67
	Average	49.30	38.65

(a) (Electrode extension = 25.4 mm; all welds made at 3 kJ/mm).

Table 2B — Relationship between Welding Current and Deposit Area(a)

Electrode Diameter (mm)	Welding Current (A)	Average Deposit Area (mm^2)	
		DCEN	DCEP
2.4	300	71.58	45.05
	400	72.18	58.61
	475	78.05	65.95
	550	89.27	80.72
	Average	77.77	62.58
3.2	300	56.50	39.38
	450	67.10	49.61
	600	70.79	58.19
	750	83.21	74.78
	Average	69.40	55.49
4.0	400	43.33	39.86
	600	56.05	45.12
	800	64.63	67.73
	1000	82.73	66.84
	Average	61.69	54.89

(a) Electrode extension = 76.2 mm; all welds made at 3 kJ/mm.

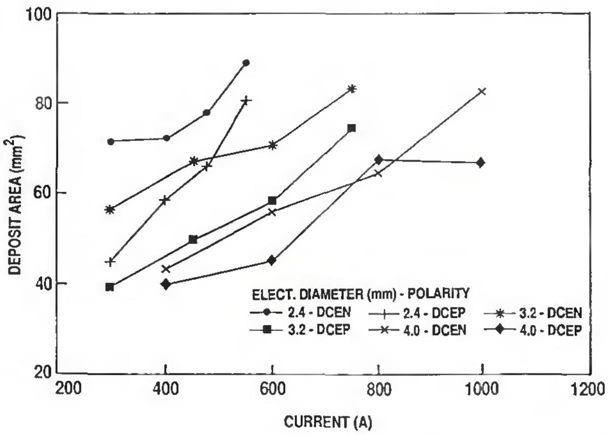

Fig. 3 — The effect of welding current on average deposit area (electrode extension = 76.2 mm, data from Table 2B).

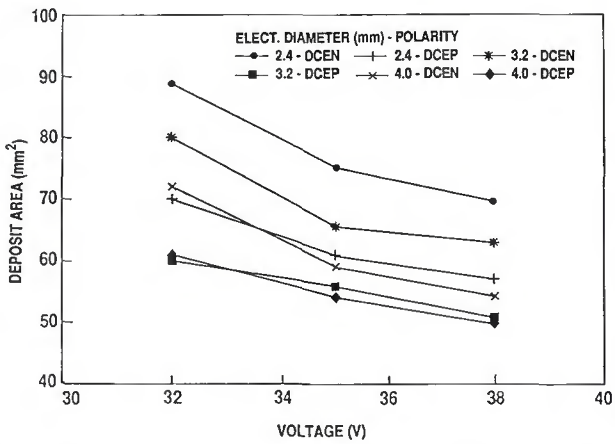

Fig. 4 — The effect of welding voltage on average deposit area (electrode extension = 76.2 mm, data from Table 3B).

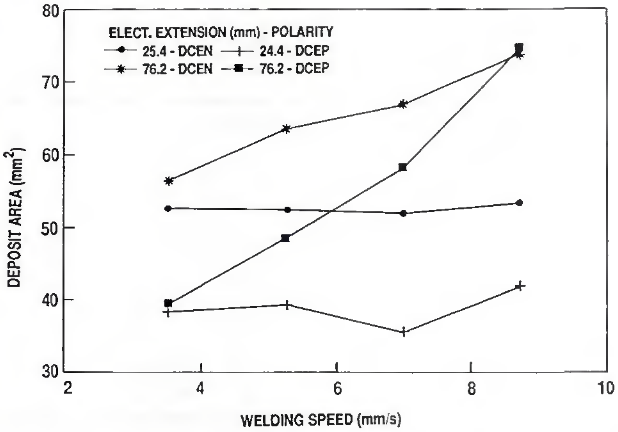

Fig. 5 — The effect of welding speed on deposit area (electrode diameter = 3.2 mm, data from Table 4A).

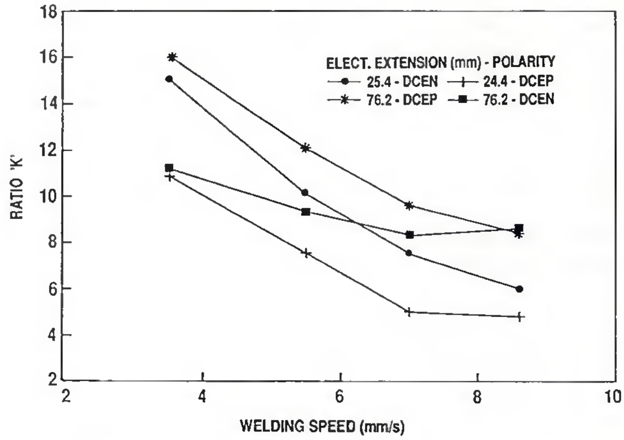

Fig. 6 — The effect of welding speed on ratio K (electrode diameter = 3.2 mm, data from Table 7A).

Table 3A — Relationship between Welding Current and Deposit Area(a)

Electrode Diameter (mm)	Welding Voltage (V)	Average Deposit Area (mm^2) DCEN	DCEP
2.4	32	53.91	45.24
	35	51.56	31.40
	38	43.92	31.68
	Average	49.80	36.17
3.2	32	54.31	43.48
	35	53.32	36.21
	38	49.50	36.48
	Average	52.38	38.72
4.0	32	48.93	44.17
	35	55.18	35.95
	38	44.52	35.84
	Average	49.54	38.65

(a) Electrode extension = 25.4 mm; all welds made at 3 kJ/mm.

Table 3B — Relationship between Welding Current and Deposit Area(a)

Electrode Diameter (mm)	Welding Voltage (V)	Average Deposit Area (mm^2) DCEN	DCEP
2.4	32	88.83	70.02
	35	75.00	60.81
	38	69.48	56.92
	Average	77.77	62.58
3.2	32	80.08	60.13
	35	65.45	55.75
	38	62.79	50.65
	Average	69.44	55.51
4.0	32	72.07	60.96
	35	58.90	54.08
	38	54.09	49.63
	Average	61.69	54.81

(a) Electrode extension = 76.2 mm; all welds made at 3 kJ/mm.

Table 4A — Relationship between Welding Speed and Average Deposit Area(a)

Welding Current (A)	Welding Speed (mm/s)	Average Deposit Area (mm^2) L = 25.4 mm DCEN	DCEP	L = 76.2 mm DCEN	DCEP
300	3.22	54.06	46.24	63.38	35.23
	3.52	48.46	35.75	51.19	42.05
	3.81	55.68	33.24	54.62	40.86
Average	3.51	52.73	38.41	56.50	39.38
450	4.78	54.05	37.55	66.92	53.46
	5.25	52.48	35.96	62.50	49.76
	5.72	50.72	44.49	61.31	42.48
Average	5.25	52.41	39.33	63.58	48.57
600	6.39	57.01	38.51	76.12	64.28
	6.99	54.21	35.12	67.92	56.85
	7.62	44.90	32.77	56.55	53.45
Average	7.00	52.04	35.47	66.86	58.19
750	8.00	52.35	48.15	83.94	87.54
	8.76	58.12	39.14	71.70	74.34
	9.48	46.70	37.38	65.70	62.46
Average	8.75	52.39	41.76	73.78	74.78

(a) Electrode diameter = 3.2 mm; all welds made at 3 kJ/mm.

nential indices of 0.42 and 0.25 for the variables I and S, respectively.

The different emphasis suggested in the above-mentioned equations may also be due to the fact that more data were obtained for the positive electrode polarity situation. In addition, all welds were deposited with a constant heat input, which made it necessary to increase the speed whenever the current or voltage was increased.

The Effect of Ratio K

In order to investigate the different behaviors of welding speed (S) in Equations 1 and 2, further analyses were carried out. Table 7A is a tabulation of a ratio, K, obtained by dividing the deposit area by the corresponding welding speed, against welding speed, for an electrode diameter of 3.2 mm. Figure 6 is a graphical representation of the effect of welding speed on ratio K for the same electrode diameter. Although the significance of ratio K has not been determined, it is interesting to note from Table 7A and Fig. 6 that for both DCEN and DCEP and both electrode extensions of 25.4 and 76.2 mm, there is a decrease in ratio K as the welding speed is increased. Tables 7B and 7C show the ratio K against average welding speed for electrode diameters of 2.4 and 4.0 mm, respectively. It is evident that in all cases ratio K decreases as the welding speed is increased. Hence, the alternate explanation for the linear relationship, Equation 1, is that it supports the above mentioned results that indicate ratio K, which is related to the deposit area, decreases as the welding speed increases.

McGlone and Chadwick's Equation

McGlone and Chadwick (Ref. 3) proposed the following equation to predict the deposit area:

$$A_d = 3.04*I^{1.33}*V^{0.03}*(1 + \text{Tan } A/2)^{0.20}*S^{-0.98}*D^{-0.21} \quad (5)$$

where S = welding speed, mm/min; and A = joint included angle, radian (all other nomenclatures are same as before).

The above relationship can be used for bead-on-plate welds by assuming the joint included angle to be zero. It agrees with Equation 4 only in a general way with respect to welding current, I, and electrode diameter, D. It is apparent from this investigation that electrode extension, L, is a major factor. Since electrode extension is not taken into account in the McGlone and Chadwick equation, it is probably the reason for low value of coefficient of multiple correlation as is given in Table 6. In addition, the McGlone and Chadwick equation is valid only for electrode positive.

Estimation of Deposit Area from Melting Rates

It is also possible to estimate the deposit area from the existing equations for computing the electrode melting rates from process parameters (Refs. 5, 9, 10). However, it has been shown (Ref. 12) that the deposit area obtained in this manner tends to be on the high side since it is assumed that all melted metal ends up in the deposit area without any losses. Computational experience in this investigation confirms this conclusion, and therefore, deposit area relationships obtained in this way are not reported.

Conclusions

1) The present work has shown that process variables influence the weld deposit area.

2) For a constant heat input of 3 kJ/mm, welds made using electrode negative polarity (DCEN), a small-diameter electrode, long electrode extension, low voltage and high welding speed produce large deposit areas.

3) The power source and flux type do not seem to have any significant effect on the weld deposit area.

4) The comparison of correlation coefficients for both linear and curvilinear regression equations correlating weld deposit area to the process variables shows no difference, which indicates that either relationship is equally suitable.

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Table 4B — Relationship between Welding Speed and Average Deposit Area[a]

Welding Current (A)	Welding Speed (mm/s)	Average Deposit Area (mm^2) L = 25.4 mm DCEN	L = 25.4 mm DCEP	L = 76.2 mm DCEN	L = 76.2 mm DCEP
300	3.51	47.99	29.29	71.58	45.05
400	4.67	47.89	34.11	72.18	58.61
475	5.55	53.63	40.47	78.05	65.95
550	6.43	49.39	41.70	89.27	80.72

(a) Electrode diameter = 2.4 mm; all welds made at 3 kJ/mm.

Table 4C — Relationship between Welding Speed and Average Deposit Area

Welding Current (A)	Welding Speed (mm/s)	Average Deposit Area (mm^2) L = 25.4 mm DCEN	L = 25.4 mm DCEP	L = 76.2 mm DCEN	L = 76.2 mm DCEP
400	4.67	41.62	34.40	43.33	39.86
600	7.00	48.29	34.74	56.05	45.12
800	9.33	43.46	43.79	64.43	67.73
1000	11.67	63.84	41.67	82.73	66.84

(a) Electrode diameter = 4.0 mm; all welds made at 3 kJ/mm.

Table 5 — Relationship between Flux Type, Power Source Setting and Average Deposit Area[a]

Welding Machine Mode	Electrode Extension (mm)	Average Deposit Area (mm^2) DCEN Linde 124	DCEN OP 121	DCEP Linde 124	DCEP OP121
Constant Current	25.4	50.54	53.24	37.08	38.85
	76.2	68.10	71.04	54.90	55.27
Constant Voltage	25.4	50.54	—	39.73	38.84
	76.2	70.99	67.49	56.17	55.62

(a) Electrode diameter = 3.2 mm; all welds made at 3 kJ/mm.

Table 6 — Statistical Data for the Multiple Correlation Equations

Equation No.	Correlation Coefficient (R)	S.E.[a] of Estimate	Intercept	S.E.[a] of Intercept	Slope	S.E.[a] of Slope
1	0.76	10.55	0.00	5.06	1.00	0.08
2	0.77	10.38	−5.31	5.33	1.10	0.09
3	0.78	10.04	0.00	3.43	1.00	0.07
4	0.81	9.29	−6.57	3.43	1.16	0.07
5	0.51	13.73	−11.97	8.77	1.77	0.26

(a) S.E. = Standard error.

Table 7A — Relationship between Ratio K and Welding Speed

Welding Current (A)	Welding Speed (mm/s)	Ratio K L = 25.4 mm DCEN	Ratio K L = 25.4 mm DCEP	Ratio K L = 76.2 mm DCEN	Ratio K L = 76.2 mm DCEP
300	3.22	16.78	14.36	19.78	10.94
	3.52	13.77	10.16	14.54	11.95
	3.81	14.61	8.72	14.36	10.72
Average	3.51	15.05	10.94	16.05	11.22
450	4.78	11.31	7.86	14.00	11.18
	5.25	10.00	6.85	11.90	9.48
	5.72	8.87	7.74	10.72	7.43
Average	5.25	10.06	7.49	12.11	9.25
600	6.39	8.92	6.03	11.91	10.06
	6.99	7.75	5.02	9.72	8.13
	7.62	5.89	4.30	7.42	7.01
Average	7.00	7.52	5.07	9.55	8.31
750	8.00	6.54	6.02	10.49	10.94
	8.76	6.63	4.47	8.18	8.49
	9.48	4.93	4.01	6.93	6.59
Average	8.75	6.03	4.77	8.43	8.55

Note: Electrode diameter = 3.2 mm.

Table 7B — Relationship between Ratio K and Welding Speed

Welding Current (A)	Welding Speed (mm/s)	Ratio K L = 25.4 mm DCEN	Ratio K L = 25.4 mm DCEP	Ratio K L = 76.2 mm DCEN	Ratio K L = 76.2 mm DCEP
300	3.51	13.67	8.34	20.39	12.83
400	4.67	10.25	7.30	15.46	12.55
475	5.55	9.66	7.29	14.06	11.88
550	6.43	7.68	6.49	13.88	12.55

Note: Electrode diameter = 2.4 mm.

Table 7C — Relationship between Ratio K and Welding Speed

Welding Current (A)	Welding Speed (mm/s)	Ratio K L = 25.4 mm DCEN	Ratio K L = 25.4 mm DCEP	Ratio K L = 76.2 mm DCEN	Ratio K L = 76.2 mm DCEP
400	4.67	8.91	7.37	9.28	8.54
600	7.00	6.90	4.96	8.01	6.45
800	9.33	4.66	4.69	6.93	7.26
1000	11.67	5.47	3.57	7.09	5.73

Note: Electrode diameter = 4.0 nn,

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