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To study the effect of welding parameters on weld bead geometry in SAW welding process

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ABSTRACT

In the present work, an effort has been made to investigate the effect of welding parameters on bead geometry. Mathematical models were developed by using 2- level half factorial technique to predict the bead geometry within the range of control parameters or operating variables for single wire submerged are welding. The models developed can be employed easily in automatic or robotic welding, in the form of program, for obtaining the desired high quality welds. Current, open circuit voltage, welding speed and nozzle-to-plate distance were taken as welding variables constant. The models were developed from the observed values, with the help of design matrix. It was found that penetration increases significantly with current, decreases with welding speed and remains unaffected by open circuit voltage & nozzle to plate distance. Reinforcement was found to increase with current and decrease with open circuit voltage, welding speed and there is no effect by nozzle to plate distance. Weld bead width was found to increase with open circuit voltage, decrease with welding speed; but 'w' increases with increase in nozzle to plate distance. The adequacies of the models were tested by use of analysis of variance technique and signification of coefficients was tested by student's-test'. The combined and main effect of different parameters involved has been presented in graphical form.

1. Introduction

The bead geometry and shape relationships affect the load carrying capacity and number of passes needed to fill the groove of a joint (Smati 1986). The shape and size of welds are known to exert a major influence on stress distribution during the solidification and shrinkage periods, and also on service performance (Shipulin 1972). The bead geometry is influence by welding parameters such as welding current, arc voltage, welding speed and contact tip-to-work distance as they govern the rate of heat input which is responsible for melting of base metal and filler wire. To have a better control over weld quality and bead geometry it is necessary to establish the relationships between welding parameters and weld bead dimensions. Also, the present trend in fabrication industries is the use of automated welding processes to obtain high production rates and high precision.

To automate a welding process it is essential to establish the relationships between welding parameters and weld bead geometry to predict and control weld bead quality (Jeffus 2004). With the growing emphasis on the use of automated welding systems, submerged arc welding is employed in semiautomatic or automatic mode in industry (Brien 1978). In such automated applications, a precise means of selection of process variables and control of bead shape has become essential because mechanical strength of welds is influenced not only by the composition of the weld metal, but also by the weld bead shape. The acceptable or appropriate weld bead shape depends on factors such as line power which is the heat energy supplied by the arc to the base plate per unit length of weld, welding speed, joint preparation etc. Hence, study and control of weld bead shape is very much essential. To achieve this precise relationship between welding parameters and the bead parameters controlling the bead shape is to be established.

2. Experimentation

2.1. Study the effect of welding parameters

The weld bead geometry obtained was studied. To study the effects of welding parameters on weld bead, following steps were followed.

- Identification of process parameters and finding their working range.
- Development of design matrix using two level half factorial technique.
- Conducting experiments as per design matrix.
- Recording of responses.
- Selection of mathematical model.
- Evaluation of coefficients of the model.
- Development of models.
- Adequacy test of developed models.
- Presentation the effects of welding parameters on bead geometry in graphical form.

2.2 Identification of the process variables and finding their working range

Welding current (I), open circuit voltage (V), travel speed (S) and nozzle-to-plate distance (N), were selected as direct welding parameters affecting bead geometry. The upper limit of a factor was coded as (+1) and lower limit as (-1) or simply (+) and (-) for the ease of recording and processing the data. Selected parameters are given in Table 1.

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2.3 Development of design matrix

The design matrix as shown in Table-2 was developed to conduct eight trial runs (2^{4-1}) = 8 two level half factorial design. The first three columns were generated by standard 2^3 two level full factorial and the forth column was generated by confounding the effect of parameter 4 with the three parameters inter action effects.

2.4 Conducting experiments

Beads on steel plates (SS- 304) having size 12×50×150 mm were deposited as per design matrix using 3.2mm diameter of copper coated mild steel wire in the form of a coil combination with flux . A constant potential transformer-rectifier type power source with a current capacity of 800 amperes at 60% duty cycle and an open circuit voltage of 20-50 volts was used. Electrode positive polarity was used. The experiments were performed in a random manner to avoid any systematic error. The complete set of eight trials was repeated thrice for the sake of determining the variance of parameters and variance of adequacy for the model. The weld samples of appropriate length were removed from the middle of weld plates and polished using standard metallographic procedures and subsequently etched with 2% Nital. Fig. 1 indicates the elements of weld bead geometry.

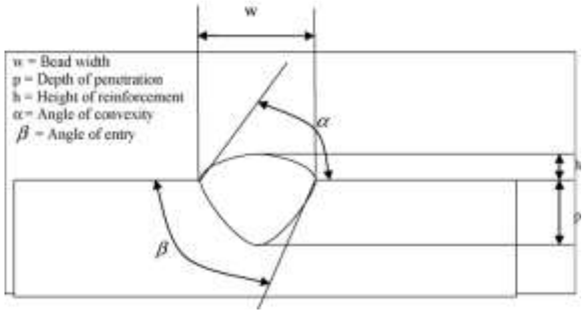

Fig .1 Elements of Bead geometry

2.5 Recording of responses

The plates were cross-sectioned at their mid points to obtain test specimens having 20 mm width as shown in Fig. 2. These specimens were polished and etched with 2% Nital. The weld bead profiles were traced using an optical profile projector at 10 X magnification from where bead dimensions i.e. penetration, bead width and reinforcement were measured and recorded in Table-3.

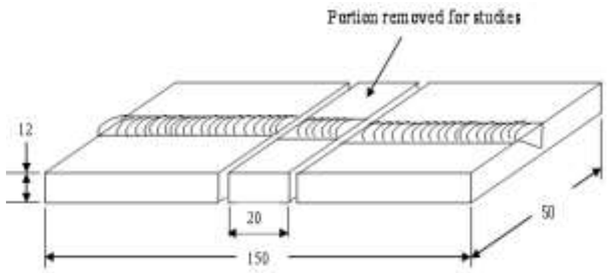

Fig. 2 Specimen Cutting Plan

2.6 Selection of Mathematical Model

The response function representing any of the weld bead dimensions could be expressed as:

Y= f (I, V, S, N) where Y is the response function i.e. weld penetration (p), weld width (w) and reinforcement (h). I, V, S and N are welding current, arc voltage, travel speed and nozzle to plate distance respectively. Assuming a linear relationship in the first instant and taking into account possible two factors interactions only, the above expression could be written as:

$$Y=b_0+b_1I+b_2V+b_3S+b_4N+b_5IV+b_6IS+b_7IN \text{ ----------- } \quad (1)$$

2.7 Evaluation of the coefficients

The regression coefficients of the selected model were calculated using Equation-2:

$$b_j = \frac{\sum_{j=1}^{N} X_{ji} Y_i}{N}, \qquad j = 0, 1 \ldots. K$$

Where

X_{ji} = Value of a factor or interaction in the coded from.

Y_i = Average value of the response parameter.

N = Number of observations.

k = Number of coefficients of the model.

The coefficients of the model and their significance were determined and recorded in Table-4

2.8 Testing significance of the coefficients

The statistical significance of the coefficients was tested by student's "t" test. The value of 't' from the standard table for eight degree of freedom and 95% confidence level is 2.3. The calculated 't' values for the coefficients are given in Table-4. The coefficients having calculated 't' value less than 2.3 are considered to be insignificant and hence dropped in the final models.

2.9 Development of mathematical models

The mathematical models after dropping insignificant coefficients are presented in Table-5

2.10 Assessing adequacy of developed models

The adequacies of the models were tested using the analysis of variance technique (ANOVA). According to this technique, if the calculated value of the 'F' ratio of the model exceeds the standard tabulated value of the 'F' ratio for a desired level of confidence (say 95%). The model may be considered adequate within the considered imit. The results of ANOVA are presented in Table-6.

3. Result and Discussion:-

3.1 Direct effects of parameters

Relationship between p, w, h, WPSF and welding current have been shown in figure – (3).

It is clear from that figure' p' and 'h' increased with an increase in welding current. Increased current increases heat input which in turn increases the amount of `molten base metal causing increase in penetration as well as bead width. Increase in welding current also increase in penetration .But at the same time 'w' and WPSF decreases with increases in welding current.

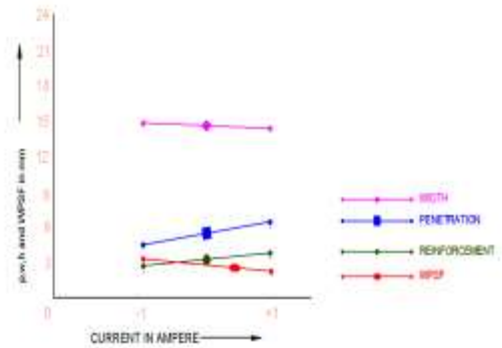

Figure – (3) Effect of welding current on Bead Geometry

Figure -4 indicates the effect of travel speed (S) on penetration, width, reinforcement height (h) and WPSF, WRFF.It is clear from figure that w,h and p decreases with increase of travel speed (S) but there is no effect of travel speed on WPSF and WRFF.

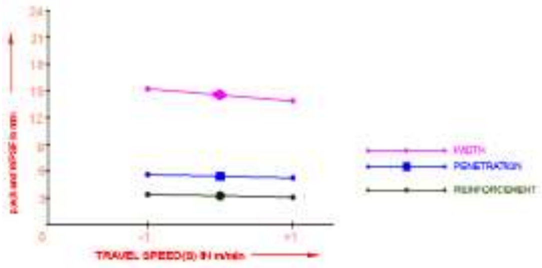

Figure -4 Effect of travel speed on weld bead geometry

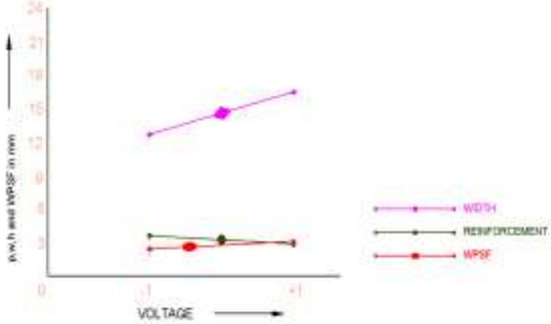

Figure -5 Effect of voltage on weld bead geometry

Figure -5 indicates the effect of welding voltage on, weld penetration, bead width, reinforcement height and WPSF .It is clear from the figure that w ,and WPSF increase with increase in voltage, but reinforcement height is slightly decreases .There is no effect of voltage on penetration and WRFF increases with increase in voltage. As travel Figure -6 indicates the effect of nozzle to tip distance (N) on p, w, h, WPSF, WRFF. It is clear from figure that w, WPSF and WRFF increases with increase of nozzle to tip distance (N).But there is no effect of nozzle to tip distance (N) on weld bead width, penetration and reinforcement.

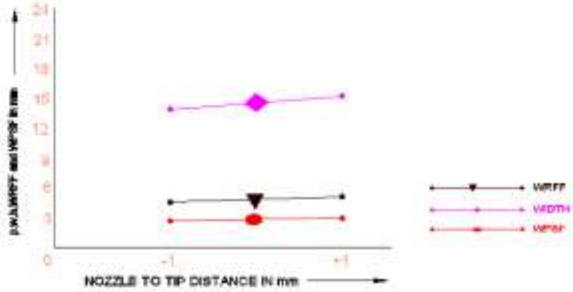

Figure -6 Effect of nozzle to tip distance on weld bead geometry.

3.2 Interactive Effects

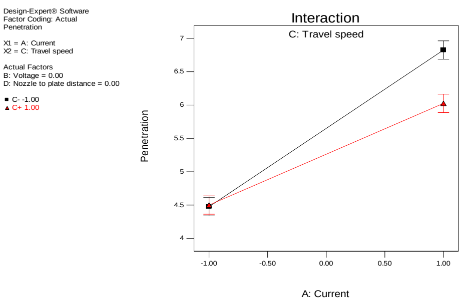

Figure -7 Interactive Effects welding current and travel speed on penetration

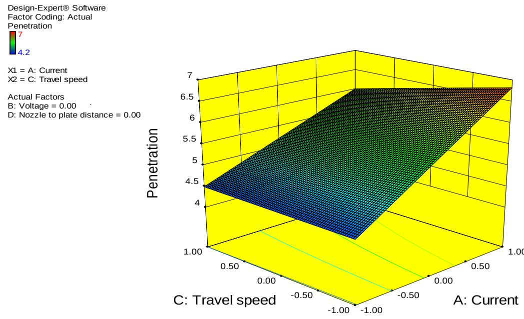

Figure – 8 Response surface due to interactive effect of welding current and travel speed on penetration

Figure -7 Shows the interaction effect of welding current and travel speed on penetration .It is clear from the figure that penetration increases with increase in welding current at any travel speed but the rate of increase is higher at low travel speed. Response surface due to interactive effect of welding current and travel speed on penetration is shown in Figure -8.

Figure -9 Shows the interaction effect of welding current and voltage on reinforcement. It is clear from figure that reinforcement (h) increases with increase in welding current (I), but decreases with increase in the welding voltage .These effects are due to' I 'having a positive effect but 'V' having a negative effect on' h'.Thus the increasing trend of 'h' with increase in 'I' decreases with increase in'V '.The interactive and response surface graph shown in Figure -9 & Figure- 10, this graph also shows the same trend in which maximum value of 'h' is obtained when 'I' is at its +1 level with 'V'is at its - 1 level.

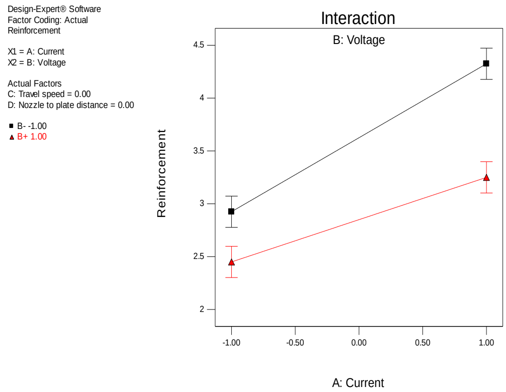

Figure -9 Interactive Effects of welding current and voltage on reinforcement

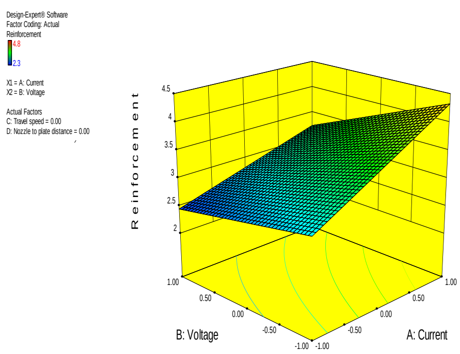

Figure -10 Response surface due to interactive effect of welding current and voltage on reinforcement

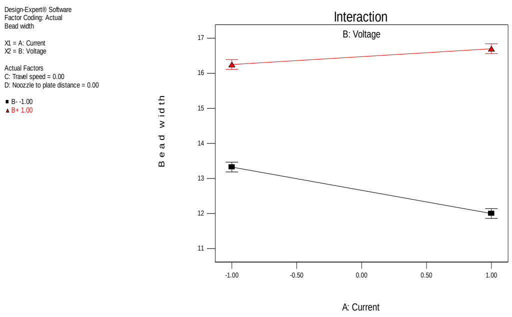

Figure -11 Interactive Effects of welding current and voltage on bead width

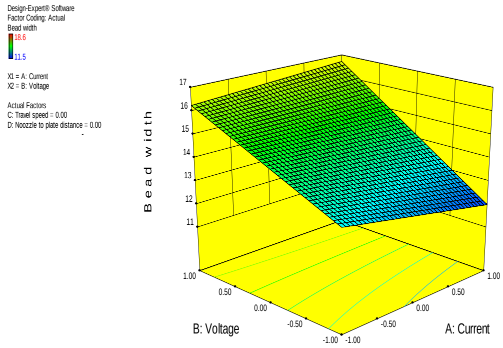

Figure -12 Response surface due to interactive effect of welding current and voltage on bead width

Interactive effect of welding current and arc voltage on bead width has been displayed in figure- (11). It is observed from the figure that bead width (W) increases with increase in 'V'. But the effect of current on bead width is less, the effect of current is mainly increase the penetration (p) and reinforcement(h).When we increase the current and decrease the voltage the value of bead width(W) is minimum and when we increase the voltage and current the value of bead width is maximum but when we decrease the current and increase the voltage the value of bead width is slightly lower than maximum value of bead width(W).So finally we get the effect of current on weld bead is very less ,the effect of current is mainly on penetration and reinforcement. Response surface due to interactive effect of welding current and voltage on bead width shown in figure -12.

4. Conclusion

The following conclusions were arrived at from the above investigations.

1. The two level half factorial technique can be employed easily for developing mathematical models for predicting weld bead geometry within the workable region of control parameters in the SAW of steel plates.
2. Interactive effect of two different parameters on weld bead geometry and response surface due to interactive effect of two different parameters on weld bead geometry is shown by graph.
3. As the current increases, p, h increases but WPSF decreases and 'w 'also slightly decreases.
4. As travel speed(s) in m/min increases then w, h and p decreases but there is no effect of travel speed(s) on WPSF on WRFF.
5. As voltage (v) increases then w, WPSF and WRFF increases and but reinforcement height (h) is slightly decreases. There is no effect of voltage on penetration (p).
6. As nozzle to tip distance (N) increases the w, WPSF and WRFF increases but there is no effect of nozzle to tip distance on' p' and 'h'.

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Table 1: Welding Parameters and their Limits

Parameters	Unit	Symbol	Limits Low (-1)	Limits High (+1)
Welding current	Amp	I	250	450
Arc voltage	Volt	V	28	32
Travel speed	m/min	S	0.45	0.55
Nozzle to Plate distance	mm	N	20	25

Table 2. Design Matrix

S.No	I 1	V 2	S 3	N 4=123
1	+	+	+	+
2	-	+	+	-
3	+	-	+	-
4	-	-	+	+
5	+	+	-	-
6	-	+	-	+
7	+	-	-	+
8	-	-	-	-

Table 3: Observed Values of Bead Geometry

Trial No.	Penetration (mm)		Bead width (mm)		Reinforcement (mm)		WPSF		WRFF	
	1	2	1	2	1	2	1	2	1	2
1	5.9	6.1	16.3	16.1	3	3.1	2.76	2.63	5.45	5.19
2	4.5	4.7	14	14	2.7	2.3	3.11	2.97	5.18	6.08
3	6.1	6	12.5	12.2	4	4	2.04	2.03	3.12	3.05
4	4.5	4.3	13	13.1	2.6	2.9	2.88	3.04	5	4.51
5	7.0	7.0	17.1	17.3	3.5	3.4	2.44	2.47	4.88	5.08
6	4.2	4.6	18.4	18.6	2.3	2.5	4.38	4.04	8	7.44
7	6.8	6.5	11.5	11.8	4.8	4.5	1.69	1.81	2.39	2.62
8	4.6	4.5	13.4	13.8	3.2	3	2.91	3.06	4.18	4.6

Table -4 Coefficients Model and of their significance

Parameter	Coefficients	b_0	b_1 (I)	b_2 (V)	b_3 (S)	b_4 (N)	b_5 (IV)	b_6 (IS)	b_7 (VS)
Penetration	Value	5.45	0.968	0.0437	-0.193	-0.0937	0.0312	-0.206	-0.006
	't' Value	98.84	17.55	0.7926	3.51	1.69	0.566	3.73	0.1132
	Significant	Yes	Yes	No	Yes	No	No	Yes	No
Bead width	Value	14.56	-0.218	1.906	-0.668	0.281	0.443	0.593	-0.706
	't' Value	240.44	3.61	31.46	11.03	2.203	7.32	9.79	11.65
	Significant	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes
Reinforcement	Value	3.23	0.55	-0.387	-0.162	-0.025	-0.15	-0.1	0.087
	't' Value	55.09	9.38	6.60	2.77	0.426	2.55	1.70	1.49
	Significant	Yes	Yes	Yes	Yes	No	Yes	No	No
WPSF	Value	2.76	-0.533	0.333	-0.083	0.138	0.0062	0.213	-0.148
	't' Value	67.31	13.01	8.13	2.04	3.38	0.152	5.21	3.62
	Significant	Yes	Yes	Yes	No	Yes	No	Yes	Yes
WRFF	Value	4.79	-0.825	1.115	-0.101	0.276	0.063	0.330	-0.335
	't' Value	41.53	7.14	9.66	0.88	2.39	0.54	2.86	2.90
	Significant	Yes	Yes	Yes	No	Yes	No	Yes	Yes

Table 5: Developed Models

S.No	Bead Geometry	Developed model
1.	Penetration	5.45 + 0.968(I) – 0.193(S) – 0.206(IS).
2.	Bead Width	14.56 - 0.2187(I) + 1.9062(V) – 0.6687(S) + 0.4437(IV) +0.5937(IS) – 0.7062(IN).
3.	Reinforcement	3.23 + 0.55(I) – 0.3875 (V) – 0.1625(S) – 0.15(VI).
4.	Shape Factor (WPSF)	2.76 – 0.533(I) + 0.333(V) + 0.138(N) + 0.213(IS) – 0.148(IN).
5.	Form Factor (WRFF)	4.79 – 0.825 (I) + 1.115 (V) + 0.276 (N) + 0.330(IS) – 0.335(IN).

Table 6: Analysis of Variance

Optimization Parameter	Degree of freedom		Variance of optimization parameter S_y^2	Standard deviation of coefficient S_{bj}	Variance of adequacy S_{ad}^2	F-Ratio of model $F_m = \frac{S_{ad}^2}{S_y^2}$	F-Ratio from table	Model whether adequate $F_m < F_t$
	S_y^2	S_{ad}^2						
P	8	3	0.024375	0.055198	0.0248	1.02	4.12	Yes
W	8	3	0.029375	0.06059	0.061366	2.08	4.12	Yes
h	8	3	0.0275	0.05863	0.06356	2.31	4.12	Yes
WPSF	8	3	0.01345	0.041003	0.04113	3.05	4.12	Yes
WRFF	8	3	0.10668	0.11548	0.1366	1.28	4.12	Yes

Nomenclature

Symbol	Meaning	Unit
p	Penetration	mm
w	Bead width	mm
h	Reinforcement	mm
WRFF	Weld reinforcement form factor	Dimension less
WPSF	Weld penetration shape factor	Dimension less
I	Welding current	ampere
V	Arc voltage	voltage
S	Travel speed	m/min
N	Nozzle to plate distance	mm