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Research Paper

ANALYSIS OF WELD BEAD GEOMETRY IN SAW AND MODELING USING CCD

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Submerged Arc Welding (SAW) is a common arc welding process which is used to join thick and heavy sections. The basic characteristics of this process are high deposition rate, ability to weld thick sections with ease and longer weld runs. The study of weld bead geometry is important, as it determine the stress carrying capacity of a weld. For the same reason, this paper highlights the analysis and study of process parameters: arc Voltage, welding current, travel speed and electrode extension, on the bead geometry response such as, bead height, bead width and bead penetration. Design Expert 8.0 with 4 factors, 5 levels, rotatable Central Composite Design. was used to develop relationship for predicting weld bead geometry, which enables to quantify the direct and interaction effects. Mathematical models prepared for the submerged arc welding of 16mm thick mild steel by using response surface methodology which co relate the process variables with the bead geometry characteristics then the adequacy of developed models were checked by using ANOVA technique. Using p-test, the significant terms were selected from the adequate models. The finally proposed models contains only the significant terms. Using the model, Graph drawn which shows the main and interaction effects of the process variables on weld bead geometry. The developed models can be used for prediction of important weld bead dimensions and control of the weld bead quality by selecting appropriate process parameter value.

Keywords: Submerged arc welding, Central composite design, Response surface methodology, Arc voltage, Weld bead geometry

INTRODUCTION

The Submerged Arc Welding (SAW) process is widely used in fabrication of pressure vessels, marine vessels, pipelines and offshore structures, this is due to the requirement of lower welder skill, good surface

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appearance, invisible arc, and, high deposition rate and deep penetration, In the conventional submerged arc welding process, due to the automatic process and the invisibility of arc, higher current (upto 800 A) can be used. Heat input is used for the higher deposition rate. In submerged arc welding, a theoretical predictions also presented by R S chandel, which gives the effects of current, electrode diameter, electrode extension and electrode polarity on the bead height, bead penetration, bead width, and melting rate. They concluded that the melting rate in SAW can be increased by using high current, a smaller diameter electrode, using straight polarity and using a longer electrode extension. The current level, and polarity affect the melting rate, bead height, bead width, and bead penetration. There is negligible change in bead height, bead width and bead penetration, when current level increased by using a smaller electrode (Chandel *et al.*, 1997). A mathematical model and contour graph is developed which used the response surface methodology which relate input parameter such as arc voltage, welding speed, electrode extension, wire feed rate to the bead geometry characteristics namely, bead height, bead width, bead penetration in SAW of pipes. A bead penetration increases and other bead responses decreases, when the nozzle to plate distance increased (Gunaraj and Murugan, 1999a). A study done on the ASTM A36 steel plate on 19 mm thickness by using positive and negative electrode by Yang *et at.* (1999) he used the linear- regression equations for computing the weld bead characteristics such as melting rate, Bead penetration, deposit area, bead height and bead width from SAW process variables namely, nozzle to plate distance, welding voltage, welding speed, and electrode diameter. He concluded that, the various features of the SAW process can be computed by the linear regression equations which is equally useful (Yang *et al.*, 1999). Another study done on the two joint areas which is bead on joint and bead on plate carried out by using RSM which developed a mathematical model which shows the effect of SAW parameters on the heat input and the areas of HAZ for low- carbon steel. From the study they also concluded that the area of the HAZ is greater for bead on plate than that for bead on joint, for the same heat input. They found that ,same trend is followed by bead on plate and bead on joint when effect of SAW parameter studied on the HAZ area (Gunaraj and Murugan, 1999b). The effect of welding parameters (welding current, arc voltage, welding speed) in SAW investigated by a proposed model using RSM at two testing temp. Of 50 centigrade and 27 centigrade on the impact strength. The purpose of the research was to predict and optimize the impact strength by using process parameter. From the above result , this can be observed voltage has no effect on impact strength whereas welding current has the most significant factor associated with impact strength then the welding speed. Using the above listed welding conditions a range of acceptable impact strength can be investigated which improve the process productivity (Benyounis *et al.*, 2004). According to Murugan and Gunaraj, the main factors affecting the bead geometry are arc voltage, wire feed rate, welding speed and electrode extension, this conclusion done by using five level four factor CCD design matrix, the purpose was to predict and control the weld bead geometry and shape relationship in submerged arc welding of pipes. To predict the three most important dimensions of the weld bead geometry and shape relationship, a mathematical model have been developed using five level factorial techniques for SAW of pipes. Then the adequacy and significance of the developed models have been checked by using f-test and t-test, respectively. From the above test this can be concluded that, wire feed rate had a significant positive effect whereas welding speed had a negative effect on most of the bead parameter. As wire feed rate was increased by –2 to +2 limit, penetration increased by 1.3 mm and penetration decrease by about 1mm as welding speed was increased from –2 to +2 limit. Arc voltage had a positive effect on bead width but had negative effect on penetration and bead height. As welding speed had negative effect on most of the bead parameter, but wire feed rate had a positive effect on be ad parameter. As wire feed rate increases, penetration, width, penetration size factor and reinforcement form factor also increases for all values of welding speed (Muruganan and Gunaraj, 2005). Another work is carried out for EWB of austenitic stainless steel by applying RSM, which establish the relationship between performance characteristics such as weld-depth, weld-width, and thermal efficiency and its influencing characteristics namely, beam power, welding velocity, focus position and distance to the sample surface. To choose the focus position at a condition of maximum thermal efficiency and welding depth, new statistical approaches were proposed (Koleva, 2005). Another investigation carried out to check the effect of laser welding parameters (laser power, welding speed and focal point position) on four responses (heat input, penetration, bead width and HAZ width) in CO_2 laser butt- welding of medium carbon steel plates of 5mm thick by applying RSM. They found that laser power has a positive effect on all the responses; heat input play a important role in weld-bead parameter and welding has a negative effect (Benyounis *et al.*, 2005).

EXPERIMENTATION

Following are the steps which are carried out by research work for fulfillment of the desired aim.

- Selection of the important process control variables.
- Identification of the useful limits of the welding parameters,viz. voltage (V), current (A), travel speed (S), and electrode extension (N).
- Developing the design matrix.
- On the basis of design matrix, conducting the experiment.
- Recording the responses viz., penetration (P), bead width (w) and reinforcement height (H).
- Development of mathematical models.
- Calculating the co-efficient of polynomial.
- Final form of the proposed models.
- Presenting the main effects and the significant interaction between different parameters in graphical forms.
- Analysis of microstructure of the welded material.
- Analysis of results and conclusion.

Selection of Important Process Control Variables

On the basis of quality of weld bead geometry, ease of control and capability of being maintained at the desired level, four independently controllable process parameters were identified namely, the arc voltage (V); the welding current (A); the travel speed (S) and electrode extension (N).the weld bead geometry parameters chosen for this study were bead height (H), bead width (W) and bead penetration (P).

Identification of Useful Limits of Welding Parameters

By varying one of the process parameters at a time while keeping the rest of them at constant value, trials run were conducted (Murugan and Parmar, 1994). The working range was fixed on the basis of inspecting smooth appearance of weld bead and absence of visible defects. The upper and lower limits were coded as +2 and –2, respectively. The coded values for intermediate values can be calculated from the formula:

$X_i = 2[2X–(X_{max} + X_{min})/(X_{max} – X_{min})$, where, X_i is the required coded value of a variable X, when X is any value of the variable from X_{min} to X_{max}; X_{max} and X_{min} are the maximum and minimum levels of the variables. The selected process parameters and their upper and lower limits together with notations and units are given in Table 1. Developing the design matrix consisting of 31 sets of coded conditions was used to carry out the experiment. For the better result, the value of alpha is chosen as 2. The first 16 conditions have been formulated as per 2^4 (two levels and 4 factors) factorial design. These factorial points represent the variance optimal design for a first order or first order plus 2 factor interaction models. The next eight experimental conditions are called as Star points, i.e., keeping one factor at the highest/ lowest level and the remaining factors at middle level. Addition of Star points allow for efficient estimation of pure quadratic terms in case of existence of curvature in the system. To check the repeatability the experimental procedures, the last seven experimental conditions are used known as centre points, i.e., keeping all the factors at the middle level.

Conducting the Experiment as per Design Matrix

The Welding Laboratory of Delhi Technological University were used for conducting the experiments with the following welding set-up:

Machine Model - QSW800, Manufactured by- Quality Engineer (Baroda Pvt. Ltd.)

A/18, Gujarat Estate, Dharamsingh Desai Marg, Chhani Road Baroda-390002.

Table 1: Limits of Process Variable

S. No.	Parameters	Units	Notation	Limits				
				–2	–1	0	+1	+2
1.	Arc Voltage	volt	V	25	28.5	32.5	36	40
2.	Arc Current	ampere	A	300	375	450	525	600
3.	Travel Speed	mm/sec	S	5	8.75	12.5	16.25	20
4.	Electrode Extension	m m	N	25	27.5	30	32.5	35

A 3.2 mm diameter copper coated mild steel wire manufactured by ESAB was used. Test specimens were prepared from 16 mm thickness AISI 1012 Mild steel plate. Dimension of each plate were 200 x 75 x 16 mm and an agglomerated flux was used. To carry out the experiment, welding is done on the plate as per the design matrix to avoid systematic error.

Recording the Responses

Specimens were cut transversely from the middle portion of each welded plate. Then these specimens were polished by rough and fine grades of emery paper and etched with 2% Nital (98% Alcohol + 2% Nitric Acid). And the bead dimensions, viz bead height (H), bead width (W) and bead penetration (P) were measured by tracing the optical profile projector on the weld bead.

DEVELPOMENT OF MATHEMATICAL MODEL

To predict particular weld bead geometry and to establish the Interrelationship between weld process parameters to weld bead response, mathematical models can be proposed as the basis for a control system for the SAW process. The response function representing any of the weld-bead dimensions can be expressed as:

$$Y = f(V, A, S, N)$$

The selected relationship being a second degree response surface, is expressed as follows:

$$Y = b_0 + b_1V + b_2A + b_3S + b_4N + b_{12}VA + b_{13}VS + b_{14}VN + b_{23}AS + b_{24}AN + b_{34}SN + b_{11}V^2 + b_{22}A^2 + b_{33}S^2 + b_{44}N_{44}2$$

Table 2: Recording of Responses

Weld No.	Input Parameters				Responses		
	V	A	S	N	Bead Height (H)	Bead Width (W)	Bead Penetration (P)
1	–1	–1	–1	–1	1.79	10.35	4.12
2	+1	–1	–1	–1	2.99	12.41	5.52
3	–1	+1	–1	–1	1.99	9.56	5.92
4	+1	+1	–1	–1	3.16	13.0	6.89
5	–1	–1	+1	–1	2.01	10.2	3.82
6	+1	–1	+1	–1	1.99	9.20	4.32
7	–1	+1	+1	–1	2.89	9.07	5.45
8	+1	+1	+1	–1	2.51	9.02	6.74
9	–1	–1	–1	+1	1.94	9.37	3.24
10	+1	–1	–1	+1	1.97	11.12	3.14
11	–1	+1	–1	+1	4.40	9.18	7.37
12	+1	+1	–1	+1	2.94	12.09	5.41
13	–1	–1	+1	+1	1.56	8.18	2.60
14	+1	–1	+1	+1	2.12	9.71	2.01
15	–1	+1	+1	+1	2.54	8.08	6.47
16	+1	+1	+1	+1	2.50	10.12	4.39

Table 2 (Cont.)

Weld No.	Input Parameters				Responses		
	V	A	S	N	Bead Height (H)	Bead Width (W)	Bead Penetration (P)
17	–2	0	0	0	3.50	8.72	4.79
18	+2	0	0	0	2.49	11.32	5.40
19	0	–2	0	0	1.61	8.13	2.65
20	0	+2	0	0	3.51	9.24	5.71
21	0	0	–2	0	3.27	13.9	4.89
22	0	0	+2	0	2.96	9.01	3.91
23	0	0	0	–2	1.93	10.23	4.84
24	0	0	0	+2	2.38	9.97	3.31
25	0	0	0	0	2.39	10.41	3.69
26	0	0	0	0	2.93	11.25	3.89
27	0	0	0	0	2..01	10.93	4.12
28	0	0	0	0	1.96	11.89	4.02
29	0	0	0	0	1.59	11.49	3.89
30	0	0	0	0	1.94	11.39	4.45
31	0	0	0	0	1.81	10.32	3.69

EVALUATION OF COEFFICIENT OF MODELS

The values of the co efficient of the response surface were calculated using regression analysis. The calculations of these coefficient for different responses were carried out using Design Expert 8.0. The calculated values are presented in Table 3.

Table 3: Regression Coefficient of Models

S. No.	Coefficient	Reinforcement Height (h)	Width (w)	Penetration (p)
1.	b_0	2.090	11.10	5.110
2.	b_1	–0.039	0.75	–0.117
3.	b_2	0.432	0.08	1.775
4.	b_3	–0.237	–0.97	–0.515
5.	b_4	0.063	–0.23	–0.202
6.	b_{12}	–0.155	0.25	–0.340
7.	b_{13}	–0.050	–0.48	0.101
8.	b_{14}	0.179	0.24	–0.420
9.	b_{23}	–0.064	–0.1	0.063
10.	b_{24}	0.189	0.16	–0.570
11.	b_{34}	–0.126	0.14	0.148

Table 3 (Cont.)

S. No.	Coefficient	Reinforcement Height (h)	Width (w)	Penetration (p)
12.	b_{11}	0.021	–0.280	0.340
13.	b_{22}	0.097	–0.610	0.341
14.	b_{33}	0.110	0.009	0.666
15.	b_{44}	–0.005	–0.250	0.044

TESTING OF MODELS

The models were also tested for some test cases. Five cases were generated, at random, by considering different combinations of the input variables (lying within their respective ranges), and for each combination the outputs were determined experimentally. The results are shown in Table 4. The model-predicted permeability values were compared with their respective experimental values. The results are summarized in Table 4, given below:

DEVELOPMENT OF FINAL MATHEMATICAL MODELS

The final developed models contain the process control variables in coded form.

$$\textit{Bead Height} = 2.09 - 0.039(V) + 0.432(A) - 0.237(S) + 0.063(N) - 0.155(VA) - 0.050(VS) - 0.179(VN) - 0.064(AS) + 0.189(AN) - 0.126(SN) + 0.021(V^2) + 0.097(A^2) + 0.110(S^2) - 0.005(N^2) \quad ...(1)$$

$\textit{Bead Width} = 11.097 + 0.745(V) + 0.075(A) - 0.974(S) - 0.229(N) + 0.251(VA) - 0.48(VS)$

Table 4: Testing of Mathematical Model

Weld No.	V (volt)	A (ampere)	S (mm/sec)	N (mm)		H (mm)	W (mm)	P (mm)
1	28.5	375	8.75	27.5	Actual	1.79	10.35	4.12
					Predicted	1.89	10.64	4.55
					% Error	–5.5	–2.8	–10.43
2	36	375	8.75	27.5	Actual	2.99	12.41	5.52
					Predicted	2.58	12.11	5.62
					% Error	13.71	2.42	–1.81
6	36	375	16.25	27.5	Actual	1.99	9.20	4.32
					Predicted	2.38	9.13	4.37
					% Error	–19.59	0.76	–1.15
11	28.5	525	8.75	32.5	Actual	4.40	9.28	8.78
					Predicted	3.39	9.18	7.37
					% Error	22.50	1.07	16.05
5	28.5	375	16.25	27.5	Actual	2.01	10.21	3.82
					Predicted	1.89	9.58	2.89
					% Error	5.97	6.17	24.34

$+ 0.236(VN) - 0.1(AS) + 0.163(AN) + 0.135(SN) - 0.28(V^2) - 0.61(A^2) + 0.09(S^2) - 0.254(N^2)$ ...(2)

Bead Penetration $= 5.11 - 0.117(V) + 1.775(A) - 0.515(S) - 0.20(N) - 0.34(VA) + 0.101(VS) - 0.42(VN) + 0.063(AS) - 0.57(AN) + 0.148(SN) + 0.34(V^2) + 0.341(A^2) + 0.666(S^2) + 0.044\,(N^2)$ ...(3)

For testing the significance of the coefficient, Design Expert 8.0 were used, which developed a model containing only significant terms. It was observed that the reduced model were better than the full model. The final reduced models containing only significant terms are given below:

Bead Height $= 2.09 + 0.432(A) - 0.23(N) + 0.021(VV)$ ...(4)

Bead Width $= 11.097 + 0.745(V) - 0.974(S) - 0.48(VS) - 0.28(VV) - 0.61(AA) - 0.254(NN)$ ...(5)

Bead Penetration $= 5.11 + 1.775(A) - 0.515(N) + 0.666(SS)$ ...(6)

RESULTS AND DISCUSSION

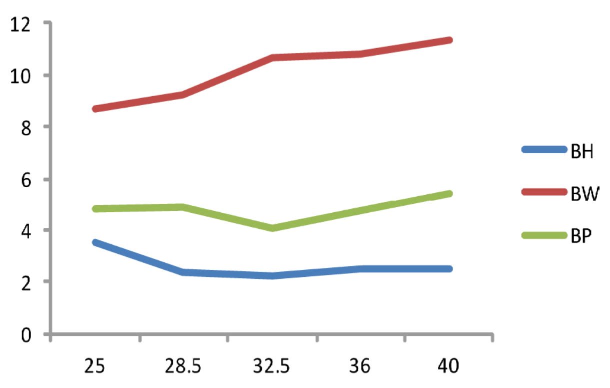
To predict the geometry of weld bead and shape relationships for the range of parameters used in the investigation by substituting their respective values in code form, the mathematical models developed above can be employed. The main and the interaction effects of the process parameters on the bead geometry were computed, based on these developed models and plotted graphically. The general trends between cause and effect shown by the results. By substituting acceptable value of bead geometry with desired accuracy, the value of the control factors can be obtained.

EFFECTS OF WELDING PARAMETER

Effect of Arc Voltage (V) on Bead Parameter

From Figure 1 it is clear that bead width continuously increases as the arc voltage reaches higher levels (40 v). This may be due to the facts that, arc length is increases as arc voltage increased and due to the increased arc length, spreading of arc cone occurs at its base, due to which more melting of work piece surface takes place instead of melting the work piece. This results in wider the bead. Due to this bead width increases as arc voltage increases. A reverse effect can be seen in bead height as voltage increases bead height decreases. An excessive increase in voltage may result in nearly a flat weld bead. Penetration decreases gradually from the lower limit of arc voltage (–2) to its center level (0), then increases for higher a level of arc voltage (+2).

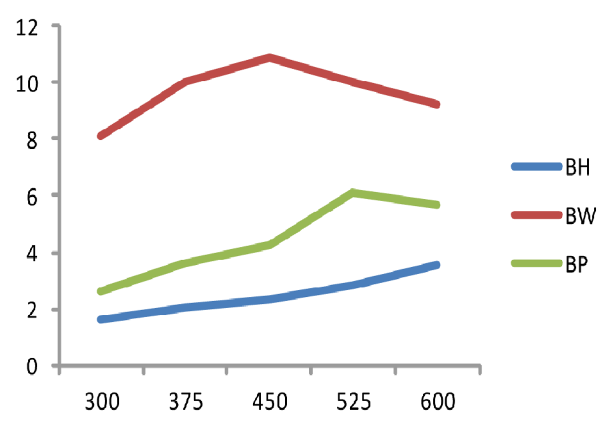
Figure 1: Direct Effect of V on Bead Geometry



Effect of Current (A) on Bead Parameter

From the Figure 2, this can be observed that, bead penetration increases gradually as the value of voltage increases, and at the highest

Figure 2: Direct Effect of A on Bead Geometry

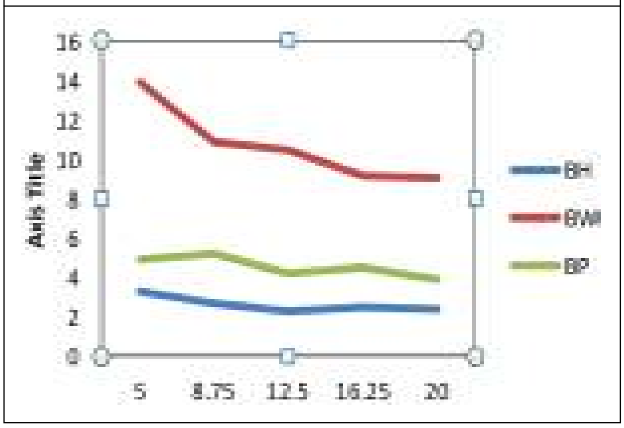


value of voltage, it decreases. A effect can be seen on bead reinforcement height which remains almost constant for rise in current from its lowest level (300A) to centre point level (450A). there is increment in reinforcement height, for higher levels of current. As current increases the temperature and hence the heat content of the droplets increases which results in more heat being transferred to the base metal. Also from the same reason, a deeper penetration can be observed. Also from Figure 2, it can be concluded that, the major portion of the line power goes in increasing the bead width while smaller portions are used in increasing the bead height and penetration when current increases from 300A to 450A. The major portion of the line power is used up in increasing the bead penetration and reinforcement height, while the bead width shows a minor reduction from its peak value of 10.86 at 450A to 10.01 at 575A, at higher levels of current (450A to 575A). This can be concluded from Figure 2, that increment in current value with other variables remaining constant, results in increased depth of penetration, weld width and increased weld bead shape and size at any cross section.

Effect of Travel Speed (S) on Bead Parameter

From Figure 3 it is clear that when travel speed increases, all the bead parameters decrease. This is because of the fact that the line power per unit length of weld bead is reduced and also the welding torch covers more distance per unit time, when the welding torch travels at a greater speed over the base metal. Decreased metal deposition rate per unit length of the bead can be found from the combined effect of lesser line power and faster electrode travel speed. Thus the penetration and the reinforcement height decreases, though the extent of decrease in reinforcement height (from 3.27 mm at 5mm/s to 2.31 mm at 12.5 mm/s) is less appreciable than the decrease in bead penetration (from 5.3 at 6mm/s to 3.24 at 18 mm/s). As the travel speed is increased, bead width decreases steadily. This is due to the reason that with increase in speed the thermal energy decreases which is transmitted to the base plate form the arc or line power per unit of the weld bead and from the same reason less filler material is deposited per unit length of the weld bead resulting in thinner and narrower weld bead. It

Figure 3: Direct Effect of S on Bead Geometry

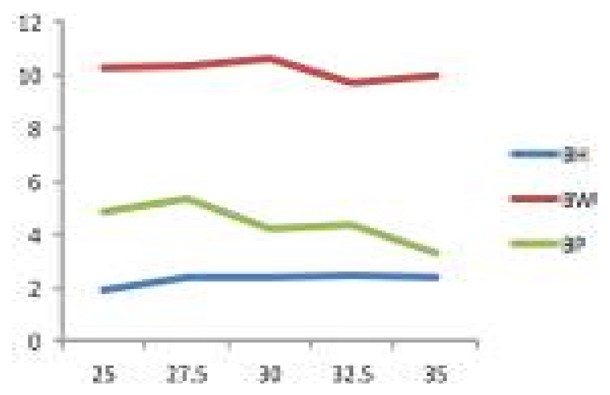


is safe to conclude that weld bead is wider at lower travel speeds, and vice versa. With increase in travel speed the bead becomes flatter.

Effect of Nozzle to Plate Distance

A result can be seen from Figure 4, as the NPD increases, the reinforcement height, welding current and heat input decreases. Due to the reduced heat input the value of reinforcement height and penetration decreases in general with the increase in NPD. When NPD increased from 25 mm to 35 mm, the value of bead width remains practically unaffected. The bead width shows increase in its value at the highest level of NPD, this could be due to the fact that when the NPD is too high, due to the increased arc length the arc cone spreads at its base. Also, at higher values of N the metal fusion rate increases slightly because of the joules heating effect.

Figure 4: Direct Effect of N on Bead Geometry

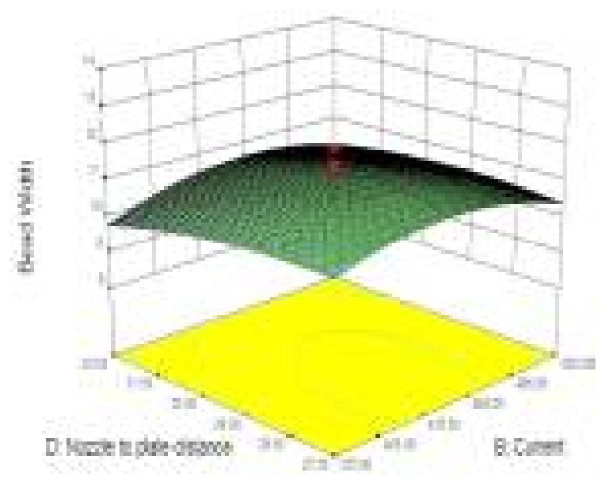


INTERACTION EFFECTS OF PROCESS VARIABLES ON BEAD GEOMETRY

Interaction Effect of A and N on W

From Figure 5, Bead width increases to maximum value and then decreases nearly back to the same value with increase in current for all levels of N. Increase in current basically results in higher melting rate of wire. From Figure 5 we can see that at lower levels of current, i.e., up to 450A the increased melting rate of wire demonstrates itself in the form of increased bead width, while at higher levels of current, i.e., from 450A to 600A, the increased melting rate of wire results in deeper penetration rather than wider bead. For a particular level of current the rate of melting of the wire is constant, but with increase in nozzle-to-plate distance the penetration also increases. This is the reason that the value of bead width is higher at lower values of N for all levels of current and vice versa.

Figure 5: Effect of Current and NPD on Bead Width



Interaction Effect of A and N on H

From Figure 6 it can be observed that the bead height increases with increase in N for all values of current A. Also it can be seen that the increase in the value of the reinforcement height is most pronounced in the case of +2 level of N, i.e., from 1.6 mm at 300 A to 3.51 mm at 600A. This is due to the fact that upon increasing the current the power per unit length

Figure 6: Effect of Current and NPD on Bead Height

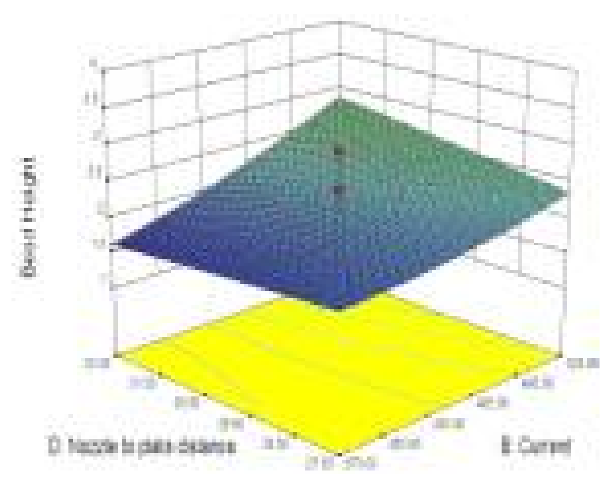
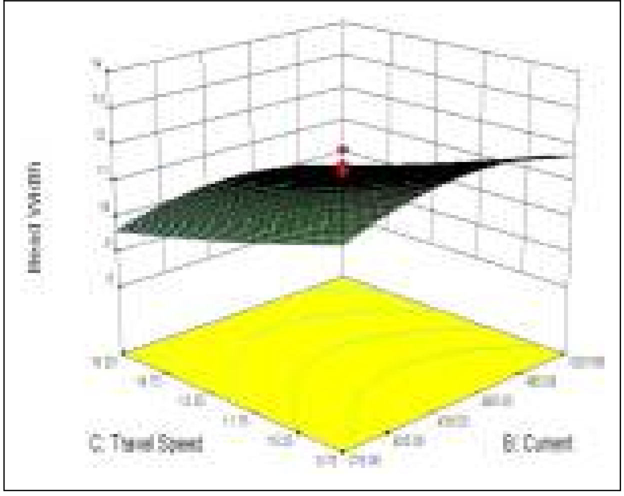


Figure 7: Effect of Current and Travel Speed



of the weld bead and current density both increases, causing larger volume of base material to melt, thus increasing the reinforcement height. This trend is also supported by the positive value of co-efficient of A in the direct effect of reinforcement height. With increase in N the momentum of the molten metal droplet from the wire is reduced, so their tendency to penetrate into the base metal is subsequently reduced as well. This explains the maximum increase in the value of reinforcement height for the +2 level of N.

Interaction Effect of V and S on W

Form Figure 7 we can observe that with increase in arc voltage the bead width increase for all levels of arc voltage when the travel speed is low, i.e., 5 mm/s and 12 mm/s, while the opposite trend is observed for higher speeds. Travel speed and arc voltage both have conflicting effects on the bead width. We already discussed that bead width decreases steadily as the travel speed is increased. This is due to the fact that with increase in speed the thermal energy transmitted to the base plate form the arc or line power per unit of the weld bead decreases. Thus less filler material is deposited per unit length of the weld bead resulting in thinner and narrower weld bead. While upon increasing arc voltage the bead width increases steadily due to widening of arc cone at its base. For lower values of speed the effect of spreading of arc cone at its base dominates negative effect of travel speed on the bead width, thus the bead width continues increasing throughout all the levels of voltage. But when the speed is increased beyond its 0th level, i.e., for 12 mm/s, 15 mm/s and 18 mm/s, the negative effect of increased travel speed on the bead width dominates over the effect of increasing arc voltage, thus the bead width decreases beyond 29 V for the higher values of travel speed.

Interaction Effect of V and A on W

From Figure 8, the value of bead width increases continuously from –2 to 0 levels of arc voltage for all values of current. After the 0 level, the value of bead width decreases with further increase of current for –1 level of current, i.e., 375A, but the decrease in arc voltage is very insignificant from 10.66 mm at

Figure 8: Effect of Current and Voltage on Bead Width

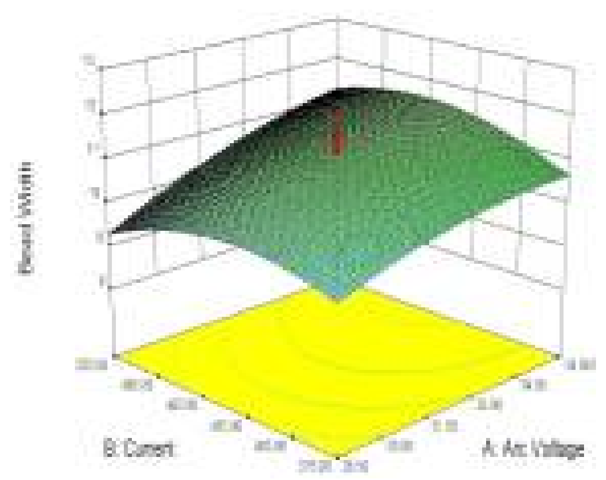
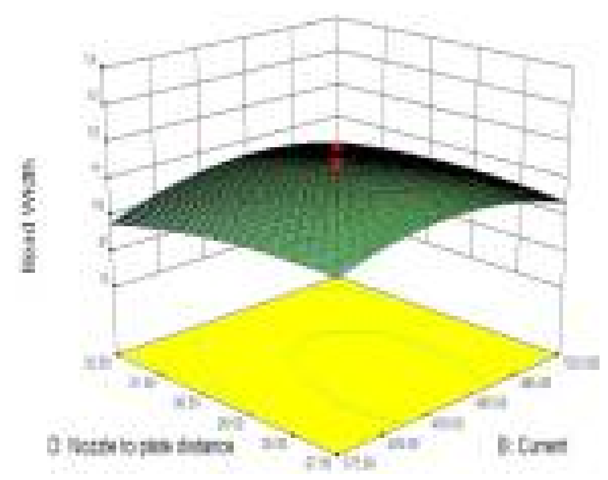


Figure 9: Effect of arc Voltage and NPD on Bead Width



32.5 volts to 11.32 mm at 40 volts. While for higher values of current the bead width continue to increase with increase of arc voltage. This may be attributed to the facts that increase in voltage results in increase in arc length and spreading of arc cone at its base, which results in more melting of work piece surface instead of melting the work piece. Also with increase in current the melting rate of wire increases and due to spreading of arc cone at its base, ultimately a wider bead results from the combined effect of increasing the arc voltage and current.

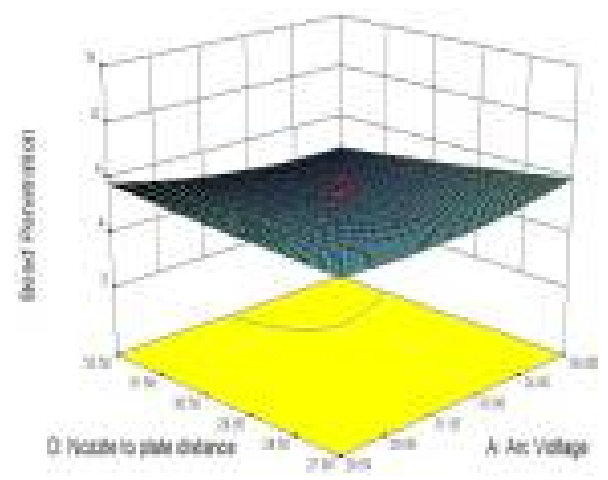
Interaction Effect of V and N on W

It can be seen from Figure 9 that the bead width increases with increase in arc voltage for all levels of N. for lower levels of N the value of bead width reaches a maximum at 0 level of arc voltage (32.5 V), followed by a decrease in the subsequent levels. The decrease in bead width with increase in arc voltage could be attributed to the lower nozzle-to-plate distance, which prevents the spreading of arc cone at its base. While a steady increase in bead width is observed for higher values of N, throughout all the levels of arc voltage. Highest value of bead width 11.32 mm, is observed for the highest level of arc voltage and nozzle-to-plate distance, i.e., 40 V and 34 mm. this could be attributed to the fact that when the NPD is too high, due to the increased arc length the arc cone spreads at its base. Also, the metal fusion rate increases slightly at higher values of N because of the joules heating effect.

Interaction Effect of V and N on P

As can be seen from Figure 10, for lower levels of N, i.e., from –2 to 0 levels (20 mm to 27 mm), the bead penetration starts from a lower value and increases steadily with increase in the levels of arc voltage. But at higher levels of NPD, the value of bead penetration starts from a high value and decreases with the increase in arc voltage. With increase in arc voltage the arc gets spread out at its base, this results in lesser penetration for high levels of N. At higher levels of N the spreading out of arc decreases the momentum of the molten metal droplets, this resulting in lesser penetration. When the N is at low level the effect of spreading out of

Figure 10: Effect of Arc Voltage and NPD on Bead Penetration

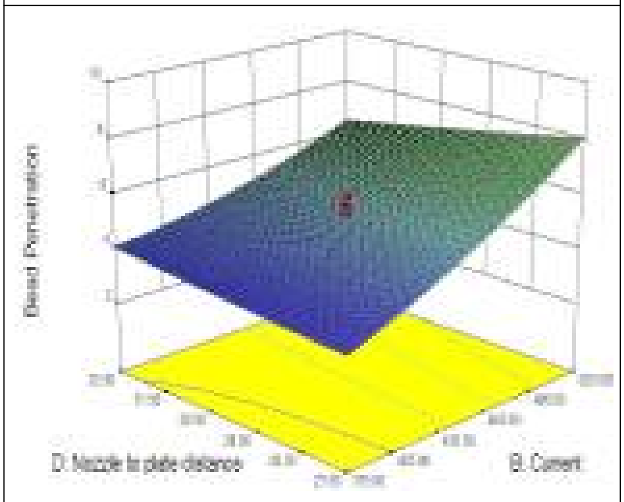


arc cone at its base is dominated by the increased melting rate of the wire, thus the bead penetration value shows steady increase with increase in arc voltage.

Interaction Wffect of A and N on P

From Figure 11, bead penetration increases steadily for all values of N throughout all the levels of current. As discussed earlier; increasing the current results in an increase of both the power per unit length of the weld bead

Figure 11: Effect of Current and NPD on Bead Penetration



and current density, hence causing larger volume of base material to melt. As current increases the temperature and hence the heat content of the droplets increases, which results in more heat being transferred to the base metal. Increase in current also results in increased momentum of the droplets which on striking the weld pool causes deeper penetration. As a result deeper penetration is observed. The effect of increase in momentum is augmented with the increase in N, which explains the higher value of bead penetration at higher levels of current and nozzle-to-plate distance.

CONCLUSION

- A four factor, five level CCD technique can be used to study the effect of weld parameters on bead geometry in SAW.
- The mathematical models developed can be used for successful prediction of bead geometry features within the pre decided range of the parameters.
- The welding current has appreciable positive effect on all the bead parameters.
- Welding speed has negative effect on the bead parameters.
- The momentum of incoming metal droplets Increases when Nozzle-to-plate distance increased, which increases the penetration but reduces the bead width.
- Increased arc voltage results in spreading out of arc cone at its base and leads to increase in bead width but lesser penetration and bead height. This effect of arc voltage with nozzle-to-plate distance is evident from the interaction plots where the value of the weld parameter reaches a

maximum and then drops down to minimum value.

- Most of the interaction effects of the process variables on the bead parameters show generally convincing trends between cause and effect.

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