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Behaviour of Welding Current in Submerged Arc Welding

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***Abstract*—Influence of the process parameters on the weld deposit area and microstructure have been studied using bead on plate submerged arc welding process. It was found that the weld deposit area was affected by weld parameters like welding wire feed rate, welding speed, open circuit voltage, and contact-tube-to-work distance. The effect of welding current on weld deposit area has been studied independently by making a separate model for welding current. This is due to the fact that it is not possible to control the current in welding in semi-automatic processes unless it is a constant current welding process. Since the open circuit voltage was also one of the parameters, therefore, controlled variation of both the parameters wasn't possible. The current automatically adjusts to a value at which the burn off rate and the wire feed rate are in equilibrium. To establish a relationship between weld deposit area and the welding parameters, two-level half-fractional factorial design was used. The adequacy of the model was tested by analysis of variance technique and the significance of the coefficient was tested by student's 't' test.**

Keywords— Weld bead geometry and shape relationships, welding parameters, dilution, Submerged Arc Welding.

I. INTRODUCTION

Submerged arc welding is a process capable of producing high output in the quality standards in a wide range of thicknesses for ferrous and stainless steels components. As the metal and the arc pool are totally under the cover of flux there is no radiation from the arc. The fumes and smoke from the process is minimal.

Submerged arc welding owing to high deposition rate, excellent surface appearance, invisible arc and lower welder skill requirement proves versatile in the fabrication of pressure vessels, marine vessels, pipelines, steel mill rollers, offshore structures, etc. The present trend in the fabrication industries is the use of automated welding processes to obtain high production rates and high precision. Submerged arc welding is preferred over other methods of because of its inherent qualities like easy control of process variables, high quality, deep penetration, smooth finish, capability to weld thicker sections and prevention of atmospheric contamination of weld pool. With the growing emphasis on the use of automated welding systems, SAW is employed in semiautomatic or automatic mode in industry.

II. EXPERIMENT

The experiments were conducted according to the random run suggested by two-level half-fractional factorial design of eight trials, which is a standard statistical tool to investigate the effects of a number of parameters on the required response (Adler, 1975). It was selected for determining the effect of four independent direct welding parameters as open circuit voltage (V), welding wire feed rate (W), welding travel speed (S) and the contact tip to work distance (N) (Pandey 2004). The weld beads were deposited by 'Bead-on-plate' technique using 300 x 100 x 12 mm mild steel flat, with 3.15 mm diameter mild steel wire along with general purpose agglomerated flux. Constant potential transformer-rectifier type power source with a current capacity of 600A at 60% duty cycle and an open circuit voltage of 0-56 V was used. The plates were chemically and mechanically cleaned to remove oxide layer and any other source of hydrogen, before welding. Weld beads were deposited using a mechanized SAW station to ensure the consistency during experiment run. Three set of eight runs were executed to determine the 'variance of optimization parameter' and 'variance of adequacy' for the models.

The limiting values of the parameters were selected on the extreme range for two levels. Determining extreme range of parameters and all possible extreme combinations were based on maintaining equilibrium between welding wire feed rate and burn-off rate along with good weld bead appearance and configurations. The selected two levels resulted in weld beads which were free from the visual defects such as Undercut, Overlap, Excessive crown height (preferably ≤ 20% of plate thickness), Excessive convexity, Non uniform ripples on the bead, Macro cracking, Surface porosity / dimpled surface, Non uniform width and Excessive spatter.

The weld beads so obtained also showed good weld metal integrity. The limiting values and the process parameters are given in Table 1.

TABLE I. TABLE 1: WELDING PARAMETERS.

Parameters	Units	Symbol	Notation	Limits	
				Lower	Upper
Open Circuit Voltage	Volts	V	1	40.0	50.0
Wire feed Rate	mm/sec	W	2	18.7	30.4
Weld Travel Speed	mm/sec	S	3	8.2	15.8
Contact Tip to Work	mm	N	4	15.0	25.0

Distance					

A. Model

The model of the type $p = f(V, W, S, N)$ was selected to develop the relationship between the weld bead penetration as a response and a particular set of direct process parameters. The equation could be written in the form of a following polynomial by taking into account all the possible two factor interactions:

$$\begin{aligned}p &= b_0 + b_1V + b_2W + b_3S + b_4N + b_{12}VW \\ &+ b_{13}VS + b_{14}VN + b_{23}WS + b_{24}WN + b_{34}SN\end{aligned} \quad \rightarrow (1)$$

Using the confounding pattern the model could be rewritten as:

$$\begin{aligned}p &= b_0 + b_1V + b_2W + b_3S + b_4N + b_5(VW + SN) \\ &+ b_6(VS + WN) + b_7(VN + WS)\end{aligned} \quad \rightarrow (2)$$

Where, $b_5 = b_{12} + b_{34}, b_6 = b_{13} + b_{24}, b_7 = b_{14} + b_{23}$

The design matrix with all the coefficients and the experimental values for the penetration (p) parameter of the weld bead geometry is listed in table 2.

TABLE 2: DESIGN MATRIX RESPONSE PARAMETERS FOR EXPERIMENTATION.

S. No.	p'	p''	p'''
1	5.4	5.8	5.3
2	5.0	4.8	4.8
3	3.4	3.3	3.4
4	2.4	3.3	3.0
5	6.6	6.5	6.4
6	7.1	7.0	6.7
7	4.3	5.0	4.5
8	3.0	2.4	2.7

The developed model for weld bead penetration was:

$$\begin{aligned}p = 4.763.0 &+ 0.388V + 1.263W - 0.46S + \\ &0.5125N - 0.263(VW + SN) - \\ &0.138(VS + WN) - 0.263(VN + WS)\end{aligned} \quad \rightarrow (3)$$

Similarly the models developed for weld bead height, weld bead width, % Dilution and Welding Current are given below:

$$\begin{aligned}h = 2.43 &- 0.26V + 0.42W - 0.43S + 0.69N \\ &- 0.32(VW + SN) + 0.18(WN + VS) - \\ &0.19(VN + WS)\end{aligned} \quad \rightarrow (4)$$

$$\begin{aligned}w = 11.47 &+ 1.12V + 0.13W - 2.31S - \\ &0.34N + 1.13(VW + SN) \\ &- 0.46(WN + VS) + 0.16(VN + WS)\end{aligned} \quad \rightarrow (5)$$

$$\begin{aligned}\%D = 61.48 &+ 3.17V + 4.04W + \\ &1.84S + 0.56N - 0.57(VW + SN) \\ &- 1.71(WN + VS) - 0.77(VN + WS)\end{aligned} \quad \rightarrow (6)$$

$$\begin{aligned}I = 384.1 &+ 7.19V + 86.56W + 4.06S + \\ &8.44N + 7.19(VW + SN) \\ &- 10.31(WN + VS) + 0.31(VN + WS)\end{aligned} \quad \rightarrow (7)$$

The adequacy of the model was determined by the analysis of variance technique. The regression coefficients were determined by the method of least squares, from which the 'F'-ratio for the polynomial was found. Cochran's test procedure was adopted for calculating the variance of optimisation parameter and testing the homogeneity of variances. The homogeneity of variances was tested before calculating the variance of optimisation parameter and it was found that the variances were homogeneous. The 'F'-ratio of the model was compared with the corresponding 'F'-ratio from the standard tables and it was found that the model was adequate within 95% level of confidence, thus justifying the use of assumed polynomial. It is important at this stage to determine whether the coefficients are statistically significant or not. The statistical significance of the coefficients was tested by applying students 't' test. The level of significance of a particular parameter is assessed by the magnitude of the 't' value associated with it. Higher the value of 't' the more significant it becomes.

B. Proposed models

The proposed model for the prediction of welding current (I), weld bead penetration (p), weld bead height (h) weld bead width (w) and percentage dilution (%D) after dropping the statistically insignificant coefficients, in the coded form are:

$$I = 384.1 + 86.56W \quad \rightarrow (8)$$

$$p = 4.71 + 1.32W \quad \rightarrow (9)$$

$$h = 2.43 + 0.42W - 0.43S - 0.32VW \quad \rightarrow (10)$$

$$w = 11.47 + 1.12V - 2.31S + 1.13VW \quad \rightarrow (11)$$

$$\%D = 61.48 + 3.17V + 4.04W \quad \rightarrow (12)$$

III. RESULTS

Welding wire feed rate (W) was the only parameter that showed statistically significant main effect on the welding current (I). Increase in welding wire feed rate (W) from 18.7 mm/s to 30.4 mm/s, resulted in an increase in the welding current (I) by a magnitude of 173.22 amperes as shown in the Fig. 1 Welding wire feed rate (W) alone has the statistically significant effect on the weld bead penetration (p) as indicated in Fig. 2. All the other main and interaction effects were statistically insignificant and hence were dropped. The wire feed rate and the travel speed showed the corresponding effect as is seen in Fig. 3 and Fig. 4 on the height (h) of the weld bead. Open circuit voltage (V) and the weld wire feed rate (W) shows significant interaction effect (VW) results in the weld bead height as shown in Fig. 5. The response surface diagram indicates the behavior of the VW on bead height in Fig. 11. The main effect due to open circuit voltage (V), welding travel speed (S) Fig. 6 & Fig. 7 and interaction effects due to open circuit voltage (V) and welding wire feed rate (W) is the resultant for the bead width (w) as shown in Fig. 8. The response surface as shown in Fig. 12 predicts the interaction performance of VW. The magnitude of weld bead width in interaction is of the order of 2.33 to 2.53 and 1.69 to 3.17. The effect on percentage dilution in the weld bead by the weld wire feed rate and the open circuit voltage is shown in Fig. 9 and Fig. 10 respectively.

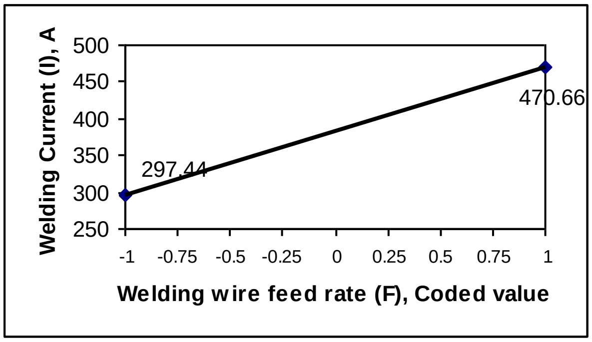

Figure 1. Main effect of welding wire feed rate (W) on welding current (I)

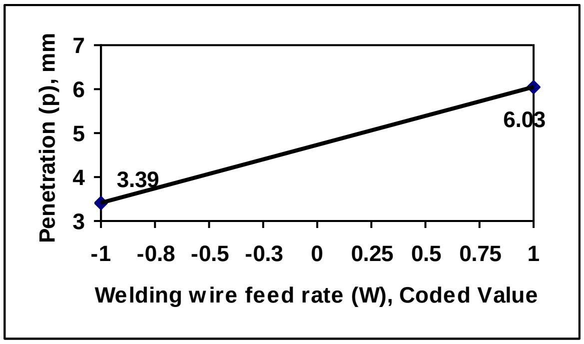

Figure 2. Main effect of welding wire feed rate (W) on bead penetration (p)

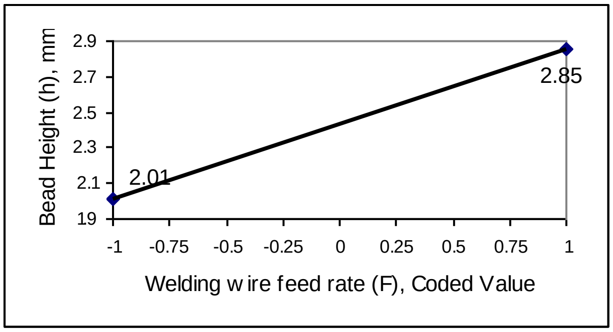

Figure 3. Main effect of welding wire feed rate (W) on weld bead height (h)

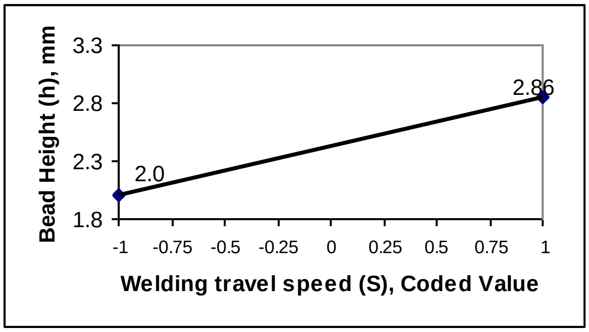

Figure 4. Main effect of welding travel speed (S) on weld bead height (h)

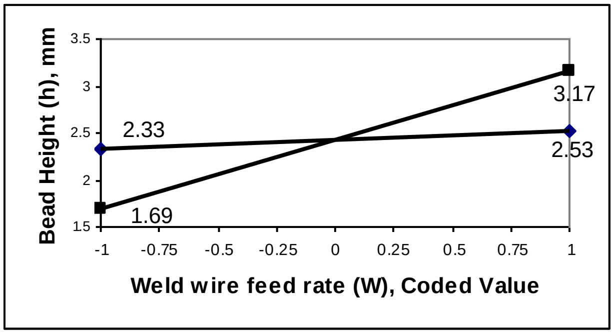

Figure 5. Effect of interaction of wire feed rate (W) and open circuit voltage on weld bead height (h)

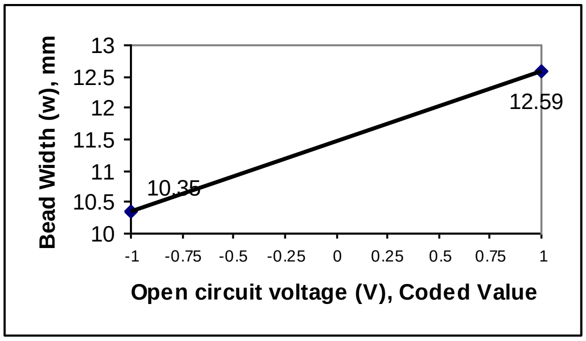

Figure 6. Main effect of open circuit voltage (V) on weld bead width (w)

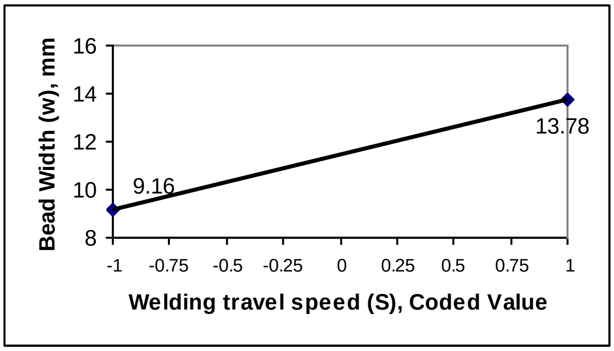

Figure 7. Main effect of welding travel speed (S) on weld bead width (w)

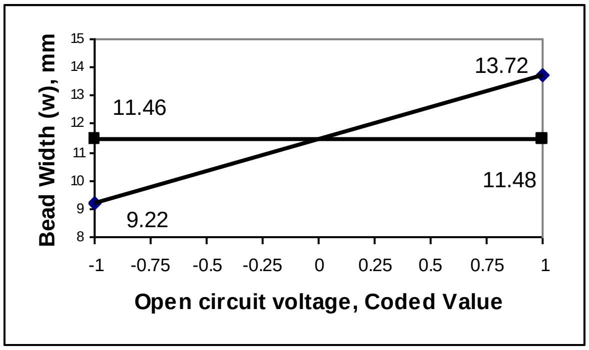

Figure 8. Effect of interaction of welding wire feed rate (W) and open circuit voltage on weld bead width (w)

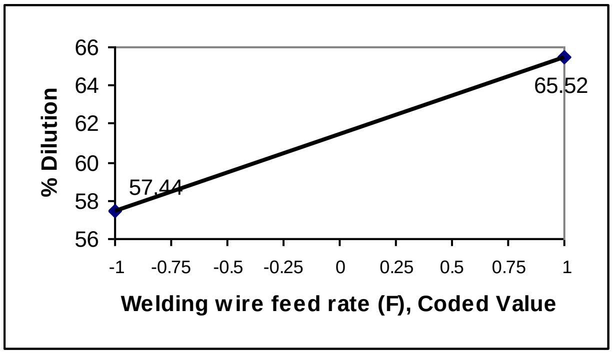

Figure 9. Main effect of welding wire feed rate (W) on % dilution (%D)

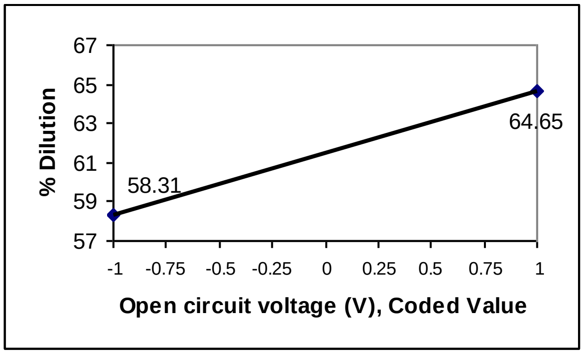

Figure 10. Main effect of open circuit voltage (V) on % dilution (D)

Response surfaces due to an interaction of two parameters for weld bead height (h) and weld bead width (w) are shown in Fig. 11& Fig. 12 respectively.

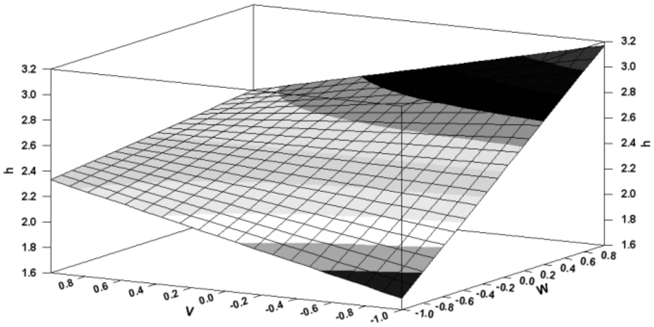

Figure 11. Interaction effect of open circuit voltage (V) and wire feed rate (W) on bead height (h).

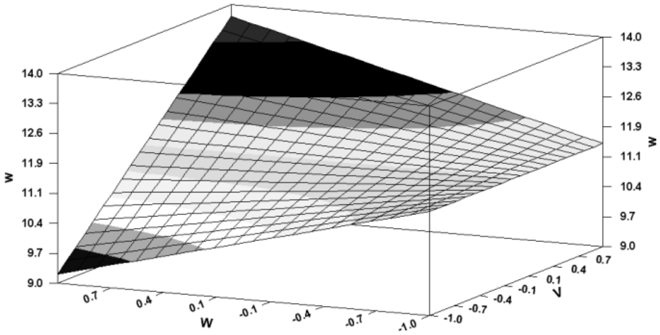

Figure 12. Interaction effect of open circuit voltage (V) and wire feed rate (W) on bead width (w).

IV. CONCLUSIONS

i. Factorial technique was found to be the powerful technique for establishing the correlations amongst the various welding parameters.
ii. Wire feed rate (W) was found to be the only significant parameter governing the welding current. All other parameters were found to be statistically insignificant, thereby resulting in a simplified model (eqn. 8).
iii. Wire feed rate was again the only significant parameter affecting the penetration (p).
iv. The equation for bead height (h), bead width (w) and percentage dilution (%D) were as per the previously known trends. However, in case of height, open circuit voltage and wire feed rate indicated the inverse interaction while for the bead width (w), open circuit voltage and wire feed rate had the direct interaction.

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