Use of Response Surface Modeling in Prediction and Control of Flux Consumption in Submerged Arc Weld Deposits

Vinod Kumar

Abstract: Submerged arc welding is preferred over other methods of welding because of its inherent qualities like easy control of process variables, high quality, deep penetration, smooth finish, capability to weld thicker sections. Since the development of submerged arc welding process, welding engineers are striving for reduction in welding cost without compromise in the performance of the weld. Flux used in submerged arc welding contributes a major part towards welding cost. In the present work, the effect of operating voltage, welding current, welding speed and basicity index on flux consumption has been studied. Flux consumption for each bead was weighed. Response surface methodology was applied to derive mathematical models to predict and control the flux consumption within the range of the parameters. It was found that flux consumption increases with the increase in operating voltage, decreases with the increase in welding current and welding speed. It also increases with the increase in basicity index.

Keywords: RSM, Design of Experiment, submerged arc welding

I. INTRODUCTION

Since the development of Submerged Arc Welding (SAW), which contributes to about 10% of the welding, attempts have been made by the technologists to increase productivity by reducing the welding consumable i.e. flux. Welding flux may costs upto 50% of the total cost of welding, therefore it may play an important role in controlling the cost of welding.

Besides economic considerations, flux consumption influences the pick up or loss of some of the alloying elements, thus the mechanical and metallurgical properties of the weld. SAW is preferred over other methods of welding of pipes because of its inherent qualities like easy control of process variables, high quality, deep penetration, smooth finish, capability to weld thicker sections.

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A flux contains organic and inorganic materials, ferro-alloys, minerals etc. The primary function of the flux in SAW is to protect the weld pool from atmospheric contamination. It reduces the heat losses, spatter and smoke and influences the arc stability and elements transfer. It also facilitates in a slower cooling rate resulting in the desired mechanical properties as well as metallurgical characteristics of the weldment. For the efficient functions it should have appropriate properties like melting range, viscosity, detachability etc. within the optimum range.

The flux consumption is mainly dependent on physical properties of the flux such as melting point, density, thermal properties, chemical composition, basicity index and welding parameters viz. wire feed rate, welding current, open circuit voltage, welding speed etc. [1-5]. The flux consumption increases with the decrease in melting point and decreases with the decrease in the density of the flux and thermal conductivity of the base material. The flux consumption initially increases with the current, reaches maximum and then decreases. The flux consumption increases with the increase in welding voltage [6]. The electrode extension and flux height have no appreciable effect on the flux consumption [1, 3].

Mohan & Pandey [7] studied the effect of welding current in submerged arc welding. Too low or high current causes the arc instability. Researchers McGlone [8] and Gupta et al [9] observed that bead width increases with an increase in current until it reaches critical value and then decreases with an increase in welding current.

As no systematic methodology to predict, control, optimize and correlate the flux consumption with the welding parameters has been reported so far. In the present study an attempt has been made to develop mathematical modeling using response surface methodology (RSM) to predict, control and correlate the flux consumption with welding parameters within the range of parameters.

II. EXPERIMENTATION

RSM is a collection of statistical and mathematical methods that are useful for modeling and analyzing engineering problems [10]. Based on Box Behnken design of response surface methodology experiments have been conducted with three different levels of process parameters to obtain bead-on- plate weldment on mild steel plates (200 x 75x 12 mm). Based on the effect on weld bead geometry, ease of control and capability of being maintained at the desired level, four independently controllable process parameters were identified namely, the open circuit voltage (a), current (b), welding speed (c) and basicity index (d). The upper and lower limits were coded as +1 and −1, respectively. The selected process parameters and their upper and lower limits together with notations and units are given in Table 1. The experiments were conducted using Ador submerged arc-welding equipment, Tornado 800 with 4 mm electrode wire

Table 1 Process control variables and their limits

Parameters	Notations	Limits		
		-1	0	+1
Voltage (volts)	A	32	35	38
Current (amperes)	B	375	425	475
Welding Speed (m/hr)	C	24	27	30
Basicity Index	D	0.6	0.9	1.2

III. Development of Model

The necessary data required for developing the response models have been collected by designing the experiments based on Box-Behnken Design (BBD) using state ease 6.0 version of design of experiment. Two transverse specimens were cut from each welded plate. These specimens were prepared by the usual metallurgical polishing methods and etched with 2% nital. The profiles of the beads were traced by using optical profile projector. The flux consumption results for the 29 experiments are given above in Table 2. The response equations for flux consumption so obtained are given below:

Flux Consmption (F) = $48.11 + 12.69 * A - 3.24 * B - 4.04 * C + 5.97 * D - 0.66 * A^2 - 4.28 * B^2 + 0.61 * C^2 - 6.30 * D^2 + 0.90 * A * B - 0.16 * A * C - 2.02 * A * D + 0.77 * B * C + 2.26 * B * D - 1.70 * C * D$

IV. Results and Discussion

The analysis of variance (ANOVA) was applied to study the effect of input parameters on the flux consumption. It revealed that the quadratic model is the best suggested model. In addition to this, the goodness of fit of the fitted quadratic model was also evaluated through 'lack of fit test'. The "Prob > F" for all these tests was found in excess of 0.05, implying that the lack of fit is insignificant. So, for further analysis this model was used.

A. The effect of Process Variables on Flux Consumption

Fig.1 shows effect of process parameters on flux consumption. It increases from 34.757 to 60.193 gms with the increase in open circuit voltage from 32 to 38 volts. This is due to the positive effect of voltage on bead width. This is also consistent with the findings of Gunuraj (1999). It can be attributed to the increase in arc length with the increase in open circuit voltage, which in turn results in spreading of the arc cone and hence higher amount of flux coming in contact with the arc. The increase in open circuit voltage also increases the quantity of heat input per unit length of the weld deposited. This causes flattening of the weld bead and more flux to melt.

As shown in Fig.1, the inverse relationship between welding current and flux consumption is due to fact that with the increase in welding current, the metal deposition rate increases and consequently the overall ratio of the flux consumption to metal deposited decreases. Further with the increase in welding current the voltage and arc length decreases. The reduced arc length reduces the surface area of the arc responsible for melting the flux.

In Fig. 1 the effect of change in welding speed on flux consumption can be explained on the basis of effect of speed on bead width. At higher welding speed there is less spread of bead, and hence less consumption of flux compared to that at lower speed. Flux consumption increases with the change in basicity index from 0.6. to 1.2. This is due to the fact that because low basicity index fluxes have high viscosity which enhances the tendency of heat concentration in the narrow zone and hence high penetration and lower bead width. This is consistent with the study conducted by Gupta (1988).

B. Interaction Effect

Response surface due to interaction of current and basicity index on flux consumption is shown in Fig.2. Fig.2 shows effect of current on flux consumption with the change in basicity index. These effects can be explained on the basis of individual effects of current and basicity index on bead width and consumption of flux.

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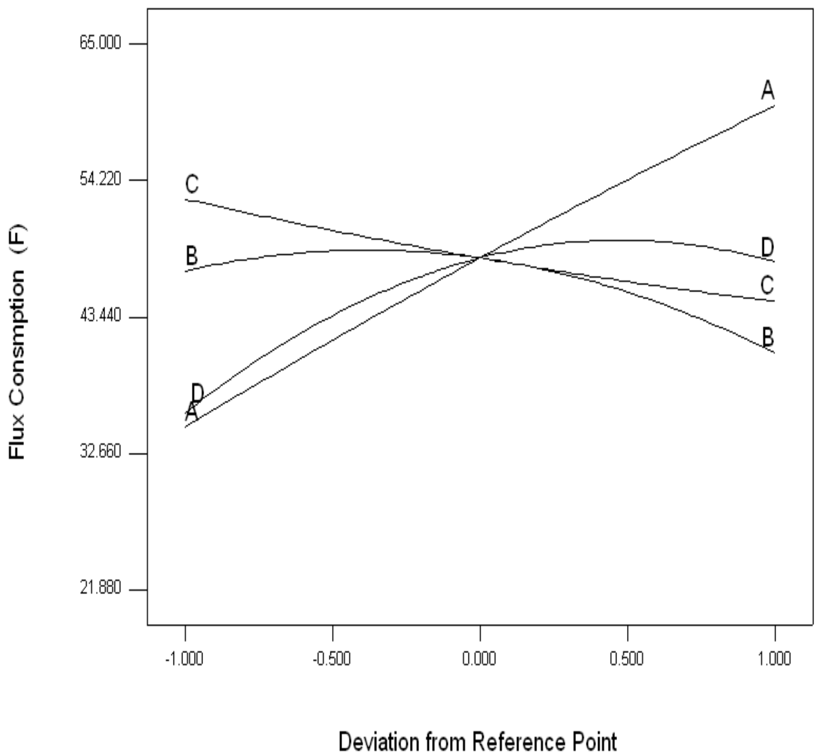

Fig.1. Effect of process variables on Flux Consumption

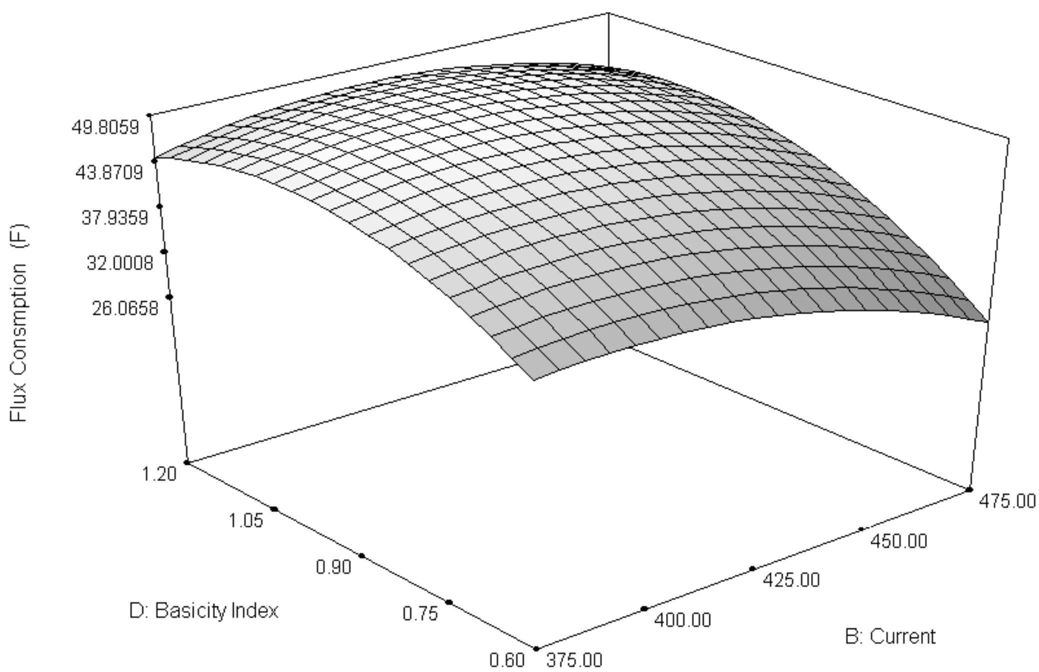

Fig.2 3D surface graphs for the Flux Consumption

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Table 2 Design values and observed values of bead width and Reinforcement

Expt. Run No.	Process Parameters				Response factors
	A Voltage (volts)	B Current (amperes)	C Welding Speed (m/hr)	D Basicity Index	F Flux Consumption (gms)
1	1	-1	0	1	50
2	-1	0	0	0	37.02
3	0	0	0	1	45.77
4	0	-1	1	1	40.29
5	-1	0	0	-1	21.88
6	0	-1	0	0	48.34
7	0	0	0	1	43.42
8	0	1	-1	1	49.53
9	0	0	0	1	50.83
10	-1	0	-1	1	40.39
11	0	0	0	1	49.08
12	1	0	0	0	60.24
13	0	0	1	-1	32.44
14	0	0	1	0	44
15	0	1	0	-1	26.09
16	1	1	0	1	52
17	1	0	0	-1	52.38
18	0	1	0	0	39.46
19	0	1	1	1	38.28
20	-1	1	0	1	31.25
21	1	0	1	1	54.23
22	0	0	-1	0	50.93
23	-1	0	0	1	30.26
24	1	0	-1	1	65
25	-1	-1	0	1	32.86
26	0	0	-1	-1	37.69
27	0	0	0	1	49.79
28	0	-1	-1	1	54.61
29	0	-1	0	-1	35.89

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V. CONCLUSIONS

On the basis of present study the following conclusions can be drawn:

1. RSM has been used effectively to develop corelation between flux consumption and welding parameters.
2. Flux consumption increased with the increase in open circuit voltage and decreased with the increase in welding current.
3. Welding speed has negative effect on flux consumption. Flux consumption also increases with the increase in basicity index.
4. The average flux consumption varied between 21.88 and 60.24, within the range of the parameters.

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