International Journal of Mechanical Engineering and Robotics Research

ISSN 2278 – 0149 www.ijmerr.com
Vol. 1, No. 3, October 2012
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Research Paper

APPLICATION OF RESPONSE SURFACE MODELING FOR DETERMINATION OF FLUX CONSUMPTION IN SUBMERGED ARC WELDING BY THE EFFECT OF VARIOUS WELDING PARAMETERS

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Purpose: Submerged Arc Welding (SAW) is a common arc welding process where the total welding cost includes the cost of the flux consumed during welding, SAW is preferable more its inherent qualities like easy control of process variables, high quality, deep penetration, smooth finish. Flux used in submerged arc welding contributes a major part towards welding cost. In SAW, selecting appropriate values for process variables is essential in order to control Heat-Affected Zone (HAZ) dimensions and get the required bead size and quality. Also, conditions must be selected that will ensure a predictable and reproducible weld bead, which is critical for obtaining high quality. In this investigation, mathematical models were developed to study the effects of process variables and heat input on various metallurgical aspects, namely, the widths of the HAZ, weld interface, and grain growth and grain refinement regions of the HAZ 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. Design/ Methodology: The experiment was designed based on a five level factorial central composite rotatable design with full replication. The experimental calculations and results graph was conducted as per the design matrix using Design Expert Software. Technique: The Response Surface Methodology (RSM) is a set of techniques that encompasses (1) the designing of a set of experiments for adequate and reliable measurement of the true mean response of interest; (2) the determining of mathematical model with best fits; (3) finding the optimum set of experimental factors that produces maximum or minimum value of response; and (4) representing the direct and interactive effects of process variables on the bead parameters through two dimensional and three dimensional graphs.

Keywords: RSM, Process parameters, Submerged arc welding, HSLA material, Design expert

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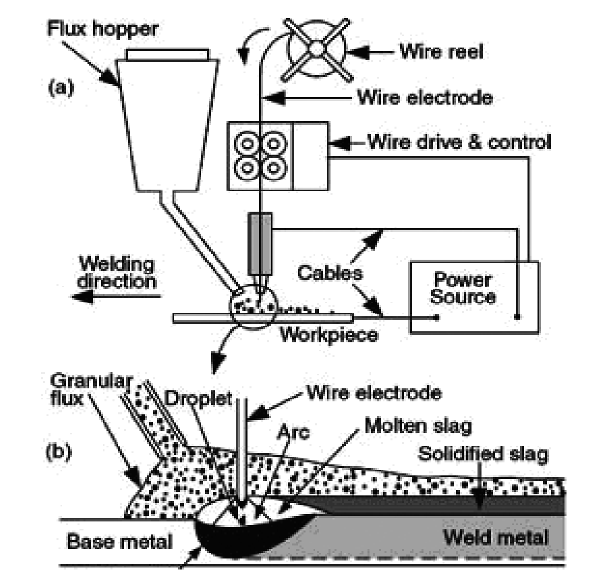
INTRODUCTION

Response Surface Methodology (RSM) is a technique to determine and represent the cause and effect relationship between true mean responses and input control variables influencing the responses as a two or three dimensional hyper surface (Chandel, 1998). The accuracy and effectiveness of an experimental program depends on careful planning and execution of the experimental procedures In Submerged Arc Welding (SAW) of various wall thickness, a common problem faced in industry is the selection of suitable values for the process parameters to the required flux consumption, bead geometry and quality, especially the bead penetration, reinforcement, bead width and dilution (Gunaraja and Murugan, 1997). In submerged arc welding (SAW), the total welding cost includes the cost of the flux consumed . In the present work, the effect of operating voltage, welding current, welding speed and nozzle to plate distance on flux consumption has been studied. Flux consumption for each bead was weighed (Vinod, 2011). 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 nozzle to plate distance and welding speed. The Figure 1 shows the submerged arc welding set up how on Base table work piece hold and the how machine moves according to the bead apply between the work pieces.

This paper deals with the application of RSM in developing mathematical models and plotting contour graphs relating important input process parameters namely the open-circuit Current (C), Voltage (V), Welding speed (S) and the nozzle-to-plate distance (D) in the SAW, through the development of a computer program find out the effect of parameters on flux consumption (Gunaraja and Murugan, 1997). During SAW process only that portion of the flux that is actually melted is consumed. The unused portion of the flux is separated from the slag and reused. The consumption of the flux is dependent upon the flux melting. The heat needed to melt the flux comes from three sources (Gunaraja and Murugan, 1997).

Figure 1: Submerged Arc Welding M/C Set Up



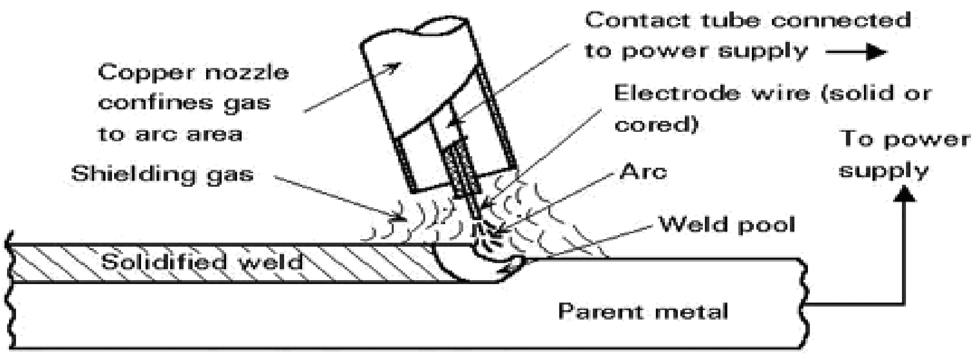
1. Conduction from the molten metal;
2. Radiation from the arc; and
3. Resistance heating of the slag.

The conduction from molten metal would depend upon the weld metal temperature and weld metal-flux contact area. This contact area is dependent upon the bead shape, hence welding parameters. 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. Although the physical and chemical properties of SAW fluxes have been studied widely, very little attention has been paid to the factors that affect its consumption. In a different work it has been shown that the flux consumption generally increases with increasing welding current reaches a maximum and then starts decreasing again. Although several authors have stated that the flux consumption can be influenced by physical properties such as density and particle size, no systematic information is presently available (Siva *et al.*, 2008).

EXPERIMENTAL PROCEDURE

The experiment was designed based on a five level factorial central composite rotatable design with full replication (Gunaraja and Murugan, 1997). The experiment was conducted as per the design matrix using TORNANDO SAW M-800 equipment at Mullana University Mullana India. Welding was done bead on material plate of High Strength Low Alloy Steel. The size of each specimen was 200*100 mm of thickness 10 mm. ESAB SA1 (E8) copper coated wire of 4 mm diameter electrode, granular flux was used for welding (Figure 2). Two transverse specimens were cut from each weldment and standard metallographic procedures were adopted. The bead profiles were drawn using a reflective type profile projector. The bead profile parameters were measured using an accurate digital planimeter (Vinod, 2011). Before starting welding on plate weighted the flux and again weight the flux after complete bead on the plate. That the way how calculated the flux consumption for each bead when the parameters selected accordingly Table 1.

Figure 2: Joining Two Metal Pieces with Submerged Arc Welding



PLAN OF INVESTIGATIONS

The research work was planned to be carried out in the following steps (Siva *et al.*, 2008):

- Identifying the process parameters;
- Finding the upper and lower limits of the control variables, viz., open-circuit voltage

Table 1: Welding Parameters and Level

Parameters	Units	Limits				
		–2	–1	0	+1	+2
Current (C)	Amp.	300	350	400	450	500
Voltage (V)	Volts	26	28	30	32	34
Welding Speed (S)	M/Hr	21	24	27	30	33
NP Distance (D)	MM	16	18	20	22	24

(V), current (C), welding speed (S), and nozzle-to-plate distance (D);

- Developing of the design matrix;
- Conducting the experiments as per the design matrix;
- Checking the adequacy of the models developed;
- Testing the significance of the regression coefficients, recalculating the value of the significant coefficients and arriving at the final mathematical models;
- Analysis of results and conclusions.

Identification of the Process Parameters

The following independently controllable process parameters were identified to carry out the experiments: open-circuit voltage (V); current (C); welding speed (S); and nozzle-to-plate distance (D) (Gunaraja and Murugan, 1997).

Finding the Limits of the Process Variables

Trial runs were carried out by varying one of the process parameters whilst keeping the rest of them at constant values. The working range was decided upon by inspecting the bead for smooth appearance and the absence of any visible defects. The upper limit of a factor was coded as +2 and the lower limit as –2, the coded values being calculated from the following relationship (Gunaraja and Murugan, 1997):

$$Xi = \frac{2[2X(X\max + X\min)]}{(X\max - X\min)}$$

where Xi is the required coded value of a variable X; and X is any value of the variable from Xmin to Xmax. The selected process parameters with their limits, units and notations are given in Table 1.

Developing the Design Matrix

The selected design matrix, is a central composite rotatable factorial design consisting of 31 sets of coded conditions. It comprises a full replication of 2^4 = 16 factorial design plus seven center points and eight star points (Chandel, 1998). All welding parameters at the intermediate level points and the combinations of each of the welding variables at either its lowest (+2) level or highest (–2) level with the other three variables at the intermediate levels constitute the star points. Thus the 31 experimental runs allowed the estimation of the linear, quadratic and two-way interactive effects of the process parameters (Table 2).

Conducting the Experiment as per the Design Matrix

The experiments were conducted as per the design matrix at random, to avoid the possibility of systematic errors infiltrating the system.

Development of Mathematical Models

The response function representing any of the weld bead dimensions can be expressed as (Murugan and Gunaraj, 2002).

$Y = f(V, C, S, D)$. The relationship selected being a second degree response surface expressed as follows: $Y = b_0 + b_1V + b_2C + b_3S + b_4D + b_{11}V_2 + b_{22}C_2 + b_{33}S_2 + b_{44}D_2 + b_{12}VC + b_{13}VS + b_{14}VD + b_{23}CS + b_{24}CD + b_{34}SD$

Table 2: Design Matrix (Flux Consumption According Experiment Limits)

Standard Limits	Experiment	Process Parameters				Responses Factors
	Run Numbers	Current (Amperes)	Voltage (Volts)	Welding Speed (M/hr)	Nozzle to Plate Distance (M.M)	Flux Consumption (Gms)
1	20	350	28	24	18	33.0
2	13	450	28	24	18	45.0
3	16	350	32	24	18	56.0
4	11	450	32	24	18	75.0
5	26	350	28	30	18	45.0
6	30	450	28	30	18	39.0
7	10	350	32	30	18	40.0
8	1	450	32	30	18	45.0
9	15	350	28	24	22	36.0
10	23	450	28	24	22	42.0
11	22	350	32	24	22	60.0
12	31	450	32	24	22	75.0
13	5	350	28	30	22	38.0
14	4	450	28	30	22	32.0
15	19	350	32	30	22	40.0
16	9	450	32	30	22	40.0
17	21	300	30	27	20	35.0
18	6	500	30	27	20	50.0
19	27	400	26	27	20	23.0
20	18	400	34	27	20	50.0
21	24	400	30	21	20	70.0
22	29	400	30	33	20	47.0
23	2	400	30	27	16	50.0
24	17	400	30	27	24	47.0
25	12	400	30	27	20	42.0
26	28	400	30	27	20	43.0
27	7	400	30	27	20	44.0
28	14	400	30	27	20	50.0
29	8	400	30	27	20	40.0
30	3	400	30	27	20	42.0
31	25	400	30	27	20	44.0

RESULTS AND DISCUSSION

The analysis of variance (ANOVA) was applied to study the effect of input parameters on the flux consumption (Siva *et al.*, 2008). It revealed that the quadratic model is the best suggested model. In addition to this, the

Figure 3: 3D Surface Graphs for the Flux Consumption Between Welding Speed and Current

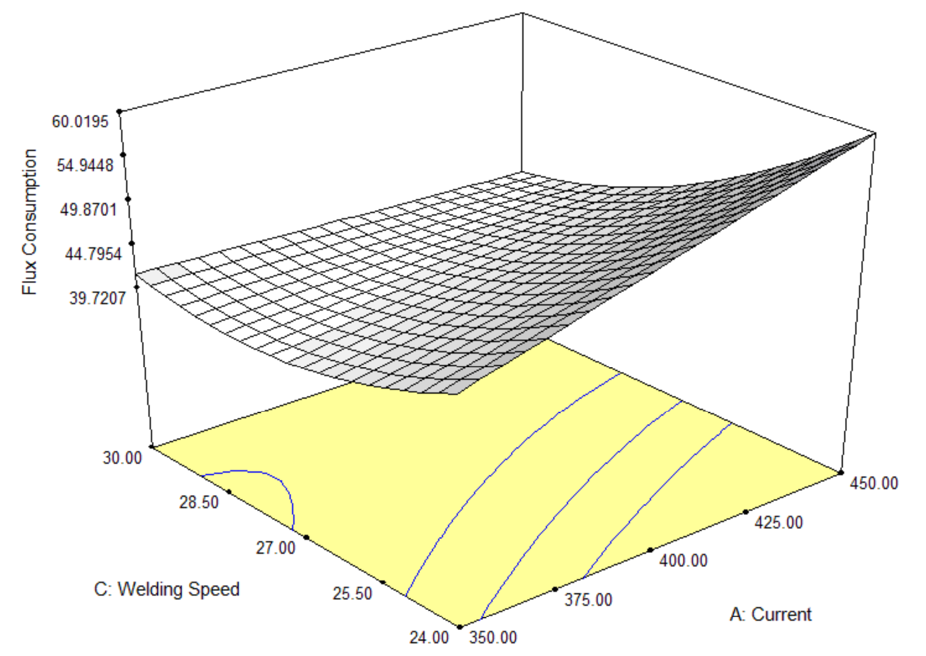


Figure 4: 3D Surface Graphs for the Flux Consumption Between Voltage and Current

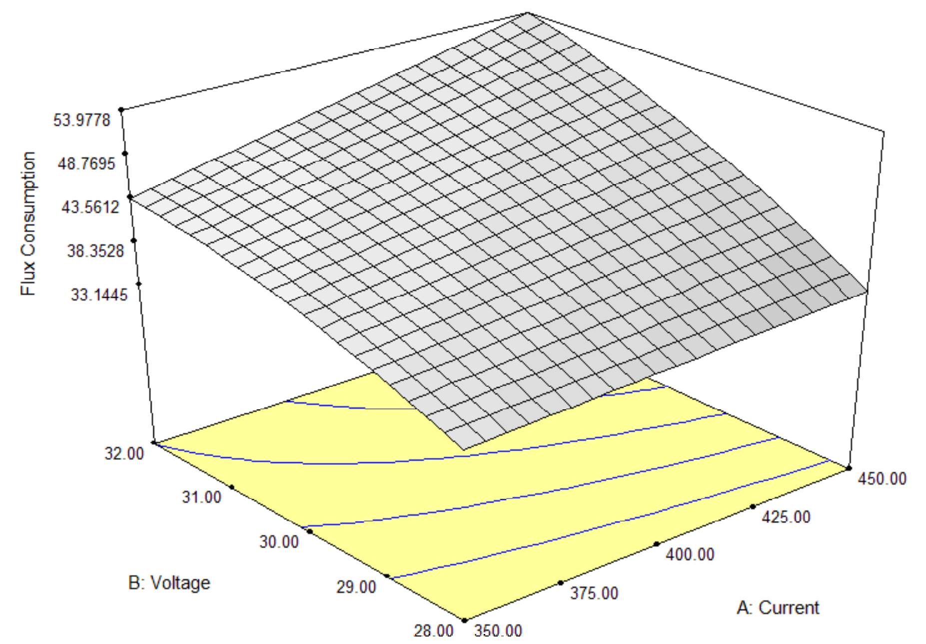


Figure 5: 3D Surface Graphs for the Flux Consumption Between Welding Speed and Voltage

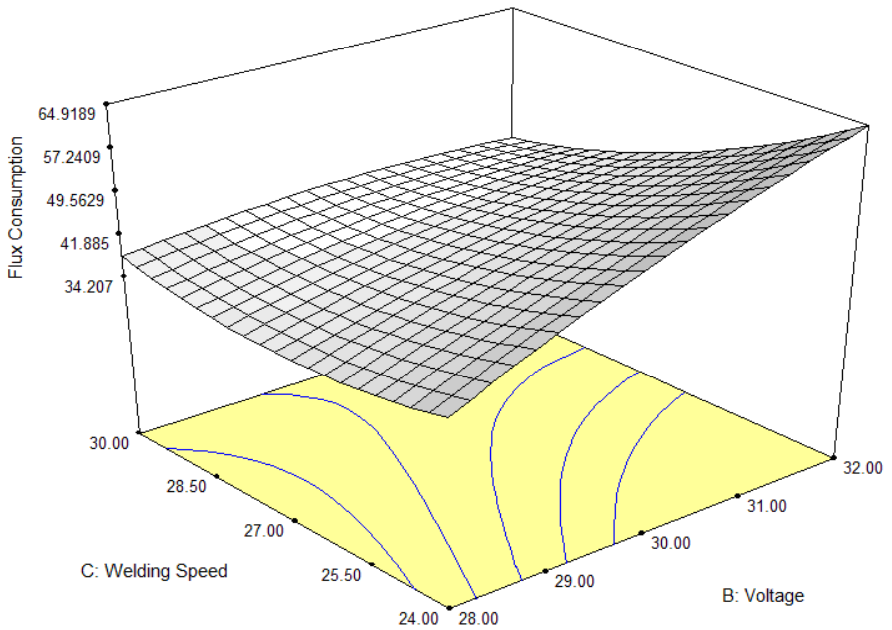
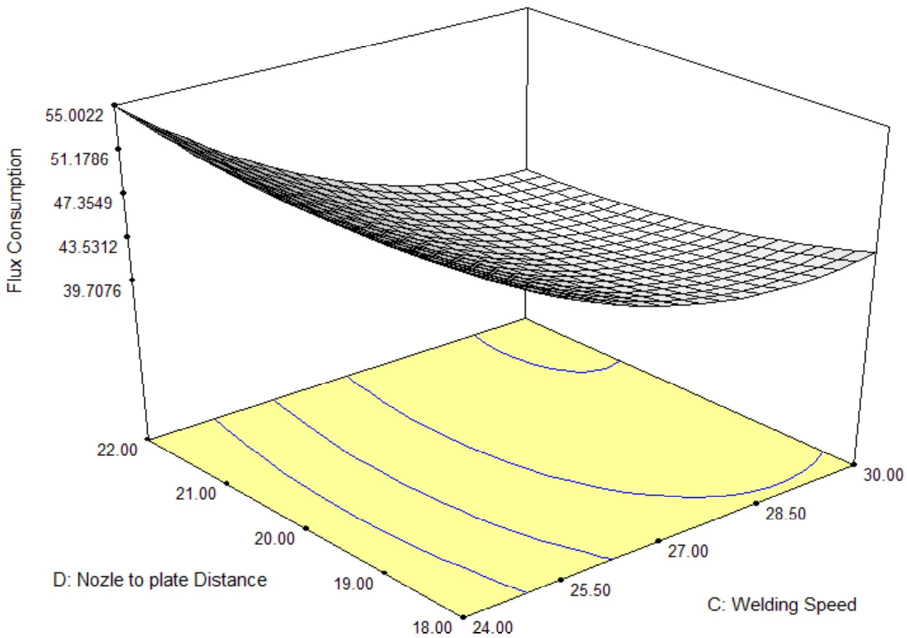


Figure 6: 3D Surface Graphs for the Flux Consumption Between Nozzle to Plate Distance and Welding Speed



goodness of fit of the fitted quadratic model was also evaluated through 'lack of fit test' (Vinod, 2011). The "Prob > F" for all these tests was found in excess of 0.001, implying that the lack of fit is insignificant. So, for further analysis this model was used.

Interaction Effects

The difference in effect of one variable when a second variable is changed from one level to another is known as interaction effect and study of interaction effects of process variables on bead dimensions is interesting and very useful for understanding the process behavior. In this study, the effect of welding current, arc voltage, welding speed and distance between tip of nozzle and work piece on the flux consumption (Figures 3 to 6).

CONCLUSION

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

- RSM can be used effectively in analyzing the cause and the effect of process parameters on response. The RSM is also used to draw contour graphs for various responses to show the interaction effects of different process parameters.
- Flux consumption increased with the increase in open circuit voltage and very small increases with increases in current.
- Welding speed has negative effect on flux consumption.
- Flux consumption also small decreases with the increase in nozzle to plate distance.

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