ENHANCEMENT OF THE WEAR RESISTANCE OF THE WELD BY USING METAL POWDER IN SUBMERGED ARC WELDING

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ABSTRACT

Several techniques are used to increase the wear resistance property of the materials because wear is a persistent service condition in many engineering applications with important economic and technical consequences. Submerged Arc Welding using metal powders is the technique of depositing a layer of material onto the surface of a component to make it more resistant to wear, corrosion than the parent metal or substrate. The alloying elements present in the metal powder greatly enhance the mechanical properties of the weld metal. In the present research, surface response methodology was employed for conducting the experiments and analyzing the effect of process parameters (open circuit voltage, tip to work distance) and wt. percentage of metal powder into the flux on the wear resistance of the weld using submerged arc welding process. The research reports that the wear resistance property of the weld metal was observed to increase significantly with the increase in the amount of metal powder addition to the flux and voltage.

Keywords: Submerged Arc Welding, Wear Resistance, Response Surface Methodology

I. INTRODUCTION

Several techniques are used to increase the wear resistance property of the materials because wear is a persistent service condition in many engineering applications with important economic and technical consequences. The effect of abrasion is particularly evident in the industrial areas of agriculture, mining, mineral processing, and earth moving. Likewise, wear is a critical concern in many types of machine components; in fact, it is often a major factor in defining or limiting the suitable lifetime of a component [1].

Submerged Arc Welding using metal powders is the technique of depositing a layer of material onto the surface of a component to make it more resistant to wear and high temperature corrosion than that of the parent metal or substrate [2]. This enhances cost effectiveness by enabling the use of a cheaper, more easily machinable parent material coated with expensive metals and alloys for achieving desired properties in specific areas of products [3].

In this research work it has been tried to increase the wear resistance property and hardness of mild steel plate using submerged arc welding process by adding metal powder into the flux. The effect of welding process parameters (voltage, tip to work distance) and the effect of percentage of metal powder in the flux on the wear resistance property and hardness of the weld metal have been investigated.

For the prediction of the effects of welding parameters and addition of metal powder to flux on the wear resistance property and hardness of the weld metal, it is essential to generate the data by conducting the experiments according to the corresponding actual conditions of welding. The experiments should supply the required information with the minimum efforts, time and resources. Therefore, in order to perform the required experiments efficiently, the experimental plan must be designed. The design of experiment is the procedure of selecting the number of trials and conditions for running them, essential and sufficient for solving the problem that has been set with the required precision.

In general, the statistical method of design of experiment is based on a more sound logic than any other approach and helps in minimizing the time and the cost of experimentation and at the same time increases the authenticity of the results [5]. Many latest techniques are available for experimental design which can be effectively used in scientific investigations of welding processes. One such important technique is Response surface methodology for evaluating the effect of the parameters and their interactions on the response.

Hence in the present work, this approach was selected for conducting the experiments and generating the data for predicting the effect of welding conditions and addition of metal powder to flux on the wear resistance property and hardness of the weld metal.

II. PLAN OF INVESTIGATION

The research work was carried out in the following steps:

- Identifying the important process control variables.
- Selecting the upper and lower limits of the control variables.
- Developing the design matrix.
- Conducting the experiments as per the design matrix.
- Recording the responses.
- Developing the mathematical models and calculating the coefficients of the polynomials.
- Evaluating the adequacy of the developed models.
- Presenting the direct effects of different process parameters on wear rate and hardness graphically.

2.1 Identification of Parameters

For defect free, predictable, controllable and higher productive welding, identification of correct welding parameters which control the weld characteristics is essential. These parameters affect the weld metal chemistry, bead shape geometry, metal transfer characteristics, heat input and microstructure of the weld metal [6]. Amongst the welding parameters, arc voltage, tip to work distance and percentage addition of metal powder to flux were selected as these are independently controllable process variables. Their effect on the wear resistance property and hardness of the weld metal was studied. These parameters were selected because these influence the penetration, deposition rate and chemical composition of weld metal. Open circuit voltage was considered in place of arc voltage for investigation because it varies linearly with arc voltage and can be controlled directly.

2.2 Selecting the Range of the Process Variables

The trial runs were conducted to select the range of the welding parameters. The range, covering the lowest and the highest level of the direct welding parameters, was carefully selected so as to maintain the equilibrium between the welding wire feed rate and burn-off rate. The basis of selection of given range for various welding parameters was that the selected range should be within the permissible limit of the parameters of the power source. Also the resultant weld should have good bead appearance, configurations and be free from visual defects viz, undercut, overlap, excessive crown height, surface porosity, non uniform ripples, macro cracking etc. All the direct and indirect parameters except the ones under consideration were kept constant. The upper limit (highest level) and the lower limit (lowest level) of a factor was coded as (+1) and (-1) respectively. The units, symbols, and the limits of the factors (parameters) are given in Table 1.

2.3 Developing the Design Matrix

Box-Behnken design can be represented in the form of design matrix where column and row correspond to levels of the factors and the different experimental runs respectively. The present design matrix is shown in Table 2.

2.4 Conducting the Experiments as Per the Design Matrix

The constant potential (flat characteristics) transformer - rectifier type power source with current capacity of 600A and open circuit voltage ranging 12-48 volts was used. Semi automatic GMAW system type was employed to conduct the experiments. This machine also had the provision for controlling the welding wire feed rate. DCEP polarity was used throughout the experimentation. The welds were laid by using 1.2 mm diameter copper coated M.S wire. The composition of the base plate is given in Table 4. The plate size used for bead on plate welds was 100 × 50 × 6 mm. Semi automatic GMAW system was used without shielding gas. The system was converted to submerged arc welding system by using a motorized trolley with adjustable travel speed and torch holder system which was fabricated at the workshop. Agglomerated flux with basicity index of 1.2 was used. Nickel based metal powder was mixed with flux in different percentages by weight. The welds were laid on the base plate using three passes; two were laid parallel and third was laid on the top of the two.

Table-1: Welding Parameters and their Range

Parameter	Unit	Designation	Range			
			Lower value		Higher value	
			Actual	Coded	Actual	Coded
Open circuit voltage (V)	Volts	A	20	-1	30	+1
Tip to work distance	mm	B	10	-1	20	+1
Metal Powder	% by wt.	C	0	-1	20	+1

Table-2: Design Matrix for Conducting the Experiments

Std	Run	Factor 1 Voltage (V)	Factor 2 Tip to work distance (mm)	Factor 3 Metal Powder (% by wt.)	Response 1 Wear rate (microns)
3	1	-1	+1	0	-
8	2	+1	0	+1	-
14	3	0	0	0	-
1	4	-1	-1	0	-
2	5	+1	-1	0	-

7	6	-1	0	+1	-
16	7	0	0	0	-
5	8	-1	0	-1	-
13	9	0	0	0	-
4	10	+1	+1	0	-
12	11	0	+1	+1	-
6	12	+1	0	-1	-
11	13	0	-1	+1	-
10	14	0	+1	-1	-
9	15	0	-1	-1	-
15	16	0	0	0	-
17	17	0	0	0	-

Table 3 Experimental Results of the Response Characteristics

Std	Run	Factor 1 Voltage (V)	Factor 2 Tip to work distance (mm)	Factor 3 Metal powder (% by wt.)	Response 1 wear rate (microns)
4	1	30.00	20.00	10.00	465
9	2	25.00	10.00	0.00	1890
2	3	30.00	10.00	10.00	645
17	4	25.00	15.00	10.00	960
16	5	25.00	15.00	10.00	1005
1	6	20.00	10.00	10.00	1355
13	7	25.00	15.00	10.00	1130
15	8	25.00	15.00	10.00	1060
14	9	25.00	15.00	10.00	1050
10	10	25.00	20.00	0.00	1530
7	11	20.00	15.00	20.00	840
3	12	20.00	20.00	10.00	1225
5	13	20.00	15.00	0.00	1985
12	14	25.00	20.00	20.00	430
6	15	30.00	15.00	0.00	1290
11	16	25.00	10.00	20.00	510
8	17	30.00	15.00	20.00	315

2.5 Recording the Responses

For the purpose of wear testing of the specimens, pin-on-disk type wear test system was used. The test specimens were in the form of pin of 10 mm diameter which was parted out from each workpiece by using carbide tip parting tool on the lathe. The disk was rotated for one hour for each test specimen and the wear rate was recorded in microns. Hardness of the weld metal of different plates was measured by using Rockwell hardness testing apparatus. For hardness testing, specimens whose wear testing was done were used as the surface of weld bead of specimens becomes flat due to wear. The observed and calculated values are given in Table 3. Chemical analysis of base plate and two weld beads, one with minimum wear rate and other with maximum wear rate was done with spectro analysis method of chemical testing. The chemical composition of base plate, weld metal with 20% metal powder added to flux whose wear rate was minimum and weld metal with 10% metal powder added to flux whose wear rate was maximum is shown in Table 4.

Table- 4: Composition of the Base Plate and Weld Beads in wt. %

Material	C	Mn	Si	S	P	Ni	Cr	Cu
Base plate	0.173	0.512	0.173	0.042	0.055	0.017	0.069	0.059
Weld bead with 20% metal powder added into flux	0.179	0.907	1.24	0.015	0.0004	11.449	2.063	0.188
Weld bead with 10% metal powder added into flux	0.177	0.731	0.473	0.032	0.0006	4.895	0.931	0.112

2.6. Development of Mathematical Models

The response function can be expressed as y = f (A, B, C). The relationship selected, being a second-degree response surface, is expressed as follows:

$Y_1 = b_0 + b_1A + b_2B + b_3C + b_{11}A^2 + b_{22}B^2 + b_{33}C^2 + b_{12}AB + b_{13}AC + b_{14}BC$

The values of the coefficients were calculated by using Design Expert Software (Box-Behnken design).

2.7. Evaluation of the Adequacy of the Developed Models

The adequacy of the models was then tested by the analysis-of-variance technique (ANOVA). The program calculates the effects for all model terms. It produces statistics such as F-values, and R-squared values for comparing the models as shown in Table 5 and Table 6.

2.8. Development of final mathematical models

The final mathematical models developed for wear rate is given below. The process control variables are in their coded form.

Wear rate $= + 1041.00 - 336.25A - 93.75B - 575.00C - 50.50A^2 - 68.00B^2 + 117.00C^2 - 12.50AB + 42.50AC + 70.00BC$ **.........Eq. 1**

In the present study A, B, C, C^2 are significant model terms for wear rate. After droping out the insignificant terms the model can be expressed as:

Wear rate $= + 1041.00 - 336.25A - 93.75B - 575.00C + 117.00C^2$

The final mathematical models developed for hardness is given below. The process control variables are in their coded form.

Hardness $= + 53.20 + 8.38A + 2.75B + 16.13C - 0.98A^2 - 1.23B^2 - 8.48C^2 - 1.00AB + 3.75AC + 0.50BC$ **...Eq.2**

In the present study A, B, C, C^2, AC are significant model terms for hardness. After droping out the insignificant terms the model can be expressed as:

Hardness = + 53.20 + 8.38A + 2.75B + 16.13C - 8.48C^2 + 3.75AC

Table 5 ANOVA for Response Surface Quadratic Model for wear rate

Source	Sum of Squares	DF	Mean Square	F Value	Prob > F	
Model	3.731E+006	9	4.145E+005	68.52	< 0.0001	significant
A	9.045E+005	1	9.045E+005	149.52	< 0.0001	
B	70312.50	1	70312.50	11.62	0.0113	
C	2.645E+006	1	2.645E+006	437.24	< 0.0001	
A^2	10737.89	1	10737.89	1.78	0.2245	
B^2	19469.47	1	19469.47	3.22	0.1159	
C^2	57637.89	1	57637.89	9.53	0.0176	
AB	625.00	1	625.00	0.10	0.7573	
AC	7225.00	1	7225.00	1.19	0.3106	
BC	19600.00	1	19600.00	3.24	0.1149	
Residual	42345.00	7	6049.29			
Lack of Fit	26125.00	3	8708.33	2.15	0.2370	not significant
Pure Error	16220.00	4	4055.00			
Cor Total	3.773E+006	16				

The Model is observed to be significant. There is only a 0.01% chance that a "Model F-Value" could occur large due to noise. Values of "Prob > F" less than 0.0500 indicate model terms are significant. In this case A, B, C, C^2 are significant model terms. Values greater than 0.1000 indicate the model terms are not significant. If there are many insignificant model terms (not counting those required to support hierarchy), model reduction may improve the model. The "Lack of Fit F-value" of 2.15 implies the Lack of Fit is not significant relative to the pure error. There is a 23.70% chance that a "Lack of Fit F-value" could occur large due to noise.

2.9. RESULTS AND DISCUSSIONS

The experiments were planned by using the parametric approach of the Box-Behnken method of the surface response methodology. The main effects of process parameters for the data are plotted. The response curves (main effects) are used for examining the parametric effects on the response characteristics.

2.9.1 Effect of Voltage on Wear Rate

The effect of voltage on wear rate has been shown in Figure 1. It has been observed that when voltage increases from 20V to 30V, wear rate decreases from 1355 microns to 645 microns. Also it can be seen from the equation 1, (wear rate = - 336.25 x voltage) that negative coefficient of voltage makes the wear rate to decrease. Increasing the arc voltage increases the arc length so that the weld bead width is increased, reinforcement is decreased and flux consumption is increased. An increase in welding voltage results in melting of more flux due to which more alloying elements enter the weld metal. Thus arc voltage affects weld metal composition which decreases the wear rate of weld metal.

2.9.2 Effect of Tip to Work Distance on Wear Rate

The effect of tip to work distance on wear rate has been shown in Figure 2. It has been observed that when tip to work distance increases from 10mm to 20mm, wear rate decreases from 1066 microns to 880 microns. Also it can be seen from the equation 1, (wear rate = - 93.75 x tip distance) that negative coefficient of tip distance makes the wear rate to decrease. Increasing the tip to work distance increases the temperature of the electrode, which decreases the penetration, but deposition rates are increased. An increase in tip to work distance increases heating effect of the electrode which melts more flux due to which more alloying elements enter the weld metal which decreases the wear rate of the weld metal. Thus wear resistance of the weld metal increases.

2.9.3 Effect of Metal Powder Addition to Flux on Wear Rate

The effect of metal powder addition to flux on wear rate has been shown in Figure 3. It has been observed that when metal powder percentage in flux increases from 0% to 20%, wear rate decreases from 1733 micron to 583 microns. Also it can be seen from the equation 1, (wear rate = - 575.00 x metal powder) that negative coefficient of metal powder makes the wear rate to decrease. An increase in metal powder percentage in the flux increases the amount of alloying elements in the flux. During welding, when flux melts more alloying elements enters the weld metal which changes the weld metal composition. As shown in table 4 that an increase in the amount of metal powder into flux increases the percentage of chromium, manganese alloying elements which decreases the wear rate of weld metal [7,8].

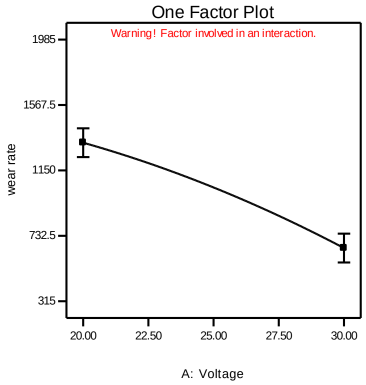

Fig. 1 Voltage v/s Wear Rate Graph

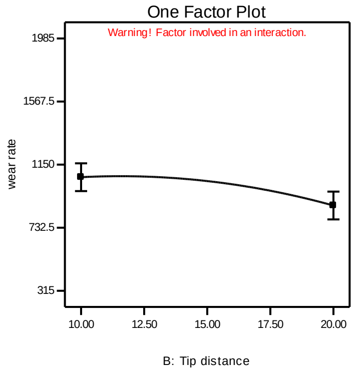

Fig. 2 Tip to Work Distance v/s Wear Rate Graph

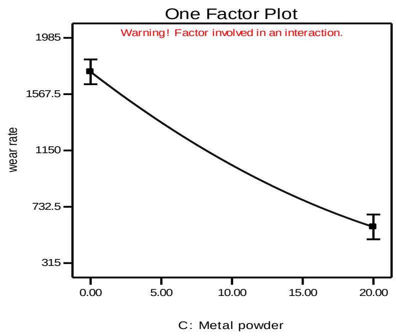

Fig. 3 Metal Powder V/S Wear Rate Graph

III. CONCLUSIONS

1. The response surface methodology could be employed for developing the models for predicting the effect of process parameters and metal powder addition to flux on wear resistance property and hardness of the weld metal within the design limit of the parameters.
2. The amount of metal powder addition to the flux and the open circuit voltage are found to affect the wear resistance and hardness of the weld metal significantly.
3. An increase in voltage decreases wear rate thus the wear resistance property of the weld metal increases.
4. Wear resistance property of the weld metal increases with an increase in the tip to work distance.
5. An increase in the amount of metal powder in the flux decreases the wear rate of weld metal.

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