Sensitivity analysis of submerged arc welding process for SA-516 Gr-70 steel

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Abstract : The quality of a weld joint is directly influenced by the welding input parameters during the welding process; Selections of optimum combination of input variables are required for better weld quality.This study is carried out on the sensitivity analysis of process parameters to find optimum weld bead geometry. Process parameters such as welding current, welding voltage , welding speed and stick-out are used as design variables, where as bead width, reinforcement are selected as a response variables. Experimental part of the study is based on two levels factorial design. A mathematical model is constructed by using multiple regression analysis, which is used to carry out sensitivity analysis. Sensitivity analysis is used to show the relative effects of input parameters on output response. In this experiment it is seen that Current and stick-out having positive effect on reinforcement, where as speed and stick-out having negative effect on weld width. .

***IndexTerms* -** multiple regression, optimisation, sensitivity analysis, weld bead geometry

- **Introduction**

Traditionally the desired welding parameters are obtained based from charts or handbook value which are difficult cumbersome and they does not ensure that chosen welding parameters are optimal for particular welding environmental. Optimum process parameters selection has been investigated by some significant studies via establishing a mathematical model correlating welding parameters with quality characteristics using different approaches [1]Even smaller change in the welding process parameters may causes unexpected welding performance. Therefore, it is important to study stability of welding parameters to achieve high quality welding. [5]In this study, mathematical relations (empirical equations) between submerged arc welding process parameters and weld bead characteristics were constructed based upon the experimental data obtained by four parameters-two levels factorial analysis. The empirical equations, simulating the submerged arc welding process approximately, were carried out by Multiple Regression Analysis and sensitivity equations were derived from these basic models. An analysis generally requires a definition of an objective function and design parameters. In this study, the objective function (quality function) was chosen as weld bead characteristics (the width, height of the weld bead) whereas process parameters (arc current, voltage, welding speed and stick-out) were selected as the design variables. The present study mainly focuses on the Response of output variables by varying the input parameters according to design of experiment. In this study response surface methodology is used as a optimisation tool. The results revealed considerable information about process parameter tendencies and optimum welding conditions.

3 Exprimental Procedureand Set up:

In this research experiment is mainly divided into six parts which is as follows

3.1 Identifying Process Parameters:

The independently controllable process parameters were identified. They are welding current (I), welding Speed (S), voltage (V), Nozzle to plate distance (N),It was found that wire feed rate is directly proportional to the welding current.

3.2 Limits Of The Process Variables:

Working range was decided by conducting trial runs and by inspecting the bead for smooth appearance and the absence of any visible defects. For deciding the working range, several trial welds were made. For determining the range of one variable, the other three variables were kept constant during trial runs. A similar procedure was adopted for determining the upper and lower limits for the welding speed and nozzle-to-plate distance. Also, trial welds were made, keeping the values of all the parameters both at their minimum and maximum values to verify quality of the weld bead, after determining the working range of the process parameters, the upper limit was coded as +1 and -1 After determining the working range of the process parameters ,the upper limit was coded as +1 and lower limit as -1.The coded value of the intermediate levels were calculated from the relationship[4-9]

$Xi=2\,x-(Xmax+Xmin)/(Xmax-Xmin)$………$eq^n1$

Where Xi the required coded value of a variable X; and X is is any value of the variable from X min to *X* max.

3.3DEVELOPING THE DESIGN MATRIX:

The selected design matrix, shown in Table 2, factorial design [4] consisting of 16 sets of coded conditions. Design matrix is blocked with their result to reduce irrelevant source of variation. Response variables bead width and reinforcement are measured by using scale and venire caliper.The selected process parameters with their limits, units and notations are given.crosssectional picture of weld bead is given below.

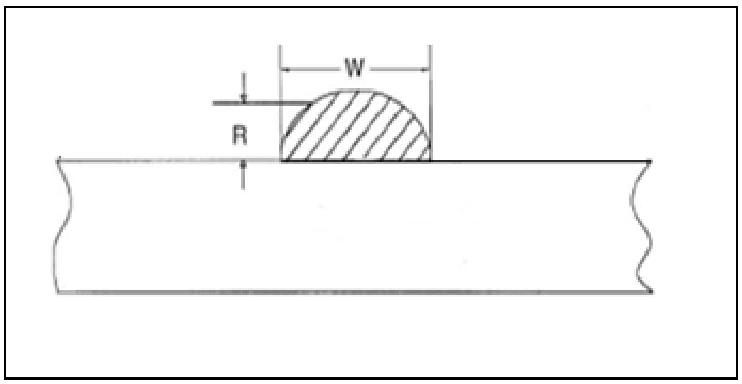

Fig:1Cross-Sectional of weld bead,where W be weld width in mm, R be the Reinforcement in mm.

3.4.DEVELOPMENT OF MATHEMATICAL MODEL:

The response function representing any of the weld bead dimensions can be expressed as [2-9]

Y=F(S, V, I, N)

Where

Y is the response (Bead width, reinforcement)

I is the welding currents, amps

S is the welding speed, Inch/min.

N is the nozzle to plate distance, mm.

The relationship selected being a First degree response surface expressed as follows:

$Y=B_0+B_1X_{1+}B_2X_2+.............+B_KX_K+\varepsilon$

3.5.CHECKING THE ADEQUACY OF THE MODELS DEVELOPED:

The adequacy of the models was tested using the analysis-of-variance technique (ANOVA). As per this technique [2-7]: The estimated coefficients obtained above were used to construct models for the response parameters. The adequacy of the models so developed was then tested by using the analysis of variance technique (ANOVA). Using this technique, it was found that calculated F ratios were larger than the tabulated values at a 95% confidence level; hence, the models are considered to be adequate

The adequacy of a fitted regression model are the coefficient of determination (R'). For the models developed, the calculated R2 and adjusted R2 values were above 80% and 70%, respectively. These values indicate that the regression models are quite adequate the validity of regression models developed were further tested by drawing scatter diagrams.The observed values and predicted values of the responses are scattered close to the 45 ° line, indicating an almost perfect fit of the developed empirical models. To improve the reliability of result, experiment were planned on the basis of response surface methodology (RSM) techniques for statistical design of experiment.

3.6.EXPERIMENTAL SET UP :

The equipment is conducted on ESAB submerged arc-welding equipment.EH-14, 2. 4mm diameter of welding rods are used. SA-516 Gr-70 steel plates of 500mm× 150mm×12mm size are selected as a working material and bead on joint with single V butt joint with 0.5–1mm root gap is consider.Flux: ADOR make F7P2 granular type is used.

Fig:2 ESAB Submerged Arc Welding Machine

TABLE 1

Chemical composition of work piece (SA-516 Gr: 70)

Carbon	Manganese	Phosphorus max4	Sulfur max4	Silicon
0.27	0.79-1.30	0.035	0.035	0.13-0.45

TABLE: 2.

Process control parameters and their limits

Variables	Natural Value		Coded Value	
Speed	20	24	-1	+1
Voltage	32	40	-1	+1
Current	300	360	-1	+1
Distance	22	25	-1	+1

TABLE:3

Design matrix

Weld conditions	Block I						Weld condition	Block II					
	Sp	Vot	Cu	Dis	Rein	Wid		Sp	Vot	Cu	Dis	Rein	Wid
1	-1	-1	-1	-1	1.1	20.02	2	1	-1	-1	-1	1.3	17.66
4	1	1	-1	-1	1.2	18.42	5	-1	-1	1	-1	1.8	20
6	1	-1	1	-1	1.9	18.1	8	1	1	1	-1	1.2	19
7	-1	1	1	-1	1.5	18.6	9	-1	-1	-1	1	2.1	19.26
10	1	-1	-1	1	2	18.14	11	-1	1	-1	-1	1.6	18.54
11	-1	1	-1	1	1.9	18.20	12	1	1	-1	1	1.4	18.08
13	-1	-1	1	1	2.4	17.60	14	1	-1	1	1	2	18.06
16	1	1	1	1	2.1	19.20	15	-1	1	1	1	2.2	18.60

(Sp-Speed, **Vol**-Voltage, **Cu**-Current, **Dis**-Distance, **Rein**-Reinforcement, **Wid**-Width)

3.7Regression Analysis :

Regression analysis is used to establish the relation between the variables. In this experiment the data was analyses by using minitab-15 software. Regression Equation Reinforcement versus speed, voltage, current, distance is given below. Reinforcement=1.79-0.0688 Speed-0.0813 Voltage+0.0812 Current+0.306Distance Whereas, Regression Equation Width verses speed, voltage, current, distance is given as Width=18.60-0.415Speed+0.380Voltage+0.0800Current-0.295distance.

TABLE 4

Analysis of variance table of block-1and block-2 for Response Variables

Response variables	S	R2	R2adj	Residual error	Design matrix
Reinforcement	0.122474	96.8%,	92.5	3	Block-1
Reinforcement	0.353742	95.1	88.6	3	Block-II
Width	0.3537	90.6	78.1	3	Block-1
Width	0.5711	75.4	42.7	3	Block-II

The models developed, the calculated R2 and adjusted R2 values were above 80% and 70%, respectively. These values indicate that the regression models are quite adequate the validity of regression models the table no.4 shows that residual error of reinforcement's for block-I and block-II are same, but R2 value and R2adj value of block-I is more than Regression equation of Reinforcement with block –I is given below.

R= 1.78 -0.0250 (Speed) -0.150 (Voltage) +0.20 (Current) +0.325 (Distance)

Thus, Reinforcement sensitivities with respect to arc

Block-II. So design matrix of block-I is take for sensitivity analysis. Whereas residual error of width block-I and block-II is same, but R2 value and R2adj value of block –I is more significant than block-II. So design matrix of block-I is take for sensitivity analysis.

4. SENSITIVITY METHODOLOGY

"Sensitivity analysis is the most important step in the optimization problems; it yields the information about the increment or decrement tendency of the design objective function with respect to the design parameter". Mathematically, sensitivity of a design objective function with respect to a design variable is the partial derivative of that function with respect to its variables. [2-3]

In this study, it is aimed to predict the tendency of weld bead characteristics due to a small change in process parameters (change in arc current, voltage, welding speed and stick-out) for SAW processes. The weld bead characteristic models can be interpreted as design objective functions and their variables as design parameters.

Reinforcement sensitivities with respect to arc current I, voltage U and speed S are:

Regression equation of Reinforcement with block –I is given below.

R= 1.78 -0.0250 (Speed) -0.150 (Voltage) +0.20 (Current) +0.325 (Distance)

Thus, Reinforcement sensitivities with respect to arc current I, voltage V speed S and stick-out (n) are:

dR/dI=0.200.....................................1.1

dR/dv=0.100 …………………... ….1.2

dR/ds=0.0250 ………………………1.3

dR/dn=0.325…………………… 1.4

Reinforcement Sensitivity of the Process parameters

Welding Speed= 20 Inch/Min

Stick-out (Nozzle to plate distance) = 25mm and Voltage=32 Volt

TABLE 5

Reinforcement sensitivity for Block-I

Welding Current	dR/dI	dR/dS	dR/dV	dR/dN
300 (-Ve)	0.200	-0.0250	-0.150	0.325
360(+Ve)	0.200	-0.0250	-0.150	0.325

TABLE 6

Width sensitivity process parameters [Block-I]

Welding Speed= 20 Inch/Min. Stick-out (Nozzle to plate distance) = 25mm and Voltage=32 Volt

Welding Current	dW/dI	dW/dS	dW/dV	dW/dN
300 (-Ve)	0.0800	-0.445	0.425	-0.260
360(+Ve)	0.0800	-0.445	0.425	-0.260

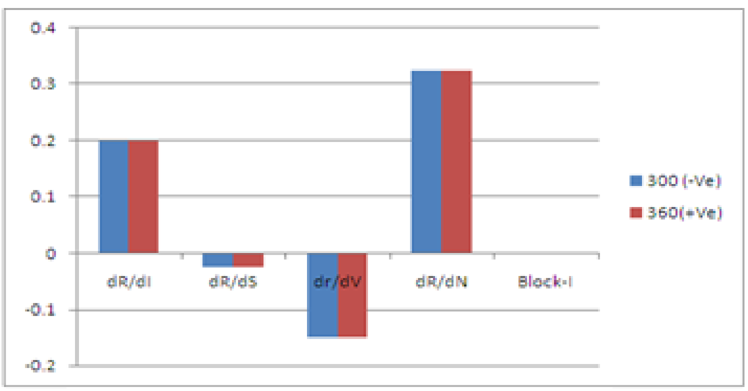

Fig: 2 Reinforcement Sensitivity (Block-I)

Figure 2 shows that height of reinforcement is more sensible to change in stick-out than other process parameters. Hence it is reasonable to control the stick-out to get desired value of reinforcement. Current and stick-out having positive effect on reinforcement. Where welding speed and voltage having negative effect on reinforcement. Increase in (V) results in increases in arc length, arc voltage and heat inputs but it has little influence on the wire fusion speed. Increase in arc length results in the spreading of arc cone at its base which leads to increases in (W). The marginal increases in the heat inputs which is utilized so reinforcement is decreases. The metal fusion rate increases at the higher value of stick-out so reinforcement is increased with stickout, because of Joules heating effect. But as the stick-out increases heat input is decreases so width is decreases with increases in stick-out. Hence Reinforcement is increased with increased in stick out.

Regression relation of Bead-Width with block-I is shown in this equation

Width= 18.5-0.44(Speed) +0.42(Voltage)-0.26 (Distance) +0.08 (Current)

$dW/dS = -0.445$…………………..1.5

dW/dI=0.0800…………………… 1.6

dW/dN=−0.260…………………..1.8

dW/dV=0.425………………………1.7

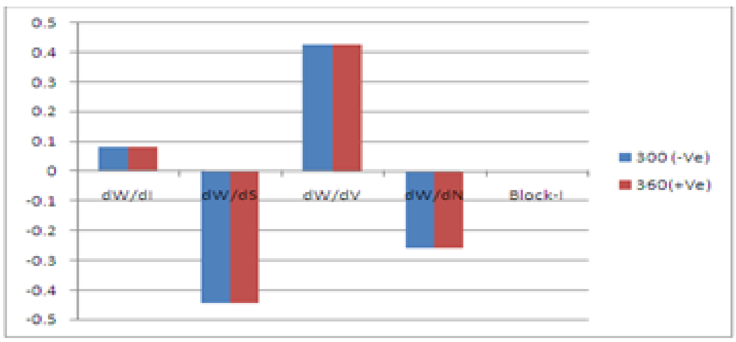

Fig: 3 Width Sensitivity (Block-I)

Figure 3 shows that the width of weld is more sensible to change in voltage and welding speed. Hence it is reasonable to control the voltage and speed to get desired value of width. From figure it is clear that current and voltage having positive effect on width, where as speed and stick-out having negative effect on weld width. Increase in the speed result lesser metal deposition rate and less heat inputs the size of weld pool reduces and hence all bead factors reduce with increase in speed. As Voltage increases width increases, reinforcement decreases. But when we consider current as an input parameter then the responses is depends upon how much resistance is applied there is must be considered. If the resistances is low at that time it gives moderate width and reinforcement but if the resistance is high at that time it doesn't gives proper reinforcement

5.CONCLUSION:

1.In the first part of this study, mathematical modelling using regression equations were developed from experimental data. The response surface methodology is adopted to develop the regression models, which were checked for their accuracy and found to be satisfactory. Then, sensitivity analysis of weld bead, bead height to variation in current, voltage, speed and stick-out in submerged arc welding process were performed.

2. Welding process parameters required for desired weld bead geometry, can effectively be predicted using mathematical models developed in this study. These mathematical models can also be used to optimise the process. In this study optimise value for reinforcement and width is 2.3mm and 18mm is found resp.

3. Sensitivity analysis was performed to identify process parameters exerting the most influence on the bead geometry. Height of reinforcement is more sensible to change in stick-out than other process parameters hence it is reasonable to control the welding speed to get desired value of reinforcement

4. Current and stick-out having positive effect on reinforcement. Where welding speed and voltage having negative effect on reinforcement. In order to decrease the reinforcement higher value of voltage and speed can be considered.

5. Bead width is very sensitive to all process parameters. Current, voltage, speed are the determining parameters for bead width.

6. Current and voltage having positive effect on width, where as speed and stick-out having negative effect on weld width

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