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ANALYSIS AND OPTIMIZATION OF PARAMETERS IN SUBMERGED ARC WELDING PROCESS USING TAGUCHI METHODS AND REGRESSION ANALYSIS

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Abstract—
Submerged arc welding process is a modest technology which is extensively used in heavy steel plate fabrication. Submerged arc welding operation is done in the current range of 200-1000 amps. As compared to the other welding process the power source is rated as 100% duty cycle. This paper deals with the application of Taguchi technique and regression analysis to determine optimal effect of all input parameters on the output parameters for submerged arc welding. The planned experiments are conducted in automatic submerged arc welding machine and S/N ratios are computed to determine the optimum parameters. The contribution of each factor is validated by analysis of variance (ANOVA) and regression analysis is conducted by statistical package of social science (SPSS) software to predict the weld bead, reinforcement, depth of penetration for given welding condition.

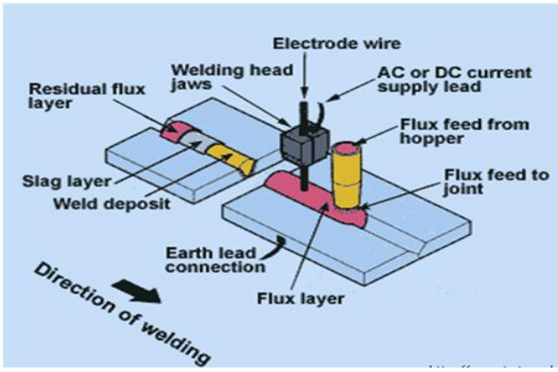
Key words- (Taguchi technique, regression analysis, optimal process parameters for SAW)

I. INTRODUCTION

Submerged arc welding process is a modest technology which is extensively used in heavy steel plate fabrication. Submerged arc welding operation is done in the current range of 200-1000 amps. As compared to the other welding process the power source is rated as 100% duty cycle. In which high heat is required to fuse the metal generated by an arc current passing through the welding wire and the work piece. The flux completely shield the welding zone from contact with atmosphere, submerged arc welding has the advantage of high welding metal quality and uniform weld finish. Deposit rate, deposit efficiency and weld speed are high in submerged arc welding & the operator skill is minimum and free of fumes and arc flash. The minimum requirement of submerged arc welding power source can be carried with constant current type AC power source of constant current type or DC source of constant voltage, DC power can give easy and accurate arc start control of bead shape is best, high deposition rate shallow penetration, AC power source is generally preferred for large dia. (>4mm) wires.

Agglomerated and sintered flux are generally used it is in granular form and capable of free flow and should not evolved appreciable amount of gases under intense heat of the welding zone, all fluxes produced some changes in the geometry of the weld bead, chemical composition. Welding current control the rate of electrode melting, the depth of fusion, and the amount of base metal melted, high current will produce a digging arc undercuts, highly narrow weld seam, and large heat affected zone (HAZ) and low current will produce unstable arc. High welding voltage will produce a wider, flatter, less deeply penetration and low arc voltage will produce stiffer arc and may improve the penetration in a deep groove joint. The welding travel speed influence the weld size and penetration, if the welding speed is higher it causes undercut, arc blow, porosity and uneven bead shape and the low welding causes heavy reinforcement and slag inclusion. If the electrode stick out is increase it reduces the energy supplied to the arc, due to which the arc voltage decreases, bead shape and depth of penetration also decreases. The heat input rate (HIR) affects the microstructure of the weld metal and HAZ. Quality of the weld deposition depends on the process parameters of submerged arc welding, thus the process variables are as follows,

a) Welding current
b) Welding speed
c) Electrode stick out
d) Welding voltage
e) Types of flux
f) Polarity
g) Joint design



1.1 Literature Survey

Gowthman et al. [**1**] study the application of Taguchi technique and regression analysis to determine the optimal process parameters for submerged arc welding.

Rati saluja et al. [**2**] study the modeling and parametric optimization using factorial design approach of submerged arc weld bead geometry for butt weld. Optimal process parameters for achieving the desired quality and relative effect of input parameters on output parameters can be obtained. Response surface methodology (RSM) technique is used to determine effect relationship between true mean response and input control variable influencing the response.

S. kumanan et al. [**3**] experiments are conducted in the semi automatic arc welding machine and S/N ratio are computed to determine the optimum parameters, the percentage contribution of each factorial is validated by multi regression analysis and ANOVA is conducted by using the SPSS software and the mathematical model is build to predict the weld bead geometry for a given input parameters over output.

Chandan deep singh et al. [**4**] study the effects of different independent input process parameters on desired response in the submerged arc welding, the effect of welding current, voltage, speed, and stick out are considered and optimizes the process parameters by using half factorial technique and ANOVA.

Dinesh verma et al. [**5**] study the effect of flux on the tensile strength, microstructure, and also study the effect of different input parameters on output response has been analyzed using the analysis of variance (ANOVA) and plotted S/N ratio to determine the best fit relationship between the response and the purposed model parameters.

Pradeep deshmukh et al. [**6**] experiments are conducted by using different input parameters on desired response on output has been analyzed by regression analysis and Taguchi method. A conformity test was also conducted and verified the effectiveness of Taguchi method.

P. Kanjilal et al. [**7**]study the combined effect of flux and welding parameters on chemical composition and mechanical properties of submerged arc weld metal the combined effect of flux and welding parameters on weld metal chemical composition and mechanical properties in SAW process were examined using rotatable design model in statistical experiments with mixture.

Jerzy Nowacki et al. [**8**]study the influence of welding heat input on submerged arc welded duplex steel joints imperfections in which quantity of welded butt joints defects has been determined. Defects were identified by a radiographic method the correct mechanical properties of the joints and value of ferrite share test have proved that submerged arc welding with heat input up to 4.0 kJ/mm fulfilled requirements. The increase of the welding heat input in submerged arc welding of duplex steel results in the decrease of occurrence and size of welding imperfections with regard to the quantity and length of imperfections.

C. S. Lee et al.[**9**] in this paper discuss the effect of welding parameters on the size of heat affected zone of submerged arc welding, It is discovered that the welding parameters influences the size of weld bead and HAZ differently which can be relate to the effect of welding parameters on the various melting efficiencies. This difference in behavior of HAZ and weld bead can be explored to minimize the harmful effect to HAZ in future welds.

II. EXPERIMENTATION

The experiment is conducted at the welding lab of Birla institute of technology, Mesra, Ranchi with the following equipment submerged arc welding machine model ATE/SA 1200, modular attachment for welding – welding heat with motorize carriage, control panel unit, data acquisition system with software to work on windows XP/7/8. Capacity was used to join the two mild steel plates of size 150mm (length) X75mm (width) X 12mm (thickness) with a single V of 35^0 angle and 5mm root height, copper coated electrode wire size 3.15mm diameter and granular flux (ESAB OK10.70L) were used.

Fig.2 Submerged arc welding setup

III. METHODOLOGY

3.1 Taguchi method

Taguchi method is a statistical quality engineering tools, which developed design of experiment based on orthogonal array, this is cost effective tools and technique used to reduce manufacturing cost for designing high quality system. Orthogonal array is a set of variables (input parameters) over the output parameters, which gives the optimum setting of process control parameters. Taguchi transformed several repeated data to another value in which the measure of the variation is present and this process is called as signal-to- noise (S/N) ratio. Which consolidate several repeated data into one value and reflects the amount of variation presents, there are different types of S/N ratio are present depending upon the types of characteristic

- Lower is better (LB)
- Nominal is best (NB)
- Higher is better (HB)

The S/N ratio for higher is better is quality characteristic can be expressed as;

$$L_{ij} = \left(\frac{1}{r} \sum_{i=1}^{r} \frac{1}{y_{ijk}^{\;2}} \right) \quad \text{………………. (1)}$$

Where L_{ij} is the loss function of the i^{th} quality characteristic in the j_{th} experiment, r is the no. of test and y_{ijk} the experiment value of the i^{th} experiment at k^{th} test.

Table 1 — Welding parameters and their levels

Symbol	Welding Parameters	Level (0)	Level (1)
A	Welding Current, A	260	300
B	Arc Voltage, V	25	30
C	Welding Speed, mm/min	140	180
D	Electrode Stick out, mm	15	20

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Careful attention is necessary to select the welding process parameters to obtain a desirable weld quality. Though many direct and indirect parameters affect the quality of weld in SAW the major key process parameters affecting the bead geometry are arc voltage, welding current, welding speed and electrode stick out. In the present study, two-levels of the four process parameters, i.e., arc voltage, welding current, welding speed and electrode stick out was considered. The values of the welding process parameter at different levels are listed in Table 1.

Table 2. L8 orthogonal array

Trail no.	Welding current, A	Welding voltage, V	Welding speed, mm/min	Electrode stick out, mm
1	0	0	0	0
2	0	0	1	1
3	0	1	0	1
4	0	1	1	0
5	1	0	0	1
6	1	0	1	0
7	1	1	0	0
8	1	1	1	1

Table3. Response of bead geometry parameters for set-I

Trail no.	Welding current, A	Welding voltage, V	Welding speed, mm/min	Electrode stick out, mm	Weld bead
1	260	25	140	15	13
2	260	25	180	20	13
3	260	30	140	20	15
4	260	30	180	15	16
5	300	25	140	20	18
6	300	25	180	15	14
7	300	30	140	15	19
8	300	30	180	20	17

Table 4.S/N ratio for weld Bead

Trail no.	MSD	S/N ratio
1	169	22.27
2	169	22.27
3	225	23.52
4	256	24.08
5	324	25.10
6	196	22.92
7	361	25.57
8	289	24.60

Table5 shows the calculation of the average S/N ratios for welding current, arc voltage, welding speed and weld bead hardness. The largest S/N_{avg} for parameter is indicated by (opt) and the effect is shown in the Fig. 1. The welding process parameter performance levels are shown in Fig1. From Table 5 the optimal bead width is obtained by applying welding current 300 A, arc voltage 30 V, welding speed 140 mm/min, and electrode stick out 20 mm for a plate of 12 mm thickness, i.e.A1-B1-C0-D1. Similarly the results for weld reinforcement, depth of penetration and weld bead hardness and their corresponding optimum levels obtained are A1-B1-C0-D1, A1-B1-C1-D0, and A1- B1-C0-D1.

Table 5.Average S/N ratio for weld bead

Weld parameters	Levels	S/N ratio
Welding current, A	0 (260) 1(300)	12.14 17.19 (opt)
Arc voltage, V	0(25) 1(30)	12.56 16.77 (opt)
Welding speed, mm/min	0(140) 1(180)	15.46(opt) 13.87
Electrode stick out, mm	0(15) 1(20)	13.84 15.49 (opt)

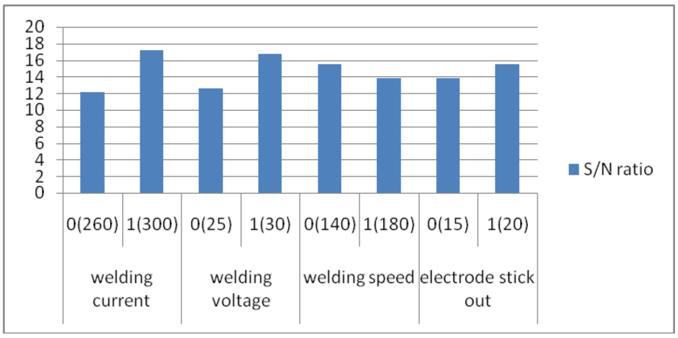

Fig. 1 . Average S/N ratio for weld bead

Table6 ANOVA analysis for bead width

Model	Std. Error	Sum of Squares	df	Mean Square	Sig.
A	11.508	28.500	1	7.125	.378
B	.028	7.375	1	2.458	.089
C	.222	35.875	1		.135
D	.028		1		.342
Error	.222		3		.836
Total	12.5		7		

3.2 Multiple Regression Analysis

Regression analysis is one of the most important statistical tools widely used for analyzing multifactor data it provides simplest, conceptual method for investigating functional relationship among variables. Regression analysis has used in many areas of application. The multiple liner regression takes the following form.

$$Y= a+b_1x_1+b_2x_2+b_3x_3+ \ldots\ldots\ldots\ldots +b_kx_k \quad \ldots\ldots (2)$$

Where Y is dependent variable which is to be predicted X_1, X_2, X_3 ………… X_K are the k known variables on which the prediction is to be made and a, b1, b2, b3 is the coefficients, the value of which is determined by the method of least squares. Multiple regression analysis is used to determine the relationship between the dependent variable of weld bead reinforcement and depth of penetration with respect to welding parameters. The regression analysis is done by SPSS software. The final models thus developed from above analysis can be represented by following equations:

Bead width = -34.833 + (6.667×10-2 × welding current) + (0.75×arc voltage) + (1.25×10-2 × welding speed) – (4.17×10-2 × electrode stick out)………………. (2)

Weld reinforcement = -7.25 + (8.33×10-3 × welding current) + (0.25 × arc voltage)…………. (3)

Depth of penetration = 16.25 + (2.5 ×10 × welding current) – (0.25 ×arc voltage) – (3.75×10-2 × welding speed)……… (4)

From the above equations, values of bead width, weld reinforcement, depth of penetration and weld bead hardness can be predicted for any given values of process parameters as shown in table 7

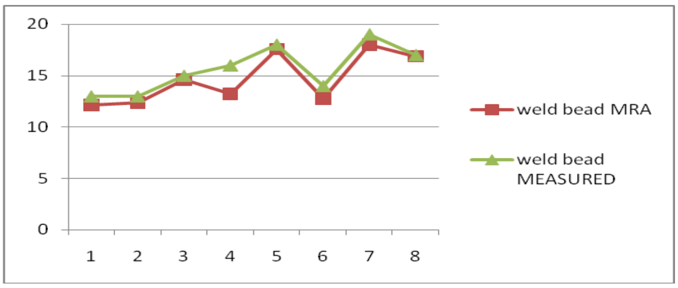

Fig. 2. Comparison of weld bead

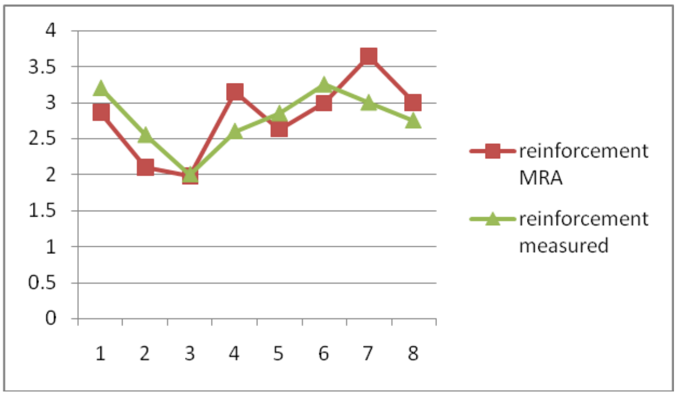

Fig. 3. Comparison of reinforcement

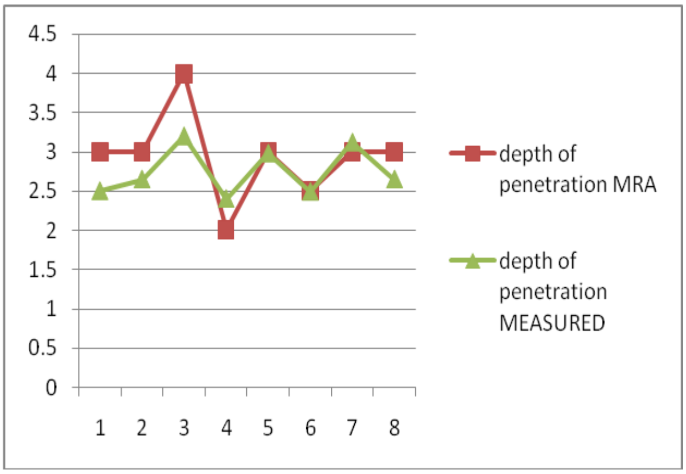

Fig. 4. Comparison of depth of penetration

IV. RESULTS AND DISCUSSIONS

Careful attention is necessary to select the welding process parameters to obtain a desirable weld quality. Though many direct and indirect parameters affect the quality of weld in SAW the major key process parameters affecting the bead geometry are arc voltage, welding current, welding speed and electrode stick out. Taguchi method is a statistical quality engineering tools, which developed design of experiment based on orthogonal array, this is cost effective tools and technique used to reduce manufacturing cost for designing high quality system. The results from the S/N_{avg} indicate that the optimal bead width is obtained by applying welding current 300 A, arc voltage 30 V, welding speed 140 mm/min, and electrode stick out 20 mm for a plate of 12 mm thickness. The output results of the predicted model are calculated for the corresponding input data, measured value from the experiment and predicted data from the regression technique are shown in table 3& 6 and comparison of weld bead, reinforcement, and depth of penetration are shown in fig.2, 3, 4

Table7. Measured value from regression analysis

Trail no.	Welding current, A	Welding voltage, V	Welding speed, mm/min	Electrode stick out, mm	Weld bead	reinforcement	Depth of penetration
1	260	25	140	15	12.125	2.86	3
2	260	25	180	20	12.37	2.10	3
3	260	30	140	20	14.625	2	4
4	260	30	180	15	13.24	3.15	2
5	300	25	140	20	17.56	2.63	3
6	300	25	180	15	12.77	3	2.5
7	300	30	140	15	18.01	3.64	3
8	300	30	180	20	16.87	3.00	3

V. CONCLUSIONS

Paper discussed the optimization tools and techniques to find out the optimum process parameters of submerged arc welding by the application of Taguchi method and regression analysis. Experiment was carried out through design of experiments and the weld bead, reinforcement, and depth of penetration is measured. Then the purposed model is used to predict the submerged arc welding process parameters for any given welding condition.

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