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Regression Analysis of Submerged Arc Welding Process Parameters with Respect to Different Electrode Angle as Well as Welding Direction

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***Abstract*— The present experiment is carried out to study the application of regression analysis to determine the optimal process parameter for submerged arc welding (SAW). The quality of welding depends on process parameter. Bead-on plate weldment obtained by SAW on mild steel plate of specification as per IS2062 Grade-B, SAIL steel, by varying electrode inclination viz. 90^0,45^0 as well as by changing welding direction, by keeping other set of parameters fixed. Transverse section in respect of welding direction of all the specimen are well surface finished, etched and measured the bead geometry. It is observed that bead width changes with the change of electrode inclination and welding direction causing change in heat input rate. Subsequently mathematical analysis is done and it is established that regression analysis can be done using the attribute to predict the optimal process parameter.**

Keywords—Response Surface Method (RSM), Submerged arc welding (SAW), Taguchi method.

I. INTRODUCTION

Submerged Arc Welding (SAW) process is generally considered as heavy welding process due to its high heat input and high metal deposition rate. The process is suitable for both butt and fillet welding. It is widely used in ship building, manufacturing of pressure vessels, railway wagon, heavy bridge members, massive water pipes etc. Various process parameters influence the bead geometry as well as weld quality. In the present experiment four parameters were varied such as Voltage (V), Travel speed(S), Wire feed rate (F), Electrode stick-out distance (N) in respect of different electrode inclination angle viz. 90^0,45^0 as well as welding direction [Table 3]. Design of experiment as per Taguchi's L16 orthogonal array is incorporated to restrict the number of experimental runs in each case. All the forty eight welded specimens were transversely sectioned in respect of welding direction and subsequently well surface finished, etched with natal solution i.e. 5% nitric acid solution in distilled water and measured the bead geometry. Bead width (W) [Fig.1] were measured and considered as output response. Janez Tusek, et al[1] have performed that twin-arc SAW have its peculiar process parameters such as the welding current type, the size of the two arcs, location and space of the two wires. Gunaraj et al [2] have employed RMS methodology to develop mathematical model to determine and represent the cause and effect relationship between true mean responses and input variables of SAW and to plot three dimensional surface graphs. They concluded that all responses decrease with increasing welding speed. Also, when nozzle to plate distance increase all response decrease, but reinforcement increases. Dongcheol kim et al. [3] Proposed a method to optimize the variables for an arc welding process using the genetic algorithm and the response surface methodology. In this study, systematic experiments done without the use of models to correlate the input and output variables. J.P.Ganigatti, et al. [4] gives a relationship with input-output of the MIG welding process by using regression analysis based on the data collected as per full-factorial design of experiments. Kumanan et al. [5] implemented Taguchi technique to determine the main process parameters of submerged arc welding process and their influences are studied by using signal-to noise ratio and analysis of variance of technique (ANOVA).The effort has also made to propose the multiple regression based mathematical model to predict the weld bead width, weld reinforcement, depth of penetration. Design of experiment approach has used to determine the main factors, viz. current, wire feed rate, travel speed and stick out, there way of affecting to weld bead parameters, influence of interaction among main parameters and finally to determine theoptimal setting for main parameter by Ghosh et al.[6]. Bead geometry optimization of SAW have been carried out by using an integrated optimization approach based on weighted principle component analysis (WPCA) and Taguchi's robust design methodology by Biswas et al.[7].

II. MATERIAL USED

IS2062 Grade-B, SAIL steel Plate Grade and Specification

- Thickness:16 mm
- Width: 50 mm
- Length: 100 mm

The chemical and mechanical properties are listed in the below:

Table 1: Chemical Properties of the steel used

Characteristics	Value (%)
Carbon	0.22max
Manganese	1.50 max
Sulphur	.045
Phosphorous	.045
Silicon	0.40max
C.E.	0.41

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Table 2: Mechanical Properties of the steel used

Characteristics	Value
Y.S(Mpa)(Min)	250
UTS (Mpa) (Min)	410
EI(%)	23
IMPACT(Min)	27 J at 0 Ā0C
Bend	2T & 3T* * 2T - <= 25mm * 3T - > 25mm

Copper coated electrode specification

- Diameter: 3.15 mm
- Chemical composition: C-0.04%, Mn-0.4%, Si-0.05%

Flux specification

- Compositions: SiO2 + TiO2= 30%, CaO + MgO= 10%, Al2O3 + MnO= 45%, CaF2= 15%
- Grain Size: 0.25 - 2.00 mm

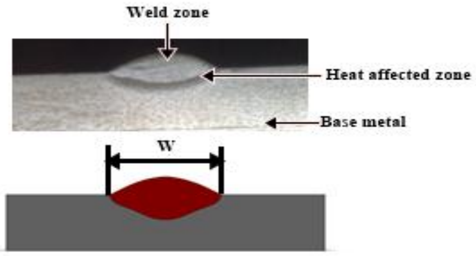

Fig.1: A schematic diagram of weld bead geometry (W: bead width).

III. METHODOLOGY

A. Experimental data

Process parameters and their range
Open circuit voltage (Volt): 29-54
Travel speed (m/min): 0.1 to 1.5
Wire feed rate (m/min): 0.5 to 4.0
Stick-out (mm): 25-31

Bead geometry for all the forty eight specimens are sequentially recorded corresponding to applied parameter setting as well as boundary conditions [Table 3].

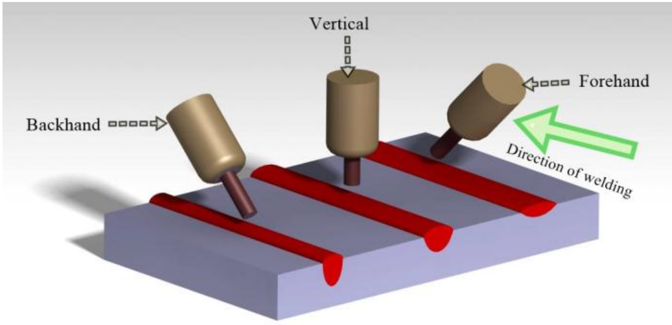

Fig.2: A schematic representation of SAW at different condition (backhand with 45^0, forehand with 90^0, forehand with 45^0).

B. Mathematical modeling

Mathematical modeling of SAW process may be established using multiple regression analysis. The purpose of multiple regressions is to predict a single variable from one or more independent variables. Mathematical models based on welding parameters such as Voltage, Travel speed, Wire feed rate and Electrode stick-out distances were obtained from regression analysis to predict Bead width. Performed SAW conditions and corresponding weld bead values are presented in Table3.

1) Regression analysis of weld bead characteristics (bead width) while the electrode is 90^0 with forehand [Table 3].

Response Surface Regression: Bead width (W) versus U, S, F, N.

Table 3: Welding condition and measured weld bead values

Specimen number	Voltage(V)	Travel speed(m/min)	Wire feed rate (knob setting point)	Electrode stick-out distance (mm)	90^0 with forehand	45^0 with forehand	45^0 with backhand
					Bead width (mm)	Bead width (mm)	Bead width (mm)
1	31	0.45	1	25	10.9910	9.6800	9.8500
2	31	0.60	2	27	11.5420	10.6810	10.8530
3	31	0.75	3	29	12.8320	14.3610	10.4210
4	31	0.90	4	31	9.0910	13.3220	9.6640
5	32.5	0.45	2	29	14.5010	16.6030	12.6470
6	32.5	0.60	1	31	7.3760	9.3210	9.6560
7	32.5	0.75	4	25	11.3430	15.1190	12.6040
8	32.5	0.90	3	27	10.4350	13.4600	10.4370
9	35	0.45	3	31	19.1400	19.9510	16.9150
10	35	0.60	4	29	15.2900	16.1620	14.2550
11	35	0.75	1	27	10.2800	8.1310	8.7210
12	35	0.90	2	25	10.5440	11.4010	9.1030
13	37	0.45	4	27	18.0710	14.3320	18.2520
14	37	0.60	3	25	18.3520	16.6900	12.8800
15	37	0.75	2	31	11.9110	14.0110	11.9110
16	37	0.90	1	29	7.3440	11.1930	8.4520

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Table 4: Analysis of Variance

Source	DF	Adj SS	Adj MS	F-value	P-value
Model	13	200.606	15.4312	10.40	0.091
Linear	4	58.717	14.6792	9.90	0.094
U	1	1.326	1.3257	0.89	0.444
S	1	35.897	35.8969	24.20	0.039
F	1	6.086	6.0856	4.10	0.180
N	1	4.462	4.4625	3.01	0.225
Square	4	25.867	6.4668	4.36	0.195
U*U	1	5.524	5.5245	3.72	0.193
S*S	1	0.089	0.0887	0.06	0.830
F*F	1	13.436	13.4362	9.06	0.095
N*N	1	4.013	4.0130	2.71	0.242
2-Way Interaction	5	9.335	1.8670	1.26	0.498
U*S	1	1.213	1.2127	0.82	0.461
U*F	1	2.615	2.6153	1.76	0.315
U*N	1	0.049	0.0490	0.03	0.873
S*F	1	4.951	4.9506	3.34	0.209
S*N	1	5.495	5.4952	3.71	0.194
Error	2	2.966	1.4832		
Total	15	203.573			

Table 5: Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
1.21786	98.54%	89.07%	0.00%

Table 6: Coded Coefficients

Term	Effect	Coef	SE Coef	T-value	P-value
Constant		19.40	2.89	6.71	0.022
U	-4.03	-2.01	2.13	-0.95	0.444
S	-8.163	-4.081	0.830	-4.92	0.039
F	3.335	1.667	0.823	2.03	0.180
N	-1.796	-0.898	0.518	-1.73	0.225
U*U	-17.92	-8.96	4.64	-1.93	0.193
S*S	0.335	0.167	0.685	0.24	0.830
F*F	-14.10	-7.05	2.34	-3.01	0.095
N*N	7.44	3.72	2.26	1.64	0.242
U*S	-2.25	-1.13	1.25	-0.90	0.461
U*F	-3.02	-1.51	1.14	-1.33	0.315
U*N	-0.255	-0.128	0.702	-0.18	0.873
S*F	-15.75	-7.87	4.31	-1.83	0.209
S*N	17.24	8.62	4.48	1.92	0.194

Regression Equation of Bead while electrode inclination $90^0$with forehand welding direction is given below:

Bead width (W) = -663 + 69.4 U - 265 S + 43.9 F - 31.6 N - 0.996 U*U + 3.3 S*S - 3.13 F*F + 0.413 N*N - 1.67 U*S - 0.335 U*F - 0.0142 U*N - 23.3 S*F + 12.77 S*N (1)

2) Regression analysis of weld bead characteristics (bead width) while the electrode is 45^0 with forehand [Table 3].

Response Surface Regression: Bead width (W) versus U, S, F, N.

Table 7: Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
1.86634	95.39%	65.46%	0.00%

Regression Equation of Bead while electrode inclination45^0 with forehand welding direction is given below:

Bead width (W) = 56 - 12.7 U - 30 S + 18.2 F + 10.4 N + 0.209 U*U + 15.2 S*S - 0.62 F*F - 0.111 N*N + 2.61 U*S - 0.563 U*F - 0.036 U*N + 9.7 S*F - 4.2 S*N (2)

3) Regression analysis of weld bead characteristics (bead width) while the electrode is 45^0 with backhand [Table 3].

Response Surface Regression: Bead width (W) versus U, S, F, N.

Table 8: Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.187603	99.94%	99.57%	94.80%

Regression Equation of Bead while electrode inclination 45^0 with backhand welding direction is given below:

Bead width (W) = 246.6 - 19.86 U + 143.9 S - 2.04 F + 3.36 N + 0.2723 U*U + 11.16 S*S + 0.368 F*F - 0.0807 N*N - 1.922 U*S - 0.0223 U*F + 0.1156 U*N + 3.09 S*F - 4.00 S*N (3)

Where,
U for Voltage
S for Travel speed
F for Wire feed rate
N for Electrode stick-out distance

IV. RESULT AND DISCUSSION

It is observed from the collected data and their subsequent analysis in the present experiment that a measurable influence occurred on the weldment due to varying electrode inclination as well as by changing welding direction. Secondly, regression analyses by response surface method results are represented in figs. 3-5 by normal probability plots corresponding to the individual welding conditions [Table 3]. Accuracy was presented in figs. 6-8 and found that percentage error for responses is less than ±5%.

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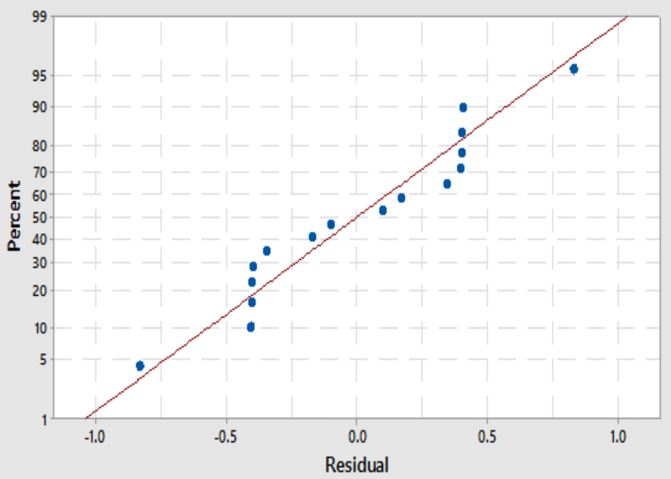

Fig.3: Normal probability plot for forehand with 90^0 (response is bead width).

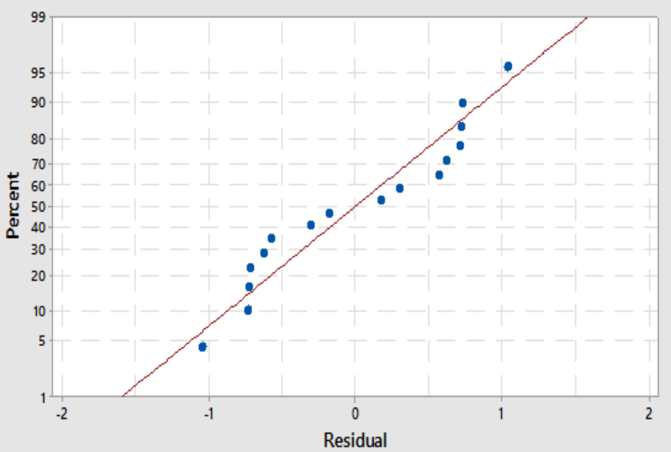

Fig.4: Normal probability plot for forehand with $45^{\ 0}$ (response is bead width).

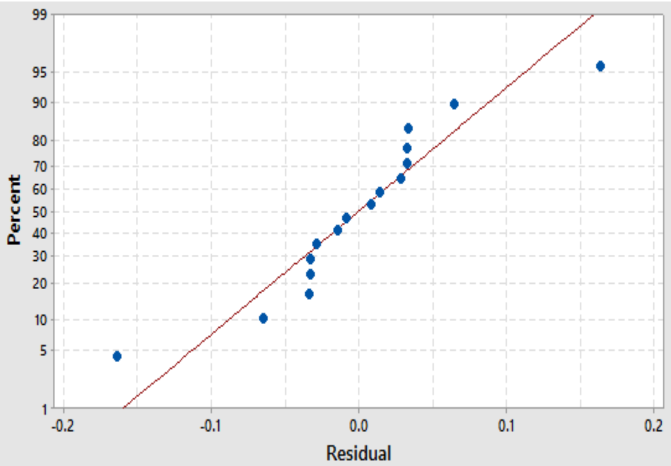

Fig.5: Normal probability plot for backhand 45^0 (response is bead width).

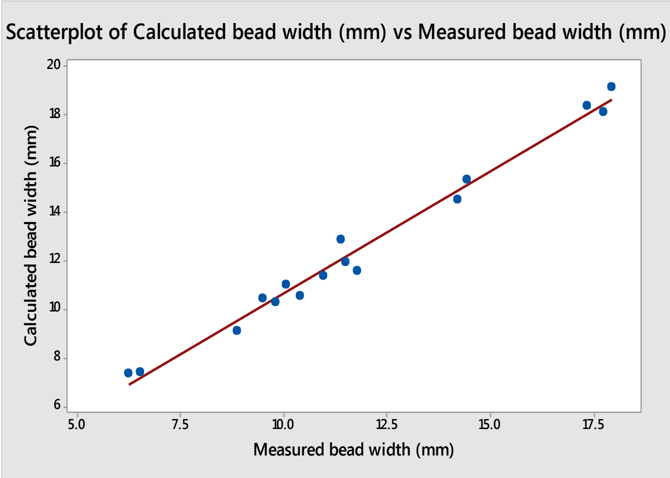

Fig.6: Accuracy of the calculated bead width valued with respect to measured data while electrode is forehand with 90^0.

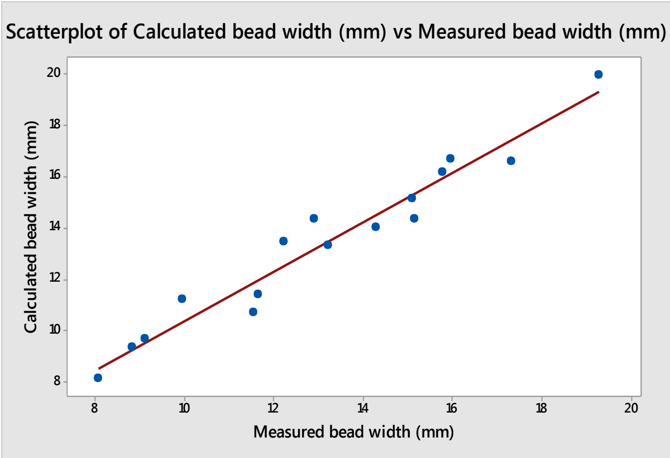

Fig.7: Accuracy of the calculated bead width valued with respect to measured data while electrode is forehand with $45^{\ 0}$.

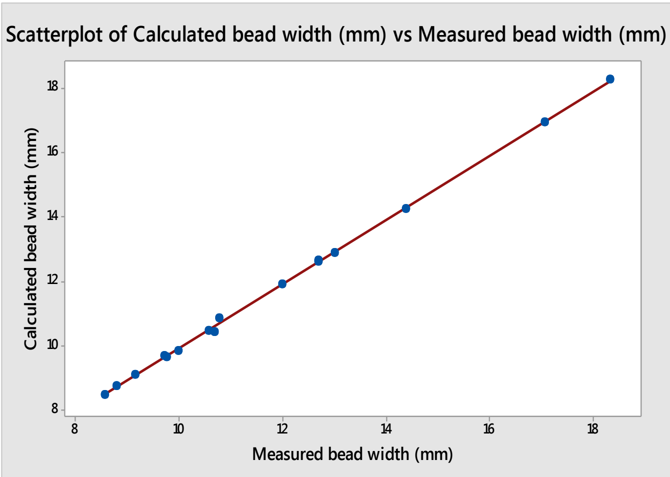

Fig.8: Accuracy of the calculated bead width valued with respect to measured data while electrode is backhand 45^0.

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V. CONCLUSION

It is established from the present experiment that a measurable influence can be achieved on the bead width of the weldment obtained by submerged arc welding on mild steel plate by varying electrode inclination as well as by changing welding direction. Regression analysis can be successfully applied to predict the weld responses. Using regration analysis by RSM mathematical model to establish relationship between input parameter (V, S, F, N) and weld bead geometry (equation .1-3). Computational results indicated that proposed Response Surface Method can efficiently and accurately predict the desird bead geometry by applying optimal process parameter.

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