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Application of Two-Level Half Factorial Design Technique for Developing Mathematical Models of Bead Penetration and Bead Reinforcement in SAW Process.

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ABSTRACT: In the present work two level half factorial design techniques is used to develop the mathematical models for bead geometry parameters like weld bead penetration and reinforcement height. The practical were performed on automatic SAW machine by making bead-on plate of 12mm thick carbon steel plates. The process variables were taken as welding current, arc voltage, welding speed and nozzle to plate distance. Main and interaction effects of process variables on the responses were analyzed with the help of 2D and 3D graphs. The models developed have been checked for their adequacy and significance by using F-test and t-test, respectively with the help of Design Expert software. Result represents that bead penetration and reinforcement increases with the increase in welding current while decreases with the increase in arc voltage and nozzle to plate distance. Nozzle to plate distance has no significant effect on both bead penetration and reinforcement.

Keywords: Bead geometry, Mathematicalmodel, Response, Two-level half factorial design technique, Design Expert Software.

I. INTRODUCTION

In today's manufacturing world the quality of the product play a vital role in the market value of the product and every manufacturing industry wants to produce their product at minimum cost without sacrificing the quality of the product. Welding is the widely used joining process in fabrication industries. It is more economical and is a much faster process compared to both casting and riveting. The submerged arc welding process is mostly used for making circumferential joints in heavy pressure vessels, boilers and pipes due to their deep penetration, high depositionrate, high speed and good surface quality [1]. The quality of weld depends on the bead geometry. The weld bead penetration, bead width and reinforcement height are the important parameters of bead geometry. So to automate the SAW process, it is must to develop the mathematical models for the bead geometry. Bead geometry depends on the process control variables such as welding current, arc voltage, welding speed and nozzle to plate distance. Many researchers have been worked for developing the relation between the bead geometry and process parameters in SAW process**.** V.K. Gupata&.Parmar et al [1986] used fractional factorial design technique to predict bead geometry parameters in SAW. S. Kumanan,J.EdwinDhas&K.Gowthaman et al [2006] Apply Taguchi technique and regression analysis to determine the optimal process parameters for submerged arc welding (SAW). Vinod Kumar et al [2011] developed mathematical models have to relate the process variable to weld bead parameters, Deepak Kumar Choudhary, Sandeep Jindal and N.P.Mehta et al [2011] conducted experiment on submerged arc welding by making bead on steel plate (SS-304) to investigate the effect of welding parameters on bead geometry. ShahanwazAlam, DR. M.I.Khan et al [2011]in their study use 2 – level full factorial technique to conduct experiment and to develop relationship mathematical models for predicting the weld bead penetration. RatiSaluja and K. M. Moeed et al [2012] conduct the experiment on SAW to get the effect of process variable on bead geometry.

In the present study attempt has been made to develop the mathematical models for bead geometry parameters like bead penetration and reinforcement height by using two – level half factorial design technique. The main and interaction effects are presented by 2Dand 3D graphs with the help of Design Expert software.

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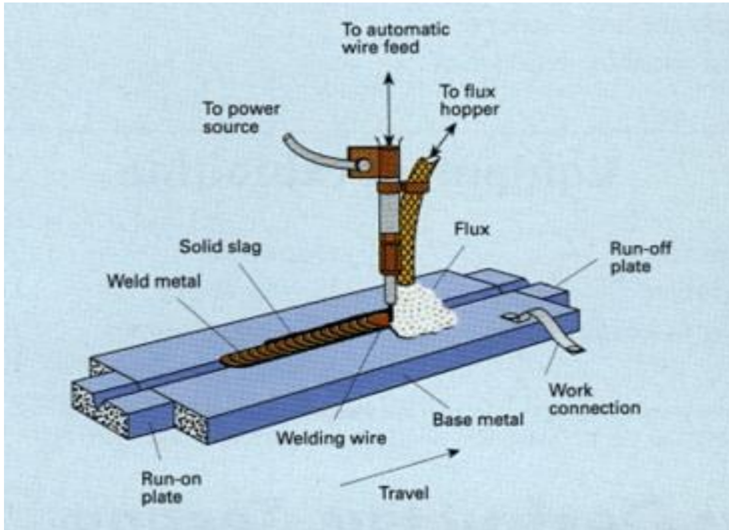

Figure 1:Process diagram-Submerged Arc Welding

III.EXPERIMENTATION

The research work was planned to be carried out in the following steps.

3.1Identification of the Process Variable and finding their Working Range

The process variables were selected on the basis of their effect on bead geometry and ease of control. Four independently controllable process variables were selected namely the welding current (I), open circuit voltage (v), travel speed(s) and nozzle to plate distance (N). The working range was fixed by conducting trail and run by varying one of the process variables at a time while keeping the rest of them at constant value. The upper and lower limits were called as+1and -1, respectively. The selected process parameters and their upper and lower limits together with notations and units are given in table 1.

Table 1: Welding Parameters with levels:

S.No.	Parameters	Unit	Symbol	Levels	
				Low (-1)	High (+1)
1	Welding current	Amp	I	250	450
2	Arc Voltage	Volt	V	30	32
3	Welding Speed	m/hr	S	27.4	36.6
4	Nozzle-to-Plate distance	mm	N	20	25

3.2Development of Design Matrix

The design matrix as shown in table 2 was developed according to the half factorial design approach to which the number of experiment combination becomes 2^{k-1} (2^{4-1}=8). The first three column were generated by standard 2^3 two level full factorial and the fourth column was generated by the relation N=I×V×S.

Table 2: Design Matrix show in coded values

S.No.	I	V	S	N = I×V×´S
1	1	1	1	1
2	-1	1	1	-1
3	1	-1	1	-1
4	-1	-1	1	1
5	1	1	-1	-1

6	-1	1	-1	1
7	1	-1	-1	1
8	-1	-1	-1	-1

3.3Conducting Experiment as per Design Matrix

The experiments were conducted on automatic submerged arc welding machine at MMEC Mullana. A constant potential transformer rectifier type power source with a current capacity of 800 amperes at 60% duty cycle and an open circuit voltage of 20-50 volt was used. The experiments were performed on carbon steel plate of size 150mm×75mm×12mm by 3.2mm diameter copper coated wire in spool form with agglomerated flux. The experiment is performed in a random manner to avoid any systematic error. The complete sets of eight trials were repeated for the sake of determining the variance of parameters and variance of adequacy for the model with help of design expert software. The weld samples of 20mm length were removed from the middle of the weld plate and polished by series of finer grades of emery paper (grades 80, 100, 200, 300, 400, 600, 800, 1000). The properly polished specimens have been etched with 2% Nital solution, which has been followed by investigation and analysis. The chemical composition of base plate is shown in table-3.

Table3: Chemical Composition of Base Plate

Composition	C	Si	Mn	P	S	Al	Cr	Cu	Ni	Mo	N_b	Ti	V
Percentage	0.2	0.4	1	0.03	0.03	0.02	0.3	0.3	0.3	0.8	0.01	0.03	0.02

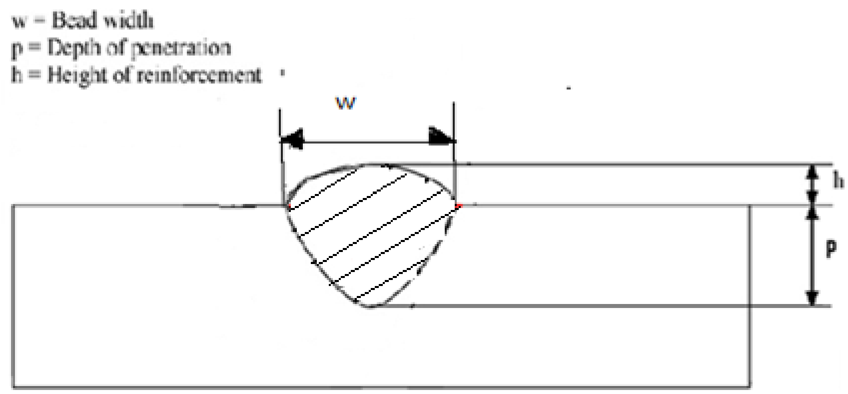

Figure 2: Bead Geometry

3.4 Recording of Responses

One transverse specimen of 20mm width is cut from mid position of the each plate. Thesespecimens were polished and etched with 2% Nital. The dimensions of weld bead geometry like penetration and reinforcement were measured with metallurgical microscope. The responses recorded are shown in table 4.

Table 4:Observed values of Bead Penetration and Reinforcement

S.NO.	I	V	S	N	Penetration		Reinforcement	
					1	**2**	**1**	**2**
1	450	32	36.6	25	3	3.2	2.05	2.1
2	250	32	36.6	20	1.41	1.5	1.4	1.2
3	450	30	36.6	20	3.32	3.39	2.5	2.9
4	250	30	36.6	25	1.5	1.61	1.64	1.5

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5	450	32	27.4	20	3.77	3.55	2.7	2.52
6	250	32	27.4	25	1.46	1.58	1.72	1.74
7	450	30	27.4	25	3.61	3.88	3.2	2.9
8	250	30	27.4	20	1.52	1.72	1.54	1.62

3.5 Selection of Mathematical Model

The response function representing any of the weld bead dimensions could be expressed as:
Y=f (I, V, S, N) where Y is the response function like bead penetration and reinforcement. I, V, S and N are welding current, arc voltage, travel speed and nozzle to plate distance respectively. Assuming a linear relationship in the first instant and taking into account possible two factors interactions only, the above expression could be written as:

$Y=b_0+b_1I+b_2V+b_3S+b_4N+b_5IV+b_6IS+b_7IN$……….. (1)

3.6Checking the Significance of the Model

ANOVA is a statistical technique, which can infer some important conclusions based on analysis based on analysis of the experimental data. The method is very useful to investigate the level of significance of influence of factors or interactions of factors on a particular response. The analysis of variance (ANOVA) test was performed to evaluate the statistical significance of the fitted linear models and factors involved in the response factors bead penetration and reinforcement. The goodness of fit of the fitted linear model was evaluated through lack of fit test. The results obtained are shown in tables 5-7. Both the fitted models are found to be significant. since for both the responses, the probability of F (PROB. >F) are observed to be less than 0.0001 i.e. there is only a 0.01% chance that "Model F-Value" larger could occurs due to noise. Values of "Prob > F" less than 0.0500 indicate model terms are significant. Values greater than 0.1000 indicate the model terms are not significant.In penetration model I, V, S and IS are significant model terms and in case of reinforcement I, V, S, IV are significant model terms.For both the models lack of fit is not significant relative to the pure error.There are 73.81% and 14.85% chance respectively for penetration and reinforcement that a " LACK OF FIT F-VALUE" larger could occur due to noise. Non significant lack of fit is good.

Table 5: Result of ANOVA for Bead Penetration

Source	Sum of Squares	Degree of Freedom	Mean Square	F - Value	P-value	Remarks
Model	15.393	4	3.848	302.916	< 0.0001	significant
I	14.861	1	14.861	1169.741	< 0.0001	significant
V	0.073	1	0.073	5.738	0.0355	significant
S	0.291	1	0.292	22.952	0.0006	significant
IS	0.168	1	0.168	13.231	0.0039	significant
Residual	0.139	11	0.0126			
Lack of Fit	0.0194	3	0.006	0.429	0.7381	not significant
Pure Error	0.12	8	0.015			
Cor Total	15.533	15				

Table 6: Result of ANOVA for Reinforcement

Source	Sum of Squares	Degree of Freedom	Mean Square	F - Value	P-value	Remarks
Model	5.539	4	1.385	46.096	< 0.0001	significant
I	4.526	1	4.526	150.661	< 0.0001	significant
V	0.351	1	0.351	11.685	0.0057	significant
S	0.439	1	0.439	14.609	0.0028	significant
IV	0.223	1	0.223	7.431	0.0197	significant

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Residual	0.33	11	0.03			
Lack of Fit	0.155	3	0.051	2.35	0.1485	not significant
Pure Error	0.176	8	0.022			
Cor Total	5.869	15				

Table7: Model summary statistics for responses

Parameters	Std. Dev.	Mean	C.V. %	Press	R-Squared	Adj R-Squared	Pred. R-Square	Adeq. Precision
Penetration	0.113	2.501	4.506	0.296	0.991	0.988	0.981	37.018
Reinforcement	0.173	2.077	8.346	0.699	0.944	0.923	0.881	17.455

3.7Evaluation of the Coefficients of the Models

The values of the coefficients of the models were calculated by design expert software package.All the coefficients were tested for their significance at 95% confidance level applying student's t- test.Coefficients are shown in table 8-9.

Table 8: Coefficients of Model for Penetration

Factor	Coefficient
Intercept	2.5
I	0.96
V	-0.067
S	-0.13
IS	-0.1

Table 9: Coefficients of Model for Reinforcement

Factor	Coefficient
Intercept	2.08
I	0.53
V	-0.15
S	-0.17
IV	-0.12

3.8 Development of Mathematical Model

The final mathematical models for the responses are presented in table 10.

Table 10:Developed Mathematical Models

S.NO.	Response	Developed model
1	Penetration	2.50 + 0.96 × I - 0.067 × V-0.13 × S-0.10 × I S
2	Reinforcement	2.08 + 0.53 × I - 0.15 × V - 0.17 × S - 0.12 × IV

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IV.ANALYSIS OF RESULT AND DISCUSSIONS

The pridicted effects of the welding parameters on the weld bead width and hardness within the range of the parameters are repersented in fig.4-17.

4.1 Main Effect of Process Parameters on Bead Penetration

Main effect of parameters on penetration are repersented in fig.3-5. Penetration increaseswith the incease in welding current while decreases with the welding speed and arc voltage.Nozzle to plate distance has no significant effect on penetration.

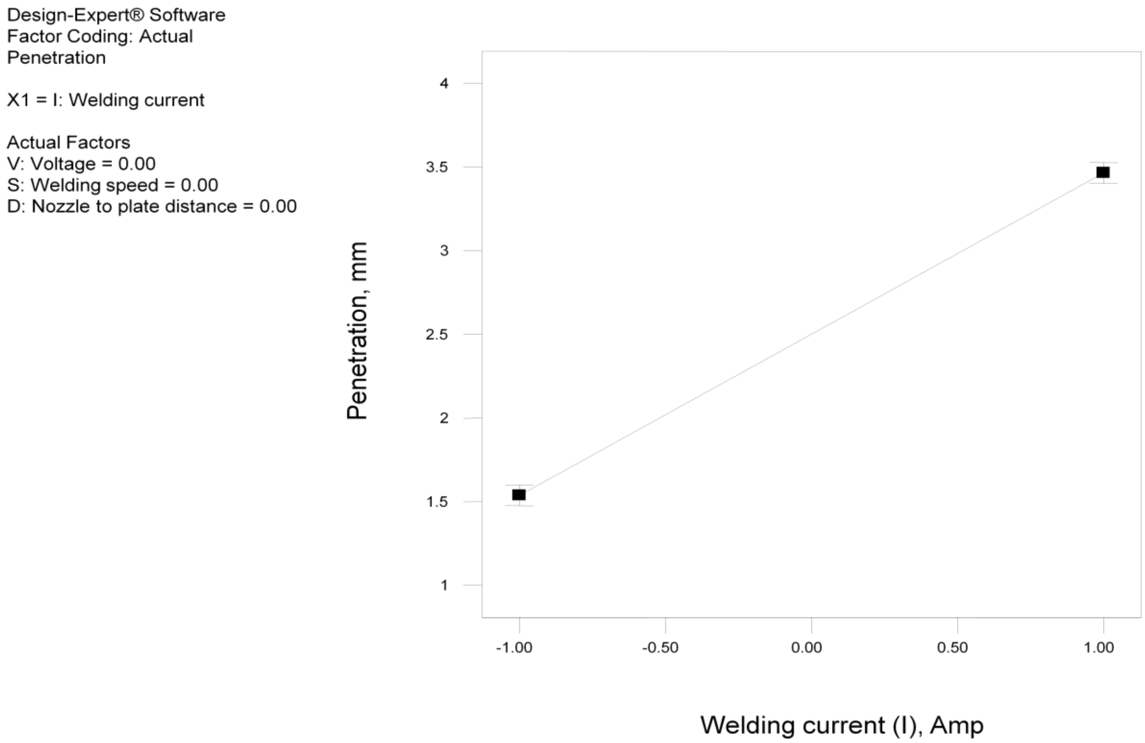

Figure 3: Effect of Welding Current on Penetration

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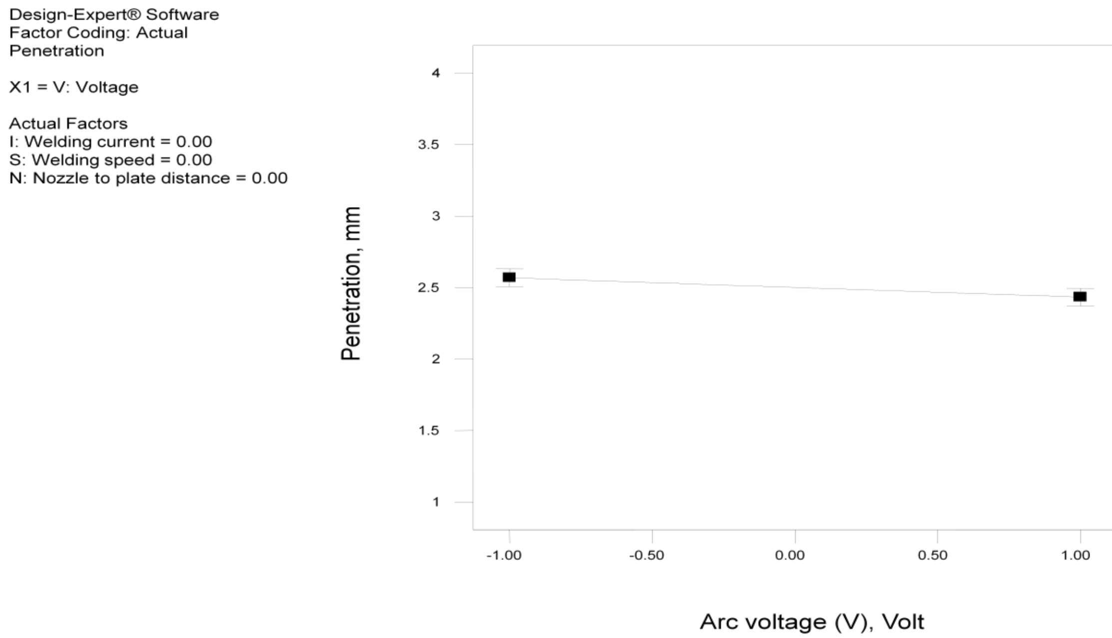

Figure 4: Effect of Arc voltage on Penetration

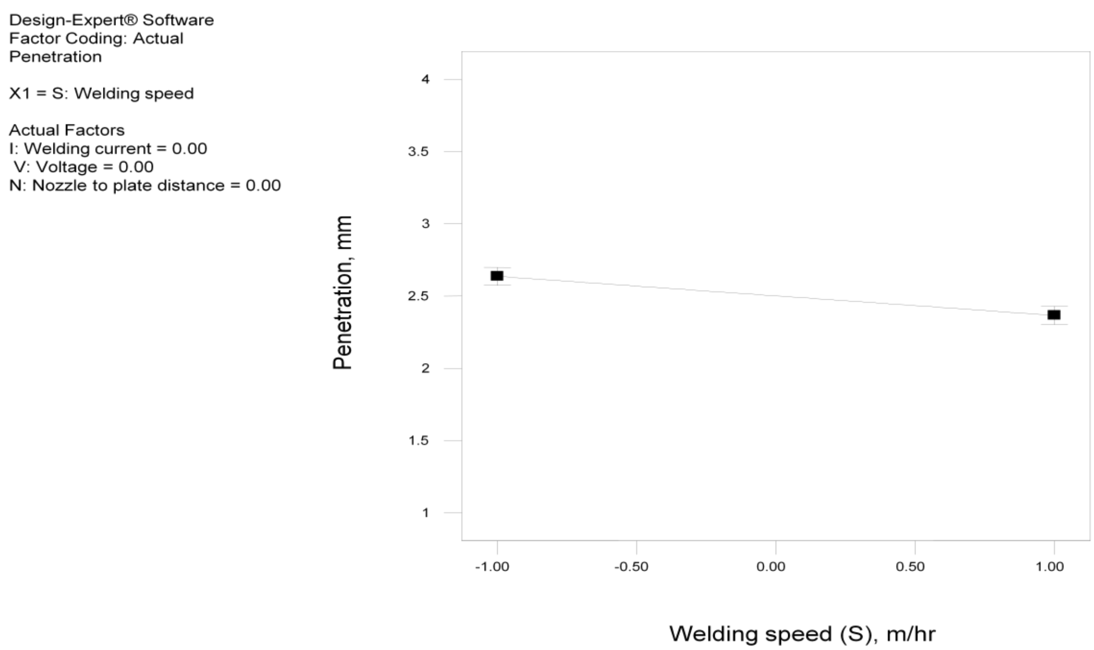

Figure 5: Effect of Welding Speed on Penetration

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4.2Main Effect of Process Parameters on Reinforcement

Main effect of process parameters on reinforcement are repersented in fig.6-8. Reinforcement increases with the incease in welding current while decreases with the increase in arc voltage and welding speed. Nozzle to plate distance has no significant effect on reinforcement.

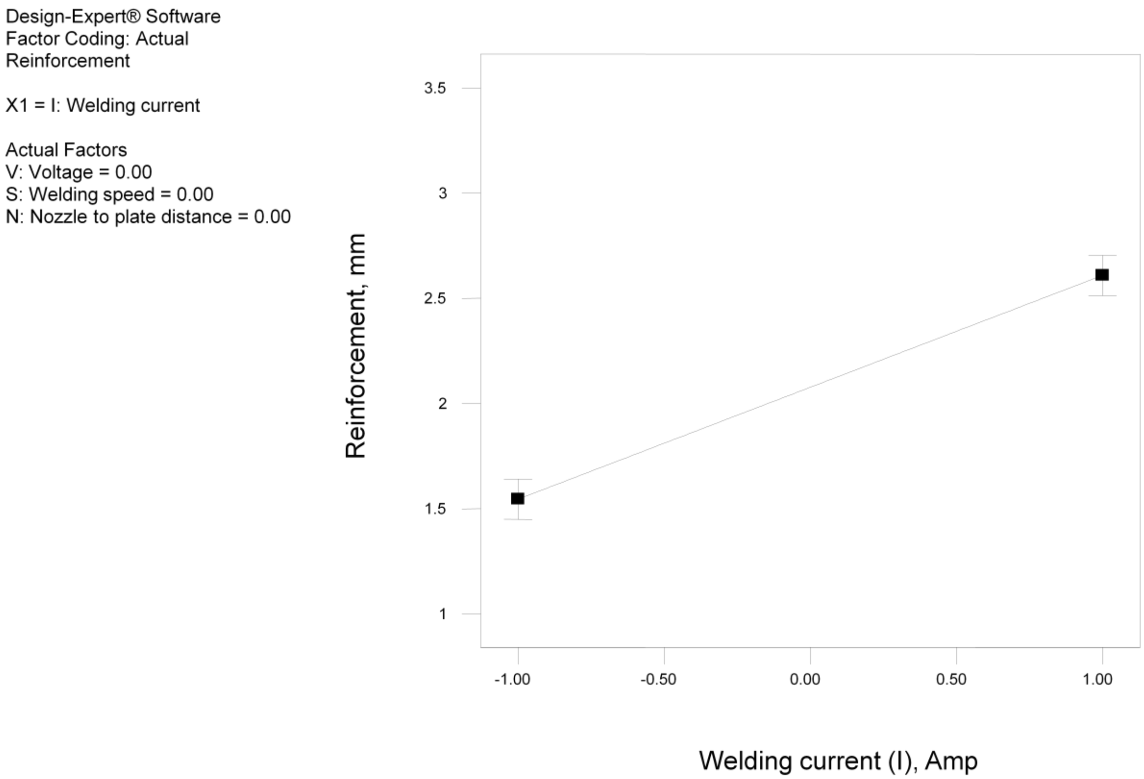

Figure 6: Effect of Welding Current on Reinforcement

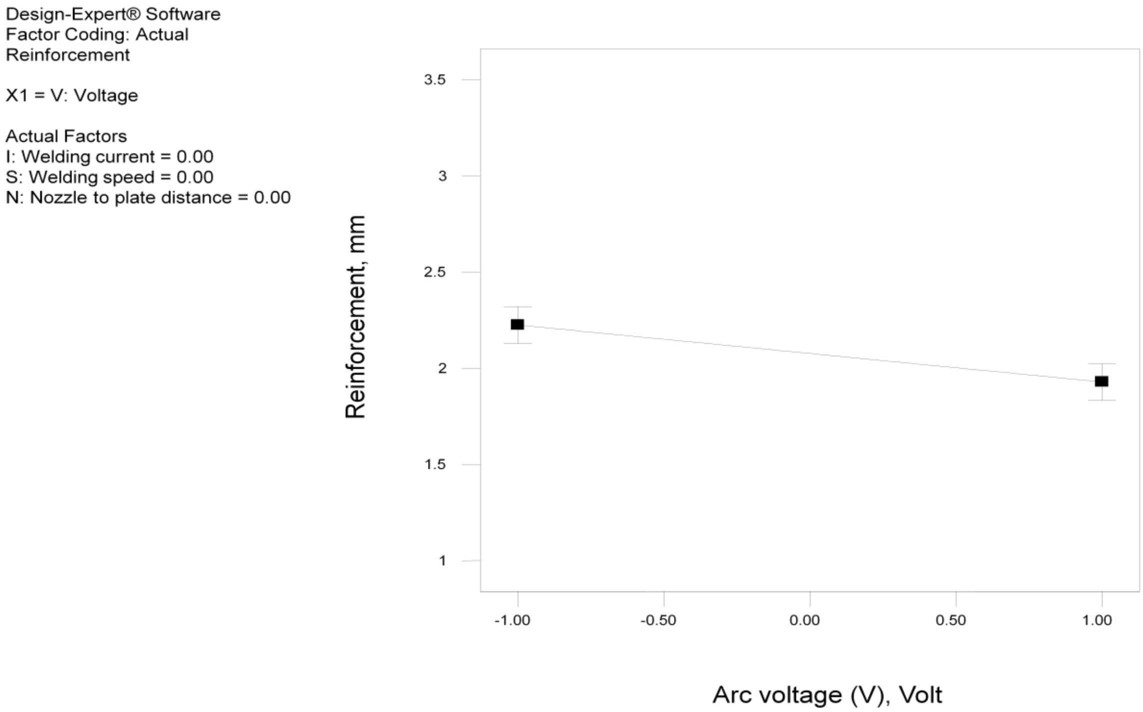

Figure 7: Effect of Arc voltage on Reinforcement

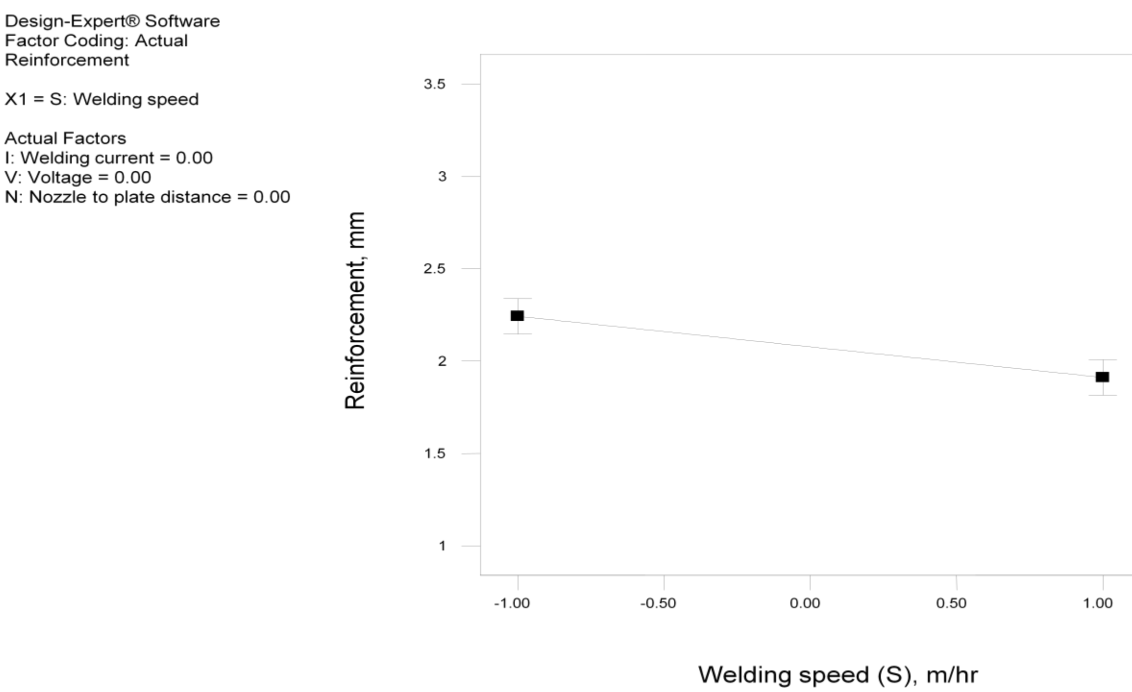

Figure 8: Effect of Welding Speed on Reinforcement

4.3Interaction Effect of Welding Current and Welding Speed onPenetration

Fig.9 shows the interaction effect of welding current and welding speed on penetration. Penetration increases with the increase of current for all values of welding speed but the rate of increase of penetration with the increase in current is higher at low value of welding speed. So welding current has positive effect and welding speed has negative effect on penetration. Response surface due to interaction effect of welding current and welding speed on penetration is shown in figure -10.

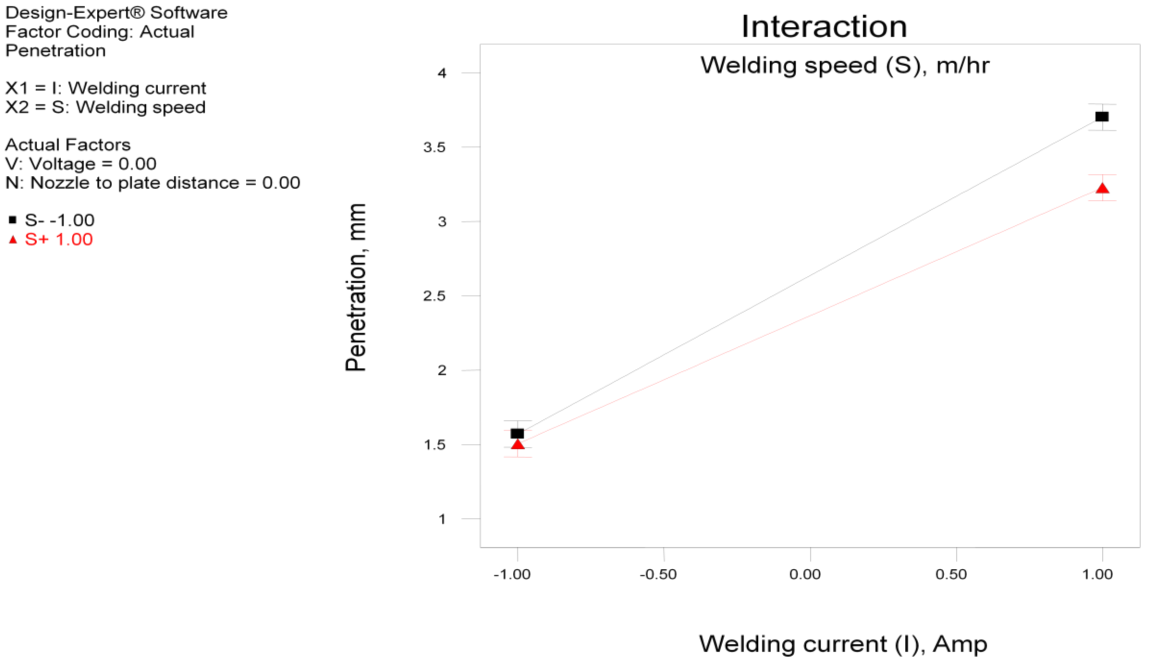

Figure 9: Interaction effect of Welding Current and Welding speed on Penetration

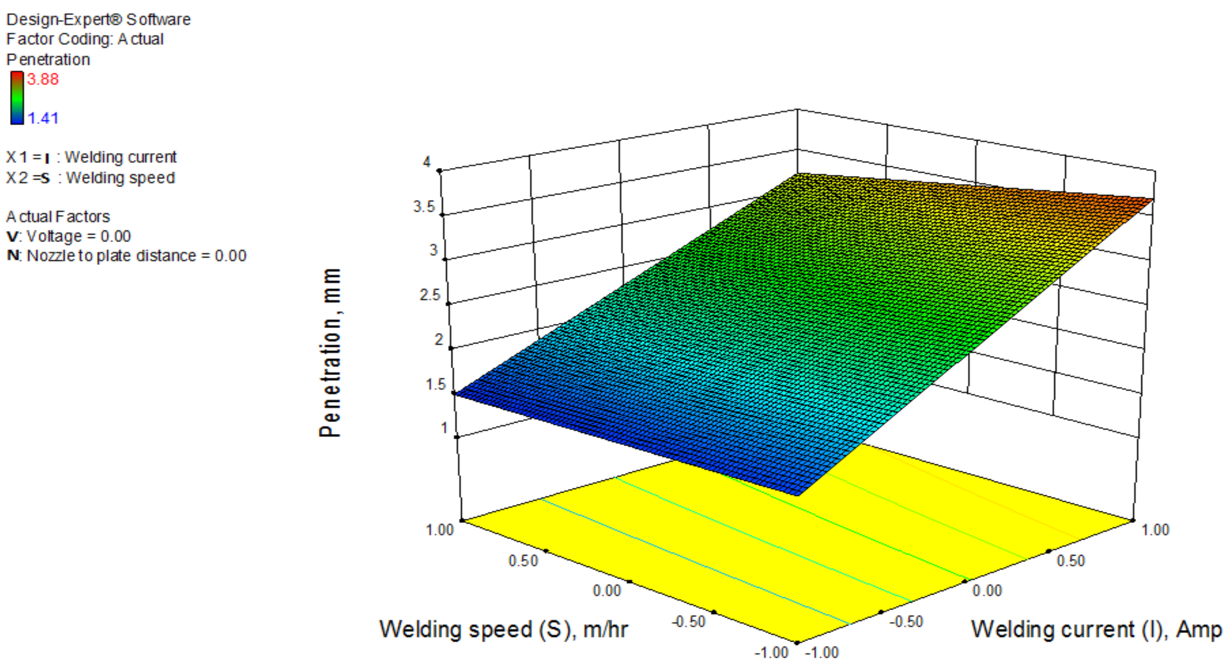

Figure 10: Interaction effect of Welding Current and Welding speed on Penetration (Response sur

4.4Interaction Effect of Welding Current and Arc Voltage on Reinforcement

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Interactive effect of welding current and arc voltage on reinforcement are shown in fig- 11. It is observed from the figure that reinforcement increases with the increase of current for all values of arc voltage within the range but the rate of increase of reinforcement with the increase of current is higher at low value of voltage. So voltage has negative effect on reinforcement and welding current has positive effect. Response surface due to interactive effect is shown in fig.-12.

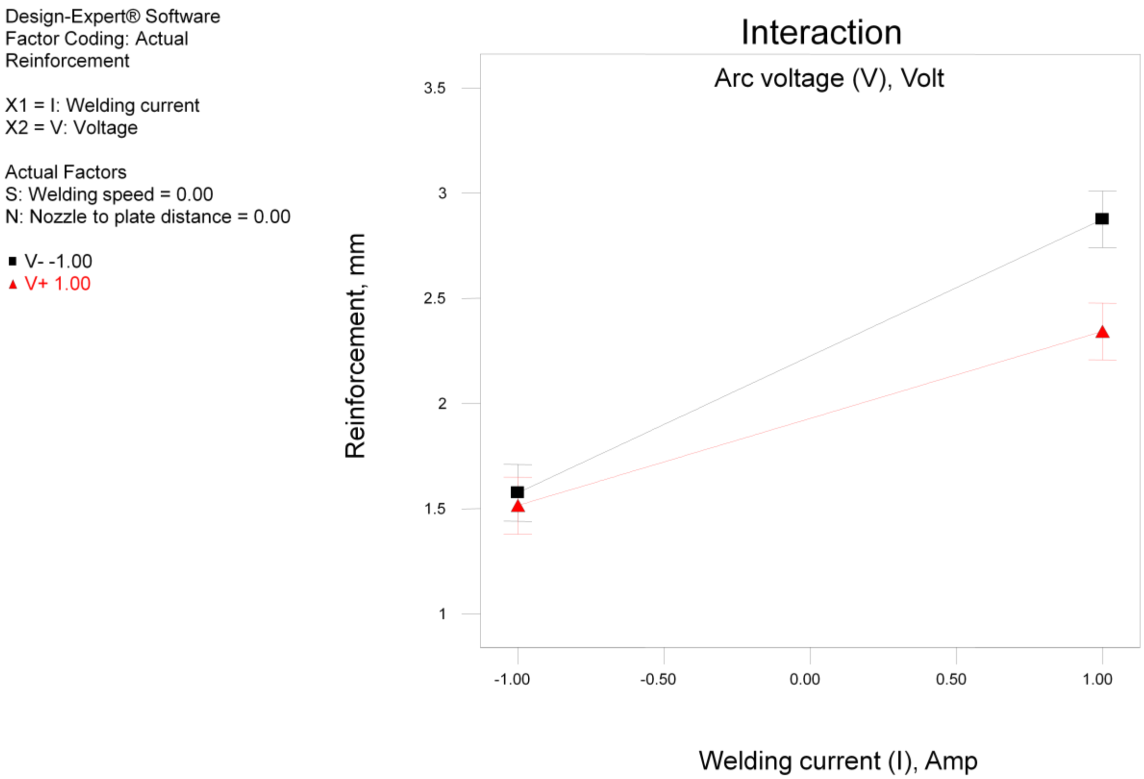

Figure 11: Interaction effect of Welding Current and Arc voltage on Reinforcement

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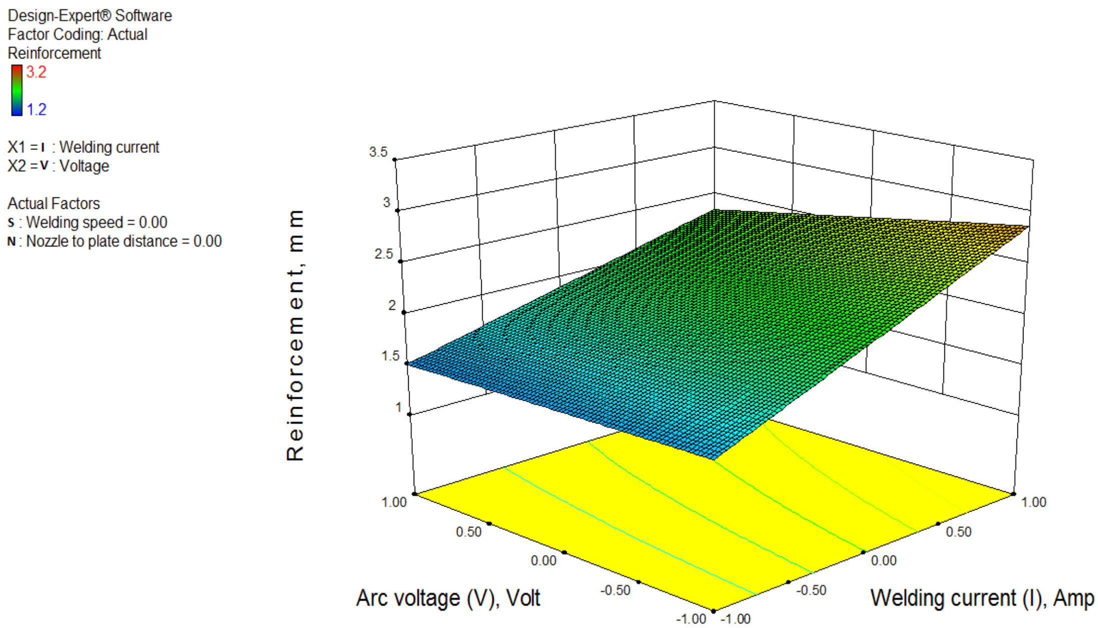

Figure 12: Interaction effect of Welding Current and Arc voltage on Reinforcement (Response Surface)

V. CONCLUSIONS

The following conclusions were drawn from the above investigation:

1. The two level half factorial techniques with design expert software can be employed easily for developing mathematical models for predicting weld bead penetration and reinforcement within the workable range of process parameters for SAW of carbon steel.
2. Design expert software is found to be effective tool for quantifying the main and interaction effect of variable on weld bead penetration and reinforcement.
3. Welding current has positive effect, but arc voltage and welding speed have negative effect on bead penetration and reinforcement.
4. Nozzle to plate distance has no significant effect on bead penetration and reinforcement.

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BIOGRAPHY

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