Investigating the Effect of Welding Parameters on Weld Bead Geometry in Submerged Arc Welding by using Response Surface Methodology

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Abstract: In the present work an attempt has been made to investigate the effect of welding parameter on bead geometry in submerged arc welding by using response surface methodology. The quality of weld depends on bead geometry of the weld which in turn depends on the process variables. The welding parameter or process parameter are Current (I), Voltage (V), Arc Travel Speed (S) and Tip distance (N), used for investigate the effect on Bead width (W), Penetration (P), Reinforcement (H), Weld penetration shape factor (WPSF), Weld reinforcement form factor (WRFF). Four factor five levels Central composite rotatable design matrix has been used in Response Surface Methodology for achieving and developing the required qualities of weld bead and mathematical models. The models developed have been checked for their adequacy and significance by using analysis of variance technique. Mild Steel used as specimen material for this investigation. It was found that penetration increases with current, decreases with Arc Travel Speed and Tip distance and remains constant with voltage. Reinforcement was found to increase with current and decrease with voltage, Arc Travel Speed and Tip distance. Weld bead width was found to increase with current, voltage, Tip Distance and decrease with Arc Travel Speed. Weld penetration shape factor was found to increase with voltage, Tip distance and decrease with welding current and Arc Travel Speed. Weld reinforcement form factor was found to increase with voltage, Tip distance and decrease with Arc Travel Speed and remains constant with welding current. The Main and Interaction effect of different parameters involved has been presented in graphical form.

Keywords: Submerged Arc Welding; Response Surface Methodology; Process Parameters; Bead Geometry

I. INTRODUCTION

The method of welding featured in this study is submerged arc welding (SAW). Submerged arc welding is a fusion welding process in which heat is produced from an arc between the work and a continuously fed bare metal electrode into the arc at a controlled rate. Granular, fusible flux is poured to form a pile surrounding the arc, blanketing the molten weld and base metal and protecting them from atmospheric contamination. Operation of the SAW process can be either semiautomatic or fully automatic. The weld is submerged under the layer of flux and slag, hence the name submerged arc welding. The main problem in saw process is to find out the optimum input parameter combination for achieving the required qualities of weld bead. The prediction of the process parameter of SAW for obtaining better weld bead geometry is very tough or difficult process. From the literature it was found that researchers have take many attempts to predict the process parameter of SAW to obtain smooth and better quality of weld bead geometry. The information regarding the welding process parameter which affect or influence the bead geometry is important because it can be applied in saw process for high productivity and cost effectiveness [1-12]. The control of weld bead was become necessary because mechanical strength of weld is affected by the weld bead geometry. The present trend in manufacturing industries is the use of automated welding processes to obtain high production rates and high precision. Hence study and control of weld bead geometry is very much essential. For this the relationship between the welding parameter and bead geometry parameter is to be established. This can be achieved by developing the mathematical models by RSM. For this a four factors five levels Central composite rotatable design matrix was used to achieve the required information about the direct and interaction effect on the output parameter. The adequacy and significance of the final models have been checked by the ANOVA [13].

II. METHODOLOGY AND EXPERIMENTATION

Response Surface Methodology with a four factor five levels Central composite rotatable design matrix used to investigate the effects of welding parameters on weld bead geometry in SAW. Response Surface Methodology was developed by Box and Wilson (1951). This is a combination of statistical and mathematical methods that are useful for modeling and analyzing of process or product. Welding current, voltage, Arc Travel Speed, Tip Distance are selected as the process parameters and their working ranges are shown in Table 1.

Table1. Process parameters and their working ranges

Sr. No.	Parameters	Levels (-2)	Levels (-1)	Levels (0)	Levels (+1)	Levels (+2)
1	Welding current, I (Ampere)	330	370	410	450	490
2	Voltage, V (volt)	28	30	32	34	36
3	Arc travel speed, S (m/hr)	22	25	28	31	34
4	Tip Distance, N (mm)	10	12.5	15	17.5	20

Central Composite rotatable design matrix allowed 31 experimental run which comprises a full replication of 2^4 (=16) factorial design plus seven center points and eight star points. The basic experiments as per design were carried out on Submerged Arc Welding machine (TORNADO SAW M-800) of Ador Fontech India Ltd. The Mild Steel Plate (PB09718A) of 150 x 100 x 12 mm has been used as a work piece material for present work. Sixteen plates of Mild steel were used for bead formation. As per the design matrix two beads on a single plate were deposited .The Thirty one beads were applied on the plates. Sectioned specimens were cut from both ends of the welded plates with the help of Power hack saw, Sizes of specimens were taken 16 mm x 100 mm x 12 mm. Specimen after cutting were polished with help of emery polished papers of grade X 1 to X 4 on double disc polishing machine. After polishing, specimens are etched with 5 % Nital solution (5 % Nitric acid and 95 % Methyl alcohol) and recording the responses. The experimentation was performed in Production Technology lab of Mechanical Engineering department at M. M. Engineering College, Mullana. The Design matrix and observed value of bead geometry are shown in Table 2.

Table 2. Design Matrix with Response Values for Weld Bead Geometry Parameters

S. No	Welding Current (I)	Voltage (V)	Arc Travel Speed (S)	Tip Distance (N)	Bead width (W)	Reinforcement (H)	Penetration (P)	Weld reinforcement form factor (WRFF)	Weld penetration shape factor (WPSF)
1.	370.00	30.00	25.00	12.50	16.3	3.1	4.8	5.25	3.3
2.	450.00	30.00	25.00	12.50	18	3.7	5.5	4.85	3.2
3.	370.00	34.00	25.00	12.50	17.8	2.5	4.7	7.2	3.7
4.	450.00	34.00	25.00	12.50	18.1	2.7	5.9	6.7	3.1
5.	370.00	30.00	31.00	12.50	13.3	3.2	5.3	4.2	2.5
6.	450.00	30.00	31.00	12.50	15	3	5	5	3
7.	370.00	34.00	31.00	12.50	15	2.4	5	6.2	3
8.	450.00	34.00	31.00	12.50	16	2.4	5.4	6.6	2.9
9.	370.00	30.00	25.00	17.50	16	2.9	4.5	5.5	3.5
10.	450.00	30.00	25.00	17.50	17.6	3.4	5.9	5.1	2.9
11.	370.00	34.00	25.00	17.50	18.3	2.6	4.3	7	4.2
12.	450.00	34.00	25.00	17.50	18.6	3	6.2	6.2	3
13.	370.00	30.00	31.00	17.50	13.9	2.8	4.3	5	3.2
14.	450.00	30.00	31.00	17.50	15.5	2.7	4.8	5.7	3.2
15.	370.00	34.00	31.00	17.50	16.2	2.5	4.3	6.4	3.7
16.	450.00	34.00	31.00	17.50	17	2.4	5.4	7	3.1
17.	330.00	32.00	28.00	15.00	14.8	2.5	5	5.9	2.9
18.	490.00	32.00	28.00	15.00	16.6	2.9	6.1	5.7	2.7
19.	410.00	28.00	28.00	15.00	15.5	3.6	5.5	4.3	2.8
20.	410.00	36.00	28.00	15.00	18.7	2.5	5.4	7.4	3.4
21.	410.00	32.00	22.00	15.00	18.5	3.1	5	5.9	3.7
22.	410.00	32.00	34.00	15.00	13.6	2.5	4.5	5.4	3
23.	410.00	32.00	28.00	10.00	15.4	2.6	4.5	5.9	3.4
24.	410.00	32.00	28.00	20.00	16.9	2.4	4.5	7	3.7
25.	410.00	32.00	28.00	15.00	16.2	2.5	4.8	6.4	3.3
26.	410.00	32.00	28.00	15.00	16	2.5	5.2	6.4	3
27.	410.00	32.00	28.00	15.00	16.2	2.5	5.1	6.5	3.2
28.	410.00	32.00	28.00	15.00	15.7	2.5	4.9	6.2	3.2
29.	410.00	32.00	28.00	15.00	15.5	2.6	4.6	6.1	3.3
30.	410.00	32.00	28.00	15.00	16.1	2.7	4.9	6	3.2
31.	410.00	32.00	28.00	15.00	16	2.4	5	6.6	3.2

III RESULTS AND DISCUSSION

The experiments were designed and conducted by employing response surface methodology. The selection of suitable model and the development of response surface models have been carried out by using statistical software, “Design Expert (DX-6)”. The regression equations for the selected model were obtained for the response characteristics, viz. Bead width (W), Penetration (P), Reinforcement (H), Weld penetration shape factor (WPSF), Weld reinforcement form factor (WRFF). These regression equations were developed using the experimental data (Table 4.2) and were plotted to investigate the effect of process variables on response characteristic. The analysis of variance (ANOVA) was performed to statistically analyze the results. The Final response surface reduced Quadratic models (using Backward Elimination Regression) is given below

W = +70.59711+0.11812* I-3.68956* V-0.77222* S-1.71000* N+0.076261* V2-0.00328125* I * V+0.035000* V * N+0.025000 * S * N (1)

H = +54.04186+0.0052111* I-2.71587* V-0.093613* S-0.69833* N+0.0000336602* I2+0.035339* V2 +0.00876182* S2-0.00109375 * I * S+0.021250* V * N (2)

P = +58.13390-0.10765* I-2.92435* V+0.93906* S+0.14663* N+0.000101812* I2+0.034475* V2-0.015936*N2 +0.00179688* I * V-0.00182292* I * S+0.0018125 * I * N-0.015833* S * N (3)

WRFF = -47.17925+0.00590703* I+2.86622* V-0.18779* S+0.37167* N-0.0000890126* I2-0.032480* V2 -0.019991 * S2+0.00239583* I * S-0.026250* V * N+0.019167 * S * N (4)

WPSF = -12.29150+0.088872 * I+0.80130* V-0.99729 * S-0.21305* N-0.0000590924* I2+0.00477246*S2 +0.014872* N2-0.00179688* I * V+0.00119729* I * S-0.0013125* I * N+0.012500* S * N (5)

A Checking the Significance and Adequacy of the Models

To test the goodness of the fit and validation of the developed models, adequacy was determined by the analysis of variance technique (ANOVA). The analysis of variance test was performed to evaluate the statistical significance of the fitted quadratic models. In addition to this, the goodness of fit of the fitted quadratic model was also evaluated through lack of fit test. The "Prob > F" for all these tests was found in excess of 0.05, meaning that the lack of fit is insignificant.

All the fitted models are reduced Quadratic models (using Backward Elimination Regression) for the Bead width (W), Penetration (P), Reinforcement (H), Weld penetration shape factor (WPSF), Weld reinforcement form factor (WRFF).These Models are significant, since for all the responses, the Prob. > F are observed to be less than 0.0001. In other words, there is only a 0.01% chance that "Model F-Value" larger than those reported in Tables-4.3 could occur due to noise. The values of "Prob > F" less than 0.05 observed for some factors involved in model equations, indicate that the contribution of these terms to the model is significant. On the other hand, the value of "Prob > F" greater than 0.10 indicates that the impact of model terms are not significant. All the not Significant Models terms are omitted. The response surface models for the Bead width (W), Penetration (P), Reinforcement (h), Weld penetration shape factor (WPSF), Weld reinforcement form factor (WRFF) are show in Table 3.

The coefficients of correlation (R^2) for all the models are observed in excess of 0.92 which inspire confidence in the developed models. The predicted and adjusted R^2 values for all the response models were in acceptable agreement which again validates the fitness of developed models. The coefficient of variation (C.V.) defined as (S.D./Mean x 100) of model is measurement of error. The low value of C.V. obtained for all the models indicates improved precision and reliability of the experiments performed. The adequate precision values, explain as signal to noise ratio for the fitted value, are significantly higher than 4 indicating the suitability of models for future prediction. A small value of Prediction error sum of square PRESS is adorable because this calculate how well the model predicts the response in new experiment. Model summary statistics for bead geometry Parameters are shown in Table 4.

Table 3. Anova for response surface of Bead width (W), Penetration (P), Reinforcement (h), Weld penetration shape factor (WPSF), Weld reinforcement form factor (WRFF)

Parameter	Source	Sum of Squares	DF	Mean Square	F Value	Prob>F	Remarks
Bead width (W)	**Model**	60.61	8	7.58	114.01	< 0.0001	**Significant**
	A	6.61	1	6.61	99.55	< 0.0001	
	B	13.20	1	13.20	198.67	< 0.0001	
	C	34.08	1	34.08	512.90	< 0.0001	
	D	1.81	1	1.81	27.31	< 0.0001	
	B^2	2.74	1	2.74	41.20	< 0.0001	
	AB	1.10	1	1.10	16.59	0.0005	
	BD	0.49	1	0.49	7.37	0.0126	
	CD	0.56	1	0.56	8.47	0.0081	
	Residual	1.46	22	0.066			
	Lack of Fit	1.04	16	0.065	0.94	0.5772	**not significant**
	Pure Error	0.42	6	0.070			
	Cor Total	62.07	30				
Reinforcement (H)	**Model**	3.76	9	0.42	55.45	< 0.0001	**Significant**
	A	0.18	1	0.18	24.40	< 0.0001	
	B	1.76	1	1.76	233.76	< 0.0001	
	C	0.57	1	0.57	75.74	< 0.0001	
	D	0.050	1	0.050	6.69	0.0172	
	A^2	0.084	1	0.084	11.14	0.0031	
	B^2	0.58	1	0.58	76.74	< 0.0001	
	C^2	0.18	1	0.18	23.88	< 0.0001	
	AC	0.28	1	0.28	36.60	< 0.0001	
	BD	0.18	1	0.18	23.98	< 0.0001	
	Residual	0.16	21	0.007531			
	Lack of Fit	0.10	15	0.006924	0.77	0.6870	**not significant**
	Pure Error	0.054	6	0.009048			
	Cor Total	3.92	30				
Penetration (P)	**Model**	7.57	10	0.76	24.32	< 0.0001	**Significant**
	A	3.45	1	3.45	110.81	< 0.0001	
	C	0.45	1	0.45	14.57	0.0011	
	D	0.15	1	0.15	4.83	0.0399	
	A^2	0.77	1	0.77	24.65	< 0.0001	
	B^2	0.55	1	0.55	17.66	0.0004	

	D^2	0.29	1	0.29	9.21	0.0065	
	AB	0.33	1	0.33	10.62	0.0039	
	AC	0.77	1	0.77	24.59	< 0.0001	
	AD	0.53	1	0.53	16.88	0.0005	
	CD	0.23	1	0.23	7.25	0.0140	
	Residual	0.62	20	0.031			
	Lack of Fit	0.39	14	0.028	0.71	0.7208	**not significant**
	Pure Error	0.23	6	0.039			
	Cor Total	8.20	30				
WRFF	**Model**	19.51	9	2.17	76.41	< 0.0001	**Significant**
	B	14.88	1	14.88	524.49	< 0.0001	
	C	0.30	1	0.30	10.70	0.0036	
	D	0.70	1	0.70	24.68	< 0.0001	
	A^2	0.59	1	0.59	20.67	0.0002	
	B^2	0.49	1	0.49	17.20	0.0005	
	C^2	0.94	1	0.94	32.99	< 0.0001	
	AC	1.32	1	1.32	46.60	< 0.0001	
	BD	0.28	1	0.28	9.71	0.0052	
	CD	0.33	1	0.33	11.65	0.0026	
	Residual	0.60	21	0.028			
	Lack of Fit	0.31	15	0.020	0.43	0.9156	**not significant**
	Pure Error	0.29	6	0.048			
	Cor Total	20.11	30				
WPSF	**Model**	3.37	11	0.31	26.77	< 0.0001	**Significant**
	A	0.40	1	0.40	34.99	< 0.0001	
	B	0.40	1	0.40	34.99	< 0.0001	
	C	0.57	1	0.57	49.84	< 0.0001	
	D	0.30	1	0.30	26.54	< 0.0001	
	A^2	0.26	1	0.26	22.59	0.0001	
	C^2	0.053	1	0.053	4.66	0.0438	
	D^2	0.25	1	0.25	21.84	0.0002	
	AB	0.33	1	0.33	28.89	< 0.0001	
	AC	0.33	1	0.33	28.89	< 0.0001	
	AD	0.28	1	0.28	24.08	< 0.0001	
	CD	0.14	1	0.14	12.29	0.0024	
	Residual	0.22	19	0.011			
	Lack of Fit	0.16	13	0.012	1.21	0.4299	**not significant**
	Pure Error	0.060	6	0.01			
	Cor Total	3.59	30				

Table 4. Model summary statistics for bead geometry Parameters

Bead Geometry Parameters	Std. Dev.	Mean	C.V. (%)	PRESS	(R^2)	Adjusted (R^2)	Predicted (R^2)	Adequate Precision (AP)
W	0.26	16.27	1.58	2.97	0.9764	0.9679	0.9521	39.358
H	0.087	2.75	3.16	0.35	0.9596	0.9423	0.9110	27.637
P	0.18	5.04	3.50	1.71	0.9240	0.8860	0.7914	19.308
WRFF	0.17	5.99	2.81	1.06	0.9704	0.9577	0.9471	32.923
WPSF	0.11	3.21	3.33	0.71	0.9394	0.9043	0.8023	24.478

IV MAIN AND INTERACTION EFFECT OF WELDING PARAMETERS ON WELD BEAD GEOMETRY

A Effect of welding Parameters on Bead Width (W)

Fig.1 shows that the effects of welding Parameters A (Current), B (Voltage), C (Arc Travel Speed), D (Tip Distance) on Bead width. It is observed from the Figure 1 that Bead width, increases with increase of Current, Voltage, Tip Distance but decrease with increase of Arc Travel Speed.

The increase in welding current increase the heat input, it results increase in weld bead width. Due to increase in heat input and weight of the weld metal deposited, bead width increase.

Bead width increase due to the increase in arc length with the increase in open circuit voltage, which in turn results in expansion of the arc cone at its base and more melting of work piece.

Weld bead width decreases steadily with the increase in Arc Travel speed. This is due to the fact that when speed increases, the thermal energy passes to the base plate from the arc or line power per unit length of the weld and less filler metal is accumulated per unit length of weld, resulting in thinner and narrower weld bead. Hence, at lower travel speeds, the weld bead is bigger in mass, whereas at higher travel speeds, it is lesser in mass. If speed decreases, the bead becomes broad, flatter and smoother. The combined effect of these factors results in decrease in bead width with the increase in Arc Travel Speed.

As the arc length increase, spreads the arc cone at its base and the metal fusion rate increases slightly at higher value of Tip Distance, so that the value of the Weld bead width increase with the increase of Tip Distance.

Figure 1(a) shows the interaction effect of welding current and Voltage on bead width. It is clear from Figure that at higher value of voltage (+1 level), when current increases then bead width increases from 16.81 mm to 17.34 mm. Again from figure at lower value of voltage (-1 level), when current increases then bead width increases from 14.80 mm to 16.38 mm.

Figure 1(b) shows the interaction effect of Voltage and Tip distance on bead width. It is clear from Figure at higher value of Tip distance (+1 level), when voltage increases then bead width increases from 15.69 mm to 17.52 mm. Again from figure at lower value of Tip distance (-1 level), when voltage increases then bead width increases from 15.49 mm to 16.62 mm.

Figure 1(c) shows the interaction effect of Arc Travel Speed and Tip distance on bead width. It is clear from Figure at higher value of Arc Travel Speed (+1 level), when Tip distance increase then bead width decrease from 17.31 mm to 15.30 mm. Again from figure at lower value of Arc Travel Speed (-1 level), when Tip distance increases then bead width decreases from 17.13 mm to 14.37 mm.

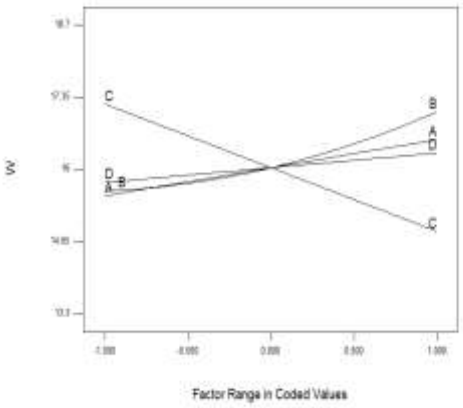

Figure 1: Effect of Welding Parameters on Bead Width (W)

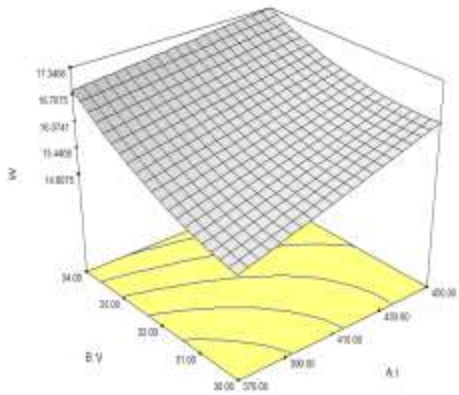

Figure 1(a): Response Surface due to Interactive effect of welding current and Voltage on bead width

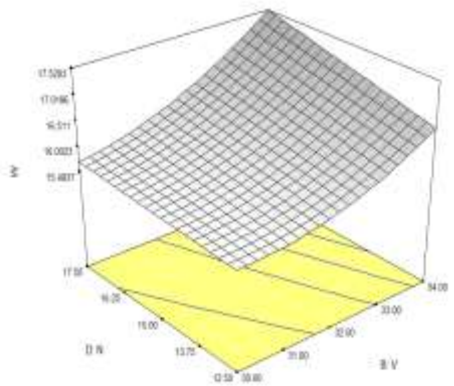

Figure 1(b): Response Surface due to Interactive effect of Voltage and Tip Distance on bead width

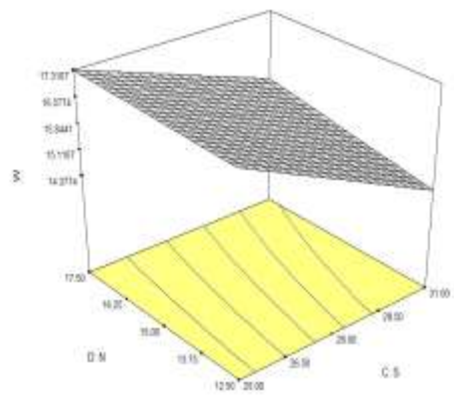

Figure 1(c): Response Surface due to Interactive effect of Arc Travel speed and Tip Distance on bead width

B Effect of welding Parameters on Reinforcement (H)

Fig. 2 shows that the effects of welding Parameters A (Current), B (Voltage), C (Arc Travel Speed), D (Tip Distance) on Reinforcement. It is observed from the Figure 2 that Reinforcement increases with increase of Current and decrease with increase in Voltage, Tip Distance and Arc Travel Speed.

The increase in reinforcement with increase in welding current is because of the higher melting rate. As higher melting rate cause some part of the filler wire to get deposited on to the weld in the form of reinforcement.

As the increase in voltage the bead width increase causes corresponding reduction in reinforcement.

The decrease in heat input, metal deposition rate and digging power of the arc with the increase in Arc Travel Speed resulting in decrease in weld metal reinforcement.

Due to the reduced heat input, reinforcement decrease as Tip Distance increases.

Figure 2(a) shows the interaction effect of Welding current and Arc Travel Speed on Reinforcement. It is clear from Figure at lower value of Arc Travel Speed (-1 level), when current increase then reinforcement increases from 2.60 mm to 3.03 mm. Again from figure at higher value of Arc Travel Speed (+1 level), when current increases then reinforcement slightly decreases from 2.55 mm to 2.46 mm.

Figure 2(b) shows the interaction effect of Voltage and Tip Distance on Reinforcement. It is clear from Figure at lower value of Tip Distance (-1 level), when voltage increase then reinforcement decreases from 3.09 mm to 2.34 mm. Again from figure at higher value of Tip Distance (+1 level), when voltage increases then reinforcement decreases from 2.79 mm to 2.46 mm.

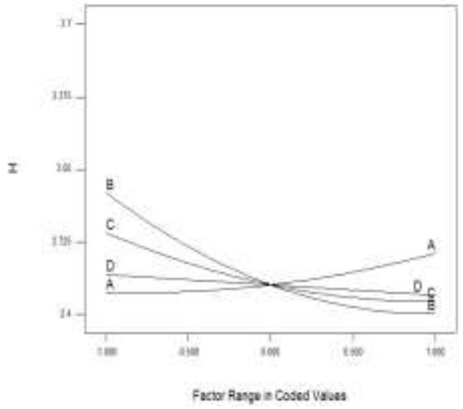

Figure 2: Effect of Welding Parameters on Reinforcement (H)

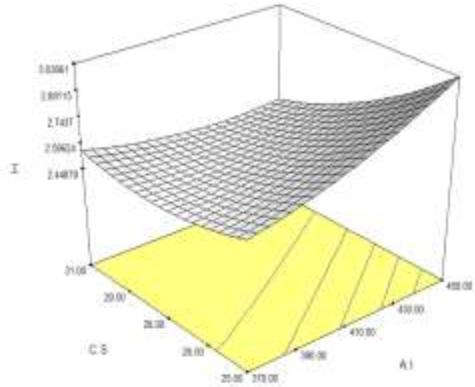

Figure 2(a): Response Surface due to Interactive effect of Current and Arc Travel Speed on Reinforcement

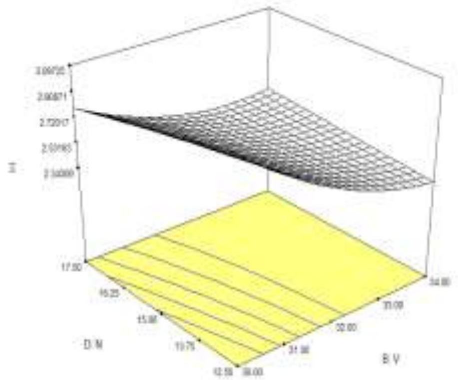

Figure 2(b): Response Surface due to Interactive effect of voltage and Tip distance on Reinforcement

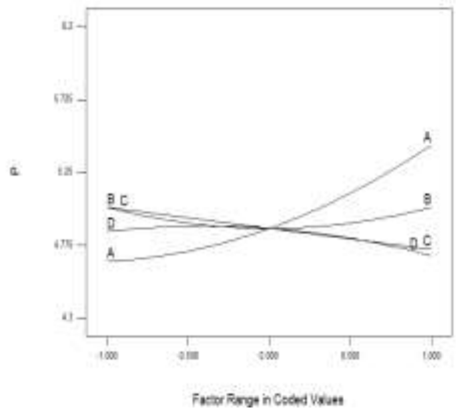

Figure 3: Effect of Welding Parameters on Penetration (P)

C *Effect of welding Parameters on Penetration (P)*

Fig. 3 shows that the effects of welding Parameters A (Current), B (Voltage), C (Arc Travel Speed), D (Tip Distance) on Penetration. Figure 3 depicts that the Voltage has least impact on penetration. It is observed from the Figure 3 that Penetration increases with increase of Current and decrease with increase in Tip Distance and Arc Travel Speed.

Increase in current gives rise to enhanced line power per unit length of the weld and higher current density, causing maximum volume of the base material to melt and hence increase in penetration.

The decrease in metal deposition rate, heat input and digging power of the arc with the increase in Arc Travel Speed, resulting decrease in weld metal penetration.

With increase of Tip Distance, Penetration decrease. This is due to the arc current and heat input decrease with increase in Tip Distance.

Figure 3(a) shows the interaction effect of Voltage and Current on Penetration. It is clear from Figure at lower value of voltage (-1 level), when current increase then penetration increases from 4.95 mm to 5.42 mm. Again from figure at higher value of voltage (+1 level), when current increases then penetration increases from 4.66 mm to 5.70 mm.

Figure 3(b) shows the interaction effect of Arc Travel Speed and Current on Penetration. It is clear from Figure at lower value of Arc Travel Speed (-1 level), when current increase then penetration increases from 4.58 mm to 5.78 mm. Again from figure we get at higher value of Arc Travel Speed (+1 level), when current increases then penetration increases from 4.75 mm to 5.07 mm.

Figure 3(c) shows the interaction effect of Tip Distance and Current on Penetration. It is clear from Figure at lower value of Tip Distance (-1 level), when current increase then penetration increases from 4.83 mm to 5.22 mm. Again from figure at higher value of Tip Distance (+1 level), when current increases then penetration increases from 4.30 mm to 5.43 mm.

Figure 3(d) shows the interaction effect of Arc Travel Speed and Tip Distance on Penetration. It is clear from Figure at lower value of Tip Distance (-1 level), when Arc Travel Speed increase then penetration slightly decreases from 4.88 mm to 4.84 mm. Again from figure at higher value of Tip Distance (+1 level), when Arc Travel Speed increases then penetration decreases from 4.96 mm to 4.45 mm.

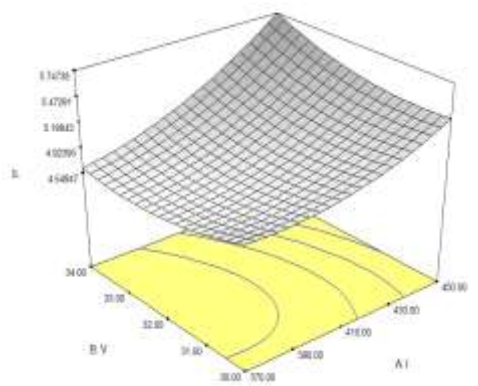

Figure 3(a): Response Surface due to Interactive effect of current and voltage on Penetration

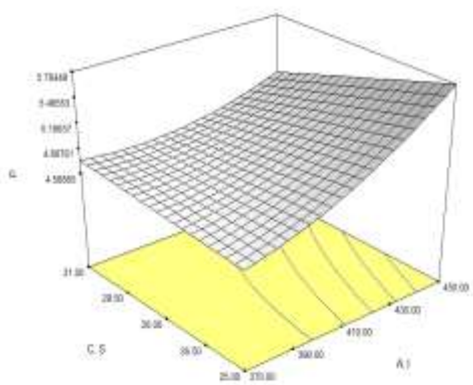

Figure 3(b): Response Surface due to Interactive effect of current and Arc Travel Speed on Penetration

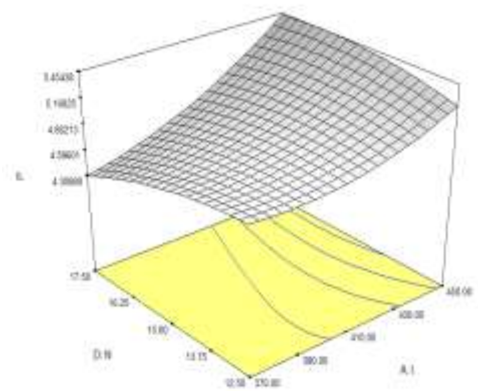

Figure 3(c): Response Surface due to Interactive effect of current and Tip Distance on Penetration

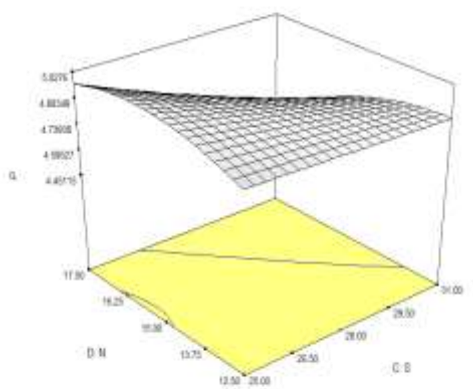

Figure 3(d): Response Surface due to Interactive effect of Arc Travel Speed and Tip Distance on Penetration

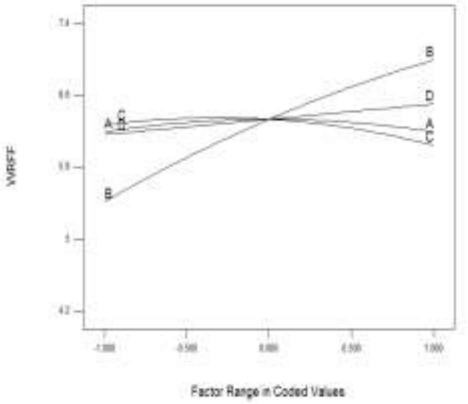

Figure 4 Effect of Welding Parameters on Weld Reinforcement Form Factor (WRFF)

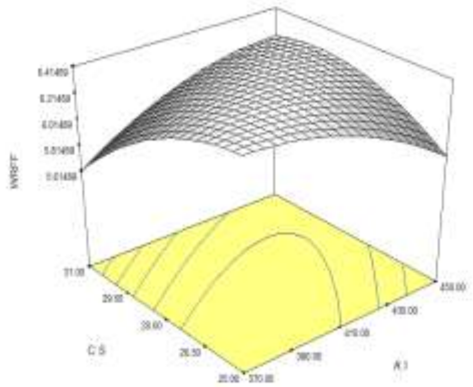

Figure 4(a): Response Surface due to Interactive effect of current and Arc Travel Speed on WRFF

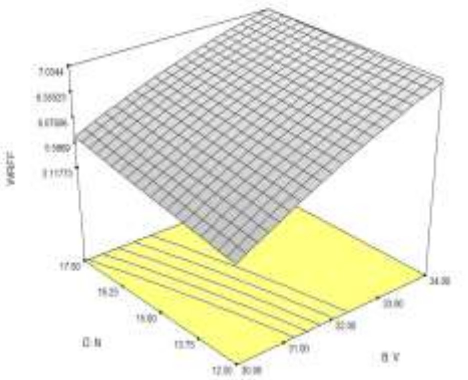

Figure 4(b): Response Surface due to Interactive effect of voltage and Tip Distance on WRFF

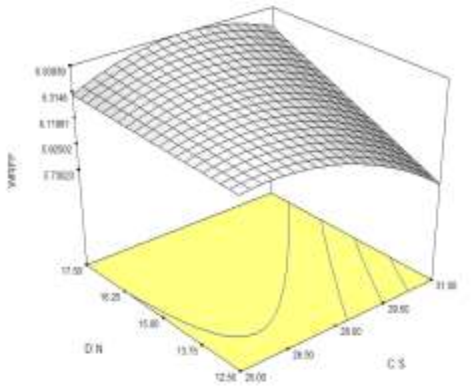

Figure 4(c): Response Surface due to Interactive effect of Arc Travel Speed and Tip Distance on WRFF

D *Effect of welding Parameters on Weld Reinforcement Form Factor (WRFF)*

Fig. 4 shows that the effects of welding Parameters A (Current), B (Voltage), C (Arc Travel Speed), D (Tip Distance) on WRFF. Figure 4 depicts that the current has least impact on WRFF. It is observed from the Figure 4 that WRFF increases with increase of voltage, Tip Distance and decrease with increase in Arc Travel Speed.

WRFF Increase due to bead width increase almost steadily but reinforcement decreases with the increase of voltage so WRFF increase as voltage increase.

Due to the less heat input and minimum metal deposition rate, the size of weld pool decrease and hence WRFF reduce with increase in Arc Travel Speed.

With the increase in Tip Distance, the Bead width and the Reinforcement increase and decrease respectively. So the WRFF increases with the increase in the Tip Distance.

Figure 4(a) shows the interaction effect of Arc Travel Speed and Current on WRFF. It is clear from Figure at lower value of Arc Travel Speed (-1 level), when current increase then WRFF decreases from 6.41 mm to 5.83 mm. Again from figure at higher value of Arc Travel Speed (+1 level), when current increases then WRFF increases from 5.61 mm to 6.18 mm.

Figure 4(b) shows the interaction effect of Voltage and Tip Distance on WRFF. It is clear from Figure at higher value of Tip Distance (+1 level), when Voltage increase then WRFF increases from 5.72 mm to 7.03 mm. Again from figure at lower value of Tip Distance (-1 level), when Voltage increase then WRFF increases from 5.11 mm to 6.95 mm.

Figure 4(c) shows the interaction effect of Arc Travel Speed and Tip Distance on WRFF. It is clear from Figure at higher value of Tip Distance (+1 level), when Arc Travel Speed increase then WRFF slightly increases from 6.29 mm to 6.35 mm. Again from figure at lower value of Tip Distance (-1 level), when Arc Travel Speed increases then WRFF decreases from 6.24 mm to 5.73 mm.

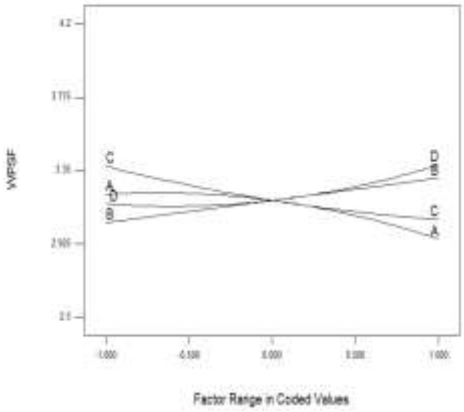

Figure 5: Effect of Welding Parameters on Weld Penetration Shape Factor (WPSF)

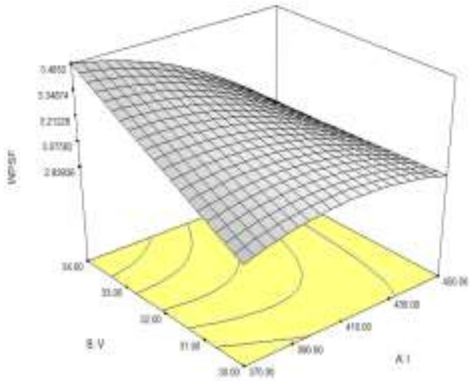

Figure 5(a): Response Surface due to Interactive effect of current and voltage on WPSF

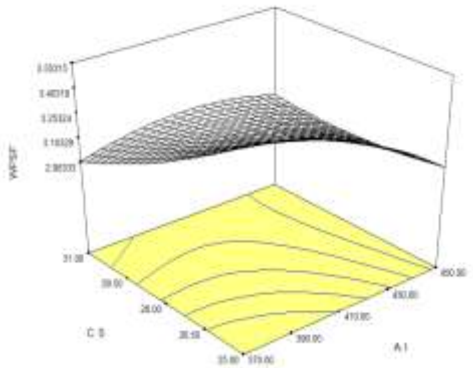

Figure 5(b): Response Surface due to Interactive effect of current and Arc Travel Speed on WPSF

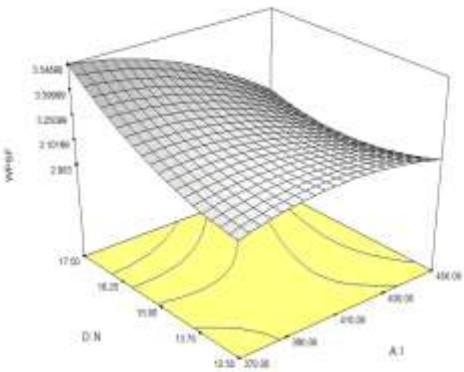

Figure 5(c): Response Surface due to Interactive effect of current and Tip Distance on WPSF

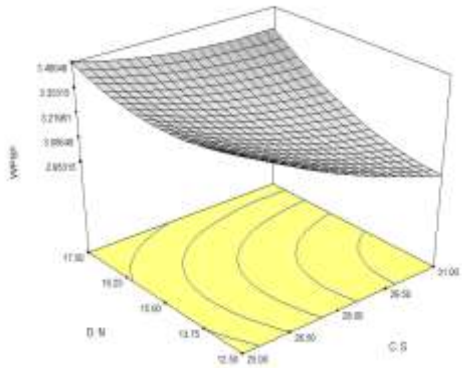

Figure 5(d): Response Surface due to Interactive effect of Arc Travel Speed and Tip Distance on WPSF

E *Effect of welding Parameters on Weld Penetration Shape Factor (WPSF)*

Fig. 5 shows that the effects of welding Parameters A (Current), B (Voltage), C (Arc Travel Speed), D (Tip Distance) on WPSF. It is observed from the Figure 5 that WPSF increases with increase of voltage, Tip Distance and decrease with increase in Current and Arc Travel Speed.

WPSF decrease as the current increase because rate of increase of Penetration is more than that of bead width with increase of current.

WPSF Increase due to bead width increase almost steadily but Penetration depicts very less impact on Voltage so WPSF increase as voltage increase.

Due to less heat input and minimum metal deposition rate, the size of weld pool decrease and hence WPSF reduce with increase in Arc Travel Speed.

With the increase in Tip Distance, the Bead width and the penetration increase and decrease respectively. So the WPSF increases with the increase in the Tip Distance.

Figure 5(a) shows the interaction effect of Welding Current and Voltage on WPSF. It is clear from Figure at higher value of voltage (+1 level), when current increases then WPSF decreases from 3.48 mm to 2.93 mm. Again from figure at lower value of voltage (-1 level), when current increase then WPSF slightly increases from 2.93 mm to 2.96 mm.

Figure 5(b) shows the interaction effect of Welding Current and Arc Travel Speed on WPSF. It is clear from Figure at lower value of Arc Travel Speed (-1 level), when current increase then WPSF decreases from 3.55 mm to 3.00 mm. Again from figure at higher value of Arc Travel Speed (+1 level), when current increases then WPSF slightly increases from 2.95 mm to 2.98 mm.

Figure 5(c) shows the interaction effect of Welding current and Tip Distance on WPSF. It is clear from Figure at higher value of Tip Distance (+1 level), when current increase then WPSF decreases from 3.54 mm to 3.02 mm. Again from figure at Lower value of Tip Distance (-1 level) when current increases then WPSF is constant.

Figure 5(d) shows the interaction effect of Arc Travel Speed and Tip Distance on WPSF. It is clear from Figure at higher value of Tip Distance (+1 level), when Arc Travel Speed increase then WPSF decreases from 3.48 mm to 3.36 mm. Again from figure we at Lower value of Tip Distance (-1 level), when current increases from then WPSF decreases from 3.44 mm to 2.95 mm.

V CONCLUSION

The Following conclusions were arrived at from the above investigation.

- The models developed can be employed for obtaining the desired weld bead dimensions.
- Response surface methodology can be employed easily for developing mathematical models for expressing important weld bead dimensions and shape relationships within the optimal range of process control variables for SAW.
- As the Welding Current (I) increases the Bead width (W) increases from 15.50 mm to 16.55 mm, Penetration (P) increases from 4.66 mm to 5.42 mm, Reinforcement (H) increases from 2.49 mm to 2.67 mm but Weld penetration shape factor (WPSF) decreases from 3.21 mm to 2.95 mm and Weld reinforcement form factor (WRFF) remains constant.
- As the Welding Voltage (V) increases the Bead width (W) increases from 15.59 mm to 17.07 mm, Weld penetration shape factor (WPSF) increases from 3.04 mm to 3.30 mm, Weld reinforcement form factor (WRFF) increases from 5.41 mm to 6.99 mm and Reinforcement (H) decreases from 2.94 mm to 2.40 mm but Penetration remains constant.
- As the Arc Travel Speed (S) increase the Bead width (W) decreases from 17.22 mm to 14.83 mm, Penetration (P) decreases from 5.02 mm to 4.74 mm, Reinforcement (H) decreases from

2.76 mm to 2.45 mm, Weld penetration shape factor (WPSF) decreases from 3.37 mm to 3.06 mm, Weld reinforcement form factor (WRFF) decreases from 6.26 mm to 6.04 mm.

- As the Tip Distance (N) increases the Bead width (W) increases from 15.75 mm to 16.30 mm, Weld penetration shape factor (WPSF) increases from 3.15 mm to 3.38 mm, Weld reinforcement form factor (WRFF) increases from 6.16 mm to 6.50 mm but Penetration (P) decrease from 4.86 mm to 4.70 mm and Reinforcement (H) decrease from 2.57 mm to 2.48 mm.
- Interaction effect of two different parameter on weld bead geometry and response surface due to interactive effect of two different parameter on weld bead geometry is shown by graphs.

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Conflict of Interest: **NIL**

