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DEVELOPING EMPIRICAL RELATIONSHIPS TO PREDICT WELD BEAD GEOMETRY OF SHIELDED METAL ARC WELDING

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ABSTRACT

Welding input process parameters are playing a very significant role in determining the weld bead quality. The quality of the joint can be defined in terms of properties such as weld bead geometry, mechanical properties and distortion. In this study, the weld bead geometry such as Depth of penetration (P), Bead width (W), Reinforcement height (H), Reinforcement angle (θ) and Dilution (D) of the Shielded Metal Arc Welding (SMAW) bead on plate made of mild steel plates are investigated. The welding input parameters such as welding current (I), welding speed (S), wind velocity (V) and wind direction (D) of empirical mathematical models have been developed using four factor, five level factorial design techniques to predict the weld bead geometry at 95% confidence level.

Keywords: SMAW, design of experiments, weld bead geometry, dilution, response surface methodology.

INTRODUCTION

Shielded Metal Arc Welding (SMAW), commonly called stick or covered electrode welding, is a manual welding process whereby an arc is generated between fluxes covered consumable electrode and the work piece. The filler metal is deposited from the electrode and uses the decomposition of the flux covering to generate a shielding gas and to provide fluxing elements to protect the molten weld metal droplets and the weld pool. Shielded Metal Arc Welding is one of the widely used electric arc welding processes [1]. Generally all welding processes are used with the aim of obtaining a welded joint with desired weld bead parameters, excellent mechanical properties with minimum distortion [2].

The weld bead geometry plays an important role in determining the mechanical properties of the welded joints. Therefore, the selection of the welding process parameters is very essential for obtaining optimal weld bead geometry [3]. The use of Design of experiment (DOE) has grown rapidly and been adapted for many applications in different areas. Design of experiments (DOEs) and statistical techniques are widely used to optimize process parameters. The application of RSM in developing mathematical models and plotting contour graphs relating important input variables namely the open-circuit voltage, wire feed rate, welding speed, and nozzle to-plate distance to some responses namely penetration, reinforcement, width and percentage dilution of the weld bead in the SAW of pipes [4]. In this investigation an attempt is made to develop an empirical relationship to predict weld bead geometry of Shielded Metal Arc Welding (SMAW) process joints using statistical tools such as design of experiments, analysis of variance and regression analysis.

In this study, the SMAW process is done on 100 mm x 50 mm x 6 mm mild steel plates. The chemical compositions of the mild steel plates IS 2062 and the welding consumable used for SMAW is E7018, size of the electrode of 4 mm are shown in Table-1.

Table-1. Chemical composition of base material and consumable (weight in %).

Material	C	S	P	Mn	Si	Cu	Fe
IS/2062	0.20	0.055	0.055	-	0.100	0.350	Balance
E7018	0.04-0.09	0.030	0.030	0.80-1.60	0.35-0.70	-	Balance

METHODOLOGY

Plan of investigations

In order to achieve the desired aim, the present investigation is planned in the following sequence:

a) Identifying the important SMAW parameters that influence the responses.
b) Finding the upper and lower limits of the identified parameters.
c) Developing the experimental design matrix.
d) Conducting the experiments as per the design matrix.
e) Recording the responses, viz. Bead width (W), Penetration (P), Reinforcement height (H), Reinforcement angle (θ) and Dilution (D)
f) Developing an empirical relationship using response surface methodology.
g) Checking adequacy of the developed relationship.

Identifying the important parameters

From the literature [5-9], and the preliminary work under taken, the factors which have a significant influence on the weld bead geometry and hence the weld quality is identified. The process parameters are welding current (I), welding speed (S), wind velocity (V) and wind direction (D).

Finding the working the limits of the parameters

Trial runs are carried out by varying one of the process parameters whilst keeping the rest of them at constant values. The working range is decided upon by inspecting the bead for smooth appearance and the absence of any visible defects. The upper limit of a factor is coded as +2 and the lower limit as -2, the coded values being calculated from the following relationship [10].

$$X_i = \frac{2[2X - (X_{\max} + X_{\min})]}{(X_{\max} - X_{\min})} \quad (1)$$

Where X_i is the required coded value of a variable X; when X is any of the variable from X_{min} to X_{max}; X_{min} is the lowest level of the variable; X_{max} is the highest level of the variable. The selected process parameters with their limits, notations and units are given in Table-2.

Table-2. Process control parameters and their levels.

S. No	Parameter	Notation	Unit	Levels				
				-2	-1	0	1	2
1	Welding current	I	Amps	140	160	180	200	220
2	Welding speed	S	mm/sec	9	12	15	18	21
3	Wind velocity	V	m/sec	1	3	5	7	9
4	Wind direction	D	Degree	0	90	180	270	360

Developing the experimental design matrix

It is decided to use four factors, five levels, central composite design matrix to optimize the experimental conditions. Table-3 shows the 30 sets of coded conditions used to form the design matrix. First 16 experimental conditions are derived from full factorial experimental design matrix (2^4=16). All the welding variables at the intermediate (0) level constitute the center points while the combinations of each welding variables at either their lowest (-2) or highest (+2) with the other three variables of the intermediate levels constitute the star points. Thus, the 30 experimental conditions allowed the estimation of the linear, quadratic and two-way interactive effects of the welding variables on weld bead geometry of SMAW. For the convenience of recording and processing experimental data, upper and lower levels of the factors have been coded as +2 and -2 respectively.

Figure-1. Experimental set up of lincoln electric welding machine.

Conducting the experiments as per the design matrix

The experiments are conducted according to the design matrix at random to avoid systematic errors creeping into the system. As per the DOE, 30 beads on plate weldments are made. The welding is carried out using Lincoln electric (Model: Precision TIG 375) as shown in Figure-1.

Recording the responses

The welded plates are cross sectioned at their mid points to obtain test specimens of 10 mm wide. These specimens are prepared by the usual metallurgical polishing methods and etched with 5% nital. The weld bead profiles are traced using a reflective type profile projector (Make: METZER-M) and the bead dimensions, viz. Bead width (W), Penetration (P), Reinforcement height (H), Reinforcement angle (θ), area of the penetration and the area of the reinforcement are measured using graph sheets. Then the percentage dilution of the bead is calculated. The observed values of W, P, H, θ the calculated values of dilution are given in Table-3.

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Table-3. Design matrix and experimental results.

Expt. No.	Coded values				Original values				Bead geometry and dilution				
	I	S	V	D	I	S	V	D	W	P	H	θ	D (%)
1	-1	-1	-1	-1	160	12	3	90	12.5	1.7	2.2	23	43.10
2	1	-1	-1	-1	200	12	3	90	14.3	1.9	2.3	28	39.39
3	-1	1	-1	-1	160	18	3	90	12.0	1.0	3.0	38	23.73
4	1	1	-1	-1	200	18	3	90	18.2	3.0	2.1	18	51.43
5	-1	-1	1	-1	160	12	7	90	13.3	2.0	2.2	32	45.59
6	1	-1	1	-1	200	12	7	90	11.8	1.2	2.2	34	31.51
7	-1	1	1	-1	160	18	7	90	13.3	2.1	3.9	48	33.33
8	1	1	1	-1	200	18	7	90	17.0	3.1	2.2	27	44.66
9	-1	-1	-1	1	160	12	3	270	15.2	1.4	1.9	22	35.48
10	1	-1	-1	1	200	12	3	270	16.0	2.0	2.0	20	45.04
11	-1	1	-1	1	160	18	3	270	15.0	2.1	2.8	30	43.01
12	1	1	-1	1	200	18	3	270	18.0	6.0	2.0	20	78.23
13	-1	-1	1	1	160	12	7	270	12.5	2.2	2.7	35	37.50
14	1	-1	1	1	200	12	7	270	15.5	2.5	2.6	22	45.45
15	-1	1	1	1	160	18	7	270	14.8	1.0	3.8	25	23.47
16	1	1	1	1	200	18	7	270	17.7	1.7	2.6	24	37.77
17	-2	0	0	0	140	15	5	180	13.2	1.0	2.8	44	23.88
18	2	0	0	0	220	15	5	180	20.2	3.1	2.2	13	50.00
19	0	-2	0	0	180	9	5	180	10.4	1.6	2.3	28	39.92
20	0	2	0	0	180	21	5	180	14.8	3.8	2.6	27	52.00
21	0	0	-2	0	180	15	1	180	13.2	2.0	2.1	38	40.63
22	0	0	2	0	180	15	9	180	15.0	2.3	1.7	14	56.34
23	0	0	0	-2	180	15	5	0	15.7	1.9	2.5	30	35.80
24	0	0	0	2	180	15	5	360	14.8	2.2	2.5	32	41.11
25	0	0	0	0	180	15	5	180	13.8	2.9	3.8	35	38.46
26	0	0	0	0	180	15	5	180	14.8	2.7	3.2	32	37.61
27	0	0	0	0	180	15	5	180	14.2	2.8	3.5	30	36.75
28	0	0	0	0	180	15	5	180	13.8	3.2	3.6	34	38.83
29	0	0	0	0	180	15	5	180	13.2	2.7	3.7	35	38.68
30	0	0	0	0	180	15	5	180	13.6	2.9	3.4	37	42.20

DEVELOPING AN EMPIRICAL RELATIONSHIP

Response Surface Methodology (RSM) is a collection of mathematical and statistical techniques that is useful for the modeling and analysis of problems in which a response of interest is influenced by several variables and the objective is to optimize this response. The response function representing any of the weld bead dimensions can be expressed [11-14] as

$$Y = f\,(I, S, V, D) \qquad (2)$$

Where Y is the response, e.g. bead width, penetration, reinforcement height etc.
I is welding current, Amps
S is welding speed, mm/sec
V is wind velocity, m/sec
D is wind direction, degree.

The second order polynomial (regression) equation used to represent the response surface 'Y' is

$$Y = b_0 + \sum b_i x_i + \sum b_{ii} x_i^2 + \sum b_{ij} x_i x_j \qquad (3)$$

and for four factors, the selected polynomial could be expressed as follows:

$$Y = b_0 + b_1(I) + b_2(S) + b_3(V) + b_4(D) + b_{11}(I^2) + b_{22}(S^2) + b_{33}(V^2) + b_{44}(D^2) + b_{12}(IS) + b_{13}(IV) + b_{14}(ID) + b_{23}(SV) + b_{24}(SD) + b_{34}(VD) \qquad (4)$$

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where $b_o$is the average of responses and b_1, b_2,….,b_{23} are the coefficients that depend on respective main and interaction effects of the parameters.

In order to estimate the regression co-efficient, a number of experimental design techniques are available. In this work, the central composite face centered design is used, which fits the second order response surface very accurately. All co-efficient are obtained by applying central composite face centered design using the Design Expert statistical software package [15]. After determining the significant co-efficient, the final relationship is developed using only those co-efficient. The final empirical relationship to predict for bead width, penetration, reinforcement height, reinforcement angle and dilution are represented in Equation,

$$\text{Width}=203.87-1.42(I)-18.97(S)-26.50(V)+0.78(D)+0.11(IS) + 0.32(IV)-9.34E-03(ID) +0.04(SV) + 0.02(SD) - 0.025(VD)+1.70E-03(I^2)+0.47(S^2)+4.35E-05(D^2)-8.68E-05(ISD)+1.37E-04(IVD)-9.77E-0(I^2V)+2.76E-05(I^2D)-2.81E-03(IS^2) \quad (5)$$

$$\text{Height}=-172.77+1.85(I)+6.35(S)+13.55(V)-5.59E-03(D)-0.06(IS)-0.15(IV)+1.74E-05(ID)+0.10(SV)-6.94E-05(SD)+7.29E-04(VD)-5.05E-03(I^2)-0.02(S^2)-0.09(V^2)-4.69E-04(ISV) +1.61E04 (I^2S) + 4.30E-04(I^2V) \quad (6)$$

$$\text{Penetration}=152.35-1.47(I)-9.23(S)-14.90(V)+0.022(D)+0.08(IS)+0.14(IV)-9.55E-04(ID)+0.39(SV)+4.87E-03(SD)+0.013(VD)+3.58E-03(I^2)-5.67E-03(S^2)-0.05(V^2)-2.64E-05(D^2) -1.51E-03(ISV)- 9.61E-04(SVD) - 1.93E-04(I^2S)-3.52E-04(I^2V) +2.95E-06(I^2D) \quad (7)$$

$$\text{Angle}=-3205.46+27.83(I)+192.97(S)+396.05(V)-1.74(D)-1.22(IS)-4.23(IV)+0.03(ID)-1.77(SV)-0.1(SD)+0.03(VD)-0.06(I^2)-4.18(S^2)-0.51(V^2)-9.52E-05(D^2)+0.01(ISV)+6.02E-04(ISD)+2.31E-03(SVD)+9.38E-04(I^2S)+0.01(I^2V)-1.01E04 (I^2D)+0.02(IS^2) \quad (8)$$

$$\text{Dilution}=2141.44-19.49(I)-48.34(S)-346.91(V)-1.64713(D) +0.21(IS) +3.58(IV)+5.90E-03(ID)+3.28(SV)+0.098(SD) +0.10(VD) +0.05(I^2) + 0.18(S^2) + 0.56(V^2) -0.01(ISV)-2.87E-04(ISD)-8.18E-03(SVD)-9.61E-03(I^2V) \quad (9)$$

ANALYSIS OF VARIANCE

The experimental results are analyzed with Analysis of Variance (ANOVA), which is used for identifying the factors significantly affecting the quality. In order to find out statistical significance of various factors like welding current in Amps (I), welding speed in mm/s (S), wind velocity in m/s (V) and wind direction in degree (D) analysis of variance (ANOVA) is performed on experimental data. Tables 4, 5, 6, 7 and 8 shows the results of the ANOVA with the for response bead width, reinforcement height, penetration, reinforcement angle and dilution respectively.

Table-4. Response for bead width.
Analysis of variance table [Partial sum of squares - Type III]

Source	Sum of squares	Df	Mean square	F Value	p-value Prob>F
Model	**126.19**	**18**	**7.01**	**28.22**	**< 0.0001**
A-Welding current	24.5	1	24.5	98.63	< 0.0001
B-Welding speed	23.4	1	23.4	94.21	< 0.0001
C-Wind velocity	1.62	1	1.62	6.52	0.0268
D-Wind direction	0.41	1	0.41	1.63	0.228
AB	8.56	1	8.56	34.44	0.0001
AC	0.86	1	0.86	3.44	0.0904
AD	0.016	1	0.016	0.063	0.8066
BC	1.27	1	1.27	5.09	0.0453
BD	0.33	1	0.33	1.33	0.2731
CD	0.28	1	0.28	1.11	0.3148
A^2	14.32	1	14.32	57.65	< 0.0001
B^2	2.69	1	2.69	10.82	0.0072
D^2	3.48	1	3.48	14.02	0.0032
ABD	3.52	1	3.52	14.15	0.0031
ACD	3.9	1	3.9	15.7	0.0022
A^2C	3.26	1	3.26	13.1	0.004
A^2D	5.27	1	5.27	21.2	0.0008
AB^2	1.37	1	1.37	5.5	0.0388
Residual	2.73	11	0.25		
Lack of Fit	1.23	6	0.21	0.68	0.6737
Pure Error	1.5	5	0.3		
Cor Total	128.92	29			

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The validity of this regression models developed is further tested by drawing scatter diagrams. A typical scatter diagram for the bead width is shown in Figure-2. 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 model [16]. The actual value is compared with predicted value as shown in Figure-3.

The Model F-value of 28.22 implies the model is significant. There is only a 0.01% chance that a "Model F-Value" this large could occur due to noise.Values of "Prob > F" less than 0.0500 indicate model terms are significant. In this case A, B, C, AB, BC, A^2, B^2, D^2, ABD, ACD, A^2C, A^2D, AB^2 are significant model terms. Values greater than 0.1000 indicate the model terms are not significant.If there are many insignificant model terms (not counting those required to support hierarchy), model reduction may improve model. The "Lack of Fit F-value" of 0.68 implies the Lack of Fit is not significant relative to the pure error. There is a 67.37% chance that a "Lack of Fit F-value" this large could occur due to noise.

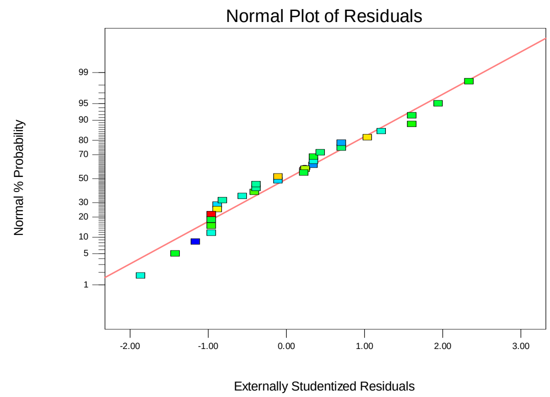

Figure-2. Normal probability plots.

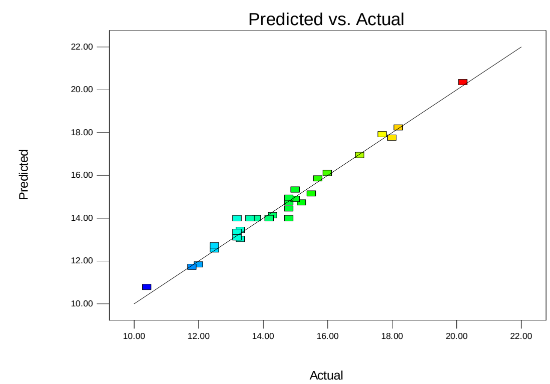

Figure-3. Correlation graph.

Table-5. Response for reinforcement height.
Analysis of variance table [Partial sum of squares - Type III]

Source	Sum of squares	Df	Mean square	F Value	p-value Prob>F
Model	10.14	16	0.63	4.05	0.0073
A-Welding current	1.35	1	1.35	8.66	0.0114
B-Welding speed	0.045	1	0.045	0.29	0.6006
C-Wind velocity	0.08	1	0.08	0.51	0.4869
D-Wind direction	3.75E-03	1	3.75E-03	0.024	0.8793
AB	1.38	1	1.38	8.84	0.0108
AC	0.14	1	0.14	0.9	0.3601
AD	0.016	1	0.016	0.1	0.7568
BC	0.11	1	0.11	0.68	0.4258
BD	5.63E-03	1	5.63E-03	0.036	0.8524
CD	0.28	1	0.28	1.76	0.207
A^2	1.05	1	1.05	6.73	0.0223
B^2	1.19	1	1.19	7.62	0.0162
C^2	3.31	1	3.31	21.17	0.0005
ABC	0.051	1	0.051	0.32	0.5789
A^2B	0.2	1	0.2	1.28	0.2781
A^2C	0.63	1	0.63	4.03	0.0659
Residual	2.03	13	0.16		
Lack of Fit	1.8	8	0.22	4.82	0.0501
Pure Error	0.23	5	0.047		
Cor Total	12.17	29			

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The validity of this regression models developed is further tested by drawing scatter diagrams. A typical scatter diagram for the reinforcement is shown in Figure-4. 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 model. The actual value is compared with predicted value as shown in Figure-5.

The Model F-value of 4.05 implies the model is significant. There is only a 0.73% chance that a "Model F-Value" this large could occur due to noise. Values of "Prob > F" less than 0.0500 indicate model terms are significant.In this case A, AB, A^2, B^2, C^2 are significant model terms. Values greater than 0.1000 indicate the model terms are not significant. If there are many insignificant model terms (not counting those required to support hierarchy), model reduction may improve model. The "Lack of Fit F-value" of 4.82 implies there is a 5.01% chance that a "Lack of Fit F-value" this large could occur due to noise.

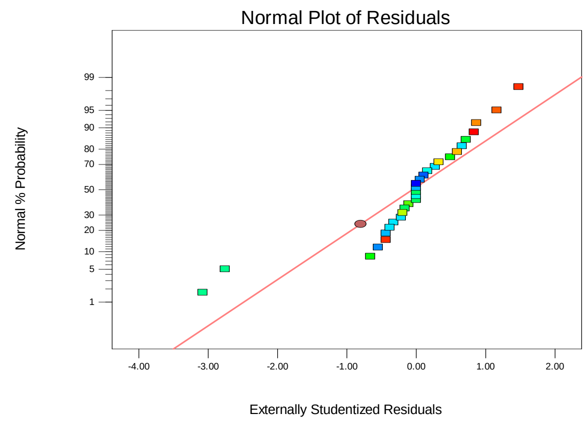

Figure-4. Normal probability plots.

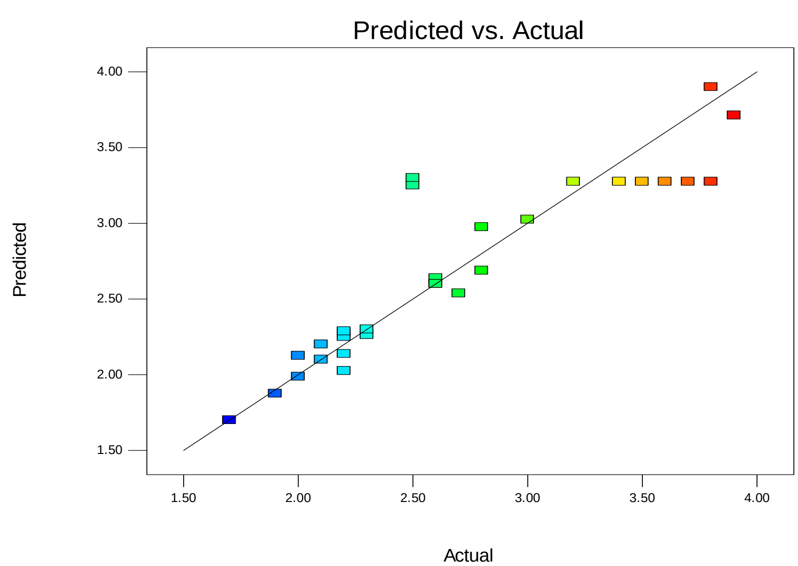

Figure-5. Correlation graph.

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Table-6. Response for penetration.
Analysis of variance table [Partial sum of squares - Type III]

Source	Sum of squares	Df	Mean Square	F Value	p-value Prob>F
Model	27.94	19	1.47	17.06	< 0.0001
A-Welding current	6.1	1	6.1	70.75	< 0.0001
B-Welding speed	2.42	1	2.42	28.06	0.0003
C-Wind velocity	0.045	1	0.045	0.52	0.4866
D-Wind direction	0.045	1	0.045	0.52	0.4866
AB	3.33	1	3.33	38.63	< 0.0001
AC	1.89	1	1.89	21.93	0.0009
AD	0.6	1	0.6	6.97	0.0248
BC	1.63	1	1.63	18.85	0.0015
BD	5.63E-03	1	5.63E-03	0.065	0.8036
CD	1.5	1	1.5	17.4	0.0019
A^2	1.25	1	1.25	14.5	0.0034
B^2	0.071	1	0.071	0.83	0.3841
C^2	0.98	1	0.98	11.31	0.0072
D^2	1.25	1	1.25	14.5	0.0034
ABC	0.53	1	0.53	6.1	0.0332
BCD	4.31	1	4.31	49.93	< 0.0001
A^2B	0.29	1	0.29	3.31	0.099
A^2C	0.42	1	0.42	4.89	0.0514
A^2D	0.06	1	0.06	0.7	0.4229
Residual	0.86	10	0.086		
Lack of Fit	0.69	5	0.14	3.97	0.0781
Pure Error	0.17	5	0.035		
Cor Total	28.81	29			

The validity of this regression models developed is further tested by drawing scatter diagrams. A typical scatter diagram for the penetration is shown in Figure-6. 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 model. The actual value is compared with predicted value as shown in Figure-7.

The Model F-value of 17.06 implies the model is significant.There is only a 0.01% chance that a "Model F-Value" this large could occur due to noise.Values of "Prob > F" less than 0.0500 indicate model terms are significant. In this case A, B, AB, AC, AD, BC, CD, A^2, C^2, D^2, ABC,BCD are significant model terms.Values greater than 0.1000 indicate the model terms are not significant. If there are many insignificant model terms model reduction may improve model. The "Lack of Fit F-value" of 3.97 implies there is a 7.81% chance that a"Lack of Fit F-value" this large could occur due to noise.

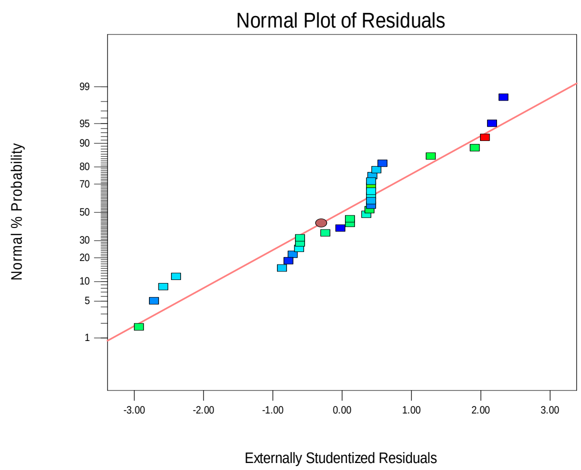

Figure-6. Normal probability plots.

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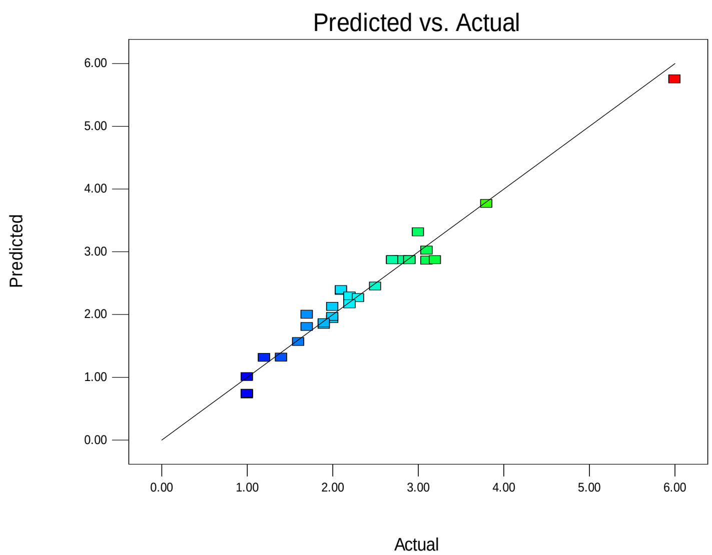

Figure-7. Correlation graph.

Table-7. Response for Reinforcement angle.
Analysis of variance table [Partial sum of squares - Type III]

Source	Sum of squares	Df	Mean Square	F Value	p-value Prob>F
Model	1896.08	21	90.29	13.87	0.0004
A-Welding current	480.5	1	480.5	73.8	< 0.0001
B-Welding speed	0.5	1	0.5	0.077	0.7887
C-Wind velocity	288	1	288	44.24	0.0002
D-Wind direction	2	1	2	0.31	0.5946
AB	121	1	121	18.59	0.0026
AC	2.25	1	2.25	0.35	0.5728
AD	4	1	4	0.61	0.4557
BC	9	1	9	1.38	0.2735
BD	12.25	1	12.25	1.88	0.2074
CD	25	1	25	3.84	0.0857
A^2	53.44	1	53.44	8.21	0.021
B^2	74.3	1	74.3	11.41	0.0097
C^2	112.01	1	112.01	17.21	0.0032
D^2	16.3	1	16.3	2.5	0.1523
ABC	30.25	1	30.25	4.65	0.0632
ABD	169	1	169	25.96	0.0009
BCD	25	1	25	3.84	0.0857
A^2B	6.75	1	6.75	1.04	0.3384
A^2C	432	1	432	66.36	< 0.0001
A^2D	70.08	1	70.08	10.76	0.0112
AB^2	85.33	1	85.33	13.11	0.0068
Residual	52.08	8	6.51		
Lack of Fit	21.25	3	7.08	1.15	0.415
Pure Error	30.83	5	6.17		
Cor Total	1948.17	29			

The validity of this regression models developed is further tested by drawing scatter diagrams. A typical scatter diagram for the reinforcement angle is shown in Figure-8. 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 model. The actual value is compared with predicted value as shown in Figure-9.

The Model F-value of 13.87 implies the model is significant. There is onlya 0.04% chance that a "Model F-Value" this large could occur due to noise.Values of "Prob > F" less than 0.0500 indicate model terms are significant.In this case A, C, AB, A^2, B^2, C^2, ABD, A^2C, A^2D, AB^2 are significant model terms.Values greater than 0.1000 indicate the model terms are not significant. If there are many insignificant model terms, model reduction may improve model. The "Lack of Fit F-value" of 1.15 implies the Lack of Fit is not significant relative to the pure error. There is a 41.50% chance that a "Lack of Fit F-value" this large could occur due to noise.

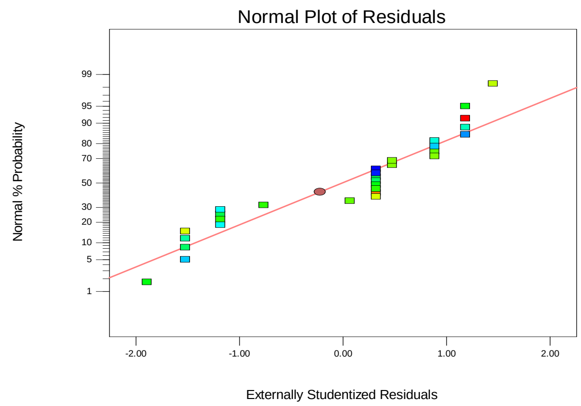

Figure-8. Normal probability plots.

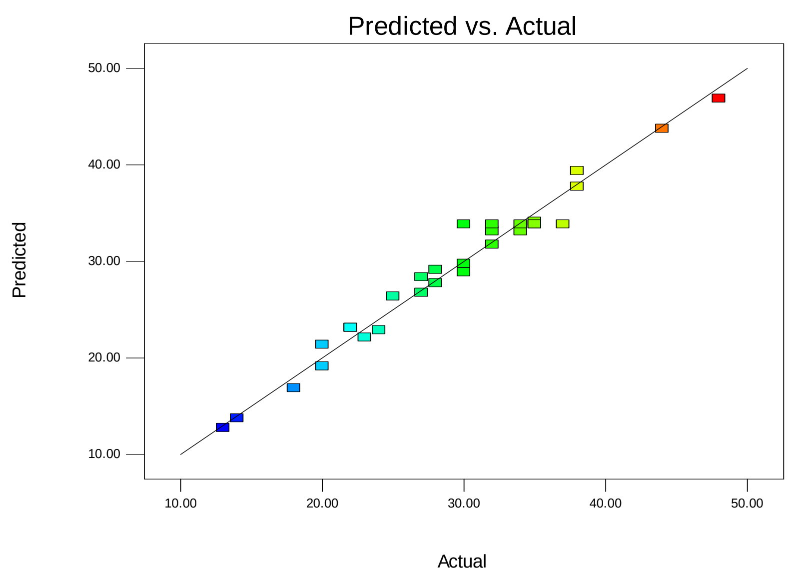

Figure-9. Correlation graph.

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Table-8. Response for dilution.
Analysis of variance table [Partial sum of squares - Type III]

Source	Sum of squares	Df	Mean square	F Value	p-value Prob>F
Model	3114.45	17	183.2	29.01	< 0.0001
A-Welding current	822.69	1	822.69	130.26	< 0.0001
B-Welding speed	56.2	1	56.2	8.9	0.0114
C-Wind velocity	123.45	1	123.45	19.55	0.0008
D-Wind direction	80.05	1	80.05	12.67	0.0039
AB	493.12	1	493.12	78.08	< 0.0001
AC	151.64	1	151.64	24.01	0.0004
AD	131.07	1	131.07	20.75	0.0007
BC	183.58	1	183.58	29.07	0.0002
BD	40.49	1	40.49	6.41	0.0263
CD	189.12	1	189.12	29.94	0.0001
A^2	11.02	1	11.02	1.75	0.2111
B^2	74.11	1	74.11	11.73	0.005
C^2	142.74	1	142.74	22.6	0.0005
ABC	40.07	1	40.07	6.35	0.027
ABD	38.43	1	38.43	6.09	0.0297
BCD	312.07	1	312.07	49.41	< 0.0001
A^2C	315.09	1	315.09	49.89	< 0.0001
Residual	75.79	12	6.32		
Lack of Fit	58.48	7	8.35	2.41	0.1746
Pure Error	17.31	5	3.46		
Cor Total	3190.24	29			

The validity of this regression models developed is further tested by drawing scatter diagrams. A typical scatter diagram for the dilution is shown in Figure-10. 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 model. The actual value is compared with predicted value as shown in Figure-11.

The Model F-value of 29.01 implies the model is significant. There is only a 0.01% chance that a "Model F-Value" this large could occur due to noise.Values of "Prob > F" less than 0.0500 indicate model terms are significant.In this case A, B, C, D, AB, AC, AD, BC, BD, CD, B^2, C^2, ABC, ABD, BCD, A^2C are significant model terms.Values greater than 0.1000 indicate the model terms are not significant. If there are many insignificant model terms (not counting those required to support hierarchy), model reduction may improve model. The "Lack of Fit F-value" of 2.41 implies the Lack of Fit is not significant relative to the pure error. There is a 17.44% chance that a "Lack of Fit F-value" this large could occur due to noise.

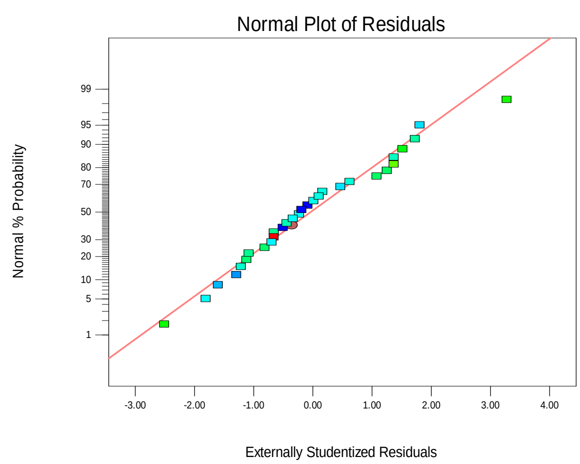

Figure-10. Normal probability plots.

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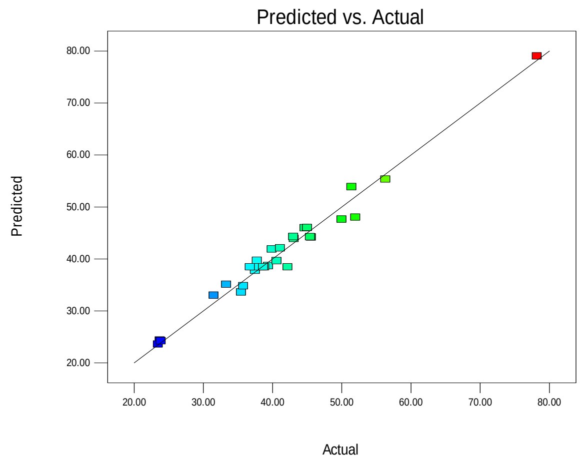

Figure-11. Correlation graph.

CONCLUSIONS

An empirical relationship is developed to predict weld bead geometry of viz. Bead width, Reinforcement height, Penetration, Reinforcement angle and Dilution of shielded metal arc welding using response surface methodology. The developed model can be effectively used to predict the weld bead geometry of shielded metal arc welding at 95% confidence level.

The welding parameters are Welding current (I), Welding speed(S), Wind velocity (V), and Wind direction (D) have the significant contributions on the responses are Bead width, Reinforcement height, Penetration, Reinforcement angle and Dilution.

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