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Research Paper

WELD BEAD GEOMETRY PREDICTION MODEL BY DESIGN OF EXPERIMENTS FOR MILD STEEL

Uma Gautam[1]* and Vipin[2]

*Corresponding Author: Uma Gautam, ✉Uma_mech_2k3@yahoo.co.in

Submerged Arc Welding (SAW) is a common arc welding process and the basic characteristics of this process are high deposition rate, ability to weld thick sections with ease and longer weld runs because of the same reason it is used to join thick and heavy sections. The stress carrying capacity of a weld determined by weld bead geometry. The models were developed in terms of Arc Voltage, Arc Current, Travel Speed, nozzle to Plate distance obtained experimentally. The Experimental data has been used to develop the models with the aid of regression analysis. The effects of cutting variables (Arc Voltage, Arc Current, Travel Speed, nozzle to Plate distance) on Bead Height, Bead Width, Bead Penetration have been investigated by Central composite Design.

Keywords: Submerged Arc Welding (SAW), Central composite design, Arc current, Travel distance, Arc voltage, Weld bead geometry

INTRODUCTION

The Submerged Arc Welding (SAW) process is widely used in fabrication of pressure vessels, marine vessels, pipelines and offshore structures, this is due to the requirement of lower welder skill, good surface appearance, invisible arc, and, high deposition rate and deep penetration, this paper highlights the analysis and study of process parameters: arc Voltage, welding current, travel speed and electrode extension, on the bead geometry response such as, bead height, bead width and bead penetration.

Researchers R S chandel, Yang *et at.*, Murugan and Gunaraj worked on the effects of current, electrode diameter, electrode extension and electrode polarity on the bead height, bead penetration, bead width, and melting rate. However the models developed by these Researchers are mostly for ferrous materials. The Bead Height, Bead Width, Bead Penetration were obtained by process variables from semi automatic submerged arc welding. The data so obtained was used to develop Responses equation with the help of Central composite Design.

[1] Department of Mechanical and Automation Engineering, GGSIPU, Delhi, India.

[2] Department of Mechanical Engineering, Delhi College of Engineering, Bawana Road, Delhi, India.

RESPONSE MODEL

The proposed relationship between the response (Bead Height) and process variables can be represented by the following:

$$(BH/BW/BP) = C\,(V^{\alpha} A^{\beta} S^{\gamma} N^{\$})\,, \quad \ldots(1)$$

Where BH is the Bead Height in mm, BW is Bead Width in mm, BP is Bead Penetration in mm, *V* is Arc Voltage (*v*),Arc current in (*A*), Travel Speed in (mm/sec), nozzle distance in (mm). *C*, ~, , ¥ are constants, ¸ is a random error.

Equation (1) can be rewritten in the following logarithmic form:

$$\log h = \log C + \alpha \log V + \beta \log A + \gamma \log S + \$ \log N + \log ¸ \quad \ldots(2)$$

The linear model of Equation (2) is:

$$y = a_0 x_0 + a_1 x_1 + a_2 x_2 + a_3 x_3 + a_4\ x_4 + a_5 \cdot \quad \ldots(3)$$

where *y* is the measured Bead Height/Bead Width/Bead Penetration, for a logarithmic scale, $x_0 = 1$ (dummy variable), and $x_1 = \log V$, $x_2 = \log A$, $x_3 = \log S$, $x_4 = \log N$, $\cdot = \log ¸$, where $\cdot$ is random error with zero mean and constant variance, $a_0 = \log C$, and a_1, a_2, and a_3 are the model parameters.

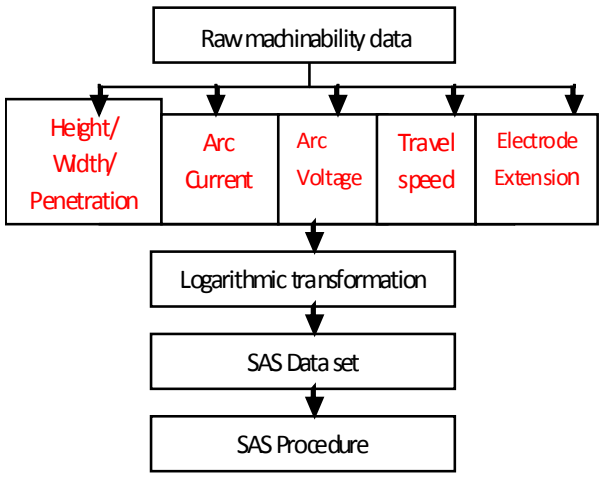
The Quadratic model for response (Bead Height/Bead Width/Bead Penetration) is expressed as:

$$y_1 = y - \cdot = b_0 x_0 + b_1 x_1 + b_2 x_2 + b_3 x_3 + b_{11} x_1^2 + b_{22} x_2^2 + b_{33} x_3^2 + b_{12} x_1 x_2 + b_{13} x_1 x_3 + b_{23} x_2 x_3 \quad \ldots(4)$$

Equation (4) is useful when the two-way interactions between V, A, S and N are significant for second-order effects.

The parameters of Equation (5) have been estimated by the regression analysis as per the scheme given below in Figure 1.

Figure 1: Program for Processing Data Vector in Regression Analysis



Source: Vipin Kumar (2009)

EXPERIMENTAL DESIGN AND CONDITIONS

Design Expert 8.0 with 4 factors, 5 levels, rotatable Central Composite Design was used to develop relationship for predicting weld bead geometry, which enables to quantify the direct and interaction effects.

Following are the steps which are carried out by research work for fulfillment of the desired aim.

- Selection of the important process control variables.
- Identification of the useful limits of the welding parameters, viz., voltage (V), current (A), travel speed (S), and electrode extension (N).
- Developing the design matrix.
- On the basis of design matrix, conducting the experiment.
- Recording the responses viz., penetration (P), bead width (w) and reinforcement height (H).

- Development of mathematical models.

Developing the design matrix consisting of 31 sets of coded conditions was used to carry out the experiment. For the better result, the value of alpha is chosen as 2. The first 16 conditions have been formulated as per 24 (two levels and 4 factors) factorial design. These factorial points represent the variance optimal design for a first order or first order plus 2 factor interaction models. The next eight experimental conditions are called as Star points, i.e., keeping one factor at the highest/lowest level and the remaining factors at middle level. Addition of Star points allow for efficient estimation of pure quadratic terms in case of existence of curvature in the system. To check the repeatability the experimental procedures, the last seven experimental conditions are used known as centre points, i.e., keeping all the factors at the middle level.

EXPERIMENTAL DETAILS

The Welding Laboratory of Delhi Technological University were used for conducting the experiments with the following welding set-up:

Machine Model-QSW800, Manufactured by-Quality Engineer (Baroda Pvt. Ltd.), A/18, Gujarat Estate, Dharamsingh Desai Marg, Chhani Road Baroda-390002.

A 3.2 mm diameter copper coated mild steel wire manufactured by ESAB was used. Test specimens were prepared from 16 mm thickness AISI 1012 Mild steel plate. Dimension of each plate were 200 x 75 x 16 mm and an agglomerated flux was used. To carry out the experiment, welding is done on the plate as per the design matrix to avoid systematic error.

Identification of Useful Limits of Welding Parameters

By varying one of the process parameters at a time while keeping the rest of them at constant value, trials run were conducted. The working range was fixed on the basis of inspecting smooth appearance of weld bead and absence of visible defects. The upper and lower limits were coded as +2 and –2, respectively. The coded values for intermediate values can be calculated from the formula:

$X_i = 2[2X - (X_{max} + X_{min})/(X_{max} - X_{min})$, where, X_i is the required coded value of a variable X, when X is any value of the variable from X_{min} to X_{max}; X_{max} and X_{min} are the maximum and minimum levels of the variables. The selected process parameters and their upper and lower limits together with notations and units are given in Table 1.

Table 1: Limits of Process Variable

S. No.	Parameters	Units	Notation	Limits				
				–2	–1	0	+1	+2
1.	Arc Voltage	volt	V	25	28.5	32.5	36	40
2.	Arc Current	ampere	A	300	375	450	525	600
3.	Travel Speed	mm/sec	S	5	8.75	12.5	16.25	20
4.	Electrode Extension	mm	N	25	27.5	30	32.5	35

Table 2: Recording of Responses

Weld No. Responses	Input Parameters				Responses		
	V	A	S	N	Bead Height (H)	Bead Width (W)	Bead Penetration (P)
1	–1	–1	–1	–1	1.79	10.35	4.12
2	+1	–1	–1	–1	2.99	12.41	5.52
3	–1	+1	–1	–1	1.99	9.56	5.92
4	+1	+1	–1	–1	3.16	13.0	6.89
5	–1	–1	+1	–1	2.01	10.21	3.82
6	+1	–1	+1	–1	1.99	9.20	4.32
7	–1	+1	+1	–1	2.89	9.07	5.45
8	+1	+1	+1	–1	2.51	9.02	6.74
9	–1	–1	-1	+1	1.94	9.37	3.24
10	+1	–1	–1	+1	1.97	11.12	3.14
11	–1	+1	–1	+1	4.40	9.18	7.37
12	+1	+1	–1	+1	2.94	12.09	5.41
13	–1	–1	+1	+1	1.56	8.18	2.60
14	+1	–1	+1	+1	2.12	9.71	2.01
15	–1	+1	+1	+1	2.54	8.08	6.47
16	+1	+1	+1	+1	2.50	10.12	4.39
17	–2	0	0	0	3.50	8.72	4.79
18	+2	0	0	0	2.49	11.32	5.40
19	0	–2	0	0	1.61	8.13	2.65
20	0	+2	0	0	3.51	9.24	5.71
21	0	0	–2	0	3.27	13.9	4.89
22	0	0	+2	0	2.96	9.01	3.91
23	0	0	0	–2	1.93	10.23	4.84
24	0	0	0	+2	2.38	9.97	3.31
25	0	0	0	0	2.39	10.41	3.69
26	0	0	0	0	2.93	11.25	3.89
27	0	0	0	0	2.01	10.93	4.12
28	0	0	0	0	1.96	11.89	4.02
29	0	0	0	0	1.59	11.49	3.89
30	0	0	0	0	1.94	11.39	4.45
31	0	0	0	0	1.81	10.32	3.69

RESULT AND DISCUSSION

Regression Analysis: log h versus log v, log a, log s, log n

The regression equation is

log h = –2.43 – 0.028 log v + 1.01 log a – 0.196 log s + 0.253 log n ...(5)

S = 0.09512; R-Sq = 40.0%

R-Sq(adj) = 30.7%;

PRESS = 0.332106;

R-Sq(pred) = 15.24%

24 rows with no replicates

Table 3: Analysis of Variance

Source	DF	SS	MS	F	P
Regression	4	0.156610	0.039153	4.33	0.008
Residual Error	26	0.235225	0.009047		
Lack of Fit	20	0.190597	0.009530	1.28	0.405
Pure Error	6	0.044628	0.007438		
Total	**30**	**0.391835**			

Source	DF	Seq SS
log v	1	0.000048
log a	1	0.135738
log s	1	0.018790
log n	1	0.002034

Table 4: Observation Table

Obs	log v	log h	Fit	SE Fit	Residual	St Resid
1	1.45	0.2529	0.3160	0.0426	–0.0632	–0.74
2	1.56	0.4757	0.3132	0.0418	0.1625	1.90
3	1.45	0.2989	0.4641	0.0423	–0.1653	–1.94
4	1.56	0.4997	0.4613	0.0415	0.0384	0.45
5	1.45	0.3032	0.2632	0.0421	0.0400	0.47
6	1.56	0.2989	0.2604	0.0413	0.0385	0.45
7	1.45	0.4609	0.4114	0.0419	0.0495	0.58
8	1.56	0.3997	0.4085	0.0410	–0.0088	–0.10
9	1.45	0.2878	0.3344	0.0424	–0.0466	–0.55
10	1.56	0.2945	0.3315	0.0416	–0.0370	–0.43
11	1.45	0.6435	0.4825	0.0421	0.1610	1.89
12	1.56	0.4683	0.4796	0.0413	–0.0113	–0.13
13	1.45	0.1931	0.2816	0.0420	–0.0884	–1.04
14	1.56	0.3263	0.2787	0.0412	0.0476	0.56
15	1.45	0.4048	0.4297	0.0417	–0.0249	–0.29
16	1.56	0.3979	0.4269	0.0409	–0.0289	–0.34
17	1.40	0.5441	0.3770	0.0453	0.1670	2.00
18	1.60	0.3962	0.3713	0.0398	0.0249	0.29
19	1.51	0.2068	0.1953	0.0481	0.0115	0.14

Table 4 (Cont.)

Obs	log v	log h	Fit	SE Fit	Residual	St Resid
20	1.51	0.5453	0.5005	0.0381	0.0448	0.51
21	1.51	0.5145	0.4520	0.0547	0.0626	0.80
22	1.51	0.4713	0.3337	0.0347	0.1376	1.55
23	1.51	0.2856	0.3538	0.0451	–0.0682	–0.81
24	1.51	0.3766	0.3907	0.0403	–0.0142	–0.16
25	1.51	0.3784	0.3738	0.0174	0.0046	0.05
26	1.51	0.4669	0.3738	0.0174	0.0931	0.99
27	1.51	0.3032	0.3738	0.0174	–0.0706	–0.76
28	1.51	0.2923	0.3738	0.0174	–0.0816	–0.87
29	1.51	0.2014	0.3738	0.0174	–0.1724	–1.84
30	1.51	0.2878	0.3738	0.0174	–0.0860	–0.92
31	1.51	0.2577	0.3738	0.0174	–0.1161	–1.24

Note: Durbin-Watson statistic = 1.98; Possible lack of fit at outer X-values (P-Value = 0.018); Overall lack of fit test is significant at P = 0.018.

The analysis of variance is shown in Table 3. The ratio of lack of fit to pure error, i.e., F-statistics is 1.98, whilst the P-statistics is 0.018. Therefore, the model is adequate for determination of Bead Height prediction. So the Bead Height with the usage of Equation (5) has been transformed in terms of V, A, S and N as

$$H = 0.38\, V^{-0.028} A^{1.01} S^{-0.196} N^{0.253} \quad ...(6)$$

It is also evident from the equation obtained that the Arc Current is a dominant factor,

Figure 1: Residual Histogram for log h

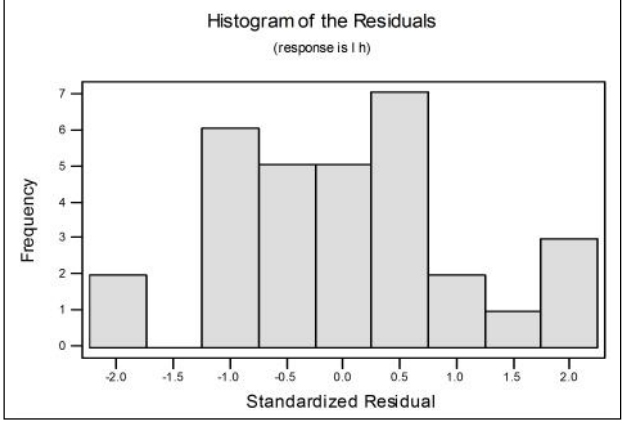


Figure 2: Residuals vs Fits for log h

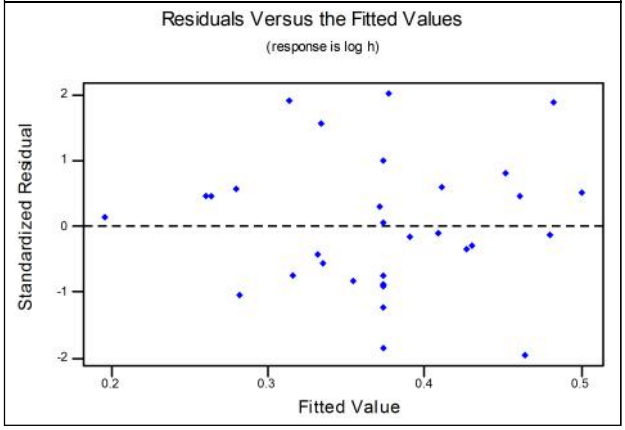
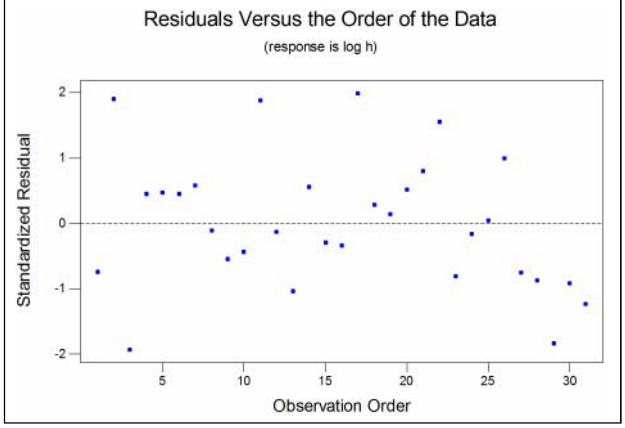


Figure 3: Residuals vs Order for log h



followed by Plate Distance, Voltage, Travel Speed because of the respective values of exponents.

Equation 6 have been used to develop Bead Height Response.

Regression Analysis: log w versus log v, log a, log s, log n

The regression equation is

log w = 0.527 + 0.638 log v + 0.078 log a – 0.282 log s – 0.260 log n ...(7)

S = 0.03978; R-Sq = 62.0%

R-Sq(adj) = 56.2%;

PRESS = 0.058836;

Table 5: Analysis of Variance

Source	DF	SS	MS	F	P
Regression	4	0.067220	0.016805	10.62	0.000
Residual Error	26	0.041141	0.001582		
Lack of Fit	20	0.038045	0.001902	3.69	0.056
Pure Error	6	0.003096	0.000516		
Total	**30**	**0.108361**			

R-Sq(pred) = 45.70%

24 rows with no replicates

Source	DF	Seq SS
log v	1	0.025415
log a	1	0.000835
log s	1	0.038821
log n	1	0.002148

Table 6: Observation Table

Obs	log v	log w	Fit	SE Fit	Residual	St Resid
1	1.45	1.01494	1.01703	0.01782	–0.00208	–0.06
2	1.56	1.09377	1.08175	0.01749	0.01202	0.34
3	1.45	0.98046	1.02849	0.01768	–0.04803	–1.35
4	1.56	1.11394	1.09321	0.01734	0.02073	0.58
5	1.45	1.00860	0.94111	0.01762	0.06749	1.89
6	1.56	0.96379	1.00583	0.01729	–0.04204	–1.17
7	1.45	0.95761	0.95257	0.01750	0.00503	0.14
8	1.56	0.95521	1.01730	0.01716	–0.06209	–1.73
9	1.45	0.97174	0.99817	0.01775	–0.02643	–0.74
10	1.56	1.04610	1.06289	0.01741	–0.01679	–0.47
11	1.45	0.96284	1.00963	0.01761	–0.04679	–1.31
12	1.56	1.08243	1.07436	0.01727	0.00807	0.23
13	1.45	0.91275	0.92225	0.01756	–0.00950	–0.27
14	1.56	0.98722	0.98697	0.01722	0.00024	0.01
15	1.45	0.90741	0.93371	0.01744	–0.02630	–0.74
16	1.56	1.00518	0.99844	0.01710	0.00674	0.19
17	1.40	0.94052	0.93337	0.01894	0.00714	0.20

Table 6 (Cont.)

Obs	log v	log h	Fit	SE Fit	Residual	St Resid
18	1.60	1.05385	1.06359	0.01665	-0.00974	–0.27
19	1.51	0.91009	0.99225	0.02011	-0.08216	–2.39R
20	1.51	0.96567	1.01586	0.01595	-0.05019	–1.38
21	1.51	1.14301	1.11843	0.02288	0.02458	0.76
22	1.51	0.95472	0.94842	0.01451	0.00630	0.17
23	1.51	1.00988	1.02664	0.01885	-0.01677	–0.48
24	1.51	0.99870	0.98866	0.01684	0.01004	0.28
25	1.51	1.01745	1.00606	0.00726	0.01139	0.29
26	1.51	1.05115	1.00606	0.00726	0.04509	1.15
27	1.51	1.03862	1.00606	0.00726	0.03256	0.83
28	1.51	1.07518	1.00606	0.00726	0.06912	1.77
29	1.51	1.06032	1.00606	0.00726	0.05426	1.39
30	1.51	1.05652	1.00606	0.00726	0.05046	1.29
31	1.51	1.01368	1.00606	0.00726	0.00762	0.19

Note: R denotes an observation with a large standardized residual; Durbin-Watson statistic = 1.35; Lack of fit test: Possible curvature in variable log a (P-Value = 0.009); Overall lack of fit test is significant at P = 0.009.

The analysis of variance is shown in Table 5. The ratio of lack of fit to pure error, i.e., F-statistics is 3.69, whilst the P-statistics is 0.056. Therefore, the model is adequate for determination of Bead width prediction. So the Bead width with the usage of Equation (6) has been transformed in terms of V, A, S and N as

$$w = -0.278\ V^{0.638}\ A^{0.078}\ S^{-0.282}\ N^{-0.2603} \quad ...(8)$$

Figure 4: Residual Histogram for log w

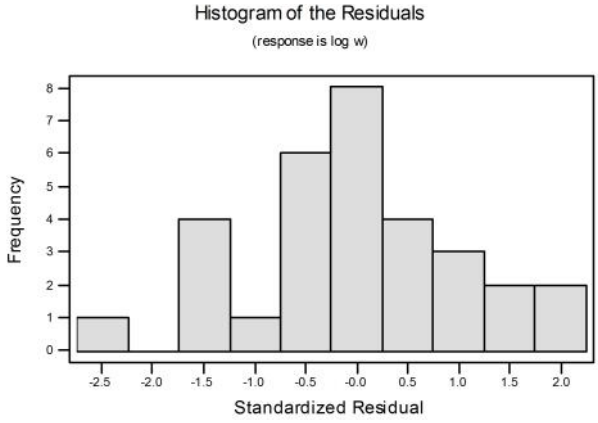


Figure 5: Residuals vs Fits for log w

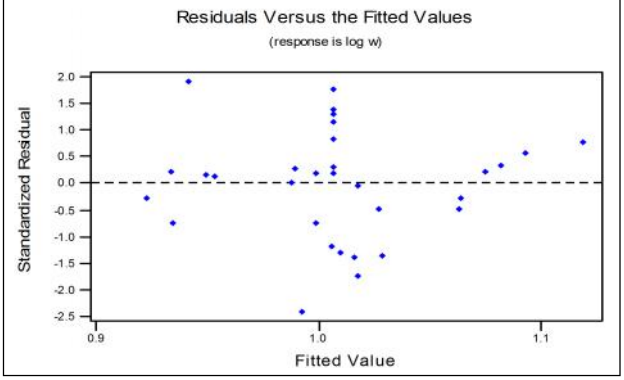
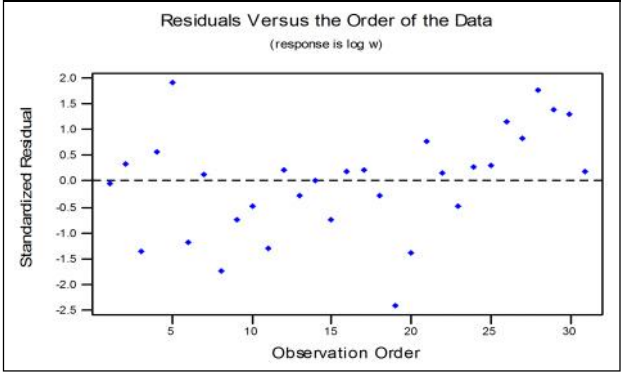


Figure 6: Residuals vs Order for log w



It is also evident from the equation obtained that the Arc Voltage is a dominant factor, followed by Arc Current, Plate Distance, and Travel Speed because of the respective values of exponents.

Equation 7 have been used to develop Bead Width Response.

Regression Analysis: log p versus log v, log a, log s, log n

The regression equation is

log p = –0.680 – 0.046 log v + 1.45 log a – 0.245 log s – 1.49 log n ...(9)

S = 0.07296; R-Sq = 73.2%;

R-Sq(adj) = 69.1%

PRESS = 0.205843;

Table 7: Analysis of Variance

Source	DF	SS	MS	F	P
Regression	4	0.378100	0.094525	17.76	0.000
Residual Error	26	0.138406	0.005323		
Lack of Fit	20	0.133500	0.006675	8.16	0.008
Pure Error	6	0.004906	0.000818		
Total	**30**	**0.516507**			

R-Sq(pred) = 60.15%

24 rows with no replicates

Source	DF	Seq SS
log v	1	0.000129
log a	1	0.278622
log s	1	0.029053
log n	1	0.070297

Table 8: Observation Table

Obs	log v	log w	Fit	SE Fit	Residual	St Resid
1	1.45	0.6149	0.6210	0.0327	–0.0061	–0.09
2	1.56	0.7419	0.6164	0.0321	0.1256	1.92
3	1.45	0.7723	0.8332	0.0324	–0.0609	–0.93
4	1.56	0.8382	0.8286	0.0318	0.0097	0.15
5	1.45	0.5821	0.5553	0.0323	0.0268	0.41
6	1.56	0.6355	0.5506	0.0317	0.0849	1.29
7	1.45	0.7364	0.7675	0.0321	–0.0311	–0.47
8	1.56	0.8287	0.7628	0.0315	0.0658	1.00
9	1.45	0.5105	0.5132	0.0326	–0.0026	–0.04
10	1.56	0.4969	0.5085	0.0319	–0.0116	–0.18
11	1.45	0.8675	0.7253	0.0323	0.1421	2.17R
12	1.56	0.7332	0.7207	0.0317	0.0125	0.19
13	1.45	0.4150	0.4474	0.0322	–0.0324	–0.50
14	1.56	0.3032	0.4428	0.0316	–0.1396	–2.12R
15	1.45	0.8109	0.6596	0.0320	0.1513	2.31R
16	1.56	0.6425	0.6549	0.0314	–0.0125	–0.19
17	1.40	0.6803	0.6445	0.0347	0.0358	0.56

Table 8 (Cont.)

Obs	log v	log h	Fit	SE Fit	Residual	St Resid
18	1.60	0.7324	0.6352	0.0305	0.0972	1.47
19	1.51	0.4232	0.3836	0.0369	0.0396	0.63
20	1.51	0.7566	0.8207	0.0293	–0.0641	–0.96
21	1.51	0.6893	0.7366	0.0420	–0.0473	–0.79
22	1.51	0.5922	0.5894	0.0266	0.0028	0.04
23	1.51	0.6848	0.7570	0.0346	–0.0722	–1.12
24	1.51	0.5198	0.5398	0.0309	–0.0200	–0.30
25	1.51	0.5670	0.6393	0.0133	–0.0723	–1.01
26	1.51	0.5899	0.6393	0.0133	–0.0494	–0.69
27	1.51	0.6149	0.6393	0.0133	–0.0244	–0.34
28	1.51	0.6042	0.6393	0.0133	–0.0351	–0.49
29	1.51	0.5899	0.6393	0.0133	–0.0494	–0.69
30	1.51	0.6484	0.6393	0.0133	0.0090	0.13
31	1.51	0.5670	0.6393	0.0133	–0.0723	–1.01

Note: R denotes an observation with a large standardized residual; Durbin-Watson statistic = 2.16; Possible lack of fit at outer X-values (P-Value = 0.019); Overall lack of fit test is significant at P = 0.019.

The analysis of variance is shown in Table 7. The ratio of lack of fit to pure error, i.e., F-statistics is 8.16, whilst the P-statistics is 0.008. Therefore, the model is adequate for determination of Bead Penetration prediction. So the Bead Penetration with the usage of Equation (8) has been transformed in terms of V, A, S and N as:

$$P = -0.167 \quad V^{-0.046} \; A^{1.45} \; S^{-0.245} \; N^{-1.49} \qquad ...(10)$$

Figure 7: Residual Histogram for log p

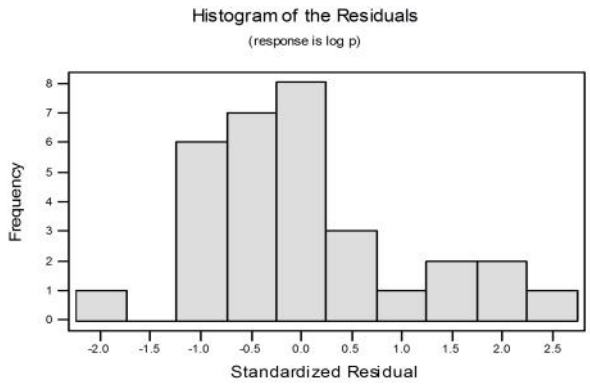


Figure 8: Residuals vs Fits for log p

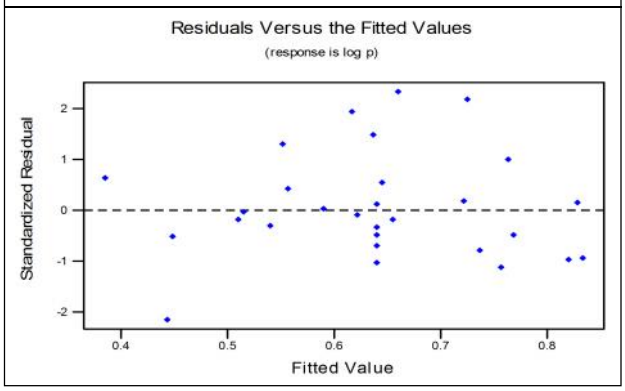
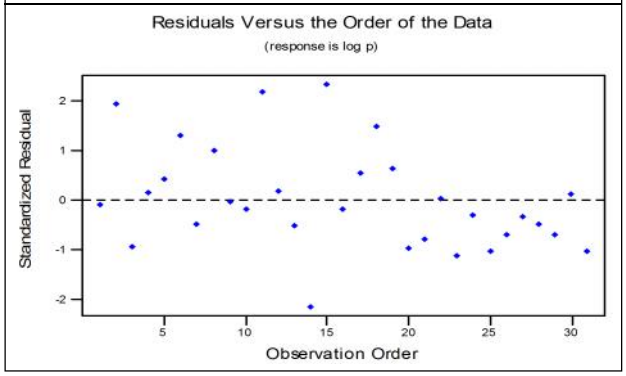


Figure 9: Residuals vs Order for log p



It is also evident from the equation obtained that the Arc Current is a dominant factor, followed by Arc Voltage, Travel Speed and Plate Distance because of the respective values of exponents.

Equation 9 have been used to develop Bead Penetration Response.

CONCLUSION

- Regression analysis has been successfully used to develop the Bead Geometry model.
- From the Equation (6) for Bead Height (H), Arc Current is a dominant factor, followed by Plate Distance, Voltage, Travel Speed.
- From the Equation (8) for Bead Width (w), the Arc Voltage is a dominant factor, followed by Arc Current, Plate Distance, and Travel Speed.
- From the Equation (10) for Bead Penetration (p), Arc Current is a dominant factor, followed by Arc Voltage, Travel Speed and Plate Distance.

REFERENCES

1. Arbizu I P and Perez C J L (2003), "Surface Roughness Prediction by Factorial Design of Experiments in Turning Processes", *Journal of Materials Processing Technology*, Vols. 143-144, pp. 390-396.
2. Chandel R S, Seow H P and Cheong F L (1997), "Effect of Increasing Deposition Rate on the Bead Geometry of Submerged Arc Welds", *Journal of Materials Processing Technology*, Vol. 72, pp. 124-128.
3. Gunaraj V and Murugan N (1999), "Application of Response Surface Methodology for Predicting Weld Bead Quality in Submerged Arc Welding of Pipes", *Journal of Material Processing Technology*, Vol. 88, pp. 266-275.
4. Taraman K and Lambert B K (1974), "A Surface Roughness Model for a Turning Operation", *International Journal of Production Research*, Vol. 12, pp. 691-703.
5. Vipin Kumar and Harish Kumar (2009), "Surface Roughness Prediction Model by Design of Experiments for Turning Leaded Gun Metal", *International Journal of Applied Engineering Research*.