Experimental Investigation of Weld Bead Geometry in Flux Cored Arc Welding Process

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***Abstract*---This paper study about, the experimental investigation of Flux-Cored Arc Welding process (FCAW) parameters in welding current, welding speed, wind velocity, wind direction with multi-response criteria using Design Expert software. Input process parameters such as welding current, welding speed, wind velocity, wind direction are selected using Design of Experiment (DOE) software for obtain the desired output. Output means bead geometry which is reinforcement, depth of penetration, bead width. Also dilution and reinforcement angle both are measured. All the desired output of reinforcement, depth of penetration, bead width dilution and reinforcement angle are analyzed by Response Surface in Central Composite Design. The Analysis of Variance (ANOVA) is also applied to identify the most significant factor.**

***Index Terms*--- welding current, welding speed, wind velocity, wind direction, Design Expert, Multi-Response criteria, Response Surface and Central Composite Design, ANOVA.**

Nomenclature:

Description	Unit	Identification
Welding Current	Amps	I
Welding Speed	mm/s	S
Wind Velocity	m/s	V
Wind Direction	Degree	D
Reinforcement	Mm	A
Penetration	Mm	B
Bead Width	Mm	W
Dilution	%	D
Angle	Degree	A

I. INTRODUCTION

Flux Cored Arc Welding (FCAW) is a semi-automatic or automatic arc welding process by fusion which is widely used on ferrous metal. The consumable electrode can have an interior flux or a mix of flux and metal powder and has a tubular form. It requires a continuously fed consumable tubular electrode containing a flux and constant voltage or less- commonly, a constant- current welding power supply. An externally supplied shielding gas is sometimes used, but often the flux itself is relied upon to generate the necessary protection from the atmosphere, producing both gaseous protection and liquid slag protecting the weld. The process is widely used in construction because of its high welding speed and portability. The FCAW process has as its energy source a DC electric arc that occurs between the fluxed cored wire and base metal in order to melt consumable electrode and base metal. FCAW uses a constant voltage welding machine and the process can use Direct Current Electrode Positive (DCEP) or Direct Current Electrode Negative (DCEN) polarity. For gas shielded flux cored arc welding, a gas bottle is needed. Welding zone protection from atmosphere contamination is assured by the products in the electrodes flux (Self-Shielded FCAW) and sometimes by additional gaseous protection (Gas-Shielded FCAW). The slag created by the flux gives an additional protection during cooling time but has to be removed after that.

In this project mild steel materials used as a base metal. The mild steel plates with 25 numbers are welded here. Dimensions of the each plate are 100*50*5. That is Length 100mm, Breadth 50mm and Thickness 5mm. Before going for main welding, must be trail the some plates for checking welding speed(S), current (I), voltage (V). The compressor or air blower is used here for wind velocity. Wind velocity range 1m/s, 3m/s, 5m/s, 7m/s and 9m/s are chosen for this welding process. Compressor or air blower direction angle must be changed from 0°, 90°, 180°, 270° and 360°. Trail pieces are welded with three welding.

a) Without weaving (Fast welding)
b) With weaving (Slow welding)
c) Moderate welding (Weaving with Normal speed)

Bead geometry

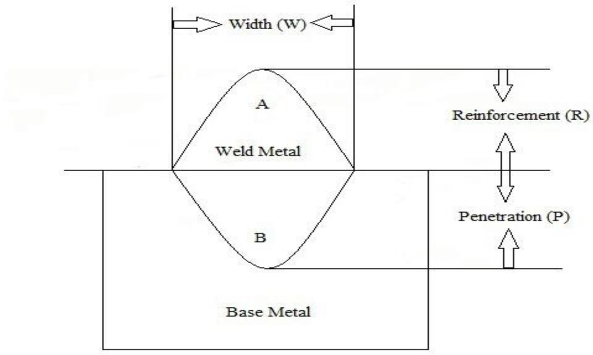


Fig.1. Weld Bead Geometry

The weld bead shape is an indication of bead geometry which affects the load carrying capacity of the weldments and number of passes needed to fill the groove of joint. The bead geometry is specified by under following factors.

1. Bead width
2. Penetration
3. Reinforcement
4. Penetration shape factor
5. Reinforcement form factor

Dilution

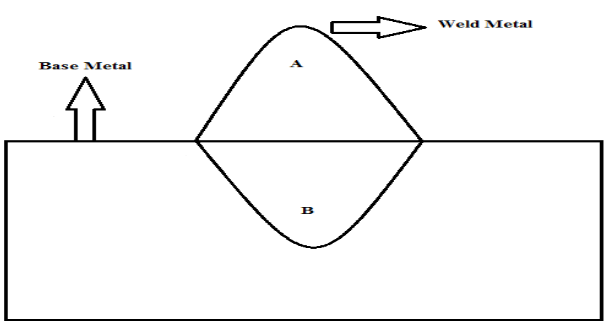


Fig.2. Dilution

Dilution Formula = $\frac{B}{A+B} \times 100$ **in %**

A-Reinforcement

B-Penetration

Angle

Angle means the bead angle that is Reinforcement angle which is measuring by using Profile Projector.

Fig.3. Profile Projector

II. EXPERIMENTAL PROCEDURE

The Flux Cored Arc Welding (FCAW) process is done in 100 mm × 50 mm × 6 mm mild steel plates. The grade of the mild steel plates IS 2062 and the welding filler wire used for FCAW is E71T1, diameter of the filler wire is 1.2 mm.

This Experiment has been done for various process parameters such as Welding current, Welding speed, Wind velocity and Wind direction to obtain bead-on-plate welding FCAW process. Welding current range is 160 Amps, 170 Amps, 180 Amps, 190 Amps and 200 Amps. Welding speed range is 5, 10, 20, 30 and 40 mm/s respectively. Wind velocity range is 1m/s, 3m/s, 5m/s, 7m/s and 9m/s are chosen for this welding process and wind velocity is measured by using Anemometer. By using Air blower (or) Compressor wind is supplied through the welding direction. Air blower (or) Compressor direction angle must be changed from 0°, 90°, 180°, 270° and 360°.

When the welding is finished, all the welded plates are cross sectioned in their mid-points to obtain test specimens of 10 mm. All these test specimens are prepared for studying of weld bead geometry by usual metallurgical Fine polishing method and Etchant with 1:3 ratio of Nitric acid and Distilled water. The weld bead profiles are measured by using Lens (or) Optical microscope with 10X times zooming view. The weld bead dimensions like Reinforcement (A), Penetration (B) and Bead width (W) are measured. Also Dilution and Reinforcement angle are measured.

The Design of Experiment software used for Analysis the weld bead dimensions. The Analysis of Variance (ANOVA) is also applied to identify the most significant factor.

Fig.4. Experimental setup of FCAW process

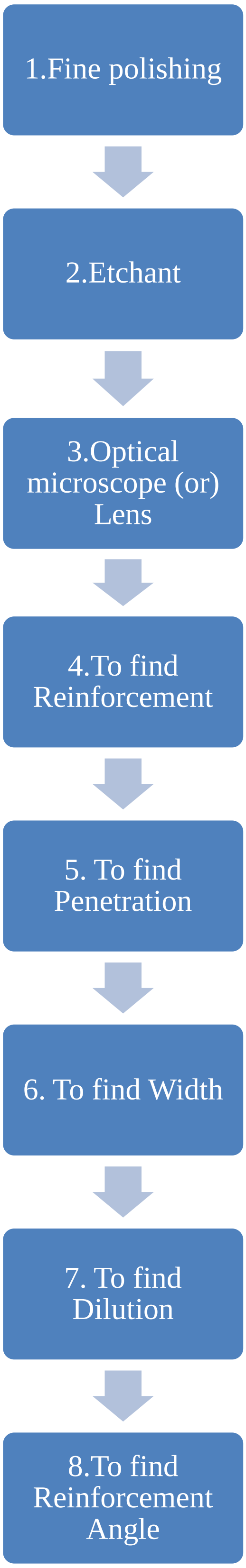
TABLE I: PROCESS CONTROL FACTORS AND LEVELS (FOR TRAIL WELDING)

S.NO	**PARAMETERS**	**NOTATIONS**	**UNITS**	**FACTORS LEVEL**				
				-2	**-1**	**0**	**+1**	**+2**
1	Welding Current	I	Amps	160	170	180	190	200
2	Welding Speed	S	Mm/s	5	10	20	30	40
3	Wind Velocity	V	m/s	1	3	5	7	9
4	Wind Direction	D	Degree	0	90	180	270	360

TABLE II: DESIGN MATRIX AND ORIGINAL VALUES OF EXPERIMENTAL WELDING PROCESS

CODED VALUES					ORIGINAL VALUES			
EX.NO	**I**	**S**	**V**	**D**	**I**	**S**	**V**	**D**
1	-1	-1	-1	-1	170	10	3	90
2	+1	-1	-1	-1	190	10	3	90
3	-1	+1	-1	-1	170	30	3	90
4	+1	+1	-1	-1	190	30	3	90
5	-1	-1	+1	-1	170	10	7	90
6	+1	-1	+1	-1	190	10	7	90
7	-1	+1	+1	-1	170	30	7	90
8	+1	+1	+1	-1	190	30	7	90
9	-1	-1	-1	+1	170	10	3	270
10	+1	-1	-1	+1	190	10	3	270
11	-1	+1	-1	+1	170	30	3	270
12	+1	+1	-1	+1	190	30	3	270
13	-1	-1	+1	+1	170	10	7	270
14	+1	-1	+1	+1	190	10	7	270
15	-1	+1	+1	+1	170	30	7	270
16	+1	+1	+1	+1	190	30	7	270
17	-2	0	0	0	160	20	5	180
18	+2	0	0	0	200	20	5	180
19	0	-2	0	0	180	5	5	180
20	0	+2	0	0	180	40	5	180
21	0	0	-2	0	180	20	1	180
22	0	0	+2	0	180	20	9	180
23	0	0	0	-2	180	20	5	0
24	0	0	0	+2	180	20	5	360
25	0	0	0	0	180	20	5	180
26	0	0	0	0	180	20	5	180
27	0	0	0	0	180	20	5	180
28	0	0	0	0	180	20	5	180
29	0	0	0	0	180	20	5	180
30	0	0	0	0	180	20	5	180

III. PROPOSED METHODOLOGY



The weld metals are surface grinded in the depth about 0.5mm for fine polished surfaces. And two (or) three times weld metals are grinded for fine polished surfaces. For Etchant the Nitric Acid and Distilled water both are mixed together in the ratio about 1:3 (i.e.) 1 % of Nitric Acid and 3 % of Distilled water. This mixed composition was applied on the weld metal surface. Then only the Reinforcement and Penetration are clearly viewed. By using Optical microscope in 10X times zooming view the Reinforcement and Penetration shapes are showed and measured by vernier. Reinforcement, Penetration and Width values are measured. Dilution is calculated by the formula and the Reinforcement Angle is measured by using Profile Projector.

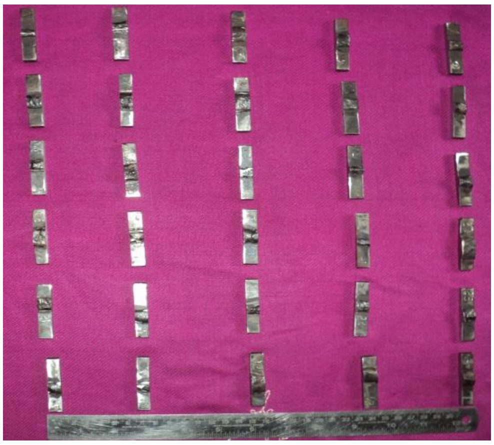


Fig.5. Specimens with Scale

Fig.6. Measuring by Microscope

IV. RESULTS AND DISCUSSIONS

TABLE III: TRANSVERSE TENSILE TEST

IDENTIFICATION	REINFORCEMENT (A)	DEPTH OF PENETRATION (B)	WIDTH	DILUTION IN %	REINFORCEMENT ANGLE θ
1	2.76	0.97	7.96	26.01	35
2	2.56	0.85	9.87	24.93	37
3	3.39	1.06	14.46	23.82	41
4	2.34	1.17	12.21	33.33	35
5	3.09	0.87	9.13	21.97	39
6	2.58	0.76	10.89	22.75	37
7	3.84	0.91	14.67	19.16	29
8	3.36	0.98	16.1	22.58	34
9	2.06	0.82	9.37	28.47	31
10	2.55	1.13	8.41	30.71	36
11	2.29	0.877	10.41	27.69	38
12	3.83	1.19	15.26	23.71	32
13	1.68	1.16	9.05	40.85	37
14	2.81	1.47	6.19	34.35	36
15	3.35	1.04	11.92	23.69	29
16	3.19	1.19	18.47	27.17	28
17	2.59	0.88	9.74	25.36	34
18	3.32	0.81	11.54	19.61	36
19	1.48	0.94	6.08	38.84	29
20	2.99	0.9	20.71	23.14	31
21	2.44	1.05	12.29	30.09	37
22	3.32	1.027	11.73	23.63	36
23	1.68	1.08	12.42	39.13	33
24	2.32	1.15	9.8	33.14	43
25	2.74	1.24	9.52	31.16	38
26	2.19	1.64	8.48	42.81	37
27	2.18	1.68	7.52	43.52	38
28	2.17	1.65	9.58	43.19	37
29	2.17	1.66	9.55	43.34	38
30	2.16	1.64	11.95	43.15	37

Output Equations

$$Width = +10.06563 + 0.58458 * I + 2.99542 * S + 0.30625 * V - 0.47708 * D + 0.67063 * I * S + 0.29563 * I * D + 0.57313 * S * V + 0.21563 * S * D + 0.86711 * S^2 + 0.52086 * V^2 + 1.23187 * I * S * D$$

$$Penetration = +1.58500 + 0.037208 * I + 0.012792 * S + 0.011125 * V + 0.060292 * D + 0.070813 * I * D - 0.059562 * S * D + 0.085813 * V * D - 0.17695 * I^2 - 0.15820 * S^2 - 0.12857 * V^2 - 0.10945 * D^2$$

$$Reinforcement = +2.30542 + 0.092500 * I + 0.35500 * S + 0.16167 * V - 0.036667 * D + 0.32750 * I * D + 0.22328 * I^2 + 0.20453 * V^2$$

$$Dilution = +41.19500 - 0.15125 * I - 2.51208 * S - 0.79458 * V + 1.25458 * D - 2.20937 * S * D + 2.31938 * V * D - 5.03885 * I^2 - 2.91260 * S^2 - 3.94510 * V^2 - 1.62635 * D^2$$

$$Angle = +37.59524 + 0.5 * I + 0.5 * S - 0.25 * V + 2.5 * D - 0.75 * I * S + 0.375 * I * V - 0.125 * I * D - 2.25 * S * V - 0.25 * S * D + 0.125 * V * D - 0.67857 * I^2 - 1.92857 * S^2 - 0.30357 * V^2 + 1.625 * I * S * V - 0.625 * I * S * D - 0.5 * I * V * D - 1.875 * I^2 * S - 0.75 * I^2 * V - 3.75 * I^2 * D - 0.75 * I * S^2$$

These all equations are obtained by using Design of Experiment software. For model the processing order of this software contains four categories such as Factorial, Response Surface method, Mixture and Combined. Here we used Response Surface method for analysis. This method has six processing order such as Modified, Mean, Linear, 2F1, Quadratic and Cubic. Also the selection of Intercept has four levels; they are Manual, Backward, Forward and Stepwise. In equations the I, S, V and D denotes welding current, speed, wind velocity and direction. Source of ANOVA table is consist of Sum of Squares, Degree of Freedom, Mean square, F value and Prob>F. Values of "Prob>F" less than 0.0500 indicate the model terms are significant also values greater than 0.1000 indicate the model terms are not significant. Some other conditions of this ANOVA for model to fit is R-Squared, Adj R-Squared, Pred R-Squared and Adeq Precision. The "Pred R-Squared" is should be reasonable agreement with the "Adj R-Aquared". "Aded Precision" is measures the single-to-noise ratio. A ratio greater than 4 is desirable then only the model can be used to navigate the design space.

V. GRAPHICAL REPRESENTATIONS

5.1 Width

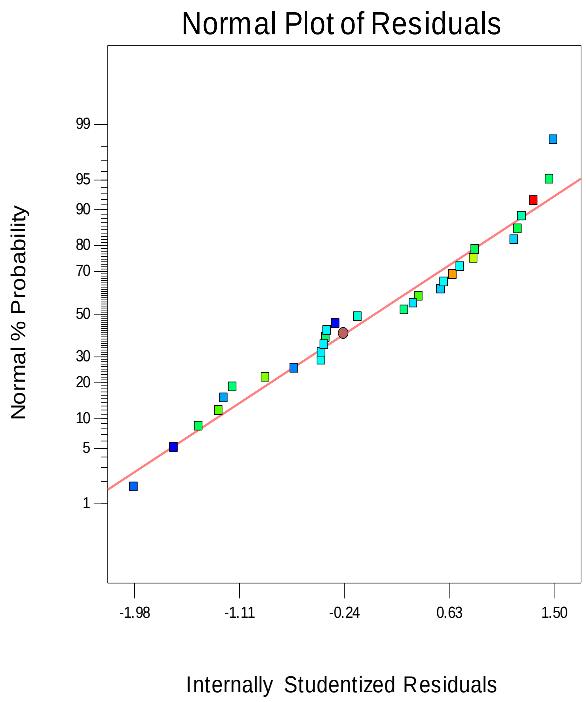


Fig.7 (a) Normal Plot of Residuals

5.2 Penetration

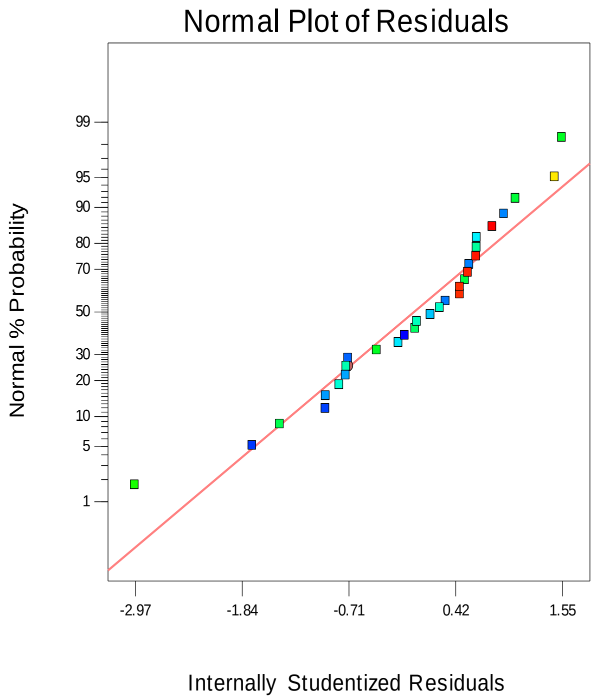


Fig.8 (a) Normal Plot of Residuals

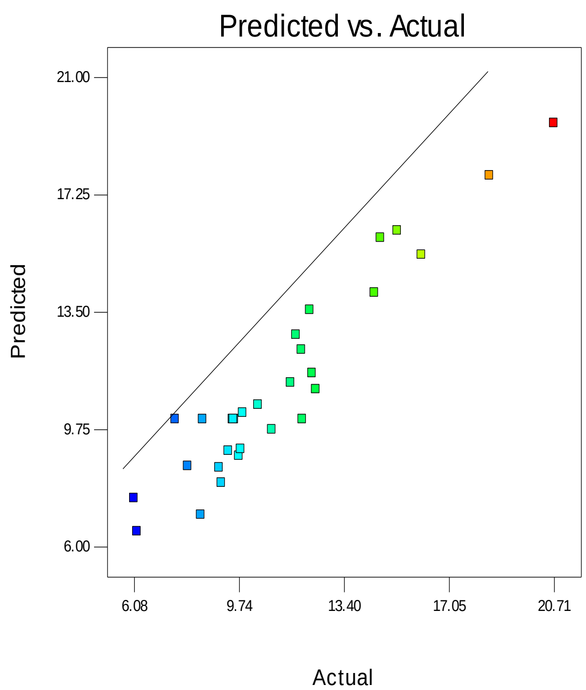


Fig.7 (b) Predicted vs. Actual

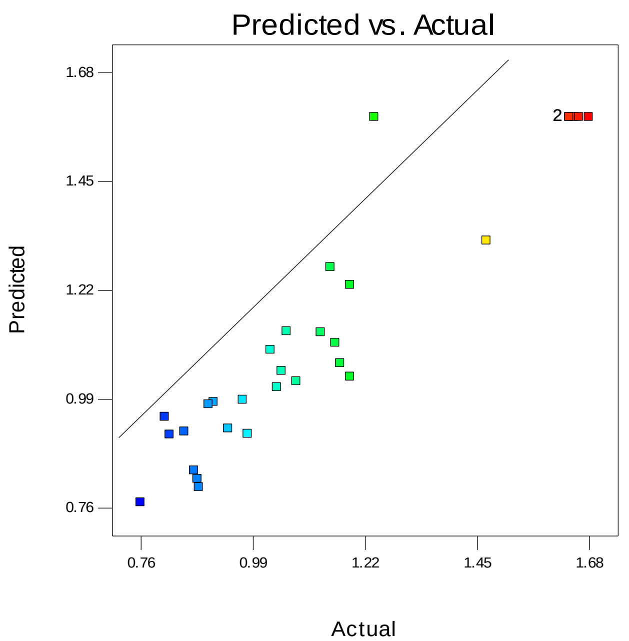


Fig.8 (b) Predicted vs. Actual

5.3 Reinforcement

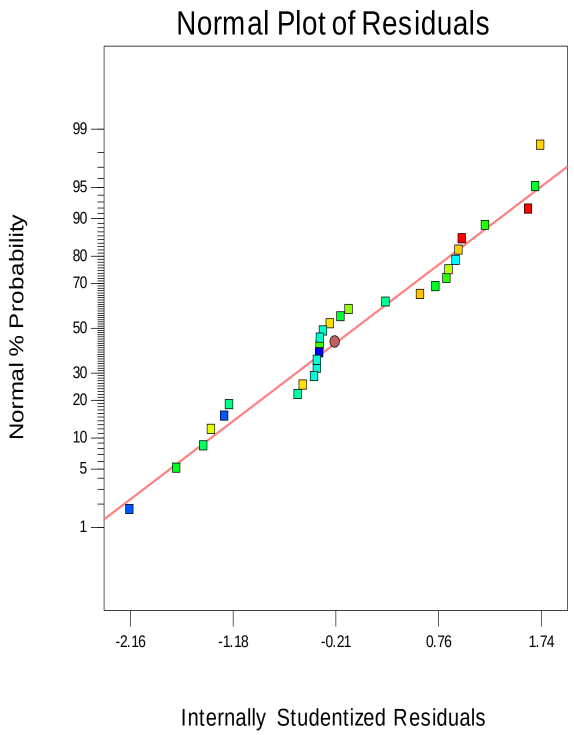


Fig.9 (a) Normal Plot of Residuals

5.4 Dilution

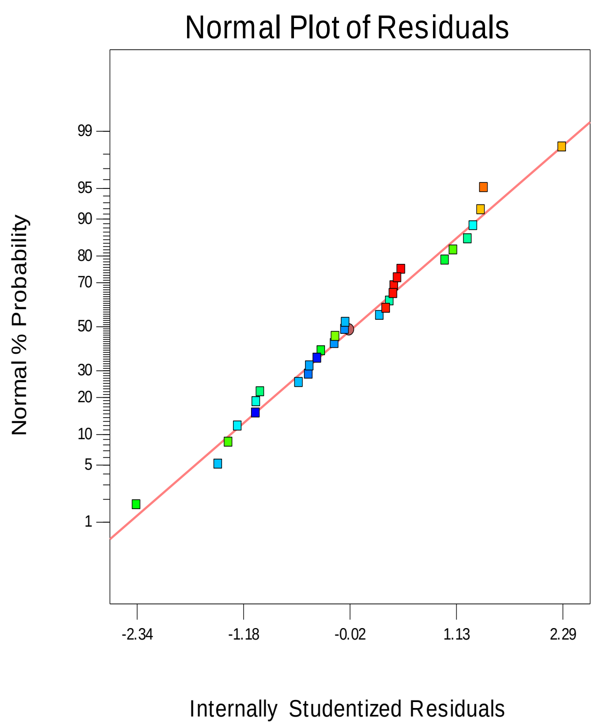


Fig.10 (a) Normal Plot of Residuals

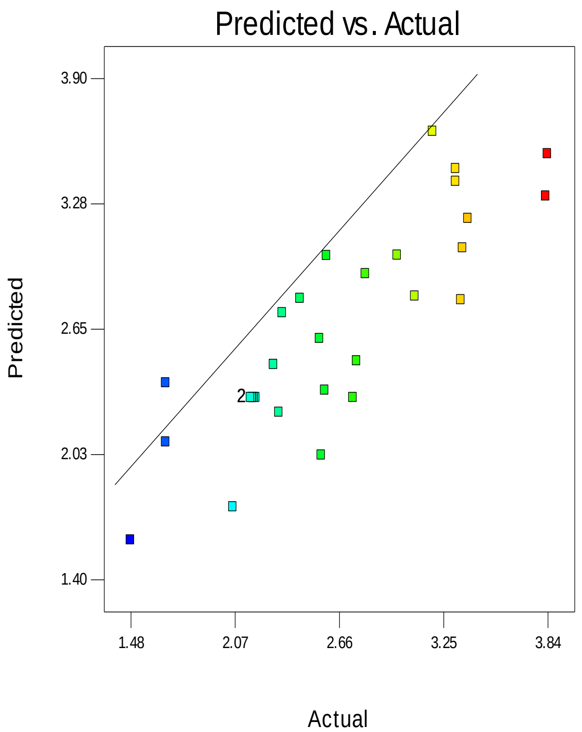


Fig.9 (b) Predicted vs. Actual

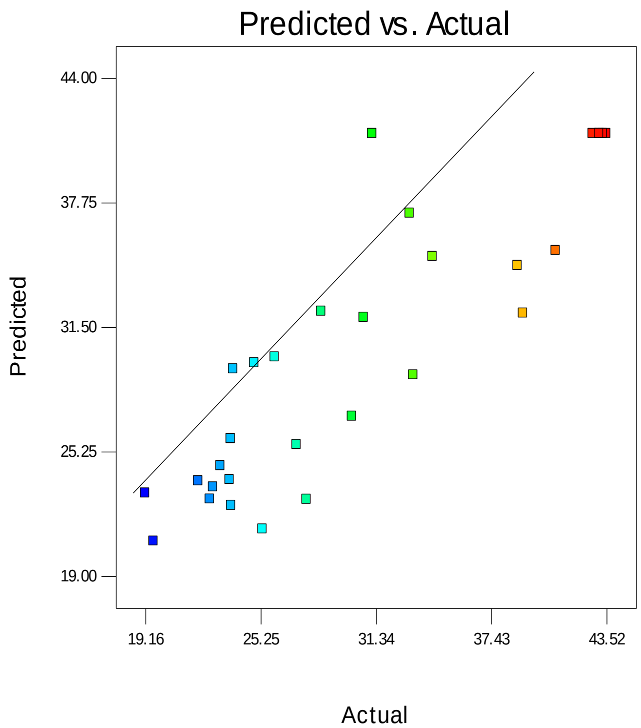


Fig.10 (b) Predicted vs. Actual

5.5 Angle

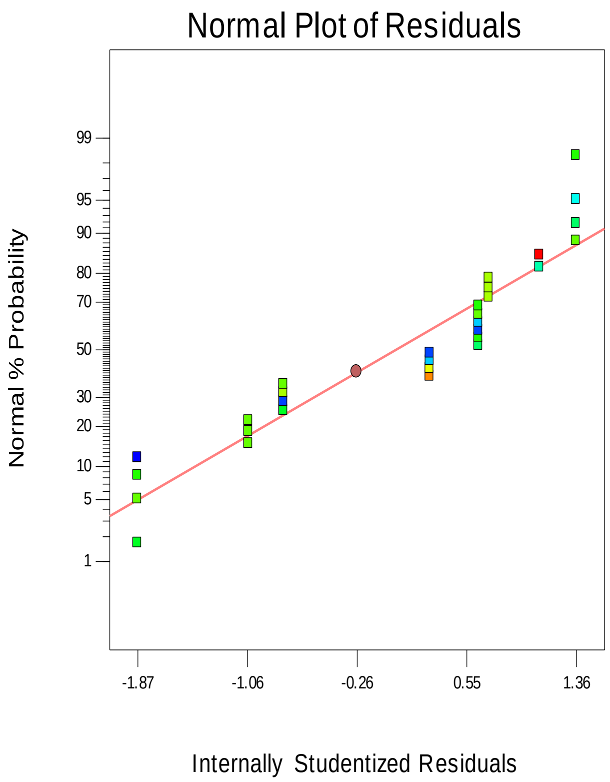


Fig.11 (a) Normal Plot of Residuals

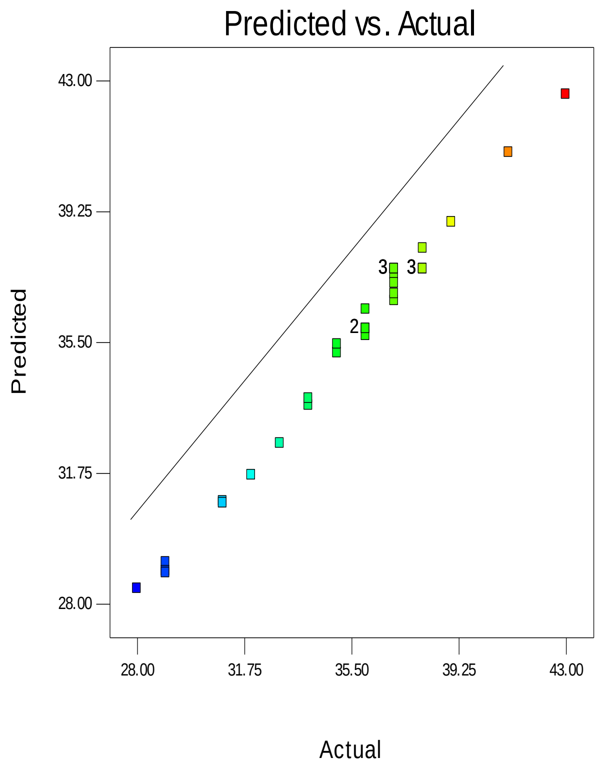


Fig.11 (b) Predicted vs. Actual

TABLE IV: AVOVA RESULT TABLE

Source	**DF**	**F Value**	**R-Squared**	**Adj R-Squared**	**Pred R-Squared**	**Adeq Precision**
Width	11	14.96	0.9014	0.8412	0.7137	15.366
Penetration	8	15.89	0.8582	0.8042	0.7283	12.348
Reinforcement	7	8.12	0.7210	0.6322	0.4022	10.550
Dilution	10	6.57	0.7757	0.6576	0.3377	7.190
Angle	20	52.59	0.9915	0.9727	0.8117	28.063

TABLE V: BASE METAL & WELD METAL CHEMICAL COMPOSITION (Weight in %)

MATERIAL	**C**	**Cu**	**Si**	**S**	**P**	**Cr**	**Ni**	**Mo**	**V**	**Mn**
IS 2062	0.20	0.350	0.100	0.055	0.055	-	-	-	-	-
E71T1	0.12	0.35	0.90	0.03	0.03	0.20	0.50	0.30	0.08	1.75

VI. CONCLUSION

Here conclude that the Design of Experiment software has been used for analysis the output values of bead geometry. Studying of bead geometry used to find quality and strength of the welded metals. Normally this kind of welding was done in heavy structure steel components such as Boiler support structures, Bridges, Steel buildings and Highway works. This welding also used in Mild and Low alloy steels, Stainless steels, High nickel alloys, Wear facing / Surfacing alloys and Porosity chances very low alloys. But here the investigation of weld bead geometry in Flux Cored Arc Welding process was done in Mild Steel (IS 2062) materials. Output results of Width, Penetration, Reinforcement, Dilution and Angle are fed into the Response Surface method for analysis the relationship between input and output values.

Study Type	:	Response Surface
Initial Design	:	Central Composite
Design Model	:	Quadratic

1. When Current and Speed increases Width also increases.
2. When Current and Direction increases Penetration is increases with decreases.
3. When Current and Direction increases Reinforcement also increases.
4. When Speed increases Dilution is decreases and Direction increases Dilution also increases.
5. When Current and Speed increases Angle is increases with decreases.

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