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Effect on width, height and penetration of V-groove butt joint weld bead by varying process parameters

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Abstract – *Weld bead geometry is influenced by a number of welding process parameters that affect the product quality of the joint. In this experimental study, an effort is made to find the effect of process parameters on bead geometry of narrow v-groove butt joint in pulsed gas metal arc welding. Three input process parameters such as wire feed rate, welding speed and groove angle were considered for three levels. The experiments are conducted on narrow v-groove butt joint of 5083-h111 aluminium alloy with groove angles of 20˚, 30˚ and 40˚ using full factorial design of experiments. The mathematical model for width, height and penetration are developed using linear regression analysis. Mean analysis for width, height and penetration done for all three input levels by ANOVA. It is observed that wire feed rate has maximum effect on width and penetration, where as groove angle has shown effect on height.*

Key Words: Wire feed rate, Welding speed, Groove angle, Narrow V-groove and Aluminium alloy.

1. INTRODUCTION

Quality of a weld joint is strongly influenced by process parameters during the welding process. This work focuses on the development of mathematical models for the selection of process parameters and the prediction of weld bed geometry. Weld bead geometry is influenced by a number of welding process parameters which affect the quality of the joint. The relation between GMAW process parameters and weld bead geometry are complex because of the number of parameters involved. In order to achieve high quality welds, mathematical models that can predict the bead geometry and shape to accomplish the desired mechanical properties of the weldment should be developed. A large number of experiments are to be conducted to predict the weld bead geometry and to develop the mathematical model. Karadeniz et al. [2] studied the effect of process parameters on penetration in gas metal arc welding which includes the study of penetration for process parameters like welding current, arc voltage and welding speed.

Lee and Um [3] studied geometry prediction of the back-bead in gas metal arc welding. Multiple regression analysis and artificial neural network were used to predict the weld geometry. These geometry predictions showed low error which can be applied for real welding process. Palani and Murugan [4] studied the selection of process parameters in pulsed gas metal arc welding, where the important parameters in pulsed gas metal arc welding are studied. Abbasi et al. [5] studied the effect of MIG welding parameters on the weld bead and shape characteristics on mild steel specimen and concluded that shape factor increases with increase in welding speed. Ganjigatti et al. [6] made an attempt to obtain a relation between input and output parameters using regression analysis in MIG welding process. Mayur S et al. [7] conducted experiments on Al 5083 using TIG welding to find the tensile strength.

S C Juang et al. [8] used Taguchi method to reduce the number of experiments and welding is done to find the bead geometry. Biswajit Das et al. [9] investigated the effect of various process parameters on depth of penetration using MIG welding.

2. EXPERIMENTAL PROCEDURE

For the experimental study, aluminium alloy 5083 H111, plate thickness 6 mm is used as base material. The aluminium alloy of 5000 (Al-Mg) series find their applications in production of vessel hulls, super structures, structural members, vessels, tanks and many other applications. The filler wire used for the welding is aluminium alloy 5183 of 1.2 mm dia. The chemical composition of the base material and filler wire is shown in Table -1.

Table -1: Chemical composition of base metal and filler wire

Element Weight %	Material used	
	5083 H111	5183
Si	0.1	0.17
Fe	0.16	0.24
Cu	0.02	0.05
Mn	0.5	0.78
Mg	4.6	4.95
Cr	0.07	0.08
Zn	0.03	-
Ti	0.06	0.02

The dimensions of the work pieces considered for this study are 100×60×6 mm and vertical milling machine is used for edge preparation. The melting point of the oxide layer is nearly three times more than aluminium so, before conducting the experiments the top surface of the work pieces are cleaned to remove the oxide layer. Mechanically this process includes scraping the work pieces with stainless steel wire brush and stainless steel wire wool until the top oxide layer is removed. This is also useful for removal of burrs formed during milling.

The experiments are conducted on narrow V-groove butt joint with zero gaps maintained between the work pieces. Experiments are carried out using Kemppi Pro Evolution 3200 welding machine and the weld beads are deposited using pulsed gas metal arc welding. In this work, argon gas is used as shielding gas which is supplied at 15 l/min, angle between the work piece and the torch is maintained constantly at 90° and the distance between the work piece and contact tip is maintained at 12mm. The speed of the work table is controlled by rheostat which moves below the torch and the work piece is fixed to the table.

The three input parameters considered for conducting the experiments are wire feed rate (WFR), welding speed (S) and groove angle (A). The selected process parameters and their levels are given in Table -2. Three parameters with three levels are considered and full factorial method is used to obtain the design matrix for conducting the experiments. The design matrix is given in Table -3.

Fig-1: Experimental setup of welding process

Table -2: Input parameters and levels used

Parameters	Level 1	Level 2	Level 3
Wire feed rate (m/min)	4.0	5.5	7.0
Welding speed (cm/min)	15	20	25
Groove angle (˚)	20	30	40

Once the welding is carried out based on the design matrix, the weld pieces are cut perpendicular to the cross-section of the weld fig -3. The cut pieces are grinded, fine grinded on emery paper polished and etched with 10% nital solution to obtain the visible grain boundary. The photographs of visible grain boundaries are obtained and these photographs are imported into AutoCAD to obtain the desired bead dimensions.

Table -3: Design matrix with input values

Ex No	WFR (m/min)	Welding speed (cm/min)	Groove angle (˚)
1	4.0	15	10
2	4.0	15	15
3	4.0	15	20
4	4.0	20	10
5	4.0	20	15
6	4.0	20	20
7	4.0	25	10
8	4.0	25	15
9	4.0	25	20
10	5.5	15	10
11	5.5	15	15
12	5.5	15	20
13	5.5	20	10
14	5.5	20	15
15	5.5	20	20
16	5.5	25	10
17	5.5	25	15
18	5.5	25	20
19	7.0	15	10
20	7.0	15	15
21	7.0	15	20
22	7.0	20	10
23	7.0	20	15
24	7.0	20	20
25	7.0	25	10
26	7.0	25	15
27	7.0	25	20

Fig-2: Work piece after welding

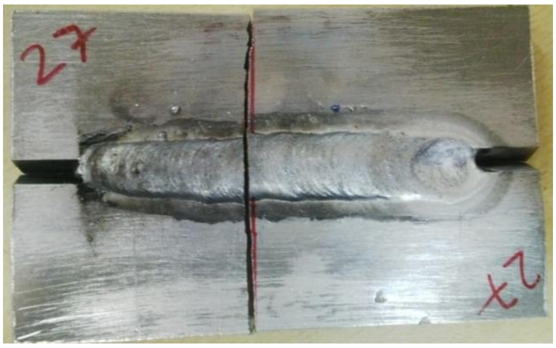


Fig-3: Work piece cut at transverse cross-section

3. RESULTS AND DISCUSSIONS

The experimental values in Table -4 are used to find out the mathematical relation between input process parameters and the bead geometry.

Table -4: Design matrix with output values

Ex No	WFR (m/min)	Welding speed (cm/min)	Groove angle (˚)	Width (mm)	Height (mm)	Penetration (mm)
1	4.0	15	10	6.844	3.394	2.956
2	4.0	15	15	6.126	2.785	2.802
3	4.0	15	20	5.77	2.621	2.965
4	4.0	20	10	6.472	2.709	3.152
5	4.0	20	15	5.258	2.245	3.327
6	4.0	20	20	5.922	2.365	4.688
7	4.0	25	10	5.845	2.455	3.159
8	4.0	25	15	5.565	2.425	3.365
9	4.0	25	20	6.178	1.736	4.156
10	5.5	15	10	9.482	3.251	3.468
11	5.5	15	15	5.009	2.954	3.956
12	5.5	15	20	7.29	2.359	3.795
13	5.5	20	10	7.274	2.484	2.812
14	5.5	20	15	8.628	2.872	3.956
15	5.5	20	20	8.553	2.216	4.174
16	5.5	25	10	7.252	2.517	4.123
17	5.5	25	15	9.055	2.163	4.347
18	5.5	25	20	8.025	1.654	4.97
19	7.0	15	10	11.901	3.476	4.562
20	7.0	15	15	9.768	2.532	4.606
21	7.0	15	20	10.469	2.345	4.158
22	7.0	20	10	9.796	3.027	5.3
23	7.0	20	15	12.692	2.773	5.364
24	7.0	20	20	11.841	2.086	5.914
25	7.0	25	10	10.567	2.674	5.06
26	7.0	25	15	10.812	2.045	5.624
27	7.0	25	20	11.434	2.215	5.424

3.1. Development of mathematical model

The relation between the input process parameters and output parameters using non linear regression equation can be expressed as:

$$Y=a*F+b*S+c*A+d*F*S+e*F*A+f*S*A+g*F*S*A+h$$

Where Y is output parameter (Width, Height and Penetration); F is wire feed rate (m/min); S is welding speed (cm/min); A is groove angle (˚), a, b, c, d, e, f, g and h are regression coefficients.

The mathematical model to establish the relationships between input and output parameters were developed using Design expert software at a confidence level of 95%, based on the experimental data collected. The regression equations in terms of actual factors thus obtained width; height and penetration are as follows

Width = 5.7 + 1.70 F - 0.200 S - 0.143 A- 0.024 F*S - 0.0143 F*A + 0.0029 S*A + 0.00149 F*S*A

Height = 2.46 + 0.580 F + 0.021 S + 0.148 A - 0.024 F×S - 0.0245 F×A -0.00441 S×A + 0.00206 F×S×A

Penetration = 1.21 + 0.50 F - 0.147 S - 0.025 A + 0.0202 F*S - 0.0036 F*A+ 0.0058 S*A-0.00037 F*S*A

The estimated multiple linear regression coefficients for the width, height and penetration are given in table-5,6,7.

Table -5: Estimated Regression Coefficients for width

Factor	Estimated regression coefficient
Constant	5.7
F	1.70
S	-0.0200
A	-0.143
F* S	-0.024
F* A	-0.0143
S* A	0.0029
F* S* A	0.00149

Table -6: Estimated Regression Coefficients height

Factor	Estimated regression coefficient
Constant	2.46
F	0.580
S	0.021
A	0.074
F* S	-0.0224
F* A	-0.0245
S* A	-0.00441
F* S* A	0.00103

Table -7: Estimated Regression Coefficients height

Factor	Estimated regression coefficient
Constant	1.21
F	0.50
S	-0.147
A	-0.025
F* S	0.0202
F* A	-0.0036
S* A	0.0058
F* S* A	-0.00037

3.2. ANOVA

Table -8: ANOVA table for reinforcement width

Source	DF	Adj SS	AdjMs	F-Value	P-Value
Regression	7	118.731	16.9616	24.49	0.000
F	1	0.324	0.3236	0.49	0.0325
S	1	0.059	0.0587	0.09	0.143
A	1	0.070	0.0698	0.10	0.750
F* S	1	0.027	0.0275	0.04	0.841
F* A	1	0.022	0.022	0.03	0.857
S*A	1	0.012	0.0123	0.02	0.893
F* S* A	1	0.099	0.0995	0.15	0.703
Error	19	12.644	0.6655	-	-
Total	26	1231.375	-	-	-
S=0.765		R-sq=81.09		R-sq(adj)=78.62	

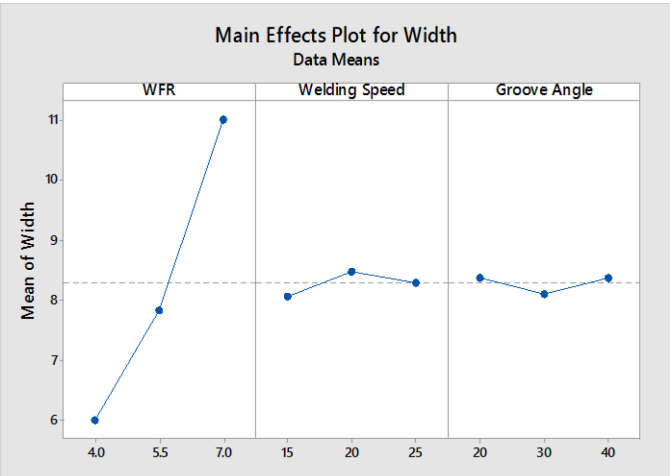


Fig-4: Main effect plot for width

From the fig -4 it is observed that width increases with increase in wire feed rate. It is also observed that width increases with interaction of welding speed and groove angle.

Table -9: ANOVA table for reinforcement height

Source	DF	Adj SS	AdjMs	F-Value	P-Value
Regression	7	4.35359	0.621941	13.28	0.000
F	1	0.03759	0.037591	0.80	0.382
S	1	0.00062	0.000625	0.01	0.090
A	1	0.01856	0.018561	0.40	0.046
F* S	1	0.02336	0.023358	0.50	0.0489
F* A	1	0.06462	0.064621	1.38	0.025
S*A	1	0.02752	0.027523	0.59	0.453
F* S* A	1	0.04774	0.047740	1.02	0.325
Error	19	0.88991	0.046838	-	-
Total	26	5.24350	-	-	-
S=0.216		R-sq=83.45		R-sq(adj)=78.45	

From the fig -5 it is observed that reinforcement height decreases with increase in welding speed and groove angle and with the increase in wire feed rate, the height also increases. It is also observed that height decreases with interaction of wire feed rate and welding speed, wire feed rate and groove angle, welding speed and groove angle.

Fig-5: Main effect plot for height

Table -10: ANOVA table for reinforcement height

Source	DF	Adj SS	AdjMs	F-Value	P-Value
Regression	7	18.5307	2.64724	13.39	0.00
F	1	0.0276	0.02755	0.14	0.043

S	1	0.0318	0.03185	0.16	0.056
A	1	0.0021	0.00207	0.01	0.693
F* S	1	0.0189	0.01893	0.10	0.760
F* A	1	0.0014	0.00140	0.01	0.934
S*A	1	0.0478	0.04784	0.24	0.628
F* S* A	1	0.0061	0.00605	0.03	0.863
Error	19	3.7555	0.19766	-	-
Total	26	22.2862	-	-	-
S=0.441		R-sq=86.89		R-sq(adj)=78.53	

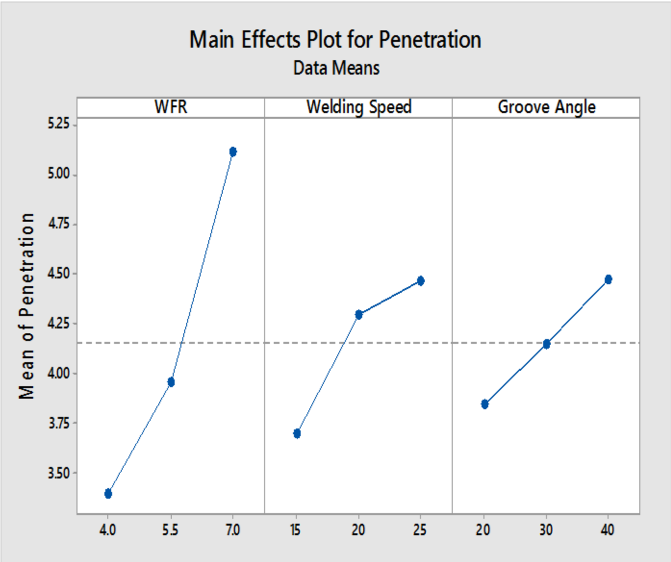


Fig-6: Main effect plot for penetration

From the fig -6 it is observed that penetration increases with increase in wire feed arte, welding speed and groove angle. It is also that penetration increases with the increase in interaction of welding speed and groove angle.

TABLE -11: Mean analysis for width

Levels	WFR (m/min)	Welding speed(cm/min)	Groove angle(°)
Level 1	5.998	8.073	8.381
Level 2	7.841	8.493	8.101
Level 3	11.031	8.04	8.387
Deviation	5.033	0.420	0.285
Rank	1	2	3

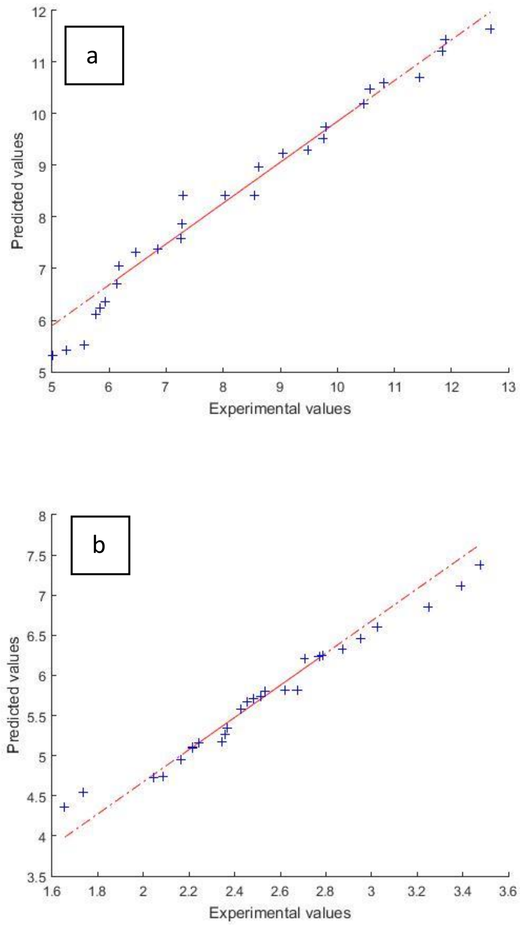
TABLE -12: Mean analysis for height

Levels	WFR (m/min)	Welding speed(cm/min)	Groove angle(°)
Level 1	2.526	2.857	2.887
Level 2	2.497	2.531	2.533
Level 3	2.575	2.209	2.177
Deviation	0.078	0.648	0.710
Rank	3	2	1

TABLE -13: Mean analysis for penetration

Levels	WFR (m/min)	Welding speed(cm/min)	Groove angle(°)
Level 1	3.397	3.696	3.844
Level 2	3.956	4.299	4.150
Level 3	5.112	4.470	4.472
Deviation	1.716	0.773	0.628
Rank	1	2	3

From the tables -11, 12, 13 it is observed that both width and penetration are majorly effected by wire feed rate followed by welding speed and groove angle. Height is effected by groove angle followed by welding and wire feed rate.



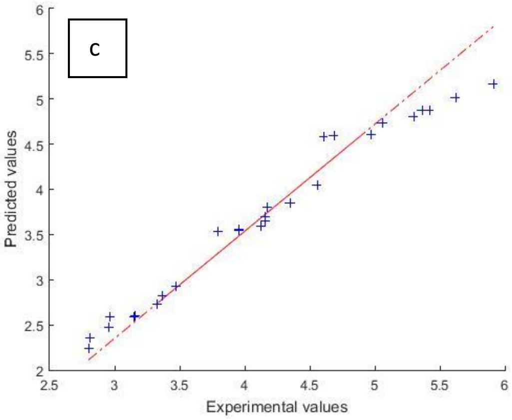


Fig-7: Experimental values vs Predicted values for (a) Width (b) Height (c) Penetration

4. CONCLUSIONS

The effect of process parameters on width, height and penetration have been studied in pulsed gas metal arc welding for narrow "V" type butt joint and the mathematical models from these experimental data is be employed to study the relation between process parameters width, height and penetration.

The following conclusions were obtained from the study:

1. Wire Feed Rate (WFR) has maximum effect on width and penetration followed by welding speed and groove angle.
2. Welding speed has intermediate influence on three parameters width, height and penetration.
3. Groove angle has least influence on width and penetration, But maximum effect on height.
4. The width, height and penetration are mainly effected by the wire feed rate and grove angle in pulsed gas metal arc welding.
5. Width and penetration are increases with increase in interaction of welding speed and groove angle but height is decreases.

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