Prediction of Bead Geometry Parameters of MIG Welded Aluminium 1200 Plates by Mathematical Modelling

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Abstract

Metal Inert Gas welding is a process in which a continuous solid wire electrode is heated and fed into the weld pool from a welding gun. In this present work, bead geometry like depth of penetration (DOP), bead width (BW) and height of reinforcement (HOR) has been analysed using a mathematical model. Weld bead geometry parameters of a fusion weld are important from a design point of view, as they affect the joint's mechanical strength and reliability during its serviceability . The present work is focused on analysing the effect of various welding input parameters like wire feed rate (WFR), welding speed (WS), and voltage (V) on the bead parameters. Aluminium grade 1200 has been selected for the present work due to its widespread utility in manufacturing pipelines, shipbuilding industry and general fabrication work. A mathematical correlation between the input and the bead parameters is attempted. To execute the tests in a structured manner and construct a mathematical model, the design of experiment (DOE) technique was utilised. Optimization of input parameters is done to have the desired levels of bead parameters within the selected working range. Response surface methodology (RSM) is used to analyse the results graphically. The developed model has been found to be adequate through the use of the Analysis of Variance approach.

Keywords: MIG welding, bead geometry, input parameters, mathematical modeling, ANOVA, RSM.

1. Introduction

MIG welding is a joining and fabrication process that has been widely used for many decades due to its benefits such as all-position welding ability, portability, versatility, ability to join all the materials whose filler wire is available and its ability to get fully automated [1]. An arc formed between a consumable metal electrode and the work-piece is used as the source of heat in this method. An externally supplied inert gaseous shield of argon, helium or their combination protects the arc and the molten pool from atmospheric contamination [2]. The consumable electrode is a wire spool that is fed through the feed rollers at a consistent rate [3]. The MIG welding is widely used for fabrication purposes because of its higher deposition rate and deeper penetration [4].

Bead geometry parameters such as DOP, BW, and HOR are widely used to adjudge the weld joint quality as they are found to have a direct bearing on the mechanical properties and performance of the weld during its service life [5]. Literature survey and past experience have shown that these bead parameters are affected by input parameters like WFR, WS and V. It is therefore important to set the right welding parameters in advance to achieve desired quality weld [6]. The geometrical form of the bead and its properties have a direct effect on the mechanical properties of the weld joints [7].

The present investigation work is performed on Aluminium plates (1200) which are widely used in a variety of applications such as spacecraft components, automobiles, ships, trains, aeroplane parts, household appliances, cans, foils etc. Aluminium plates of 4 mm thickness were butt-welded using MIG welding equipment as illustrated in Fig. 1. The experiments for this work were conducted in a structured manner by using statistical techniques of design of experiments. A three-level, three-factor face centred design was used and a total of 20 experimental runs were carried out as suggested by the design matrix developed by the design expert software. A mathematical model was developed to establish a relationship between the input parameters and the response parameters. The model's adequacy was tested using the ANOVA approach, and the results were graphically analysed using the RSM technique. The parameters were optimised to have the desired levels of bead parameters within the selected working range.

Fig. 1.The Experimental Setup

Researchers have attempted to forecast and explain the impact of welding parameters on weld bead through a variety of methods. The following is a list of some of the published research of several researchers in this field.

A study on the effect of MIG welding parameters on the mechanical properties of Aluminium alloy 5052 was conducted, and it was discovered that all MIG process factors (V, wire-speed, gas flow) have a substantial effect on the tensile and microhardness of the welded [8]. When the welding parameters were optimised and P-values for the various factors were obtained, it can be concluded that welding current and welding voltage are the main parameters among the three controllable factors that influence tensile strength during Mig welding (welding current, V, WFR)[9]. Based on Taguchi's design of experiments and ANOVA analysis, MIG welding contributes 36.8 per cent of welding current, 32.9 per cent of gas flow, and 30.3 per cent of feed rate. TIG welding contributes 93.2 per cent of the welding current and 6.8 per cent of the gas flow. Electric current is regarded as the most important characteristic in both MIG and TIG welding [10]. MIG welding was used to join AA6061-T6 metal in various shielding gas compositions. As a result, macro/microstructure studies and the mechanical properties of welded junctions were investigated. The porosity ratio in the weld joint reduced as the He content in the shielding gas composition increased due to the strong heat conductivity and ionisation energy of the He gas. In macro analyses of welded joints employing shielding gas with helium contents of 75% and 100%, no pores were observed [11]. On high strength aluminium alloy joints generated by MIG welding and TIG welding, the impacts of continuous current and pulsed current techniques were investigated [12]. The BW was found to increase with the increase in voltage and WFR and reduced with the increase in WS, whereas HOR was found in an overall increase with an increase in WS, WFR and decreased with the increase in voltage. Also, WRFF was found in an overall decrease with an increase in WS, WFR, and voltage in the study of MIG welded aluminium 1200 plates to determine bead geometry [13].

The above survey shows that very limited work has been reported on Aluminium alloy 1200. This has been the motivation behind carrying out the present investigative work.

2. Materials and Methodology

The welding power source of the rated capacity of 400 amps with flat VI characteristics was used. Welding fixtures were used to keep the joint aligned during the welding process. For making the weld joints, a mechanised welding manipulator was used to ensure a consistent pre-set WS. The range of WS obtainable from this system are 0-50 cm per minute.

The base metal selected for the present study is Aluminium 1200, cut to a size 120 mm x 75 mm x 4 mm on a band saw machine. A total of 40 pieces were cut for 20 butt welded joints between them as shown in Fig. 2. Table 1 shows the input parameters along with their working ranges. Aluminium 4043 wire of 1.2 mm diameter was used as filler with Argon as shielding gas with a constant flow rate of 15 lpm.

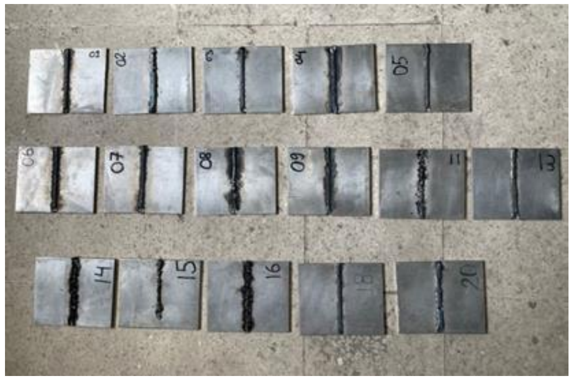


Fig. 2. The welded specimens.

Table 1. Input parameters and their values.

	Input Parameter	Symbol	Unit	Levels		
				-1	0	-1
1	WFR	A	m/min	3	4	5
2	WS	B	cm/min	40	45	50
3	V	C	V	20	22	24

All the 20 welds were then prepared for bead geometry investigations by using standard polishing techniques involving coarse, fine and ultra-fine polishing on rotary disc apparatus. These pieces were etched with Keller's. The etched specimen is shown in Fig. 3. This etched sample is further used to calculate the bead parameters.

Fig. 3. Weld test piece (Etched specimen).

3. Developing the design matrix observation table

DOE method was used to generate a three-factor, three-level matrix with a total of 20 runs using the face centred technique. The prepared specimens after etching were subjected to measurement of BW, HOR and DOP. The input parameters are selected on the basis of the past literature survey and some test runs conducted on the material. The input parameters with the measured values of these three response parameters are shown in observation table 2.

Table 2. Observation Table.

Std	Run	WFR m/min	WS cm/min	Voltage V	Response 1 BW mm	Response 2 HOR mm	Response 3 DOP mm
17	1	0	0	0	7.92	1.88	1.66

6	2	1	-1	1	8.77	2.01	2.30
20	3	0	0	0	8.12	1.89	3.27
14	4	0	0	1	7.73	2.17	1.81
4	5	1	1	-1	7.31	2.22	2.24
12	6	0	1	0	8.80	2.23	2.07
11	7	0	-1	0	8.58	1.95	1.94
5	8	-1	-1	1	5.81	1.95	0.95
7	9	-1	1	1	7.52	2.04	1.19
18	10	0	0	0	6.82	1.96	1.95
3	11	-1	1	-1	2.90	1.63	0.61
19	12	0	0	0	8.01	1.94	2.83
10	13	1	0	0	7.32	2.46	2.16
1	14	-1	-1	-1	2.90	1.64	0.53
2	15	1	-1	-1	7.23	2.04	3.84
9	16	-1	0	0	2.65	1.54	0.33
15	17	0	0	0	6.32	1.46	1.75
13	18	0	0	-1	5.43	1.94	1.82
16	19	0	0	0	8.04	2.09	1.69
8	20	1	1	1	10.65	2.67	3.86

4. Results and discussions

4.1 Developing Mathematical model

The following are the mathematical equations developed by the DOE software to express the direct, interaction and quadratic relationships of the input parameters with the responses:

$$HOR = 1.93 + 0.2606A + 0.1182B + 0.1375C \qquad (1)$$

$$DOP = 2.01 + 1.08A + 0.1071C - 0.1147AC + 0.4155BC - 0.4897A^2 + 0.2718B^2 \qquad (2)$$

$$BW = 79.63 + 38.04A + 1.52B + 21.62C + 0.8732AC + 1.54BC + 11.27A^2 + 7.81B^2 + 0.5076C^2 \qquad (3)$$

4.2 Testing the significance of the developed models

The developed models were then tested for their adequacy by ANOVA technique and the findings are represented in table 3. In all three models, the calculated value of F-ratio is found to be greater than its tabulated value, as a result, all of the models are suitable.

Table 3. ANOVA Results

S. No.	Response	Sum of Square	df	Mean Square	F-Value	p-Value	R^2	Adequate

1	BW	79.63	9	8.85	18.75	<0.0001	0.9441	Yes
2	HOR	1.19	9	0.1327	3.22	0.0414	0.7434	Yes
3	DOP	13.99	9	1.55	3.65	0.0280	0.7665	Yes

4.3 Direct effects of the input parameters on bead geometry

4.3.1 Direct effect of input parameters on BW

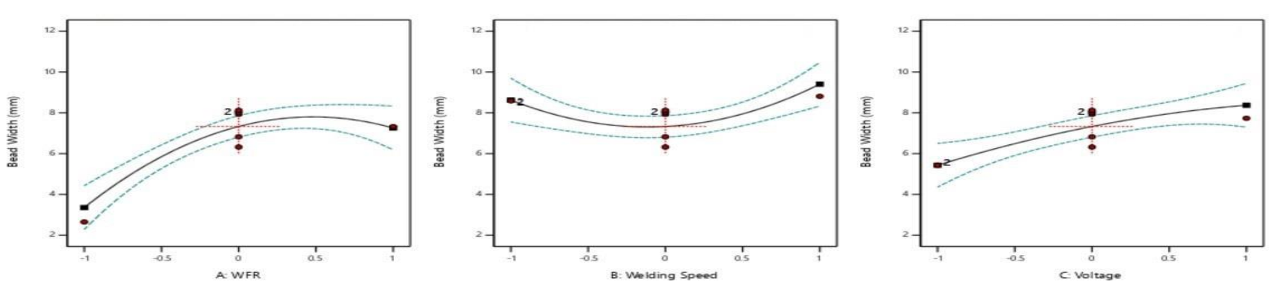


Fig. 4. Direct effect of input parameters on BW.

WFR has a positive effect on BW. WS has initially negative, then positive effect on BW. V has a positive effect on BW, as shown in Fig. 4. The probable reason for these trends is that as WFR increases, the amount of weld current increases as well, resulting in more filler metal melting and spreading over a larger area, resulting in an increase in width. With the increase in WS, the heat input per unit weld decreases and less time is available for the filler wire to mix with base metal resulting in the lesser spread of filler on the base metal surface. V has a strong positive effect on bead geometry, which could be related to the fact that as V increases, the overall arc energy also increases, and the weld bead redistributes itself as the arc spreads wider, resulting in a wider bead.

4.3.2 Direct effect of input parameters on HOR

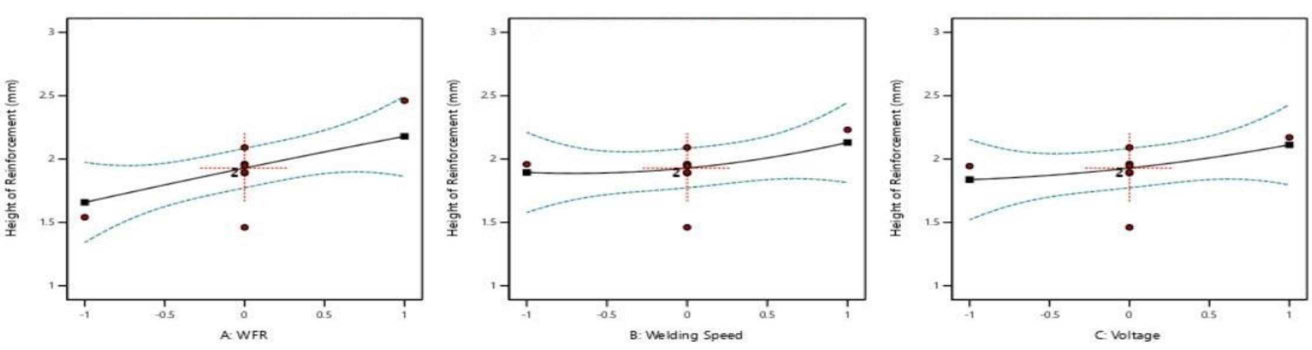


Fig. 5. Direct effects on HOR.

According to Fig. 5., WFR has a positive, WS has a nominal positive effect and V has a slight positive effect on HOR. The most probable explanation for these trends is that when WFR increases, the amount of weld current also increases, resulting in increased melting of filler metal, which produces an increase in HOR. The HOR increases as the WS increases. This is most likely because as the speed increases, metal does not have the opportunity to enter the weld and instead sits on the base plate, resulting in an increase in the HOR.

4.3.3 Direct effect of input parameters on DOP

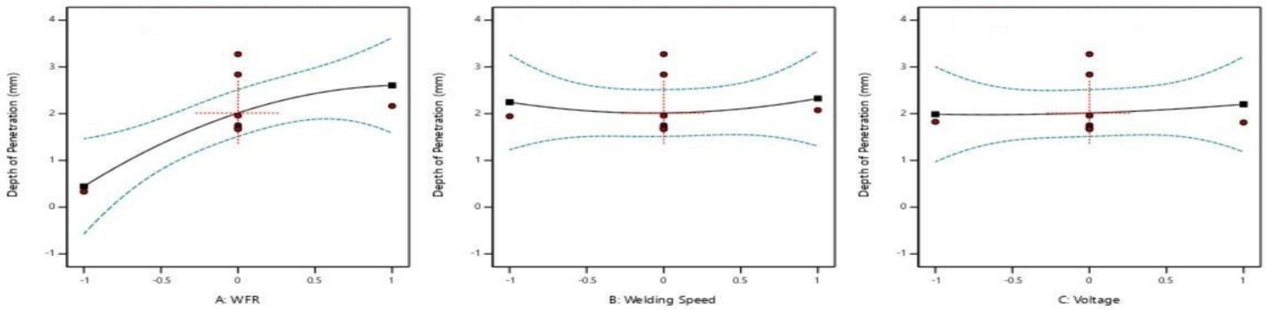


Fig. 6. Direct effects on DOP.

From Fig. 6., it can be clearly seen that WFR has a positive effect on DOP as with the increase in WFR, the amount of heat input into the weld increases and the arc digging force also increases giving rise to a deeper weld. WS is found to have a slight decreasing effect as with the increase in WS, the heat input into the weld decreases resulting in less molten base metal and hence less DOP. V is found to have a slight positive effect on DOP as with the increase in V, the total heat input into the weld also increases thereby increasing the DOP.

4.4 Interactive effects of the input parameters on bead geometry

4.4.1 Interaction effects of WS, WFR and V on BW

Interaction effects of WS, WFR and V on BW are shown as surface plots in Fig. 7-9.

It is evident that WS has initially negative and then positive effect on BW. The initial negative effect can be attributed to the fact that with the increase in WS the deposited metal does not get an opportunity to spread. However, the positive effect can be explained as the dominating interaction and positive effects of V and WS. WFR has found to have a positive effect on BW in all the cases which is quite logical because with the increase in WFR heat input increases resulting in more filler metal melting which thus gets an opportunity to spread over a wider area, increasing the BW. V has also been found to have a positive effect on BW as at increased V the arc line also increases as a result, the arc spreads wider, redistributing the molten metal across a larger width.

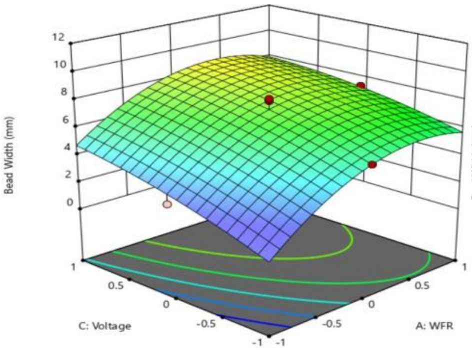


Fig. 7. Effects of V and WFR on BW.

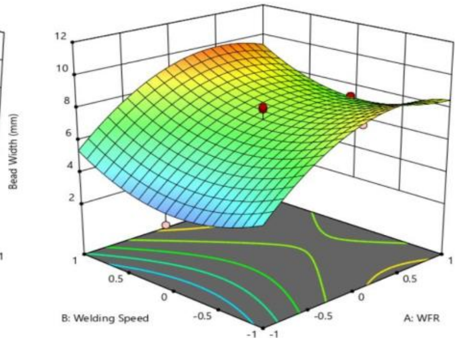


Fig. 8. Effects of WS and WFR on BW**.**

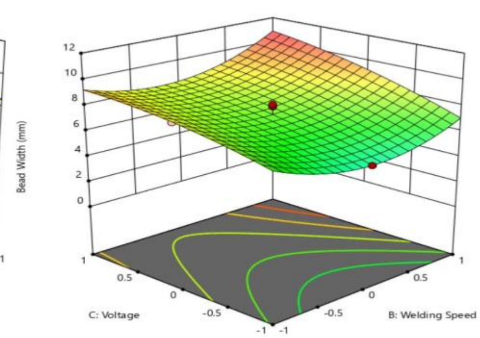
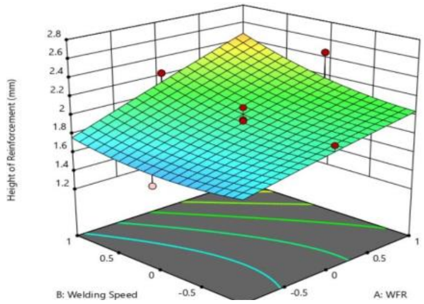


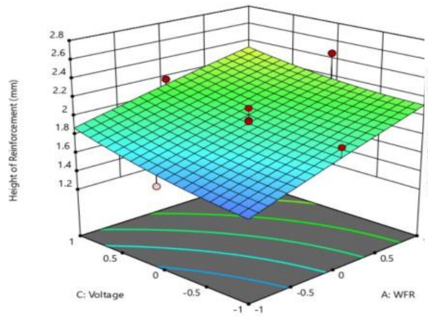
Fig. 9 Effects of V and WS on BW.

4.4.2 Interaction effects of WS, WFR and V on HOR

Interaction effects of WS, WFR and V on HOR are shown as surface plots in figure 10-12.

It is clear from the graph that the WS has a positive effect on HOR. The possible reason could be that with the increase in WS the deposition of the metal on the base metal is superficial and it does not plunge into the pool thereby slightly increasing the HOR. The WFR has a positive effect on HOR because of a larger amount of filler metal deposition due to more melting of the same. V however is found to have a slight positive effect on HOR which is in contradiction to normal trend which is positive. The probable reason for this anomaly could be the presence of dominating positive effects of other interacting factors.





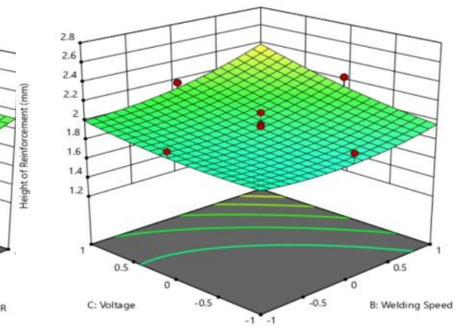
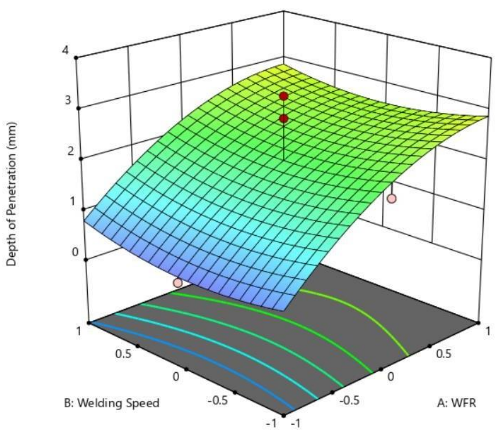


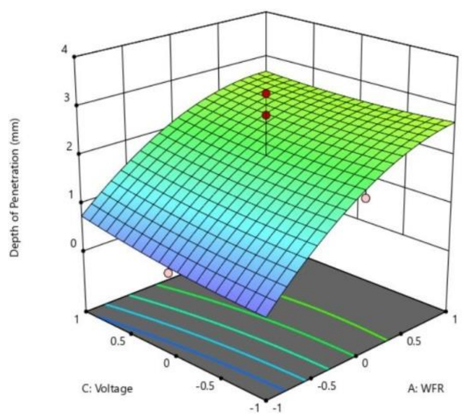
Fig. 10. Effects of WS and WFR on HOR . **Fig. 11.** Effects of WFR and V on HOR **Fig. 12.** Effects of WS and V on HOR

5.4.3 Interaction effects of WS, WFR and V on DOP

Interaction effects of WS, WFR and V on DOP are shown as surface plots in figure 13-15.

It can be clearly seen that WS has a slight negative effect on DOP. The probable reason could be the reduced heat input into the weld at higher weld speeds. WFR has a significant positive effect on DOP because of more heat input and more digging effect of the arc at higher WFR's. The V has a slight positive effect on DOP as with the increase in V, the total heat input into the weld also increases thereby increasing the DOP.





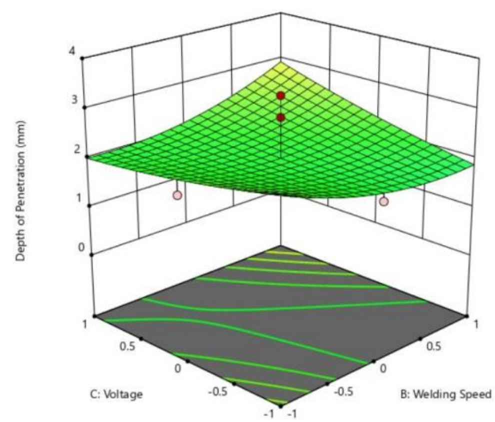


Fig. 13. Effects of WS and WFR on DOP **Fig. 14.** Effects of WFR and V on DOP **Fig. 15**. Effects of WS and V on DOP.

5. Conclusion

The following conclusion can be drawn from the experimentation:

- WFR and V are found to have a positive effect on BW. WS however has a negative first and then positive effect on BW.
- All three parameters are found to have a positive effect on HOR. WFR has the most dominating effect followed by WS and then V.
- WFR has a significantly positive effect on DOP, followed by V. WS however has a slightly negative effect on DOP.
- The optimum parameters for achieving maximum penetration of 3.39 mm are; WS=40 cm/min, V=20 V and WFR=5 m/min.
- The optimum parameters for achieving a maximum BW of 10.50 mm are; WS=50 cm/min, voltage=24 V and WFR=7.0 m/min.
- The optimum parameters for achieving a minimum HOR of 2.06 mm are; WS=40 cm/min, V=20V and WFR =3 m/min.

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