Mathematical Modelling to Predict Bead Geometry Parameters of MIG Welded Aluminum 6063 Plates

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Abstract. The purpose of this research is to evaluate the effect of various operational parameters like voltage, weld speed, torch angle, nozzle to plate distance (NPD), and wire feed rate on bead geometry of welds on aluminum 6063 plates. This aluminum grade has a wide range of applications, from industrial to home. The bead geometry properties of a fusion weld are essential from a design standpoint because they affect the joint's mechanical strength and dependability throughout its usage. Bead width (BW), depth of penetration (DOP), and height of reinforcement (HOR) are all essential bead parameters, which need to be considered while commenting on bead geometry of a weld. An experiment series was performed with the statistical technique of design of experiments, using the central composite rotatable design (CCRD) method. This resulted in a mathematical model that correlated bead geometry parameters with various input parameters. RSM (Response Surface Methodology) is used for the graphical analysis of the results obtained. The suggested framework aims to optimize the input variables in order to attain the specified bead parameter values.

Keywords: Welding; Bead Geometry; Aluminum 6063; Mathematical Model; ANOVA; RSM

1 Introduction:

Metal Inert Gas (MIG) welding is a prominent arc welding technique [1]. During mig welding an arc is created by the heat generated between the filler material and the work piece. Pressurized inter gas is used to create a curtain which protects the arc and the molten mass from contamination. The inert gas may be helium, argon or a mixture of both [2]. Mig welding is widely used to manufacture pressure vessels, automobiles, food processing equipment, and general steel fabrication. Due to complete automation continuous long welds have become easier to manufacture allowing mig to be used in a wide range of applications [3]. The geometry of the bead formed during the welding process effects the strength and failure rate of the weldments, it is paramount to identify optimal welding parameters to achieve an acceptable weld bead [4].

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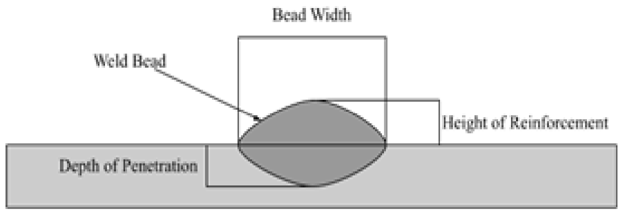

Fig 1. Characteristics of Weld Bead

Bead geometry is measured using the Depth of Penetration (DP), Bead Width (BW), and Hight of Reinforcement (HOR) which are widely used to assess the weld since they have a direct impact on the weldment's quality and performance over a period [5]. Upon colling, the shrinkage of the bead is affected by its cross-sectional area and height, which impacts residual stresses and, as a result may cause distortion, making proper bead geometry crucial. [6].

2 Literature Survey:

Researchers employed several methods to anticipate and articulate the effect of welding parameters on the weld bead. The following is a partial list of studies published by several researchers on the subject.

wire feed rate has a positive effect on bead penetration while weld speed has a negative effect. Furthermore, voltage has a positive impact on bead width but a detrimental impact on penetration and reinforcement height [7]. Another investigation of MIG welding of HSLA steel found that increasing weld speed has a negative impact on reinforcement height and bead width welding speed has no major effect on penetration. It also indicates that when voltage rises, penetration and bead width grow to their maximum value, however reinforcement height falls. The main elements that influenced these outcomes were voltage, weld speed, and gas flow rate [8]. Further, torch angle and NPD have opposite effects on penetration. As the torch angle rises, so does the penetration, but as the NPD rises, it lowers. The maximum weld bead was attained by setting the Torch angle to its highest value and applying minimum values for all other relevant parameters [9].

In the case of low carbon steels, higher voltage and wire feed rate cause an increase in weld width, whereas weld speed and NPD have no effect. It also states that NPD and weld speed have a negative impact on reinforcement height, whereas other factors have a minor effect. According to the findings, voltage and wire feed rate have a positive impact on penetration, however NPD and weld speed have no visible effect [10]. For stainless steel 409L plates, the interplay of wire feed rate and voltage was found to be the most important of the combined impacts. The bead geometry was shown to be most affected by voltage, weld speed, and wire feed rate [11].

In most developing countries, aluminum 6063 is processed in huge quantities at low cost, and it has good structural strength, corrosion resistance, weldability, and is resistant to cracking under stress [12]. However, relatively little work on the aluminum alloy 6063 has been documented. This has been the driving force behind the investigation currently underway.

Table 1: Composition specification for Aluminum 6063

Material	Al	Si	Cu	Mn	Mg	Zn	Ti	Fe	Ni	Cr
Weight%	98.33	0.4830	0.0008	0.0083	0.4051	0.0165	0.0145	0.1799	0.0047	0.0040

3 Materials and Methodology

3.1 Identification and selection of working limits for welding variables

Several early experiments were carried out by altering the input variables while keeping the others constant. When determining the working range for various parameters, the procurement of a uniform weld bead and the lack of any obvious faults were taken into account. Each parameter's operating limits were set at five different levels. The levels were labelled as follows: (+2) highest, (0) medium, (-2) lowest, (1) and (-1) intermediate. Table 2 lists the input parameters and their relative levels.

Table 2. Working range of input parameters

S no.	Input Parameters	unit	-2	-1	0	1	2
1	Voltage	Volts	16	18	20	22	24
2	Weld Speed	cm/min	30	35	40	45	50
3	Wire Feed rate	mm/min	3	4	5	6	7
4	Nozzle to plate distance	mm	10	12.5	15	17.5	20
5	Torch Angle	degrees	-30	-15	0	15	30

3.2 Development of the design matrix

The fractional factorial technique was used to structure the experiments, in which all of the selected input parameters were adjusted at the same time to record their direct and interaction effects. The Central Composite Rotatable Design (CCRD) technique was used to build the design matrix, which comprised of 32 experiments [(2^4=16) + (2*5 =10) +(2*3=6) =32], where 16 runs are factorials, 6 runs are center points, and 10 runs are star points. By altering these elements according to the matrix generated, parameters of the bead geometry were detected. The acquired values were examined through the utilization of design expert software. Subsequently, a mathematical model was formulated, and through an analysis of the matrix that had been constructed, the optimal bead geometry was ascertained. The design matrix produced by the software is presented in Table 3.

Table 3: Design Matrix

Std	Run	voltage	wire feed	weld speed	NPD	torch angle	width	height	depth
		volt	mm/min	cm/min	mm	degree	mm	mm	mm
10	1	1	-1	-1	1	1	9.34	3.429	6.445
3	2	-1	1	-1	-1	-1	5.432	3.842	1.181
6	3	1	-1	1	-1	1	11.211	2.961	5.077
14	4	1	-1	1	1	-1	8.438	3.75	2.766
5	5	-1	-1	1	-1	-1	2.195	3.656	3.232
26	6	0	0	0	0	2	10.526	3.145	4.895
15	7	-1	1	1	1	-1	7.91	3.569	3.57
2	8	1	-1	-1	-1	-1	8.98	3.512	2.565

12	9	1	1	-1	1	-1	5.793	3.649	1.542
4	10	1	1	-1	-1	1	5.728	3.365	1.273
22	11	0	0	2	0	0	5.965	3.323	2.012
31	12	0	0	0	0	0	7.418	3.416	2.873
32	13	0	0	0	0	0	9.414	3.498	2.567
18	14	2	0	0	0	0	13.625	3.334	2.983
21	15	0	0	-2	0	0	7.379	3.621	2.443
7	16	-1	1	1	-1	1	7.533	3.416	2.19
13	17	-1	-1	1	1	1	5.703	3.422	1.369
16	18	1	1	1	1	1	7.75	3.411	1.845
11	19	-1	1	-1	1	1	10.678	3.382	4.524
24	20	0	0	0	2	0	9	3.742	4.516
27	21	0	0	0	0	0	9.486	3.314	4.229
20	22	0	2	0	0	0	8.027	3.575	1.97
19	23	0	-2	0	0	0	6.343	3.421	2.571
23	24	0	0	0	-2	0	6.115	3.54	1.839
29	25	0	0	0	0	0	8.676	3.416	3
17	26	-2	0	0	0	0	8.893	3.474	2.737
9	27	-1	-1	-1	1	-1	7.399	3.778	2.736
30	28	0	0	0	0	0	9.75	3.643	3.348
28	29	0	0	0	0	0	8.596	3.465	2.712
8	30	1	1	1	-1	-1	10.325	3.424	1.965
25	31	0	0	0	0	-2	5.938	4.031	1.754
1	32	-1	-1	-1	-1	1	7.082	3.326	2.282

3.3 Experimental setup

Using a semi-automatic setup, MIG welding was performed on aluminum plates with dimensions of 150mm*150mm and a thickness of 6 mm in the current study. A welding power source with a current capacity of 400 Amps and flat VI characteristics was used. The speed of the mechanized welding unit used for this job is 0-50 cm/min. Argon was employed as a shielding gas, with a 10 lpm delivery rate. On aluminum plates, bead on plate welding was performed. Voltage, weld speed, torch angle, nozzle plate distance, and wire feed rate were the parameters chosen.

Fig. 2. Experimental Setup

3.4 Developing the mathematical models

$$WIDTH = 8.96 + 0.96A + 0.17B + 0.42D + 0.73E + -1.09AB + 0.94AC + -0.89AD - 0.47AE + 0.69BC + 0.10BD - 0.25BE - 0.46CD + -0.11CE + 0.51A^2 - 0.500852 * B^2 - 0.62C^2 - 0.40D^2 - 0.23E^2$$

$$HIGHT = 3.46 + 0.02B + -0.17E + -0.02A^2 + 0.03D^2 + 0.02E^2$$

$$DEPTH = 2.84 + 0.12A - 0.39B + 0.43D + 0.48E - 0.75AB + 0.38AE + 0.16BC + 0.29BD - 0.14BE - 0.67CD - 0.47CE + 0.1DE$$

3.5 Model Adequacy verification

To verify the adequacy of the model f and p values were evaluated. Since the software calculated values are less that the tabulated values, the model is deemed adequate. With p values less than 0.05 the lack of fit is insignificant. The model is adequacy and significance satisfactory with more a reliability of more than 90%.

Table 4: Model Adequacy

	SS	df	MS	F-Value	p-Value	R^2	Significant
Depth	24.91	10	2.49	5.7	0.0011	0.8493	Yes
Width	33.24	5	6.65	7.64	0.0025	0.9346	Yes
HOR	0.9547	5	0.1909	13.7	<0.0001	0.9214	Yes

Table 5: Model lack of Fit

SS	df	MS	F-Value	p-Value	Significant
5.16	11	0.4692	1.28	0.4155	No
5.9	6	0.9873	1.34	0.3825	No
0.3021	21	0.0014	1.2	0.4611	No

4 Results and Discussion

4.1 DEPTH

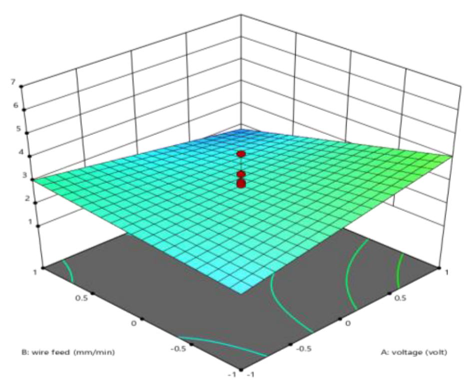

Fig 3. Depth of penetration reaches a maximum when wire feed rate

Fig3. Shows that the depth of penetration reaches a maximum when wire feed rate and voltage are maximum due to excess filler material being present. Voltage when increased keeping the wire feed constant shows an increase in depth of penetration due to higher arc temperature.

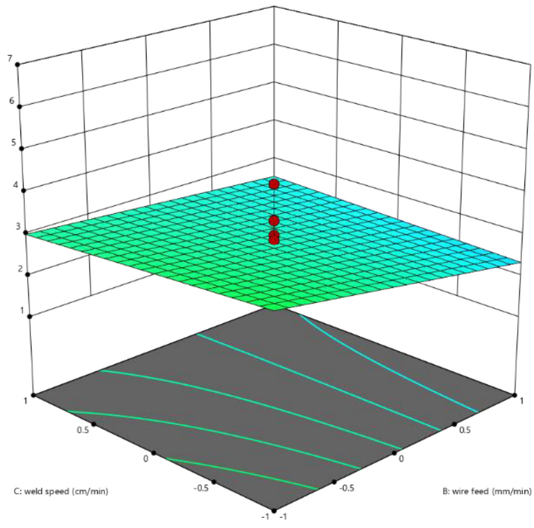

Fig. 4. Interaction of Wire Feed and Weld Speed on Depth of Penetration

Fig. 4 depicts a decrease in depth with an increase in weld speed. This occurs because a higher weld speed allows less time for fusion, leading to reduced penetration. The depth of penetration is seen to be highest when wire feed is at its maximum and weld speed is at its minimum, as the additional material being fed is allowed more time to be heated to higher temperatures, resulting in deeper penetration.

4.2 HEIGHT

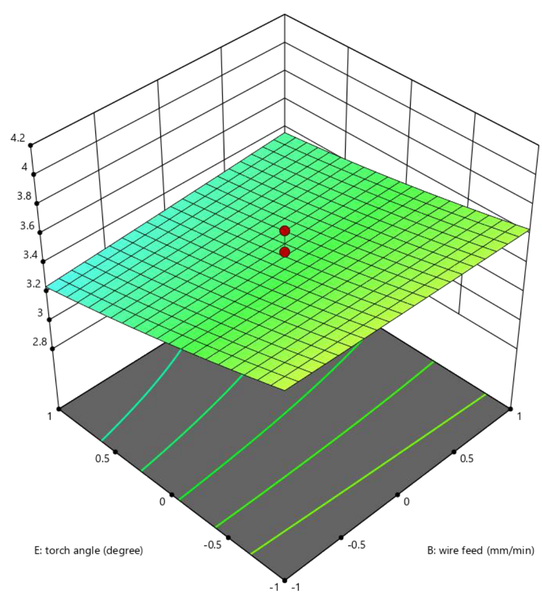

Fig. 5. Interaction effect of Torch Angle and Wire Feed Rate on Height of Reinforcement

We can infer from the aforementioned Fig. 5 that for all values of wire feed rate, the height of reinforcement reduces for increasing values of torch angle. Higher torch angle causes the weld bead to spread in the lateral direction to a greater extent with causes reduction of the height if reinforcement. However, as wire feed rate increases, the height of reinforcement increases due to the presence of a greater amount of filler material at the weld.

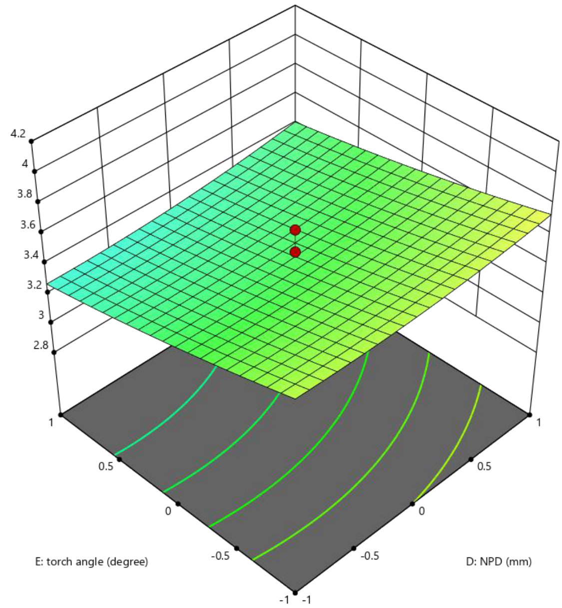

Fig. 6. Interaction effect of Torch angle and NPD on Height of Reinforcement

It is observed that Height of reinforcement increases for all values of torch angle with an increase in NPD. This is observed because higher NPD results in a narrower arc which allows a higher deposition of filler material in the vertical direction and the increased distance causes lesser penetration thereby increasing the height of reinforcement.

4.3 WIDTH

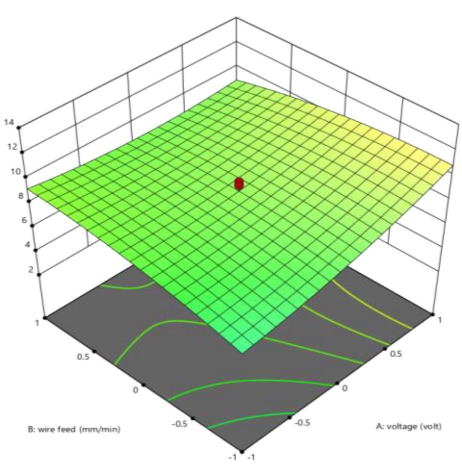

Fig 7. Interaction effect of Wire Feed Rate and voltage on Bead Width

Figure 7 clearly shows that the width of the bead is at its minimum when both voltage and wire feed rate are at their lowest values. As the values of voltage and wire feed rate increase, they have a positive effect on bead width. This is because of the increased availability of filler material and the widening of the arc spread due to rising voltage, leading to a wider bead.

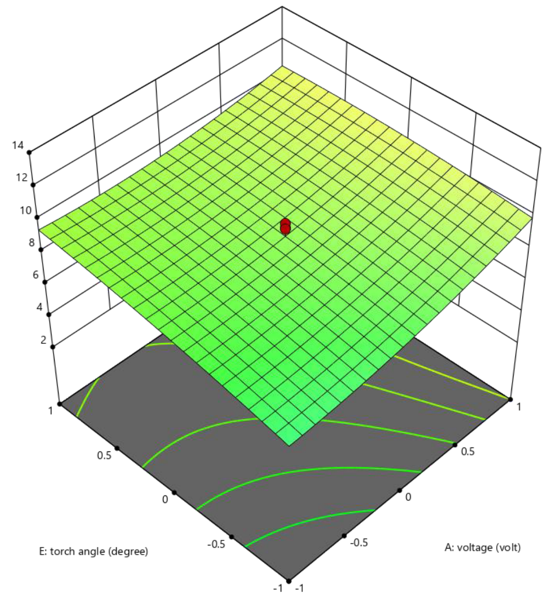

Fig 8. Interaction effect of Torch Angle and voltage on bead width

From Fig 8, It is clear that voltage and torch angle have a positive influence on bead width. This is owing to the fact that at higher torch angle the filler material travels more distance as a result it comparatively cools off before it makes contact with the plate. Additionally, at higher voltage levels, the arc spread widens, increasing bead width.

5 Conclusions:

From the investigation conducted, the following conclusions have been derived:

- ANOVA Analysis of the Central composite rotatable design (CCRD) was found suitable in the current study.
- The depth of penetration was found to be positively affected by voltage and wire feed rate, while it was negatively impacted by weld speed.
- The height of reinforcement was negatively affected by torch angle, while it was positively impacted by NPD and wire feed rate.
- The width of the weld bead was found to be positively affected by voltage, wire feed rate, and torch angle.
- The optimum combination of input values achieved are: voltage = 18.1 volts, wire feed = 3.99 mm/min, weld speed = 43.77cm/min, NPD = 12.5 mm and torch angle = 14.85 degrees.
- The output values achieved at the optimum combination are: depth of penetration = 4.988mm, height of reinforcement = 2.961mm and width = 11.383mm.

References:

1. Ganjigatti J. & Pratihar D. & RoyChoudhury A., "Modelling of the MIG welding process using statistical approaches", pp.-1-3, November 2006.
2. R Sachin, A. Sumesh, U.S. Upas “Study of Mechanical Properties and Weldability of Aluminium Alloy and Stainless steel by Gas Metal Arc Welding”, pp. 2, 2020
3. Pandit M., Sood S., Mishra P., Khanna P., "Mathematical analysis of the effect of process parameters on the angular distortion of MIG welded stainless steel 202 plates by using the technique of response surface Methodology", pp.-1-2, December 2019.
4. Chaudhry C., Badwal K., Khanna P., “Effect of Welding Parameters on the Weld Bead Profile of Submerged Arc Welded Low Carbon Steel Plates”, pp.-1, January 2022
5. Pandit M., Sood S., Mishra P., Khanna P., “Mathematical analysis of the effect of process parameters on the angular distortion of MIG welded stainless steel 202 plates by using the technique of response surface Methodology”, pp-1-2, June 2020
6. D.S. Nagesh, G.L. Datta, “Prediction of weld bead geometry and penetration in shielded metal-arc welding using artificial neural networks” pp-2, January 2002
7. Murugan N., Gunaraj V., “Prediction and control of weld bead geometry and shape relationships in submerged arc welding of pipes”, pp-9, July2002
8. Shoeb M., Parvez M., Kumari P., “Effect of Mig Welding Input Process Parameters on Weld Bead Geometry on Hsla Steel”, pp-9-13, January 2013
9. Zevedo S., Resende A., “Effect of angle, distance between electrodes and TIG current on the weld bead geometry in TIG-MIG/MAG welding process”, pp-5-9, March 2021
10. Narayana A., Srihari T., “Optimization of Weld Bead Geometry in Mig Welding Process Using Response Surface Methodology”, pp- 5-9, September 2012
11. Narang R., Maheshwari V., Khanna P., “Prediction of bead geometry parameters in MIG welded stainless steel 409L plates by mathematical modelling”, pp-8, October 2020
12. Alaneme K., Bodunrin M., “Corrosion Behavior of Alumina Reinforced Aluminium (6063) Metal Matrix Composites”, pp-2-3, November 2014
13. Fouda A.S., Al-Sarawy A.A., Ahmed F.SH., and El-Abbasy H.M., "Corrosion Inhibition of Aluminium 6063 Using Some Pharmaceutical Compounds", ISSN 2070-2051, Protection of Metals and Physical Chemistry of Surfaces, 2009, Vol. 45, No. 5, pp. 635–643. © Pleiades Publishing, Ltd., 2009, pp.-1, April 2009