IJREAT International Journal of Research in Engineering & Advanced Technology, Volume 5, Issue 1, Feb - Mar, 2017
ISSN: 2320 – 8791 (Impact Factor: 2.317)
www.ijreat.org

PREDICTION OF WELD BEAD GEOMETRY IN PULSED MIG WELDING

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ABSTRACT

Quality of a weld joint is strongly influenced by process parameters during the welding process. Therefore, it is essential to study the effect of process parameters on the bead geometry to enable effective control of these parameters. The process parameters that were employed during the experimentation were wire feed rate and welding speed. The main objective of this study is to predict the weld bead geometry in MIG, PULSE MIG and DOUBLE PULSE MIG. The accuracy of the predicted bead penetration, bead height and bead width are compared with experimentally obtained and predicted values for Square Butt welds. The experiment is conducted on 5083 Aluminium alloy as base metal and 5183 as filler wire. Mathematical models are developed to get bead width, height of penetration and depth of penetration.

KEYWORDS: *MIG welding, Accuracy, Process Parameters,*

I. INTRODUCTION

Welding is a process of joining two more pieces of the same or dissimilar materials to achieve complete coalescence. This is the only method of developing monolithic structures and it is often accomplished by the use of heat or pressure at their contacting surfaces.

Until 1948, GMAW was finally developed, a smaller diameter electrode and a constant voltage power source was used. In 1953, the use of carbon dioxide as a welding atmosphere was developed, and it quickly gained popularity in GMAW, since it made welding steel more economical. In 1958 and 1959, the short-arc variation of GMAW was released, which increased welding versatility and made the welding of thin materials possible while relying on smaller electrode wires and more advanced power supplies. It quickly became the most popular GMAW variation.

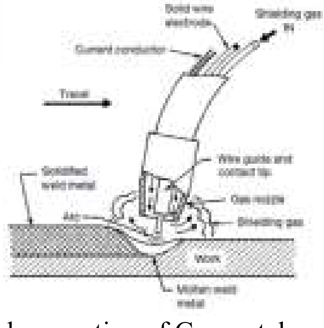


Figure 1.1 Principle operation of Gas metal arc welding process

Gas Metal Arc Welding (GMAW) (also known as Metal Inert Gas or MIG welding), an electric arc is created between the work piece and a consumable bare wire electrode. The arc constantly melts the wire as it is fed to the weld puddle. The weld metal is shielded from the atmosphere by a flow of an inert gas, or gas mixture. The MIG process operates on direct current, usually with the wire electrode positive. This is known as reverse polarity.

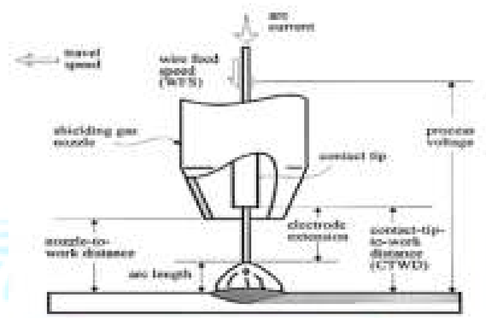


Figure 1.2 GMA welding parameters and terminology

The term modes of transfer are used to describe the process by which the wire electrode is melted and deposited into the puddle. The most common way to classify metal transfer is according to the size, frequency, and characteristics of the metal drops being transferred. There are four modes of metal transfer:

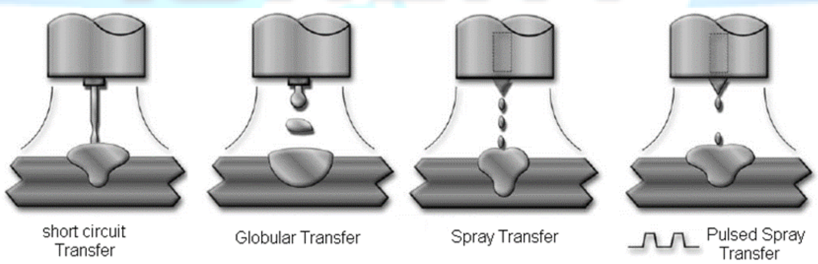


Figure 1.3 Basic metal transfer modes in GMAW

II. LITERATURE SURVEY

Palani and Murugan [1] studied the effect of process parameters on the bead geometry to enable effective control of these parameters and achieved by developing equations to predict the weld bead dimensions in terms of process parameters. Nouri et al. [2] studied the effect of P-GMAW variables on dilution and weld bead geometry in cladding X65 pipeline steel with 316 L Stainless steel. Kim et al. [3] developed an algorithm that enables the determination of process variables for optimised bead geometry for robotic GMA welding.

Kim et al. [4] developed a mathematical model for the selection of process parameter and the prediction of bead geometry in robotic GMA welding. The results obtained shows that developed mathematical models can be applied to estimate the effectiveness of process parameters for a given bead geometry.

Kumar et al. [5] developed an arc rotation mechanism and taken four input process parameters. The experiments were conducted on square butt joint plate of 5083 H111 aluminium alloy. It is observed from the investigation that eccentricity has maximum effect on convexity followed by arc rotational speed, ratio of wire feed rate to travel speed and wire feed rate.

Kim et al. [6] developed mathematical models that correlate welding process parameters to the weld bead geometry. Experimental results are compared to outputs obtained using formulae relating input variables to output parameters and also utilized to develop a mathematical model explaining the relationship between gas metal arc welding variables and weld bead geometry. Kim et al. [7] studied the relationship between process variables and bead penetration for robotic CO_2 arc welding process and develop the mathematical models to predict the desired bead penetration.

Juang and Tarng. [8] selected the process parameters for obtaining an optimal weld pool geometry in the tungsten inert gas welding of stainless steel is presented. The geometry of the weld pool has several quality characteristics, to consider these quality characteristics together in the selection of process parameters. The modified Taguchi method is adopted to analyse the effect of each process parameter on the weld pool geometry. Experimental results are provided to illustrate the proposed approach.

Menzemer et al. [9] Arc welding is economically affordable and efficient method for the joining of aluminium alloy structures that find extensive use in the industries of transportation and building construction. Palani and Murugan [10] predicted the wire feed rate for the set of parameters, a mathematical model was developed from the results obtained by conducting experiments.

From the above literature survey, it can be concluded that no work has been gone on the prediction of weld bead geometry in MIG, PULSE MID and DOUBLE PULSE MIG welding when used on Aluminium alloy (5083) as base metal and 5183 filler wire.

III. EXPERIMENTAL SETUP AND METHODOLOGY

The equipment used in this work comprise of gas metal arc welding machine (PROMIG 530), automatic feeding weld bed, DC Motor, rheostat. For automatic feeding of weld bed, arrange the weld bed is connected to lead screw and lead screw is connected to DC Motor. When the motor rotates, due the connection between the motor and lead screw, lead screw rotates. So the weld bed automatically feed in opposite directions. By varying position of the pointer on the rheostat, the speed of DC Motor varies accordingly. The maximum speed is obtained.

Figure 3.1 Experimental setup

The wire feed rate is varied by using the knob present on the PROMIG machine. Keeping the welding torch fixed at a position and giving moment to the weld bed by varying the position of pointer on rheostat the speed is controlled. Finishing the adjustments, switching on the MIG one gets the welding on the weld plate.

After that the welding plate is cut, to obtain two cross-sections, and metallurgical finish is given to each one of the surfaces and calculation the depth of penetration, height of reinforcement and bead width are done.

In this PROMIG530 machine, for automatic wire feeding, uses MIG welding with 4 sequence starts switch function, MIG-4T.This machine can control and display the welding parameters like plate thickness, wire feed speed, current, and voltage and also checking the shielding gas. Nozzle-to-plate distance and gas flow rate are constant for all experimental runs. In this work, the experiments are done by varying welding parameters in different combinations.

Table 3.1: Specifications of Wire feeder

Specifications of Wire Feeder PROMIG 530 Automotive	
Working Voltage	50V DC
Rated Power	100W
Maximum Load	60% 520 amp
	100% 440 amp
Filler wires diameter (mm)	0.6 - 2.4
Operation Principle	4 Rolls
Maximum Spool Size	15 Kg/300 mm
Dimensions (mm)	L X W X H (640 X 230 X 430)
Weight (Kg)	21

3.1. Methodology

1) Identifying the important process control variables.

2) Conducting the experiments.

3) Recording the responses viz., penetration (P), bead width (W) and height of reinforcement (R)

4) Development of mathematical models.

5) Presenting the effects of process parameters in graphical form and analysing the results.

3.2 Levels of Experimentation

In our experiments, we have three levels for each of the process parameters tabulated in table 3.2

Table 3.2 Levels of each Process Parameters

Input Parameters	Level 1	Level 2	Level 3
Wire Feed Rate (m/min)	4	5	6
Welding Speed (cm/min)	10	15	20

IV. OBSERVATIONS

Experimental runs were conducted on the 6.35 mm thick Aluminium plate by varying different wire feed rate and different speeds. The surface plates were cross-sectioned at a distance of approximately 25mm from the end of the test specimen. These specimens were ground, polished and etched with a solution of 15% sodium hydroxide (NaOH) solution. Weld bead profiles were traced and the bead dimensions viz., width (W), penetration (P) and reinforcement (R) were measured. All this is done keeping the distance between the Nozzle-to-plate is constant and equal to about 14mm at constant gas (Argon) flow rate=16 litre/min for all experimental runs.

Table4.1: Responses of Bead geometry of MIG, Pulse MIG, Double Pulse welding

Sl.no	Feed (m/min)	Speed (cm/min)	Width (mm)			Reinforcement (mm)			Penetration (mm)		
			MIG	Single pulse	Double pulse	MIG	Single pulse	Double pulse	MIG	Single pulse	Double pulse
1	4	10	7.20	7.49	6.38	4.49	3.45	3.46	1.13	1.88	1.25
2	4	15	4.57	5.67	4.28	2.64	3.35	3.26	0.56	1.52	0.97
3	4	20	4.43	4.45	4.39	2.59	2.12	2.55	0.88	1.28	0.97
4	5	10	9.67	12.15	9.76	5.67	5.07	4.14	0.99	1.71	1.22
5	5	15	7.01	8.18	5.72	3.22	2.83	3.49	1.31	1.71	1.25
6	5	20	5.47	7.27	6.45	3.26	2.86	5.38	1.28	1.49	1.14
7	6	10	6.13	13.8	9.98	3.69	5.04	4.78	1.18	1.58	0.97
8	6	15	7.97	11.03	10.91	4.09	4.22	4.36	1.69	1.57	1.84
9	6	20	8.42	9.82	9.09	4.73	4.41	3.82	1.28	1.44	1.56

V. DEVELOPMENT OF MATHEMATICAL MODELS

Mathematical models are developed by using DataFit. Three equations are developed for each of the three output parameters considered:

- Bead Width,
- Height of Reinforcement,
- Weld bead penetration.

The response function representing any of the weld bead dimensions can be expressed as:

$$y = f(f, s) \qquad \ldots \qquad (1)$$

Where,
Y is the response function i.e. Penetration, Bead width and Reinforcement
F: Wire Feed Rate, m/min S: Welding speed, cm/min

The obtained mathematical model(s), using the second order polynomial (regression) equation used to represent the response surface for two factors could be expressed as given below

$$Y = a + b \times f + c \times S + d \times f2 + e \times S \times f + f \times S2 \quad \text{.... (2)}$$

Where, a, b, c, d, e, f = regression variables

These regression variables are dependent on the observed parameters of width, depth and penetration, and also the input parameters that are mentioned above.

5.1 Estimation of coefficients of the model

The coefficients (regression variables) obtained for the three output parameters, using the Data Fit software.

5.1.1 MIG WELDING

The response function for the Bead Width using data fit software:

$$W= 3.22+6.57*f-1.86*S-0.93*f^2+0.25*S*f+1.47*S^2 \quad \text{..... (3)}$$

The response function for the Height of reinforcement is:

$$H= 11.94+1.73*f-1.74*S-0.34*f^2+0.14*S*f+2.99*S^2 \quad \text{..... (4)}$$

The response function for the Depth of Penetration is:

$$P = -1.30+0.75*f-4.13*S-7.49*f^2+0.01*S*f-2.60*S^2 \quad \text{..... (5)}$$

5.1.2 PULSE MIG WELDING

The response function for the Bead Width is:

$$W= -7.63+8.46*f-1.20*S-0.49*f^2-4.70*S*f+3.47*S^2 \quad \text{..... (6)}$$

The response function for the Height of reinforcement is:

$$H= 11.76-1.50*f-0.74*S+0.17*f^2+3.45*S*f+1.44*S^2 \quad \text{..... (7)}$$

The response function for the Depth of Penetration is:

$$P = 1.27+0.56*f-9.84*S-9.18*f^2+2.25*S*f-1.53*S^2 \quad \text{........ (8)}$$

5.1.3 DOUBLE PULSE MIG WELDING

The response function for the Bead Width is:

$$W= 12.83-0.28*f-1.32*S+0.19*f^2+5.50*S*f+2.81*S^2 \quad \text{..... (9)}$$

The response function for the Height of reinforcement is:

$$H= -11.85+7*f-0.38*S-0.63*f^2-2.49*S*f+1.26*S^2 \quad \text{..... (10)}$$

The response function for the Depth of Penetration is:

$$P = 3.42-1.023*f-1.18*S+5.68*f^2+4.43*S*f-6.60*S^2 \quad \text{..... (11)}$$

VI. RESULTS AND DISCUSSIONS

In MATLAB, non-linear regression analysis is used to develop mathematical models in this work to predict the weld bead geometry. To ensure the accuracy of the non-linear regression models to predict the weld bead depth of penetration, height of reinforcement and width, the experimental results and predicted results through non-linear regression analysis are compared. The predicted model bead geometry viz. Penetration, Height of Reinforcement and Bead width through the mathematical models and experimental values are compared in graphs below.

6.1 Scattered graphs for MIG welding:

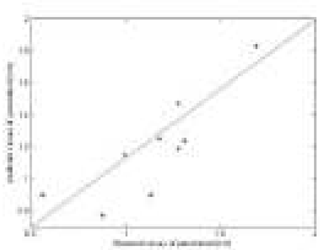


Figure6.1a. Penetration

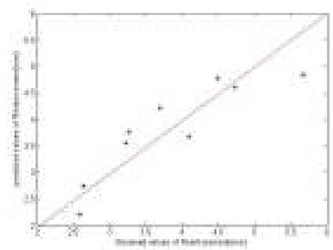


Figure6.1b Height of Reinforcement

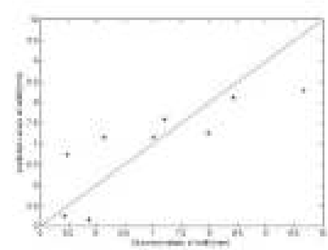


Figure 6.1.c Width

6.2 Scattered graphs for Pulse MIG welding:

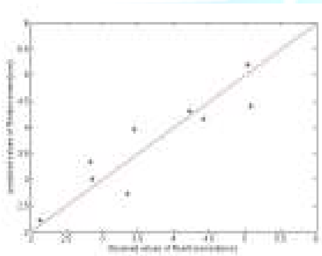


Figure6.2a. Penetration

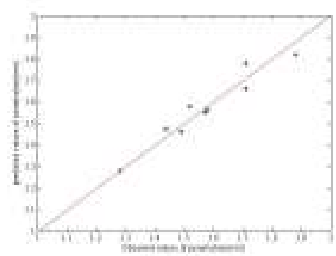


Figure6.2b Height of Reinforcement

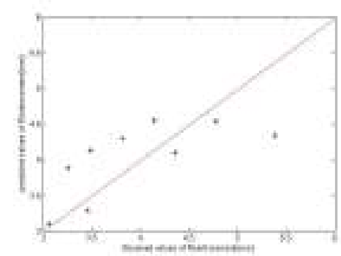


Figure 6.2c Width

6.3 Scattered graphs for Double Pulse MIG Welding:

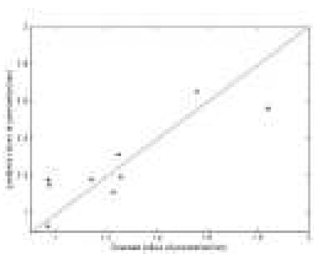


Figure6.3a. Penetration

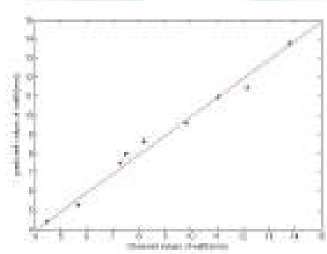


Figure6.3b Height of Reinforcement

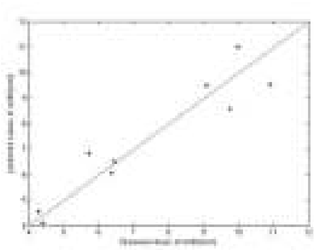


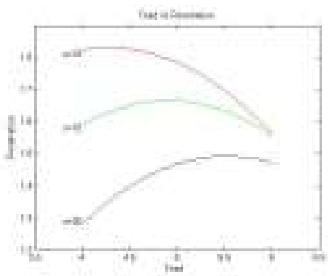
Figure 6.3c Width

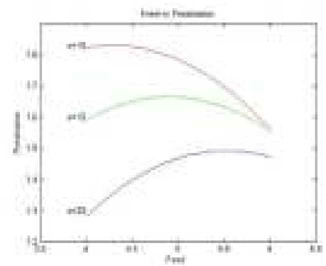
6.4 Effects of welding variables on bead geometry

Based on the mathematical models developed, the effects of welding process parameters on the bead parameters are studied. The effects of various process variables on the bead geometry are presented below.

6.4.1 Effect of process variables on depth of penetration

In MIG, Single Pulse MIG and Double Pulse MIG welding, feed rate is the first parameter to be considered for the depth of penetration. In MIG, Single Pulse MIG welding, there is a decrease in penetration with welding speed after reaching the maximum depth of penetration. But in double pulse MIG welding, depth of penetration increases with welding speed and feed. This is due to, at higher welding speeds, the weld pol becomes smaller and provides less cushioning effect and causing deeper penetration





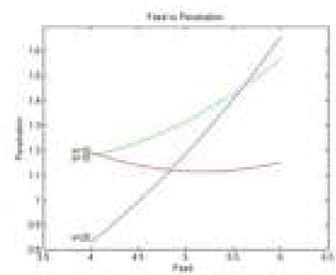
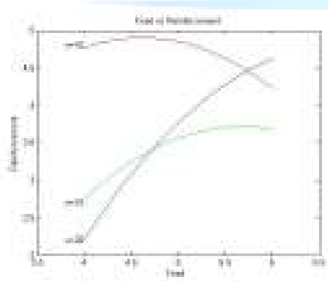
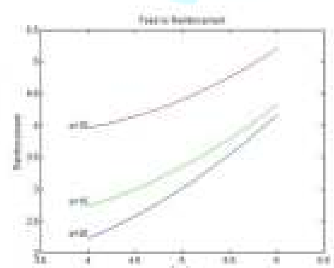


Figure6.4.1a MIG welding   Figure6.4.1b Single Pulse MIG   Figure6.4.1cDouble pulse MIG

6.4.2 Effect of process variables on Height of Reinforcement

In MIG welding, it is observed that an increase in wire feed rate results in an increase in reinforcement, whereas with an increase in welding speed, the reinforcement decreases, which may be attributed to the fact that the fusion rate of the wire is kept constant for all the values of welding speeds. But in Pulsed MIG welding, the height of reinforcement increases with feed rate and welding speeds.





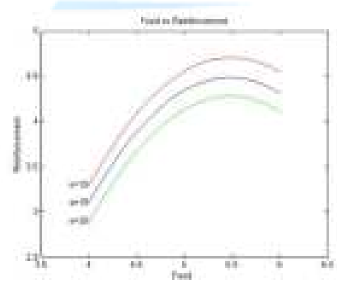


Figure6.4.2a MIG welding   Figure6.4.2b Single Pulse MIG   Figure6.4.2cDouble pulse MIG

6.4.3 Effect of process variables on Bead width

In MIG welding, it is observed that the current and welding speed have contrasting influence on width similar to reinforcement. It can be noted that the bead width increase with an increase in current. Higher deposition rate with higher fluidity of the molten wire may be attributed for this increase in bead width with current

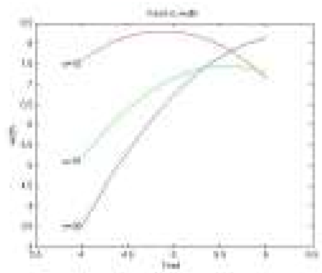


Figure6.4.3a MIG welding

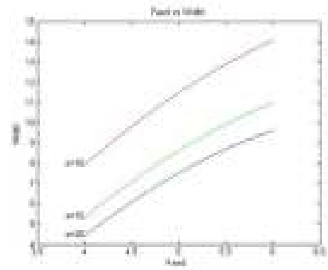


Figure6.4.3b Single Pulse MIG

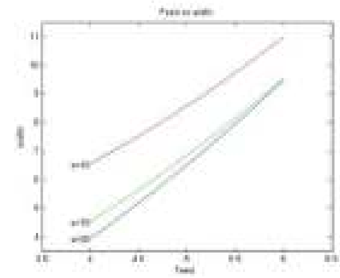


Figure6.4.3cDouble pulse MIG

VII. CONCLUSIONS

1. In the present work an attempt has been made to establish input – output relationships in the MIG, PULSE MIG and DOUBLE PULSE MIG welding process by using non-linear regression analysis.
2. The effect of process parameters on bead geometry have been studied for the three processes by using Square butt weld technique.
3. Mathematical models were developed for the effect of weld bead geometry (penetration (P), bead height (H), bead width (W)) by controlling two process variables such as wire feed rate and welding speed using multiple regression equations.
4. The values of Penetration and Width increases as wire feed rate and welding speed increases, whereas height of reinforcement decreases as wire feed rate and welding speed increases.
5. The percentage error for the penetration and height of reinforcement in pulse and double pulse MIG welding is less than 20%.
6. The percentage error for the width in pulse and double pulse MIG welding is less than 15%.

ACKNOWLEDGEMENTS

The authors would like to thank everyone, who supported me throughout my work.

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