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RESEARCH ARTICLE OPEN ACCESS

Development of Fuzzy Logic Models for the Predection of Weld Bead Geometry in Pulsed Gas Metal ARC Welding

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ABSTRACT

The quality of weld joint is influenced by process parameters during the welding process. In order to achieve high quality welds, input process parameters should be controlled. In this investigation four input process parameters such as arc rotational speed, ratio of wire feed rate to travel speed, wire feed rate and eccentricity are considered**.**The experiments were conducted on square butt joint plate of 5083 H111 aluminium alloy using full factorial design of experiments. Output parameters like bead penetration, bead height, bead width are measured. The fuzzy models for bead penetration, bead height and bead width are developed using fuzzy logic. This fuzzy model has been used for prediction of output parameters. Accuracy analysis of weld bead geometry is also performed.It is observed that % of error is less than 10% in most of the cases for bead height and width and less than 20% for bead penetration.

KEY WORDS; WELDING, 5083 H111 aluminium alloy, fuzzy logic

1. INTRODUCTION

The joining of metals is an important part of the work in many industries. Technicians make use of many different metal joining techniques in order to ensure that the finished parts will possess the required strength. Welding of steel is of particular importance to constructional engineers. Most of the metal fabrication industries have adopted welding procedures as an efficient and economical means of joining two metal pieces permanently.Gas metal arc welding (GMAW), sometimes referred to by its subtypes metal inert gas(MIG) welding or metal active gas (MAG) welding, is a welding process in which an electric arc forms between a consumable and the work piece metal(s), which heats the work piece metal(s), causing them to melt, and join. Along with the wire electrode, a shielding gas feeds through the welding gun, which shields the process from contaminants in the air. The process can be semi-automatic or automatic. A constant voltage, direct current power source is most commonly used with GMAW, but constant current systems, as well as alternating current, can be used. There are four primary methods of metal transfer in GMAW, called globular, short-circuiting, spray, and pulsed-spray, each of which has distinct properties and corresponding advantages and limitations.Originally developed for welding aluminum and other non-ferrous materials in the 1940s, GMAW was soon applied to steels because it provided faster welding time compared to other welding processes. The cost of inert gas limited its use in steels until several years later, when the use of semi-inert gases such as carbon dioxide became common. Further developments during the 1950s and 1960s gave the process more versatility and as a result, it became a highly used industrial process. Today, GMAW is the most common industrial welding process, preferred for its versatility, speed and the relative ease of adapting the process to robotic automation. Unlike welding processes that do not employ a shielding gas, such as shielded metal arc welding, it is rarely used outdoors or in other areas of air volatility. A related process, flux cored arc welding, often does not use a shielding gas, but instead employs an electrode wire that is hollow and filled with flux.

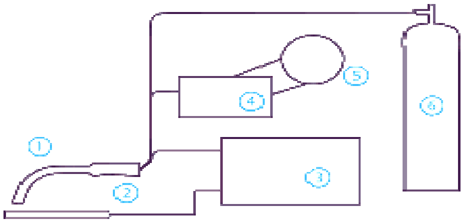

Fig.1.1 MAW Circuit diagram.

(1) Weldingtorch **(2)**Workpiece, **(3)** Powersource, **(4)** Wirefeedunit,**(5)** Electrode source, **(6)** Shielding gas supply

LITERATURE REVIEW

It has been observed that many researchers have developed mathematical models and applied soft computing techniques eg. neural networks, neuro-fuzzy approach, genetic algorithm etc. for prediction of the weld bead geometry.Chan et al. (1999) developed the artificial neural network model for prediction the weld geometry. Lee et al. (2000) presented multiple regression analysis and artificial neural network for the prediction of back-bead geometry. The input process parameters considered are arc current, welding voltage and welding speed. Kim et al. (2002) attempted an intelligent algorithm to understand relationships between process parameters and bead height, and to predict process parameters on bead height through a neural network and multiple regression methods for robotic multi-pass welding process. Kim et al. (2003) reported mathematical models for the selection of process parameters and the prediction of weld bead geometry. The input process parameters considered are arc current, welding voltage and welding speed. Lee et al. (2006) developed mathematical model of the welding control system and identified the system's parameters. The sliding surface is used as the input variable to reduce the number of fuzzy reasoning rules, in comparison with the conventional two-dimensional fuzzy logic control(FLC) algorithm. Palani et al. (2006) derived a mathematical model for the prediction of weld bead geometry and process parameters. It consists a three factor, five level factorial design for 317L flux cored stainless steel wire with IS:2062 structural steel as base plate. Carrino et al. (2007) applied neuro-fuzzy methods for increasing productivity and prediction of the weld bead geometry. This paper focuses on a study carried out in order to increase productivity in gas metal arc welding (GMAW) processes by optimizing the deposition rate of the filler metal. To reach this aim, a possible solution was found in developing an adaptive system that is able to control and keep the wire feed speed constant at a desired and optimal value. This control has been accomplished by regulating an opportune variable typical of the welding process; in this case, the attention was focused on the welding current intensity whose elements were determined by training an artificial neural network (ANN) with experimental data, obtained from bead on plate weld.

Manonmani et al. (2007) developed mathematical equations using a three factor 5- level factorial technique to predict the geometry of weld bead in butt joint of austenitic stainless steel 304 sheet of 2.5 mm thickness plate Ganjigatti et al. (2008) Studied modeling of the MIG welding process using statistical approaches. In this paper, an attempt is made to determine input-output relationships of the MIG welding process by using regression analysis based on the data collected as per full-factorial design of experiments. The effects of the welding parameters and their interaction terms on different responses have been analyzed using statistical methods. Both linear as well as nonlinear regression analyses are employed to establish the input-output relations. The results of these regression techniques are compared and some concluding remarks are made. Rao et al. (2009) developed multiple regression analysis for the prediction of weld bead geometry. The input process parameters considered are wire feed rate, plate thickness, pulse frequency, pulse current magnitude, and travel speed.

Siva et al. (2009) attempted a genetic algorithm (GA) to optimize the process parameters for achieving the desired bead geometry variables. This paper highlights the development of such mathematical equations using multiple regression analysis, correlating various process parameters to weld bead geometry in PTA hard facing and nickel-based alloy over stainless steel 316 L plates. The experiments were conducted based on a five factor, five level central composite rotatable design matrix. A genetic algorithm (GA) was developed to optimize the process parameters for achieving the desired bead geometry.

Kannan et al. (2010) presented mathematical models to predict clad bead geometry and its shape relationships of austenitic stainless steel claddings deposited by gas metal arc welding process. Acaroglu et al. (2011) applied fuzzy logic models for selection of proper tunnel boring machine and optimization of design parameters and prediction of their performance of rolling forces of disc cutters. These disc cutters are used for determination of thrust, torque and power requirement of TBMs as well as prediction of their performance. Kumar et al. (2011) developed arc rotation mechanism and developed nonlinear regression models for the prediction of weld bead geometry. The input process parameters considered are arc rotational speed, ratio of wire feed rate to travel speed, wire feed rate and eccentricity.

3.1 Experiment procedure

Figure 3.1 and Figure 3.2 represent a schematic diagram of the experimental setup and a photograph of the corresponding arc rotation mechanism systemrespectively.

Fig.3.1 Experimental Setup

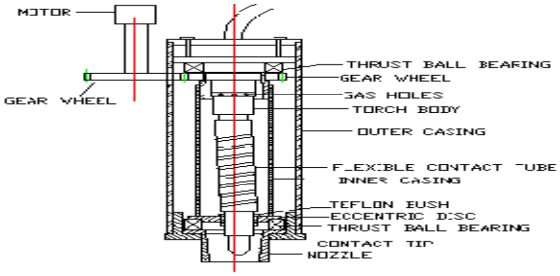

Fig.3.2 Arc rotation mechanism

Table 3.1 Chemical composition of materials Element weight%

SL NO	Materials used	Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti
1	5083 H111	0.1	0.16	0.02	0.5	4.6	0.07	0.03	0.06
2	5183	0.17	0.24	0.05	0.78	4.95	0.08	-	0 .02

Experiments are carried out using Kemppi Pro Evolution 3200 welding machine and the weld beads are deposited using pulsed GMA welding. Pure argon gas is used as shielding material and is supplied at the rate of 17 l/min. Direct current electrode positive (DCEP) with electrode to work angle and the distance between the contact tip and work piece is maintained at 90^{o} and 17 mm respectively .The work is fixed on a platform whose speed is controlled by rheostat and moves below the torch.

3.2 Input parameters

The four input process parameters considered for conducting the experiments were identified. They are arc rotational speed (N), ratio of wire feed rate to travel speed (F/S), wire feed rate (F) and eccentricity (E). A large number of trial experiments are conducted with the square butt joint plate by varying one of the process parameters while keeping remaining parameters at constant value, to find the proper range of the process parameters. The selected values of the process parameters together with their units and notations are given in Table 3.2. The experiments are conducted using full factorial design of experiment (Montgomery, D. C., 2006). As per this technique, total numbers of experiments considered for conducting the experiments are 3^4=81 as there are four input process parameters each at three levels. The levels for input process parameters were considered based on the preliminary studies conducted.

Table 3.2 Input Parameters and their limits

Input parameters	**Units**	**Notation**	**Factors levels**		
			low	**medium**	**high**
Arc Rotational speed	Rpm	N	100	500	900
Wire feed rate/travel speed		X	30	40	50
Wire feed rate	m/min	F	4	5.5	7

3.3 Measuring the dimensions of bead geometry

Fig.3.3 Weld Bead after Macro-Etchin

3.4 Dimensions of weld bead geometry

Table 3.3 Dimensions of weld bead geometry

EXP NO	**N rpm**	**X**	**F m/min**	**E Mm**	**Penetration mm**	**Height mm**	**Width mm**
1	100	30	4	2	1.01	4.24	10.5
2	500	30	4	2	0.73	3.75	11.5

3	900	30	4	2	0.67	3.5	12.34
4	100	40	4	2	1.21	4.75	11.18
5	500	40	4	2	0.85	4.53	13.11
6	900	40	4	2	0.75	4.15	13.91
7	100	50	4	2	1.51	5.51	12.75
8	500	50	4	2	1.01	4.92	14.03
9	900	50	4	2	0.85	4.81	14.93
10	100	30	5.5	2	2.91	4.05	10.52
11	500	30	5.5	2	2.22	3.95	11.69
12	900	30	5.5	2	1.41	3.84	12.81
13	100	40	5.5	2	3.16	4.85	12.02
14	500	40	5.5	2	2.5	4.8	13.73
15	900	40	5.5	2	1.88	4.54	15.06
16	100	50	5.5	2	3.93	5.63	13.41
17	500	50	5.5	2	2.78	5.38	15.04
18	900	50	5.5	2	2.35	5.2	15.59
19	100	30	7	2	5.35	4.1	13.2
20	500	30	7	2	5.89	4.02	13.06

FUZZY LOGIC METHOD

4.1.1 Fuzzy inference system

4.1.2 A Fuzzy Inference System (FIS) is a way of mapping an input space to an output space using fuzzy logic. A FIS tries to formalize the reasoning process of human language by means of fuz Mathematical concepts within fuzzy reasoning are very simple.

Fuzzy logic is flexible: it is easy to modify a FIS just by adding or deleting rules. There is no need to create a new FIS from scratch.Fuzzy logic allows imprecise data (it does NOT work with uncertainty): it handles Elements in a fuzzy set, i.e. membership values. For instance, fuzzy logic works with 'He is tall to the degree 0.8' instead of 'He is 180cm tall'.Fuzzy logic is built on top of the knowledge of experts: it relies on the know-how of the ones who understand the system.Fuzzy logic can be blended with other classic control techniques

4.2 DEVELOPMENT OF FUZZY MODEL FOR PREDICTION OF BEAD WIDTH

Procedure

1. Open fuzzy tool page on command box.
2. Four input parameters such as rotational speed (N), ratio of wire feed rate to travel speed (F/S), wire feed rate (F) and eccentricity (E) has been considered.
3. Output parameters are bead width, height and bead penetration.
4. Input parameters values are entered individually. FIS page was opened click edit and again click add variable, the four input variables individually given.
5. The same procedure is repeated for the output variable variable also.
6. Double click the first input variable give the range of the membership values and give the names of the values like as low, medium, high.
7. Same procedure for the remaining three input variables.
8. Open output variable give the range of the membership value. Membership values of output variable divided in to nine equal parts. Names of values is below low (L_1), Low (L_2), above low (L_3),below medium (M_1), Medium (M_2), abovemedium (M_3), below high (H_1), High (H_2), above high (H_3) are given.
9. Form the total 81 rules of input to output variables.
10. Click the view on view ruler page and click the rules. Open rule viewer page give the input values in left side of the input ranges automatically shows the predicted values.

Same procedure for the remaining output variables of bead height and penetration

		LOW	**MEDIUM**	**HIGH**
ROTATIONAL SPEED (N) , rpm	-	100	500	900
WIRE FEED RATE/TRAVELSPEED (X)	-	30	40	50
WIRE FEED RATE (F), m/min	-	4	5.5	7
ECCENTRICITY (E), mm	-	2	3.5	5

OUTPUT VARIABLES MEMBERSHIP FUNCTIONS

Membership functions of output variable range of bead width,Below low (L_1), Low (L_2), Above low (L_3),Below medium (M_1), Medium (M_2), Above medium (M_3), Below high (H_1), High (H_2), Above high (H_3).

Table 4.2 Output variable range of bead width

	BL (L_1)	**L** (L_2)	**AL** (L_3)	**BM** (M_1)	**M** (M_2)	**AM** (M_3)	**BH** (H_1)	**H** (H_2)	**AH** (H_3)

BEAD WIDTH (mm)	10.5 - 12	12 - 13.5	13.5 - 15	15 - 16.5	16.5 - 18	18 - 19.5	19.5 - 21	21 - 22.5	22.5 - 24

Error Analysis of Bead Width (W)

Table 4.3 Error Analysis of Bead Width (W)

EXP NO	**EXPERIMENT VALUES**	**PREDICTED VALUES**	**% OF ERRORS**
1	10.5	11.1	-9.60
2	11.5	11.1	3.60
3	12.34	12.7	-2.83
4	11.18	11.1	0.72
5	13.11	12.7	3.23
6	13.91	14.2	-2.04
7	12.75	12.7	0.39
8	14.03	14.2	-1.20
9	14.93	14.2	5.14
10	10.52	11.1	-5.23
11	11.69	11.1	5.32
12	12.81	12.7	0.87
13	12.02	12.7	-5.35
14	13.73	14.2	-3.31
15	15.06	15.8	-4.68
16	13.41	12.7	5.59

17	15.04	15.8	-4.83
18	15.59	15.8	-1.33
19	13.21	12.7	4.02
20	13.06	12.7	2.83

4.3 DEVELOPMENT OF FUZZY MODEL FOR PREDICTION OF BEAD HEIGHT

Table 4.4 Input variables of bead height

		LOW	**MEDIUM**	**HIGH**
ROTATIONAL SPEED (N) , rpm	**-**	100	500	900
WIRE FEED RATE/TRAVELSPEED (X)	**-**	30	40	50
WIRE FEED RATE (F), m/min	**-**	4	5.5	7
ECCENTRICITY (E), mm	**-**	2	3.5	5

Error Analysis of Bead Penetration (P)

Table 4.9 Error Analysis of Bead Penetration (P)

EXPNO	**EXPERIMENTVALUES**	**PREDICTEDVALUES**	**%OFERRORS**
1	1.01	1.05	-3.81
2	0.73	0.75	-2.67
3	0.67	0.75	-10.67
4	1.21	1.35	-10.37
5	0.85	0.75	13.33
6	0.75	0.75	0.00
7	1.51	1.65	-8.48
8	1.01	1.05	-3.81
9	0.85	0.75	13.33

10	2.91	3.15	-7.62
11	2.22	2.45	-9.39
12	1.41	1.35	4.44
13	3.16	3.15	0.32
14	2.5	2.45	2.04
15	1.88	1.95	-3.59
16	3.93	3.85	2.08
17	2.78	2.45	13.47
18	2.35	2.45	-4.08
19	5.35	5.25	1.90
20	3.89	3.85	1.04

RESULTS AND DISCUSSION

The fuzzy model has been developed with the experimental results for predicting the bead width, height and penetration. In this work, FIS Modeling was used to validate with experimental results for given conditions. It has been found that results generated by the designed fuzzy model are close to the experimental results with good accuracy.

1. It is observed from that Figure 5.1 % of error is less than 6%positive and less than 9% negative in bead width
2. It is observed from that Figure 5.2 scatter diagram of bead width shows the close to the experimental results with good accuracy.
3. It is observed from that Figure 5.3 % of error is less than the 7% positive and less than 8% negative in bead height.
4. It is observed from that Figure 5.4 scatter diagram of bead height shows the close to the experimental results with good accuracy.
5. It is observed from that Figure 5.5 % of error is less than 20% positive and less than 20% negative in bead penetration.
6. It is observed from that Figure 5.6 scatter diagram of bead penetration shows the close to the experimental results with good accuracy

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