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Research Paper

FUZZY MODEL PREDICTION FOR EFFECT OF WELDING SPEED ON WELD BEAD PROFILE AND DILUTION OF IS 2062 E250 A-STEEL IN MIG WELDING

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Fuzzy logic technique contains a potential to give a simplified control of various engineering and non-engineering applications. The rule-based character of fuzzy models allows for a model interpretation in a way that is similar to the one humans use to describe reality. Conventional methods for statistical validation based on numerical data can be complemented by the human expertise that often involves heuristic knowledge and intuition. In the present work the modelling of the effect of weld speed on the weld bead profile i.e. on depth of penetration, weld bead width, reinforcement height, the effect of weld speed on the weld bead dilution i.e. penetration area and reinforcement area has been done using Fuzzy Inference System (FIS). In this experiment the MIG butt welds of IS 2062 E250 mild steel plates to be welded using CO2 as shielding gas. Welding speed is select as process variable while arc voltage, welding current, wire feed rate distance between the nozzle and the plates are fixed in this experiment.

Keywords: Adaptive Fuzzy Inference System (ANFIS), Clustering, Sugeno Fuzzy Inference, Mig-Welding, Weld Bead

INTRODUCTION

Modeling and control techniques based on fuzzy sets attempt to combine numerical and symbolic processing into one framework. On the one hand, fuzzy systems are knowledge-based systems consisting of linguistic if then rules that can be constructed using the knowledge of experts in the given field of interest. On the other hand, fuzzy systems are also universal approximations that can realize nonlinear mappings. This duality allows qualitative knowledge to be combined with quantitative data in a complementary way. Compared to other nonlinear approximation techniques, fuzzy systems provide a more transparent representation of the nonlinear system under study, and can also be given a linguistic interpretation in the form of rules. In this way, process data can be translated in a model and analyzed in a manner

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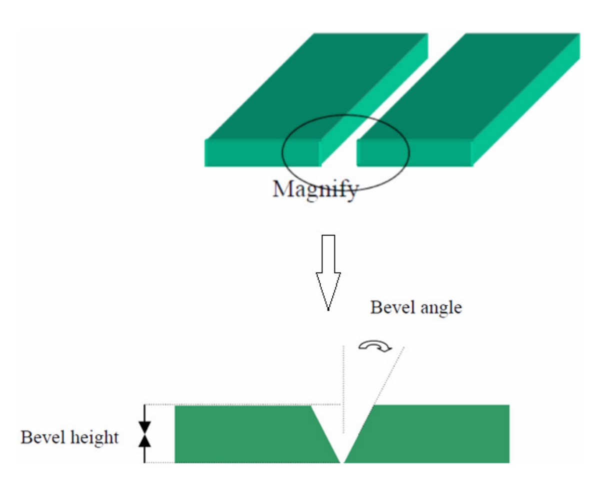
very similar to what people are acquainted with. The rules extracted from data can be validated by experts, and combined with their prior knowledge to obtain a complete system model describing the reality over the entire domain of interest. GAS METAL ARC welding (GMAW) is a process that melts and joins metals by heating them with an arc established between a continuously fed filler wire electrode and the metals. The process is used with shielding from an externally supplied gas and without the application of pressure. In the 1920's, the basic concept of GMAW was introduced. However, it was not commercially available until 1948. At first it was considered to be, fundamentally, a high-current density, small diameter, bare metal electrode process using an inert gas for arc shielding. The primary application of this process was for welding aluminum. As a result, the term MIG (Metal Inert Gas) was used and is still a common reference for the process. Subsequent process developments included operation at low-current densities and pulsed direct current, application to a broader range of materials, and the use of reactive gases (particularly CO2) and gas mixtures. This latter development has led to formal acceptance of the term gas metal arc welding (GMAW) for the process because both inert and reactive gases are used. There are two operation modes of GMAW, which are semiautomatic and modes. All commercially important metals such as carbon steel, high-strength low alloy steel, stainless steel, aluminum, copper, titanium and nickel alloys can be welded in all positions with this process choosing the appropriate shielding gas, electrode, joint design and welding variables.

EXPERIMENTAL PROCEDURE

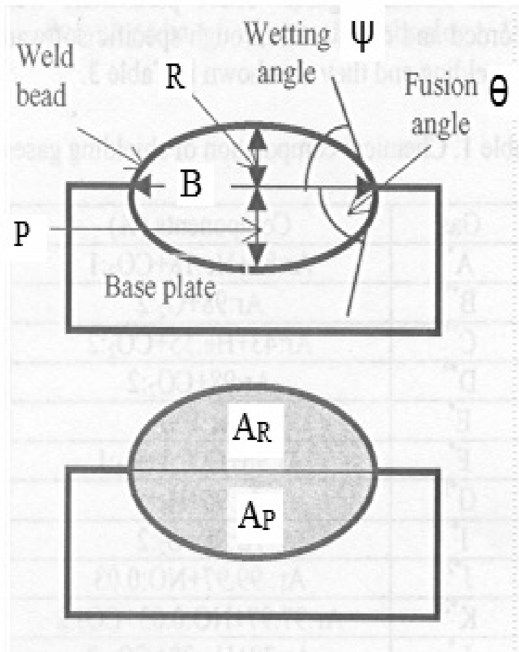
Mild steel plates (IS2062 E 250A) with the dimensions of 5x40x70 are prepared with the bevel angle of 30° as shown in Figure 1. After proper preparation; plates are placed on the workbench. In each placement, distance between the nozzle and work piece and the electrode extension were 19 and 10 millimeters, respectively. The orientation of the welding electrode with respect to the weld joint was 55°-60° After checking the Pressure of shielding gas cylinder, which was set to 50kg/cm^2 and 4 kg/cm^2, welding was started. Both plates were welded at single pass.

Figure 1: Mild Steel Specimen With Single v Groove



Visual inspection is done not only to see the surface of the weld but also get any clues about what is underneath the surface of the weld. Typical weld defects such as spatter "metal particles left after welding, which do not form part of the weld" and undercut "an irregular groove at a toe of a run in the base metal" (C Wu *et al*., 2004) can be inspected by this technique. In order to understand the interrelationship between process variable weld speed m/min and weld bead profile other parameters are kept constant. CYBER SHOT SONY 7.5 M PIX. Digital camera and image analysis software were used to accurately measure the weld bead profile Figure 2 defines the weld bead profile studied. The weld profile, including bead width (B) and reinforcement height (R) and penetration (P).

Figure 2: Schematic Diagrams for Weld Bead Profile



R: Reinforcement height

P: Penetration

B: Width

A_P: Penetration area

A_R: Reinforcement area

Dilution% = AP / (A_P + A_R) x 100

The visual appearances and image analysis of these five specimens, are shown at Figures 3-12, respectively.

Figure 3: Image Analysis of the Specimen No.1 at Weld Speed of 169.76mm/min

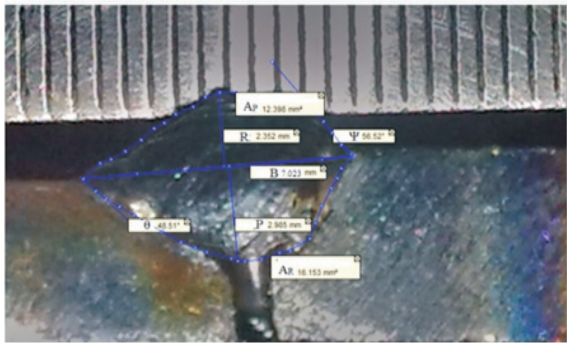


Figure 4: Visual Appearance of the Specimen No.1 at Weld Speed of 169.76mm/min

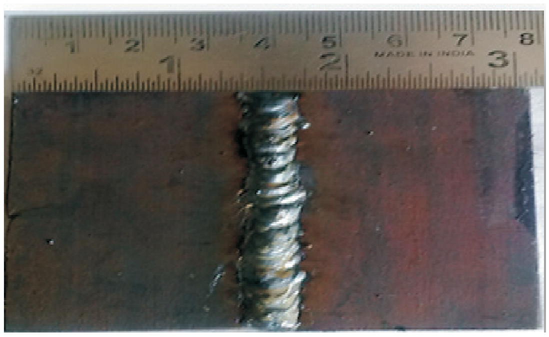


Figure 5: Image Analysis of the Specimen No. 2 at Weld Speed of 140.00mm/min

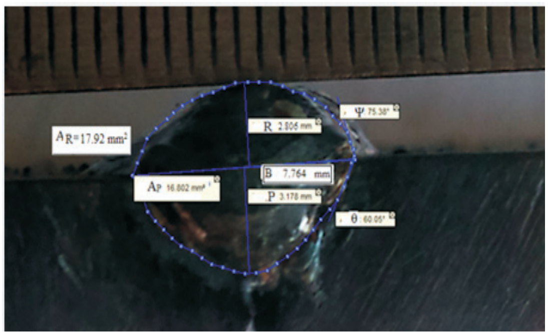


Figure 6: Visual Appearance of the Specimen no. 2 at Weld Speed of 140.00mm/min

Figure 7: Image Analysis of the Specimen No.3 at Weld Speed of 131.25 mm/min

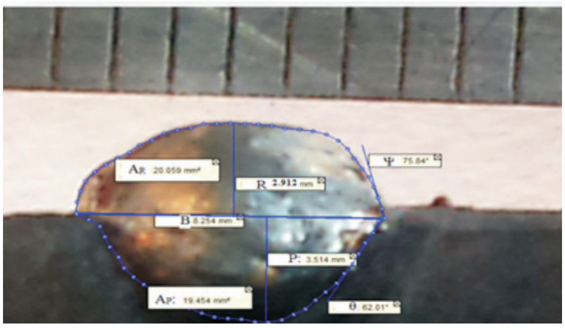


Figure 8: Visual Appearance of the Specimen No. 3 at Weld Speed of 131.25mm/mi

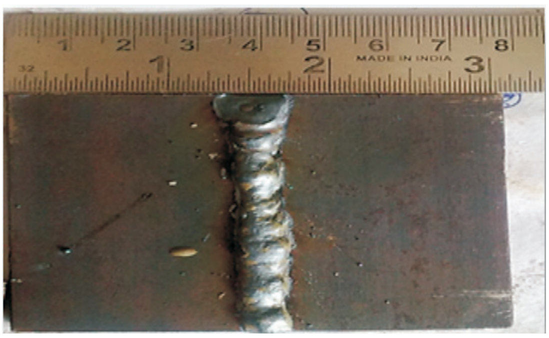


Figure 9: Image Analysis of the Specimen No. 4 at Weld Speed of 106.22 mm/min

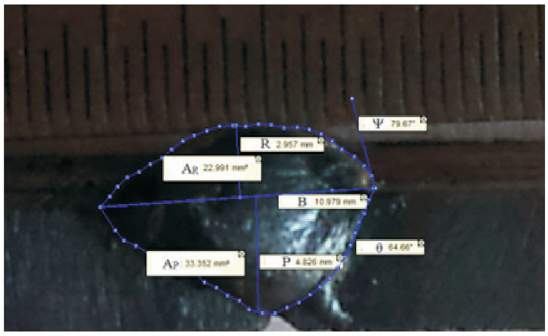


Figure 10: Image Analysis of the Specimen No. 4 at Weld Speed of 106.22 mm/min

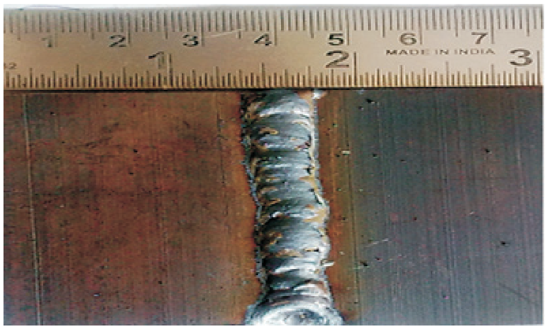


Figure 11: Image Analysis of the Specimen No. 5 at Weld Speed of 94.83 mm/mi

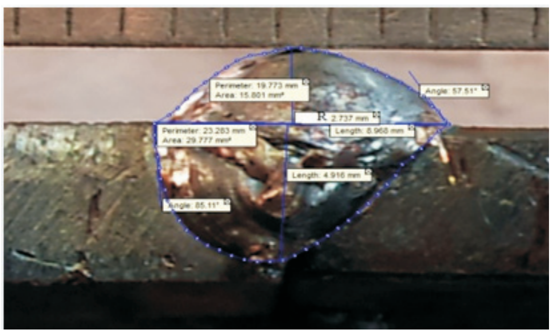


Figure 12: Visual Appearance of the Specimen No.5 at Weld Speed of 94.83 mm/min

IDENTIFICATION OF INPUT AND OUTPUT VARIABLES

The Sugeno fuzzy model of for Weld Bead Profile for various parameters has been made by considering the input parameters as Arc Time and Weld Speed and output as the Depth of Penetration.

Input Parameter

Arc-Time: 24.74 Sec to 44.30 Sec

Weld-Speed: 94.83mm/min to 169.76mm/min.

Output Parameter

Depth of Penetration: 2.985 mm to 4.916 mm.

Membership Functions for Input and Output Variables

Figure 13: Input Membership Function Arc Time (t)

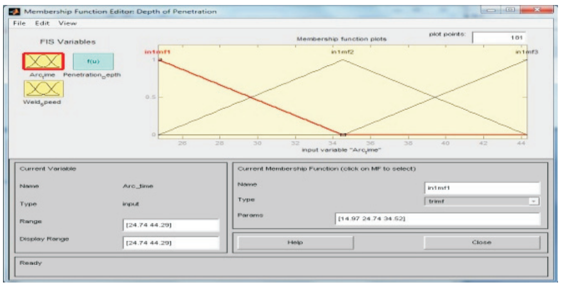


Figure 14: Input Membership Function Weld Speed (S)

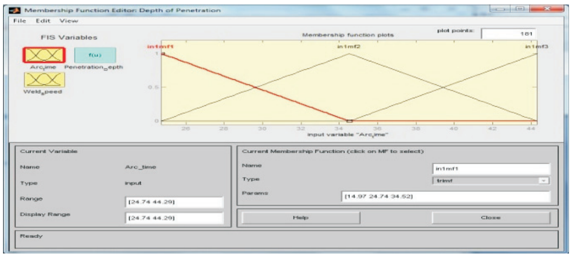
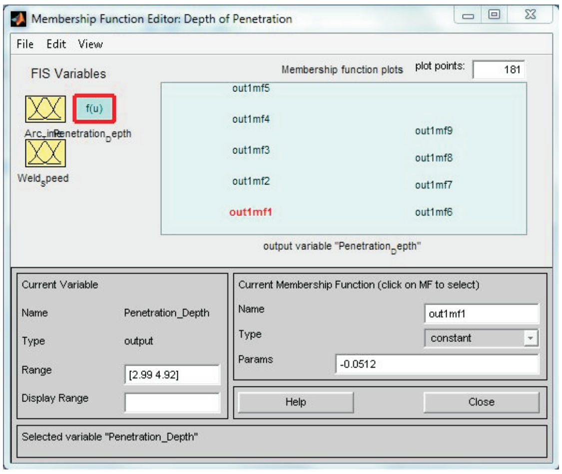


Figure 15: Output Membership Function Depth of Penetration



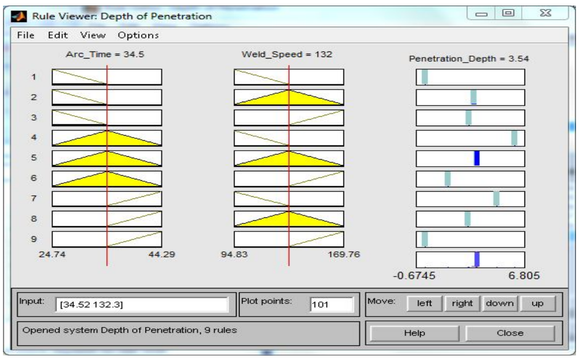
Fuzzy Rules Employed for Effect of Weld Speed on Depth of Penetration

The set of fuzzy rules applied to develop the fuzzy model are given follow:

1. If (Arc_Time is in1mf1) and (Weld_Speed is in2mf1) then (Penetration_Depth is out1mf1)
2. If (Arc_Time is in1mf1) and (Weld_Speed is in2mf2) then (Penetration_Depth is out1mf2)
3. If (Arc_Time is in1mf1) and (Weld_Speed is in2mf3) then (Penetration_Depth is out1mf3)

4. If (Arc_Time is in1mf2) and (Weld_Speed is in2mf1) then (Penetration_Depth is out1mf4)
5. If (Arc_Time is in1mf2) and (Weld_Speed is in2mf2) then (Penetration_Depth is out1mf5)
6. If (Arc_Time is in1mf2) and (Weld_Speed is in2mf3) then (Penetration_Depth is out1mf6)
7. If (Arc_Time is in1mf3) and (Weld_Speed is in2mf1) then (Penetration_Depth is out1mf7)
8. If (Arc_Time is in1mf3) and (Weld_Speed is in2mf2) then (Penetration_Depth is out1mf8)
9. If (Arc_Time is in1mf3) and (Weld_Speed is in2mf3) then (Penetration_Depth is out1mf9)

Figure 16: Rule Viewers Penetration Depth Fuzzy Model

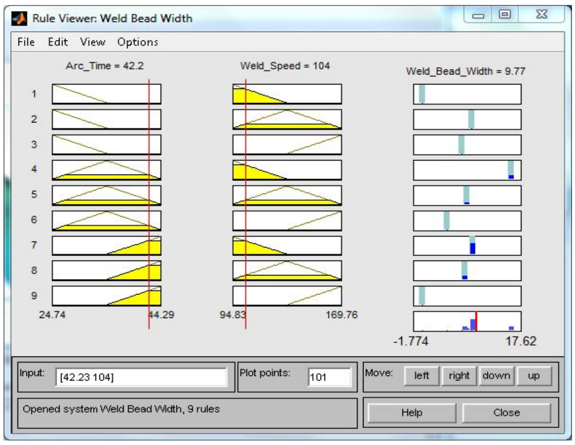


Fuzzy Rules Employed for Effect of Weld Speed on Weld Bead Width

The set of fuzzy rules applied to develop the fuzzy model are given follow:

1. If (Arc_Time is in1mf1) and (Weld_Speed is in2mf1) then (Weld_Bead_Width is out1mf1)
2. If (Arc_Time is in1mf1) and (Weld_Speed is in2mf2) then (Weld_Bead_Width is out1mf2)
3. If (Arc_Time is in1mf1) and (Weld_Speed is in2mf3) then (Weld_Bead_Width is out1mf3)
4. If (Arc_Time is in1mf2) and (Weld_Speed is in2mf1) then (Weld_Bead_Width is out1mf4)
5. If (Arc_Time is in1mf2) and (Weld_Speed is in2mf2) then (Weld_Bead_Width is out1mf5)
6. If (Arc_Time is in1mf2) and (Weld_Speed is in2mf3) then (Weld_Bead_Width is out1mf6)
7. If (Arc_Time is in1mf3) and (Weld_Speed is in2mf1) then (Weld_Bead_Width is out1mf7)
8. If (Arc_Time is in1mf3) and (Weld_Speed is in2mf2) then (Weld_Bead_Width is out1mf8)
9. If (Arc_Time is in1mf3) and (Weld_Speed is in2mf3) then (Weld_Bead_Width is out1mf9)

Figure 17: Rule Viewers Weld Bead Width Fuzzy Model



Fuzzy Rules Employed for Effect of Weld Speed on Height of Reinforcement.

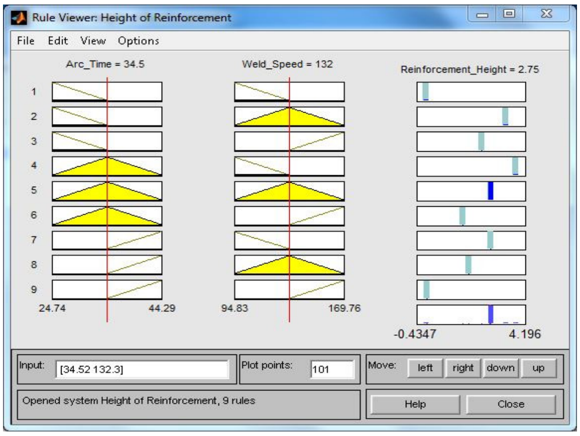
The set of fuzzy rules applied to develop the fuzzy model are given follow:

1. If (Arc_Time is in1mf1) and (Weld_Speed is in2mf1) then (Reinforcement_Height is out1mf1)
2. If (Arc_Time is in1mf1) and (Weld_Speed is in2mf2) then (Reinforcement_Height is out1mf2)
3. If (Arc_Time is in1mf1) and (Weld_Speed is in2mf3) then (Reinforcement_Height is out1mf3)
4. If (Arc_Time is in1mf2) and (Weld_Speed is in2mf1) then (Reinforcement_Height is out1mf4)
5. If (Arc_Time is in1mf2) and (Weld_Speed is in2mf2) then (Reinforcement_Height is out1mf5)
6. If (Arc_Time is in1mf2) and (Weld_Speed is in2mf3) then (Reinforcement_Height is out1mf6)
7. If (Arc_Time is in1mf3) and (Weld_Speed is in2mf1) then (Reinforcement_Height is out1mf7)
8. If (Arc_Time is in1mf3) and (Weld_Speed is in2mf2) then (Reinforcement_Height is out1mf8)
9. If (Arc_Time is in1mf3) and (Weld_Speed is in2mf3) then (Reinforcement_Height is out1mf9)

Fuzzy Rules Employed for Effect of Weld Speed on Penetration Area

The set of fuzzy rules applied to develop the fuzzy model are given follow:

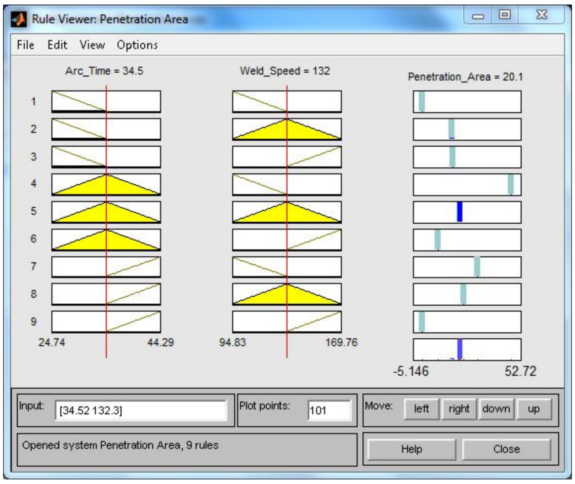
Figure 18: Rule Viewers for Height of Reinforcement Fuzzy Model



1. If (Arc_Time is in1mf1) and (Weld_Speed is in2mf1) then (Penetration_Area is out1mf1)
2. If (Arc_Time is in1mf1) and (Weld_Speed is in2mf2) then (Penetration_Area is out1mf2)
3. If (Arc_Time is in1mf1) and (Weld_Speed is in2mf3) then (Penetration_Area is out1mf3)
4. If (Arc_Time is in1mf2) and (Weld_Speed is in2mf1) then (Penetration_Area is out1mf4)
5. If (Arc_Time is in1mf2) and (Weld_Speed is in2mf2) then (Penetration_Area is out1mf5)
6. If (Arc_Time is in1mf2) and (Weld_Speed is in2mf3) then (Penetration_Area is out1mf6)
7. If (Arc_Time is in1mf3) and (Weld_Speed is in2mf1) then (Penetration_Area is out1mf7)
8. If (Arc_Time is in1mf3) and (Weld_Speed is in2mf2) then (Penetration_Area is out1mf8)

9. If (Arc_Time is in1mf3) and (Weld_Speed is in2mf3) then (Penetration_Area is out1mf9)

Figure 19: Rule Viewers for Penetration Area Fuzzy Model

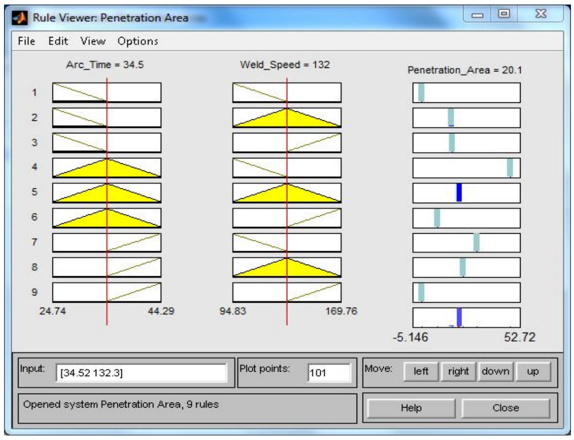


Fuzzy Rules Employed for Effect of Weld Speed on Reinforcement Area

The set of fuzzy rules applied to develop the fuzzy model are given follow:

1. If (Arc_Time is in1mf1) and (Weld_Speed is in2mf1) then (Reinforcement_Area is out1mf1)
2. If (Arc_Time is in1mf1) and (Weld_Speed is in2mf2) then (Reinforcement_Area is out1mf2)
3. If (Arc_Time is in1mf1) and (Weld_Speed is in2mf3) then (Reinforcement_Area is out1mf3)
4. If (Arc_Time is in1mf2) and (Weld_Speed is in2mf1) then (Reinforcement_Area is out1mf4)
5. If (Arc_Time is in1mf2) and (Weld_Speed is in2mf2) then (Reinforcement_Area is out1mf5)
6. If (Arc_Time is in1mf2) and (Weld_Speed is in2mf3) then (Reinforcement_Area is out1mf6)
7. If (Arc_Time is in1mf3) and (Weld_Speed is in2mf1) then (Reinforcement_Area is out1mf7)
8. If (Arc_Time is in1mf3) and (Weld_Speed is in2mf2) then (Reinforcement_Area is out1mf8)
9. If (Arc_Time is in1mf3) and (Weld_Speed is in2mf3) then (Reinforcement_Area is out1

Figure 20: Rule Viewers for Penetration Area Fuzzy Model



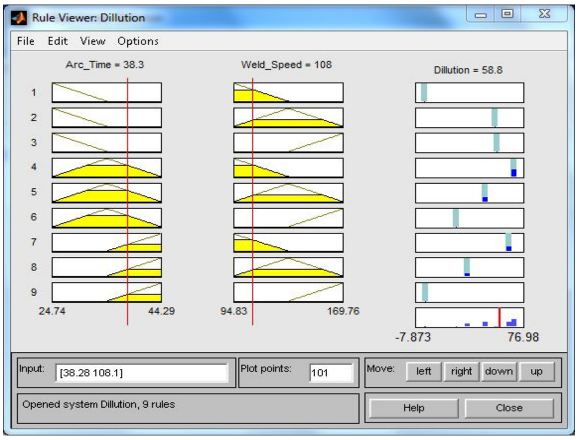
Fuzzy Rules Employed for Effect of Weld Speed on Reinforcement Area

The set of fuzzy rules applied to develop the fuzzy model are given follow:

1. If (Arc_Time is in1mf1) and (Weld_Speed is in2mf1) then (Dillution is out1mf1)
2. If (Arc_Time is in1mf1) and (Weld_Speed is in2mf2) then (Dillution is out1mf2)
3. If (Arc_Time is in1mf1) and (Weld_Speed is in2mf3) then (Dillution is out1mf3)
4. If (Arc_Time is in1mf2) and (Weld_Speed is in2mf1) then (Dillution is out1mf4)

5. If (Arc_Time is in1mf2) and (Weld_Speed is in2mf2) then (Dillution is out1mf5)
6. If (Arc_Time is in1mf2) and (Weld_Speed is in2mf3) then (Dillution is out1mf6)
7. If (Arc_Time is in1mf3) and (Weld_Speed is in2mf1) then (Dillution is out1mf7)
8. If (Arc_Time is in1mf3) and (Weld_Speed is in2mf2) then (Dillution is out1mf8)
9. If (Arc_Time is in1mf3) and (Weld_Speed is in2mf3) then (Dillution is out1mf9)

Figure 21: Rule Viewers for Dilution Percentage Fuzzy Model



Influence of Weld Speed on Depth of Penetration

This study is based on the weld bead profile measurement and Dilution% of the MIG butt welds with varying welding speed, and by keeping the other welding parameters constant. IS2062 E 250 A .Mild steel plates were examined with the different welding speeds in this study. The total Five IS 2062 E250A specimens were visually examined on image analysis software in order to measure the weld bead profile which includes the measurement of reinforcement height (R), weld width (B), penetration (P). Heat input (Q) was calculated according to the equation (1) below. As can be seen from the Table 4.1, voltage value i.e. 20V falls between ranges of 14 to 22 volts. Hence, short circuiting transfer mechanism preserved during the experiment- (1)

$$Q = \frac{\{\text{Ampere (A)} * \text{Voltage (V)}\}}{\text{Travel Speed cm/sec)}} \qquad ...(1)$$

Table 1: Presents the Experimental Results of Dependency of Different Parameters on Arc Time and Weld Speed with Fuzzy Logic Results.(1)

Input Variables			Depth of Penetration			Weld Bead Width			Height of Reinforment		
S.No.	Arc time (sec)	Weld speed (min/min)	(P) exp. mm	P Fuzzy	% Deviation	(B) exp. mm	(B) mm Fuzzy	% Deviation	HOR(R) exp. (mm)	R. Fuzzy	% Deviation
1	24.74	169.76	2.985	2.99	0.16750419	7.023	7	0.32749537	2.352	2.38	1.19047619
2	30	140	3.178	3.18	0.06293266	7.76	7.75	0.12886598	2.806	2.85	1.568068425
3	32	131.25	3.514	3.51	0.11383039	8.254	8.25	0.04846135	2.912	2.91	0.068681319
4	39.54	106.22	4.826	4.84	0.29009532	10.979	11	0.19127425	2.957	2.96	0.101454177
5	44.29	94.83	4.916	4.92	0.08136697	8.968	8.97	0.02230152	2.737	2.74	0.109609061

Table 2: Presents the Experimental Results of Dependency of Different Parameters on Arc Time and Weld Speed with Fuzzy Logic Results

Input Variables			Penetration Area			Reinforment Area			Dilution %		
S.No.	Arc time (sec)	Weld speed (min/min)	(P) exp. mm²	Pa mm² Fuzzy	% Deviation	(Ar) exp. mm²	(A)r mm² Fuzzy	% Deviation	Ap/(Ap+Ag) x100 exp.	Ap/(Ap+Ag) x100 Fuzzy	% Deviation
1	24.74	169.76	16.153	16.1	0.32811242	12.39	12.4	0.08071025	56.57	56.6	0.053031642
2	30	140	16.802	16.8	0.01190334	17.92	17.9	0.11160714	48.39	48.3	0.185988841
3	32	131.25	19.45	19.4	0.25706941	20.05	20	0.24937656	49.22	49.3	0.162535555
4	39.54	106.22	33.352	33.4	0.14391941	22.99	23	0.04349717	59.19	59.3	0.185842203
5	44.29	94.83	29.77	29.9	0.43668122	15.8	16	1.26582278	65.32	65.4	0.122473974

It has already been finalized that there are 9 rules to predict the Depth of Penetration depending upon the input parameters; on Arc Time and Weld Speed, for MISO fuzzy model. These rules were implemented in MATLAB environment using Sugeno -type of fuzzy inference system in fuzzy logic toolbox. Control surface given in Figure 22 shows the inter dependency Depth of Penetration depending upon the input parameters; on Arc Time and Weld Speed. Table 1 presents the experimental results and results with fuzzy logic In order to see the effect of weld speed on depth of penetration (P) at, arc voltage of 20 V welding current of 110 amps, CTWD of 19 mm and wire speed of 5.198 m/min, All five specimens with welding speed of 169.76 mm/min, 140.00 mm/min, 131.25 mm/min 106.22 mm/min and 94.83 mm/min were compared. The Table 1 tabulates the five depths of penetration (P) values at each weld speed values and Figure 23 shows the graphical representation of them.

Figure 22: Control Surface of Fuzzy Model Showing Inter Dependency Depth of Penetration on Arc Time and Weld Speed

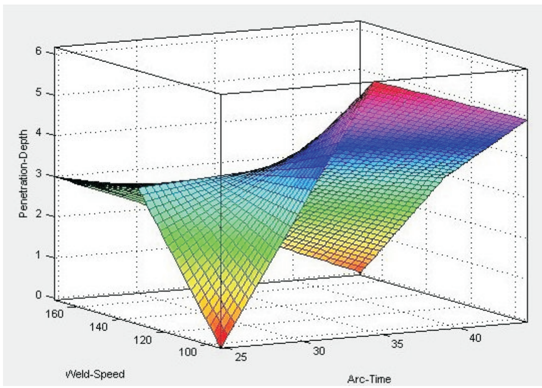


Figure 23: Depth of Penetration vs Weld Speed

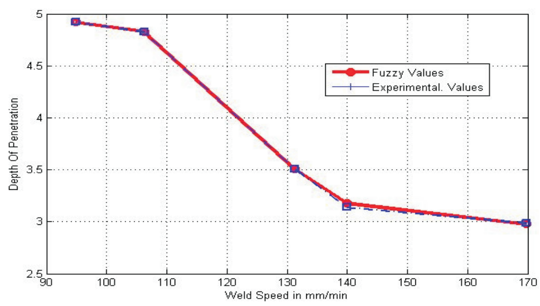


Figure 22 gives the influence of Weld speed on Depth of Penetration using developed fuzzy model and experimental model for Mig welding.As the weld speed during welding decreases the depth of penetration increases in the specimen. For example weld speed of 169.76 mm/min ,depth of penetration is 2.99 mm and for weld speed 94.83 mm/min the depth of penetration is 4.92 is A comparison was made between the predicted values acquired from the Fuzzy model and performed experimental values.

Influence of Weld Speed on Weld Bead Width

Figure 24 shows the inter dependency Weld Bead Width depending upon the input parameters; on Arc Time and Weld Speed.

Figure 24: Control Surface of Fuzzy Model Showing Inter Dependency Weld Bead Width on Arc Time and Weld Speed

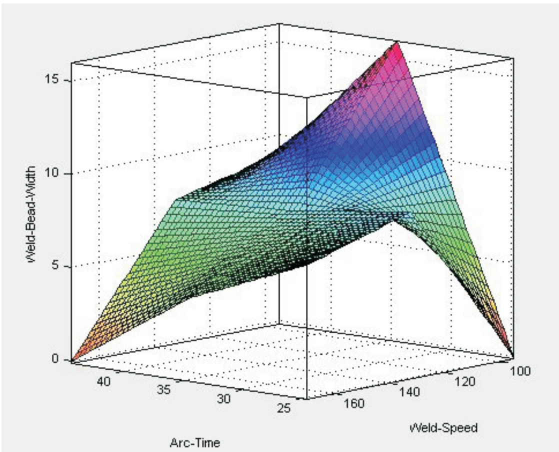
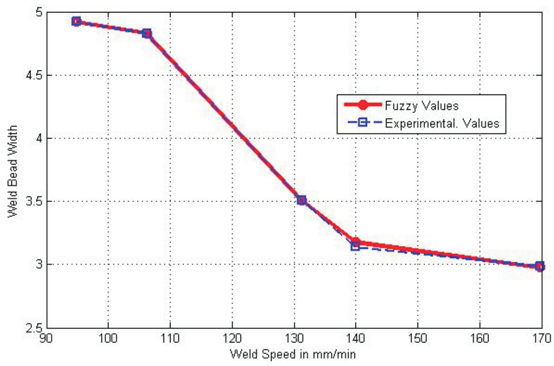


Figure 25 gives the influence of Weld speed on Weld Bead Width using developed fuzzy model and experimental model for Mig-welding. As the weld speed during welding decreases the Weld Bead width increases in the specimen. For example weld speed of 169.76 mm/min, Weld Bead width is 7.023 mm and for weld speed 94.83 mm/min the Weld Bead width is 8.968 mm. A comparison was made between the predicted values acquired from the Fuzzy model and performed experimental values.

Figure 25: Weld Bead Width vs Weld Speed



Influence of Weld Speed on Height of Reinforcement.

Figure 26 shows the inter dependency of height of reinforcement depending upon the input parameters; on arc time and weld speed.

Figure 26: Control Surface of Fuzzy Model Showing Inter Dependency of Height of Reinforcement on Arc Time and Weld Speed

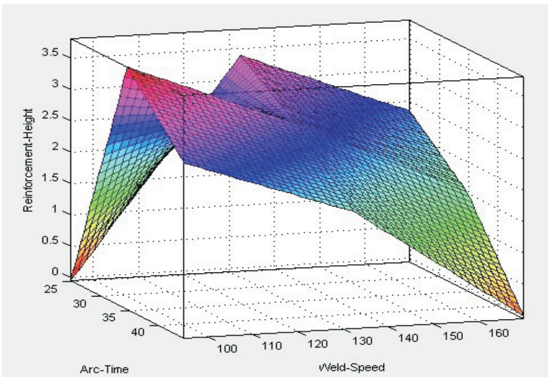
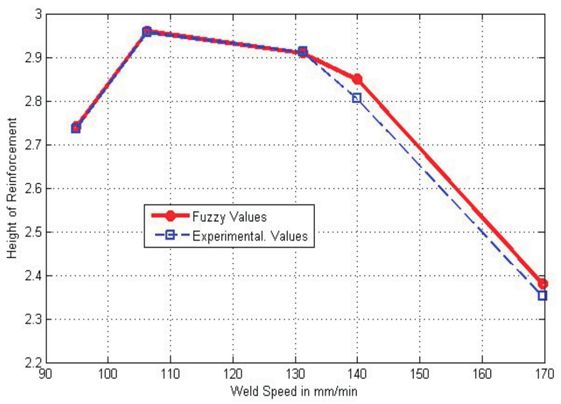


Figure 27 gives the influence of Weld speed on Height of Reinforcement using developed fuzzy model and experimental model for Mig-welding. As the weld speed during welding decreases the Height of Reinforcement decreases in the specimen. For example weld speed of 169.76 mm/min, Height of Reinforcement is 2.35 mm and for weld speed 94.83 mm/min the Height of Reinforcement is 2.73 mm. A comparison was made between the predicted values acquired from the Fuzzy model and performed experimental values.

Figure 27: Height of Reinforcement vs Weld Speed



Influence of Weld Speed on Penetration Area (Pa)

Figure 28: Control Surface of Fuzzy Model Showing Inter Dependency Penetration Area on Arc Time and Weld Speed

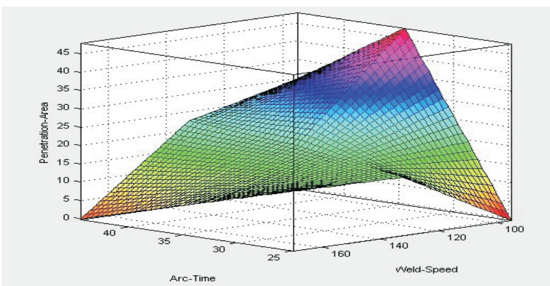
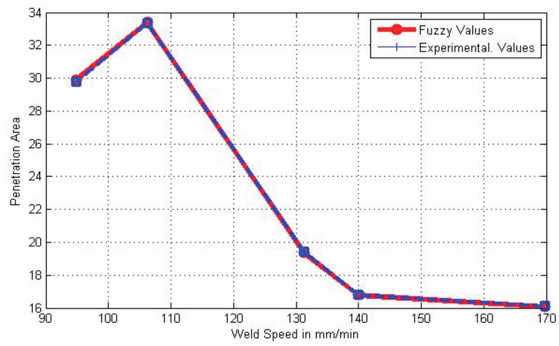


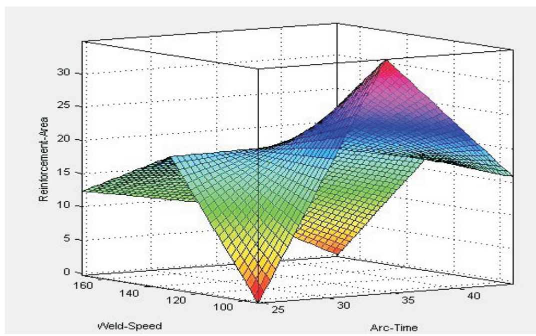
Figure 28 gives the influence of Weld speed on Penetration Area using developed fuzzy model and experimental model for MIG - welding. As the weld speed during welding decreases the Penetration Area decreases in the specimen. For example weld speed of 169.76 mm/min Penetration Area is 16.153 mm2 and for weld speed 94.83 mm/min the Penetration Area is 29.77mm2. A comparison was made between the predicted values acquired from the Fuzzy model and performed experimental values.

Figure 29: Penetration Area vs. Weld Speed



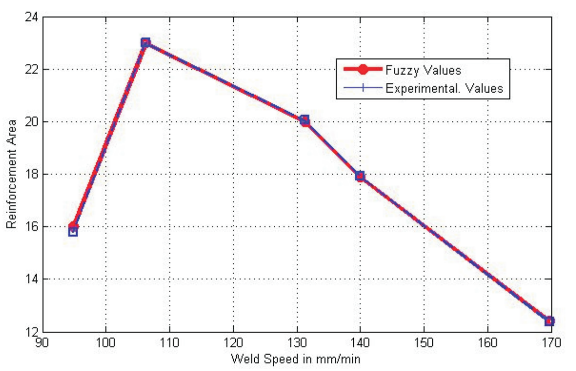
Influence of Weld Speed on Reinforcement area (Ar)

Figure 30: Control Surface of Fuzzy Model Showing Inter Dependency of Reinforcement Area on Arc Time and Weld Speed



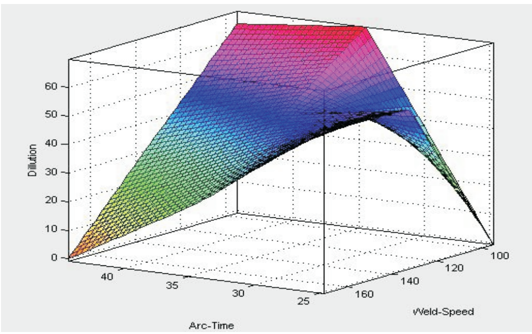
Figures 30 and 31 gives the influence of Weld speed on Reinforcement Area using developed fuzzy model and experimental model for MIG -welding. As the weld speed during welding decreases the Reinforcement Area decreases in the specimen. For example weld speed of 169.76 mm/min Reinforcement Area is 12.4 mm2 and for weld speed 106.22 mm/min Reinforcement Area is 22.99 mm2. A comparison was made between the predicted values acquired from the Fuzzy model and performed experimental values.

Figure 31: Reinforcement Area vs. Weld Speed



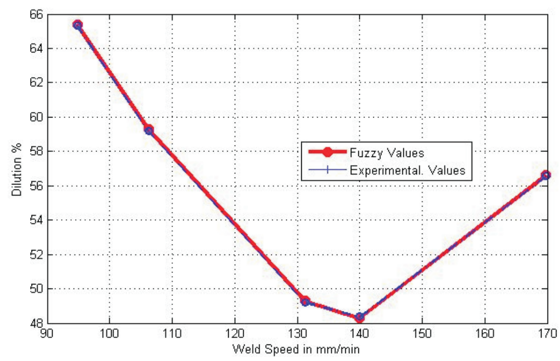
Influence of Weld Speed on Dilution%.

Figure 32: Control Surfaces of Fuzzy Model Showing Inter Dependency of Dilution %. on Arc Time and Weld Speed



Figures 32 and 33 gives the influence of Weld speed on Dilution %using developed fuzzy model and experimental model for MIG - welding. As the weld speed during welding decreases the Dilution % decreases in the specimen. For example weld speed of 169.76 mm/min Dilution % is 56.6 % and for weld speed 94.83 mm/min the Dilution % is 65.4 Dilution % . A comparison was made between the predicted values acquired from the Fuzzy model and performed experimental values.

Figure 33: Dilution % vs. Weld Speed



CONCLUSION AND SCOPE FOR FUTURE WORK

Conclusion

This paper has set out to apply the fuzzy logic to predict the Effect of Welding Speed on Weld Bead Profile and Dilution of IS 2062 E250 A-steel in MIG Welding

In this paper, SUGENO fuzzy model is developed using FIS and validated with experimental results for given conditions. It has been found that results generated by the designed fuzzy model are very close to the experimental results with 98% accuracy.

After investigating the significance of developed model, it has been observed that the probability of the model to predict accurate results is 98%. With this much accuracy, model can be used by the practicing engineer who would like to get quick answers for on-line intelligent control and/or optimization.

Fuzzy logic system was found to be very flexible and easy to comprehend and hence can act as an alternative to the conventional modeling techniques.

Present work supports that fuzzy logic technique can be introduced as a viable alternative to carry out analysis without conducting actual experiments. Fuzzy logic allowed the modeling and on-line control problem to be treated simultaneously.

Future Scope

In the present work six separate fuzzy models are presented .In future there is possibility to go for MIG-Welding model in fuzzy modeling. In present work we presented SUGENO fuzzy model to predict the Effect of Welding Speed on Weld Bead Profile and Dilution of IS 2062 E250 A-steel in MIG Welding , in future there is possibility to go for Adaptive Neuro-Fuzzy Inference Systems (ANFIS) approach for same presented model. Present work has been concentrated to develop Multi Input Single Output (SIMO) fuzzy model, but there is scope to go for Multi Input Multi Output (MIMO) model

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