

Use of Orthogonal Arrays in Design of a Fuzzy Logic Controller to Predict the Proof Stress for the TIG Welded Al-65032



K. Ankamma, P.V.R. Ravindra Reddy

Abstract: Fuzzy logic controller (FLC) is well suited where there is a considerable amount of uncertainty in the process. The material properties of a weldment in TIG welding depend on welding parameters like shielding gas pressure, current, torch angle, Electrode size, electrode projection, arc length etc. It is also influenced by the joint parameters like groove angle, land, root gap, preheating temperature. But a lot of noise parameters like variation of base material properties, variation in quality of inert gas used, variation in ambient conditions, variation in workmanship etc introduce uncertainties in the process. To deal with such uncertainties an FLC is designed and validated. In the current work, four parameters namely inert gas pressure, current, groove angle of the joint and preheating temperature of base metal are considered as input variables and the influence of these variables on the 0.2% proof stress is studied. Three linguistic terms are used for each parameter. To minimise the number of experiments in designing data base an L-9 orthogonal array is chosen for experimentation. TIG welding is carried and data base with 9 rules are formulated. For the input and out variables Triangular membership function is selected and FLC is designed. The FLC is validated with 5 more experiments. Mamdani approach is used to develop the Fuzzy controller.

Keywords: Index terms: Orthogonal array, Fuzzy logic controller, TIG welding, Triangular function, Mamdani approach, crisp value, Membership function

I. INTRODUCTION

A fuzzy logic controller is described by a set of rules of type IF (condition) THEN (action) to convert the language control strategy acquired from a human expert into a well-adapted automatic control strategy [1]. Fuzzy logic controllers are extensively used in many engineering application [2-6] Al-65032, one of the most commonly used precipitation hardening aluminum alloy for general purpose use. Aluminium alloys are difficult to weld materials. TIG is extensively used for welding aluminium alloys. TIG welding process is affected by number of parameters individually and combinedly with a high complexity of interactions.

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The complex interaction of the parameters result into a wide variation in the weldment properties, geometry, and metallurgical features.

II. INPUT PARAMETER SELECTION

The input variables selected are pressure, current, groove angle and preheating. Three linguistic terms for the FLC design, are selected for each parameter; Low, Medium and High. For 4 parameters with 3 linguistic terms, the size of the rule base is 4^3 . i.e 64. So a minimum of 64 experiments are to be conducted for developing the rule base which involves a huge cost and time. So for reducing the no. of experiments an orthogonal array L-9 is selected for experimentation.

Experiments conducted with the Taguchi Orthogonal arrays will give the reasonably accurate results even in partial factorial case. So in the current work the validity of this hypothesis is tested.

The 3 levels of the parameters selected after initial experiments are provided in table 1. With four parameters and three levels Orthogonal array L9 was selected for the experimentation and the levels of the parameters shown in table 1 are assigned to the OA and presented in table 2.

Table 1: The input variables

S.No	Input Parameter	Level 1	Level 2	Level 3
1.	Pressure (KPa)	104	125	139
2.	Current (Amps)	145	150	160
3.	Groove angle (Deg)	45	60	70
4.	Pre-heating (OC)	125	150	175

III. EXPERIMENTATION

Standard test pieces with dimensions 150mm X 150mm X 6mm are cut from the Al-65032 alloy sheet are prepared with an a saw machine. The plates are grooved to the desired angle on a milling machine. The milled pieces were engraved with a specific number for identification. The pieces were pickled. A ready to weld sample of weld specimen is shown in Fig 1 and the test pieces are presented in Fig 2.

Table 2: OA after assigning the values

Run	Pressure (KPa)	Current (Amps)	Groove angle (Deg)	Pre-heating (OC)
1.	104	145	45	125
2.	104	150	60	150
3.	104	160	70	175
4.	125	145	60	175

5.	125	150	70	125
6.	125	160	45	150
7.	139	145	70	150
8.	139	150	45	175
9.	139	160	60	125

Experiments are conducted on welding machines presented Fig 3.

The Tensile test was carried out and 0.2% proof stress values for various trials are presented in Table 3. For all the parameters output values at the levels 1, 2, 3 are summed up and averaged. The averaged values are given in table 3 against A1, A2 and A3 and the values are plotted in Fig 4 to know the variation.



Fig 1 A sample of specimen before welding



Fig 2: Tensile test pieces



Fig. 3 TIG 355 Welding Power Source

Table 3: Proof stress values for various trials

Run	Pressure	Current	Angle	Pre-heating	proof stress
1	1	1	1	1	102.7
2	1	2	2	2	115.2
3	1	3	3	3	114.9
4	2	1	2	3	113.8
5	2	2	3	1	113.1
6	2	3	1	2	114.9
7	3	1	3	2	122.5
8	3	2	1	3	110.4
9	3	3	2	1	115.2
A1	110.93	113	109.33	110.33	
A2	113.93	112.9	114.73	117.53	
A3	116.03	115	116.83	113.03	

IV. DESIGN OF FUZZY LOGIC CONTROLLER

In the current work for the design of FLC (Fuzzy logic controller) Mamdani method is used. Fig 4 reveals that the variation in proof stress is almost linear. So, a triangular membership function is chosen for simplicity. As the experiments are conducted at three levels, for each input three linguistic terms are used to denote low, medium and high. Table 4 presents the linguistic terms selected for the input parameters. The triangular membership functions of the pressure, Current, Groove angle and preheating are given in Fig 5, Fig 6, Fig 7, and Fig 8 respectively. The triangular membership function of the output, proof stress is presented in Fig 9.

Table 4: input & output variables and their linguistic terms

S.No	INPUT VARIABLE	LOW	MEDIUM	HIGH
1	PRESSURE	LP	MP	HP
2	CURRENT	LC	MC	HC
3	GROOVE ANGLE	LG	MG	HG
4	PRE-HEATING	LH	MH	HH
5	PROOF STRESS	LS	MS	HS

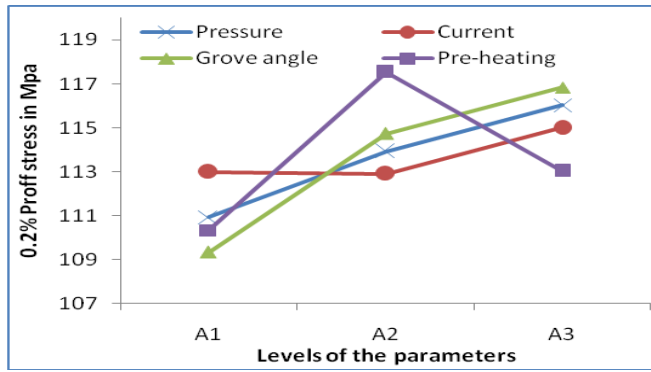


Fig 4: the Average response of Proof stress at various levels

The rule base, from the results of experiment illustrated in table 3 is designed and given in table 5. Since for the reduction of no. of experiments, partial factorial experimentation is done a rule base of 9 rules can only be obtained instead of 64 rules.

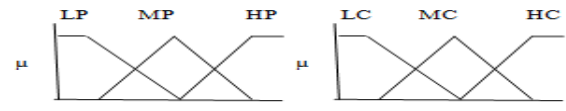


Fig 5: Pressure

Fig 6: Current

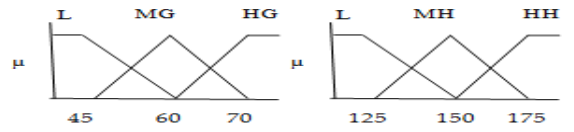


Fig 7: Groove Angle

Fig 8: Pre-heating

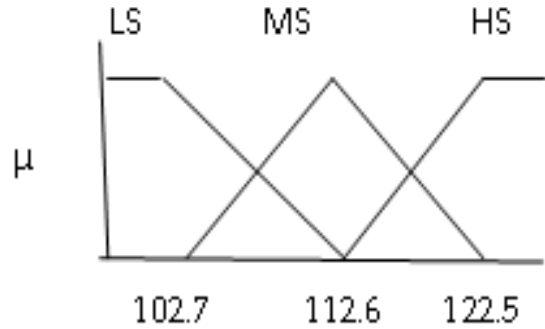


Fig 9: Proof Stress

Table 5: Rule Base

Run	Pressure	Current	Angle	Pre-heating	Proof stress
1	LP	LC	LG	LH	LS
2	LP	MC	MG	MH	MS
3	LP	HC	HG	HH	MS
4	MP	LC	MG	HH	MS
5	MP	MC	HG	LH	MS
6	MP	HC	LG	MH	MS
7	HP	LC	HG	MH	HS
8	HP	MC	LG	HH	MS
9	HP	HC	MG	LH	MS

V. VALIDATION OF THE FLC

The design of FLC is validated by conducting one more set of experiments with different values. The input and output values of the experiments are presented in table 6.

Table 6: Experimental results for validation

Run	Pressure	Current	Angle	Pre-heating	Proof stress MPa
1	110	146	50	130	107.4
2	120	146	55	170	112.5
3	120	157	50	140	110.9
4	135	146	55	140	113.1
5	135	152	50	170	114.1
6	135	157	55	130	114.2

A sample calculation is provided here under for the first case i.e Pressure 110 KPa, Current 146 A, groove angle 50° and preheating 130° C. From the Fig 10 it is noted that 110 KPa pressure can be termed as low pressure or medium pressure with different membership functions. The membership functions can be calculated by similarity of triangles and found out as $\mu_{LP}=0.714286$ and $\mu_{MP}=0.285714$

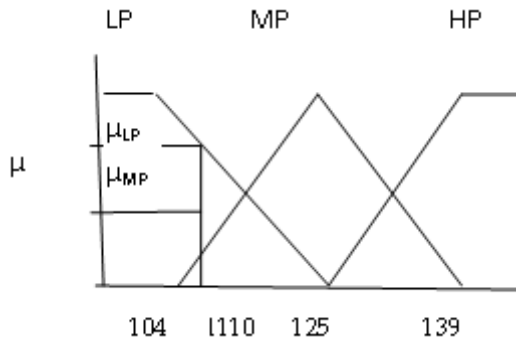


Fig 10: Sample calculation for Pressure

Similarly membership functions pressure, current, groove angle and preheating can be calculated as $\mu_{LC}=0.8$ and $\mu_{MC}=0.2$; $\mu_{LG}=0.666667$ and $\mu_{MG}=0.333333$; $\mu_{LH}=0.8$ and

$\mu_{MH}=0.2$. So there 16 possible rules those can be fired and are presented in table 7. Firing strength of each rule can be found out by taking the minimum value of the membership of functions of each rule. For example firing strength of rule 1 given in table 7 can be found out as

$$\text{Min}(\mu_{LP}, \mu_{LC}, \mu_{LA}, \mu_{LH}) =$$

$$\text{Min}(0.714286, 0.8, 0.666667, 0.8) = 0.666667$$

Similarly the firing strength of each rule is found out and are given in the table 7. But the database only consists of 2 rules Fuzzified outputs as evident from table 3; Rule 1 and rule 12 calculations are done on these two rules and corresponding values obtained from experiments are compared with the calculated values.

From Fig 3 the two rules can be stated as,

Rule 1: If Pressure is LP and current is LC and Groove angle is LG and preheating is LH then the Impact Energy is LI

Rule 12: If Pressure is LP and current is MC and Groove angle is MG and preheating is MH then the Impact Energy is LI

The representation the above two rules on the triangular membership function are graphically presented in Fig 12 and Fig 13.

Table 7: Firing strength of the rules

Rule	Pressure	Current	Angle	Pre-heating	Firing strength
1	LP	LC	LG	LH	0.666667
2	LP	LC	LG	MH	0.2
3	LP	LC	MG	LH	0.333333
4	LP	MC	LG	LH	0.2
5	MP	LC	LG	LH	0.285714
6	LP	LC	MG	MH	0.2
7	LP	MC	MG	LH	0.2
8	MP	MC	LG	LH	0.2
9	MP	LC	MG	LH	0.2
10	LP	MC	LG	MH	0.2
11	MP	LC	LG	MH	0.2
12	LP	MC	MG	MH	0.2
13	MP	MC	MG	LH	0.2
14	MP	LC	MG	MH	0.2
15	MP	MC	LG	MH	0.2
16	MP	MC	MG	MH	0.2

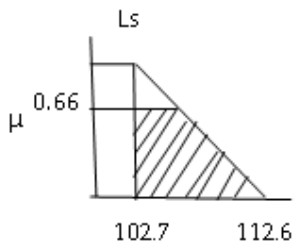


Fig 11: Rule 1

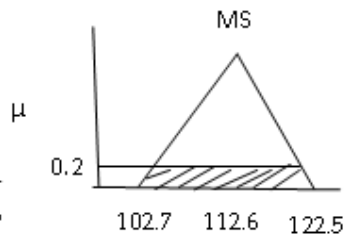


Fig 12: Rule 12

Centre of area = (area of rectangle X centre of rectangle+ area of the triangle and centre of the triangle)/ (area of the rectangle + area of the triangle) Similarly area of hatched trapezium is found out by the area of trapezium formula.

Table 8: Area and centre of areas

RULE	AREA	CENTRE
1	4.6	106.367
12	3.937	112.6

Centre of sums method is applied for defuzzification. The hatched areas of the membership functions and the centers of areas shown in the Fig 11 and 12 are computed and presented in the table 8. Areas can be easily calculated by the geometry i. Sum of area of a triangle and a rectangle for each case. Length of the rectangle and the base of the triangle can be found out by similarity of triangles. Centre of the rectangle is at half of its length and centre of the triangle is 1/3 of its length. The centre of whole area is obtained by weighted average.

Table 9: Comparison of values from FLC and experiment

Run	Pressure	Current	Angle	Pre-heating	Impact Energy(in J)		% Error
					Exp.	FLC	
1	110	146	50	130	107.4	109.24	-1.75
2	120	146	55	170	112.5	114.63	-1.89
3	120	157	50	140	110.9	109.85	0.98
4	135	146	55	140	113.1	114.73	-1.48
5	135	152	50	170	114.1	116.21	-1.92
6	135	157	55	130	114.2	117.98	-3.39

The Defuzzified output can be calculated by the equation (1)

$$\text{Defuzzified output} = \frac{A_1 * C_1 + A_{12} * C_{12}}{A_1 + A_{12}} \dots \dots (1)$$

Defuzzified output for this case is computed to be 109.24 MPa

Similarly for the other four cases of validation experimentation, the values given by the FLC are calculated and compared with the experimental values. The comparison is illustrated in table 9. From table 9 it observed that the error in absolute terms ranges from 1.91% to 8.75% which may be treated to be acceptable. Hence this FLC can be used to predict the impact energy for any given parameters of shielding gas pressure, current, groove angle and preheating temperature

VI. CONCLUSIONS

In the current work a Fuzzy logic controller is developed for predicting the 0.2% Proof stress of aluminium alloy AL 65032 weldment, using Mamdani approach. As design of FLC becomes complex with the increase of number of input parameters, the concept of orthogonal array used for

experimentation in the development of data base and rule base. Even though a partial data base is developed with the reduced experimentation to save the time, cost and effort, the maximum error in the prediction is found out to be 3.39%. So development of knowledge base using Taguchi technique proved to be accurate enough to design a low cost FLC. Further investigations may be carried out to tune this controller using neural net works or genetic algorithm as the data is getting generated in due course. This off line FLC can be integrated in intelligent manufacturing systems for controlling the process in auto mode and at the same time tuning the FLC continuously to produce the synergic effect.

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