Development of a Fuzzy Logic Controller for the Estimation of Ultimate Tensile Strength for the TIG welded Al-65032

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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 workman ship etc introduce the into 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 parameters and the effect of these parameters on the ultimate tesnsile strength is studied. Three linguistic terms are used for each parameter. To minimise the no. 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. Triangular membership function is selected for the input and out variables and FLC is designed. The FLC is validated with 5 more experiments. Mamdani approach is used to develop the Fuzzy controller.

Key words: 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]. Fuzzilogic controllers are extensively used in many engineering application [2-6]
Al-65032 is a precipitation hardening aluminium alloy that and one of the most common alloys of aluminium for general purpose use. Aluminium alloys are difficult to weld materials. Tungsten Inert gas Welding (TIG) is extensively used for welding aluminium alloys. TIG welding process is influenced by number of parameters individually and combinedly with a high complexity of interactions. 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 variable selected is 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 43. 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.

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 (^{O}C)	125	150	175

The three levels of the parameters selected after preliminary experiments are given 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.

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. Hydrochloric Acid is used for the process. A ready to weld sample of weld specimen is presented in Fig 1 and the test pieces are shown in Fig2. Experiments are conducted on welding machines presented Fig 3.

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

The tensile test was carried out. The UTS 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 presented in the 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

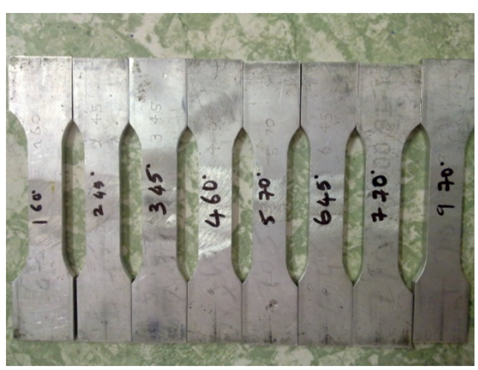

Fig 2: Tensile test samples

Fig. 3 TIG 355 Welding Power Source

Table 3; Ultimate Tensile strength values for various trials

Run	Pressure	Current	Angle	Pre-heating	UTS(MPa)
1	1	1	1	1	185.2
2	1	2	2	2	190.3
3	1	3	3	3	192.5
4	2	1	2	3	193.5
5	2	2	3	1	191.8
6	2	3	1	2	184.9
7	3	1	3	2	186.8
8	3	2	1	3	180.7
9	3	3	2	1	185.5
A1	189.33	188.50	183.60	187.50	
A2	190.07	187.60	189.77	187.33	
A3	184.33	187.63	190.37	188.90	

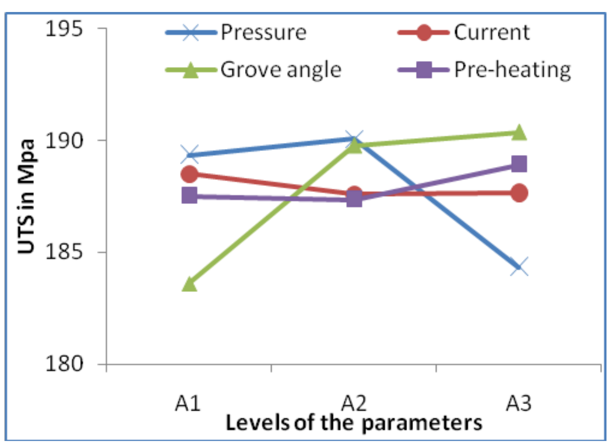

Fig 4: the Average response of Proof stress at various levels

IV. DESIGN OF FUZZY LOGIC CONTROLLER

Mamdani approach is used for the design of FLC (Fuzzy logic controller). Fig 4 reveals that the variation in ultimate tensile strengh is almost linear. So for simplicity sake a triangular membership function is chosen. 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 6, Fig 7, Fig 8 and Fig 9 respectively. The triangular member ship function of the output, impact energy is presented in Fig 10.

Table 4: input & output variables and their linguistic terms

Run	Pressure	Current	Angle	Pre-heating	UTS
1	LP	LC	LG	LH	MU
2	LP	MC	MG	MH	HU
3	LP	HC	HG	HH	HU
4	MP	LC	MG	HH	HU
5	MP	MC	HG	LH	HU
6	MP	HC	LG	MH	MU
7	HP	LC	HG	MH	MU
8	HP	MC	LG	HH	LU
9	HP	HC	MG	LH	MU

Table 5: Rule Base

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.	Impact Energy	LU	MU	HU

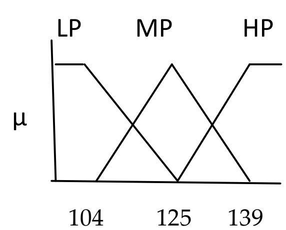

Fig 5: Pressure

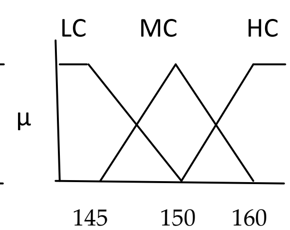

Fig 6: Current

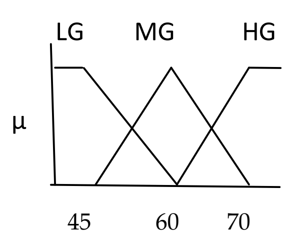

Fig 7: Groove Angle

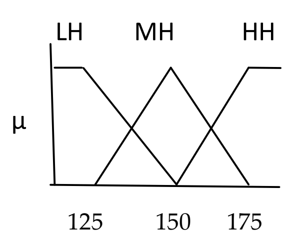

Fig 8: Pre-heating

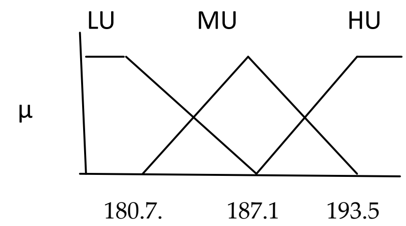

Fig 10: UTS

From the results of the experimental shown in table 3, the rule base 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.

V. VALIDATION OF 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 5

Table 6: Experimental results for validation

Run	Pressure	Current	Angle	Pre-heating	UTS
1	110	146	50	130	186.8
2	120	146	55	170	188.1
3	120	157	50	140	185.25
4	135	146	55	140	185.25
5	135	152	50	170	184.45
6	135	157	55	130	184.4

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

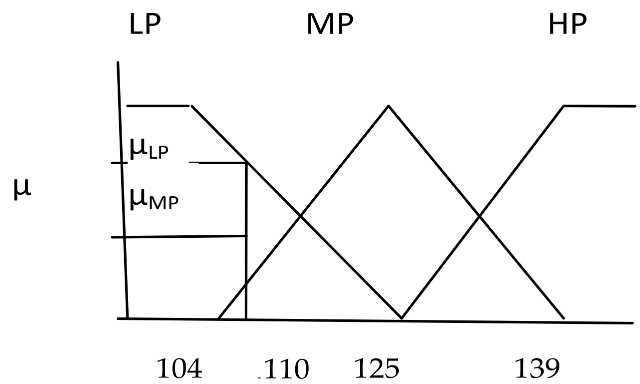

Fig 11: sample calculation for Pressure

A sample calculation is provided here under for the first case i.e Pressure 110 KPa, Current 146 A, groove angle 50^0 and preheating 130^0 C

From the Fig 11 it is noted that 110 Kpa pressure can be termed as low pressure or medium pressure with different membership functions. The member ship functions can be calculated by similarity of triangles and found out as μ_{Lp}=0.714286 and μ_{MP}=0.285714

Similarly membership functions pressure, current , groove angle and preheating can be calculated as μ_{LC}=0.8 and μ_{MC}=0.2; μ_{LG}=0.666667 and μ_{MG}=0.333333; μ_{LH}=0.8 and μ_{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 member ship of functions of each rule. For example firing strength of rule 1 given in table 7 can be found out as

Min (μ_{LP},μ_{LC} , μ_{LA} ,μ_{LH})= 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 MU

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

The representation the above two rules on the triangular membership function are graphically presented in Fig 11 and Fig 12

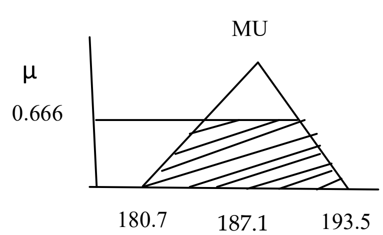

Fig 11: Rule 1

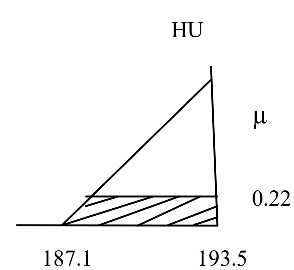

Fig 12: Rule 12

Table 8. Area and centre of areas

Rule	Area	Centre
1	5.69	187.1
12	1.253	191.4

Table 9. Comparison of values from FLC and experiment

Run	Pressure	Current	Angle	Pre-heating	UTS		% Error
					Exp.	FLC	
1	110	146	50	130	186.8	187.9	-0.58887
2	120	146	55	170	188.1	193.2	-2.71132
3	120	157	50	140	185.25	183.7	0.83671
4	135	146	55	140	185.25	186.5	-0.67476
5	135	152	50	170	184.45	188.9	-2.41258
6	135	157	55	130	184.4	185.3	-0.48807

Centre of sums method is applied for defuzzificaiton. The hatched areas of the membership fucntions and the centres of areas shown in the Fig 12 and 13 are computed and presented in the table 8. Areas can be easily calculated by the geometry i.e 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 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)

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

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

Defuzzified output for this case is computed to be 187.9 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 0.49% to 2.71% which may be treated to be acceptable. Hence this FLC can be used to predict the UTS for any given parameters of shielding gas pressure, current, groove angle and preheating temperature

VI. CONCLUSIONS

In the current work a Fuzzilogic controller is developed for predicting the UTS of the of aluminium alloy AL 65032 weldment, using Mamdani approach. As design 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 2.71%. 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 algorithms as the data is getting generate 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.

REFERENCES

[1] Kheireddine Lamamra, Farida Batat, Fouad Mokhtari "new technique with improved control quality of nonlinear systems using an optimized fuzzy logic controller" Expert Systems With Applications, vol.145 (2020) pp.1-9

[2] Stefano Pietrosanti, Feras Alasali, Willam Holerbaum, "Power Management system for RTG crane using fuzzy logic cotroller", Sustainable Energy Technologies and Assessments, vol.37, Feb 2020.pp 1-15.

[3] Tianhu Zhang, Yuanjun Liu , Yandi Rao, Xiaopeng Li , Qingxin Zhao, "Optimal design of building environment with hybrid genetic algorithm, artificial neural network, multivariate regression analysis and fuzzy logic controller" Building and Environment Vol. 175 (2020), pp.1-10

[4] A.K.D. Velayudhan, "Design of a supervisory fuzzy logic controller for monitoring the inflow and purging of gas through lift bags for a safe and viable salvaging operation", Ocean Engineering, vol.171 (2019), pp.193-200.

[5] Najib El Ouanjli, Saad Motahhir, Aziz Derouich, Abdelaziz El Ghzizal, Ali Chebabhi, Mohammed Taoussi “Improved DTC strategy of doubly fed induction motor using fuzzy logic controller” Energy Reports 5 (2019) pp.271–279

[6] Jorge Martinez-Gil, Jose Manuel Chaves-Gonzalez, “Automatic design of semantic similarity controllers based on fuzzy logics”, Expert Systems with Applications 131 (2019) pp.45–59.