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Fuzzy Logic Optimization of Weld Bead for Rutile Based Fluxes in Submerged Arc Welding

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Abstract: *This paper presents the study carried out on low carbon steel plates, which is most widely used in all sort of fabrication work in heavy industries. TiO_2-Al_2O_3-CaO based flux was designed to optimize its constituents for weld bead width, penetration and reinforcement on submerged arc welding by the use of fuzzy logic optimization process. Taguchi L9 orthogonal array was used to design the flux system. Quality of the weld is judged by the features such as weld bead. The most important features of weld bead are weld bead width, penetration and reinforcement. Fuzzy logic and ANOVA analysis was used to optimize the welding parameters.Confirmation test is carried out to test the validity of the process.*

Keywords: *Fuzzy logic, Taguchi analysis, L9 Orthogonal array, ANOVA, Flux system*

1. INTRODUCTION

Submerged arc welding is a high quality arc welding processvery effectively and efficiently used in heavy industries for the fabrication process. Fuzzy logic and Taguchi analysis is used to optimize the submerged arc welding process parameters. Tarng et al.[1]. Applicability of fuzzy logic to predict the hardness of the melted zone in submerged arc welding which is affected by combined effect of TiO_2nano-particles and welding input parameters.Aghakhani et al. [2]. Application of fuzzy logic analysis and desirability function is used to optimize the multiple quality characteristics of submerged arc welding process parameters of SA 516 Grade 70 steel. Sateesh et al. [3].Fuzzy logic and desirability approach are applied to optimize the input parameters considering multiple output variables simultaneously in laser butt welding for tensile strength and bead profile. Sathiya et al. [4]. Hybrid process is also used in some of the welding processes to optimize the process parameters. Fuzzy logic and desirability function along with grey analysis is used tooptimize the welding process parameters such as welding current arc voltage and electrode stick out in flux cored arc welding process. Sateesh et al. [5,6].Laser welding is the process to join dissimilar metals that is the demand of the industry because it is low cost, light weight and very good in weld strength. Fuzzy logic and regression analysis was applied to obtain the optimal tensile strength in Laser welding process. Bhujbal et al. [7]. Fuzzy logic and grey relational analysis is used to optimize the EDM process parameters and Zirconium-containing diamond like carbon coatings [8, 9]. Grey and fuzzy is used to optimize the multiobjective process parameters for CNC turning of GFRP/Epoxy composite. Vasudeven et al. [10].In the present study an attempt has been made to optimize the welding process based on the composition of flux constituents. Several researchers have attempted to optimize the process based on welding condition parameters.

2. EXPERIMENTAL METHOD

2.1 FLUX PREPARATION

In the present work varying percentage of, NiO, MnO and MgOhave been added in the fluxes. The fluxes have been designed with the help of Ternary phase diagram. L9 orthogonal array was used to design the flux it means that three factors along with three levels were considered. Factors along with their levels are shown in Table 1. Composition of TiO_2flux is shown in Table 2. Design matrix for the flux is shown in Table 3.

TABLE 1: Flux Factors Level

	Code	NiO	MnO	MgO
Level 1	A	60	50	85
Level 2	B	80	70	95
Level 3	C	100	90	105

TABLE 2 .TiO_2 Based Flux Composition

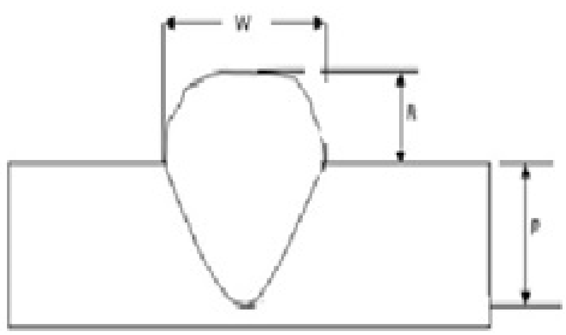
Constituents	Al_2O_3	TiO_2	CaO	CaF_2	K_2 SiO_3
Wt % in gms	297	560	543	150	2:1 ratio

2.2 EXPERIMENTAL CONDITION

A constant voltage DC SAW welding machine was used for welding mild steel plate of 300x150x22 mm^3 using 3.15 mm diameter wire of grade EL 8 DIN 8557:SI by bead on plate arrangement . The plates were mechanically cleaned before the welding was performed. The open circuit voltage 32v was kept constant for all welds made with titanium dioxide flux. Trolley speed was 20 cm/min and electrode stick out was 2.5 mm. Total 9 experiments, with all TiO_2 basedflux constituents were conducted. Other welding conditions are shown in Table 4.

TABLE 3. Design Matrix

S.No	NiO	MnO	MgO
1	1	1	1
2	1	2	2
3	1	3	3
4	2	1	2
5	2	2	3
6	2	3	1
7	3	1	3
8	3	2	1
9	3	3	2



W= Width, P = Penetration, R= Reinforcement

Fig. 1. Weld bead width, Penetration and Reinforcement

3. METHOD OF ANALYSIS

After the experimental runs the welded plates were cleaned to remove the slag. From the center of the plate, a transverse section was taken; sectioned portion was polished and etched with 2% of nital solutionto find out the bead geometry parameters as shown in figure.1. This was done with the help of Adobe Photoshop software. The results so obtained are tabulated in Table 5.

TABLE 4: Welding Condition Parameter

Parameter	**Unit**	**Value**
Open Circuit Voltage	V	32
Current	A	500
Trolley Speed	cm/min.	20
Electrode stick out	mm	2.5
Type of Flux		TiO_2 Based

4. TAGUCHI PROCEDURE

Taguchi has given a method, design of experiments that is very effective tool to optimize the process for high quality performance with less economy. This system uses an orthogonal array design that can reduce the repetition of experiment. Other design procedure has so much number of experiments that the analysis becomes a tedious job to perform all experiments.

Similar level of factors for Taguchi orthogonal array design can reduce the analysis to a simple and systematic way.

There are some uncontrolled factors they affect the output of process. These factors are called noise factors, where as our derived responses are termed signal. The variation of index is known as S/N ratio. This is basically of three types such as lower is better, higher is better and nominal is better. The control factors that may contribute to decrease variation can be very easily identified by looking at the variation present in the response; this only can enhance the quality of the process. In our case the weld bead width, penetration and reinforcement are the responses. Measured responses are tabulated in Table 5.

For smaller is better
$$\frac{S}{N} = -10\log_{10}\left\{\frac{\sum_{i}^{n} y_i^2}{n}\right\} \quad (1)$$

For higher is better
$$\frac{S}{N} = -10\log_{10}\left\{\frac{\sum_{i}^{n}\left(\frac{1}{y_i^2}\right)}{n}\right\} \quad (2)$$

TABLE 5: Measured Responses, MPC1 and S/N Ratio

W (mm)	P (mm)	R (mm)	Normalized			MPCI	S/N Ratio
			(W)	(P)	(R)		
23.3	6.5	7.1	0.66	0.0	1.0	0.588	-4.612
35.2	5.3	6.1	0.59	0.30	0.68	0.599	-4.451
40.6	6.1	5.3	0.0	0.48	0.0	0.247	-12.14
25.5	9.1	7.8	0.99	0.16	0.90	0.686	-3.273
30.8	7.7	7.2	0.63	0.36	0.64	0.579	-4.746
32.8	4.8	6.4	0.28	0.74	0.46	0.591	-4.568
24.4	11.1	8.7	0.94	0.04	0.73	0.617	-4.194
27.9	7.0	8.0	1.0	0.53	0.89	0.750	-2.498
36.9	6.3	7.9	0.70	1.0	0.48	0.733	-2.697

In our case smaller is the better is used, for weld bead width and larger is the better is used for penetration that is shown by equation no.1 and 2 respectively. Where Y_1, Y_2 = Result of experimental observation; m = target value; and n = Number of repetitions.

5. FUZZY LOGIC

A fuzzy logic unit consists of fuzzifier, membership functions, a fuzzy rule base, an inference engine, and a defuzzifier. The fuzzifier makes use of membership functions to fuzzify the signal to- noise ratios that had been generated by the response. Next, the inference engine performs fuzzy reasoning on fuzzy rules to generate a fuzzy value by this. Finally, the defuzzifier converts the fuzzy value into a multi performance criteria index (MPCI). The structure of the three-input-one-output fuzzy logic unit is shown in Figure1,"The input are weld bead width, penetration and reinforcement and output is (MPCI). The fuzzy rule base consists of a group of if–then control rules with the two inputs, $x1$ and $x2$, and one output y, that is:

Rule 1: if $x1$ is $A1$ and $x2$ is $B1$ then y is $C1$ else
Rule 2: if $x1$ is $A2$ and $X2$ is $B2$ then y is $C2$ else

Rule n: if $x1$ is $An$and $x2$ is Bnthen y is Cn.

Ai, Bi and $Ci$are fuzzy subsets defined by the corresponding membership functions.

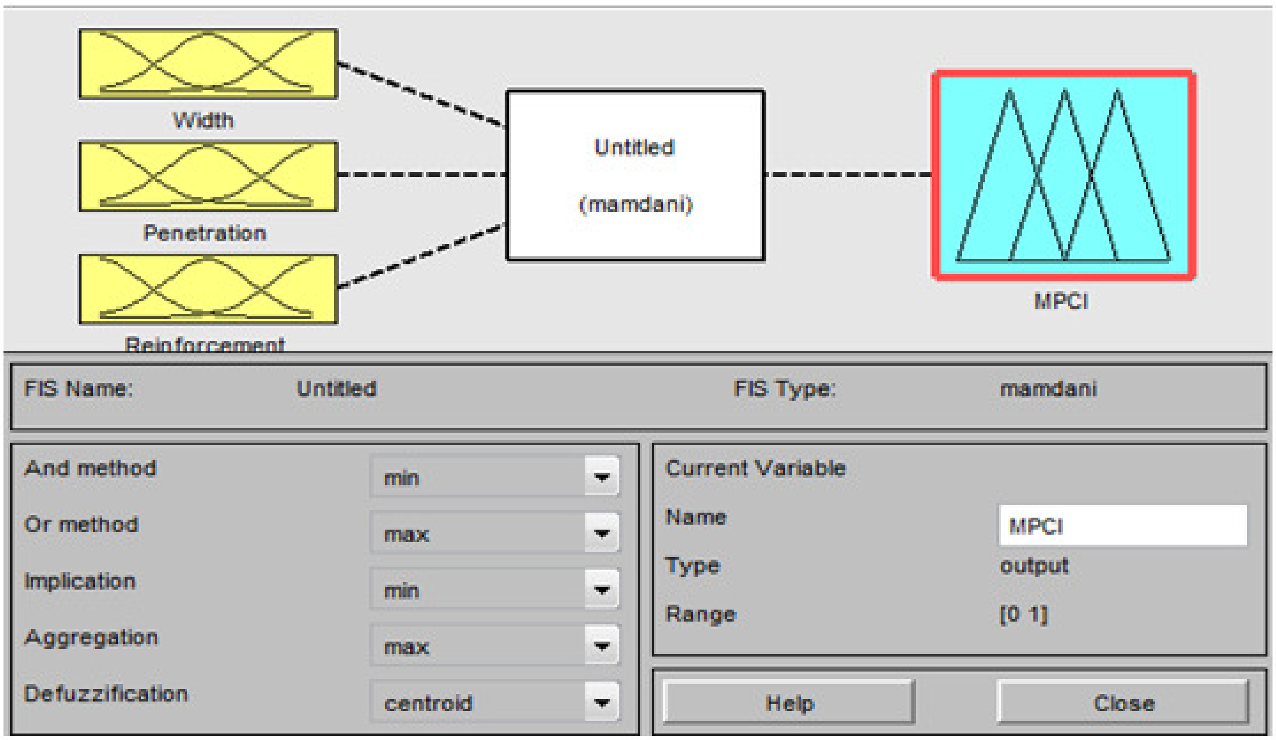


Fig. 2. Fuzzy Logic with Mamdani interference for present study

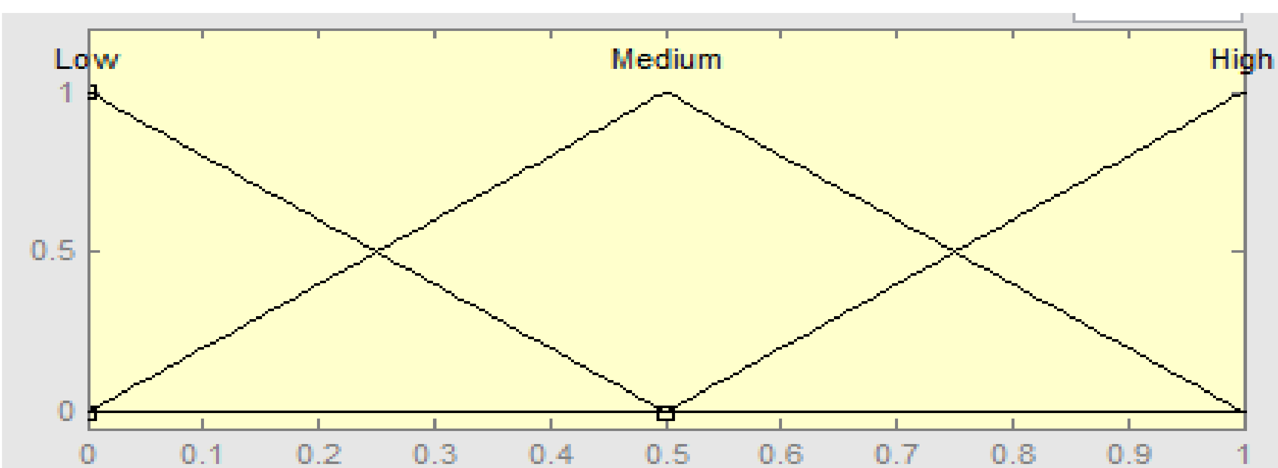


Fig. 3. Membership functions for input variables

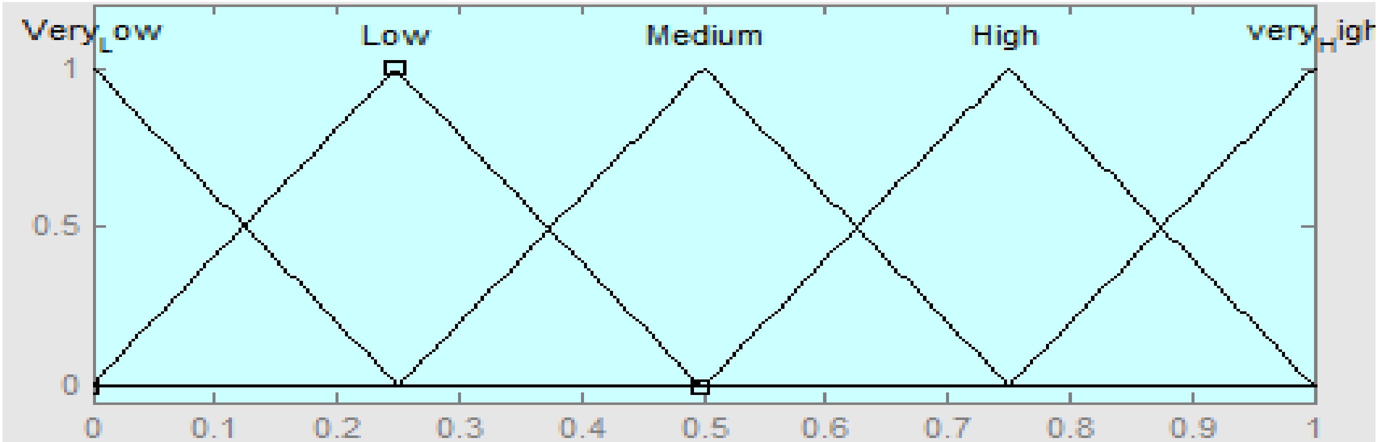


Fig. 4. Membership Functions for Output response or MPCI

In the present study, three fuzzy subsets are assigned in the three inputs as well as one output. Details about the proposed fuzzy model are presented in Figure 2. Nine fuzzy rules are directly derived based on the fact that the larger the signal-to noise ratio is, the better the performance characteristic shown in Table 5. Figure 3 and Figure 4 represent the membership function of input and output respectively.

6. RESULTS

Proposed fuzzy model which comprises of three inputs and one output fuzzifies the input data using three triangular membership functions for each input and output. Using fuzzy logic rules in mumdani interference, multi-performance criteria index (MPCI) in numerical value is calculated for each experiment using centroid method of defuzzification as shown in Table 6.

Table 7 shows the average MPCI of each flux alloying element for their each level. These averages MPCI scores are plotted in graphical form for each level of alloying element in Figure 5. This graphical representation also confirms the result of fuzzy model suggested as A3B2C2the optimal parameter levels.

TABLE 6: Average MPCI for each level ofNiO, MnO and MgO

Average MPCI			
Levels	NiO	MnO	MgO
1	0.478	0.630	0.643
2	0.618	**0.642**	**0.672**
3	**0.70**	0.523	0.481

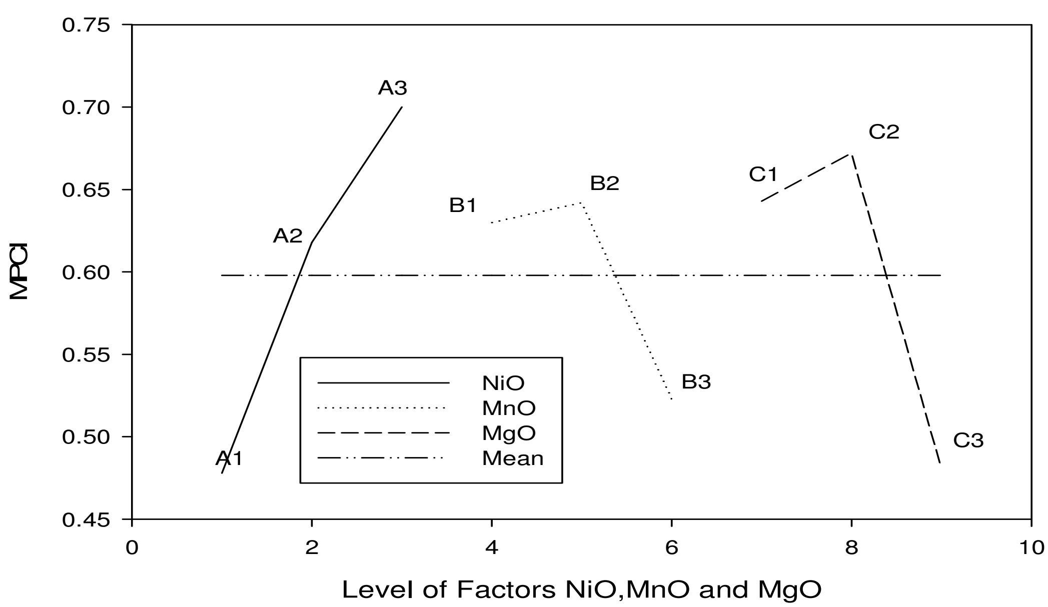


Fig. 5. MRPI score v/s levels of each flux alloying elements

7. CONFIRMATORY TEST

The final step is to verify the result based on the performance of Taguchi method. Optimized value of S/N ratio is calculated by using equation 3 at the optimal level A3B2C2 for MPCI.

$$\eta_{opt} = \eta_m + \sum_{i=1}^{q} (\eta_i - \eta_m) \quad (3)$$

In the above equation $\eta_{OPT}$is the optimum value of S/N ratio at the selected optimum level. η_m is the overall mean of S/N ration $\eta_i$is the average value at the first optimum level and so on. The result of confirmatory test shows that S/N ration improved as 2.87 for MPCI. It is represented in Table 8.

TABLE 7: Result of Confirmatory Test at 32V for MPCI

	Initial condition		Optimal condition	
		Average	Predicted	
Selected level	A1B1C1		A3B2C2	
MPCI S/N(db)	0.588 -4.61	0.598 -4.66	0.818 -1.74	
	S/N ratio Improved 2.87			

8. CONCLUSIONS

From this study following conclusions are drawn-

1. Using Taguchi orthogonal array, 9 TiO_2 based agglomerated fluxes are prepared and three responses were measured as weld bead width, penetration and reinforcement.

2. Multi-objective optimization is done using Fuzzy Logic model for weld bead of weld zone.

3. A3B2C2are suggested as the optimal level of alloying elements in TiO_2 based flux by fuzzy model for optimal weld bead width, penetration and reinforcement.

4. S/N ration improved as 2.87for MPCI.

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