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Development of a Fuzzy Model in Plasma Transferred Arc Welding using Cobalt based Hard Facing Alloy

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Abstract:
Plasma Transferred Arc Welding (PTAW) has attracted increasing attention for its effective protection against corrosion, thermal shock, and abrasion. The quality of hard faced components depends on the weld bead geometry and dilution, which must be properly controlled and optimized to ensure better desirable mechanical characteristics of the weld. Good weld is achieved by selecting the right input parameters in this process and hence study of these input variables such as welding current, speed, etc. gives us a good analysis of how to achieve desirable weld bead characteristics using the known input variables. The shape of weld bead geometry obtained in the PTA welding process is an indication of the quality and health of a good weld. In this study, different weld beads would be deposited using PTA process with different parameters (welding current, travel speed and powder feed rate) using cobalt based powdered filler metal. A Fuzzy Interface System (FIS) is adopted to compare the out parameters for achieving desired Hardness, Width, Height and the Percentage of Fe content after welding.

Keywords:*Fuzzy, arc welding, hard facing alloy*

I. INTRODUCTION

Plasma-transferred arc welding (PTA welding) is a thermal process for applying wear and corrosion resistant layers on surfaces of metallic materials. The plasma arc melts the surface of the base material. At the same time, the powdery filler material is inserted into the arc and also molten. During solidification, a bond between the filler material and the base material is developed. The advantages of this process are a low dilution rate, a small heat-affected zone and a high deposition rate. The production of the powdery filler material is much easier compared to similar welding wires and welding rods. Thus, many surface properties needed for special applications can be economically produced. Cobalt-based alloys are known by their high resistance to wear and corrosion under severe conditions. These alloys have about 30% wt chromium, 4 to 17% wt tungsten and 0.1 to 3% carbon [1]. The dilution effects can play a major role as alloying occurs between the substrate and the coating alloy, during the metallurgical bonding of a surface welding procedure. Since wear resistance of cobalt based alloys depends on their microstructure), changes on the chemical composition of the alloy could affect their performance.Hard facing with Plasma Transferred Arc (PTA) welding technique can result on high quality deposits, with low dilution and high deposition rates [4].

Experiments were conducted by using cobalt based hard facing alloy. In this study current, table speed and Powder Feed rate were taken at 3 different levels. Experiments were designed using L_{27} orthogonal array. The three levels for the factors are shown in the table.

Table1. Factor and levels for the experiments

S.No	Parameter	Unit	Level 1	Level 2	Level 3
1	Current	Ampere	130	141	150
2	Table Speed	mm/min	98.151	123.78	150.796

TEST Engineering & Management
January - February 2020
ISSN: 0193 - 4120 Page No. 6968 - 6976

3	Powder feed rate	gms/min	29.35	36.85	42.75

A portable hardness measuring setup is used to measure the hardness (HRC) of the samples and the Percentage of Fe content is measured by using Positive Material Identification (PMI) which is a latest X - Ray Fluorescence (XRF) by which Positive Material Identification where low level radiation is fired at the material and the energy levels reflected back from each element to be measured.


Fig.1. Work piece after mounting

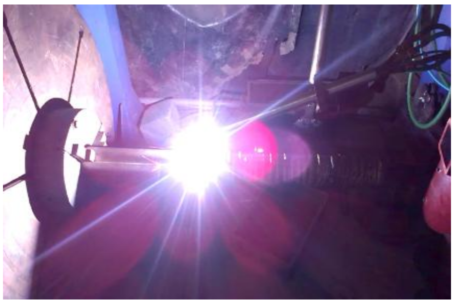


Fig.2. PTAW Process


Fig.3. Cross section Test


Fig.4. Liquid PenetrantTesting


Fig.5. Liquid PenetrateTest result


Fig.6. Portable Hardness Test


Fig.7. Cross section Test Result


Fig.8. Finished Work piece

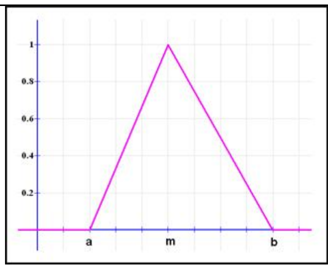
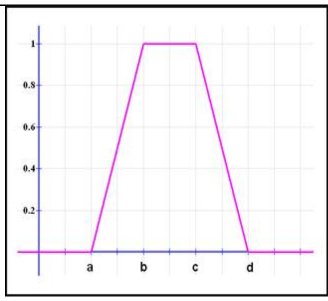
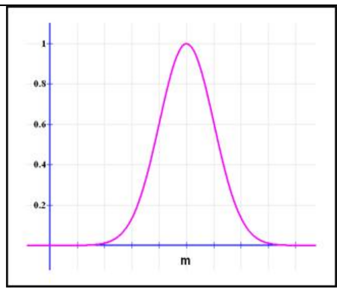
II. Fuzzy Logic

Fuzzy logic is a form of many-valued logic in which the truth values of variables may be any real number between 0 and 1, considered to be

January - February 2020
ISSN: 0193 - 4120 Page No. 6968 - 6976

"fuzzy". By contrast, in Boolean logic, the truth values of variables may only be 0 or 1, often called "crisp" values. Fuzzy logic has been employed to handle the concept of partial truth, where the truth value may range between completely true and completely false. Furthermore, when linguistic variables are used, these degrees may be managed by specific (membership) functions.Since the fuzzy system output is a consensus of all of the inputs and all of the rules, Fuzzy logic systems can be well behaved when input values are not available or are not trustworthy. Weightings can be optionally added to each rule in the rule base and weightings can be used to regulate the degree to which a rule affects the output values. These rule weightings can be based upon the priority, reliability or consistency of each rule. These rule weightings may be static or can be changed dynamically, even based upon the output from other rules

Table2. Fuzzy Mathematical Functions

Name of the Function	Mathematical Representation	Graphical Representation
Triangular Function : defined by a lower limit **a**, an upper limit **b**, and a value **m**, where **a < m < b**.	$\mu_A(x) = \begin{cases} 0, & x \le a \\ \frac{x-a}{m-a}, & a < x \le m \\ \frac{b-x}{b-m}, & m < x < b \\ 0, & x \ge b \end{cases}$	
Trapezoidal function: defined by a lower limit **a**, an upper limit **d**, a lower support limit **b**, and an upper support limit **c**, where **a < b < c < d**.	$\mu_A(x) = \begin{cases} 0, & (x < a) \text{ or } (x > d) \\ \frac{x-a}{b-a}, & a \le x \le b \\ 1, & b \le x \le c \\ \frac{d-x}{d-c}, & c \le x \le d \end{cases}$	
Gaussian function: defined by a central value **m** and a standard deviation **k > 0**. The smaller k is, the narrower the "bell" is.	$\mu_A(x) = e^{-\frac{(x-m)^2}{2k^2}}$	

The following conditions are framed; these conditions are common for entire data sets[1-12]. The values are categorized into three categories namely LOW, MEDIUM and HIGH which is shown in the table

Table 3. Fuzzy Conditions

Parameters	LOW	MEDIUM	HIGH
HARDNESS (HV)	24 to 32	32 to 35	35 to 38
WIDTH (mm)	9 to 11.5	12 to 13	13 to 16.5
HEIGHT (mm)	2.5 to 3.5	4 to 4.5	4.5 to 5
Fe Content (%)	3 to 10	11 to 15	16 to 30

TEST Engineering & Management

January - February 2020
ISSN: 0193 - 4120 Page No. 6968 - 6976

Table 4. Fuzzy Rules For Factors And Responses

S.No	Current (C)	Table Speed (T)	Powder Feed Rate (P)	(HRC)	Width (mm)	Height (mm)	(Fe)
1	MEDIUM	LOW	MEDIUM	MEDIUM	MEDIUM	LOW	MEDIUM
2	MEDIUM	LOW	LOW	HIGH	MEDIUM	LOW	MEDIUM
3	MEDIUM	LOW	HIGH	MEDIUM	MEDIUM	MEDIUM	MEDIUM
4	MEDIUM	MEDIUM	MEDIUM	MEDIUM	LOW	MEDIUM	MEDIUM
5	MEDIUM	MEDIUM	LOW	MEDIUM	MEDIUM	LOW	MEDIUM
6	MEDIUM	MEDIUM	HIGH	MEDIUM	LOW	HIGH	LOW
7	MEDIUM	HIGH	MEDIUM	MEDIUM	LOW	LOW	LOW
8	MEDIUM	HIGH	LOW	MEDIUM	LOW	HIGH	LOW
9	MEDIUM	HIGH	HIGH	HIGH	LOW	LOW	MEDIUM
10	LOW	LOW	MEDIUM	MEDIUM	LOW	MEDIUM	LOW
11	LOW	LOW	LOW	MEDIUM	MEDIUM	MEDIUM	MEDIUM
12	LOW	LOW	HIGH	MEDIUM	MEDIUM	HIGH	MEDIUM
13	LOW	MEDIUM	MEDIUM	HIGH	LOW	MEDIUM	MEDIUM
14	LOW	MEDIUM	LOW	MEDIUM	LOW	MEDIUM	HIGH
15	LOW	MEDIUM	HIGH	MEDIUM	MEDIUM	HIGH	LOW
16	LOW	HIGH	MEDIUM	HIGH	LOW	LOW	MEDIUM
17	LOW	HIGH	LOW	HIGH	LOW	MEDIUM	LOW
18	LOW	HIGH	HIGH	HIGH	MEDIUM	LOW	LOW
19	HIGH	HIGH	HIGH	LOW	HIGH	MEDIUM	MEDIUM
20	HIGH	LOW	MEDIUM	LOW	HIGH	HIGH	LOW
21	HIGH	LOW	LOW	LOW	HIGH	LOW	HIGH
22	HIGH	MEDIUM	HIGH	LOW	HIGH	HIGH	MEDIUM
23	HIGH	MEDIUM	LOW	LOW	LOW	LOW	HIGH
24	HIGH	MEDIUM	MEDIUM	LOW	MEDIUM	MEDIUM	MEDIUM
25	HIGH	HIGH	MEDIUM	LOW	LOW	MEDIUM	MEDIUM
26	HIGH	HIGH	LOW	MEDIUM	MEDIUM	LOW	HIGH
27	HIGH	LOW	HIGH	LOW	MEDIUM	MEDIUM	MEDIUM

The Fuzzy rules are applied on the Corresponding responses and these rules are applied on the Fuzzy Interface System (FIS) using Matlab 7.0 Software

The Fuzzy Interface System (FIS) is created with three inputs (Current, Table Speed and Powder feedrate) and four outputs (Hardness, Width, Height and Fe content) [13-15]

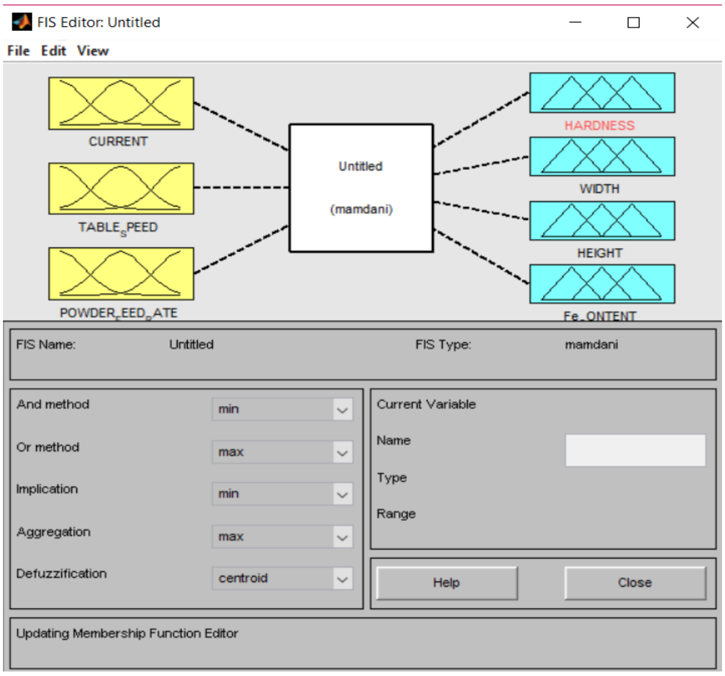


Fig. 9.Fuzzy Interface System

Fuzzy Rules are entered as per the values framed in Table 4 with Low, Medium and High as the values

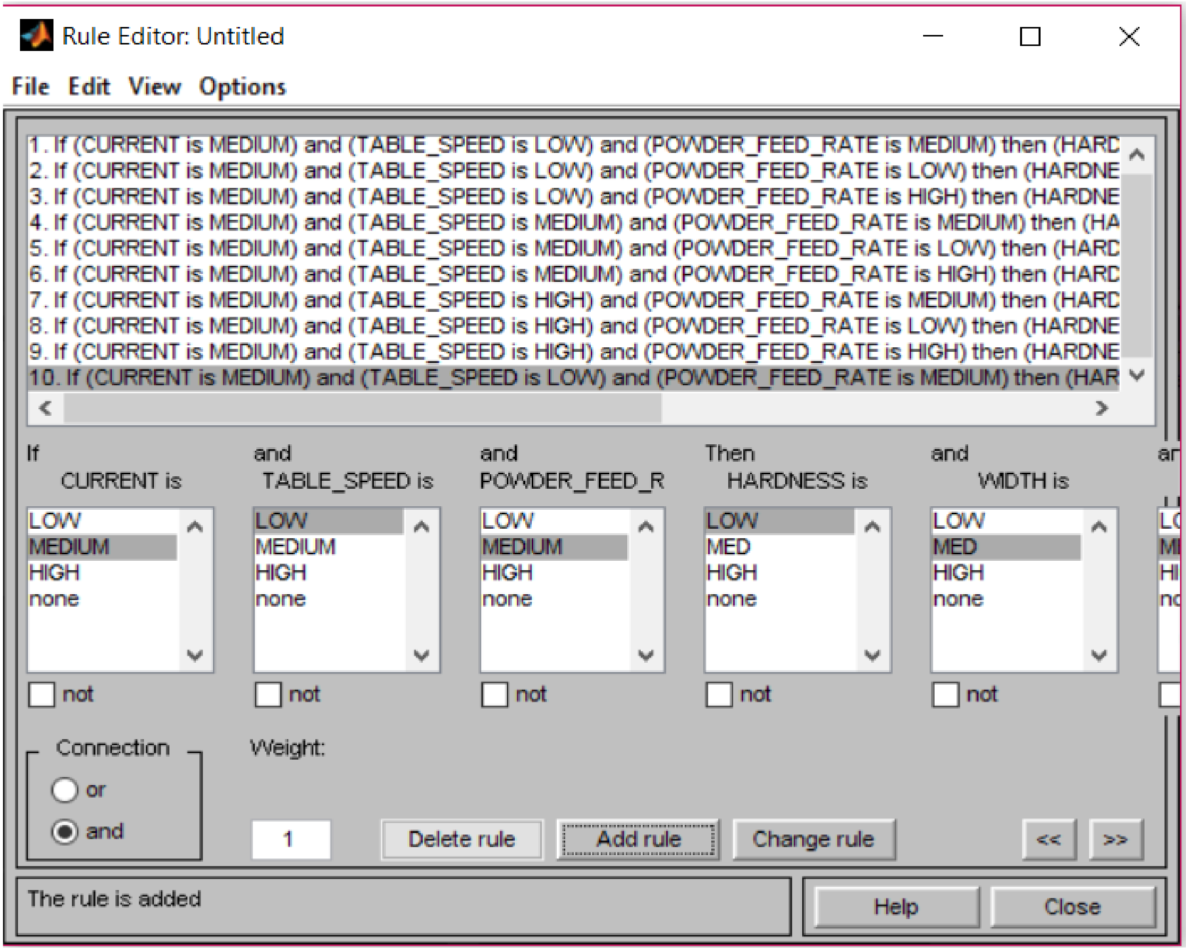


Fig.10. Fuzzy Rule Editor

January - February 2020
ISSN: 0193 - 4120 Page No. 6968 - 6976

S.No	Current (C)	Table Speed (T)	Powder Feed Rate (P)	(HRC)	HRC Predicted	% Difference	Width (mm)	Width Predicted	% Difference	Height (mm)	Height Predicted	% Difference	(Fe)	Fe content Predicted	% Difference	Defects	Status
1	140	98.15	36.85	34.5	33.15	3.913	13	12.36	4.92	3.5	3.25	7.14	14.84	16.25	8.68	Scattered	Average
2	140	98.15	29.35	35.2	36.24	2.870	12.5	13.16	5.02	3.5	3.31	5.43	12.67	12.23	3.47	No Defect	Good
3	140	98.15	42.75	34.9	36.17	3.511	13	13.27	2.03	4	3.39	9.25	12.94	12.48	3.55	Crack	Good
4	140	123.8	36.85	36.4	33.15	8.929	11.5	12.05	4.56	4.5	4.35	3.33	12.47	12.36	0.88	Lack of fusion	Average
5	140	123.8	29.35	36.7	37.14	1.185	12	12.45	3.61	3.5	3.48	0.57	15.52	16.05	3.30	No Defect	Excellent
6	140	123.8	42.75	33.2	33.35	0.450	10	10.65	6.10	5.5	5.47	0.55	3.64	3.96	8.08	Lack of fusion	Poor
7	140	150.8	36.85	35	34.12	2.514	9	8.45	6.11	2.5	2.69	7.06	5.28	5.36	1.49	No Defect	Excellent
8	140	150.8	29.35	36.5	39.15	6.769	10.5	11.25	6.67	6.5	6.74	3.56	3.53	3.45	2.27	Crack, Under cut	Poor
9	140	150.8	42.75	35.6	33.65	5.478	9.5	10.5	9.52	3.5	3.74	6.42	15.94	15.62	2.01	No Defect	Good
10	130	98.15	36.85	24.3	26.15	7.075	11	11.48	4.18	4.5	4.36	3.11	8.84	8.25	6.67	No Defect	Average
11	130	98.15	29.35	28.3	30.25	6.446	12	13.05	8.05	4.5	4.84	7.02	14.85	14.26	3.97	Pin hole, under cut	Poor

January - February 2020
ISSN: 0193 - 4120 Page No. 6968 - 6976

12	130	98.15	42.75	33.4	33.15	0.749	12.5	13.45	7.06	6	6.26	4.15	13.41	13.54	0.96	Scattered	Poor
13	130	123.8	36.85	36.5	37.25	2.013	11	11.25	2.22	4.5	4.15	7.78	10.93	11.26	2.93	Pin hole	Average
14	130	123.8	29.35	33.4	33.45	0.149	11.5	12.36	6.96	4	3.87	3.25	19.11	20.35	6.09	Crack	Good
15	130	123.8	42.75	33.4	35.15	4.979	12.5	12.47	0.24	5.5	5.45	0.91	9.59	10.15	5.52	Scattered	Average
16	130	150.8	36.85	35.7	39.15	8.812	11	11.48	4.18	3.5	3.65	4.11	10.54	10.69	1.40	Scattered	Poor
17	130	150.8	29.35	38	34.23	9.921	11	11.47	4.10	4.5	4.26	5.33	6.64	7.15	7.13	No Defect	Average
18	130	150.8	42.75	37.9	38.15	0.655	13	14.37	9.53	3	3.14	4.46	8.37	9.15	8.52	Pin holes	Excellent
19	150	150.8	42.75	27.7	31.25	11.360	13.5	14.26	5.33	4.5	4.17	7.33	14.15	15.15	6.60	No Defect	Good
20	150	98.15	36.85	27.7	24.97	9.856	16.5	17.36	4.95	5.5	5.68	3.17	5.44	5.78	5.88	No Defect	Poor
21	150	98.15	29.35	30.6	32.69	6.393	14	15.25	8.20	3	3.16	5.06	20.85	21.26	1.93	Pin holes	Average
22	150	123.8	42.75	30.6	33.78	9.414	15	16.23	7.58	5.5	5.36	2.55	12.18	13.26	8.14	Crack, Pin hole	Poor
23	150	123.8	29.35	25.7	28.36	9.379	11.5	12.36	6.96	3.5	3.36	4.00	22.73	23.26	2.28	No Defect	Excellent
24	150	123.8	36.85	31.1	33.24	6.438	12	12.58	4.61	4	4.12	2.91	12.96	12.64	2.47	No Defect	Good
25	150	150.8	36.85	32	33.26	3.788	11	11.25	2.22	4.5	4.32	4.00	16.2	16.36	0.98	Scattered	Average
2	1	15	29	32	33.	3.5	12	13	5.	3	3.	4.76	29	28.	3.	Scattered	Poor

6	5 0	0. 8	.3 5	.5	7	61	.5	.1 6	02		15		.1 7	15	5 0		
2 7	1 5 0	98 .1 5	42 .7 5	32	35. 08	8.7 80	12 .5	13 .2 5	5. 66	4. 5	4. 12	8.44	14 .2 6	15. 28	6. 6 8	Scattered	Poor

The above table shows the experimental and predicted valuesof Hardness, Height, Width and Fe content with the corresponding defects and status of the sample

III. CONCLUSION

In this study Welding experiments were conducted by using the parametric approach of the Taguchi's method with L27 orthogonal array. Inputs were simulated in Fuzzy Interface system with fixed rules. A Fuzzy model was developed to predict the Hardness, Dimensions and Fe content over the experimental region. The experimental values are compared with the fuzzy model and it is found that the maximum Percentage Error of 11.36% for hardness, 9.53% for Width, 9.25% for Height and 8.68% for Iron content, thus underlying the satisfactory performance of the prediction model.This conforms the reliability of Fuzzy Logic as one of the most accuratePrediction approaches.

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