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An Implementation of Fuzzy Logic Technique to Predict the Material Removal Rate in Abrasive Water Jet Machining Process

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ABSTRACT

In this study, the material removal rate values, obtained using machining abrasive water jet (AWJM), were modelled using fuzzy logic. The input variables considered are pressure, abrasive flow rate, orifice diameter, focusing tube diameter and standoff distance while the output variable was material removal rate (MRR). Fuzzy logic was developed using Matlab 2013.The mean absolute percentage errors (MAPE) of the predicted values was employed to compare the results with the previously published results obtained using response surface method technique. . The results showed that the predictive model using fuzzy logic model has reduced the errors by 0.28%, which means, using fuzzy logic model to predict material removal rate is sufficiently accurate.

Keywords: *Prediction, Material Removal Rate, Fuzzy logic model.*

1. Introduction

Abrasive water jet cutting is a novel machining process capable of processing wide range of hard-to-cut materials. The cutting power is obtained by means of a transformation of a hydrostatic energy (400MPa) into a jet of an ample kinetic energy (nearly 1000 m/s) to disintegrate the material. The required energy for cutting materials is obtained by pressurizing water to ultrahigh pressure and forming an intense cutting stream by focusing high-speed water through a small orifice. The use of the AWJ cutting is based on the principle of erosion of the material by the impact of jets. Each of the two components of the jet, i.e. the water and the abrasive material has a specific purpose. The primary purpose of the abrasive material within the jet stream is to provide the erosive forces. Abrasive water jet process is similar to Abrasive Jet Machining AJM excluding that in this case water is used as a carrier fluid in place of gas. These processes offer merit of cutting electrically non-conductive as well as difficult to machine materials comparatively more rapidly and efficiently than other processes.

Figure 1 shows the cutting head of AWJM which includes mainly orifice abrasive mixer, focusing tube, and nozzle [1], and was a studied prediction of MRR and SR for Aluminum 6061 alloy by machining through Abrasive water jet machining parameters in put pressure, abrasive flow rate, orifice diameter, focusing tube diameter and standoff distance on the response (MRR) using Fuzzy Logic (FL) [2].

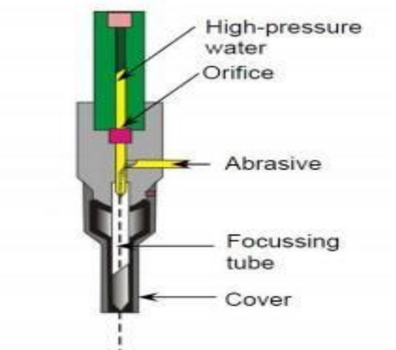

Fig. 1: Cutting head of AWJM [1].

The objectives of this paper are stated as follows:

- To predict material remove rate (MRR) using Fuzzy logic, as a function of five different parameters pressure, abrasive flow rate , orifice diameter, focusing tube diameter and standoff distance ,
- To compare results with a previous work.

2. Experimental details

2.1. Material

Copper Iron Alloy was the target material used in this experiment.

2.2. Experimental design

The number of experiments shown in Table 1 was obtained from previous work [1]. As there are five input parameters namely water pressure, abrasive flow rate, orifice diameter, nozzle diameter and standoff distance therefore total 26 experiments were studied. The output response selected for these experiments is Material Removal Rate (MRR). The MRR has been calculated using the following expression.

$$MRR= (W_i – W_f) / T_m (1)$$

where:

W_i = Initial Weight (kg).

W_f= Final Weight (kg).

T_m = Machining Time(min).

The upper (+1) and lower (-1) levels of all the four parameters and their designations are shown in Table 2.

Table 1: Experimental Data of Cutting (AWJM) of Copper Iron Alloy.

Exp. No.	Pressure (Bar)	Abrasive flow rate (kg/min)	Orifice diameter (mm)	Focusing tube diameter (mm)	Standoff distance (mm)	MRR (mm^3/min)
1	3400	0.55	0.33	0.99	3	897.8
2	3600	0.55	0.33	0.99	1	1000.03
3	3600	0.55	0.3	1.05	2	961.93
4	3600	0.55	0.33	0.9	3	918.21
5	3800	0.55	0.33	0.9	2	1043.96
6	3600	0.55	0.33	0.99	2	928.76
7	3400	0.4	0.33	0.99	2	762.29
8	3600	0.7	0.35	0.99	2	985.39
9	3800	0.55	0.33	0.99	3	987.8
10	3800	0.55	0.3	0.99	2	1025.41
11	3600	0.55	0.33	0.99	3	907.89
12	3400	0.55	0.33	1.05	2	800.02
13	3600	0.4	0.33	0.99	1	920.3
14	3600	0.55	0.33	0.99	2	922.4
15	3600	0.55	0.35	0.9	2	948.38
16	3600	0.55	0.3	0.9	2	950.62
17	3400	0.55	0.33	0.9	2	817.84
18	3600	0.55	0.33	0.99	2	897.8
19	3600	0.4	0.3	0.99	2	827.89
20	3400	0.55	0.35	0.99	2	814.54
21	3800	0.4	0.33	0.99	2	961.93
22	3600	0.7	0.33	0.99	3	997.56
23	3600	0.7	0.33	0.99	1	987.8
24	3600	0.4	0.35	0.99	2	846.98
25	3600	0.4	0.33	0.9	2	863.27
26	3600	0.55	0.35	0.99	3	928.76

Table 2: Factors and their levels

Levels	Pressure (Bar)	Abrasive flow rate (kg/min)	Orifice diameter (mm)	Focusing tube diameter(mm)	Standoff distance (mm)
Low	3400	0.4	0.3	0.9	1
Medium	3600	0.55	0.33	0.99	2
High	3800	0.7	0.35	1.05	3

Table 3: Fuzzy Rule for AWJM of Copper Iron Alloy.

1. IF Pressure is Low AND Abrasive flow rate is Medium AND Orifice diameter is Medium and Nozzle diameter is Medium AND Standoff distance is High THEN Material removal rate is Low.
2. IF Pressure is Medium AND Abrasive flow rate is Medium AND Orifice diameter is Medium and Nozzle diameter is Low AND Standoff distance is Low THEN Material removal rate is Very High..

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26. IF Pressure is Medium AND Abrasive flow rate is Medium AND Orifice diameter is High and Nozzle diameter is Medium AND Standoff distance is High THEN Material removal rate is Medium.

3. DEVELOPMENT OF THE MODEL

Fuzzy logic is a highly flexible and non-linear modeling technique with an ability to learn the relationship between input variables and output features [3]. The most successful applications of fuzzy set theory is observed in modeling the experimental data involving certain uncertainties between the relationships of input process variables and responses[3][4]. Its major features are the use of linguistic variables rather than numerical variables. Linguistic variables are defined as the variables whose values are sentences in natural language (such as low, medium and high) and can be represented by fuzzy sets. Fuzzy sets are characterized by fuzzification, membership functions, a fuzzy rule, an inference system and a defuzzification inference. The structure of five inputs, one output fuzzy logic controller developed for this present research is shown in Figure 2. The inputs values to the model were given in linguistic form and after fuzzification, the outputs were obtained in crisp form.

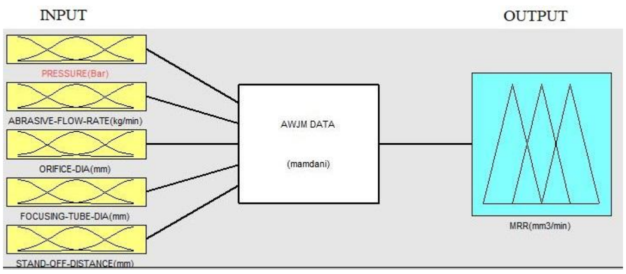

Fig. 2: Input-Output Parameters of Fuzzy Logic Control Model.

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The fuzzy rules are expressed in the form of fuzzy conditional statements R_i of the type R_i: if x is small, y is large THEN z is large Where x and y are fuzzy variables, and small and large are labels of fuzzy set.

If there are i= 1to n rules, the rule set is represented by union of these rules, R= R_1 else R_2 else. R [3].

A fuzzy logic controller is based on a collection of control rules. The execution of these rules is governed by the compositional rule. In this study, the triangular membership functions were used for the input process parameters such as water pressure, abrasive flow rate, orifice diameter, nozzle diameter and standoff distance to predict the material removal rate in AWJM of Copper Iron Alloy.The membership function for each input variables were divided into three levels (low, medium and high) and output variable was divided into six levels (very very low, very low, low, medium, high and very high).The fuzzy logic controller was Median type and contained a rule base. This base comprised of groups of rules and each output was defined by twenty-six rules. The rules based on knowledge to predict the material removal rate in AWJM of Copper Iron Alloy are given in Table 3.

The fuzzy inputs are linguistically divided into three levels such as low (L), medium (M) and high (H) which shown in Figure 3.

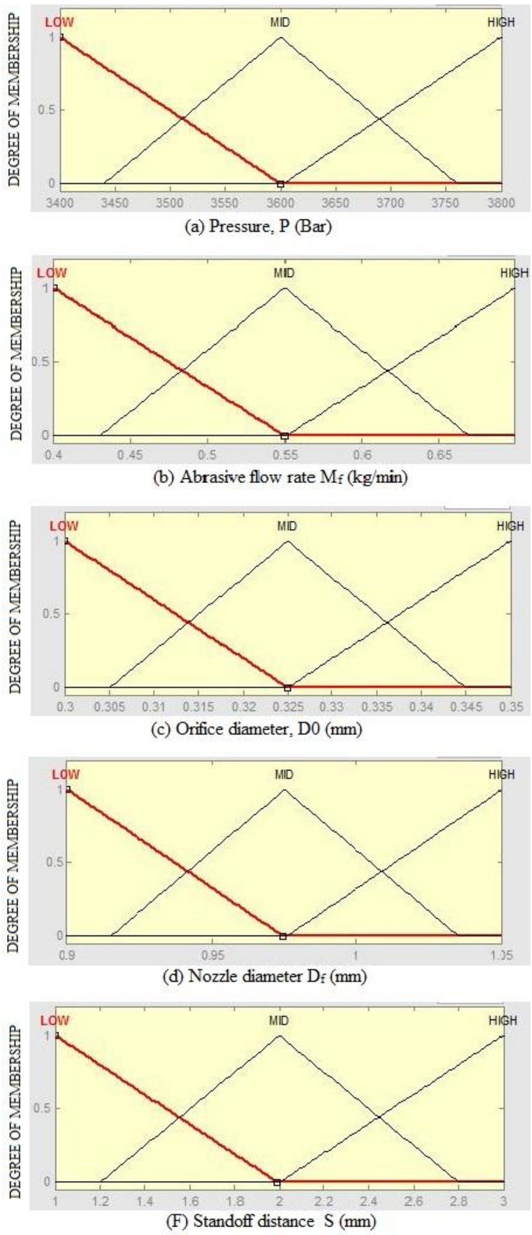

Fig. 3: Membership functions for input process parameters: (a) Pressure, P (b) Abrasive flow rate, M_f (c) Orifice diameter, D_0 (d) Nozzle diameter, D_f and (F) Standoff distance, S of AWJM of Copper Iron Alloy

Figure 4 shows the fuzzy output linguistically divided into six levels such as v v low (VVL), very low (VL), low (L), medium (M), high (H) and very high (VH).

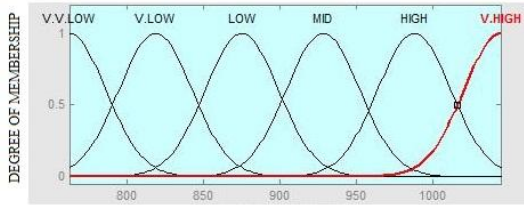

Fig. 4: Material removal rate MRR (mm3/min).

4. Simulation of Fuzzy Logic Model

In this study, the fuzzy model has been developed based on 26 experiments of AWJM of Copper Iron Alloy process parameters. The fuzzy model was simulated for test cases that has been done within the range of the fuzzy set. The experiments was conducted for the three levels of each process parameters. The purpose of the simulation was to minimize the error of outputs for test case experiments. A MATLAB Simulink model was developed to predict material removal rate of the AWJM of Copper Iron Alloy process. Moreover, to confirm the adequacy of fuzzy logic model, the predicted values of the material removal rate predicted by using the proposed fuzzy model were compared with the previously published predicted values of the material removal rate of the AWJM of Copper Iron Alloy process by using RSM, these comparison is shown in Table 4 (Appendix) with their mean absolute percentage error (MAPE).The MAPE for the predicted of material removal rate by using the proposed fuzzy logic model is lower than the predicted of material removal rate by using RSM, percentage of the error was observed to be 0.28 % .

5. Conclusions

In this study, an attempt was made to predict the material removal rate in AWJM of Copper Iron Alloy as affected by the pressure, abrasive flow rate, orifice diameter, focusing tube diameter and standoff distance. The fuzzy clustering technique used was found to be adequate for establishing the relationship between the input process parameters and the output.The developed fuzzy logic model was also tested by comparing the results with a previously published results using RSM technique. The comparison was carried out based on the mean absolute percentage error between the predicted values and the experimental values and is shown in Figure 5.The fuzzy model gave lower mean absolute percentage error.

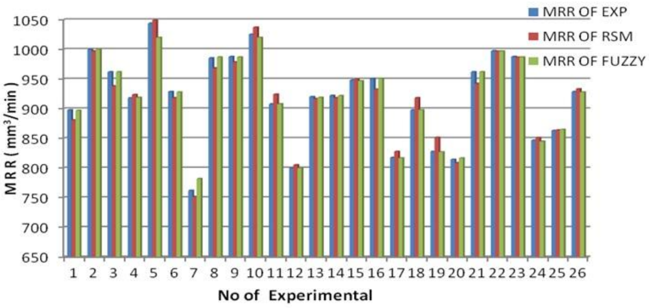

Fig. 5: Comparison of results between experimental and predicted MRR using RSM and fuzzy logic.

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APPENDIX

Table 4: The Experimental, Predicted and Mean Absolute Percentage Error of the Material Removal Rate of the AWJM of Copper Iron Alloy for Test Cases.

No.	Experimental MRR, (mm^3/min)	Predicted MRR, Using Fuzzy, (mm^3/min)	Predicted MRR, Using RSM,(mm^3/min)	Error Using Fuzzy (%)	Error Using RSM (%)
1	897.8	897	880.93	0.000891	1.878906494
2	1000.03	1000	997.11	3E-05	0.291186314
3	961.93	962	938.19	7.28E-05	2.467892154
4	918.21	919	923.71	0.00086	0.599155912
5	1043.96	1020	1049.13	0.022951	0.495263181
6	928.76	928	918.39	0.000818	1.116425826
7	762.29	782	751.80	0.025856	1.375881882
8	985.39	987	968.45	0.001634	1.718833863
9	987.8	987	978.60	0.00081	0.931023537
10	1025.41	1020	1037.33	0.005276	1.16340927
11	907.89	908	924.33	0.000121	1.810895979
12	800.02	800	805.25	2.5E-05	0.654058586
13	920.3	919	916.79	0.001413	0.380924047
14	922.4	922	918.39	0.000434	0.434618007
15	948.38	947	949.67	0.001455	0.136459278
16	950.62	951	932.76	0.0004	1.878030128
17	817.84	817	827.91	0.001027	1.232423151
18	897.8	898	918.39	0.000223	2.293504511
19	827.89	827	851.72	0.001075	2.879229729
20	814.54	817	808.75	0.00302	0.710341972
21	961.93	962	942.45	7.28E-05	2.024161633
22	997.56	997	996.82	0.000561	0.073196499
23	987.8	987	986.82	0.00081	0.098440879
24	846.98	845	851.37	0.002338	0.519131503
25	863.27	865	864.11	0.002004	0.097367683
26	928.76	928	933.38	0.000818	0.497468291