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ROUGHNESS OF A MACHINED SURFACE IN MILLING OPERATION FOR FERROUS AND NON FERROUS A FUZZY LOGIC BASED MODEL TO PREDICT SURFACE MATERIALS USING HSS END MILL CUTTING TOOL

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ABSTRACT

Nowadays every manufacturing and industrial industry has to focus on the manufacturing of quality products. Manufacturing of these kinds product with higher accuracy, better surface finish, lower maintenance and lower process planning and manufacturing cost are very important factor that can achieved by using non-conventional optimization techniques instead of conventional techniques. Many of non-conventional optimization techniques like Fuzzy Logic approach based technique, Genetic algorithms, Artificial Neural Network, Particle Swarm optimization, Ant colony optimization, Scatter search technique and simulated Annealing etc. are used to optimization of surface roughness.

Milling is a machining operation in which workpiece is fed below the cylindrical rotating multi point cutting tool, multi point cutting tool having multiple cutting edges. On the basis of literature review, many machining parameters such as cutting speed, feed rate, depth of cut, cutting fluid pressure etc. and performance parameters as surface roughness, material removal rate, tool wear ratio, tool vibration etc., were observed for CNC milling operation. The correct selection of machining parameters is very important factor to achieve best performance measure.

In this research work, spindle speed (SS), feed rate (FR) and depth of cut (DOC) are selected as machining parameters while surface roughness is considered as performance parameters to perform end milling operation on the workpiece materials of 6101 Aluminum alloy, Copper of electrolytic grade and Mild Steel 2062 by using High Speed Steel (HSS) end mill cutter of 12 mm diameter. Minimum experiment trials are designed by Taguchi based L9 (3^3) orthogonal array with the help of Minitab 17.0 software and a fuzzy logic approach based model is taken as to predict the value of surface roughness of a machined surface in 6101 aluminum alloy, Copper of Electrolytic grade and Mild Steel 2062 milling operation using HSS end mill cutter of 12 mmdiameter. Three membership functions are allocated to be connected with each input of the model. The predicted results achieved via fuzzy logic model are compared to the experimental result. The result demonstrated settlement between the fuzzy model and experimental results with the 95.618% model accuracy for 6101 aluminum alloy material, 83.849% for copper (Electrolytic grade) and 98.334% Mild Steel 2062.

KEYWORDS: CNC Milling machine, Aluminum milling, Copper milling, Mild Steel milling, Surface roughness, Machining Parameters, Performance Parameters, Fuzzy logic Approach based model.

INTRODUCTION

At present many of conventional machining tool has been replaced by CNC machine tools. Among the metal cutting methods, milling is one of the most widely used manufacturing processes in manufacturing industry in which a multi-point cutting tool with multiple cutting edges removes desired material from the surface of a work piece.

Ferrous material like 6101 aluminum alloy and Copper of electrolytic grade, and non-ferrous material of Mild Steel 2062 which is widely used and easily available in the market. Mechanical and physical properties of these materials play a vital role for many different manufacturing and industrial applications. Manufacturing of these kinds product with higher accuracy, better surface finish, lower maintenance, lower process planning and manufacturing cost are very important factor to every industry. To achieve these aspects non-conventional technique like fuzzy logic can be used.

Surface roughness or simply called as roughness is the measure of surface texture. Its unit is µm (Micrometers). It can be defined as the vertical deviation of real surface from ideal surface. If the deviation is more, it is said as rough surface and if the deviation is less, it is said as smooth surface.

The surface roughness data obtained by measurement can be used to determine the surface roughness parameter. There are many different roughness parameters in use, but R_a (Center line average roughness) is the most common. Other common parameters are namely Ten point mean roughness (R_z), Root mean square roughness (R_q), Skewness (R_{sk}), Kurtosis (R_{ku}) and Mean line peak spacing (R_{sm}). Surface roughness is mainly affected by different machining parameters, such as spindle speed (SS), feed rate (FR), depth of cut (DOC).
On the basis of literature review, Fuzzy logic has great capability to capture human commonsense reasoning, decision-making and other aspects of human cognition. Fuzzy logic shows that it overcomes the limitations of classic logical systems, which impose inherent restrictions on representation of imprecise concepts. Vagueness in the coefficients and constraints may be naturally modelled by fuzzy logic. Modelling by fuzzy logic opens up a new way to optimize cutting conditions and also tool selection. This paper implements the fuzzy logic approach based model to cultivate the rule model in order to predict the value of surface roughness of a machined surface during end milling operation using High Speed Steel (HSS) end mill cutter of 12 mm diameter with four flutes. The fuzzy logic theory based model has the following structure as shown in Fig. 1 which is step by step discussed below:
1. Fuzzification: Fuzzification is as making something like fuzzy.
2. Fuzzy rule base: In the rule base, the if-then rules are applied to fuzzy rules.
3. Fuzzy inference engine: Fuzzy inference engine produces a map of the fuzzy set in the space entering the fuzzy set of input parameters and in the space leaving the fuzzy set of performance parameter, according to the rules if-then.
4. Defuzzification: Defuzzification making something non fuzzy.
which some techniques have been used to perform various operations of CNC milling. This paper brings to the forefront the work done in this area, the techniques used along with the results established.

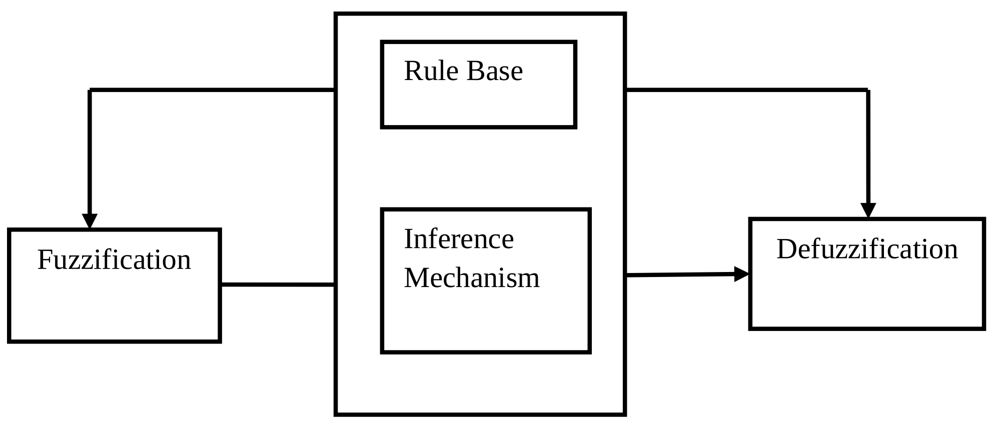

Fig. 1 The structure of a fuzzy system

LITERATURE SURVEY

Aguero E. et. al. [1] has studied on "fuzzy model of cutting process on a milling machine."

Y. M. Ali et. al. [2] has done work on Surface roughness prediction of ground components using a fuzzy logic approach.

Joseph C. Chen et. al. [3] Worked on an effective fuzzy-nets training scheme for monitoring tool breakage.

J.C. Chen et. al. [4]investigated a fuzzy net based multilevel in-process surface recognition system in milling operation.

V. Susanto et. al.[5]Worked on a fuzzy logic based in-process tool-wearmonitoring System in face milling operations.

Ashif Iqbal et. al. [6]have discussed ona fuzzy expert system for optimization of high-speed milling process.

Shibendu Shekhar Roy [7] has done work on an adaptive-network based fuzzy approach for prediction of surface roughness in end milling.

Amit Joshi & Pradeep Kothiyal, [8] applied "Investigating effect of Machining Parameters of CNC milling on Surface finish by Taguchi Method".

Jignesh G. Parmar et. al. [9]has worked on "Prediction of surface roughness for end milling process using Artificial Neural Network".

Ahmed A. D. et. al. [10] have done an experimental work on a fuzzy logic based model to predict surface roughness of a machined surface in glass milling operation using CBN grinding tool.

Patel K. P.[11] has done work on experimental analysis on surface roughness of CNC end milling process using Taguchi Design Method.

V V K Lakshmi et.al. [12] Conducted experiment on modeling and optimization of process parameters during end milling of hardened steel.

Pinki Maurya et.al. [13] have done work onimplementation of taguchi methodology to optimization of CNC end milling process parameters of AL6351 –T6.

R Ashok Raj et. al. [14] has done an experiment on "Optimization of milling parameters of EN8 using Taguchi methodology".

Anish Nair & Dr. P Govindan [15]were investigated "Multiple Surface Roughness Characteristics Optimization in CNC End Milling of Aluminium using PCA".

K. Simunovic et. al. [16]has done an experiment on Predicting the Surface Quality of Face Milled Aluminums Alloy Using a Multiple Regression Model and Numerical Optimization.

Kannan S. et. al. [17] has worked on modeling and optimization of face milling Operation based on response surface methodology and genetic algorithm.

J. S. Pang et. al. [18]have worked on taguchi design optimization of machining parameters on the CNC end milling process of halloysite nanotube with aluminium reinforced epoxy matrix (HNT/Al/Ep) hybrid composite.

G. Harii Krishna Rao et. al. [19] has investigated the effect of cutting parameters on the surface roughness of MWCNT reinforced epoxy composite using CNC end-milling process.

D S Sai Ravi Kiran et. al. [20] have worked on multi objective optimization of tool life and total cost using 3- level full factorial method in CNC end milling process.

Anmol Kumar et. al. [21] investigated the optimization of cutting parameters of AISI H13 with multiple performance characteristics equipment's and material.

Based on the literature review it is found that the optimization of machining parameters to achieve minimum surface roughness for ferrous and non-ferrous materials such as 6101 aluminum alloy, Copper of electrolytic grade and Mild Steel 2062 from Taguchi's L9 orthogonal array using Minitab Software, Fuzzy logic approach based model using MATLAB Software has yet not been attempted hence this can be taken as research problem.

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EXPERIMENTATION

Selection of the workpiece:

The 6101 aluminum alloy, Copper (Electrolytic grade) and Mild Steel 2062 are selected, as shown in fig 2 (A), 2 (B) and 2 (C), as the work material for the experiment study. The selection of these three materials is based on their extensively industrial application. The chemical composition, physical properties and application of these materials are discussed in Table 3.4, 3.5 and 3.6 respectively.

Dimension of specimens are taken 90*70*10 mm.

Fig. 2 (A) 6101 aluminum alloy

Fig 2 (B) Copper (Electrolytic)

Fig. 2 (C) Mild Steel 2062

Table 1 (A):Chemical Composition and Physical Properties of 6101 Aluminum alloy:-

Chemical composition of Aluminum alloy 6101 in % max value

Aluminum (Al)	Balance
Boron (Br)	0.06 % max
Chromium (Cr)	0.03 % max
Copper (Cu)	0.1 % max
Iron (Fe)	0.5 % max
Magnesium (Mg)	0.35-0.7 %
Manganese (Mn)	0.03 % max
Remainder Each	0.03 % max
Remainder Total	0.01 % max
Silicon (Si)	0.3-0.7 %
Zinc (Zn)	0.1 % max

Physical properties of 6101 Aluminum alloy

Density (lb / cu. in.)	0.097
Specific Gravity	2.7
Melting Point (Deg F)	1090
Thermal Conductivity	1200
Modulus of Elasticity Tension	10
Tensile strength	97 Mpa
Yield strength	76 Mpa
Elastic modulus	70-80 GPa

Table 1(B):Chemical Composition and Physical Properties of Copper Electrolytic grade:-

Chemical composition of Copper Electrolytic Grade

Element	**Content (%)**
Aluminum, Al	97.3-98.3
Silicon ,Si	0.50-0.90
Iron, Fe	0.60-1
Manganese, Mn	0.2
Zinc, Zn	0.1
Copper, Cu	0.1
Titanium, Ti	0.08
Chromium, Cr	0.05
Magnesium, Mg	0.05
Remainder each	0.05
Remainder Total	0.15

Physical Properties of Copper Electrolytic Grade	
Melting Point	1083°C
Density	8.92 g/cm³
Specific heat	385 J/Kg °K
Thermal conductivity	393 W/m°K
Thermal expansion coefficient	(20-200°C) 17.3 x 10-6 Per °C
Electrical conductivity	100 % IACS
Electrical Resistivity	0.0172 x10-6 microhm /m
Modulus of elasticity	11800 N/mm²

Table 1(C):Chemical Composition and Physical Properties of Mild Steel 2062:-

Chemical Composition of Mild Steel 2062:-In % max value

Carbon (%) Max	0.23	+0.02 Tolerance
Manganese (%) Max	1.5	+0.05 Tolerance
Sulphur (%) Max	0.045	+0.005 Tolerance
Phosporous (%) Max	0.045	+0.005 Tolerance
Silicon (%) Max	0.4	+0.03 Tolerance

Physical Properties of Mild Steel 2062:-

Tensile Strength Min, Mpa	mm	240
Yield Stress, Min, Mpa	<20 mm	250
	20-40 mm	240
	>40 mm	230
% Elongation at gauge length 5.65 √So	min	23
Bend Test	min	

	Carbon Equivalent (%) Max	0.42		

The results and discussion may be combined into a common section or obtainable separately. They may also be broken into subsets with short, revealing captions.

Selection of machine tool:

The end milling operation of the selected workpieces is conducted on EMCO Concept MILL 250 machine tool with HSS End mill cutting tool of 12 mm diameter.

Selection of Input Process Parameters:
To conduct CNC milling operation spindle speed, feed rate and depth of cut are selected as input process parameters. Table 2 shows the selected input process parameters and their levels:

Table 2: Independent Process Parameter and their levels for 6101 aluminum alloy, Copper Electrolytic Grade and Mild Steel 2062

INDEPENDENT PARAMETERS	UNITS	6101 ALUMINUM ALLOY			COPPER ELECTROLYTIC GRADE			MILD STEEL 2062		
		Levels			Levels			Levels		
		I	II	III	I	II	III	I	II	III
Feed Rate	mm/rev	900	1000	1100	200	300	400	300	400	500
Spindle Speed	RPM	4500	5000	5500	3000	3500	4000	2500	3000	3500
Depth of Cut	mm	0.3	0.4	0.5	0.5	0.7	0.9	0.20	0.25	0.30

Orthogonal Array:
In this work **L9 (3^3)** OA has been used to carry out the experiment.

Performance parameter:

Surface roughness is selected as output or response parameter which is measured by surface roughness tester.

Mechanism and evaluation of Surface Roughness
Surface roughness or simply called as roughness is the measure of surface texture. Its unit is µm (Micrometers). It can be defined as the vertical deviation of real surface from ideal surface. If the deviation is more, it is said as rough surface and if the deviation is less, it is said as smooth surface. Surface Roughness generally measured by portable type Taylor-Hobson surf tester.

EXPERIMENTAL RESULT

The experimental tests are carried out using the proposed experimental set-up. The measured values of surface roughness are summarized in Table 4 (A), (B) and (C).

Table 4 (A) for Aluminum Alloy 6101		***Table 4 (B) for Copper of electrolytic Grade***		***Table 4 (C) for Mild Steel 2062***	
EXP NO.	MEASURED SURFACE ROUGHNESS, R_A (MM)	EXP. NO.	MEASURED SURFACE ROUGHNESS, R_A (MM)	EXP NO.	MEASURED SURFACE ROUGHNESS, R_A (MM)
1	0.92	1	1.44	1	3.12
2	0.74	2	0.92	2	2.28
3	0.70	3	0.84	3	2.16
4	0.58	4	0.50	4	2.08
5	0.68	5	0.70	5	1.48
6	0.64	6	0.30	6	1.06
7	0.56	7	0.72	7	1.92
8	0.64	8	0.40	8	1.51
9	0.58	9	0.42	9	1.42

FUZZY LOGIC BASEDMODEL TO PREDICT SURFACE ROUGHNESS

The relationship between input process parameters which are the spindle speed, feed rate and depth of cut with the output parameter which is surface roughness of a machined surface in three different materials of Aluminum alloy 6101, Copper of electrolytic grade and Mild Steel 2062 milling operation were referred to construct the rules. Fuzzy linguistic variables and fuzzy expression for input process and output performance parameters are shown in Table 5 (A), Table 5 (B) and Table 5 (C) respectably. For each input variable, three membership functions were used which are Low, Medium and High. Theoutput variable (roughness) also used three membership functions; Best, Average and Worst.

Membership Functions for Input and Output Fuzzy Variables

In selecting the membership functions for fuzzification, In this model, each input and output parameter has three membership functions. Gauss shape of membership function is applied to describe the fuzzy sets for input variables. In output variables fuzzy set, triangular shape of membership functions are used. Triangular membership function is generally used and possesses gradually increasing and decreasing characteristics with only one definite value. The input variables have been divided according to the experiment parameter ranges. Membership functions for fuzzy set input variables are shown in Figs.3 (A), (B) and (C) respectively. Moreover, Fig.4 shows the membership functions for the output surface roughness fuzzy set.

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Table 5 (A) Fuzzy Linguistic and Abbreviation of each parameters for 6101 Aluminum alloy.

INPUTS		RANGE
Parameters	Linguistic Variables	
Feed Rate, FR (mm/min)	Low, Medium, High	900-1100
Spindle Speed, SS (RPM)		4500-5500
Depth of Cut, DoC (mm)		0.3-0.5
OUTPUT		RANGE
Roughness, SR (µm)	Best, Average, Worst	0.56-0.92

Table 5 (B) Fuzzy Linguistic and Abbreviation of each parameters for Copper Electrolytic grade

INPUTS		RANGE
Parameters	Linguistic Variables	
Feed Rate, FR (mm/min)	Low, Medium, High	200-400
Spindle Speed, SS (RPM)		3000-4000
Depth of Cut, DOC (mm)		0.5-0.9
OUTPUT		RANGE
Roughness, SR (µm)	Best, Average, Worst	0.30-1.44

Table 5 (C) Fuzzy Linguistic and Abbreviation of each parameters for Mild Steel 2062

INPUTS		RANGE
Parameters	Linguistic Variables	
Feed Rate, FR (mm/min)	Low, Medium, High	300-500
Spindle Speed, SS (RPM)		2500-3500
Depth of Cut, DOC (mm)		0.2-0.3
OUTPUT		RANGE
Roughness, SR (µm)	Best, Average, Worst	1.06-3.12

Structure of fuzzy rules

A set of 9 rules have been constructed based on the actual experimental surface roughness of a machined surface in Aluminum, Copper and Mild Steel milling operation using HSS end mill cutting tool. Experimental results were simulated in the MATLAB software on the basis of Mamdani fuzzy logic rule base system.

Membership functions for input and output variables

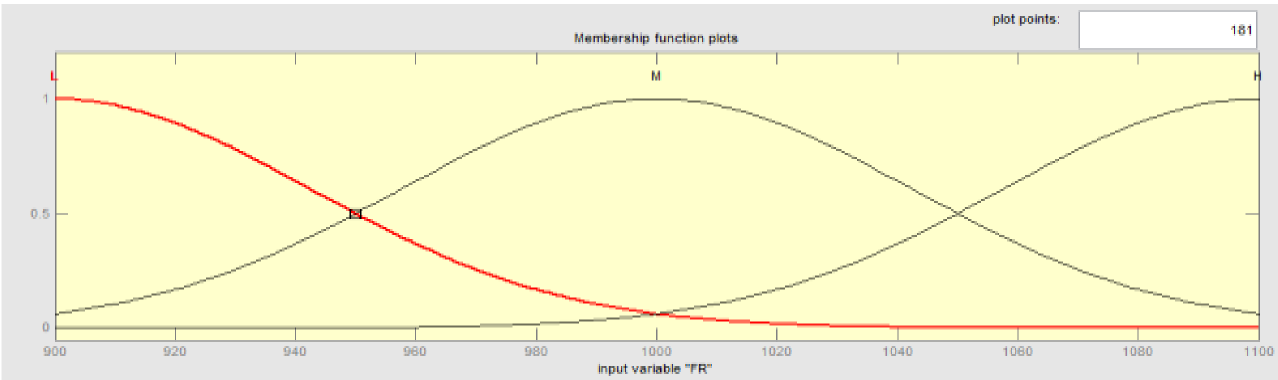

Fig. 3(A) Input Variable "Feed Rate"

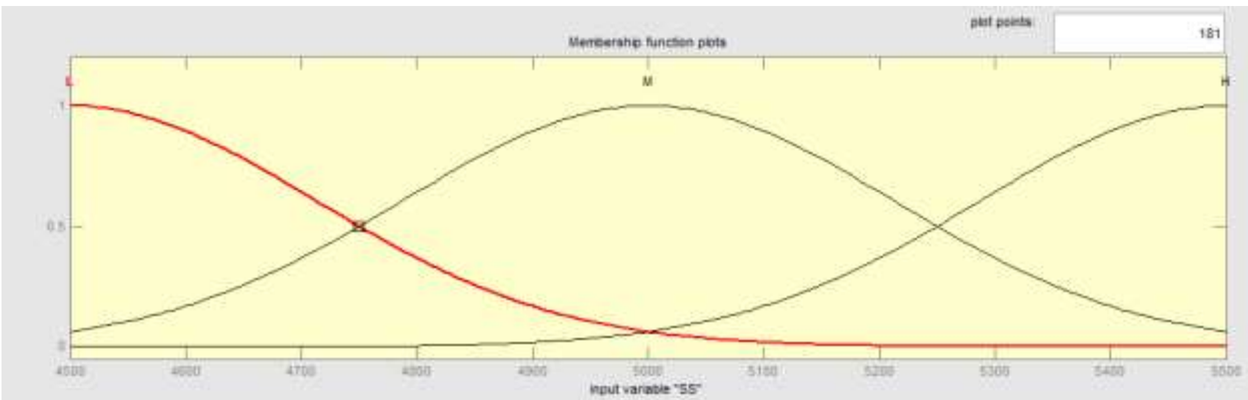

Fig. 3(B) Input Variable "Spindle Speed"

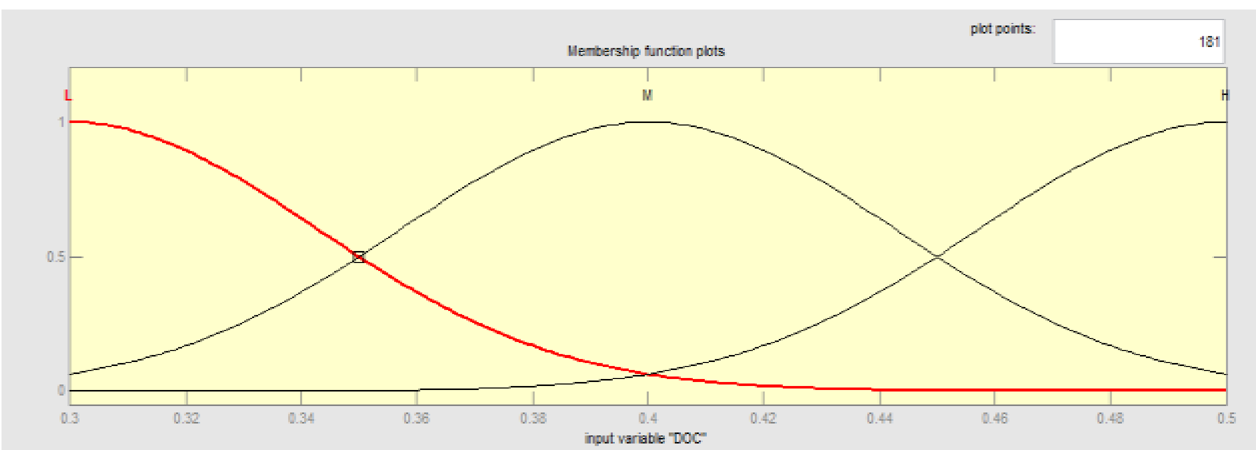

Fig. 3(C) Input Variable "Depth of Cut"

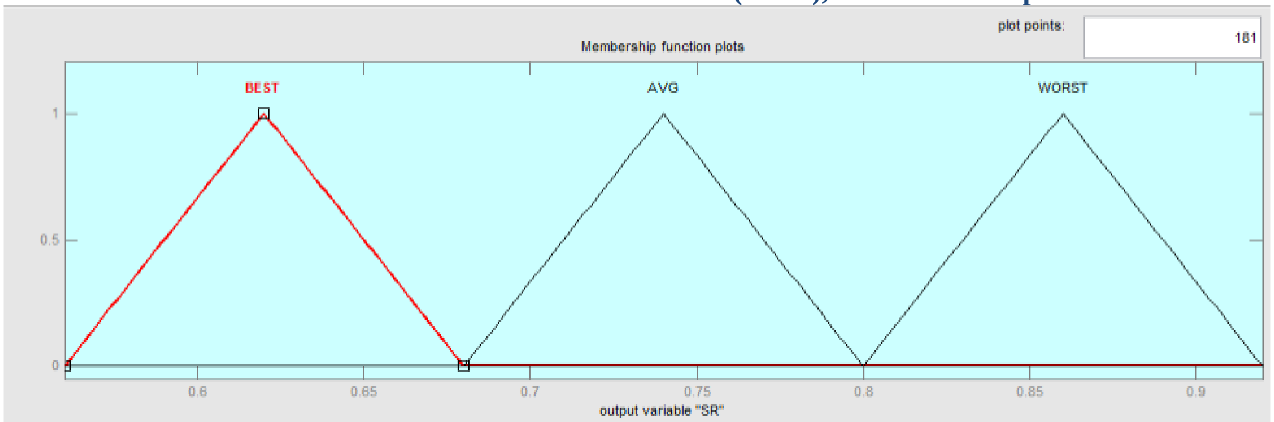

Fig. 4 Output Variable "Surface Roughness"

Defuzzification

Defuzzification is the process of converting a fuzzy quantity to a precise value, just like fuzzification is the process of converting precise value to a fuzzy quantity. In defuzzification process, seven methods are available in literatures to be used by researchers for defuzzifying methods which include centroid of Area, weight area, center of sum, mean of max, center of largest area, first (or last) of maximum method. The selection of method is important and it greatly effects the speed and accuracy of the model. In this model, centroid of area defuzzification method is used for three different materials due to its extensive capability in giving more accurate result compared to the other methods. In this method, the resultant functions are developed by considering the union of each rule, which means that the overlapping of output set is counted as one, providing more result. **Figure 5** displays the graphical representation of defuzzification method. The shape refers to the remaining area of active fuzzy sets that are controlled by the related fuzzy rules.

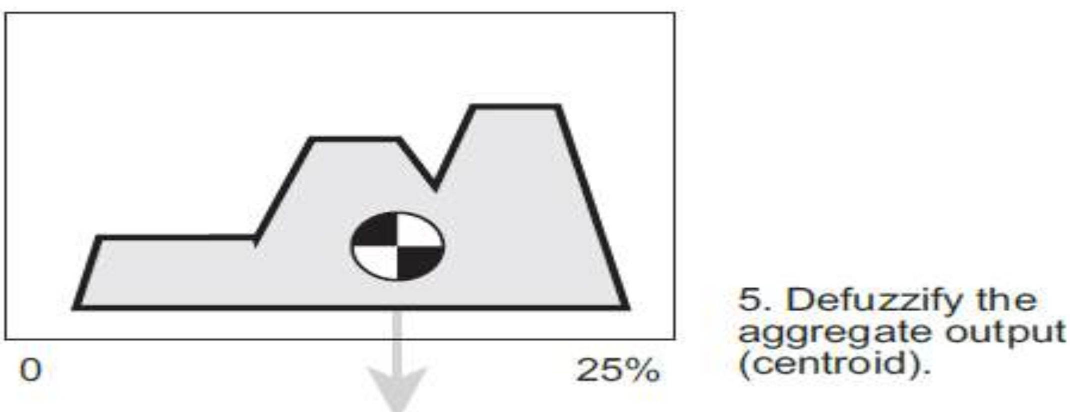

Fig. 5 Graphical of Centroid Area Method

Figure 6 (A) and (B) are the examples to shows the relationship between input parameters change and surface roughness of machined surface in milling operation of three different materials like 6101 Aluminum alloy, Copper of electrolytic grade and Mild Steel 2062 predicted by fuzzy logic based model.

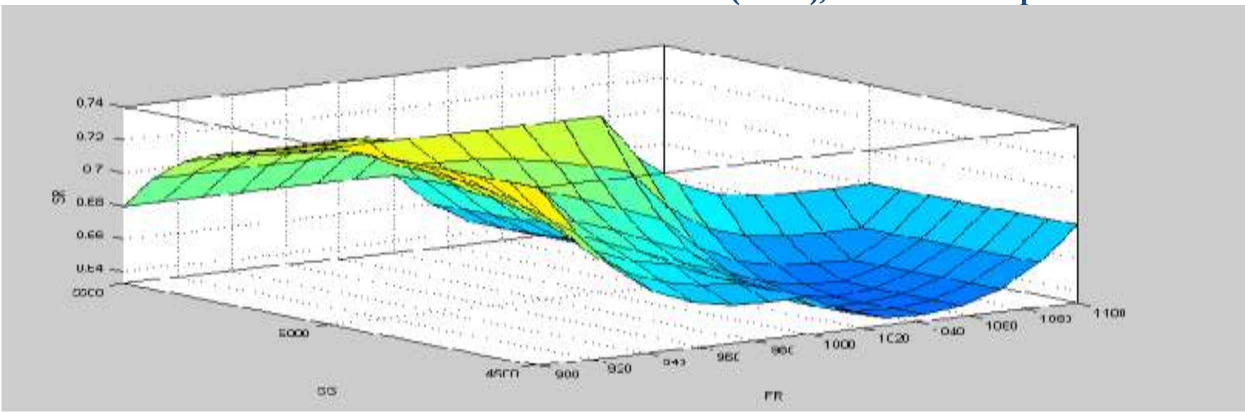

Fig.6 (A) Surface roughness in relation to change of Feed rate and Spindle speed

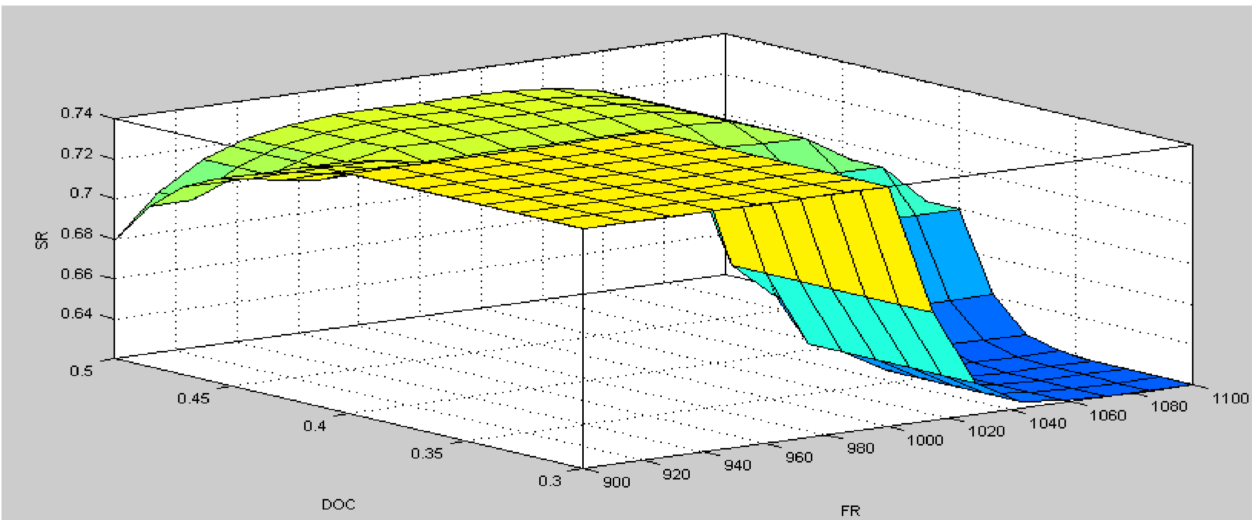

Fig 6 (B) Surface roughness in relation to change of Feed rate and Depth of cut

INVESTIGATION OF FUZZY MODEL ACCURACY AND ERROR

➢ ***Individual Error %***

The individual error percentage is obtained by the formulae of individual error percentage which is the divination of the absolute difference of the predicted and measured value and the measured value.

$$e_i = \left(\frac{|R_m - R_p|}{R_m}\right) \times 100\%$$

Where e_i is the individual error, and R_m and R_p are measured and predicted value of surface roughness.

➢ ***Accuracy and Model Accuracy***

The aim of calculation of accuracy is the measurement of the closeness of the predicted value to the measured value. The model accuracy is calculated as the average of all individual accuracies as shown in Equation (8).

$$A = \frac{1}{N}\sum_{i=1}^{N}\left(1 - \frac{|R_m - R_p|}{R_m}\right) \times 100\%$$

Where A is the Model accuracy and N is total number of performed experiment.

Prediction of the accuracy and error for work piece of 6101 aluminum alloy:-

Table 6 shows the prediction of the accuracy and error for the workpieces of 6101 Aluminum Alloy.

Table 6 Prediction of the accuracy and error for the workpieces of 6101 Aluminum Alloy

No. of Exp.	Parameters (Inputs)			Surface roughness (Output) (µm)		Error %	Accuracy %
	A	B	C	Measured Surface roughness R_a	Predicted Surface roughness R_a		
1	900	4500	0.3	0.92	0.825	10.326	110.326
2	900	5000	0.4	0.74	0.74	0	100
3	900	5500	0.5	0.7	0.74	-5.714	94.286
4	1000	4500	0.4	0.58	0.655	-12.931	87.069
5	1000	5000	0.5	0.68	0.727	-6.912	93.088
6	1000	5500	0.3	0.64	0.633	1.093	101.093
7	1100	4500	0.5	0.56	0.633	-13.036	86.964
8	1100	5000	0.3	0.64	0.62	3.125	96.875
9	1100	5500	0.4	0.58	0.633	-9.138	90.862

The prediction of model accuracy for workpiece of 6101 aluminum alloy is 95.618 % which was calculated by the formulae of Model accuracy.

Prediction of the accuracy and error for work piece of Copper Electrolytic grade:-

Table 7 shows the prediction of the accuracy and error for the workpieces of Copper Electrolytic grade.

Table 7 Prediction of the accuracy and error for the workpieces of Copper Electrolytic grade

NO. OF EXP.	PARAMETERS (INPUTS)			SURFACE ROUGHNESS (OUTPUT) (MM)		ERROR %	ACCURACY %
	A	B	C	Measured Surface roughness R_a	Predicted Surface roughness R_a		
1	200	3000	0.5	1.44	1.19	17.361	117.361
2	200	3500	0.7	0.92	0.87	5.435	105.435
3	200	4000	0.9	0.84	0.87	-3.571	96.429
4	300	3000	0.7	0.5	0.55	-10	90
5	300	3500	0.9	0.7	0.861	-23	77
6	300	4000	0.5	0.3	0.525	-75	25
7	400	3000	0.9	0.72	0.861	-19.583	80.417
8	400	3500	0.5	0.4	0.448	-12	88
9	400	4000	0.7	0.42	0.525	-25	75

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The prediction of model accuracy for workpiece of Copper of electrolytic grade is 83.849 % which was calculated by the formulae of Model accuracy.

Prediction of the accuracy and error for work piece of Mild Steel 2062:-
Table 8 shows the prediction of the accuracy and error for the workpieces of Mild Steel 2062

Table 8 Prediction of the accuracy and error for the workpieces of Mild Steel 2062

NO. OF EXP.	PARAMETERS (INPUTS)			SURFACE ROUGHNESS (OUTPUT) (MM)		ERROR %	ACCURACY %
	A	B	C	Measured Surface roughness R_a	Predicted Surface roughness R_a		
1	300	2500	0.2	3.12	2.71	13.141	113.141
2	300	3000	0.25	2.28	2.09	8.333	108.333
3	300	3500	0.3	2.16	2.02	6.481	106.481
4	400	2500	0.25	2.08	2.09	-0.481	99.519
5	400	3000	0.3	1.48	1.48	0	100
6	400	3500	0.2	1.06	1.48	-39.623	60.377
7	500	2500	0.3	1.92	2.02	-5.208	94.792
8	500	3000	0.2	1.51	1.48	1.987	101.987
9	500	3500	0.25	1.42	1.41	0.704	100.704

The prediction of model accuracy for workpiece of Mild Steel 2062 is 98.370 % which was calculated by the formulae of Model accuracy.

CONCLUSION

In this research work, spindle speed (SS), feed rate (FR) and depth of cut (DOC) are selected as machining parameters while surface roughness is considered as performance parameters to perform end milling operation on the workpiece materials of 6101 Aluminum alloy, Copper of electrolytic grade and Mild Steel 2062 by using High Speed Steel (HSS) end mill cutter of 12 mm diameter. Minimum experiment trials are designed by Taguchi based L9 (3^3) orthogonal array with the help of Minitab 17.0 software and a fuzzy logic approach based model is taken as to predict the value of surface roughness of a machined surface in 6101 aluminum alloy, Copper of Electrolytic grade and Mild Steel 2062 milling operation using HSS end mill cutter of 12 mm diameter. Three membership functions are allocated to be connected with each input of the model. The predicted results achieved via fuzzy logic model are compared to the experimental result. The result demonstrated settlement between the fuzzy model and experimental results with the 95.618% model accuracy for 6101 aluminum alloy material, 83.849% for copper (Electrolytic grade) and 98.334% Mild Steel 2062.

Fig. 7 (A) Before Machining

Fig. 7 (B) After Machining

Fig. 8 (A) Before Machining

Fig. 8 (B) After Machining

Fig. 9 (A) Before Machining

Fig. 9 (B) After Machining

MODEL ACCURACY

Table 9 shows the prediction of model accuracy based on fuzzy logic model for three different workpiece materials.

Table 9 Prediction of model accuracy based on fuzzy logic model

SR. NO.	WORKPIECE MATERIAL	PREDICTED MODEL ACCURACY
1	6101 aluminum alloy	95.618%
2	Copper of Electrolytic Grade	83.849%
3	Mild Steel 2062	98.334%

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