ANOVA And Fuzzy Logic Approach For Optimization Of Surface Finishing And Material Removal Rate In Face Milling Of Al5083 Alloy

Ch. Devi Prasanna Kumar, Y.Venkata Ramana Murty, G. Ramprasad

Abstract: In the present study, to measure the optimum controlled parameters for face milling operation of Al5083 materials under semi coolant conditions. Analysis of variance (ANOVA) in Mini Tab and fuzzy logic control in MATLAB software are used to effectively develop an analytical analysis for surface roughness and material removal rate. The experimental controlled parameters such as spindle speed, radial depth of cut, axial feed rate, and axial depth of cut are consideration for the present study. The experimental conditions are plan based on Taguchi L27 array with controlled parameters using carbide inserts (ASX 445). Significant results on surface roughness are spindle speed and interaction parameters between spindle speed and axial feed rate with contribution of 30.94 % and 33.47% respectively.

Index Terms: Aluminium 5083 alloy; Surface texture; Material Removal Rate; Taguchi method; ANOVA; Fuzzy logic control..

1. INTRODUCTION

In the industrial application of Aluminum 5083 alloy are floating vessels, ship building, high speed train wagons, drilling rigs, and car body manufacturing industries. Najiha [1] used central composite design of response surface methodology and determined the optimum operation parameters for end milling process of AA6061T6 under wet cooling condition and tested the adequacy using ANOVA. Sravanthi [2] used Regression Analysis and Taguchi Method to determine the optimized parameters for improving the quality of surface finish and rate of material removal of a component using carbide tool tips. Routara [3] investigated the influence of machining parameters on surface quality of components using CNC end milling, by developing second order mathematical models to predict the parameters using response surface methodology. The optimum cutting conditions are obtained using response optimization technique. Bala [4] applied Taguchi method to find the optimum process parameters for machining hardened steel. Emmanuel [5] utilized orthogonal array, the signal- to-noise ratio, and analysis of variance to study the performance characteristics in turning operation of Al6063 metal matrix composites. Saurabh [6] investigated the machinability of mild steel under turning process using conventional lathe machine by studying the effect of tool rake angle and feed on material removal rate where the response variable is modeled using Taguchi and ANOVA techniques. Gaurav [7] analyzed the MRR considering feed, depth of cut and spindle speed for machining Al6063 by employing Taguchi method.

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Nur [8] studied the influence of micro end milling process parameters on surface roughness and material removal rate using multi-process micro machine tools with tungsten carbide tool tip to machine methyl methacrylate work pieces. Unapathi [9] used design of experiments to optimize the tool life, for the machining of 7075 Aluminum alloy, by varying the spindle speed, feed rate and depth of cut. Jagannadha [10] developed mathematical equations to analyze to effects of parameters on material removal rate and surface finish for machining Al6063 using CNC, by employing regression analysis to find out significant parameters. Atiqah [11] analyzed the effect of micro end milling process parameters on material removal rate and surface roughness using multi-process micro machining tools by using Taguchi method to design the experiments. Deepika [12] conducted experiments to enhance surface finish and material removal rate for the machining of Al6082 workpiece on a CNC machine using carbide tool tip. John [13] conducted experiments using response surface methodology to machine metal matrix composites with Al7075 reinforced with SiC to analyze effects of process parameters on surface finish and material removal rate. Turgay [14] utilized Taguchi technique and regression analysis to investigate the machinability of Hadfield steel with PVD TiAlN and CVD $TiCN/Al_2O_3$ inserts in dry milling conditions with CNC vertical milling machine and determined the effect of machining parameters on flank wear and surface finish using ANOVA. Paulo [15] studied the influence of cutting parameters on surface roughness and laminate plate damage of CFRP under milling process. The experiments are designed using Taguchi method and the significant parameters are determined using ANOVA. Bernie [16] developed a neutral network based surface roughness system to limit the surface roughness to a desired value and the system is validated using experimental demonstration. Wang [17] studied the impact of micro end milling parameters on roughness of the workpiece using micro machine tip by designing the experiments using statistical methods. Kasman [18] investigated the relationship between surface roughness and process parameters while machining AA7075 aluminum alloy with EDM. Taguchi method and ANOVA are utilized in the study. Quinsata [19] investigated the roughness parameters by simulating 3D surface topography under multi-axis machining with a ball end cutter tool. The results are verified with experimental procedure.

2 EXPERIMENTAL WORK

2.1 Specimen Material

The specimens used in present research work is Aluminum 5083 alloy material in face milling operation with dimensions of 50 x 45 x 20 mm shows in Fig.1. Chemical composition of Aluminum 5083 alloy shows in Table 1

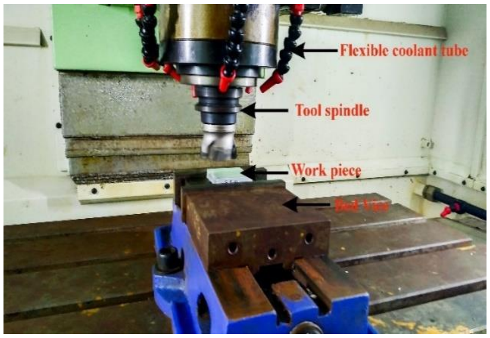

Fig. 1*. Aluminum 5083 alloy material with the experimental setup*

TABLE 1

CHEMICAL COMPOSITION OF ALUMINUM 5083 ALLOY

Elements	Composition (%)
Chromium (Cr)	0.04-0.26
Copper (Cu)	0.0-0.1
Iron (Fe)	0.0-0.4
Magnesium (Mg)	4.0-4.9
Manganese (Mn)	0.4-1.0
Silicon (Si)	0.0-0.4
Titanium (Ti)	0.0-0.15
Zinc (Zn)	0.0-0.25
Aluminum (Al)	Remain balance

2.2 Experimental Procedure

In this Experimental analysis, the CNC milling machine variables are spindle speed (RPM), axial feed rate (mm/min), and axial depth of cut (mm). In the design of experiments such as ANOVA and Taguchi, noise to signal ratios help to determine the effect of parameter and interaction between parameters in the experimentation. Table 2 shows the factors of experimental level.

TABLE 2

FACTORS OF THE EXPERIMENTAL LEVELS

Factors	Units	Grade-1	Grade-2	Grade-3
Spindle speed	RPM	1200	1400	1600
Axial feed rate	mm/min	60	120	180
Axial depth of cut	mm	0.4	0.8	1.2

The face milling operations are conducted on the CNC vertical milling center (LMW JV-55) using the 50 mm diameter of a cutter with 4 inserts shows in Fig.2. The BT-40 tool holder consists of 4 ASX 445 type carbide inserts used in experimental work shows in Fig.3. Table 3 shows the specification of the CNC vertical milling machine (LMW JV-55).

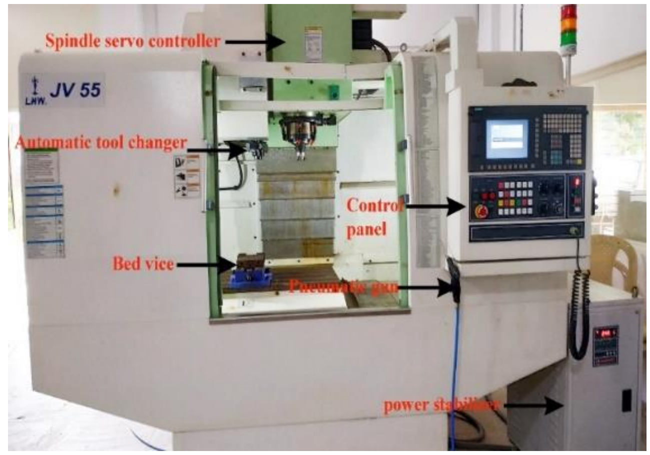

Fig. 2*. CNC Vertical milling center*

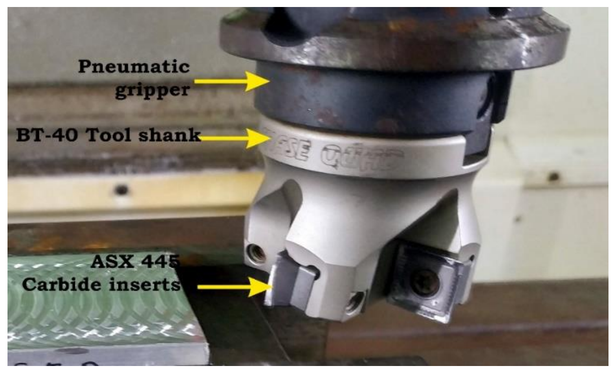

Fig. 3*. Carbide inserts with the tool holder*

TABLE 3

SPECIFICATION OF CNC VERTICAL MILLING MACHINE (LMW JV-55)

Specifications	Dimensions
Stroke of X- axis, Y-axis, and Z-axis	575 mm,410 mm and 460 mm
Table size	900 x 430 mm
Bore tapper	BT-40
spindle speed	6000 RPM
feed rate	10 m/min
No of tool	20
Controller type	Siemens control

2.3 Surface Roughness

Surface texture is the corresponding deviation from the form of three dimension surface. [20] Majorly surface texture consists of roughness, waviness, machining operation lay direction, and flaws. In surface texture, roughness and waviness formed by variation in the surface of different short wavelengths, identified by the hills and valleys of different spacing lengths and amplified. Waviness may chance to occur the machining center unbalance, specimen deflection, vibration during machining, and warping forces in working environments. The direction of lay in a surface pattern helps to estimate the manufacturing and production methodology. Flaws are unwanted and unexpected interruptions in the surface texture. Fig.4 shows the surface texture of work piece.

TABLE 4
OPERATING CONDITION OF SURFACE TEST (SJ-310)

Controls	Options
Measuring tool	Surf test
Operator	Mitutoyo
Comment	Ver 2.00
Standard	ISO 1997
Profile	R
Sample length (λs)	2.5 µm
N	5
Cut-Off	0.8 mm
Filter	GAUSS

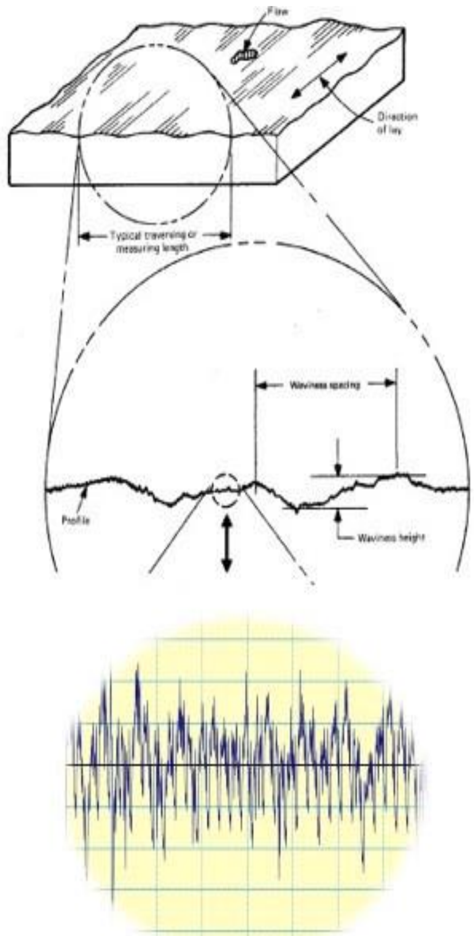

***Fig. 4**. Surface texture of work piece*

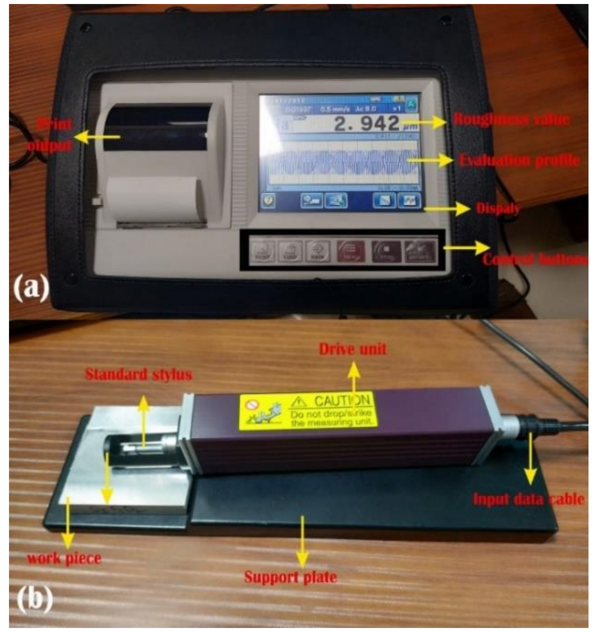

***Fig. 5**. Surface roughness a) instrument (Surf test SJ-310), b) detector arrangement*

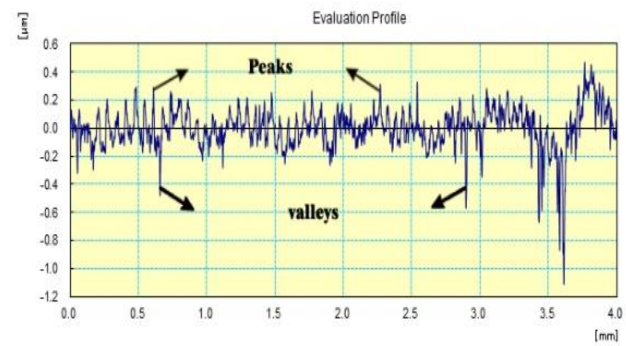

***Fig. 6**. Evaluation profile of milling operation*

A statistical analysis of surface roughness is required for the constructs of a relationship between controlled parameters and response variable parameters. The statistical analysis of surface roughness data from the surf test (SJ-310) is done with the help of MINI TAB 17.0 is shows in Table 5. When the 'Gauss' filter selected on surface roughness measurement taken escape range is 0.079 Inch for every travesal length of testing. Operating condition of Surf test (SJ-310) shows in Table 4. Fig.5.shown surface roughness a) instrument (Surf test SJ-310) b) detector arrangement.Fig.6 shown the evaluation profile of milling operation.

TABLE 5
EXPERIMENTAL CONDITION OF SURFACE ROUGHNESS

S.no	Spindle speed(RPM)	Axial feed rate(mm/min)	Axial depth of cut(mm)	Trail-1 (µm)	Trail-2 (µm)	Trail-3 (µm)	Ra (µm)
1	1200	60	0.4	0.578	0.169	0.386	0.3776
2	1200	60	0.8	0.182	0.180	0.122	0.1613
3	1200	60	1.2	0.325	0.322	0.266	0.3043
4	1200	120	0.4	0.093	0.115	0.124	0.1106
5	1200	120	0.8	0.152	0.097	0.139	0.1792
6	1200	120	1.2	0.116	0.182	0.138	0.1453
7	1200	180	0.4	0.188	0.190	0.184	0.1873
8	1200	180	0.8	0.234	0.168	0.173	0.1916
9	1200	180	1.2	0.261	0.182	0.168	0.2036
10	1400	60	0.4	0.092	0.101	0.095	0.0961
11	1400	60	0.8	0.094	0.102	0.080	0.0925
12	1400	60	1.2	0.094	0.101	0.084	0.0935
13	1400	120	0.4	0.193	0.173	0.088	0.1513
14	1400	120	0.8	0.171	0.152	0.099	0.1406
15	1400	120	1.2	0.088	0.152	0.081	0.1076
16	1400	180	0.4	0.098	0.089	0.128	0.1054
17	1400	180	0.8	0.089	0.123	0.108	0.1066
18	1400	180	1.2	0.112	0.134	0.114	0.1222
19	1600	60	0.4	0.199	0.184	0.158	0.1803
20	1600	60	0.8	0.190	0.175	0.083	0.1493
21	1600	60	1.2	0.166	0.126	0.131	0.1416
22	1600	120	0.4	0.230	0.103	0.095	0.1426
23	1600	120	0.8	0.243	0.206	0.283	0.2447
24	1600	120	1.2	0.170	0.224	0.208	0.2006
25	1600	180	0.4	0.112	0.080	0.080	0.0906
26	1600	180	0.8	0.127	0.234	0.069	0.1433
27	1600	180	1.2	0.198	0.214	0.121	0.1776

2.4 Material Removal Rate

MRR is the material removing rate per minute time. Generally higher material remove rate occurs at the maximum condition of cutter diameter, feed rate, and axial depth of cut in milling operation. Its offer to shorten in surface finish. The surface finish of machining compound is depended on the parameter of material removal rate. If the MRR is high, surface texture of compound should be of higher value. Table 6 shows machining parameters for material removal rate (MRR).

$$MRR = V_f \times D_b \times Doc$$

Whereas,

V_f = feed velocity, mm/min
D_b = bore diameter, mm
Doc = axial depth of cut, mm

TABLE 6
MACHINING PARAMETERS FOR MATERIAL REMOVAL RATE (MRR)

S.no	Spindle speed(RPM)	Axial feed rate(mm/min)	Axial depth of cut(mm)	Radial depth of cut (mm)	MRR(mm^3/min)
1	1200	60	0.4	15	360
2	1200	60	0.8	15	720
3	1200	60	1.2	15	1080
4	1200	120	0.4	15	720
5	1200	120	0.8	15	1440
6	1200	120	1.2	15	2160
7	1200	180	0.4	15	1080
8	1200	180	0.8	15	2160
9	1200	180	1.2	15	3240
10	1400	60	0.4	30	720
11	1400	60	0.8	30	1440
12	1400	60	1.2	30	2160
13	1400	120	0.4	30	1440
14	1400	120	0.8	30	2880
15	1400	120	1.2	30	4320
16	1400	180	0.4	30	2160
17	1400	180	0.8	30	4320
18	1400	180	1.2	30	6480
19	1600	60	0.4	45	1080
20	1600	60	0.8	45	2160
21	1600	60	1.2	45	3240
22	1600	120	0.4	45	2160
23	1600	120	0.8	45	4320

24	1600	120	1.2	45	6480
25	1600	180	0.4	45	3240
26	1600	180	0.8	45	6480
27	1600	180	1.2	45	9720

3 RESULTS AND DISCUSSION

3.1 Statistical results for surface roughness and MRR

The data shows in the table, for surface finishing and MRR are reported to ANOVA to calculate the significant values in the experimental condition, at confidence level 95 % and the ANOVA results for controlled and combined parameters are shows in Table 5and 6 respectively. Table 7and 8. Shows statistical results for surface roughness and material removal rate respectively.

TABLE 7

STATISTICAL RESULTS FOR SURFACE ROUGHNESS

Parameters	DoF	Contribution (%)	Adj.SS	Adj.MS	F-Value	P-Value	Significant
A	2	30.94	0.035364	0.017682	12.19	0.004	#
B	2	4.02	0.004596	0.002298	1.58	0.263	
C	2	0.93	0.001059	0.000529	0.36	0.705	
A x B	4	33.47	0.038262	0.009565	6.59	0.012	#
A x C	4	8.34	0.009535	0.002384	1.64	0.255	
B x C	4	12.15	0.013892	0.003473	2.39	0.136	
Error	8	10.15	0.011607	0.001451			
Total	26	100					

TABLE 8

STATISTICAL RESULTS FOR MATERIAL REMOVAL RATE

Parameters	DoF	Contribution (%)	Adj.SS	Adj.MS	F-Value	P-Value	Significant
D	2	28.35	37324800	18662400	144	0.001	#
B	2	28.35	37324800	18662400	144	0.001	#
C	2	28.35	37324800	18662400	144	0.001	#
D x B	4	4.72	6220800	1555200	12	0.002	#
D x C	4	4.72	6220800	1555200	12	0.002	#
B x C	4	4.72	6220800	1555200	12	0.002	#
Error	8	0.79	1036800	129600			
Total	26	100					

Where,

A is spindle speed, RPM
B is an axial feed rate, mm/min
C is an axial depth of cut, mm
D is a radial depth of cut, mm
indicated that significant value

In statistical analysis, the smallest probability value is a more significant effect on surface roughness and material removal rate. Table 7 shows that the speed and interaction between speed and axial feed rate of Al5083 work material have more significant on surface roughness. Table 8 shows all control parameters are significant in material removal rate. The significant value for surface roughness is 0.004 and 0.012, their contribution values are 30.94% and 33.47%. Similarly, the significant value for material removal rate is 0.001, and contribution values are 28.35%. Fig.7 shows that optimum surface roughness of Al5083 obtained from the moderate spindle speed, depth of cut, and high axial feed rate. Fig.8 observed that material removal rate high at the maximum condition of all controlled parameters.

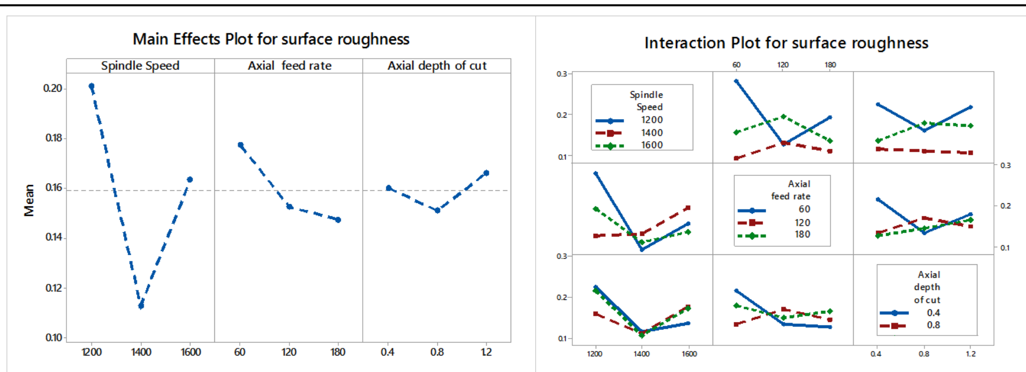

***Fig. 7**. Main and interaction process plot for surface roughness*

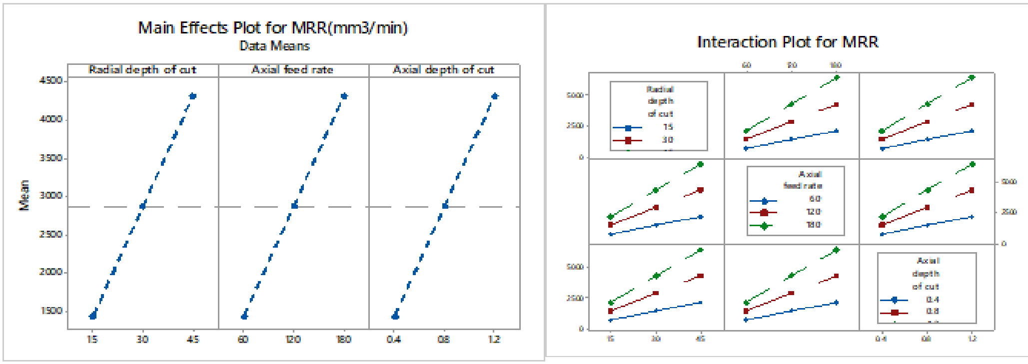

***Fig. 8**. Main and interaction process plot for Material removal rate*

From Fig.7 shows optimum surface roughness of Al5083 obtained from the moderate spindle speed, depth of cut and high axial feed rate. Similarly Fig. 8 observed that material removal rate high at maximum condition of all controlled parameters.

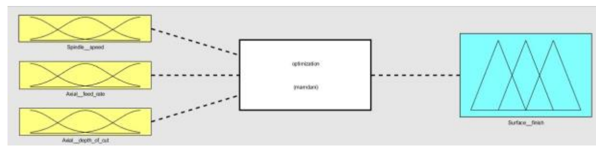

***Fig. 9**. Main fuzzy logic interface system*

3.1 Fuzzy logic control

The fuzzy logic control discussion about related information in fuzzy logic inference used command at the MATLAB programming software. The number of inputs depend upon the memory of utilize machine interface. If the no of inputs are more, the time taken process the results should be depend on fuzzy interface system (FIS). In this work, input parameters used in surface finishing and material removal rate are spindle speed, axial feed rate and axial depth of cut. “Mamdani” type fuzzy interface used to analysis the optimize the output parameters with help of some defined rule shows in Fig.9, Fig.10 and Fig.11. Fuzzy logic is computing based approach on “degree of truth” more than usual to “true or false”. The decision making are represent value in between zero to one, if one indicated true value and zero value indicated to false value in FIS. Fig.12 shows rule view for surface roughness.

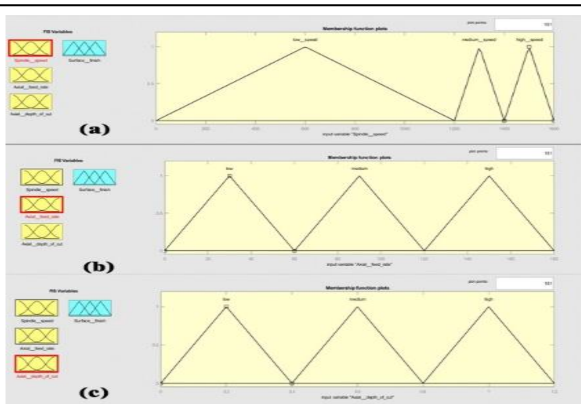

***Fig. 10**. Fuzzy logic design modular inputs (a) spindle speed, (b) axial feed rate and (c) axial depth of cut*

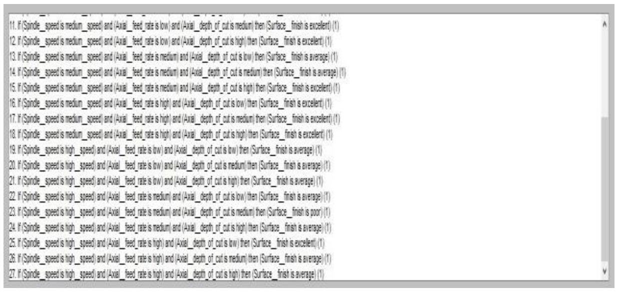

***Fig. 11.** Fuzzy logic rules for surface roughness*

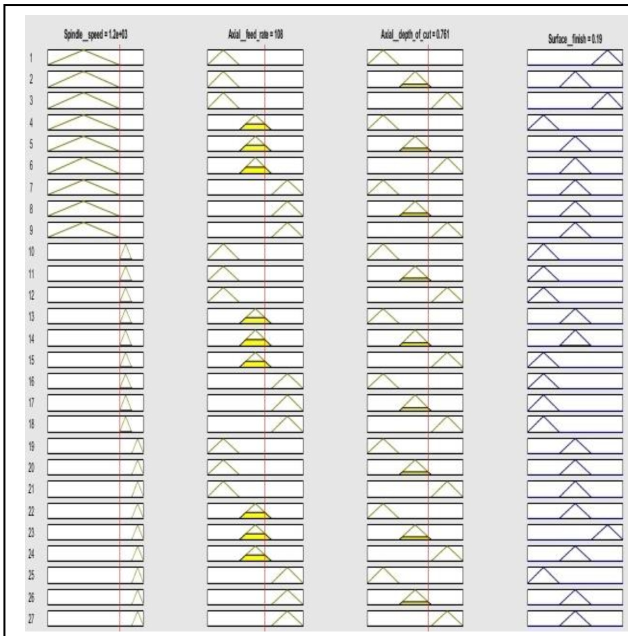

***Fig. 12.** Rule view for surface roughness*

TABLE 9

PERCENTAGE OF ERROR BETWEEN EXPERIMENTAL AND FUZZY LOGIC VALUE

S.no	Control parameters	Experimental results	Fuzzy logic results	Percentage of error between experimental and fuzzy logic value
1.	Spindle speed, RPM	1200	1203	0.24
2.	Axial feed rate, mm/min	120	108	10
3.	Axial depth of cut, mm	0.8	0.761	4.875
4.	Surface finish, µm	0.179	0.19	5.78

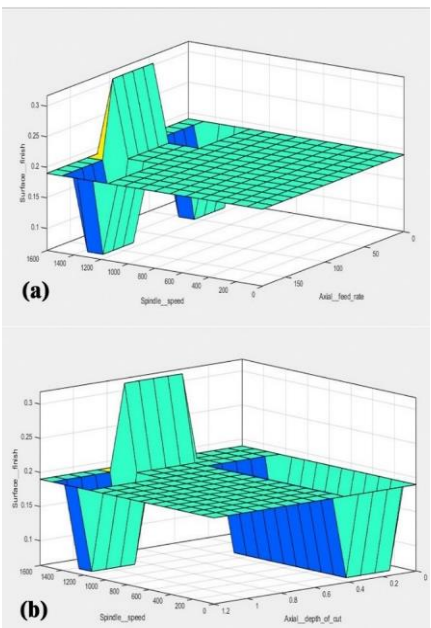

***Fig. 13**. Surface roughness results (a) spindle speed and axial feed rate, (b) spindle speed and axial depth of cut*

ANOVA and fuzzy logic design are used for conducted on Al5083 alloy materials and machined milling operation with different controlled parameters such as spindle speed, axial feed rate, and axial depth of cut. Surface roughness and material removal rate on a material can be measured through experimental values and analytical equations. Fig.13 shows 3d surface roughness results verses (a) spindle speed and axial feed rate (b) spindle speed and axial depth of cut. Table 9. Shows percentage of error between experimental and fuzzy logic value and the maximum percentage of error is 10 % in axial feed rate. Fig.14 shows a comparison between the experimental value and fuzzy logic value.

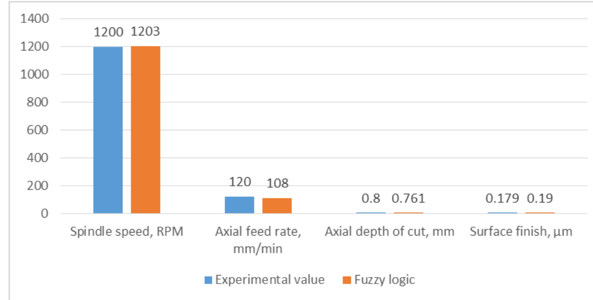

***Fig. 14.** Comparison between the experimental and Fuzzy logic value*

4 CONCLUSIONS

The specimens of Al5083 are machining by milling face operation. Optimization of surface finishing and MRR experimental condition values are developed from the Taguchi L27 methodology.

1) The optimization of surface finishing and MRR at the machining operated controlled parameters are spindle speed, axial feed rate and axial depth of cut.
2) The optimized surface roughness is obtained at the speed of 1200 RPM with a 30.94% contribution, axial feed rate of 120 mm/min, and depth of cut is 0.8 mm.
3) Maximum 33.47 % contribution obtained from the interaction between spindle speed and axial feed rate. All controlled parameters and their interaction between parameters are significant on material removal rate.
4) The optimal cutting parameters for MRR for Al5083 material are radial depth of cut 45 mm, axial feed rate 180 mm/min, and axial depth of cut 1.2 mm.
5) A good correlation is observed between experimental and fuzzy logic results.

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