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Artificial Fuzzy Intelligence Modeling for Inconel 718 Machining with CBN Tool

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ABSTRACT

The inconel 718 is difficult to cut thigh temp thermal resistant material widely used for aerospace applications [17]. Generally carbide cutting tools prefer for machining. In this paper attempt has been made to understand the influence on machining by CBN cutting tool. Since, material is of high value neuro fuzzy based inference system to get predictive responses.

1. INTRODUCTION

The inconel 718 is very famous nickel based alloy due to peculiar its properties. Its properties like high hardness, strength and thermal stability when subjected to high temperature region, leads this material for wider applications [31, 32]. The age hardening machining of inconel is difficult to cut. Due to the high specific density cost per kg also high. Artificial intelligence network based model predict machining responses is wise option to select desired parameters.

2. EXPERIMENTATION

The experimentation was carried out using Gildemeister CTX 310 Eco CNC Lathe with CBN cutting insert CNGA 120408 in dry environment. Speed and feed considered as machining parameters to evaluate surface roughness and material removal rate as machining responses.

3. WORK PIECE MATERIAL AND CUTTING TOOL

The work material used was Inconel 718 round bar of Φ 29 mm. The chemical composition and mechanical properties of the work piece are given in Tables 1 and 2, respectively.

Table 1: The chemical composition of inconel 718

Element	***Ni (+Co)***	***Ti***	***Cr***	***Nb(+Ta)***	***Al***	***Fe + Other***
Weight (%)	50-55	0.65-1.5	17-21	4.75-5.5	0.2-0.8	Balance

Table 2: The mechanical properties of inconel 718

Density	8.19 g/cm^3
Melting point	1260–1336 ºC
Specific heat	435 J/kg K
Average coefficient of thermal expansion	13 lm/m K
Thermal conductivity	11.4 w/m K
Ultimate tensile strength	1240 MPa

Design of experiment

The following cutting conditions were employed in this investigation. Three level two factorial DOE is prepared with constant depth of cut. Surface roughness and material removal rate are the machining responses.

Table 3: Machining parameters and levels for turning with CBN inserts

Machining Parameters	Levels		
	Low	Medium	High
Speed (m/min)	80	100	120
Feed (mm/rev)	0.10	0.15	0.2
Depth of cut (mm)	0.2	0.2	0.2

Effect of CBN cutting tool on surface finish and Material Removal rate

Dr. Genichi Taguchi is regarded as the foremost proponent of robust parameter design, which is an engineering method for product or process design that focuses on minimizing variation and/or sensitivity to noise. When used properly, Taguchi designs provide a powerful and efficient method for designing products that operate consistently and optimally over a variety of conditions. The goal of robust experimentation is to find an optimal combination of control factor settings that achieve robustness against (insensitivity to) noise factors.

Table 4: Natural log of the standard deviations vs. the control factors

Responses	**S/N ratio formulas**	**Use when the goal is to...**	**Probable Data**
Ra -Smaller is better	$S/N=-10\log(\Sigma Y^2)/n))$	Minimize the response	Non-negative with a target value of zero
MRR - Larger is better	$S/N=-10\log(\Sigma\square 1/Y^2)/n)$	Maximize the response	Positive

Linear Model Analysis: SN ratios versus Speed, Feed

Taguchi Analysis: Ra versus Speed, Feed

Table 5: Estimated Model Coefficients for SN ratios Ra

Term	**Coef**	**SE Coef**	**T**	**P**
Constant	35.4370	0.1742	203.404	0.000
Speed 80	2.9903	0.2464	12.137	0.000
Speed 100	-1.0958	0.2464	- 4.448	0.011
Feed 0.10	0.1223	0.2464	0.496	0.646
Feed 0.15	0.1285	0.2464	0.521	0.630

S = 0.5227 R-Sq = 97.4% R-Sq(adj) = 94.9%

Taguchi Analysis: MRR versus Speed, Feed

Table 6: Estimated Model Coefficients for SN ratios MRR

Term	**Coef**	**SE Coef**	**T**	**P**
Constant	3.26007	0.06638	49.110	0.000
Speed 80	0.48112	0.09388	5.125	0.007
Speed 100	-0.96912	0.09388	-10.323	0.000
Feed 0.10	-0.25568	0.09388	-2.724	0.053
Feed 0.15	0.03363	0.09388	0.358	0.738

S = 0.1992 R-Sq = 96.6% R-Sq(adj) = 93.3%

Table 7: Response Table for Signal to Noise Ratios

	Ra- Smaller is better		**MRR- Larger is better**	
Level	**Speed**	**Feed**	**Speed**	**Feed**
1	38.43	35.56	3.741	3.004
2	34.34	35.57	2.291	3.294
3	33.54	35.19	3.748	3.482
Delta	4.88	0.38	1.457	0.478
Rank	**1**	**2**	**1**	**2**

The level averages in the response tables show that the S/N ratios were minimized for Ra and maximized for MRR. Figure 1 and 2 shows S/N ratios.
The optimal parametric combination for **CBN** coated tool gives minimum surface roughness cutting condition 80 m/min speed with 0.15 mm/rev whereas for maximum cutting condition 80 mm/min speed with 0.15 mm/rev

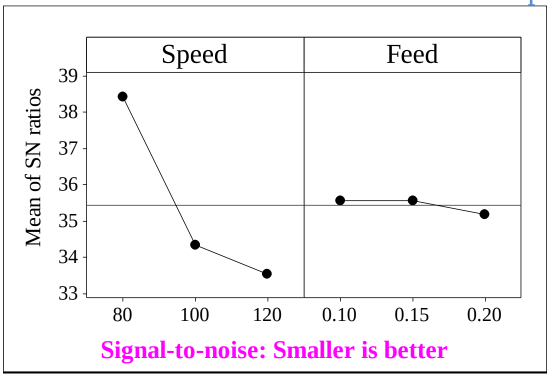


Figure 1: Main Effects Plot of Ra for SN ratios

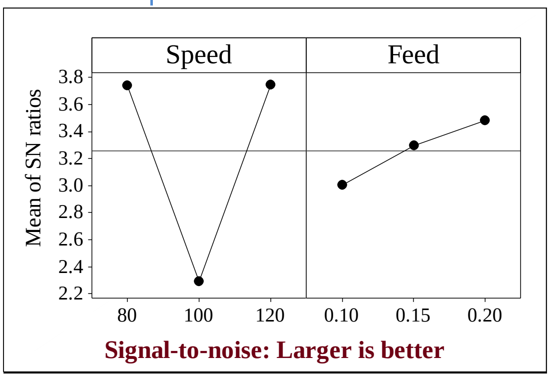


Figure2: Main Effects Plot of MRR for SN ratios

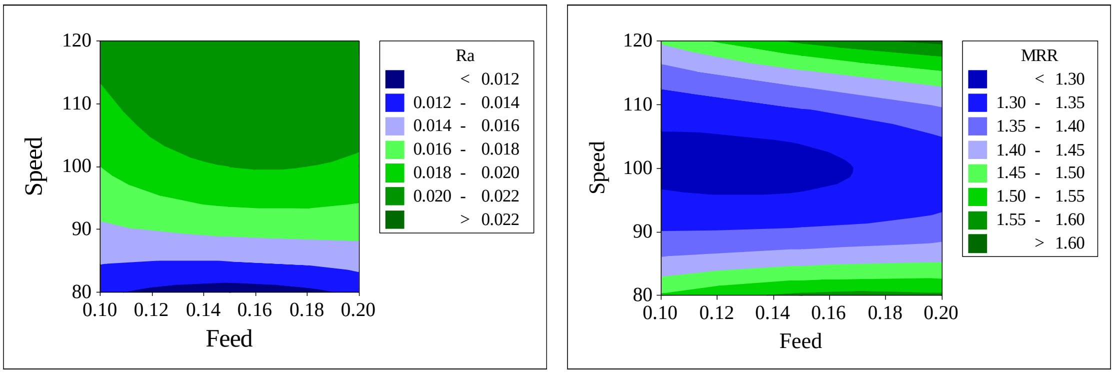


Figure 3: Contour Plot of Ra and MRR vs. Speed, Feed

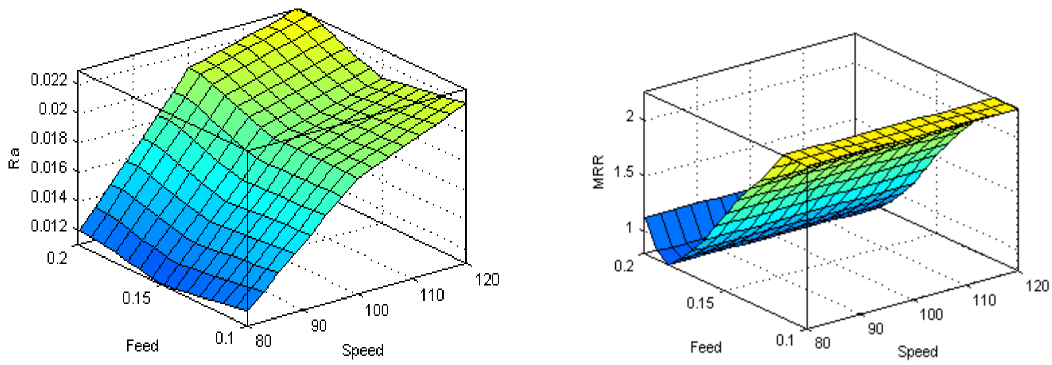


Figure 4: Surface Plot of Ra and MRR vs. Speed, Feed

ANFIS model for surface roughness (Ra) for machining with CBN tool

Experimental result used as training and testing data to develop the ANFIS method. The settings of cutting speed include 80, 100 and 120 m/min; those of feed rate include 0.01, 0.15, 0.2 mm/rev. The value of surface roughness was measured after turning according to the above machining conditions and then used as the training and testing data in ANFIS, as listed in Table 8 and 9 respectively

Table 8: Training data

Runs	Speed (m/min)	Feed (mm)	Ra (µm)
1	80	0.10	0.012
2	80	0.15	0.011
3	80	0.20	0.012
4	100	0.10	0.019
5	100	0.15	0.019

6	100	0.20	0.021
7	120	0.10	0.022
8	120	0.15	0.021
9	120	0.20	0.023

Table 9: Testing data

Runs	Speed (m/min)	Feed (mm)	Ra (μm)
1	80	0.10	0.010
2	80	0.15	0.010
3	80	0.20	0.010
4	100	0.10	0.015
5	100	0.15	0.016
6	100	0.20	0.016
7	120	0.10	0.015
8	120	0.15	0.016
9	120	0.20	0.017

Fuzzy Membership functions of Ra for CBN cutting

The initial value for the adaptation of parametric pace was 2. The membership function of every input parameter within the architecture can be divided into three areas, i.e. low, medium and high. Figure: 5 show the initial and final membership functions of the three turning parameters derived by training via the triangular membership function. In. this the initial membership function only experience very limited changes in the low, medium and high areas. Figure 6 shows the membership functions of parameter Feed. The initial value for the adaptation of parametric pace was 0.01.

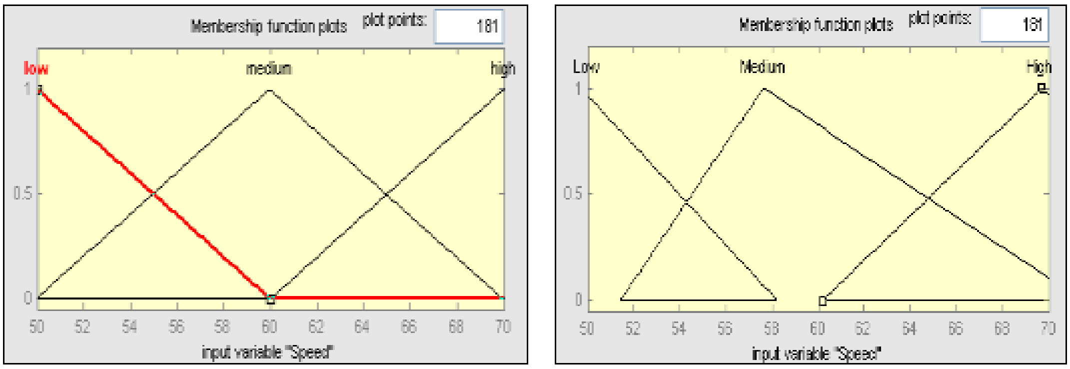


Figure: 5 Initial and final membership function for cutting speed for Ra

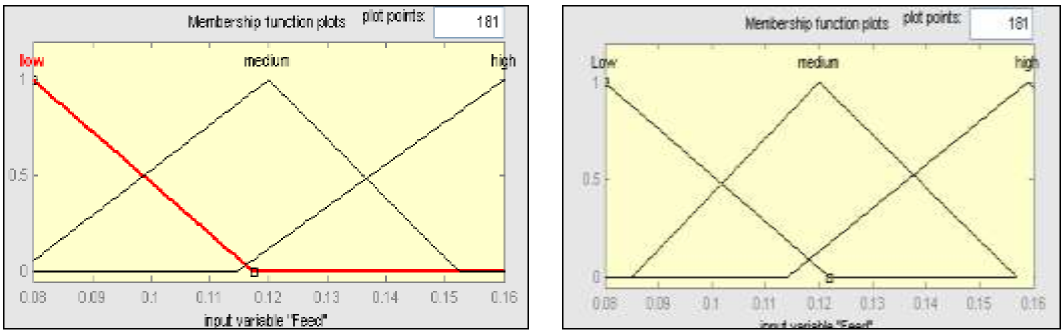


Figure 6: Initial and final membership function for feed for Ra

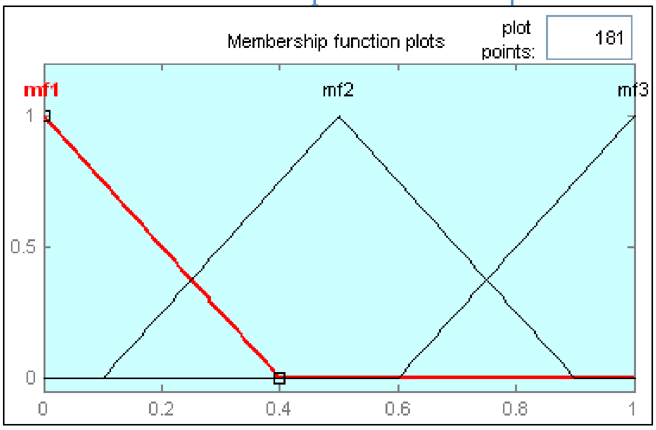
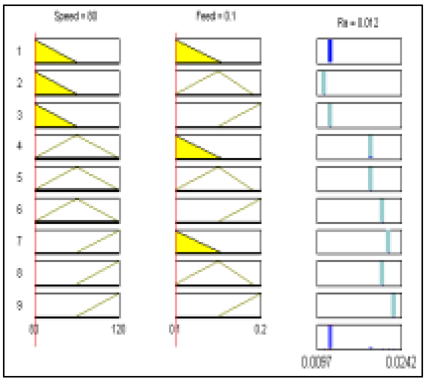
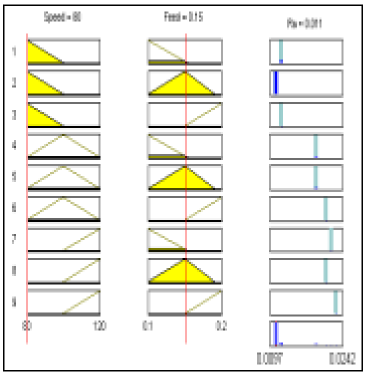


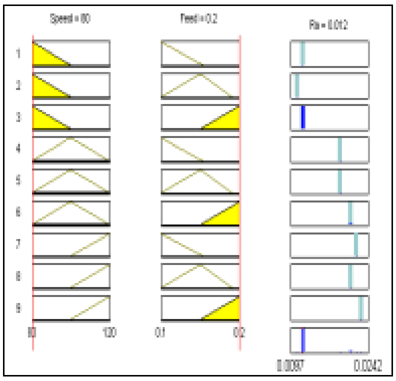
Figure 7: Membership function for Output response Ra

ANFIS rule viewer for Ra at various speed, feed condition when inconel 718 machined with CBN inserts

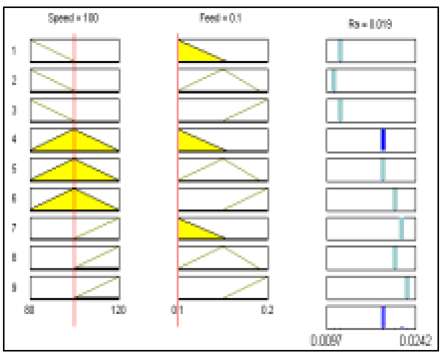
If (Speed is Low) and (Feed is Low) then Ra is out 1mf1……………..….(1)
If (Speed is Low) and (Feed is Medium) then Ra is out 1mf2………….(2)
If (Speed is Low) and (Feed is High) then Ra is out 1mf3……………..(3)

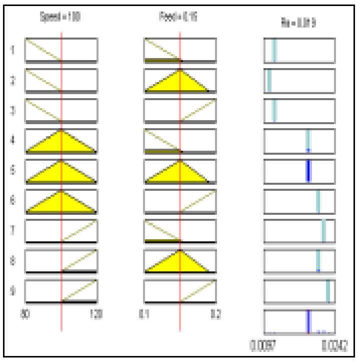


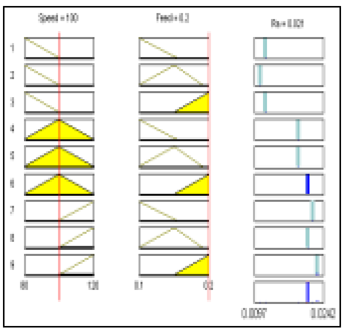




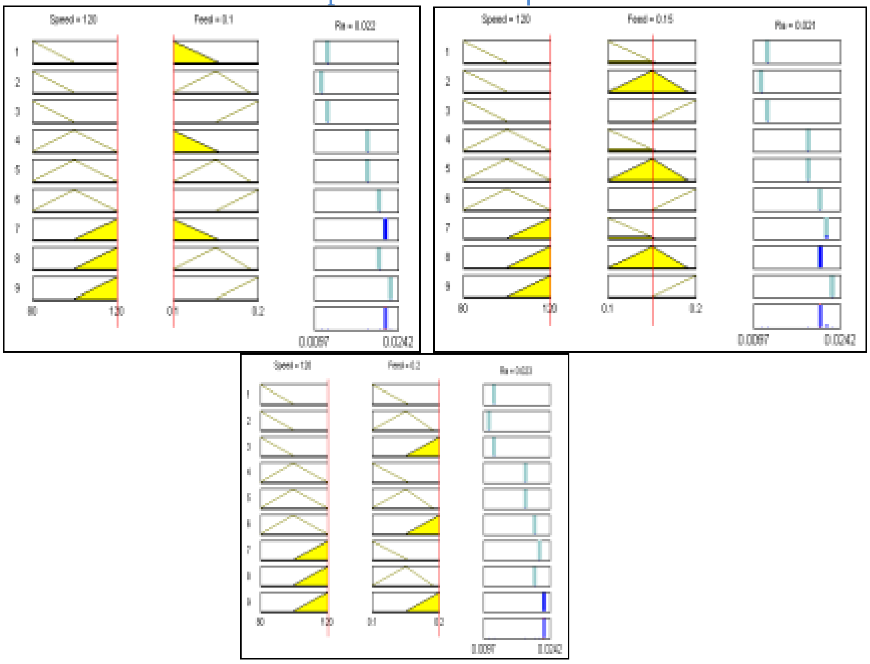
If (Speed is Medium) and (Feed is Low) then Ra is out 1mf4…………..(4)
If (Speed is Medium) and (Feed is Medium) then Ra is out 1mf4 ……...(5)
If (Speed is Medium) and (Feed is High) then Ra is out 1mf6………....(6)







If (Speed is High) and (Feed is Low) then Ra is out 1mf7……………..(7)
If (Speed is High) and (Feed is Medium) then Ra is out 1mf8………….(8)
If (Speed is High) and (Feed is High) then Ra is out 1mf9…………...…(9)



ANFIS model for surface roughness (MRR) for machining with CBN tool

Experimental result used as training and testing data to develop the ANFIS method. The settings of cutting speed include 80, 100 and 120 m/min; those of feed rate include 0.01, 0.15, 0.2 mm/rev. The value of Material removal rate was measured after turning according to the above machining conditions and then used as the training and testing data in ANFIS, as listed in Table 10 and 11 respectively

Table 10: Training data

Runs	Speed (m/min)	Feed (mm)	MRR (cm^3/min)
1	80	0.10	1.505
2	80	0.15	1.612
3	80	0.20	1.505
4	100	0.10	1.328
5	100	0.15	1.254
6	100	0.20	1.328
7	120	0.10	1.411
8	120	0.15	1.612
9	120	0.20	1.612

Table 11: Testing data

Runs	Speed (m/min)	Feed (mm)	MRR (cm^3/min)
1	80	0.10	1.505
2	80	0.15	1.505
3	80	0.20	1.612
4	100	0.10	1.254
5	100	0.15	1.328
6	100	0.20	1.328
7	120	0.10	1.505
8	120	0.15	1.505

9	120	0.20	1.612

Fuzzy Membership functions of MRR for CBN cutting

The initial value for the adaptation of parametric pace was 2. The membership function of every input parameter within the architecture can be divided into three areas, i.e. low, medium and high. Figure 8 show the initial and final membership functions of the three turning parameters derived by training via the triangular membership function. In. this the initial membership function only experience very limited changes in the low, medium and high areas. Figure 9 shows the membership functions of parameter Feed. The initial value for the adaptation of parametric pace was 0.01.

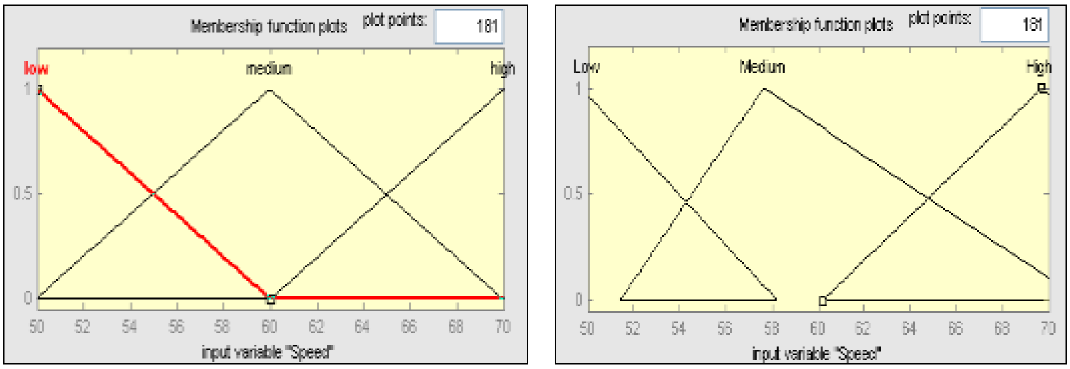


Figure 8: Initial and final membership function for cutting speed for MRR

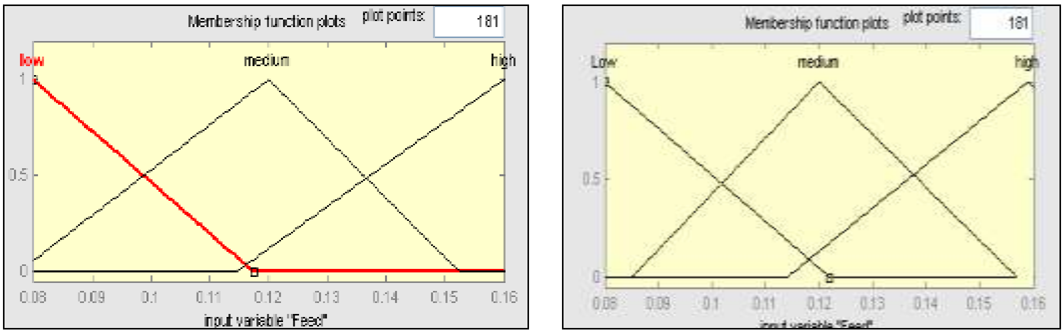


Figure 9: Initial and final membership function for feed for MRR

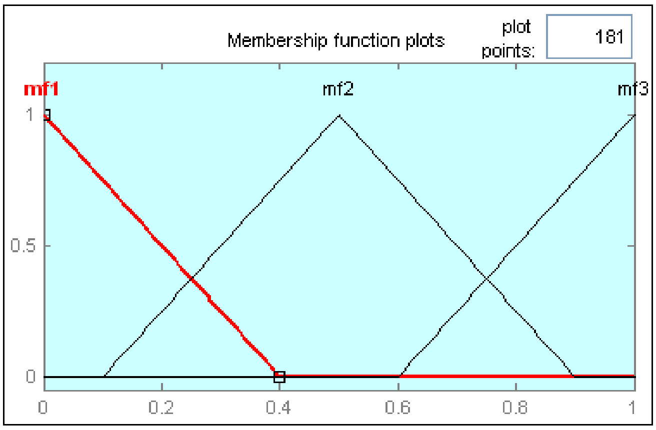
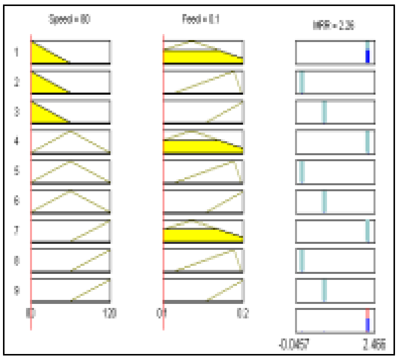
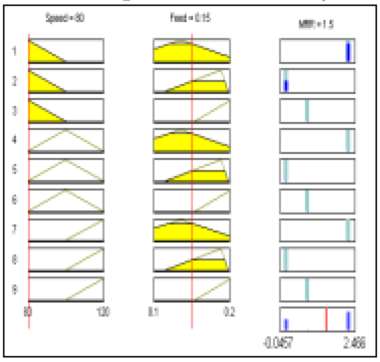
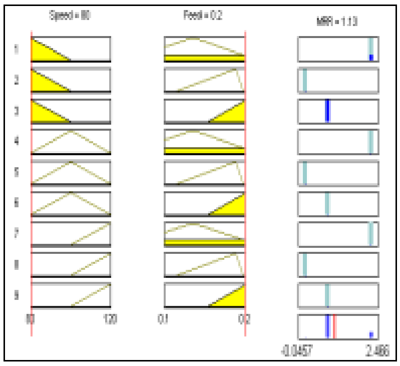


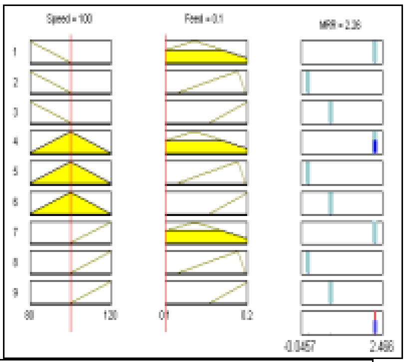
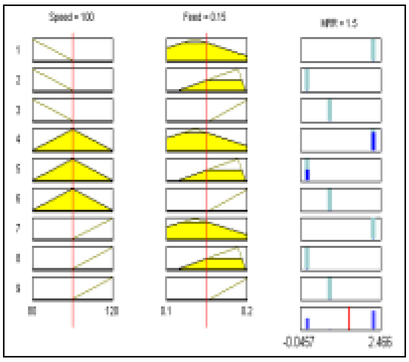
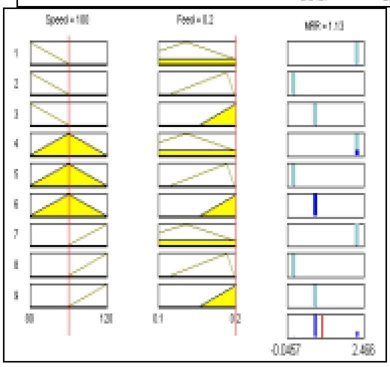
Figure 10: Membership function for Output response MRR

ANFIS rule viewer for MRR at various speed, feed condition when inconel 718 machined with CBN inserts

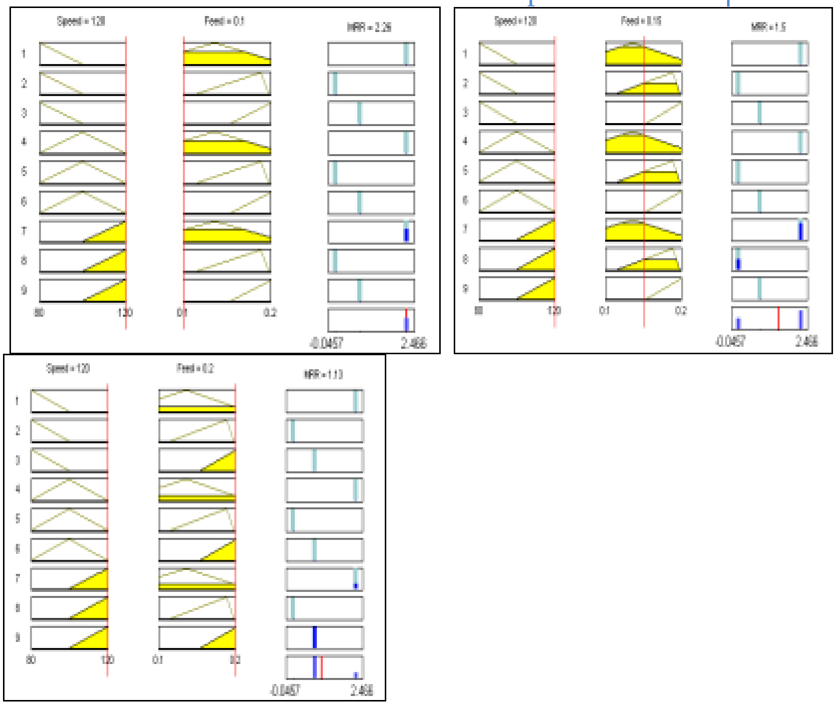
If (Speed is Low) and (Feed is Low) then MRR is out 1mf1……………..…..(1)
If (Speed is Low) and (Feed is Medium) then MRR is out 1mf2…………..(2)
If (Speed is Low) and (Feed is High) then MRR is out 1mf3……………...(3)

If (Speed is Medium) and (Feed is Low) then MRR is out 1mf4…………...(4)
If (Speed is Medium) and (Feed is Medium) then MRR is out 1mf4 ……...(5)
If (Speed is Medium) and (Feed is High) then MRR is out 1mf6……….....(6)

If (Speed is High) and (Feed is Low) then MRR is out 1mf7……………..(7)
If (Speed is High) and (Feed is Medium) then MRR is out 1mf8…………(8)
If (Speed is High) and (Feed is High) then MRR is out 1mf9…… ..…...…(9)



The comparative assessment of various models for IN718 turning with CBN carbide tool

Table 12: Response table and predicted values of Ra and MRR (CBN)

Runs	Speed m/min	Feed mm	DoC mm	Ra Actual (µm)	Ra Replicate (µm)	Ra Reg (µm)	Ra ANFIS (µm)	MRR Actual (cm^3/min)	MRR Replicate (cm^3/min)	MRR Regression (cm^3/min)	MRR ANFIS cm^3/min)
1	80	0.10	0.2	0.012	0.013	0.010	0.012	1.505	1.505	1.521	2.260
2	80	0.15	0.2	0.011	0.011	0.010	0.011	1.612	1.505	1.547	1.500
3	80	0.20	0.2	0.012	0.013	0.010	0.012	1.505	1.612	1.552	1.130
4	100	0.10	0.2	0.019	0.017	0.015	0.019	1.328	1.254	1.257	2.260
5	100	0.15	0.2	0.019	0.021	0.016	0.019	1.254	1.328	1.308	1.500
6	100	0.20	0.2	0.021	0.018	0.016	0.021	1.328	1.328	1.338	1.130
7	120	0.10	0.2	0.022	0.019	0.015	0.022	1.411	1.505	1.470	2.260
8	120	0.15	0.2	0.021	0.021	0.016	0.021	1.612	1.505	1.546	1.500
9	120	0.20	0.2	0.023	0.020	0.017	0.023	1.612	1.612	1.601	1.130

Figure 11 and Figure 12 shows good agreement of predicted responses. The response values of machining of inconel 718 confirm the model adequacy with similar trend pattern

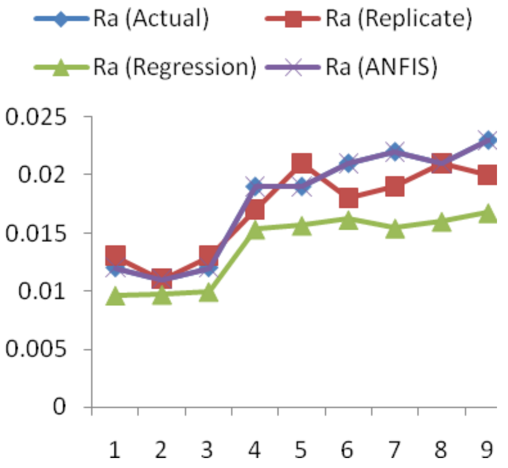


Figure 11: Comparative trends Ra

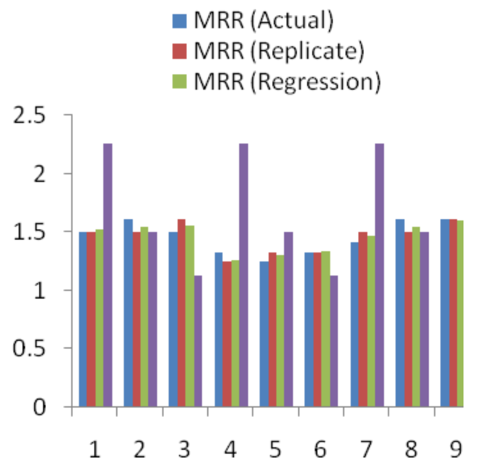


Figure 12: Colum chart of MRR

Conclusion

In this work, Inconel 718 has been machined for under dry condition using CBN cutting tools. Taguchi analysis for best optimized fit for each alternative is used. Fuzzy inference system used to obtain predictive intelligence option to select process parameters. The work also highlighted to compare the performance characteristics such as surface roughness and Material removal rate using various cutting variants. The optimal parametric combination for **CBN** coated tool gives minimum surface roughness cutting condition 80 m/min speed with 0.15 mm/rev whereas for maximum cutting condition 80 mm/min speed with 0.15 mm/rev

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