Journal of Material Science and Mechanical Engineering (JMSME)
p-ISSN: 2393-9095; e-ISSN: 2393-9109; Volume 3, Issue 3; April-June, 2016 pp. 231-234

http://www.krishisanskriti.org/Publication.html

Fuzzy Rule Based Optimization in Machining of Inconel 718

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Abstract—*Inconel 718 are commonly used in the aerospace and automotive industries due to its excellent physical and mechanical properties. With the growing of Inconel 718 in aforesaid industries, machining of these materials has become a major concern for the manufacturing industries. The recent knowledge and state of art of machining Inconel 718 unfortunately is seemed to be insufficient for its optimal economic utilization. This paper presents an optimization study made on machining of Inconel 718 rods with different machining parameters. Here, machining parameters viz. spindle speed, feed rate and depth of cut are considered. Fuzzy rule based modelling approach combined with Taguchi's robust design philosophy has been adopted to evaluate the optimal process parameters thereby satisfying conflicting requirements of material removal rate (MRR) and surface roughness of the machined Inconel 718. Effectiveness of the proposed model has been illustrated in this study.*

Keywords*: Inconel 718, fuzzy rule, Taguchi's robust design*

1. INTRODUCTION

The demand of nickel based super alloys particularly Inconel 718 have been increased in aerospace and automotive industries due to their favourable physical and mechanical properties such as high yield strength, excellent fatigue resistance, low thermal conductivity and good corrosion endurance in severe conditions, particularly in making components for jet engines and gas turbines. Therefore, it is essential to analyse the machinability behaviour of these materials to reduce the surface roughness and maximize the material removal rate(MRR). Literature in this field highlights various aspects of machining to study process behaviour and parametric influence so that high quality finished parts in terms of dimensional accuracy and surface finish can be produced.

Pawade and Joshi [1]have utilized a multi-objective optimization approach for simultaneous optimization of surface roughness and cutting forces in high-speed turning of Inconel 718 using Taguchi grey relational analysis (TGRA). Thakur et al. [2]has developed the relationship among degree of work hardening and tool life as a function of cutting parameters like cutting speed, feed, depth of cut, untreated tungsten carbide and post-cryogenic-treated tool in machining of Inconel 718. Zhu et al. [3] studied of tool wear in the machining of nickel-based super alloys. Rajiv et al. [4] has studied the effects of spindle speed, feed rate and depth of cut in turning of Inconel 718. Jafarian et al. [5]examined the effects of the machining parameters including cutting speed, feed rate and depth of cut for improving surface integrity in terms of residual stress and surface roughness in finish turning of Inconel 718.

Although many research has been carried out to study the effects of machining parameters in turning operation of INCONEL 718 with several MCDM techniques, an attempt has been made in this paper to investigate the effects of machining conditions by using Fuzzy inference system with Taguchi Approach

2. EXPERIMENTATION

2.1 Work Material

Inconel 718 having dimension diameter and length has been used as work piece material.

2.2 Design of Experiment (DOE)

Taguchi method has been implemented to generate the orthogonal array for diminishing the number of experiments as it minimizes the source of variation on the quality characteristics of the product to reach the target value. In the present study, three machining parameters (spindle speed, feed rate and depth of cut) varied in three different levels have been used to optimize the machining condition. Table 1 indicates selected process control parameters and their limits. The most suitable array based on Taguchi's method has been found as L_9 orthogonal array used for the present study and represented in table 2.

Table 1: Process parameters and domain of experiment

Sl. No.	Process parameters	Notation	Level 1	Level 2	Level 3
1	Spindle Speed	N	257	386	566
2	Feed rate	f	1.5	2	2.5
4	Depth ofcut	d	0.5	1	1.5

Table 2: Design of experiment (L_{16} OA)

N	f	d
257	1.5	0.5
257	2	1
257	2.5	1.5
386	1.5	1
386	2	1.5
386	2.5	0.5
566	1.5	1.5
566	2	0.5
566	2.5	1

2.3 Performance characteristics measurements

The manually operated lathe has been used for the turning of Inconel 718. Corresponding MRR and surface roughness (Ra) values have also been computed by using following equation:

$$MRR = \frac{W_i - W_f}{\rho \times t_m} \; mm^3/\min \qquad (1)$$

Here, W_i is the initial weight of the work piece in gm, W_f is the final weight of the work piece in gm, ρ is the density of work material (8.2gm/mm^3), t_m is the machining time in minute.

The surface roughness has been measured by the Talysurf (Taylor Hobson, Surtronic 3+) having a stylus that slides over the surface based on carrier modulating principle.

3. METHODOLOGY

The present study focused on the variation of process parameters on the performance evaluation criterion in turning of Inconel 718 using Fuzzy Taguchi approach. The study illustrates the applicability, effectiveness and flexibility of this method.

Step 1: Normalization of input response

It is necessary to normalize responses to ensure that all the attributes are equivalent and the same formal. Experimental data that has been shown in Table 3 has to be normalized.

Table 3: Experimental Data

Sl. No.	MRR	Ra
1.	466.9538	1.92
2.	675.2871	1.87
3.	787.5	2.12
4.	1075.825	1.63
5.	1134.67	1.84
6.	589.9686	2.05
7.	654.8	2.24
8.	389.1282	1.76
9.	1219.268	1.83

The given MRR response is normalized by the following equations:

$$N_{ij} = \frac{X_{ij} - (X_{ij})_{\min}}{(X_{ij})_{\max} - (X_{ij})_{\min}} \qquad (1)$$

For surface roughness parameter:

$$N_{ij} = \frac{(X_{ij})_{\max} - X_{ij}}{(X_{ij})_{\max} - (X_{ij})_{\min}}, \qquad (2)$$

where, Nij = Normalized value, (Xij)max= Maximum value of response parameter, (Xij)min= Minimum value of response parameter and Xij = Value of response in ithcolumn and jth row of design matrix.

Table 4: Normalized data

Sl. No.	N-MRR	T-Ra
1.	0.09375	0.52459
2.	0.344712	0.606557
3.	0.479885	0.196721
4.	0.827206	1
5.	0.898092	0.655738
6.	0.241936	0.311475
7.	0.320033	0
8.	0	0.786885
9.	1	0.672131

Step 2: Application of fuzzy logic

Individual normalized values (for MRR and roughness which is furnished in Table 4) have been fed as inputs to the FIS (Fig. 1). In assessing the output MPCI, each input factor has been expressed using seven linguistic variables viz. "very low (VL)", "low (L)", "fairly low (FL)", "medium (M)" "fairly high (FH)", "high (H)", "very high (VH)" (Fig. 2-3). In present analysis, the trapezoidal membership function has been used to convert crisp inputs into fuzzy values. On the basis of fuzzy rules (Table 5), the Mamdani implication method has been employed for fuzzy inference reasoning [6]. To obtain a rule,

$$R_i : if x_1 is A_{i1}, x_2 is A_{i2}, and x_s is$$

Then y_i is C_i, $i = 1,2,.........., M$ (3)

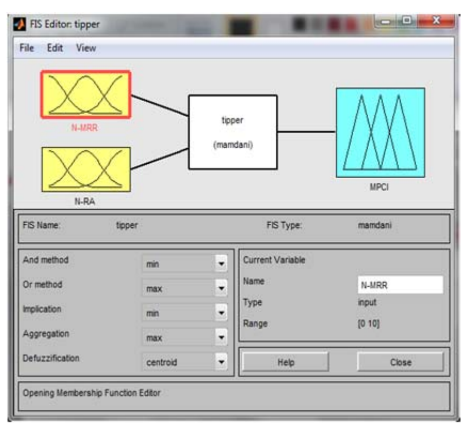

Fig. 1: FIS System

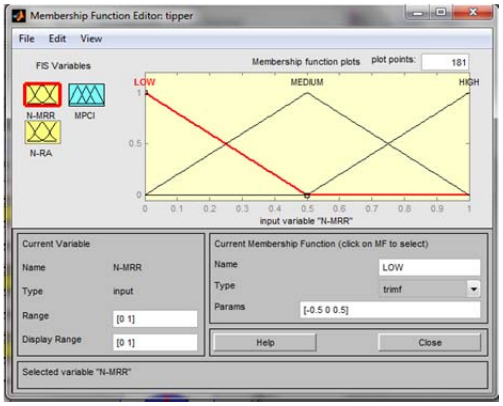

Fig. 2: Membership function for N-MRR

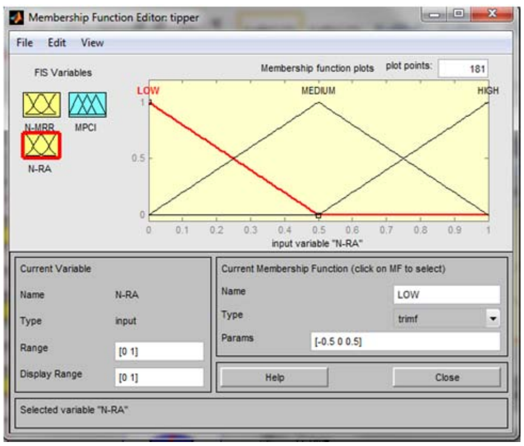

Fig. 3: Membership function for N-Ra

Table 5: MPCI and Corresponding MPCI

Sl. No.	MPCI	S/N ratio	Predicted-S/N ratio
1	0.33	-9.62972	-0.26654
2	0.479	-6.39329	
3	0.353	-9.04451	
4	0.807	-1.86253	
5	0.699	-3.11046	
6	0.351	-9.09386	
7	0.233	-12.6529	
8	0.39	-8.17871	
9	0.766	-2.31542	

The output $u_{agg}(y)$ of Mamdani- type fuzzy inference system has to be expressed by a crisp value for the next operation of the fuzzy controller. Centre of gravity (COG) method has been adapted for the defuzzification.

$$Y_0 = \frac{\sum_{i=1}^{m} y_i u_{agg}(y_i)}{\sum_{i}^{m} u_{agg}(y_i)} \quad (4)$$

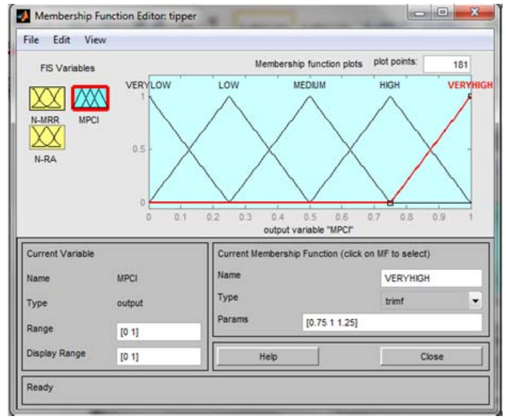

Fig. 4: Membership function for MPCI

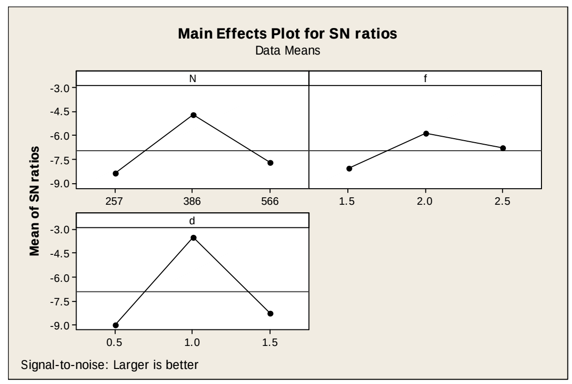

Fig. 5: Optimal parametric combination

The Fuzzy based rule matrix has been shown in Table 6. The MPCI value has been evaluated from FIS output (Table 7).

Step 3: Taguchi optimization technique

The optimal machining condition has been determined by using S/N ratio plot of MPCI. For computing the S/N ratio, Higher-the-Better (HB) criterion has been adopted.

$$\eta_{ij} = -10\log\left(\frac{1}{n}\sum_{j=1}^{n}\frac{1}{y_{ij}^2}\right) \quad (5)$$

Here, y_{ij} is the ith experiment at the jth test, n is the total number of the tests.

Fig. 4 represents the optimal parameter combination $N_{386} f_2 d_1$.

The predicated S/N ratio of MPCI (-0.26654) has been evaluated which has been seemed highest among all calculated S/N ratios of MPCIs in Table 7.

4. CONCLUSION

The present study focused on the variation of process parameters on the performance evaluation criterion during the turning of Inconel 718 by utilizing Fuzzy integrated with Taguchi method. method. Fuzzy inference system as been easily applicable to aggregate the conflicting performance characteristics based on fuzzy rules. The study illustrates the applicability, effectiveness and flexibility of this method.

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