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Optimization of Hot Turning Parameters by using Taguchi based Grey Relation Analysis

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Abstract: This paper investigates the multi response optimization of machining parameters in hot turning of Inconel 718 based on Taguchi based grey relational analysis technique. Cutting parameters such as cutting speed, feed rate, depth of cut and temperature of workpiece were taken as process parameters where as surface roughness, tool wear and material removal rate (MRR) were considered as performance characteristics for the present study. From the Taguchi based grey relational, an optimum level of cutting parameters has been identified. Furthermore, analysis of variance (ANOVA) has been carried out and identified that feed rate is the dominant process parameter on multiple performance characteristics.

Keywords; Hot turning, surface roughness, Tool wear, Grey relation analysis.

I. Introduction

It is difficult to obtain good surface finish and longer tool life while working with materials having high strength and wear resistance in conventional machining. Inconel 718 superalloy is one such material with excellent wear resistance, corrosive resistance and good strength and hence, has wide applications such as in aerospace, gas turbine, cryogenic storage tanks, nuclear fuel element spacers, pump body components, down hole shafts, wellhead parts (García et al. 2013). The high operating temperature in hot turning process imparts softness on the material under investigation, which eases the machining process and further reduces the high cost of changing and sharpening cutting tools. Softening of the workpiece in hot machining is a more effective method than strengthening the cutting tool in conventional machining. Earlier research has shown that the selection of a proper heating method eliminates the undesirable structural changes in the workpiece and reduces the machining cost (Kitagae et al. 1990). Chen and lo (1974) presented the results of an experimental investigation into the factors affecting tool wear in a direct current method of hot machining alloy steels and considerable improvement in tool life was recorded. Wang et. al (2002) studied the parametric optimization of multi-objective precision turning using grey relational analysis and proposed optimum process parameters of precision CNC turning. The tool life can be improved by an external magnetic field in hot turning of materials which possess challenges during machining. In hot machining of manganese steel using liquid petroleum gas (LPG), the tool life is increased by the selection of proper cutting speed and feed rate, whereas depth of cut and workpiece temperature play minor roles on tool life (Ozler 2004). Tosun (2002) computed the tool life during hot machining of manganese steel using artificial neural network and regression analysis method and reported that the cutting speed, feed rate, and workpiece temperature around 600 °C yield the longest tool life for carbide insert. Grey relational analysis based on grey system theory is the solution for solving the problem of complicated interrelationships among the multi-response. In grey-based Taguchi method, a multi-response process optimization problem can be converted to a single-response optimization problem where overall grey relational grade serves as the single objective function or response function to be optimized (Amin et al. 2007). The proposed methodology of combining grey relational analysis and Taguchi method has wide applications in multi-response problems like optimization of machining parameters in hot turning of Inconel 718 using the tungsten carbide (WC) insert. The TiC coated WC inserts has been chosen for this work because of abundant availability and economic reasons. In hot turning of stainless steel AISI 316 using liquid petroleum gas (LPG) the optimum parameters were determined based on grey relation analysis (GRA) (Ranganathan and Senthilvelan, 2011). By using Taguchi method for improved the tool life and surface finish and optimizing the cutting parameters in hot turning operations (Ozler, 2004). The current work uses oxy-acetylene heating technique for thermal enhancement to machine Inconel 718 with TiC coated carbide inserts. The machining parameters and responses were studied and analyzed with Taguchi based grey relation technique. Finally, analysis of variance (ANOVA) and confirmation test have been conducted to validate the predicted values.

II. Material and Methodology

An Inconel 718 rod of 35 mm diameter and 100 mm length was used for experiments. The chemical composition of Inconel 718 with hardness 40 HRC is shown in Table 1. TiC coated carbide insert with SNMP 120408 specification was used as a cutting tool. The input parameters range were decided on the basis of machine capability and pilot experiments. The selected range of input parameters are shown in Table 2. In this paper L9 orthogonal array is employed to analyze experiments. For conducting experiments, an oxy acetylene heating setup was used to heat the work piece material as shown in Fig. 1. Oxy acetylene heating is one of the best choices for hot machining it requires low cost equipment the heat transfer to the workpiece is very low, although the gross heat available and the energy transfer density will be low and metallurgical damage of the workpiece is low. The flame was generated through the nozzle of the torch. A special attachment was used to move the torch mounted on carriage to provide a flexible movement of heat source while machining. During all the experiments, the distance between the torch and workpiece is 25 mm. Flow rates for acetylene and oxygen were adjusted by pressure regulator and kept constant to get a neutral flame, which was used throughout the machining.

Table 1 Chemical composition of Inconel 718

Element	C	Ti	Cr	Fe	Ni	Nb	Mo
%	8.24	0.59	14.81	15.46	54.39	4.10	2.41

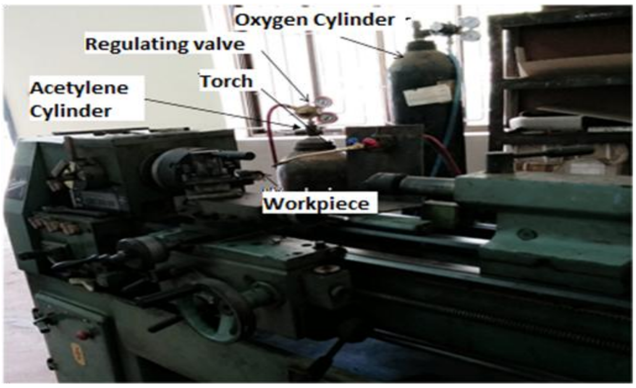

Fig.1. Hot machining setup

Table 2 Hot turning process parameters and their levels

Symbol	Process parameters	Units	Levels		
			I	II	III
A	Cutting speed	m/min	34.08	54.97	85.21
B	Feed rate	mm/rev	0.048	0.096	0.143
C	Depth of Cut	mm	0.2	0.4	0.6
D	Workpiece Temperature	^{o}C	150	350	550

Table 3 Experimental results

Exp. No.	A	B	C	D	Surface roughness R_a (μm)	Flank wear (mm)	MRR (cm^3/min)
1	1	1	1	1	1.54	0.16	0.33
2	1	2	2	2	1.59	0.08	1.39
3	1	3	3	3	0.82	0.05	2.96
4	2	1	2	3	1.09	0.15	1.05
5	2	2	3	1	1.96	0.13	3.16
6	2	3	1	2	0.56	0.16	1.57
7	3	1	3	2	1.26	0.36	2.45
8	3	2	1	3	0.98	0.32	1.63
9	3	3	2	1	1.32	0.33	4.87

III. Results and Tables

3.1 Taguchi based Grey relational analysis

Taguchi method was employed to optimize the single response variable. The multi-response variables are complicated and difficult to solve. Grey relational analysis based on the grey system is a statistical technique to solve multi response optimization. Black in the system represents lack of information, whereas white represents abundance of information. Thus, a system that contains information that is either incomplete or uncertain is called a grey system. Grey relation is a relation with incomplete information. The grey relational analysis is actually measurement of the absolute value of the data difference between sequences and is also used to measure approximate correlation between sequences (Fung 2003). Grey relational analysis assists in making decisions in imperfect and unclear situations and computes the influence of various factors and their relation. In the present work, experiment were conducted as per Taguchi L_9 orthogonal array experimental design and responses of surface finish, tool wear and metal removal rate were tabulated for each trial in Table 3. The following steps were implemented to perform the optimization of hot turning parameters.

i) Normalizing the experimental results

The grey relational analysis procedure involves preprocessing the data, in which the responses obtained are normalized to reduce the variability. As the raw data cannot be compared, the data sequence is normalized between 0 and 1 to make it comparable irrespective of data ranges and units (Fung 2003). The means of normalizing the data depends on characteristics and various methodologies of data preprocessing are proposed for the grey relational analysis (Deng 1989). Some responses obtained need to be maximized and some need to be minimized. Maximizing metal removal rate (MRR) increases the production rate thus enhancing productivity of a process. For MRR, higher the better quality characteristic was chosen and original sequence is normalized with equation 1.

$$\eta_i(k) = \frac{x_i(k) - \min x_i(k)}{\max x_i(k) - \min x_i(k)} \text{---------- (1)}$$

Where$\eta_i(k)$ is sequence after data processing $x_i(k)$,i=1,2,……m*;* k= 1,2…n , where *m* is the total number of experiments and *n* is the total number of performance characteristics. In this paper *m*=9 and *n*=3.

Low surface roughness and low tool wear are most desired characteristics of any machining process. So lower the better quality characteristic was considered for both surface roughness and tool wear. The original sequence of surface roughness and tool wear are normalized with equation 2.

$$\eta_i(k) = \frac{\max x_i(k) - x_i(k)}{\max x_i(k) - \min x_i(k)} \text{------------ (2)}$$

The normalized experiment results computed with equations 1 and 2 are tabulated in Table 4.

Table 4 Normalized responses

Exp. No	Surface Roughness	Flank wear	MRR
1	0.302	0.645	0
2	0.264	0.903	0.233
3	0.814	1	0.579
4	0.621	0.677	0.158
5	0	0.741	0.623
6	1	0.645	0.273
7	0.500	0	0.467
8	0.700	0.129	0.286
9	0.457	0.096	1

i) Grey relational coefficient calculation

To express the relation between best normalized value and actual normalized value of performance characteristic, Grey relation coefficient is determined. The grey relation coefficient $\varepsilon_i(k)$for the i^{th} performance characteristic for k^{th}

experiment can be computed as follows using equation 3 and results were tabulated in Table 5.

$$\boldsymbol{\varepsilon_i(k)} = \frac{\Delta_{min}+\xi\Delta_{max}}{\Delta_{oi}(k)+\xi\Delta_{max}} \text{------------ } \mathbf{(3)}$$

Where Δ_{oi} denotes the absolute value of the difference between current value ($\eta_i{}^o(k)$) and largest normalized value ($\eta_i{}^*(k)$) and ξ is the distinguishing coefficient and lower value of ξindicates higher distinguishing ability. Considering all the process parameters are equally weighing the value ofξ is considered as 0.5.

Table 5 Grey relation coefficients and grey relation grade

Exp. No	Grey Relational Coefficient			Grey Grade	Order
	Surface Roughness	Flank wear	MRR		
1	0.416	0.584	0.333	0.3337	8
2	0.404	0.837	0.394	0.4093	4
3	0.729	1	0.543	0.5681	1
4	0.569	0.607	0.372	0.3874	6
5	0.333	0.659	0.570	0.3908	5
6	1	0.584	0.407	0.4981	2
7	0.500	0.333	0.484	0.3293	9
8	0.625	0.364	0.412	0.3504	7
9	0.479	0.356	1	0.4589	3

ii) Grey relation grade calculation

Grey relation grade was determined by averaging the obtained grey relational coefficient. This value is used to evaluate the multiple performance characteristics and is determined as follows.

$$\gamma_i(k) = \frac{1}{m}\sum_{i=0}^{m}\omega_i\,\epsilon_i(k) \text{------- (4)}$$

Where γ_i is the grey relation grade of the k^{th} experiment, $\omega_i$is the weighting factor for the i^{th} performance characteristic ($0<\omega_i<1$) and m is the number of performance characteristics. Table 5 tabulates the weighted grey relational grade based on the above specified and is computed according to equation 4. Therefore, a higher Grey relational grade means that the corresponding parameter combination is closer to the optimal. The mean response for the Grey relational grade with its grand mean and the main effect plot of the Grey relational grade are very important because the optimal process condition can be evaluated from this plot. The means of grey relational grade for each level of process parameters namely cutting speed, feed rate, depth of cut and workpiece temperature were calculated using Minitab 17.0 and tabulated in the Table 6, the combination of $A_1B_3C_3D_3$ shows the largest value of grey relational grade for the factors *A*, *B*, *C*, and *D*, respectively. Figure 2 summarizes grey relational grade obtained for each process parameter and at each level. The larger the grey relational grade the closer is the response to ideal value and optimum performance will be delivered.

Table 6 Response table for grey relational grade

Symbol	Process Parameters	Grey relational grade		
		Level 1	Level 2	Level 3
A	Cutting speed (m/min)	**0.437**	0.4254	0.3795
B	Feed rate (mm/rev)	0.3501	0.3835	**0.5084**
C	Depth of cut (mm)	0.3941	0.4185	**0.4294**
D	Workpiece temperature	0.3945	0.4122	**0.4353**

3.2 Analysis of variance (ANOVA)

ANOVA is a technique to categorize the effect of individual factors. ANOVA was performed using the grey relational grade values to identify the significant factors. The percentage contribution of each factor calculated from ANOVA was used as the criterion for judging the effect of each factor.The percentage contribution of each process parameter over grey relation grade is represented in Table 7. From Table 7 it can be observed that the feed rate is most influential with 80.63%, cutting speed 10.71% ,workpiece temperature 4.85% and depth of cut has less influence 3.67%.

Table 7. ANOVA of grey relational grade

Source	Degree of freedom	Sum of squares	Mean square	% Contribution
A	2	0.005548	0.002774	10.71
B	2	0.041743	0.020871	80.63
C	2	0.001965	0.000983	3.79
D	2	0.002515	0.001258	4.85
Total	8	0.051771		100

3.3 Confirmation experiments

The confirmation experiments were carried out to verify the improvement in performance characteristic as given by Taguchi based grey relation analysis. The estimated grey relational grade $\gamma_{predicted}$ can be calculated using equation.

$$\gamma_{predicte\ d} = \gamma_m + \sum_{i=1}^{N}(\gamma_0 - \gamma_m) \text{------------ (5)}$$

Whereγ_m is the total mean of the grey relational gradeγ_0 is the mean of the grey relational grade at the optimal levels, and N is the number of the machining parameters that significantly affects multiple-performance characteristics. The estimated grey relational grade for optimum parameters is computed according to equation 5. Table 8 enlists the results of confirmation experiments using optimal cutting parameters. As shown in Table 8 tool wear reduced from 0.16 µm to 0.05 µm, surface roughness from 1.54 µm to 0.82 µm and metal removal rate increases from 0.33 to 2.96 cm^3/min and improvement of grey relation grade by 23%. From this it can be clearly observed that multiple performance characteristics are greatly improved.

Table 8 Results of cutting performance using initial and optimum cutting factors

Level	Raw Data	Predicted	Optimal process parameters
	$A_1B_1C_1D_1$	$A_1B_3C_3D_3$	$A_1B_3C_3D_3$
Surface roughness (μ_m)	1.54		0.82
Material removal rate (Cm^3/min)	0.33		2.96
Tool wear (mm)	0.16		0.05
Grey grade	0.33	0.568	0.568
Improvement of the grey relation grade = 23%			

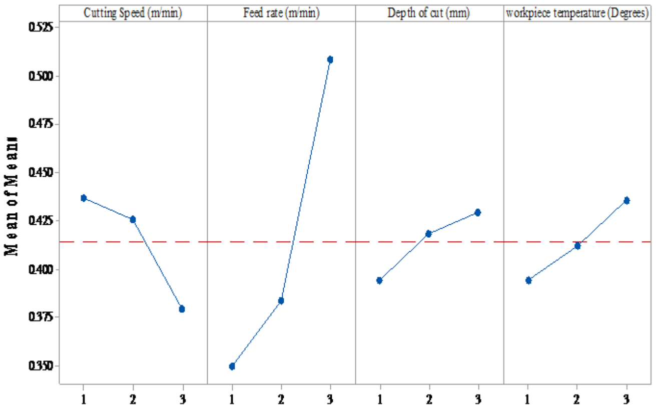

Figure 2 Effect of machining parameters on grey relational grade

IV.Conclusion

The following conclusions have been derived by applying the grey analysis on hot turning of Inconel 718.

- The optimal process parameters that have been identified to yield the best combination of hot turning parameters are cutting speed (V_c) at 34.16 m/min, feed rate (f) at 0.143 mm/rev and workpiece temperature at 550 °C.
- From the ANOVA results, feed rate identified as most influenced factor with 80% contribution, while cutting speed has 10%, workpiece temperature has 4.85% and depth of cut as 3.87 % influence on the surface roughness, tool life, and metal removal rate in hot turning of Inconel 718. The machining parameters set at their optimum levels can ensure significant improvement in the process parameters.
- Taguchi based grey relation analysis improved the grey relation grade by 23 % , thus improved the hot turning performance.

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