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EXPERIMENTAL STUDY AND OPTIMIZATION OF MACHINING PARAMETERS IN MILLING PROCESS OF INCONEL-718

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ABSTRACT

The aim of this study was to optimize the end milling of Inconel 718, a hard-to-machine alloy, owing to its nickel content, using Grey Relational Analysis (GRA). The primary goal was to identify and implement the optimal cutting parameters. One of the key parameters investigated was the diameter of the tool and speed of the spindle. The study results reveal that 0.9 mm depth of cut, 1400 rpm spindle speed, and 8 mm tool diameter resulted in significant improvements. Compared to 0.54 cc/min before, the material removal rate (MRR) is much higher from 2.16 to 2.16 cc/min after. The surface roughness (Ra) was approximately 0.742 m, and the material removal rate (MRR) was approximately 0.208 m. There are profound implications for the aerospace and automotive industries, which frequently use Inconel 718. The machining efficiency and product quality can be improved by implementing the identified optimal parameters. GRA can be useful in optimizing Inconel 718 machining in a manner that improves both material removal rates and surface quality, thus demonstrating its feasibility and originality.

Keywords: Grey Relational Analysis, Inconel 718, Material Removal Rate, Surface Roughness, Optimization

1. INTRODUCTION

Inconel 718, a nickel-chromium superalloy, is renowned for its resistance to extreme temperatures, corrosion, and oxidation, making it ideal for aerospace, chemical processing, and nuclear power applications. Comprising nickel, chromium, iron, niobium, and molybdenum, its tailored composition ensures exceptional performance under high-stress conditions.

Key challenges in machining Inconel 718 include optimizing cutting parameters to balance material removal, surface finish, and tool wear. Studies highlight the importance of precision in these parameters to enhance machining efficiency and durability (Rubaiee et al., 2022). The application of Grey Relational Analysis (GRA) has provided innovative insights into the interplay of machining variables, contributing to better surface quality and material removal rates (Machno et al., 2020).

Efforts to optimize machining processes for Inconel 718 promise to improve efficiency and quality across industries reliant on this critical material.

2. LITERATURE REVIEW

Prajapati et al. (2012) proposed precision-machining of parts using CNC milling, a commonly used machining technique. They optimized the feed rate, spindle speed, and depth-of-cut by using the Taguchi technique. Using surface roughness and material removal rate as its main focus, the study sought to improve product quality.

Joshi Amit et al. (2022) used the Taguchi Methodology to investigate how end milling parameters, such as feed rate, depth-of-cut, and spindle speed, affect surface finish. Analysis of Variance (ANOVA) and a Standard Orthogonal Array were used in the study to determine the most important factors for surface finish modeling.

The effect of Boron Nitride Coating on the wear behavior of carbide cutting tools during grinding of Inconel 718 was studied by Halil Caliskan and Bilal Kursuncu (2016). Surface roughness and tool wear in relation to cutting length were the main subjects of study. Wear mechanisms were determined using energy dispersive spectroscopy and scanning electron microscopy.

Altin and M. Nalbant (2007) studied the effects of cutting speed on tool wear and tool life when machining Inconel 718 with ceramic tools. The experiments employed silicon nitride-based ceramic tools with different geometries and qualities.

H.Z. Li, H. Zeng, and X.Q. Chen (2006) conducted an experimental investigation on changes in cutting force and tool wear during finish grinding of Inconel 718 using carbide-coated inserts. The study investigated the effect of cutting speed and observed surface damage, such as crater damage, on the rake. The aim of the study is to understand how flank wear is formed under different grinding conditions.

Nitin et al. (2017) examined how to determine the best machining parameters for Inconel 718 photochemical machining (PCM) and how those parameters affect surface topology. With an emphasis on surface quality, the study sought to determine ideal parameter values using the Taguchi L27 orthogonal array, using ferric chloride ($FeCl3$) as an etchant.

Manish et al. (2008) improved Inconel 718 alloy turning by using the Box Behnken design technique. Reducing cutting forces, improving surface quality, and increasing metal removal rates are their main goals. The machining process is adjusted using Response Surface Methodology (RSM).

Basmacı et al. (2023) focused on optimizing the machining process of Inconel 718, a nickel-based superalloy. Through experimental studies, they analyzed the impact of cutting parameters on cutting forces, tool wear, and surface roughness. By employing gray relational analysis (GRA) and analysis of variance (ANOVA), they identified coolant type as the primary influencer of surface roughness, while cutting speed predominantly affected cutting forces.

3. METHODOLOGY

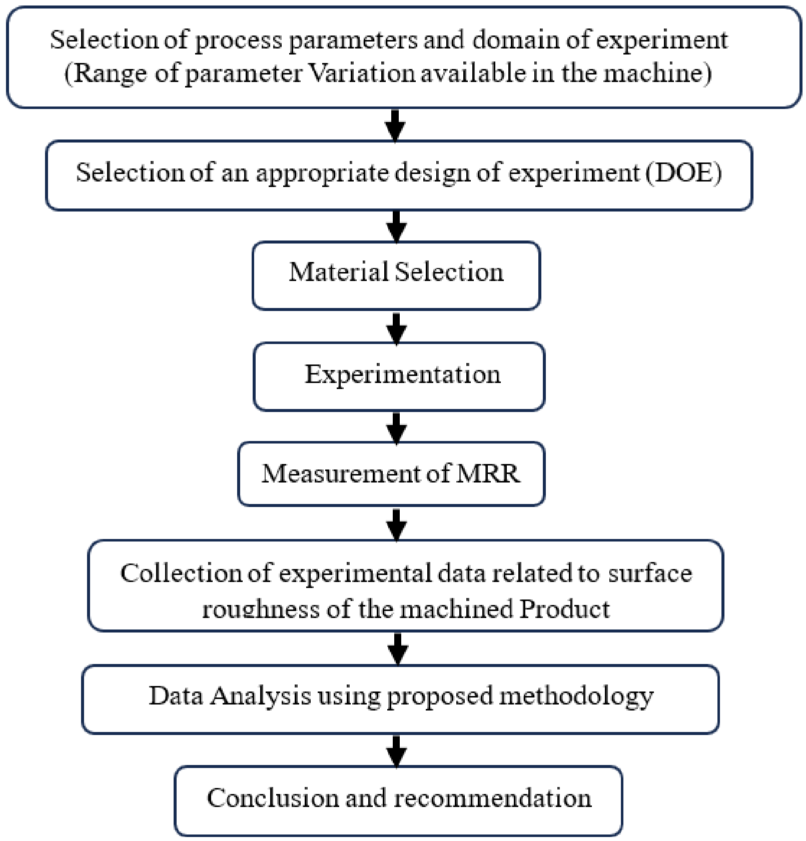
The optimization of machining parameters for Inconel 718 focuses on minimizing surface roughness and maximizing material removal rate (MRR). The process begins with selecting Inconel 718 and carbide cutting tools. Experiments are conducted on a CNC milling machine under dry cutting conditions, with parameters varied systematically using the Taguchi method and an L9 orthogonal array.

Surface roughness is measured using a Talysurf meter, and MRR is calculated from material removal and machining time. Grey Relational Analysis (GRA) is applied to normalize the data, compute grey relational grades, and rank parameter combinations. Optimal machining parameters are identified from these rankings, balancing surface roughness and MRR. Confirmation experiments validate the optimization, ensuring reliable and improved machining outcomes for Inconel 718.

4. EXPERIMENTAL WORK AND SETUP

The experimental setup involves CNC milling of Inconel 718 using carbide tools under dry cutting conditions. Various machining parameters, including tool diameter, spindle speed, and depth of cut, are investigated across different levels using Taguchi's orthogonal array. Surface roughness and material removal rate are measured to evaluate machining performance.

Procedural steps for the present work have been listed below:



5. EXPERIMENT DETAILS

This experiment focuses on CNC milling of Inconel 718 with carbide tools, exploring variations in tool diameter, spindle speed, and depth of cut under dry cutting conditions. Below Table 1 describes the specific setup and parameters used for the CNC milling process in this experiment.

Table 1 Experimental Setup and Parameters for CNC Milling of Inconel 718

Machine tool	CNC milling machine
Work material	Inconel 718
Tool material	Carbide tool
Tool diameter	6,8,10 mm
Feed	300 mm/min
Speed	1400,1600,1800 rpm
Depth of cut	0.3,0.6,0.9 mm
Cutting environment	Dry

Table 2 Machining Parameters and Their Levels

The machining parameters and their levels encompass variations in tool diameter, spindle speed, and depth of cut to explore their effects on the CNC milling of Inconel 718.

Parameter	Units	Level-1	Level-2	Level-3
Tool diameter	mm	6	8	10
Speed	Rpm	1400	1600	1800
Depth of cut	mm	0.3	0.6	0.9
Tool		Carbide tool		
Work piece		Inconel 718		

Taguchi's orthogonal array of L9 is most suitable for this experiment.

Table 3 L9 orthogonal array

S.no	Tool diameter (mm)	Speed	Depth of cut (mm)
1	1	1	1
2	1	2	2
3	1	3	3
4	2	1	2
5	2	2	3
6	2	3	1
7	3	1	3
8	3	2	1
9	3	3	2

In the above Table 3, the columns 1, 2 and 3 represents the levels of factors corresponding to the particular variable presented in the column. For the above coded values of machining parameters, actual setting values are presented in below table.

Table 4 Actual Setting Values for the Coded Values

S.no	Tool diameter(mm)	Speed (rpm)	Depth of cut (mm)
1	6	1400	0.3
2	6	1600	0.6
3	6	1800	0.9
4	8	1400	0.6
5	8	1600	0.9
6	8	1800	0.3
7	10	1400	0.9
8	10	1600	0.3
9	10	1800	0.6

Fig 1. Material after machining process

6. SURFACE FINISH MEASUREMENT

Talysurf surface roughness meter: Talysurf meter instrument is widely used to measure the shape or form of components. A profile measurement device is usually based on a tactile measurement principle. The surface is measured by moving a stylus across the surface. As the stylus moves up and down along the surface, a transducer converts these movements into a signal which is then transformed into a roughness number and usually a visually displayed profile. Multiple profiles can often be combined to form a surface representation.

Fig 2. Talysurf instrument for measuring surface roughness

7. RESULTS

The Taguchi calculated for each sequence is taken as a response for the further analysis. The smaller-the-better quality characteristic was used for analyzing the TAGUCHI, since a smaller value indicates the better performance of the process. The number of repeated test is one, since only one relational grade was acquired in each group for this particular calculation of S/N.

The Taguchi calculated for each sequence is taken as a response for the further analysis. The larger-the-better quality characteristic was used for analyzing the TAGUCHI, since a smaller value indicates the better performance of the process. The number of repeated test is one, since only one relational grade was acquired in each group for this particular calculation of S/N ratio.

Table 5 Machining Parameters and Their Levels

Parameter	Level-1	Level-2	Level-3
Tool diameter (mm)	6	8	10
Speed (Rpm)	1400	1600	1800
Depth of cut (mm)	0.3	0.6	0.9
Tool	Carbide (HRC 45)		
Work piece	INCONEL 718		

Table 6 Experimental results for SR and MRR

S.no	Tool dia	Speed (rpm)	DOC (mm)	Ra(µm)	MRR (cc/min)
1	6	1400	0.3	0.742	0.540
2	6	1600	0.6	0.711	1.080
3	6	1800	0.9	0.433	1.620
4	8	1400	0.6	0.188	1.440
5	8	1600	0.9	0.306	2.160
6	8	1800	0.3	0.278	0.720
7	10	1400	0.9	0.506	2.700
8	10	1600	0.3	0.817	0.900
9	10	1800	0.6	0.759	1.800

Here MRR was calculated by using below formula and surface roughness was measured by talysurf meter.

MRR=(f*w*d)/1000 (cc/min)

f=feed (mm/min)

w=width of tool (mm)

d= depth of cut (mm)

GRA (Grey Relational Analysis) procedure

Step 1

Table 7 Experimental results for SR and MRR

s.no	Tool dia (mm)	Speed(rpm)	DOC (mm)	Ra (μm)	MRR (cc/min)
1	6	1400	0.3	0.742	0.540
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6	8	1800	0.3	0.278	0.720
7	10	1400	0.9	0.506	2.700
8	10	1600	0.3	0.817	0.900
9	10	1800	0.6	0.759	1.800

Step 2

If the target value of the original sequence is infinite, then it has a characteristic of the "higher is better". The original sequence can be normalized as follows:

$$x_i^* = \frac{x_i^o(k) - \min x_i^o(k)}{\max x_i^o(k) - \min x_i^o(k)} \qquad \text{........Eq .(5.1)}$$

When the "lower is better" is a characteristic of the original sequence, then the original sequence should be normalized as follows:

$$x_i^* = \frac{\max x_i^o(k) - x_i^o(k)}{\max x_i^o(k) - \min x_i^o(k)} \qquad \text{........Eq .(5.2)}$$

Table 8 The sequence after data pre-processing

S.no	"Higher is better"	"Lower is better"
1	0.0000	0.1192
2	0.2500	0.1685
3	0.5000	0.6104
4	0.4166	1.0000
5	0.7500	0.8124
6	0.0833	0.8569
7	1.0000	0.4944
8	0.1666	0.0000
9	0.5833	0.0922

Step 3

$$x_i^*(k) = 1 - x_i^* \qquad \text{........Eq .(5.3)}$$

Table 9 The deviation sequence

s.no "Higher is better"

M.R.R "Lower is better"

Surface roughness

s.no	"Higher is better"	"Lower is better"
1	1.0000	0.8808
2	0.7500	0.8315
3	0.5000	0.3896
4	0.5834	0.0000
5	0.2500	0.1876
6	0.9167	0.1431
7	0.0000	0.5056
8	0.8334	1.0000
9	0.4167	0.9078

Step 4

Grey relational grade:

In grey relational analysis, the measure of the relevancy between two systems or two sequences is defined as the grey relational grade. When only one sequence, x0(k), is available as the reference sequence, and all other sequences serve as comparison sequences, it is called a local grey relation measurement. After data pre-processing is carried out, the grey relation coefficient & (k) for the kth performance characteristics in the ith experiment can be expressed.

$$\xi_i\,(k) = \frac{\Delta_{min} + \zeta\ \Delta_{max}}{\Delta_{oi}\ (k) + \ \zeta\ \Delta_{max}}$$

Table 10 Grey relational grade

s.no	"Higher is better"	"Lower is better"
1	0.3333	0.3621
2	0.4	0.3755
3	0.5	0.5620
4	0.4615	1
5	0.6667	0.7271
6	0.3529	0.774
7	1	0.4972
8	0.3749	0.3333
9	0.5454	0.3551

Step 5

Table 11 Rank order

Final grade	order
0.3477	9
0.3877	7
0.5310	5
0.7307	2
0.6969	3
0.5651	4
0.7486	1
0.3539	8
0.4502	6

8. RESULTS FROM GRA

Table 12 response table for SR and MRR with GRA grade and rank order:

s.no	Tool dia	Speed(rpm)	Doc(mm)	MRR(mm)	Ra(μm)	GRA grade	Rank
1	6	1400	0.3	0.540	0.742	0.347	9
2	6	1600	0.6	1.080	0.711	0.387	7
3	6	1800	0.9	1.620	0.433	0.531	5
4	8	1400	0.6	1.440	0.188	0.7307	2
5	8	1600	0.9	2.160	0.306	0.6969	3
6	8	1800	0.3	0.720	0.278	0.5651	4
7	10	1400	0.9	2.700	0.506	0.7486	1
8	10	1600	0.3	0.900	0.817	0.3539	8
9	0	1800	0.6	1.800	0.759	0.4502	6

GRA grade for input parameters:

$$\gamma i = \left(\frac{1}{n}\right) \sum_{k=1}^{n} \zeta_{\mathrm{i}}\,(\mathrm{k})$$

Table 13 GRA grades

	Level -1	Level -2	Level-3	Max-min	order
Tool dia	0.4221	0.6642	0.5175	0.2421	1
Speed	0.609	0.4795	0.5154	0.1295	3
doc	0.422	0.5228	0.6588	0.2364	2

From the above table 13 , i.e,: 0.2421 > 0.2364 > 0.1295. Hence, tool dia is the most effective factor for the performance.

Conformation experiment

Once the optimal level of machining parameters is selected the final step is to predict and verify the improvement of the performance characteristics using the optimal level of the machining parameters.

Table 14 results of machining performance using initial and optimal machining parameters

	Initial machining parameter	Optimal machining parameter	
		prediction	experiment
Setting level	$A_1B_1C_1$	$A_2B_1C_3$	$A_3B_1C_3$
Surface roughness	0.742	0.208	0.506
Material removal rate	0.540	2.16	2.7
Grey relational grade	0.3477	0.8988	0.7486

9. CONCLUSION

The objective of this work is to provide optimum output responses by optimizing input parameters using Grey Relation Analysis (GRA) calculations for achieving economical manufacturing. The GRA (grey relation analysis) optimization techniques were conducted for the outputs got from the experiments to find out optimal process parameters which gives better machining efficiency within the constrain of economy. It has been also found that the optimal cutting parameters for the machining process lies at 8mm of tool diameter, 1400rpm for speed and 0.9 mm for depth of cut. The surface roughness (Ra) is improved from 0.742 to 0.208 μm and the material removal rate (MRR) is greatly increased from 0.54 to2.16 cc/min.

CONFLICT OF INTERESTS

None.

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