Selection of cutting parameters for the machinability of Inconel 718 using Grey Relational Analysis

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Abstract. Inconel 718 is considered to be most difficult to machine superalloy because of its high shear strength, work hardening and precipitation hardening. Abrasive particles which are in microstructure have tendency have forming chip to be welded to tool and form built up edge (BUE) making it more difficult to machine. Friction between tool and material and its low thermal conductivity results in high temperature generation. Certain tools such as Ceramics are present which machine this material at prime cutting conditions. This paper addresses the cutting parameters needed most for providing low surface roughness

1 Introduction

Inconel 718 is one such nickel based alloy which is characterized by high strength, good oxidation, fatigue and creep resistance at high temperature. These properties are of great interest in domains such as the ones cited before, but result in an added difficulty in machining. Its high strength, hardening tendency and low thermal conductivity results in cutting processes including high forces and temperatures points. The machining of these materials, accordingly, is associated with low machinability and productivity, where tool wear, finishing accuracy and/or high production costs greatly limit the efficiency.

Ceramics tool is one of the cutting tool that is being used for cutting this hard material as it can operate at high speeds and depth of cut required to machine generate suficient heat to enable machining. These cutting tools have tendence to operate at high temperature and hard machinability environments which provide a better surface to the material.

CNC milling machine is one of the advanced machines that is being used for the machinability of Inconel 718 which can operate at elevated temperature conditions providing greater accuracy to the toola nd better dimensional tolerance features to the workpiece. These machines provide high productivity and can find a space in machining field for better finishing and quality of substrates being used.

2 Machining Parameters

2.1 Cutting speed: It is the relative velocity between the cutting tool and the surface of the work piece it is operating on. The unit of cutting velocity is revolutions per minute (rpm).

2.2 Feed Rate: It is the relative velocity at which the cutter is advanced along the work piece. The unit of feed rate is millimeters per min (mm/min).

2.3 Depth of Cut: The thickness that is removed as a work piece is being machined. The unit of depth of cut is millimeters (mm).

2.4 Surface Roughness: Defects may occur either in material surfaces during processing or after use, and defect analysis of in essential for providing the information to improve effectiveness, efficiency and durability of surfaces. Surface roughness also known as surface profile (Ra) is a measurement of surface finish. It is a topography at a scale that might be consider "texture" on the surface. Surface roughness is a quantitative calculation of the relative roughness of a linear profile area expressed as a single numeric parameter (Ra).

3 Experimental set-up

3.1 Cnc Milling Machine

The experimental study was carried out in wet cutting conditions on a high-speed milling machine equipped with a maximum spindle speed of 1800 rpm, feed rate of 10m/min and a 25-kw drive motor. The below figure shows the work bench of a cnc machine.

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Fig 1 Working environment of CNC milling machine

3.2 Workpiece

The work piece material used was Inconel 718 in the form of a 75mm (length), 50 mm (width) and 40 mm (height) block. To provide maximum rigidity, the work piece material is mounted onto the machine table.

Fig 2 Workpiece sample of Inconel 718

3.3 Ceramic Tool Insert

The tool used for end milling operation is Ceramic tool. The grade of the ceramic tool is AS20. The coating layer on the ceramic tool is Si_3N_4 . The ISO range of the ceramic tool is (S05-S20).

Fig 3 Sample of Tool Insert

3.4 Surface profilometer

Surface profilometer is the measuring instrument used to measure the roughness of a surface and gives the result as the average distance between the two peaks of the regular profile. The equipment consists of measuring tip, cantilever transducer and a control system to plot the profile of surface in 2D graph and calculate the mean value of it. The setup is done in such a way that the tip is just placed on the surface of the specimen (which is indicated by the blue line on the screen) and the firm placement of the body. By pressing the start button, the measuring tip starts to travel finite pre-defined distance (20mm, may differ with settings) on the irregular profile of the surface and comes back to the original position. The cantilever type transducer provides free oscillation movement to the tip while the instrument body is firmly fixed. This movement is converted into digital data directly by the transducer and profile is plotted. Based on the plotted graph the profilometer calculates the mean value and the result is obtained.

Fig 4 Surface Profilometer

3.5 Stop watch

Stop watch is a time piece designed to measure the amount of time taken to do a particular task. It measures the time from when it is activated to whenever it is deactivated. The stop watch is started and stopped manually.

Fig 5 Stop Watch

3.6 Tool maker's Microscope

Tool maker's microscope is used for the measuring very small distances on objects like peak distance of the bolt treads, gear tooth, etc. The specimen is placed on the glass plate (stage glass) where the source of light is fixed underneath, and the plate is connected to the guiding screw with handle for the adjustments.The image view from the scope has thin line of cross and the center of the cross is to be set on the starting point of the measurement. For the tool wear measurement, the end line of the grey surface shown on the microscope is set as the starting point and the distance to the end of the circumference of the tool insert is measured by rotating vertical handle.

Fig 6 Mitutoyo Tool Maker's Microscope

4 Methodology

4.1 L9 Array

Thisexperiment was done using Taguchi orthogonal array technique. Taguchi method uses a special design of orthogonal arrays to study the entire parameters with a small number of experiments. Taguchi's L9 orthogonal array is used to define the 9 trial conditions. The process parameters are listed in below table.

Table 1. Process parameters and their levels

Parameter	Unit	Symbol	Level 1	Level 2	Level 3
Cutting Speed (V)	*rpm*	A	400	600	800
Feed Rate (f)	*mm/min*	B	5	10	15
Depth of cut (d)	*mm*	C	0.2	0.4	0.6

The experimental layout using L9 orthogonal array is shown . Nine experimental runs are carried out using different combinations of the process parameters as mentioned. Surface Roughness for all the different combinations were found. The different experimental values of the output parameters are shown in Table 2.

Table 2. Experimental layout of L9 array

Experiment No	Process Parameter A	B	C	Average X
1	1	1	1	1.038
2	1	2	2	0.607
3	1	3	3	0.943
4	2	1	2	0.736
5	2	2	3	1.532
6	2	3	1	0.471
7	3	1	3	1.710
8	3	2	1	0.632
9	3	3	2	0.569

4.2 Setting up the Eigen-value matrix, input original data

$$X = \begin{bmatrix} X_1(1) & X_1(2) & X_1(3)\ldots\ldots & X_1(n) \\ X_2(1) & X_2(2) & X_2(3)\ldots\ldots & X_2(n) \\ X_3(1) & X_3(2) & X_3(3)\ldots\ldots & X_3(n) \\ \vdots & \vdots & \vdots & \vdots \\ X_m(1) & X_m(2) & X_m(3)\ldots\ldots & X_m(n) \end{bmatrix}$$

Where

m –no. of listed experimental runs
n –no. of influence factors
$X_m(n)$ –corresponding value of the m experimental run and n influence factor
An Eigen value matrix is setup according to the experimental run and the corresponding influence factors. In the corresponding values of the matrix, m represents the number of listed experimental runs and n represents the number of influence factors.
For example:
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• $X_1(1)$ means that the corresponding value represents the first experimental run and the first influence factor.
• $X_6(3)$ means that the corresponding value represents the sixth experimental run and the third influence factor.

Table 3. Process parameters and their Original data of the influence factors

Experimental Run	Surface Roughness (μm)
1	1.038
2	0.607
3	0.943
4	0.736
5	1.532
6	0.471
7	1.710
8	0.632
9	0.569

4.3 Standardized data transformation using formulas

After the first step all the values are subjected to a transformation process. This transformation process is based on the influence factors.

Influence factors refer to the output parameters of the experiment. The influence factors is surface roughness.

Defect-type Factor: The smaller the better

$$X_m(n) = \frac{max[X_m(n)] - X_m(n)}{max[X_m(n)] - min[X_m(n)]} \quad (1)$$

Medium-type factors are the influence factors that we tend to be near a certain standard value. Thus we use the medium-type factor transformation formula when we want values to be near to a standard reference value. The maximum value in each column is denoted by max[X_m(n)] and the minimum value in each column is denoted by min[X_m(n)].

4.4 Calculation of Grey Relational Degree

4.1.1 Selection of the best value for each influence factor

The best value for each influence factor is selected Surface Roughness should be less. Hence the least value of Surface Roughness is selected and chosen as the referential series for further calculation.

Table 4. The referential series and standardized data

Experimental Run	Surface Roughness (μm)
X0	0.144
1	0.890
2	0.619
3	0.786
4	0.144
5	1.000
6	0.000
7	0.870
8	0.9217
9	0.542

4.1.2. Getting the absolute difference of compared series and referential series

The difference between the obtained standardized data and the referential series is found. This is done to indicate the relational degree between 2 measurement sequences.

4.1.3. Find out the minimum and maximum

The maximum and minimum value of each influence factor is found. The maximum value is denoted as max[X_m(n)] and the minimum value is denoted as X_m(n).

4.1.4. Choose the constant p

The constant p is known as the distinguishing co-efficient. The distinguishing co-efficient p is between 0 and 1. Generally, p is set to 0.5.

4.1.5.Calculation of relational co-efficient and relational degree using formula.

For every value of surface roughness and material removal rate, relational co-efficient and relational degree has to be found out. Relational coefficient can be calculated by,

$$\tau_m(n) = \frac{\Delta min + p\Delta max}{\Delta X_m(n) + p\Delta max} \quad (2)$$

Relational degree can be calculated by,

$$r_m(n) = \Sigma\, (w\tau_m) \quad (3)$$

Table 5. The relational degree and ranking

	Surface Roughness (µm)	Relational Degree	Rank
w	0.9		
τ1	0.4872	0.4385	4
τ2	0.6334	0.5701	7
τ3	0.5346	0.4811	6
τ4	1.3364	1.2028	1
τ5	0.4455	0.4001	2
τ6	1.0000	0.9000	9
τ7	0.4965	0.4468	5
τ8	0.4747	0.4272	3
τ9	0.6925	0.6232	8

5 Results and discussion

At the end of Grey Relational Analysis (GRA), the experimental run or trial with the highest value gets the first rank. The ranks of all the experimental runs are mentioned in below table:

Table 6. The ranking of the experimental runs

Rank	1	2	3	4	5	6	7	8	9
Experimental Run	4	5	8	1	7	3	2	9	6

After getting the results, graphs for surface roughness for different cutting speeds were plotted.

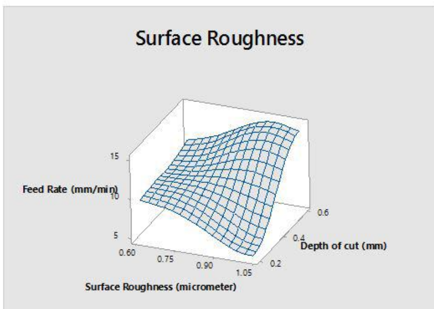

Fig 7 Surface Roughness for Spindle Speed 400 rpm

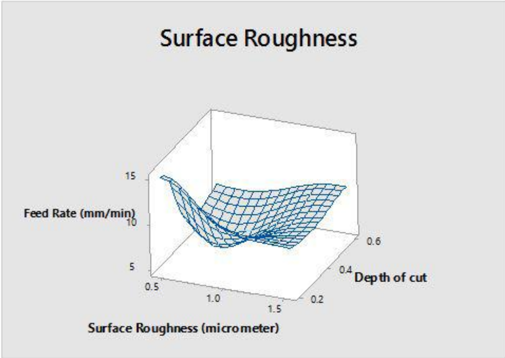

Fig 8 Surface Roughness for Spindle Speed 600 rpm

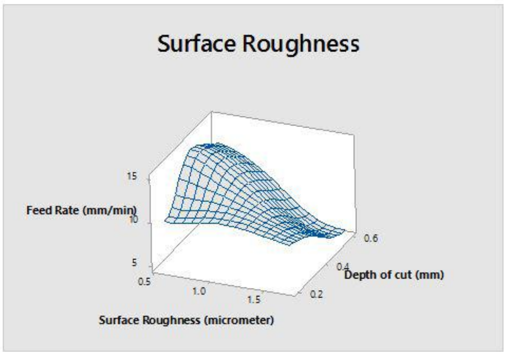

Fig 9 Surface Roughness for Spindle Speed 800 rpm

6 Conclusion

The optimal conditions for minimal surface roughness in improving the surface is found at cutting speed of 600 rpm, feed rate of 5 mm/min and depth of cut 0.4 mm. Grey relational analysis is depicting as an effective tool in determing the machinability of inconel 718 using ceramic tool insert. The hardened alloy can be machined at this environment conditions for providing higher surface finish and cutting conditions can be improved in wet machining.

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