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IMPROVEMENT OF SURFACE INTEGRITY WHEN FINISH TURNING INCONEL 718 USING CERAMICS

*Aruna M[1], Dhanalakshmi V[2] and Sankaranarayanasamy K[3]

[1]Department of Mechanical Engineering, Velammal College of Engineering and Technology, Madurai, 625 009, India.
[2]Department of Mechanical Engineering, Thiagarajar College of Engineering, Madurai, 625 015, India.
[3]Department of Mechanical Engineering, National Institute of Technology, Tiruchirapalli, 620 015, India.

ABSTRACT

Inconel 718, a high strength, thermal resistant nickel based alloy, is mainly used in the aircraft industries. It is essential to study the quality of machined surface since it directly affects the performance of the parts produced. In this work, surfaces generated when machining Inconel 718 alloy with ceramic tools at different cutting conditions are studied. The optimal cutting data are obtained using Taguchi's Optimization technique and ANOVA. The correlation obtained is compared with the experimental results. The experimental test results show that acceptable surface finish can be achieved when machining Inconel 718 with high pressure coolant supply.

Keywords: *Inconel 718, Ceramics, Surface Integrity.*

1. Introduction

Heat resistant super alloys (HRSA) are the types of alloys which find applications in the hottest parts of gas turbine, nuclear reactors and so on. These alloys are used since they have the ability to maintain excellent mechanical strength at elevated temperatures. In addition to retaining the strength and hardness at elevated temperatures, they also exhibit good resistance to both corrosion and creep. These properties make them suitable for applications in oil, petrochemical, medical, aerospace, submarines, nuclear reactors and steam power plants. Among these HRSA, nickel based alloys are widely used in air craft engines. Inconel 718 is one of the most widely used nickel based alloy in aircraft industries for the manufacture of discs, castings, rings, blades and engine mounts. However, HRSA have poor machinability. The excellent strength retention at high temperature, results in high cutting forces and reduction in cutting tool performance. Due to the difficulty in machining of these alloys, it is essential to monitor the quality of the machined surface, since it is directly related to the components performance, longevity and reliability. Severe failures occur by fatigue, creep and stress concentration. Hence, it is necessary to satisfy the surface integrity requirements in machining of these components [1].

Surface integrity is a generic term for describing quality of the surface and sub surface of a machined component. Surface roughness, metallurgical transformation and residual stresses are the measures of surface integrity. Requirements in the aerospace industry have led to the production of alloys with high strength-to-weight ratio and corrosion resistance, resulting in concentration of temperature at the tool cutting edge during machining. The high temperature gradient causes significant cutting tool wear. The principal effect of tool wear on the sub layer condition is the temperature generated by friction. This results in plastic deformation of the machined surface sub layer, due to the thermal expansion of the microstructure. Additionally, the temperature field reduces the yield strength of the sub layer material. Hence, it is important for the design and manufacturing engineers to possess a detailed knowledge on the effects of cutting tools on the quality of machined components [2].

In process measurement of surface integrity and residual stress are impracticable for industries [3]. Hence, it is the task of the research institutions to provide industry with valuable data. This paper, specifically deals with the measurement of surface roughness generated by finish turning of Inconel 718 using ceramic insert.

2. Literature Review

Poor machinability of Inconel 718 is associated with the factors such as galling and welding of work material on the tool rake face and thereby producing built up edge at lower temperatures. In addition, the presence of hard abrasive carbides in their microstructure accelerates the tool wear, and their relatively low thermal conductivity promotes poor machinability [4]. Tool materials with improved

*Corresponding Author - E- mail: aruna1m@yahoo.co.in

elevated temperature hardness, like cemented carbides (including coated carbides), ceramics and cubic boron nitride (CBN) are frequently used for machining nickel base super alloys [5].

To improve productivity, high speed machining (HSM) using ceramics is found to be one of the possible alternatives. HSM provides advantages such as work piece softening and chip control. Ceramic and CBN tools have superior hot hardness. To date, there has been a considerable amount of research published on the performance of these tools in the machining of HRSA [6]. Ceramic inserts have superior hot hardness and can be used at high speeds, an order of magnitude higher than that of coated carbides [7].

In order to minimize the heat generated at the tool - work piece interface, use of high pressure coolant is recommended. The advantages of high cooling technology include significant improvement in tool life, effective chip segmentation and efficient cooling and lubrication [8]. High pressure jet assisted machining is still not widely used because of the lack of the fundamental level of understanding about the process [9]. A lot of research work is carried out on the effects of operating parameters on tool life, when machining nickel based super alloys. However, little of this data refers to the effects of machining on work piece surface integrity [10]. The major problems reported are surface tearing, cavities, cracking, metallurgical re-crystallization, plastic deformation, increased micro hardness and the formation of residual stresses.

The machined surfaces under optimum cutting conditions in turning of Inconel 718, using round and rhomboid shaped pure oxide and mixed oxide ceramic tools, show good surface finish and less damage. The poor thermal conductivity of Inconel 718 retains more amount of heat on the surface, which leads to poor surface finish [11]. The optimal cutting conditions are selected based on the response variable (surface finish) which is strongly influenced by input parameters using Taguchi's Optimization [12, 13].

In this work, experiments are carried out in finish turning of Inconel 718 using ceramic inserts, under high speed and high pressure coolant conditions and surface integrity is studied using SEM.

3. Experimental Work

Inconel 718, with a diameter of 35mm is used as the work piece material. A triangular shaped ceramic cutting tool is used for finish turning of Inconel 718. The machining is carried out in PMT-S25 CNC lathe with a spindle speed range from 18 to 1800 rpm. To select the cutting parameters namely cutting speed, feed rate and the depth of cut, Taguchi's Optimization is used.

3.1 Experimental procedures

This experiment selects three influential cutting parameters, such as depth of cut, cutting speed, feed rate, as shown in Table 1. In this work L9 (3X2) is chosen for the experimental tests. Machining experiments are conducted for the L9 array. Machining at various cutting speeds and feeds are carried out at wet conditions using alkalomine fatty acid as coolant. The coolant is supplied at a pressure of 17 bar. Taguchi's Optimization methods combine the experiment using design theory and the quality loss function concept for the robust design of products and process. Orthogonal array is one of the important tools used in the experimental design of Taguchi method. In the turning process, indexable ceramic inserts with chip breakers are used. The machining tests are performed as an intermittent turning operation on a cylindrical bar.

Table 1: Cutting Parameters

Cutting Parameters	Selected values (Levels)
Cutting speed (m/min)	100,150 & 200
Feed rate (mm/rev)	0.1, 0.15 & 0.20
Depth of cut (mm)	0.5

Surface roughness measurement is carried out using Taylor Hobson Surtronic 3+, and is shown in the Fig. 1. In this measurement, roughness average denoted as 'Ra' is considered and the measured 'Ra' values are reported in the subsequent sections.

Fig. 1 Taylor Hobson Surtronic 3+

3.2 Analysis of the S/N ratio and ANOVA

Taguchi's Optimization method is used for the plan of experiment as it employs a generic signal-to-noise (S/N) ratio to quantify the present variation. Depending on the particular type of characteristics involved, different S/N ratios may be applicable, including "smaller the better" (SB), "nominal the best" (NB), and "higher the better" (HB). Here, S/N ratio for smaller the better condition is considered and the equation for the same is given below.

$$\eta = -10 \log\left[\frac{S}{N}\,\text{ratio}\right] \qquad (1)$$

and

$$\frac{S}{N}\,\text{ratio} = \frac{1}{n}\left[Y1^2 + Y2^2 + \ldots + Yn^2\right] \qquad (2)$$

In the above equation, 'Y' represents the characteristic property, 'n' denote the number of repetitions and 'η' denotes the observed value, i.e., the calculated value of the S/N ratio. Using the above equations, S/N ratios for surface roughness are calculated and are shown in Table 2.

Table 2: L9 Orthogonal Array with Experimental Results and S/N Ratio

Cutting Speed (m/min)	**Feed rate** (mm /rev)	**Depth of cut** (mm)	**Surface Roughness** (µm)	**S/N Ratio**
100	0.10	0.5	0.030	30.4576
100	0.15	0.5	0.025	32.0412
100	0.20	0.5	0.040	27.9588
150	0.10	0.5	0.045	26.9357
150	0.15	0.5	0.044	27.1309
150	0.20	0.5	0.052	25.6799
200	0.10	0.5	0.033	29.6297
200	0.15	0.5	0.046	26.7448
200	0.20	0.5	0.035	29.1186

The main effects plot for the S/N ratios are plotted for the various cutting parameters namely cutting speed and feed rate and are shown in Fig. 2. From this figure, it is found that the cutting speed is more significant as the slope gradient is very large compared to the feed rate and the results of the response ranking is shown in table.3.

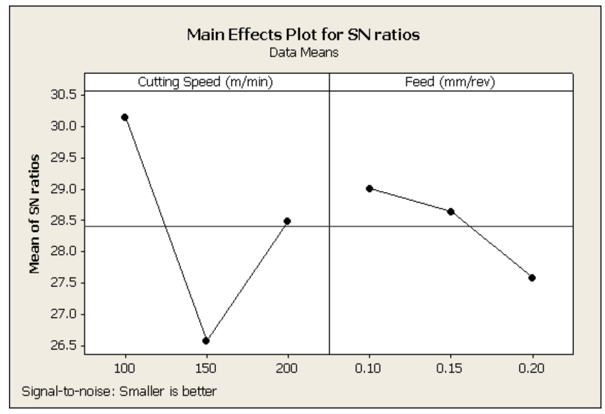


Fig. 2 Main Effects Plot for S/N Ratio

Table 3: Response Table for S/N Ratios, Smaller is Better

Level	**Cutting Speed**	**Feed rate**
1	30.15	29.01
2	26.58	28.64
3	28.50	27.59
Delta	3.57	1.42
Rank	1.00	2.00

Analysis of variance for surface roughness shown in Table 4 and the main effects plot shown in Fig. 2 reveal that, choosing cutting speed 100 m/min, feed rate 0.10 mm/rev gives the greater surface roughness within the range of experiments based on smaller the better characteristics. Fig. 3 shows the interaction plot for S/N ratio. This figure indicates that there is dominant interaction between the cutting speed and feed rate within the selected range of experiments.

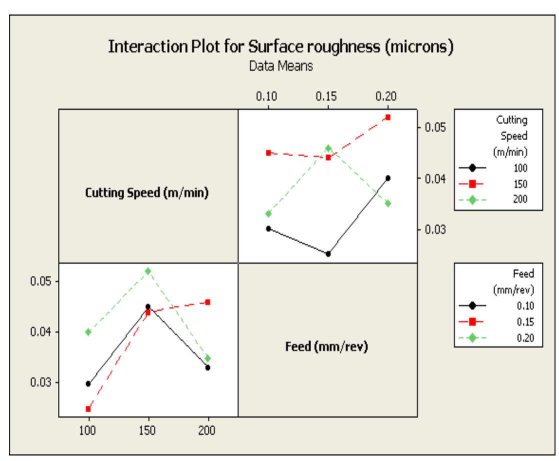


Fig. 3 Interaction Plot for Surface Roughness

Table 4: Analysis of Variance for Surface Roughness, using Adjusted SS for Tests

Source	DF	Sequential Sum of Squares	Adjusted Sum of Squares	Adjusted Mean Square	Fisher Test	Probability
Cutting Speed	2	0.0003562	0.0003562	0.0001781	3.73	0.122
Feed	2	0.0000616	0.0000616	0.0000308	0.64	0.572
Error	4	0.0001911	0.0001911	0.0000478		
Total	8	0.0006089				

Table 4 shows the analysis of variance for surface roughness using adjusted SS tests. In general, if the percent contribution falls below 15%, it implies that the quality characteristics of the experiment are under a precise control. In contrast, if the percent contribution of the error factor exceeds 50%, it means that certain significant factor is overlooked and the experiments must be reviewed again. It is found from the Table 4 that the cutting speed is the most significant cutting parameter which affects surface roughness.

3.3 Correlation & confirmation test

The correlation between the factors (cutting speed and feed) and the measured surface roughness to minimize the roughness average is obtained by multiple linear regressions. The regression equation generated is as follows.

$$Ra = 0.0199 + 0.000063\, v + 0.0633\, f \qquad (3)$$

Once the optimal level of the design parameters are selected, the final step is to predict and verify the improvement of the quality characteristic using the optimal level of the design parameters. Table 5 shows the machining parameters chosen for machining Inconel 718. Table 6 shows the experimental values and confirmation results for surface roughness.

From Table 6, it is observed that the calculated error falls in the range of 16.27% to 15.76%. This result is within 95% confidence interval of the predicted optimal value of the selected machining characteristics ‘Ra’. Thus it is proved that, the linear equation correlate the evaluation of the surface roughness to perform the machining operation at higher cutting speed by a responsible degree of approximation.

4. Results and Discussion

From the observations it is found that by increasing the cutting speed, the Ra value is reduced.

Table 5: Cutting Parameters

Cutting Parameters	Selected values (Levels)
Cutting speed (m/min)	120, 160 & 190
Feed rate (mm/rev)	0.125, 0.16 & 0.190
Depth of cut (mm)	0.5

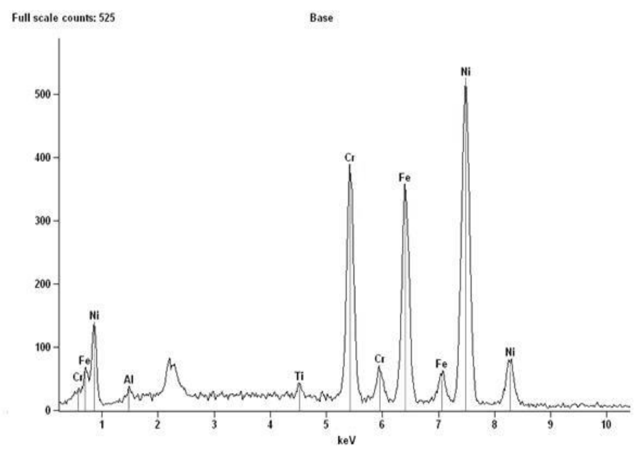
Table 6: Experimental Values and Confirmation Results for Surface Roughness

Test No.	Experimental value	Model value	Error (%)
A	0.043	0.0360	16.27
B	0.048	0.0404	15.83
C	0.052	0.0438	15.76

The XRF analysis of the machined surface of Inconel 718 is carried out and shown in Fig. 4. The observations show that the surface obtained is flawless with equal amount of deposition of elements. Absorption fluorescence correction factor for all the elements is listed along with the figure.

Fig. 5(a) shows the surface after machining of Inconel 718 at the condition 100 m/min., 0.15 mm/rev, 0.5 mm. The microscopic examination of the surface reveals that medium surface finish with little damage. Micrographs of the machined surfaces show that micro-pits and re-deposited work material are the main damages to the surfaces. Too small micro-pits are viewed on the surface.

Fig. 6 shows the micrographs of surfaces generated at the condition 150 m/min., 0.15 mm/rev, 0.5 mm. It is observed that the surfaces generated consist of well-defined uniform feed marks running perpendicular to the direction of relative work-tool motion with no evidence of plastic flow. Micro-pits are viewed on the machined surface. From the Fig, it is observed that the surface obtained after machining is smooth except few peaks. In addition, surface damage in the form of flash and tear are seen.



Quantitative Results Base

Element	Net Counts	ZAF	Weight %	Atom %	Formula
Al	172	4.110	1.08	2.23	Al
Ti	292	0.996	0.87	1.02	Ti
Cr	5995	0.942	18.80	20.20	Cr
Fe	5913	0.972	23.71	23.71	Fe
Ni	9839	1.077	55.54	52.85	Ni
Total			100.00	100.00	

ZAF-absorption fluorescence correction factor

Fig. 4 XRF Analysis of the Surface after Machining (200 m/min, 0.15 mm/rev, 0.5 mm)

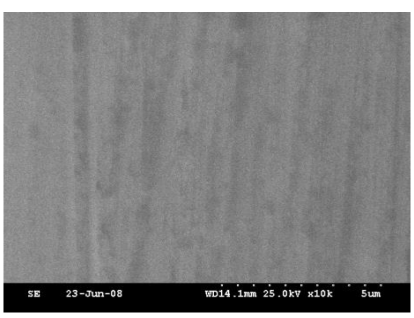


Fig. 5 Surface at 100 m/min

Fig. 7 shows the surface after machining at the cutting condition 200 m/min., 0.15 mm/rev, 0.5 mm. Surface finish is good at this condition. SEM Photograph reveals finer and smoother tool marks on the work piece surface, and lower surface roughness on the machined work piece.

Fig. 6 Surface at 150 m/min

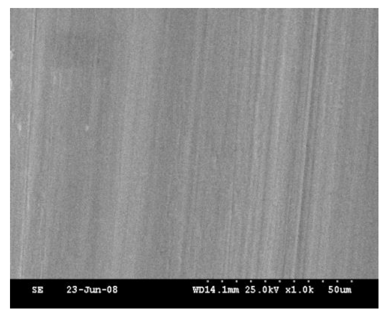


Fig. 7 Surface at 200 m/min

From the above figures obtained, it is observed that the surface finish obtained at high speed and feed rate conditions are good.

5. Conclusion

This paper presents the findings of an experimental investigation on the effect of cutting speed, feed, cutting speed and depth of cut on the surface roughness when finish turning Inconel 718. It is found from the results that good surface finish is obtained using ceramic tool, when machining Inconel 718 at the selected cutting conditions. The optimal cutting condition for good surface finish is 200 m/min. and 0.15 mm/rev from this observation. Hence, it is concluded that performance of ceramic tool is better at high cutting speeds under wet conditions.

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