Effect of High Speed Cutting Parameters on the Surface Characteristics of Superalloy Inconel 718

D. G.Thakur*, B. Ramamoorthy**, L. Vijayaraghavan**

Abstract—**The present paper is an attempt to study the effect of machining parameters on the surface characteristics/quality of the machined part with respect to the specific cutting pressure, microstructural alteration and microhardness while high speed dry turning of superalloy Inconel 718. The present approach and results will be helpful for understanding the machinability and surface characteristics of Inconel 718 during high speed dry turning for the manufacturing engineers.**

Index Terms— **Specific cutting pressure, microhardness, microstructural alteration.**

I. Introduction

Superalloy, Inconel 718 is one of the important alloys among all the Nickel and Nickel based alloy. Inconel 718 has found its niche in many industries, owing to its unique properties. Inconel 718 material is widely used in as aircraft engine parts, steam turbine power plants, space vehicles, medical applications, marine applications, pollution control equipment, automotive sector etc. But due to peculiar characteristics such as lower thermal conductivity, work hardening, presence of abrasive carbide particles, hardness, affinity to react with tool material etc. makes it difficult to machine. Hence, it is classified as "Difficult-to-cut materials". Cost effective machining with generation of good surface finish on the Inconel 718 components during turning operation is a challenge to the manufacturing engineers in practice [1-5].

Since machining is basically a finishing process with specified dimensions, tolerances and surface finish, the type of surface that a machining operation generates and its characteristics are of great importance in manufacturing.

Carbide cutting tools are the oldest amongst the hard cutting tool materials. Tungsten carbides are mainly used for continuous cutting operations Carbide tools are used to machine nickel-base superalloys in the speed range of 10–30 m/min. However, with the increasing demand to achieve fast material removal rate and better surface quality high speed machining was introduced. For nickel based alloys, the concept of high speed machining refers to speeds over 40 m/min approximately [5-9].

Considering all the above facts the present work aims to study the influence of different machining parameters on the surface characteristics of superalloy Inconel 718 during high speed turning. Test results were analyzed for achieving better machining performance during high speed machining of Inconel 718 with tungsten carbide tool insert (K20).

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II. Experimental Details

A. *Work piece material*

The work material used was Inconel 718. The microstructure and EDAX profile of Inconel 718 are shown in the Fig. 1 (a) & (b) respectively. The major elements in the Inconel 718 are chromium which is essential to assure high temperature oxidation resistance, where as other alloying elements are important to guarantee high temperature strength, especially creep resistance [3].

Typical major composition and properties of Inconel 718 are shown in Table 1 and Table 2.

Table 1 Major composition of Inconel 718.

Elements	Ni	Cr	Nb	Al	Ti
% Wt.	54.4	17.5	4.90	0.66	0.96

Table 2 Properties of Inconel 718

Density	8200 Kg/m^3
Melting point	1260-1336 ^{0}C
Specific heat	435 J/kg K
Avg. coeff. of thermal expansion	13 µm/m K
Thermal conductivity	11.4 W/m K
Ultimate tensile strength	1240 MPa

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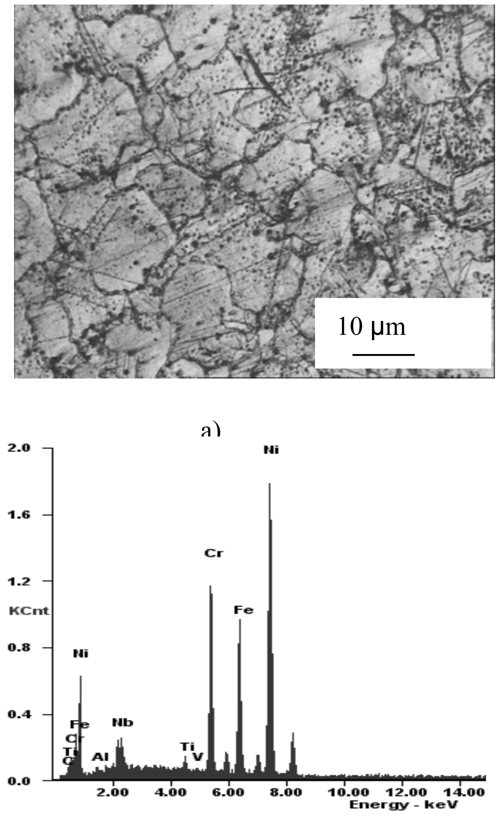

Fig. 1 a) Microstructure of Inconel 718
b) EDAX profile of Inconel 718.

B Cutting tool

Tungsten carbide cutting tool inserts (K20) was used for the high speed turning tests. Table 3 shows the tool nomenclature.

Table 3 Tool nomenclature

Rake angle (γ^0)	Clearance angle (α^0)	Inclination angle (λ^0)	Approach angle (Ψ^0)	Included angle (β^0)	Nose radius (r) mm
-6	6	-6	75	90	0.8

C. Experimental setup and cutting conditions

Machining tests were carried out on a precision high speed VDF lathe under dry conditions. The machining operation involved continuous high speed turning at various cutting parameters such as cutting speed, Vc (40 m/min – 60 m/min), feed, f (0.05 – 0.09 mm/rev), depth of cut, d (0.5mm).

III. Results and Discussions

A. Specific cutting pressure

The specific cutting pressure was chosen as a process indicator to determine the machinability of Inconel 718. It is usually influenced by the cutting speed and material. For a given chip section, i.e., depth of cut (d) and feed (f) combination, any variation of cutting force with cutting speed can be attributed to the variation in specific cutting pressure. The specific cutting pressure is largely dependent on area of the chip section (d×f). The quality of the machined surface is significantly influenced by the status of the cutting wedge, the specific cutting pressure/cutting force, which are indirect indicators of the status of the cutting wedge, can be used as a process indicator. Hence, any change in the specific cutting pressure can be attributed to the loss of form stability of the cutting wedge. For all the conditions tested, the specific cutting pressure (ks) was estimated from the measured cutting force value using the following equation:

$$ks = Fc / A = Fc / f * d \ (N/mm^2)$$

where F_c is the cutting force, and A is the undeformed chip cross-sectional area, which is the product of the feed rate (*f*) and depth of cut (d).

Effect of cutting speed on the specific cutting pressure is shown in Fig. 2. The specific cutting pressure is a function of cutting force and also specific cutting pressure decreases with increasing speed for a given feed and depth of cut. At low values of the feed rate, the material is subjected to lower strain rate. Also, the results indicate a reduction of specific cutting pressure as cutting speed is increased at constant feed rate and depth of cut, probably due to the reduction of the shear strength of the material caused by the increase of temperature in the cutting zone.

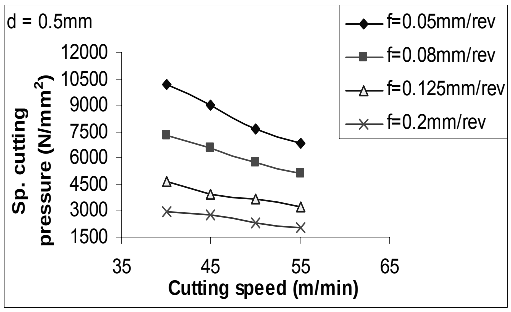

Fig. 2 Influence of cutting speed and feed on specific cutting pressure.

B. Micro structural Analysis

High speed machining corresponds to an increase in strain, strain rate and temperature. Consequently, the metallurgical transformations are expected in the matrix due to plastic deformation and material volume changes associated with thermal gradients.

Fig. 3 show typical microstructures observed below the machined surface, is an attempt to find some alterations caused by the chip removal process. It is seen clearly from the microstructure of raw material before machining that it consists of equiaxed grains of gamma (γ) austenitic phase. But, after machining there was grain refinement and grain deformation (Fig. 3 b and c). From figures it is clearly observed that in the case of the machined surfaces that there are deformed grains with deformed twin bands and also some slip lines gets formed during cutting process. From the microstructure it was observed that in case of machining of Inconel 718 the plastic deformation rate is high compared to other steels having equivalent hardness. It means that the amount of plastic deformation in cutting low thermal conductivity material, Inconel 718 is high.

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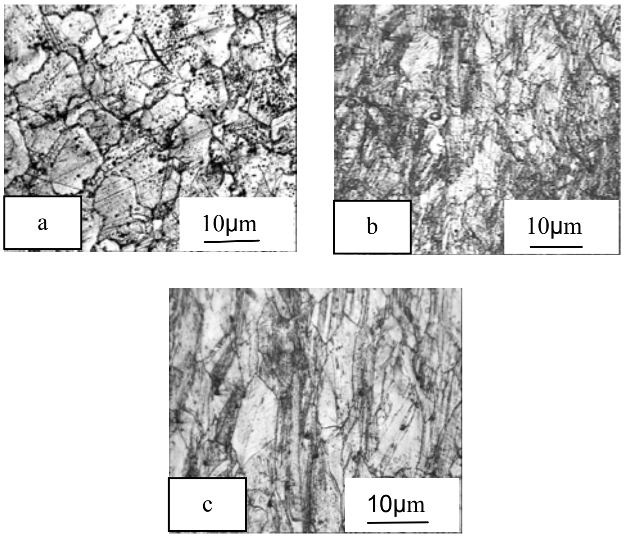

Fig. 3 SEM images of micro structural variations due to high speed machining As received material, b) Machined surface at 50m/min, c) Machined surface at 60m/min, 0.08mm/rev, 0.5mm.

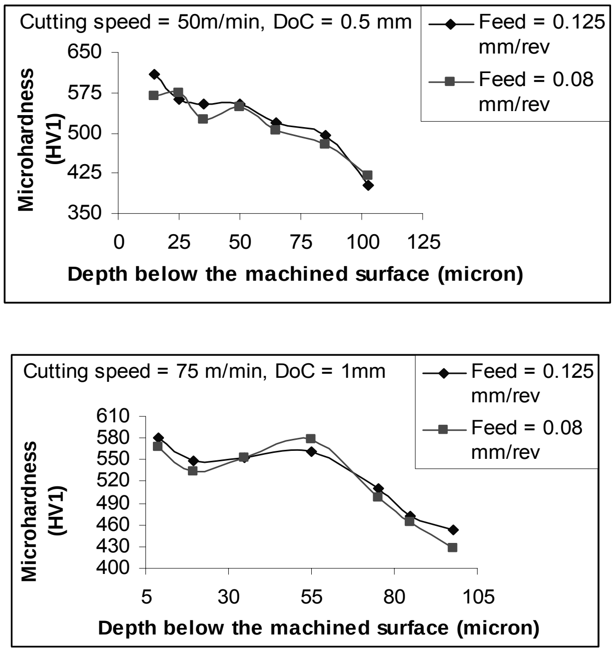

Fig. 4 Micro hardness variations below the machined surface of Inconel 718.

C Micro hardness Variations

Machining normally induces a severe plastic deformation in the material. The samples were encapsulated in an epoxy mold and then subjected to a series of soft polishing stages and then the micro hardness was measured. The changes in microhardness of the workpiece surface and subsurface (in the matrix) were measured normal to the machined surface using a Vicker's microhardness tester. The microhardness measurements for two samples were repeated five times for each sample. Enough spacing between indents and from the edge of the sample was provided. Micro hardness is higher near the machined surface layer and decreases rapidly as the depth increases. There is steep hardness gradient exists from the machined surface to the bulk material surface (Figure 4). This is due to the fact that the region confined to the surface is subjected to maximum workhardening. This can be attributed to the increase in the dislocation density due to increased plastic deformation. The plastic deformation behavior of the austenitic matrix plays a major role in the machining characteristics of Inconel 718. It is evident that variation in the degree of work hardening is a function of process parameters (Fig. 4). Up to a depth of 60 µm below the machined surface the correlation exists between both the cutting parameters but after this region there is a steep gradient in the micro hardness variation nature. Thus, based on workhardening characteristics analysis, it is seen that up to 60 µm below the machined surface, an interaction between cutting speed and feed and depth of cut have a significant influence. The depth of plastic deformation zone beneath the machined surface layer extends approximately upto 100µm. The microhardness near the surface was found approximately about 1.5 to 1.75 times the bulk material micro hardness (351 HV).

IV CONCLUSIONS

1. Specific cutting pressure can be used as the one of the important process parameter to understand the status of the cutting edge. Hence, any change in the specific cutting pressure can be attributed to the loss of form stability of the cutting wedge.

2. Microstructural and Micro hardness analysis showed that the kinetics of the plastic flow of the Inconel 718 matrix is highly dependent on the cutting conditions. Microstructural analysis of the machined surfaces and chips indicated metallurgical phase changes as a result of cutting under dry conditions. Plastic deformation of the matrix was the prominent mode of the sub surface damage occurred under dry cutting conditions. It was found that the austenitic matrix phase affects the depth of plastically deformed zone beneath the machined surface. The degree of work hardening and its extent can be reduced by using properly optimized cutting parameters during high speed machining.

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