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# Experimental study on Machinability of Inconel 718 Using Ultrasonic Vibration Assisted Turning

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## Abstract

Nowadays, the demand of Inconel 718 has increased tremendously in the aerospace, petroleum, automobile, and nuclear industries due to its superior chemical and mechanical properties. Inconel 718 withstands its strength at extreme temperature conditions. However, machining of Inconel 718 is a serious challenge due to its inherent properties like high strength and poor thermal conductivity. Hence Inconel 718 has been grouped under difficult-to-machine materials. In the present study, ultrasonic vibration has been employed at the tip of the cutting tool and termed as ultrasonic assisted turning (UAT) for machinability improvement of Inconel 718. UAT is expected to improve surface finish and extend the cutting tool life. In the present work, machinability of Inconel 718 has been studied experimentally by using an indigenously developed ultrasonic vibration turning setup. Comparative results on surface roughness and tool wear have been presented for both UAT and conventional cutting (CT) processes.

**Keywords:** Inconel 718, Machining, Ultrasonic Assisted Turning, Tool wear, Surface roughness

## 1. INTRODUCTION

Inconel 718 belongs to a class of Ni-alloys, and sub-class of Inconel. It is a renowned nickel-based superalloy, having excellent mechanical, chemical, creep-rupture, corrosion resistance and thermal-resistant properties at extreme temperature conditions [1]. These outstanding properties of Inconel 718 are acquired through its chemical composition. For instance, the combined presence of nickel, titanium and aluminum in its composition leads to its high temperature strength[2]. It's widely used in the areas of aerospace for the production of gas turbine and jet engine components [3]. In addition, it's also used to manufacture components for marine engineering, automotive, petroleum engineering, nuclear plant and cryogenic tanks[1][3][4].

However, these inherent properties of Inconel 718 by themselves hinder its machinability. For instance, (i) high strength and hardness of Inconel 718 lead to increase in cutting force components, (ii) low thermal conductivity of Inconel 718 leads to accumulation of high heat in the machining zone and creates a micro-weld at the edge of the cutting tool tip thereby aiding built-up-edge (BUE) formation, and (iii) high chemical affinity of Inconel 718 for many tool materials leads to diffusion and oxidation wear that shorten tool life[3]. Due to the aforementioned reasons, machining of Inconel 718 is not an easy task and hence it has been grouped under difficult-to-cut materials.
To enhance machinability of Inconel 718, several efforts like heat assisted, different cooling assisted and vibration assisted machining processes have been performed. Implementation of ultrasonic vibration assisted turning (UAT) is one of those techniques which is employed to enhance cutting of Inconel 718. UAT is a combination of ultrasonic vibration and conventional cutting operation. It includes imposing of a high frequency ultrasonic vibration on the cutting tool at different directions (tangential, radial and feed) during turning process. For the ultrasonic assisted turning process, the acoustic horn is used as cutting tool holder in addition to amplitude amplification. During the cutting process the vibration, which is imposed on the cutting tool, changes the continuous cutting process into intermittent cutting process. This non continuous cutting process reduce the tool-workpiece contact, therefore, extending the tool life, lowering cutting force and improving the surface finish. Also, tool chatter which has been formed due to machine tool vibrations will be suppressed to a certain extent by the counter vibration of the cutting tool[5]. However, the ultrasonic vibration will be effective when the cutting speed ($V_c$) is less than the speed of tool vibration, which is called critical speed ($V_{cr}$) i.e. $V_c < V_{cr}$ and $V_{cr}$ can be determined by equation (1). If the critical speed is higher than the cutting speed, there is no effect of ultrasonic vibration on the cutting process and the process is then considered as continuous cutting process [6]. This scenario impede usage of ultrasonic vibration for higher cutting speed processes.

$$V_{cr}=2\pi af \quad (1)$$

where, $V_{cr}$ is the critical speed, $a$ is the amplitude of vibration of the tip of cutting tool and $f$ is the frequency of the ultrasonic generator.
A number of researchers have contributed on ultrasonic assisted turning of Inconel 718. V. I. Babitsky et al [7] studied about aviation materials (C236, Inconel 718 and mild steel) using ultrasonic assisted turning. For Inconel 718, they have reported 40-50% surface finish improvement within the domain of their parametric conditions like frequency(20kHz), amplitude (20µm), feed rate (0.05mm/rev), depth of cut (0.8mm) and cutting speed(10-25m/mm). Another experimental and simulation study by V. I. Babitsky et al [8] reported 50% reduction in surface roughness for ultrasonic assisted turning of Inconel 718. Also, they have reported that the temperature is higher in ultrasonic assisted turning at the tip of the tool and chips.

A.V. Mitrofanov et al [9] developed a 3D finite element model for ultrasonic assisted turning of Inconel 718. The model was aimed to study the effects of machining parameters and cooling environment. From their study, during wet ultrasonic assisted machining, early chip curling, 20-25% reduction of cutting force, and about 60ºC reduction in temperature at the cutting zone have been reported. Using similar approach, N. Ahmed et al[10] investigated the influence of vibration and machining parameters on cutting forces for both experimental and FE simulations during UAT of Inconel 718. From the FE analysis, they have reported that increasing amplitude from 7.5 to 30µm



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and frequency from 10 to 30 kHz reduced the average cutting force by 52% and 47% respectively. Also, the experimental study established that the cutting force increased with feed rate during UAT process. However, with application of lubricant, the cutting forces were reduced by 30% when compared to dry cutting. C Nath and M. Rahman [6] added that 'tool-workpiece contact ratio (TWCR)' has a significant effect on ultrasonic cutting process, which mainly depends on the vibration parameters and cutting speed. Moreover, they have reported that better surface finish can be obtained at lower cutting speed ranges during ultrasonic assisted cutting of Inconel 718.

Generally, from the literature review it can be depicted that as a common method for ultrasonic assisted cutting process almost all experimental work have been investigated with a frequency of 20 kHz.

This paper attempts to study the machinability of Inconel 718 by applying a vibration (frequency of 30 kHz) on the cutting tool tip in wet environment. Surface roughness and tool wear results have been investigated and compared for CT and UAT.

## 2. MATERIALS AND METHODS

For the experimental study, 70 mm diameter and 300 mm length of Inconel 718 round bar has been used. According to mass spectrometer analysis, the chemical composition of Inconel 718 employed for machining includes: Ni-52.26%, Cr-18.63%, Nb-4.98, Mb-3.15%, Fe-18.32%, Ti-1.12% and Co-0.43%. Experiments were conducted on Leadwell T6 CNC Lathe machine coupled with indigenously designed and fabricated ultrasonic fixture. The fixture has been attached to a Kistler dynamometer in the place of a regular tool holder. The vibration is transferred to the tip of the cutting tool with (i) high frequency (30 kHz) from the ultrasonic generator, (ii) amplitude from transducer amplified by using customized acoustic horn fabricated from Ti6Al4V alloy. The vibration gets transmitted to the cutting tool through the acoustic horn which is also used as a tool holder. In this setup, ultrasonic vibration to the cutting tool is imparted in the tangential direction, since this direction has merits like lower cutting force, lower cutting temperature, lower built up edge (BUE), and better surface quality compared to feed and radial directions [11]. New grade tungsten carbide insert with PVD AlTiN coating (KENNAMETAL: CNMG 120408) has been used for the cutting process. The tool grade and geometry is suitable for interrupted cutting and machining of high-temperature alloys due to improved edge toughness as recommended by the manufacturer's catalogue. Machining process outputs, such as surface roughness and tool wear, were measured by Taylor-Hobson Talysurf and SteReo Discovery Microscope (V20: Carl Zeiss) respectively. Experimental setup of the ultrasonic vibration assisted turning process is given in Figure 1. Also, the summary of machining conditions are given in Table 1.

Table 1 Summary of Cutting Conditions

| Items | Item parameters |
|---|---|
| Workpiece | Inconel 718, (70 mm diameter and 300 mm length) |
| Cutting tool | Carbide Insert, CNMG 120408, KC5025 grade, PVD with AlTiN Coated |
| Cutting speed | 25 m/min, 35 m/min, and 45 m/min |
| Feed rate | 0.04 mm/rev, 0.08 mm/rev, 0.12 mm/rev |
| Depth of cut | 0.5 mm |
| Frequency | 30 kHz |
| Amplitude | 15μm |


**Figure 1 Ultrasonic assisted turning experimental setup**

## 3. RESULTS AND DISCUSSION

### 3.1 Effects of Cutting Speed and Feed on Surface Roughness

According to the experimental results, for the cutting conditions given in the Table 1, lower surface roughness were recorded for lower cutting speeds in case of UAT. As shown in **Figure 2,** for cutting speed 25-35m/min, at all feeds (0.04mm/rev, 0.08mm/rev and 0.12mm/rev), the surface roughness (Ra) values got reduced by 25-45% for UAT compared to that of CT. However, at cutting condition (f=0.12mm/rev and $V_{C}$=45m/min) a slight higher Ra value has been observed in UAT than CT. The nominal increase in surface roughness for UAT at higher speed and feed may be due to increased tool-work contact ratio (TWCR) at higher speed[6]

### 3.2. Tool Wear Comparison for CT and UAT

For flank wear and nose wear measurement, cutting conditions (a depth of cut 0.5mm, a feed of 0.12 mm/rev, and a cutting speed of 45m/min) were selected. To understand clearly the tool wear progression, measurement has been done after 20 mm and 40 mm length of cut. **Figure 4** depicts that for both 20 mm and 40 mm length of cut, flank wear has been lower in UAT than CT. It has been also observed that flank wear progresses by 15% for both CT and UAT after 20 mm and 40 mm length cuts. However, in UAT flank wear is less by nearly 20% compared to CT after 40 mm length of cut. Similarly, the SteReo Discovery Microscope images of flank wear given in **Figure 3 (b)**, shows lower flank wear in UAT over CT

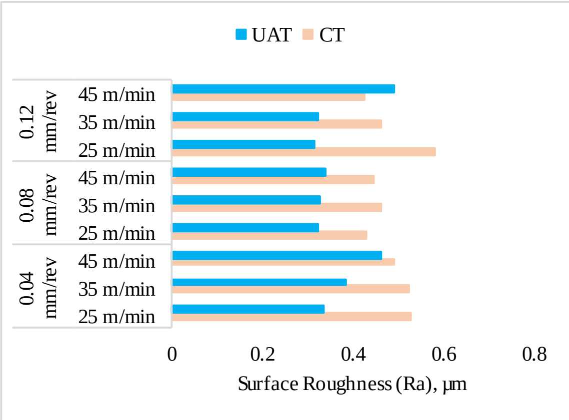
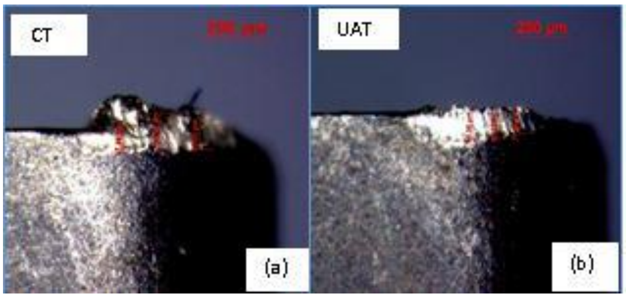



**Figure 2 Effects of cutting speed and feed on surface roughness for CT and UAT processes**




**.Figure 3 SteReo Discovery Microscope images of flank wear for (a) CT and (b) UAT after 40 mm length of cut**

Similarly, **Figure 6** illustrates that for 20 mm and 40 mm length of cuts, lesser nose wear has been achieved in UAT than in CT. Nose wear increases approximately by 48% and 24% in CT and UAT respectively after 20 mm and 40 mm length of cuts. In UAT, nose wear is lesser by 10% and 24% for 20 mm and 40 mm length of cuts respectively compared to CT. Therefore, both flank wear and tool nose wear were significantly lower for UAT compared to that of CT. Further, the SteReo Discovery Microscope images of nose wear given in **Figure 5 (b)**, shows lower nose wear in UAT compared to CT. This could be due to the inherent effect of ultrasonic vibration which has helped in providing the intermittent tool-workpiece contact in case of UAT as compared to continuous engagement of tool and workpiece in CT. The effects of ultrasonic assisted cutting reflect an increased surface finish and reduction in tool flank and nose wear.

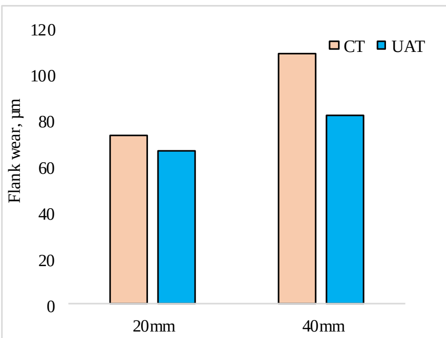



**Figure 4. Flank wear after 20 mm and 40mm length of cut**

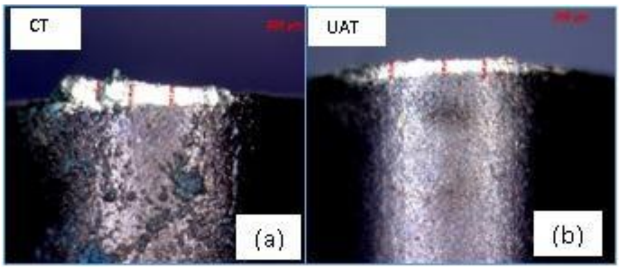



**Figure 5 SteReo Discovery Microscope images of nose wear for (a) CT and (b) UAT after 40 mm length of cut**

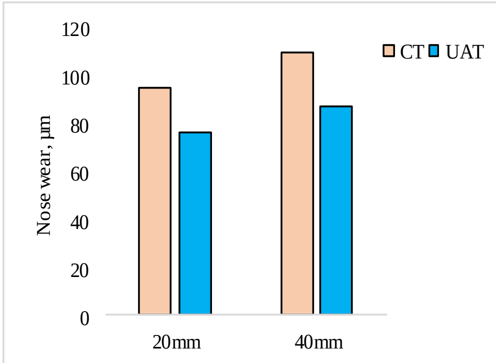



**Figure 6 Nose wear after 20 mm and 40mm length of cut**

## 4. CONCLUSIONS

To enhance the machinability of Inconel718 superalloy ultrasonic assisted turning is performed at various machining parameters (feed rates and cutting speed). After experimentation, the following conclusions have been drawn:

1. In UAT better surface finish has been obtained at lower cutting speed. Surface roughness, Ra values get reduced by 25-45% for the cutting speed 25-35m/min respectively compared to CT.
2. Lower flank wear has been observed in UAT for both 20 mm and 40 mm length of cuts. The flank wear is lowered by 20% approximately in UAT compared to CT. Similarly, for UAT nose wear is lowered by 10% and 24% for 20 mm and 40 mm length of cuts respectively compared to CT. Therefore, implementation of UAT for machining of Inconel 718 provide a better surface quality with longer tool life than CT.

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