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EXPERIMENTAL INVESTIGATIONS OF TOOL WEAR IN VIBRATION-ASSISTED TURNING OF INCONEL 718

In the current paper, the effect of tool wear for a constant period of time (360 s) during conventional and ultrasonic assisted machining of Inconel 718 is investigated in terms of cutting forces, temperature, and deviation measurements. For fixed process parameters turning experiments have been performed with and without the application of tangential vibration. Ultrasonic assisted turning (UAT) experiments have been compared with conventional turning (CT). The experimental results reveal that cutting forces and temperature increase linearly in the case of UAT whereas remaining constant in CT for a constant period of time. Besides the tool wear rate in the case of UAT is more than that in the CT.

Keywords: Inconel 718; Ultrasonic assisted turning; Dry machining; Deviation; Cutting forces; Temperature

1. Introduction

Inconel 718 is a Nickel-based superalloy, it has been extensively used in jet engine applications (blade and disk alloy) because of its yield strength memory at high temperatures as well as its high formability and weldability [1-4]. This superalloy has been widely used in the energy, power, biomedical and other fields because of its high corrosion resistance, good thermal fatigue resistance, high-temperature strength and high thermal stability [5]. In addition, this alloy is also used for high-temperature applications in gas turbines, turbocharger rotors, nuclear reactors, and a variety of structural applications in the form of wrought, cast and powder metallurgy products [6,7]. For the design and manufacturing of turbine blades, the directionally solidified nickel-based superalloys encounter a renewed interest because of their enhanced mechanical strength than polycrystal for a large range of temperatures [8,9].

Inconel 718 consists of different precipitates such as γ', γ'', δ, TiC, Ni_3C, etc [9-11]. Hence it has high strength and high hardness. Although high strength and high corrosion resistance of Inconel materials make the machining difficult due to the failure of cutting tools. Ultrasonic assisted machining method is an advanced technique for machining hard-to-cut materials. In this method, a tangential unidirectional vibration is imposed on the cutting tool. The tool vibrates sinusoidally with amplitude. With the incorporation of periodic movement on the cutting tool, the cutting forces decrease, and machined surface finish is improved. However, the tool will fail by brittle fracture if there are excessive vibrations or shocks during ultrasonic-assisted machining.

Hard-to-machine materials have been investigated by several researchers using conventional and vibration-assisted turning. Devillez et al. [12] investigated on the machining of nickel-based heat resistant superalloy using wet and dry turning tests. By varying the cutting speeds, the residual stresses and surface integrity have been studied. Ni and Ti-based alloys have been studied using conventional and vibration-assisted machining by Maurotto et al. [13]. With the application of vibration-assisted machining, there is a reduction in cutting forces and an improvement in material removal rate and surface quality [10]. Chandra Nath et al. [14] studied the effect of ultrasonic vibration cutting in the machining of low alloy steel. They performed the machining experiment with and without the application of ultrasonic vibration for different cutting parameters. They concluded that the ultrasonic vibration cutting has lower tool flank wear as compared to conventional turning under all cutting conditions. They have also reported that the highest tool wear and higher cutting forces for a feed rate of 0.2 mm/rev.

In the current research, the effect of tool wear during machining of Inconel 718 with and without the application of tangential vibration is investigated. The machining of Inconel 718 is challenging due to its high strength and hardness. This

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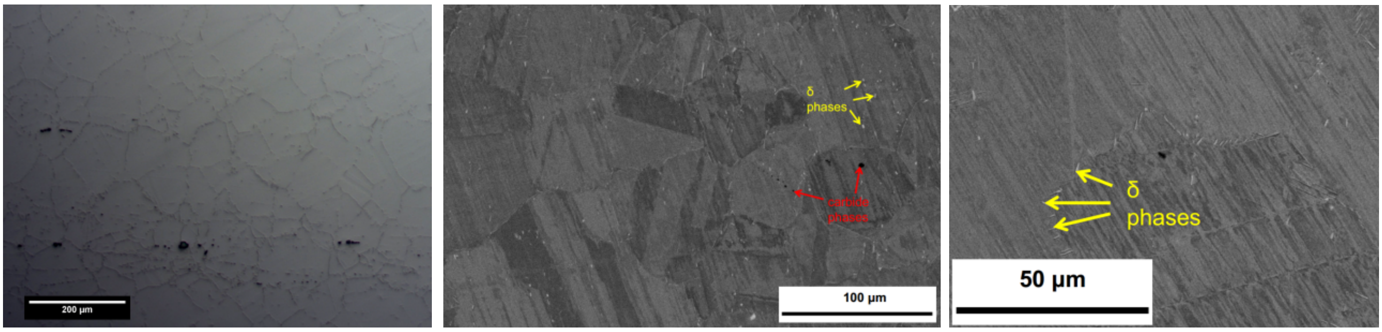


Fig. 1. Microstructure of Inconel 718 at different magnifications

paper focuses on the cutting forces, the temperature in the process zone, surface roughness, and tool wear for both conventional and ultrasonic-assisted turning (UAT). It is clear from the previous studies that ultrasonic assisted machining has been successfully incorporated for machining hard-to-cut materials. Hence the main focus of this work is to study the machining behavior of Inconel 718 using UAT and compare it with the conventional turning (CT).

2. Experimental procedure

Inconel 718 with a diameter of 108 cm has been used as a workpiece material for machining. It has a nominal chemical composition of 54 wt% Ni, 17.6 wt% Cr, 18 wt% Fe, 5.3 wt% Nb, 1.01 wt% Ti, 2.6 wt%C, 0.7 wt% Al. For the microstructural characterization, samples are metallographically prepared to disclose the microstructural information (grain size and grain morphology) [15]. The microstructure of the Inconel 718 is characterized by optical microscopy. As can be seen in Fig. 1, the grain structure along with primary carbide precipitates of Inconel 718 is shown in the micrograph. The average grain structure of the Inconel 718 is 90 μm.

Dry turning experiments have been performed on a lathe machine. A cemented carbide cutting tool with a 7.3° rake angle and 70° approach angle has been used (see Fig. 2). Machining parameters have been fixed with a depth of cut 100 μm, feed rate, and cutting speed are 0.1 mm/rev and 20 m/min respectively. In the case of ultrasonic assisted turning, the tooltip is vibrating in a tangential direction with a frequency of 16 kHz and an amplitude of 10 μm.

The cutting forces are measured using a piezoelectric type dynamometer Kistler 9257B mounted under the tool holder and a multichannel charge amplifier connected to a data acquistion system. The average temperature in the process zone is measured using the thermal camera. Tool wear of the tool and surface roughness of the machined workpiece were examined by using Alicona Infinite Focus Standard.

3. Results and discussion

Cutting forces

The cutting forces with respect to the time (s) for Inconel 718 are presented in Fig. 3 for CT and in Fig. 4 for UAT. As can be seen from Fig. 3 and 4, the cutting forces reduce approximately 50% for UAT as compared to CT. This is due to the average stresses generated in the workpiece, and therefore, the interaction forces between the material and the cutting tool are substantially smaller for UAT. The reduction in cutting forces for Inconel 718 of some 60% [16].

Higher force reduction in the main cutting force (tangential force) and then followed by radial force. An important observation was that force components remain constant for a machining period (360 s) in the case of CT. However, the forces in UAT are increased linearly with an increase in the machining period due to excessive wear effects as compared to CT.

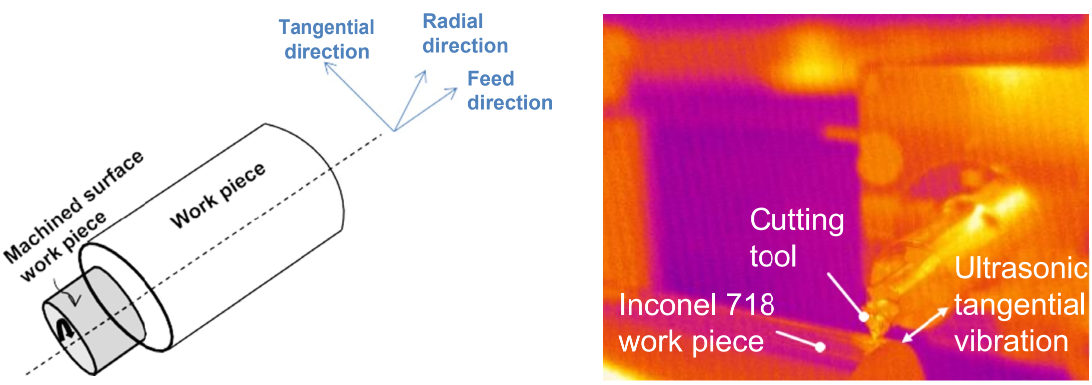


Fig. 2. A schematic diagram of the workpiece along with cutting directions (left), and an image of the cutting tool in ultrasonic tangential vibration (right)

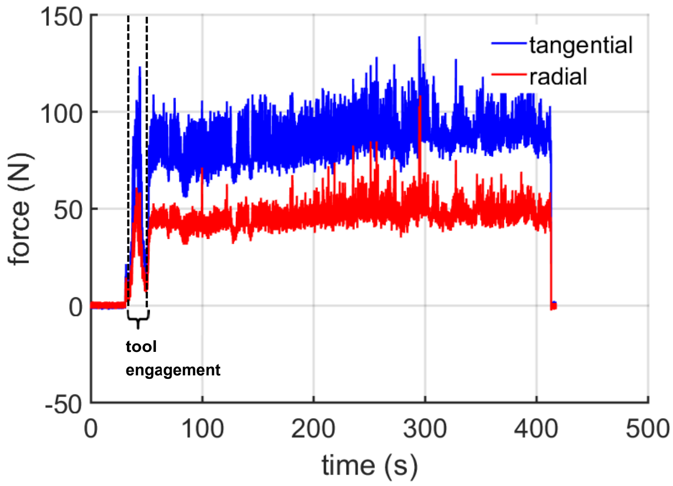


Fig. 3. Tangential and radial force in conventional turning for Inconel 718

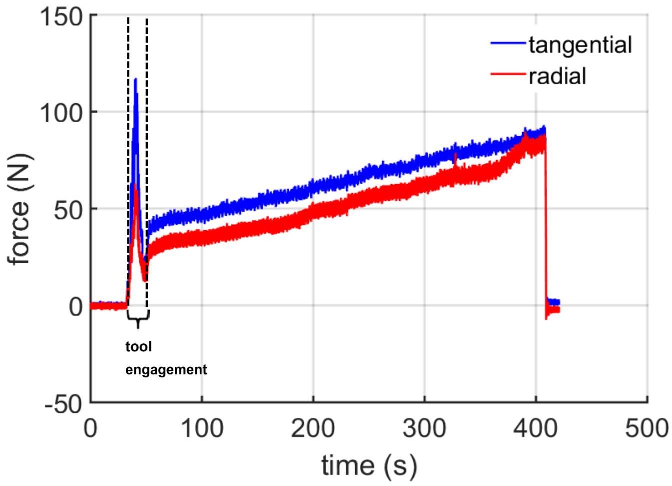


Fig. 4. Tangential and radial force in ultrasonic assisted turning for Inconel 718

Measurement of temperature

To study the temperature in the process zone, the thermal camera is used to measure the temperature in CT and UAT. The graphs of the average temperature values as a function of the time period for Inconel 718 are presented in Fig. 5 and Fig. 6. Fig. 5 reveals the average temperature is a constant with an increase in the machining period in CT. However, in the case of UAT, the temperature increases linearly because of the higher tool crater wear rate compared to CT (Fig. 6). The ultrasonic vibration significantly added to the reduction in the cutting temperature in turning of Inconel 718 [17]. The reduction may be assigned to the ultrasonic tangential vibratory motion in UAT.

Tool wear

Tool wear is one of the parameters that influence the tool life and hence influence the quality of the machined surfaces. The gradual wear rate of the tool takes place due to crater or flank wear. In general, the crater wear occurs due to the friction at the chip-tool interface as well as the abrasive action of the microchips whereas the flank wear occurs because of the friction between the tool-work interface and abrasive action between tool-work interfaces [18]. Two cutting inserts are used for machining with CT and UAT. For both machining operations, the same machining parameters are used. For the comparison of tool wear, each tool is machined for a 360-s machining period. The results of the tool wear along with height deviation for both the machining conditions are presented in Figs 7-9. Fig. 9 shows the higher deviation of UAT wears from the reference surface as compared to Fig. 8 of CT wear. Each color corresponds to the difference in deviation values. The possible reasons for the higher tool wear rate in UAT may be due to excessive vibrations on the tool in UAT and hence the brittle failure of the tool material.

4. Summary

In this work, the tool life, cutting forces, and the tool morphology and wear have been investigated for machining of Inconel 718 with cement carbide tool. In particular, machining

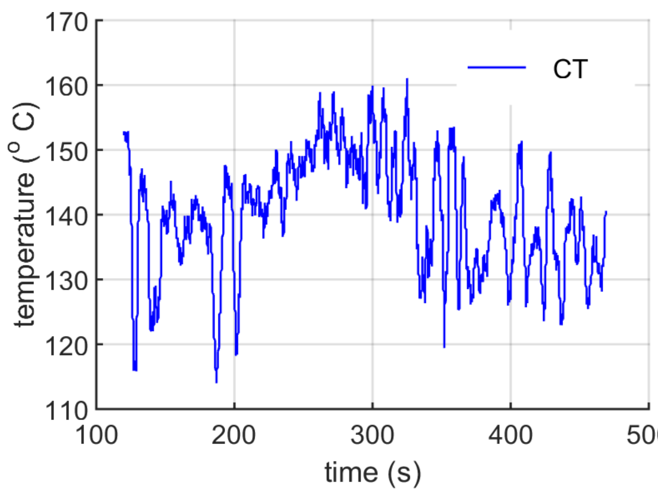


Fig. 5. Average temperature in process zone in CT for Inconel 718

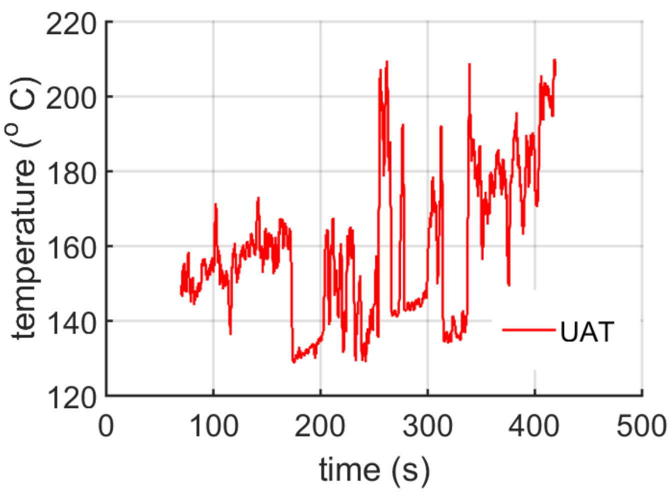
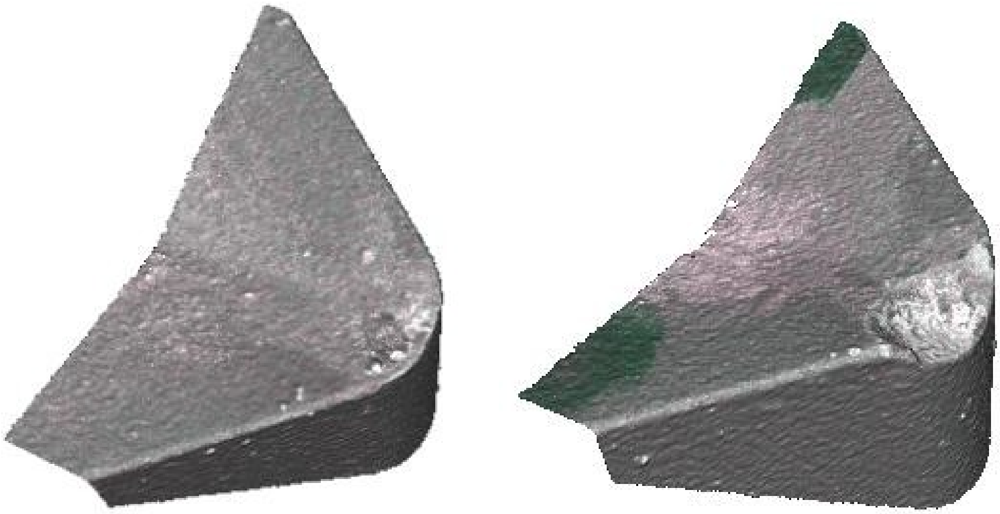


Fig. 6. Average temperature in process zone in UAT for Inconel 718



(A) (B)

Fig. 7. Tool wear for a 360 s machining period in (A) Conventional turning, and (B) Ultrasonic assisted turning

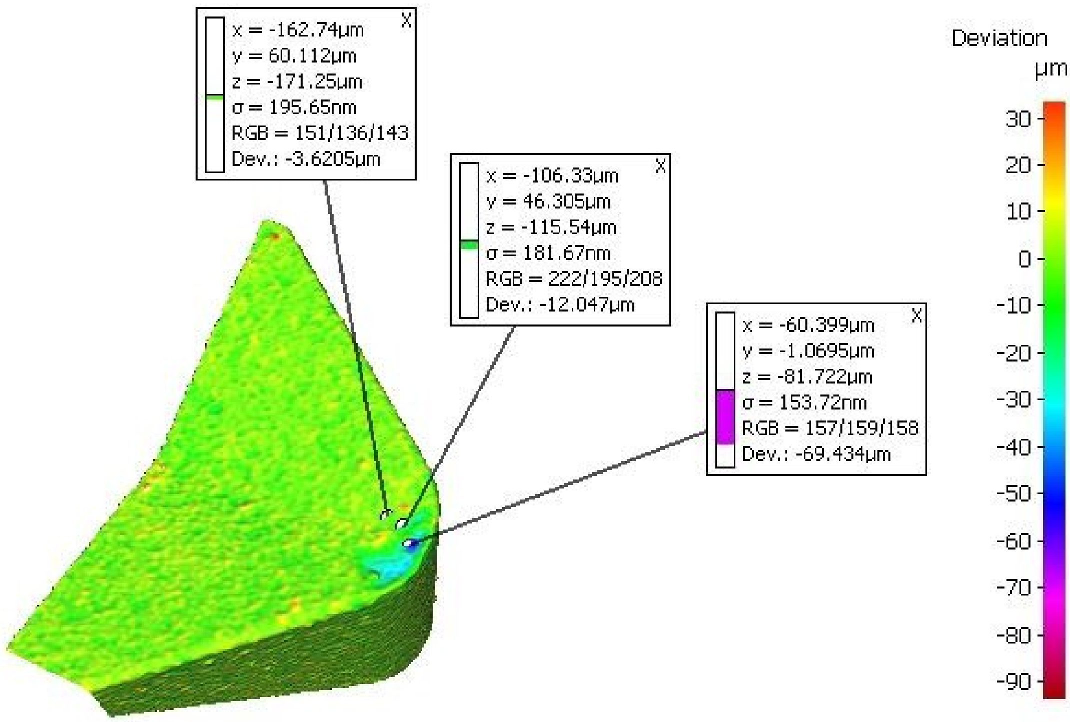


Fig. 8. Height deviation from the reference surface in CT. Deviations are clearly visible by color visualization

with conventional and ultrasonic assisted machining has been considered. The cutting forces increase linearly in the case of UAT as compared to constant forces in CT. This is due to the excessive wear effects during machining of UAT. In addition, the temperature increases linearly in the case of UAT because of the increase in the tool crater wear rate. From the tool wear, it is clear that a higher deviation in the case of UAT wears as compared to CT wear. This is due to the excessive vibrations on the tool in UAT and hence the brittle fracture of the tool material. In the case of UAT, the cutting forces and temperature increases linearly because of higher tool wear rate as compared to CT.

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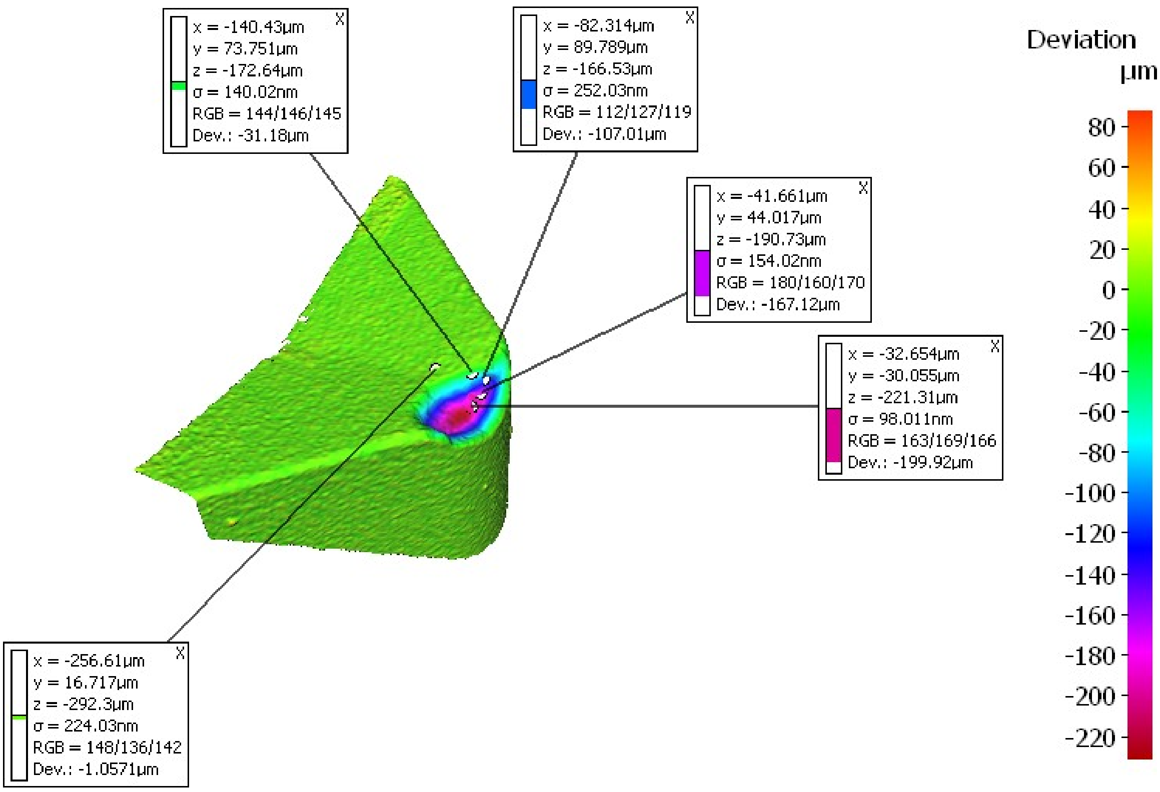

Fig. 9. Height deviation from the reference surface in UAT. Deviations are clearly visible by color visualization

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