Experimental investigations on ultrasonic assisted turning of inconel 718

Pranesh Dutta*, Tejasv Jotswani, Gaurav Bartarya

Indian Institute of Technology Bhubaneswar, Bhubaneswar, India

Presented in International Conference on Precision, Micro, Meso and Nano Engineering (COPEN - 12: 2022)
December 8 - 10, 2022 IIT Kanpur, India

KEYWORDS

Ultrasonic Assisted Turning,
Inconel 718,
Chip Behaviour.

ABSTRACT

Inconel 718 is widely used in industry due to its excellent mechanical properties, which include high resistance to fatigue load, withstanding the corrosive environment, and creep resistance. However, because of these properties, the turning process is severe on tools and generates a great deal of force to cut. Because ultrasonic vibrations could reduce cutting force and thus damage the tool, ultrasonic-assisted machining was a possible solution to these problems. In this study of ultrasonic-assisted tuning, an ultrasonic linear vibration was applied to the tool in the direction of the cutting velocity in the experimental setup used. The results of the experiments revealed that when ultrasonic vibration was used, the cutting force and chip width were reduced compared to when it was not used. The chip formed had a smoother surface, indicating smooth rubbing with the tool, resulting in a better surface finish.

1. Introduction

Superalloys, due to their extraordinary mechanical characteristics, are used widely in the industry; like Aerospace industry uses 80% of superalloys like Inconel 718 and Titanium, whereas 45-50% of gas turbine material is nickel alloys. Due to their exceptional properties to withstand the highly corrosive environment, creep resistance, and high resistance to fatigue loading, the nickel-based alloys are widely utilized for aero engine blades and disks under high-pressure in turbines and compressors.

Inconel 718 has high strength and heat resistance (HSTR), making it the chief contender for jet aero engines. Due to its toughness, Inconel 718 is difficult to machine and causes some issues, such as,

- Extremely high cutting forces cause metallurgical damage to the workpiece and strain hardening and distortion in the final machined components due to induced stresses.
- Its superior mechanical qualities come with work hardening and high-temperature tensile strength, but this causes significant damage to the work surface during traditional machining operations and severely affects the cutting tool life.

1.1. Ultrasonic assisted turning (UAT)

Ultrasonic vibration-assisted Machining is used for milling, drilling, grinding, and turning superalloys. It has been shown that Ultrasonic Assisted Turning (UAT) may significantly improve the machining of difficult-to-cut metals. It is a sophisticated method of metal cutting in which high-frequency, low-amplitude vibration signatures are overlaid on the motion of a cutting tool. Compared to conventional turning (CT), this approach enables considerable advantages like lower cutting forces and significant improvement in surface quality and tool life. As a result, UAT would unquestionably extend the life of the tools while also improving the quality of the machined material. Though it has been reported that the speed ratio (the ratio of Cutting Velocity to Maximum Vibrating Velocity) of 0.6 was found to be the highest above which the effect of UAT starts to diminish (Dutta & Bartarya, 2021). In the UAT of Inconel 718, the chip produced is continuos (Babitsky et.al., 2004). The cutting forces are reduced, and the surface finish is better when compared to conventional turning (Maurotto et. al., 2012).

*Corresponding author E-mail: pd29@iitbbs.ac.in

https://doi.org/10.58368/MTT.22.4.2023.60-65

Chip formation is an important aspect of metal-cutting processes that interact with several process factors. It has revealed metal removal mechanics and crucial friction phenomena in cutting processes (Ning et. al., 2008). Understanding the impact of machining parameters and the relative motion between the cutting insert and workpiece material on chip formation is critical for managing and optimizing cutting processes. Changes in chip formation can also impact the thermo-mechanical behaviour at the machining zone between the insert and workpiece, resulting in tool failure and poor machining quality (Thakur et al., 2009). This work seeks to characterize the UAT of Inconel 718 using chip morphology to establish the effect friction between chip and the tool in UAT, which can improve tool life.

2. Experimental Setup

An Ultrasonic Assisted Turning (UAT) setup comprising a vibrating head and positioning slide has been installed on a heavy-duty HMT make NH-22 lathe. A stacked piezoelectric transducer known as a Bolted Langevin Transducer (BLT) is utilized to transform the electrical pulses produced by the power supply into a mechanical vibration. The transducer's vibration amplitude is transmitted and modified by a stepped horn, providing desired vibration amplitude to the insert. The design of the horn is essential because it determines whether or not the insert can vibrate, which is necessary to generate a high-frequency (ultrasonic) cyclic contact and separation between the tool and the workpiece. Because the amplitude produced by the BLT transducer is relatively low, a horn has been designed with an amplification ratio of 1:1.5, so the separation time can be accomplished relatively quickly. The operation's specific requirements determine the type of material used to design the horn. Researchers have used a wide variety of materials to make the horn, including aluminium, iron, titanium, and many others. In the current configuration (shown in figure 1), the titanium alloy (Ti-6Al-4V) has been used as the material for the vibrating horn as it has a high strength-to-weight ratio and endurance limit for fatigue loading compared to other metals and alloys. This increases the fatigue life of the horn, which is beneficial as the horn is subjected to a highly dynamic machining load.

Experiments were carried out on an Inconel 718 round bar having a diameter of 30mm and a length of 200mm. A Cubic Boron Nitride (CBN) cutting insert (Make: SECO, CCGW120408S-01020-L1-B) was used as the cutting tool material. The insert has a clearance angle of 7º to keep the flank face from rubbing against the workpiece during machining. The insert is fixed with the horn to ensure the cutting velocity is perpendicular to the cutting edge and with a 90º approach angle.

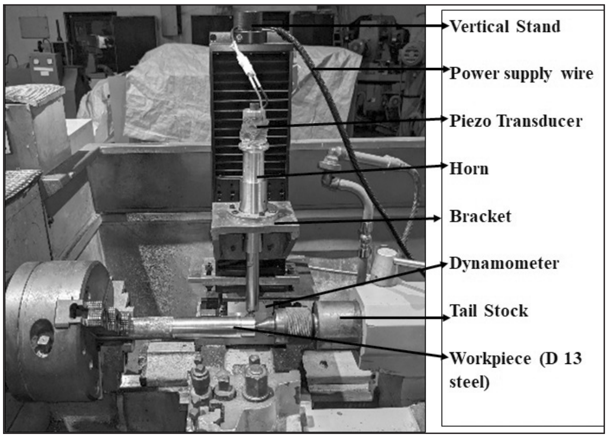

Fig. 1. Ultrasonic assisted turning setup.

Cutting forces and surface roughness produced during machining were measured. During machining, cutting forces were measured using a 6-component Kistler piezoelectric dynamometer (Model-9257B) and a multi-channel charge amplifier (Model-5070A). Finally, using the Dynoware program, the filtered and amplified signal values are shown as machining forces in the feed (Fx), radial (Fy), and cutting (Fz) directions. The Mitutoyo surface roughness measuring instrument was used to determine surface roughness (Model-SJ 210). The chip form and size are studied using a handheld microscope (Make-Dinolite). A detailed microscopic examination of the chip was performed using a Zeiss Scanning Electron Microscope.

3. Results and Discussions

Experiments were performed in Continuous Turning (CT) and UAT environments to analyze the effect of the UAT process on the Inconel machining using force analysis, chip morphology, and surface roughness produced. The results are discussed below.

3.1. Cutting forces

The cutting forces are measured by taking average forces for 10s duration. The CT experiments were performed under a cutting speed was taken as 47m/min, feed 0.05 mm/rev, and depth of cut

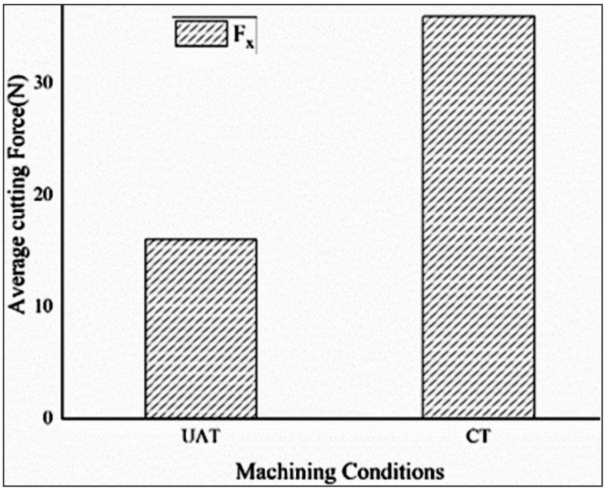

Fig. 2. Comparison of average cutting force for UAT and CT.

0.15 mm, and for UAT, the tool is vibrated at an ultrasonic frequency of 20 KHz with an amplitude of 16.5 µm keeping other machining conditions as in CT. The vibrating velocity is applied in the cutting velocity direction (X-axis). The speed ratio in the cutting direction is 0.4. A reduction of around 44% was observed for UAT when compared to conventional turning. The lower cutting forces are due to the intermittent nature of cutting. The disengagement of the cutting insert with the workpiece under UAT reduces the time the tool engages with the workpiece, reducing the average cutting force.

3.2. Chip formation

When evaluating the effectiveness of cutting operations, one crucial factor frequently considered is the morphology of the chips produced. The combined effects of the type of cut, the properties of the work material, the geometry of the cutting insert, the cutting parameters, and other factors determine the types of chips produced.

In UAT, the tool vibrates at an amplitude of 16.5 µm and an ultrasonic frequency of 20 KHz, due to which the chip and the tool have a periodic attachment and detachment. This can be seen in figure 3(b). In figure 3(a), the chips produced in CT show shear bands that are fused. The chips generated when machined using UAT show a distinctive layer with an average shear band thickness of 17.5µm. The unique shear layer is because the detachment of the cutting insert from the primary shear zone stops the chip formation.

For both UAT and CT, the side of the machined chip that rubs with the tool's rake face is shown

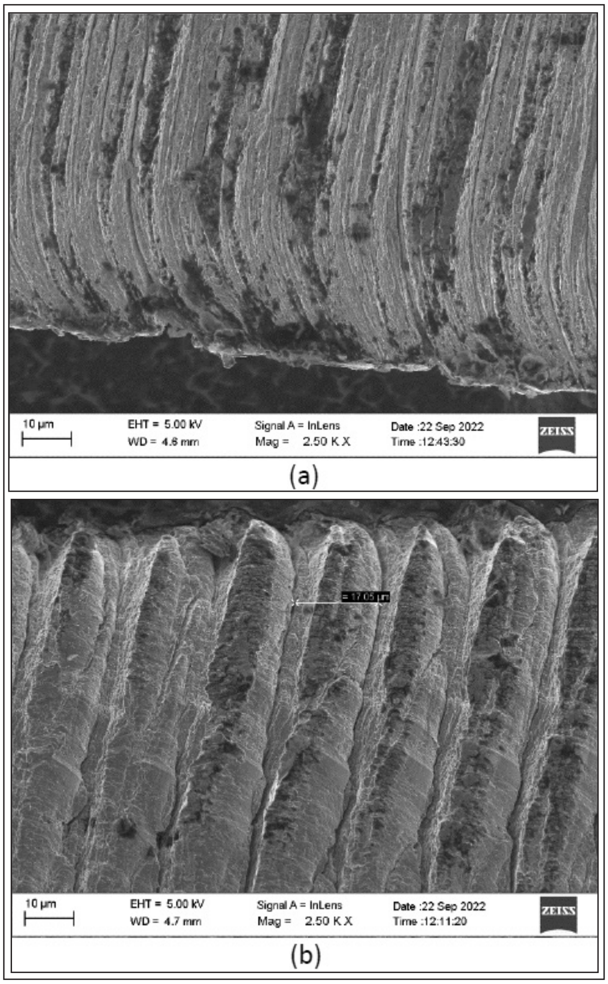

Fig. 3. Formation of shear bands during machining of Inconel 718 during (a) CT and (b) UAT.

in figures 4(a) and 4(b), respectively. The chip formed in CT has pits and a rough surface, which means a high friction force between the tool face and the chip; this may lead to a built-up edge on the tool. The chip formed in the UAT process has a much smoother surface, indicating less friction force between the cutting insert and the chip. Low frictional force reduces the overall machining forces and can improve the tool life and reduce the formation of BUE on the insert tip. The formation of a smooth surface when ultrasonic vibration is added to the cutting tool, sticky length is reduced. The width of the chip UAT is 8% lower when compared to CT.

The chip generated during the CT of Inconel is clumped in nature, as shown in figure 5(a) while machining Inconel 718 using UAT produces straight but broken chips. The reversal of the tool velocity vector during retraction of the cutting insert tip with the workpiece reduces the chip tool contact time and length (Brehl & Dow, 2008). The reduced contact length and time make less

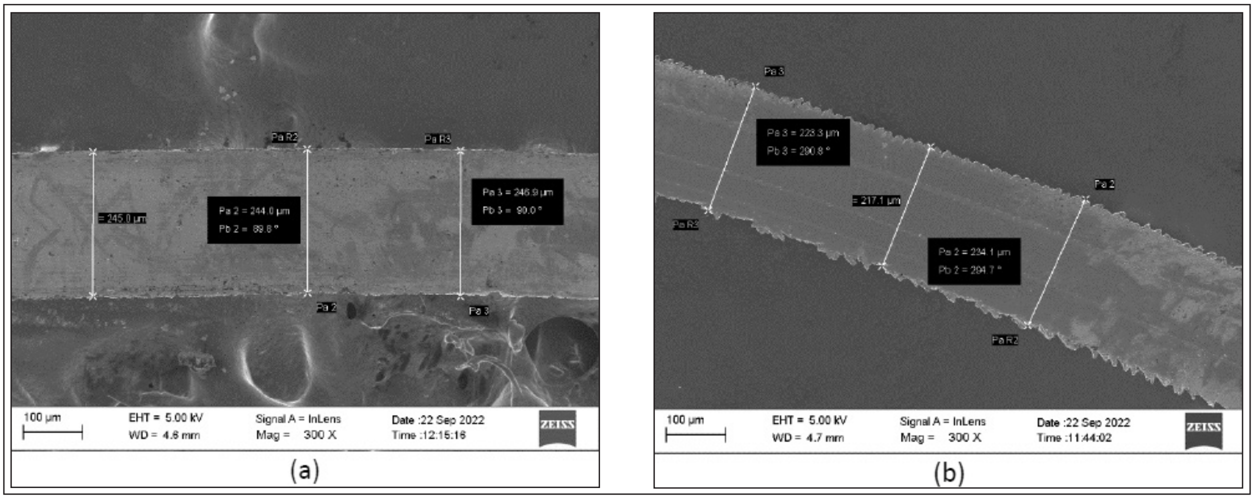

Fig. 4. Chip surface in contact with the tool when machined (a) CT and (b) UAT.

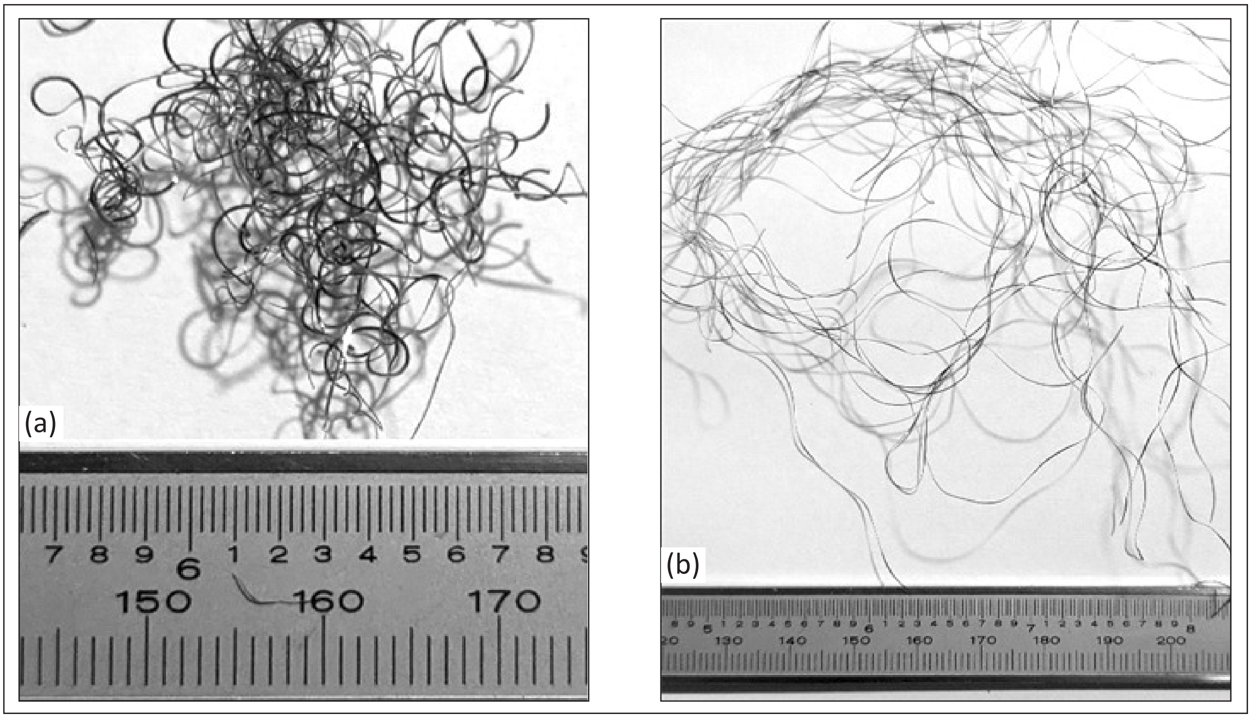

Fig. 5. Chip generated in the machining of inconel 718 using (a) CT and (b) UAT.

heat generation in the secondary shear zone. Reduced machining forces, reduced contact time between tool and chip, and lower heat generation in the secondary shear zone enable even heating of the chip in UAT.

This leads to the chip's formation with a large curvature radius, which is evident in fig 5 (b).

3.3. Machined surface

The amplitude of ultrasonic waves has a significant impact on surface roughness. The turning experiments are performed under cutting conditions of 47 m/min, 0.15 mm depth of cut, and 0.05 mm/rev feed; the resulting histogram is shown in Fig. 6. The machined surface roughness of UAT increases as the ultrasonic amplitude increases.

Under the same cutting conditions, Inconel 718 turning tests using CT and UATare performed. Figure 7 depicts a photograph of the machined surface using UAT and CT. In contrast to the image of the workpiece's surface obtained through UAT, which was dullish because of the intermittent contact between the workpiece and the cutting tool during UAT. Meanwhile, the surface of the workpiece obtained via CT is shining brightly.

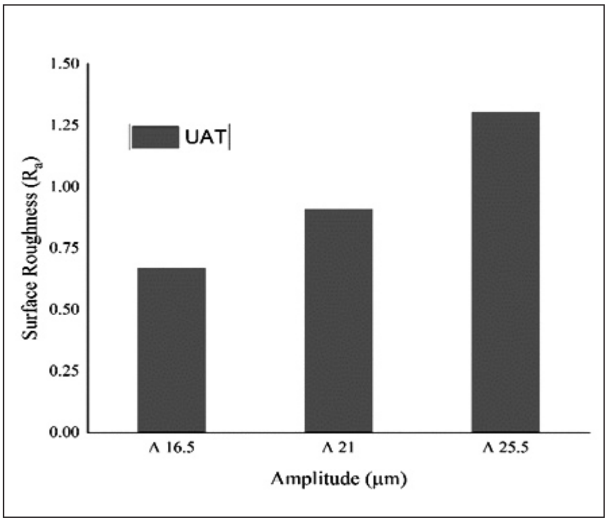

Fig. 6. Surface Roughness of the machined surface generated in UAT at various amplitude.

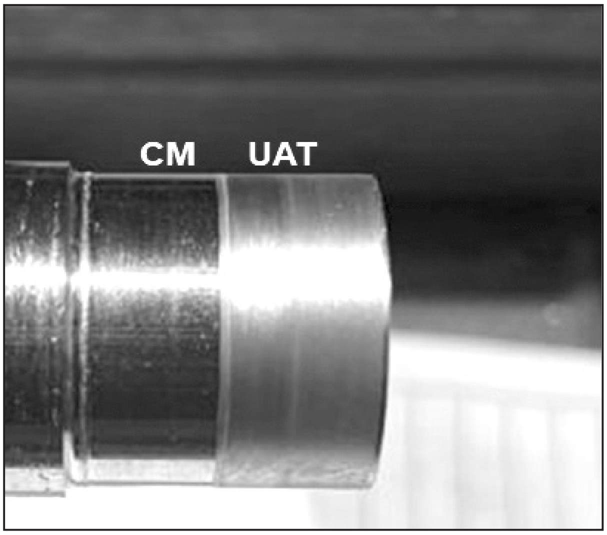

Fig. 7. Photograph of the surface generated in UAT and CT.

The ultrasonic vibrations act on the cutting insert regularly and machine the workpiece's surface, generating vibration spots on the machined surface of the UAT in the direction of vibration applied (cutting direction). Xu et al., (2020) found that the surface generated using UAT has small waves of peaks and troughs. But the surface generated when machining using CT has scratches, grooves and build-up edges. This can be seen in figure 6. The CT surface, though shiny, is filled with scratches and grooves, reducing the machined surface's surface quality.

4. Conclusion

The main focus of this study was on the experimental analysis of UAT. Turning experiments were done on Inconel 718 using CT AND UAT techniques. The machined workpiece's surface roughness, the topography of the surface, chip shape and cutting force were studied and analyzed. When Inconel 718 was machined using UAT, the results showed that it could be machined better than when it was machined using CT.

- The average force generated in cutting the workpiece is reduced in UAT.
- The chips formed using UAT have less width than those formed during CT. The reduction is chip width decreases the active part of the cutting edge in contact with the tool, reducing the load on the tool.
- The smoother formation chip surface formed when moving along the rake face indicates decreased friction between the chip and the cutting insert, which leads to reduced frictional forces when machining using UAT.
- The surface roughness increases with the increase in vibration amplitude in UAT.
- The machined surface formed during CT has a shiny surface, whereas the surface generated in UAT has a dull surface.

References

Babitsky, V. I., Mitrofanov, A. V., & Silberschmidt, V. V. (2004). Ultrasonically assisted turning of aviation materials: Simulations and experimental study. *Ultrasonics, 42*(1-9), 81-86.

Brehl, D. E., & Dow, T. A. (2008). Review of vibration-assisted machining. *Precision Engineering, 32*(3), 153-172.

Dutta, P., & Bartarya, G. (2021). On the improvement of process performance of hard turning using vibration-assisted machining. *Journal of Micromanufacturing, 4*(2), 207-215.

Maurotto, A., Muhammad, R., Roy, A., Babitsky, V. I., & Silberschmidt, V. V. (2012). Comparing Machinability of Ti-15-3-3-3 and Ni-625 Alloys in Uat. *Procedia CIRP, 1*(1), 330-335.

Ning, L., Veldhuis, S. C., & Yamamoto, K. (2008). Investigation of wear behavior and chip formation for cutting tools with nano-multilayered TiAlCrN/NbN PVD coating. *International Journal of Machine Tools and Manufacture, 48(*6), 656-665.

Thakur, D. G., Ramamoorthy, B., & Vijayaraghavan, L. (2009). Machinability investigation of Inconel 718 in high-speed turning. *The International Journal of Advanced Manufacturing Technology, 45*(5), 421-429.

Xu, Y., Gao, F., Zou, P., Zhang, Q., & Fan, F. (2020). Theoretical and experimental investigations of surface roughness, surface topography, and chip shape in ultrasonic vibration-assisted turning of Inconel 718. *Journal of Mechanical Science and Technology, 34*(9), 3791-3806.

Pranesh Dutta did his Masters from Indian Institute of Technology Guwahati. Before that, he completed his B.Tech from IGIT Sarang. He is currently a Ph.D scholar at Indian Institute of Technology Bhubaneswar. His Preliminary area of intrest is in hybrid machining techniques. He has done work in developing experimental setup; Roating tool electrochemical drilling, and Ultrasonic Vibration Assisted Turning Setup.

Tejasv Jotswani did his dual degree in Masters of technology from Indian Institute of Technology Bhubaneswar. He is currently working as Strategic Cloud Engineer in Google.
(E-mail: tj10@iitbbs.ac.in)

Dr. Gaurav Bartarya did his Masters and Ph.D from Indian Institute of Technology Kanpur. Before that, he completed his B.Tech from GBPUAT Pantnagar. He is currently working as Assistant Professor at Indian Institute of Technology Bhubaneswar, INDIA. His preliminary area of interest is conventional machining of hard materials. He has worked extensively on surface integrity issues in hard turning of steel, concerned with process performance modelling and surface integrity issues like white layer, tensile residual stresses etc. prevailing during hard turning. He also works in advance machining processes, incremental forming and reverse engineering.
(E-mail: bartarya@iitbbs.ac.in)