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The Effect of Externally Applied Ultrasonic Sound Wave on the Cutting Tool during Dry Turning Operation of Mild Steel

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ABSTRACT
The present paper investigates the effect of externally applied ultrasonic sound waves on the flank wear of the cutting tool and chip morphology during the dry turning operation of a mild steel bar. Ultrasound was applied by using two ultrasonic transducers from both sides of the tool post of the lathe machine during the turning process in an attempt to reduce tool wear and surface roughness. Two high-speed steel (HSS) cutting tools had been used and Cutting parameters were kept constant for both ultrasound and conventional machining operation. The result indicated the application of ultrasound significantly reduced the flank wear of the tool and noteworthy improvement was also eminent in chip behavior after the implementation of ultrasound.

Keywords: Ultrasound, Flank wear, Chip Morphology, Ultrasonic transducer.

1. Introduction

Machining is a part of the manufacturing process where cutting tools are used to provide workpieces (metals, glass, ceramics, wood, etc.) their intended geometric shape and surface finish. Turning is a machining operation where usually job rotates and cutting tool which is also known as tool bit remains standstill. During turning operation, friction between the cutting tool and workpiece removes material from the surface of the piece of work. This friction also removes material from the cutting tool and creates tool wear which is a major concern in the machining operation. Tool wear reduces tool life, and because of tool wear cutting tools need to be frequently changed which negatively affects the finished products. Several types of tool wear happen on tool surfaces such as flank wear (also known as nose wear, face wear), crater wear, abrasive wear, diffusion wear, etc. Various methods have been suggested to reduce tool wear such as cryogenic cooling [1], application of external electromotive force sources [2], increasing the contact length of the tool [3], optimizing tool geometry and cutting condition [4] [5], ultrasonic machining [6], etc. Among them, ultrasonic machining has been a promising technology since the 50-60s to improve machining operations because of its cost-effectiveness and became popular after the 80s because of its widespread application. Application of ultrasonic sound wave reduces cutting force up to 50%, improves roundness close to 40-50%, and surface finish up to 25-50% [7]. A group of researchers demonstrated that ultrasound ameliorates the machining process as when applied concurrently diminishes tool wear and improves the quality of the finished goods [8]. Patwari et al. were able to reduce tool wear on WC coated carbide insert when external ultrasonic sound wave at a frequency of 60 kHz was applied from both sides of the tool holder during turning operation [9]. Another study showed, 40 kHz ultrasonic sound wave improves the chip behavior, surface finishing, and reduces tool wear significantly during turning operation [10]. Ngoc-Hung Chu et al. manifested that if the ultrasonic sound was used in the drilling operation it can remove materials 3.5 times faster if compared with the conventional drilling operation, 3.5 times reduction in temperature and 6 times cutback in torque was also found during ultrasonic sound assisted drilling (UAD) operation respectively [11]. Babitsky et al. presented that Ultrasonic transducers which can provide 20 kHz ultrasound can improve the surface condition of the product up to 50% [12]. Babitsky et al. in another study introduced that 20 kHz ultrasound can do significant improvement in average surface roughness and peak to valley roundness on intractable materials [13].

Although several studies had been done on ultrasound-assisted turning operation, more research is required to fully understand the effect of externally applied ultrasound on tool wear. In this study, flank wear of the HSS cutting tool, when two ultrasonic transducers applied ultrasound externally from both sides of the tool holder has been discussed thoroughly and the advantages of ultrasound machining over conventional machining have been weighted up.

2. Experimental details

2.1 Equipment used in the experiment

Lathe Machine: Ultrasound and conventional turning operations were performed on a horizontal lathe machine. The main specifications of that lathe machine were: horsepower of driving motor is 3 hp, the distance between headstock and tailstock center is 26 cm, and a maximum 10-inch diameter work/job can be swung over the lathe bed.

Sound Pressure Level Meter: A sound pressure level meter was utilized to evaluate the sound pressure level

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and eventually the amplitude of sound waves from it. The measured sound pressure level was 107 dB.

Ultrasound transducer: Two ultrasonic transducers of 28 kHz homogenous resonance with drivers were used. The transducer power, driver card power, and operating plate voltage of these transducers were 60W, 100W, and 220V respectively.

Fig 1: Ultrasonic Transducer

Electric Switch Board: An electric switchboard was exclusively designed to manipulate the intensity of ultrasound waves. It consists of three components: switch, regulator, and bulb. Switches were used to initiate and cease the transducers, regulators to govern the voltage, and bulb to visually determine the intensity.

Fig 2: Voltage Driver

Optical Microscope: An analog optical microscope was used to measure the flank wear on the cutting tool. It can precisely measure up to 0.01 mm.

Magnet: Two powerful artificial round-shaped magnets were used to attach the transducer holders with the lathe machine.

Cutting Tool: Two high-speed steel (HSS) cutting tool was used in this experiment. The cutting tool used in this experiment had height and width of 10mm, 8-degree end cutting edge angle, 6-degree and 12-degree end relief angle, 4-degree side rake angle, and hardness of 62 to 64 RC.

Fig 3: HSS Cutting Tool

Workpiece: Mild steel bar was used as a workpiece in this experiment. The diameter and length of the job were 59.1 mm and 332.4 mm respectively.

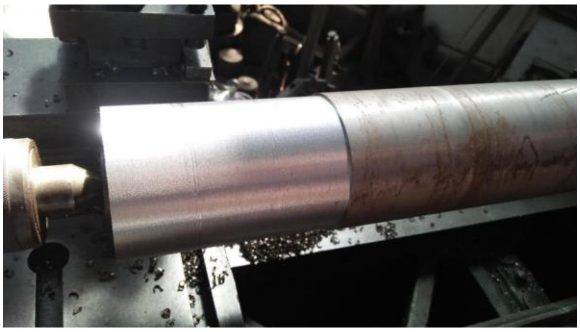

Fig 4: Mild Steel Workpiece

Ultrasonic Transducer Holder: Two rectangular column type structures made from wood with a hole to hold the ultrasound transducers. Thin rectangular metal bar was glued to the bottom of the wooden structures so that they can be attached to the lathe machine by magnets.

2.2 Experimental Procedure

First, the job was fitted to the lathe machine and the HSS cutting tool was placed under the optical microscope to check initial wear. Secondly, the cutting tool was attached to the tool post to perform the turning operation. Then, ultrasonic transducers were placed on both sides of the tool post and connected to the 220V AC power source. Before starting the turning operation, depth of cut, feed rate, and cutting velocity were chosen. Their value has been mentioned in table 1.

Table 1 Value of depth of cut, cutting velocity, and feed rate

Depth of Cut (mm)	Cutting Velocity (RPM)	Feed Rate (mm/rev)
1.5	130	0.1

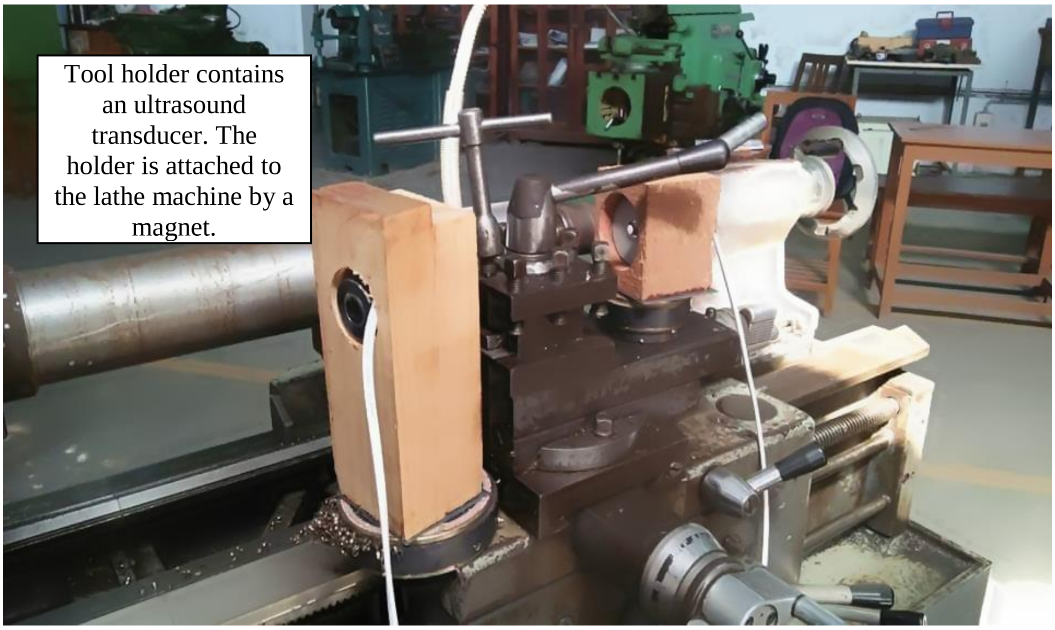

Fig 5: experimental setup

The turning operation was performed continuously on the job for 2 minutes. After that, the cutting tool was removed from the tool post of the lathe machine, and the flank wear was measured under the optical microscope. The cutting tool was placed three times under the microscope to minimize human error. Then, the above-mentioned ultrasound machining process was repeated 3 more times.

Then, the conventional turning operation was performed exactly same way by using a new identical cutting tool. However, main difference was ultrasonic transducers were not turned on this time. The depth of cut, feed rate, and cutting velocity were kept the same in the process.

3. Results and Discussion

3.1 Effect of Ultrasound on Tool Wear

Tool wear found in the ultrasound turning operation was compared with the conventional turning operation. The effect of 28 kHz ultrasound on tool wear is shown in Table 2 and Fig 6. It can be deduced from the Table 2 and Fig 6 is that application of ultrasound at tool holder is responsible for less flank wear at the cutting tool. After each turning operation, the cutting tool was carefully observed under the optical microscope three times to minimize error. From Table 2, it can be observed that after 2 minutes of turning operation, the percentage wear reduction at the cutting tool was 10%. Nevertheless, as the cutting time progressed, percentage wear reduction also increased. It is transparently clear from the data in Table 2 that after 8 minutes of turning operation, the percentage wear reduction at the cutting tool was substantial and approximately 42% reduction in tool wear was noticed. Fig 6 represents the wear data in Table 2 and from the curves in Fig 6, the difference in tool wear with and without ultrasound within a time-span of 8 minutes can be observed. This equation was implemented to calculate percentage wear reduction:

Percentage wear reduction =
{(Flank wear without ultrasound – Flank wear with ultrasound) / Flank wear without ultrasound} × 100%

Table 2 Percentage of Flank Wear Reduction

Survey Serial No	Time of Cutting (min)	Flank wear with Ultrasound (mm)	Flank wear without Ultrasound (mm)	% wear reduction
1	2	0.027	0.030	10
2	2	0.033	0.040	17.50
3	2	0.037	0.050	26
4	2	0.040	0.070	42.86

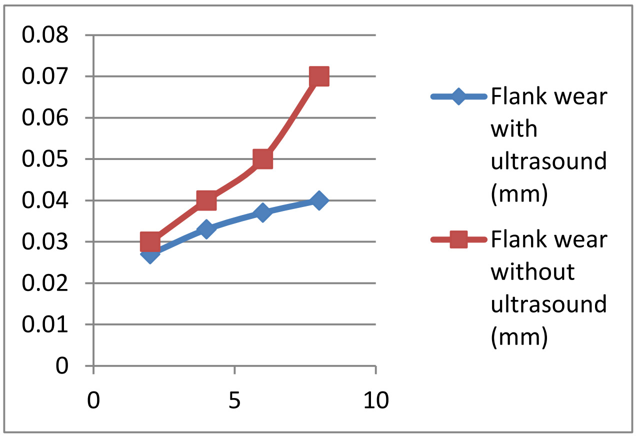

Fig 6: Variation of Flank Wear on cutting tool to time

From Table 2 and fig 6, it is clear that Ultrasound helps to reduce tool's flank wear and these findings match with other studies [8]. The application of ultrasound may have reduced vibration of the cutting tool during machining operation. So, little irregular friction between the cutting tool and the workpiece may have attributed to the reduction in tool wear. Nonetheless, more study is required to fully understand the mechanism.

3.2 Effect of ultrasound on chip morphology

During machining operation, material is removed from the job/workpiece and this material is removed in forms of chips. The chips are an important aspect of machining operation because the surface finish and quality of the product can be predicted from the chip morphology [15]. Mainly three types of chip production take place during turning operation: discontinuous or segmental chip, continuous chip, and continuous chip with the built-up edge. Continuous chips are desirable in the machining operation because it improves the quality of the surface finish of the finished products whereas discontinuous or segmental chips decline the quality of the products [16].

The chip produced during conventional machining and ultrasound machining had been collected for analysis. During the conventional turning operational, discontinuous chips were produced (Fig. 7). On the other hand, when 28 kHz ultrasound was imposed on the cutting tool continuous chips were produced (Fig. 8). From the observation, it can be inferred that ultrasound applied to the tool post has the potential to improve surface finish.

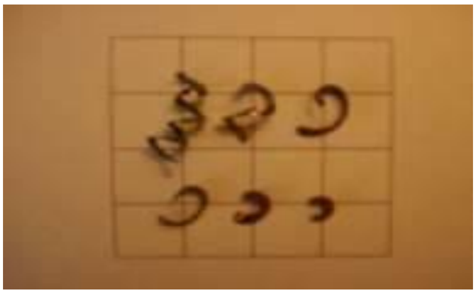

Fig 7: Discontinuous Chip

Fig 8: Continuous Chip

The original aim of this work was to observe the effect of ultrasonic sound waves on cutting tools and chip morphology. The observed result is in marked harmony with the expectation. The result has significant importance in the field of manufacturing as the application of ultrasonic sound wave may reduce tool wear and surface roughness of the finished products substantially. However, more advanced study can fully unravel its true potential.

4. Conclusion

Based on the present experimental investigation, it can be deduced that the Application of ultrasound during turning operation is a promising technique to reduce tool wear, improve chip morphology, and to gain higher productivity in manufacturing. It was noticed that as cutting time increases, the difference between flank wear on the tool with and without ultrasound also increases. Percentage wear reduction after 2 minutes of turning operation was 10% whereas after 8 minutes it was 42.86%. In addition, the production of continuous chips was noticed during ultrasound machining which is extremely desirable during turning operation. Alternately, discontinuous chips were produced in the conventional turning operation which degrade the surface quality of the finished products.

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