Ultrasonic Assisted Machining Methods: A Review

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Abstract: Ultrasonic assisted machining is performed by applying a certain vibration to the cutting tool or to the workpiece to improve the tool life and surface properties in finishing process applications. This method reduces cutting forces and increases tool life. One of the most important hybrid methods developed in recent years is hot ultrasonic assisted machining. Within the scope of this study, literature review was performed to investigate these machining methods. Advantages and disadvantages of these methods were discussed.

Keywords: Ultrasonic Assisted Machining, Vibration, Tool Life, Unconventional Machining, Hot Machining, Hot Ultrasonic Assisted Machining

I. INTRODUCTION

Modern product designs and manufacturing technologies are changing day by day. In this context, there are many innovative methods used in manufacturing and many methods applied to improve these processes. Some of the methods developed (cryogenic machining, machining with self-propelled rotary tool, turn milling, vibration assisted machining etc.) work on different principles compared to the traditional manufacturing methods, while the others are implemented with modifications [1-3].

Due to their unique properties, titanium and nickel based alloys are generally selected in major industries such as aerospace, automotive, biomedical and petro-chemical industries. These alloys have superior strength and exceptional corrosion resistance at high temperatures. In addition to their high mechanical properties, low density of titanium serves the purpose of weight reduction in structures However, machining of these alloys is still problem because they are in the class of difficult-to-cut materials [4-5]. To overcome the poor machinability of refractory materials, recent investigations develop different types of machining methods. Ultrasonic Assisted Turning (UAT) is a recently proposed material removal operation based on intermittent cutting of material which is obtained through vibrations on cutting tool generated by an ultrasonic system. This method uses high frequency-low amplitude vibrations and so cutting tool is prevented from a continuous contact with workpiece. Compared to conventional turning, the most important advantages are given as reduced cutting forces, enhanced surface quality and lowered residual stresses in workpiece [6-13]. Hot machining is another method for the machining of intractable materials. The basic principle in this method is that the surface of workpiece is heated up to a specified temperature below the recrystallization temperature of material. By this heating, cold-work hardening is prevented and thereby reducing the resistance to cutting. In recent studies, hot machining is combined with ultrasonic assisted machining [14].

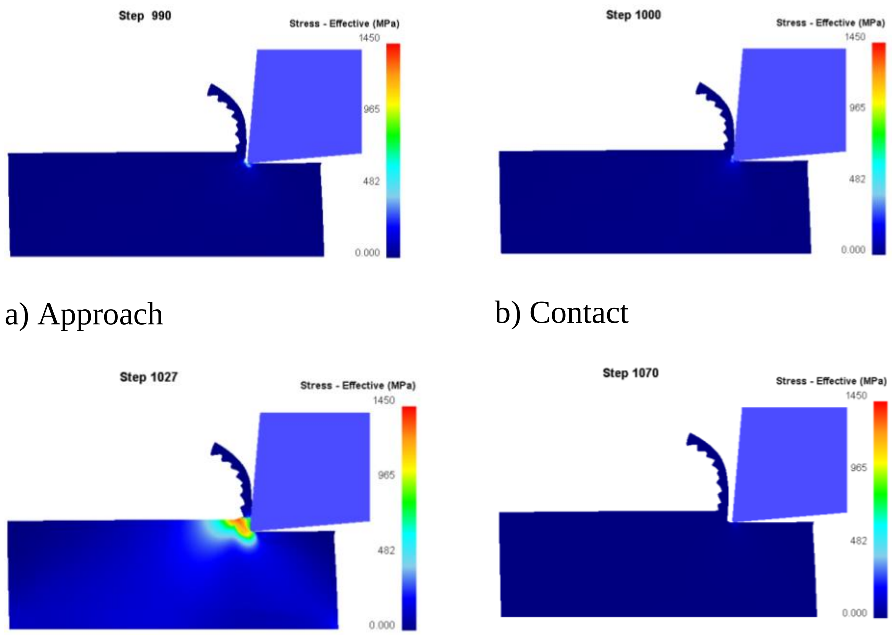
There are several studies using these machining methods to investigate chatter vibrations. Chatter vibrations are directly related to surface roughness of workpiece since they are formed with a self-excited mechanism between tool and workpiece. A wavy surface profile is formed on workpiece due to both previous cycle and structural vibrations in turning. [15]. Chatter stability limits represent the axial cutting depths where the chatter vibrations are not observed until these limits during machining and therefore, the determination of chatter stability limits is very crucial to achieve chatter-free operations. In order to predict stable cutting depths and optimize machining conditions, there are several experimental-numerical studies in literature [16-24]. By using different machining methods (ultrasonic assisted machining, hot machining, hot ultrasonic assisted machining etc.), chatter vibrations can be prevented easily [25-26].

In this study, a literature review was conducted for ultrasonic assisted machining methods. Advantages and disadvantages of these methods were discussed.

II. MACHINING METHODS

A. Ultrasonic Assisted Machining

Ultrasonic assisted machining is performed by applying a certain vibration to the cutting tool or to the workpiece. This method is beneficial for machining equipment which means that significant life extension for cutting tools is attained by reducing tool wear [27-29]. The steps of this process are given in Figure 1. There are four stages:1-Approach, 2-Contact, 3- Immersion, 4-Back off.



a) Approach b) Contact

c) Immersion d) Back off

Figure 1. The stages of ultrasonic assisted machining process [2].

An ultrasonic assisted machining set up with components is given in Figure 2.

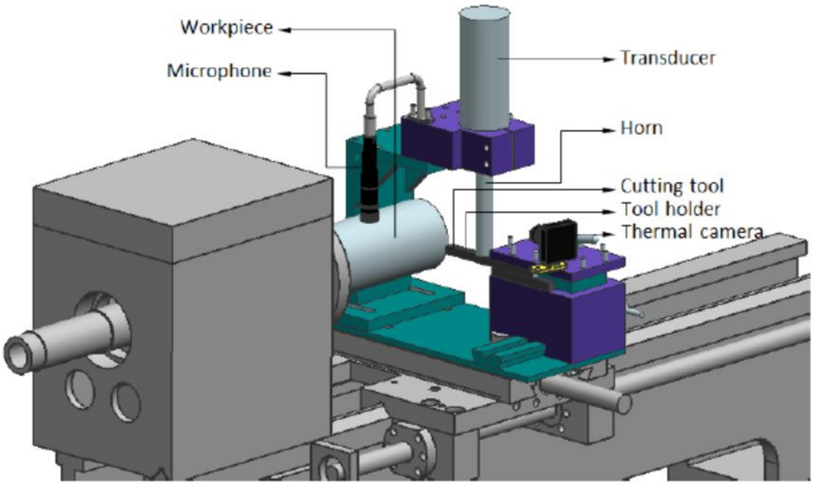


Figure 2.Ultrasonic assisted machining set-up

In order to study the mechanics of this novel cutting technology, different studies have been carried out. In terms of surface quality, Shamoto et al. [30-31] developed a model to estimate the surface roughness considering the size of vibration marks on the surface of workpiece. Some past studies investigated the relationship between the vibration characteristics of cutting tool and surface topography of workpiece by creating models simulating the vibrational cutting operations [32-33]. Guo et al. [34] proposed a model for simulation of surface characteristics in ultrasonic assisted machining considering chip thickness and elastic recovery of material. Some earlier studies [35-40] focused on the surface texture in vibrational cutting operations Zhang et al. [41-42] studied the cutting forces by developing an analytical model based on geometrical relationships in vibration cutting operation. Liu et al. [43] performed a parametric study for ultrasonic assisted machining of brittle materials where brittle fracture prevails the mechanism of material removal. Even though vibrational cutting method is proposed for hard materials, the method was used for machining of aluminum alloys in past studies [6], [35], [44], [45] and based on the results, vibration assisted cutting contributes to process improvement for aluminum alloys in terms of surface roughness and cutting forces. In addition to low hardness materials, Ding et al. [46] stated that ultrasonic method decreases cutting forces in the process and thereby eliminating lamellar brittle fracture and pit originating from carbon fibers fracture. Considering tool life, Patil et al. [27] and Nath et al. [47] stated that UAT method provides increase in tool life in addition to decreased surface roughness on the order of 30% to 40%. UAT produces beneficial results on the wear mechanism of cutting tools. Tool wear in particular, built-up edge (BUE) and flank wear is reduced in ultrasonic assisted machining compared to conventional method [48].

B. Hot Ultrasonic Assisted Machining

Even though the advantages of hot machining are well-known, there are very limited numbers of studies combining hot machining and vibrational cutting operations in literature. Some researchers performed a study on this hybrid machining technique in 2011. This new method is called Hot Ultrasonic Assisted Turning (HUAT) and ensures many advantages [49-51, 54]. An experimental set up is given in Figure 3.

Based on the small number of studies, cutting forces are decreased by the application of ultrasonic vibrations on cutting tools and a further reduction in cutting forces is realized as the operation turns into HUAT method by heating workpiece [49], [52]. Beside the reduction of cutting forces, HUAT decreases surface roughness of workpiece because of the softening of workpiece material which produces easier chip flow relative to tool surface [53].

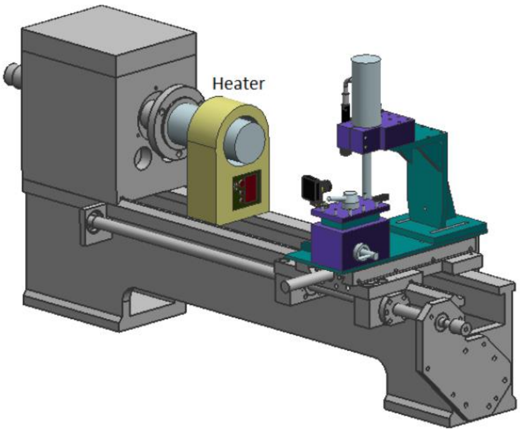


Figure 3. Heat resistance furnace with ultrasonic assisted equipment.

III. ADVANTAGES/DISADVANTAGES OF THESE METHODS

The benefits of the ultrasonic assisted machining can be summarized as follows:

1. Reduction of shear forces and stresses: The one-dimensional and two-dimensional vibration assisted machining changes chip geometry and the interaction between the workpiece and the tool changes to produce thinner and smaller chips. The reduction of cutting forces results in low stresses. Periodic intervals provide good cooling. The opposite tool-rubbing friction occurs.

2. Reduction of cutting temperatures: The formation of a gap due to the periodic movement of the tool-workpiece allows the heat to be distributed between the tool and the workpiece and creates a cooling effect. Particularly, in a two-dimensional elliptical vibration assisted machining process, the workpiece-tool contact area varies at different points and it reduces the temperature.

3. Increase of tool life: Reduction of cutting forces, stresses and periodic intervals makes it easy to machine so the tool life increases. The intermittent contact cools the cutting tool and reduces wear.

4. Increase of surface quality: Low cutting forces reduce the vibration amplitude of the workpiece. Low friction triggers low temperatures, cracks under the surface are reduced and non-continuous chip formation reduces surface roughness.

5. Machining of brittle materials in the ductile regime: The low cutting forces on the cutting tool reduce the depth of cut under the machined surface and prevent micro cracks from progressing. Therefore, it increases the ductile shear regime.

6. Prevention of chatter vibrations [54] .

7. Prevention of built-up edge chip formation: Reduction of instantaneous pressure-bending stresses and reduction of cutting force provide intermittent chip formation.

One of the drawback of ultrasonic assisted machining is that this process is carried out at low cutting speeds (nearly below 80 m/min).The benefits of the hot ultrasonic assisted machining are nearly same with ultrasonic assisted machining except of some points given below:

1. Increasing cutting temperature causes decrease in tool life.

2. Continuous chip formation occurs.

3. Surface roundness is worse compared to ultrasonic assisted machining.

IV. CONCLUSIONS

In this study, ultrasonic assisted machining techniques were explained. A literature review was conducted. According to literature survey, we obtained the following statements:

1. Considering the current piezoelectric capacity, this method loses its effect over certain (specified) cutting speeds.

2. This method reduces the average cutting forces.

3. It significantly increases the tool life.

4. It significantly reduces surface roughness and roundness. Also, this method reduces the amount of form errors such as planarity. Especially, it is important to make textured structures at micro size.

5. It allows to machine extremely brittle parts, such as optical applications with higher cutting depth values.

6. Chip morphology changes.

According to literature studies, a significant decrease in cutting forces is observed with hot machining and the tool life is also decreases. Hot ultrasonic assisted machining combines the advantages of these

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Ethical statement: The authors declare that they have followed ethical responsibilities.

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