# An Analysis on Utilization of Titanium Metal Effective Of Machine Parameters of Ultrasonic Machine

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***Abstract – Titanium alloys are utilized especially in applications that require a good combination of high strength, low mass and good corrosion resistance in aggressive environments. However, mechanical properties prejudge titanium alloys to hard machinability. Machining of titanium alloys is usually accompanied by cooling with liquids or gasses. One of the most effective cooling approaches is cooling by liquid nitrogen. Liquid nitrogen decreases temperature of tool, but also increases strength, hardness and brittleness of workpiece. One of the most suitable machining methods to machine hard and brittle materials is ultrasonic machining. In this article, rotary ultrasonic machining of titanium alloys under cryogenic conditions is analyzed.***

***Advanced ceramics are likely candidates for many industrial applications due to their superior properties. However, their high machining costs lead to limited applications. Rotary ultrasonic machining (RUM) is one of the cost-effective machining processes available for drilling holes in advanced ceramics. This paper reports on investigations in the last few years on RUM process of advanced ceramics. Emphasis is given on the effect of RUM process parameters (such as applied static load, rotational speed, ultrasonic power and vibration amplitude, abrasive grit size and coolant) on machinability parameters (such as material removal rate, tool wear and surface roughness). Results on tool wear and edge chipping are also reported.***

***Titanium and its alloys are finding prime applications in industries due to their unique properties. However, high cost of machining is one of the limiting factors for their widespread use. Tremendous efforts are being made to improve the existing machining processes and new processes are being developed to reduce the machining cost in order to increase the titanium market. However, there is no report on the systematic study of the effects of machining variables on output parameters in rotary ultrasonic machining of titanium and its alloys. This paper presents as experimental study on rotary ultrasonic machining of a titanium alloy. The cutting force, material removal rate, and surface roughness when rotary ultrasonic machining of a titanium alloy have been investigated using different machining variables.***

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## OVERVIEW

Advanced ceramics are likely candidates for many industrial applications because of their superior properties, such as chemical inertness, high hardness and wear resistance, high strength and stiffness at elevated temperatures, high strength-to-weight ratio, corrosion resistance, and oxidation resistance.

However, advanced ceramics are difficult to be machined into desired shapes and dimensions due to their high hardness, non-electrical conductivity and brittleness. It was reported that the machining cost for ceramic components could be as high as 90% of the total cost.

Ultrasonic machining (USM) is considered as “probably the most frequently used machining method for advanced ceramics” besides grinding. Figure 1 shows a schematic illustration of USM. USM accomplishes the removal of material by the abrasive action of a grit-loaded slurry, circulating between the work piece and a tool that is vibrated at small amplitude and high frequency. However, the poor abrasive slurry flow in drilling deep holes, low material removal rate due to abrasive slurry, low accuracy in drilling small holes and considerable tool wear preclude wider application of USM .

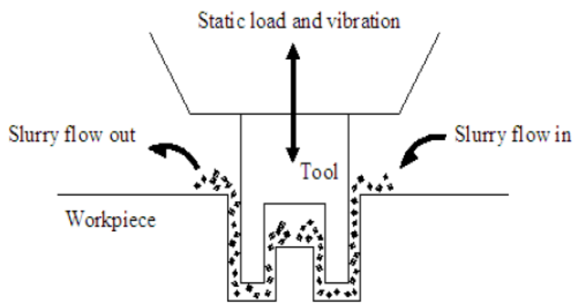


**Figure 1: Schematic illustration of ultrasonic machining.**

Rotary ultrasonic machining (RUM) is one of the cost-effective machining processes available for drilling holes in advanced ceramics. RUM is a hybrid machining process that combines the material removal mechanisms of diamond grinding and USM, resulting in higher material removal rate (MRR) than that obtained by either diamond grinding or USM. RUM also gives superior surface finish, improved hole accuracy, capability to drill deep holes and low tool pressure. Figure 2 is a schematic illustration of RUM. A core drill tool with metal-bonded diamond abrasives in rotational motion, ultrasonically vibrated simultaneously, is fed towards the work piece at a constant federate or constant force (pressure). Coolant is pumped through the core of the drill in order to wash away the debris, prevent jamming of drill tool and keep both drill and work piece cool.

Titanium is the fourth most abundant metal found in the earth's crust, and the ninth most used metal in industry . Titanium and its alloys are finding prime applications in defense, aerospace, and other industries due to their superior properties (such as high strength, creep strength, stability, fatigue strength, fracture toughness, fabric ability, and corrosion resistance at elevated temperatures) .

In 1990, the total market of titanium alloy in the USA and Europe, who consume about 66% of the world's titanium, was 25,000 tons and 9,500 tons respectively. In 2003, 98,000 tons of titanium and its alloys were produced worldwide. The major usage of titanium and its alloys is for manufacturing compressor blades, stator blades, rotors, and other parts in turbine engines. Other applications of titanium and its alloys include such industries as military, automotive, chemical, medical, and sporting goods.

Since rotary ultrasonic machining was invented in 1964 , the effects of its control variables (rotational speed; vibration amplitude and frequency; diamond type, size and concentration; bond type; coolant type and pressure; etc.) on its performances (material removal rate, cutting force, surface roughness, etc.) have been investigated experimentally. Efforts have also been made to develop models to predict the material removal rate in rotary ultrasonic machining from control variables. Please note that no work has ever been reported on rotary ultrasonic machining of titanium and its alloys.

Commercial production of titanium began in the 1950s (Singh and Khamba, 2006). It has become an important material especially in spacecraft and aircraft, where it is primary applied to production of jet engines and airframe components. These components demand high geometric accuracy and low roughness of surface. Machining of titanium alloys is accompanied by high tool wear and low tool life. Worn tool can reach neither required accuracy, nor roughness. Rotary ultrasonic machining is able cost-effective machining hard machinable materials with relative high material removal rate and it also reaches high precision and low roughness. It makes rotary ultrasonic machining suitable for machining of titanium alloys, especially under cryogenic condition.

## IMPACT OF CONTROL PARAMETERS ON RUM DRILLING EFFICIENCY

This paper is aimed to review the effects of RUM process parameters (such as rotational speed, applied static load, ultrasonic vibration amplitude, etc.) on the RUM performances (such as MRR, tool wear, surface roughness or hole clearance) of advanced ceramics, based on previous experiments done by other researchers.

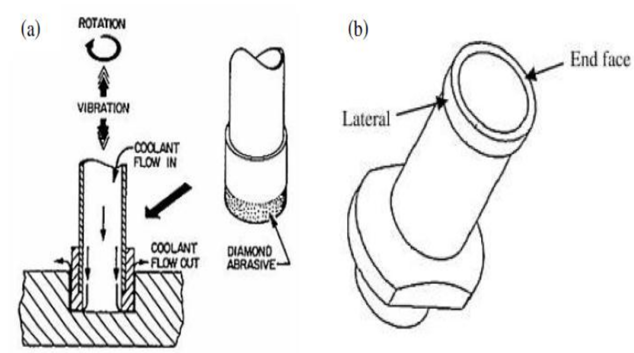


**Figure 2: Schematic illustration of rotary ultrasonic machining (a) RUM process (b) 3D view of the RUM tool.**

## IMPACT OF STATIC FORCE

The static force has remarkable effect on RUM drilling performance. For advanced ceramic materials like magnesium stabilized zirconia and alumina, as the static force increases, material removal rate will increase.

From Figure 3(a), it is noted that the MRR was seen to decrease at the highest value of the static load. Zhang et al. explained that higher loads will decrease the amplitude of tool tip vibration and will prolong the contact time, and if the force is excessive, the tool cannot vibrate properly and swarf cannot be flushed away effectively, thus resulting in a decrease in MRR. For ceramic matrix composite like C/SiC , as the static force increases, MRR will increase; and hole clearance will decrease.

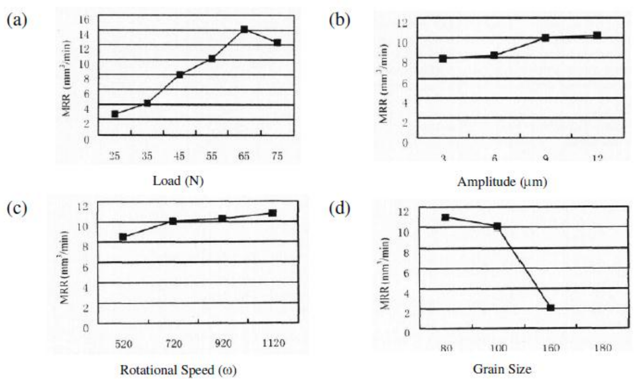


**Figure 3: Effect of control variables on material removal rate of alumina .**

There are limited literatures reported on the effect of vibration frequency on RUM performance. Generally high vibration frequencies (usually _ 20 kHz) are used in the reported experiments.

The relationship between the vibration amplitude and the drilling force for various ceramics and soda-glass is shown in Figure 4. The plots at amplitude zero indicate the force in conventional core drilling. It shows that a significant reduction of drilling force can be achieved when ultrasonic vibration is applied.

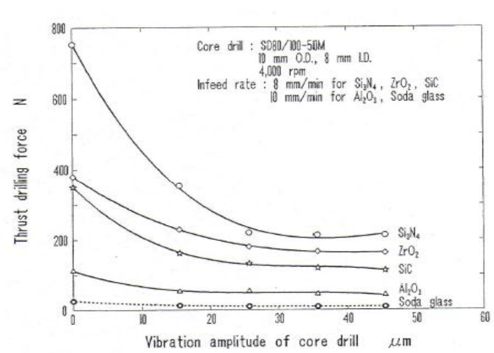


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**Figure 4: Effect of vibration amplitude on cutting force**.

Li et al. reported that the MRR for RUM would increase with the increase of ultrasonic power. Vibration amplitude is also increased as the ultrasonic power controls the vibration amplitude. As vibration amplitude increases, the cutting depth of each diamond abrasive bonded on the core drill will increase so that MRR for each diamond abrasive will also increase. The increase of MRR for each diamond abrasive will lead to the increase of MRR for the entire RUM process.

## TOOL USE

In RUM of advanced ceramics, it is difficult to separate diamond grains from grinding debris . Zeng et al. reported that the microscope method was used for investigation into tool wear mechanism in RUM of SiC. A special fixture was designed for holding the tool in order to ensure that the same area of the tool was observed every time. The topography was observed on both the end face and lateral face of the tool.

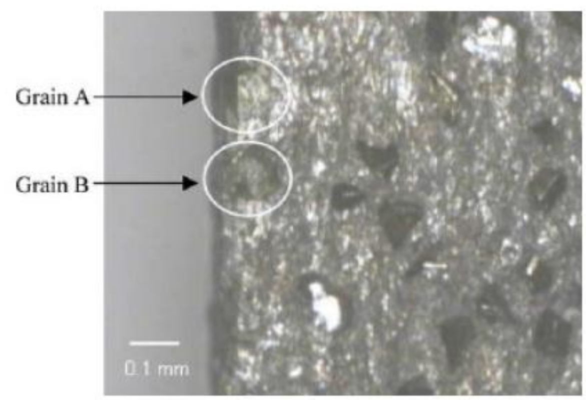


**Figure 5: Tool lateral face before drilling test on SiC. Grains A and B were dislodged after 16 drilling tests .**

Use of Tool Lateral Face **:** Figure 5 shows the tool topography on lateral face before any drilling test was performed. After 16 drilling tests were performed, wear of the diamond grains at the edge of the lateral face (close to the end face) was quite severe. Two diamond grains (grain A and grain B as indicated in Figure 5) at the edge were dislodged after 16 drilling tests.

It is clearly shown that the diamond grain dislodgment is due to bond fracture in RUM of SiC. Some diamond grains were pulled out of the metal bond prematurely, before completing their effective working lives. A grain completely pulled out of the metal bond results in a hole on the tool end face. Weakening of the interfaces between diamond grains and metal bond may be due to mechanical impact and high temperature.

## METHODOLOGY

Titanium has the highest strength-to-weight ratio of any metal. Therefore, titanium and its alloys have high utility in manufacturing sector. Also, titanium has excellent corrosion resistance. However, their properties prejudge titanium alloys to hard-machinability. They can reach value of yield strength up to 1400 MPa (Boyer, 1996; Peters and Leyens, 2009).

Therefore, high cutting forces are required for machining of titanium. Higher cutting forces generate more process heat. Titanium alloys have poor thermal conductivity and it causes high temperature at the tool, because generated heat cannot be fast enough to be lead away by chips and it remains in tool-workpiece interface. This effect decreases tool life and increase tool wear.

Pure titanium has two allotropic modifications. Alpha-titanium is present up to 882 °C and it is characterized by hexagonal close-packet (HPC) lattice. Over this temperature, up to melting point (1668 °C), beta-titanium is present, which is characterized by body centered cubic (BCC) lattice (Hong et al., 2001). However, we can affect resultant structure of titanium alloys at room temperature by adding alloying elements. Consequently, three structure types can be obtained at room temperature: alpha structure, alpha + beta structure, and beta structure. Beta-titanium alloys are characterized by higher mechanical properties and they can be heat-treatable. In comparison to other titanium alloys, beta-titanium alloys offer higher tensile strength due to deeper hardenability, increased fatigue strength and better forming properties (Machai and Biermann, 2011). In this article, the investigation of titanium alloy resultant phase to suitability to rotary ultrasonic machining under cryogenic condition is planned. There will be investigation of its influence to cutting forces, too. Representative of alpha-titanium alloys is Titanium Gr. 2. Alpha+beta-titanium alloys representative is Titanium Gr. 5. Finally, Titanium Gr. 19 is representative of beta-titanium alloys. Chosen titanium alloys and their chemical composition are recorded in Table 1. Chemical composition has been reached by EDX analysis.

| Material | Chemical composition [wt. %] | | | | | | Phase |
|---|---|---|---|---|---|---|---|
| | Ti | Al | V | Cr | Zr | Mo | |
| Titanium Grade 2 | 100 | - | - | - | - | - | α |
| Titanium Grade 5 | 89,96 | 5,81 | 4,23 | - | - | - | α + β |
| Titanium Grade 19 | 73,12 | 3,39 | 8,08 | 5,98 | 4,62 | 4,80 | β |

**Table-1 : Chemical composition and present phases in investigated titanium alloys.**

Rotary ultrasonic machining (RUM) is a hybrid machining process, which combines advantages of USM and diamond grinding. It achieves higher material removal rate than can be obtained by either diamond grinding or USM (Hu, 2002). In addition, it can reach higher precision and lower roughness compared to USM. RUM is cost-effective machining technology available for milling hard and brittle materials, like glass and ceramics. Even during machining such hard-machinable materials, it can reach superior surface finish, improved accuracy of holes, capability to drill deep holes, etc. In contrast with USM, RUM utilizes rotating tool with diamond abrasive bonded on active part of tool. There the coolant is also used, but in this case coolant does not carry abrasive particles. Primary application of coolant is also for removing of chips.

During rotary ultrasonic machining, the cutting force along the feed direction was measured by a KISTLER 9257 dynamometer (Kistler Instrument Corp, Amherst, NY, USA). The dynamometer was mounted atop the machine table and beneath the workpiece. The electrical signals from the dynamometer were transformed into numerical signals by an A/D converter. Then the numerical signals to measure the cutting force were displayed and saved on the computer with the help of LabVIEWTM (Version 5.1, National Instruments, Austin, TX, USA). The sampling frequency to obtain the cutting force signals was 100 Hz. A typical curve of cutting force versus time. The cutting force reported in this paper is the maximum cutting force on the cutting force curve. The maximum cutting force, not the average cutting force, was selected as one of the variables investigated in almost all the previous studies. It is of the major concern because it determines the maximum stress in the workpiece, the maximum deflection or deformation of the machine, and the damage to the cutting tool.

## CONCLUSION

It is commonly known that the machining of titanium alloys is performed at slow cutting speeds and it is accompanied by rapid tool wear. One of the most significant methods to increase tool life is utilizing of coolants. Cryogenic cooling has the biggest impact on increasing of tool life from all cooling approaches (Yildiz and Nalbant, 2008). Cryogenic cooling is utilized even in ultra-precision machining (Kakinuma et al., 2012).

Use of rotary ultrasonic machining is another way how to machine hard-machinable materials and to reach high quality of the machined surface. RUM is especially suitable for hard and brittle materials. Therefore, cryogenic cooling could enhance machining process.

In the present paper, the effects of three machining variables (spindle speed, feedrate, and ultrasonic power) on three output variables (cutting force, MRR, and surface roughness) while rotary ultrasonic machining of a titanium alloy are studied. The following conclusions can be drawn from the study:

1) The spindle speed has significant effects on cutting force and surface roughness, but its effects on material removal rate are not significant. Cutting force and surface roughness decrease as the spindle speed increases.

2) The feedrate has significant effects on cutting force, material removal rate, and surface roughness. Cutting force, material removal rate, surface roughness increases significantly as the feedrate increases.

It can be concluded that the material removal rate increases with increases of applied static load, ultrasonic power and amplitude of tool vibration, rotational speed and grain size. The surface roughness or hole clearance tends to increase with the increase of vibration amplitude and abrasive grit size but decrease with high applied static load. The reported coolant types have no significant effect on MRR and surface roughness but provide better performance at certain pressure.

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