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An Investigation about Utilization of Titanium Attribute In UM

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Abstract – This paper presents a review on the problems encountered in machining titanium and application of USM in machining titanium and its alloys. Experiments have been conducted to assess the effect of three factors-tool material, grit size of the abrasive slurry and power rating of ultrasonic machine on machining characteristics of titanium (ASTM Grade I) using full factorial approach for design and analysis of experiments. It has been concluded that all factors have significant effect on Material Removal Rate (MRR), Tool Wear Rate (TWR) and surface roughness of the machined surface. Two-way interactions having significant effect on MRR, TWR and surface roughness have also been identified using Minitab14 software. The levels for each factor that contribute the most to the variation in machining performance of USM of titanium have also been established. It has been concluded that titanium is fairly machinable with USM process. Moreover, the surface finish obtained is better than many of the other non-traditional processes.

In this study, the Chemical-Assisted Ultrasonic Machining (CUSM) method is introduced in order to improve the efficiency of conventional USM method. To obtain the chemical effects, a low concentration hydrofluoric acid solution is added to the abrasive slurry with glass as workpiece. This paper investigates the effect of different input materials on Material Removal Rate (MRR) and Surface Roughness (Ra) in Chemical assisted Ultrasonic Machining (CUSM) process. The effect of various input parameters on output responses is analyzed using statistical techniques such as ANOVA. Main effect plots for the significant factors and their interactions have been used to determine the optimal design for output response. Through various experiments and comparison with conventional results, the superiority of our novel method is verified.

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INTRODUCTION

Glass is known as a representative functional material for optics, electronics, thermodynamics and fluidics and so on. The conventional fabrication methods for these glass materials include diamond turning, electrochemical discharge machining, Ultrasonic machining, wet/dry etching and laser ablation Processing. Among them, the ultrasonic machining process is a process which removes materials by the impact motion of ultrasonic-vibrated abrasive particles, is non-thermal, non-chemical, and non-electrical.

Ultrasonic Machining (USM) is of particular interest for the machining of non-conductive, brittle work piece materials such as engineering ceramics. Because the process is non-chemical and non-thermal, materials are not altered either chemically or metallurgically. The process is able to effectively machine all materials harder than HRC 40, whether or not the material is an electrical conductor or an insulator. Holes as small as 76μmin diameters can be machined. However, despite the above benefits, ultrasonic machining has a low material removal rate and gives low surface quality. In this study, a Chemical-Assisted Ultrasonic Machining (CUSM) method is introduced

to overcome former disadvantages. To get the chemical effect, a low concentration of hydrofluoric acid was added to the abrasive slurry. In order to get optimal conditions, an investigation of the machining mechanism and several experimental works was carried out and compared with conventional USM method. As a result, an increase in material removal rate and improved the surface roughness is obtained.

With the development of technology, the scientists and technologists in the field of manufacturing are facing more and more challenges. Technologically advanced industries such as aeronautics, nuclear reactors and automobiles have been demanding high strength temperature resistant (HSTR) materials having high strength to weight ratio. Researchers in the area of materials science are developing materials having higher strength, hardness, toughness and other diverse properties. This also needs the development of improved cutting tool materials so that productivity is not hampered.

It is a well-established fact that during conventional machining processes an increase in the hardness of work material results in a decrease in the economic cutting speed. It is no longer possible to find tool materials which are sufficiently hard and strong to cut (at economic cutting speeds) materials such as titanium, stainless steel, nimonics, fiber-reinforced composites, ceramics and stellites. Production of complex shapes in such materials is still more difficult using conventional methods. Other higher level requirements such as better surface quality, low value of tolerances, higher production rates and miniaturization pose greater problems in machining of such materials. Making of holes (shallow entry angles, non-circular, micro holes, large aspect ratio, contoured holes and holes without burr) in difficult to machine materials is another area where extensive research is the need of the hour .

Ultrasonic Machining (USM) is a non-conventional mechanical material removal process used for machining both electrically conductive and non-metallic materials; preferably those with low ductility (Gilmore, 1989; Moreland, 1988) and a hardness above 40 HRC (Gilmore, 1990; Haslehurst, 1981) for example, inorganic glasses, ceramics, nickel alloys, etc. The process came into existence in 1945 when L. Balamuth was granted the fist patent for the process. USM has been variously termed ultrasonic drilling; ultrasonic cutting; ultrasonic abrasive machining and slurry drilling.

In USM, high frequency electrical energy is converted into mechanical vibrations via a transducer/booster combination, which are then transmitted to an energy focusing as well as amplifying device: horn/tool assembly. This causes the tool to vibrate along its longitudinal axis at high frequency; usually >20 kHz with an amplitude of 12–50 μm (Kennedy and Grieve, 1975; Kremer, 1991). The power ratings range from 50 to 3000 W and a controlled static load is applied to the tool. Abrasive slurry, which is a mixture of abrasive material; for example, silicon carbide, boron carbide or aluminium oxide suspended in water or some suitable carrier medium is continuously pumped across the gap between the tool and work (~25–60 μm). The vibration of the tool causes the abrasive particles held in the slurry to impact the work surface leading to material removal by microchipping (Moreland, 1984). Figure 1 shows the basic elements of an USM set up using a magnetostrictive transducer.

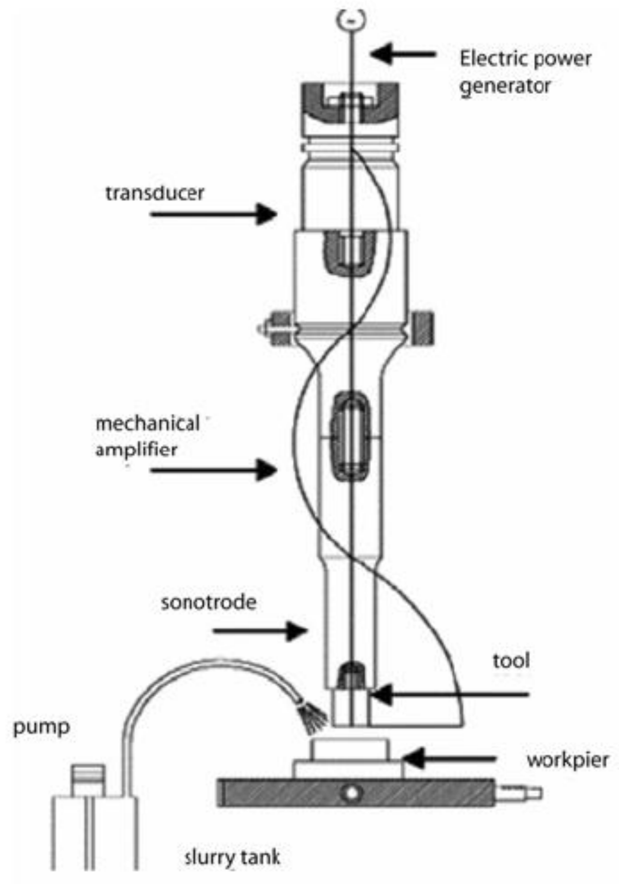

Figure 1 Ultrasonic machining set up.

The aim of this research work carried out, which is being presented in this paper, is to identify potential significant factors contributing to machining performance of USM of titanium (ASTM Grade I) in terms of three machining performance indices-MRR, Tool Wear Rate (TWR) and surface roughness of the machined surface. The problems experienced in machining titanium with conventional and other unconventional machining methods have also been reviewed. Finally, the most significant levels for each of the factors undertaken in this study have also been established using statistical testing.

REVIEW OF LITERATURE

A comprehensive review of literature on diverse aspects of ultrasonic machining and machining of titanium (using USM) has been presented here. A detailed review has also been performed for Taguchi's concept of Robust design for designing the experiments. It had helped to formulate the problem by a systematic identification of the areas to be explored in this investigation.

To identify the potential factors affecting material removal rate in USM, a cause and effect diagram was constructed. As the diagram indicates, the material removal rate in USM is dependent on four primary factors workpiece; tool; slurry and machine related factors. The literature corresponding to these factors has been reviewed and presented here.

The machining of titanium and its alloys is generally cumbersome owing to several inherent properties of the material. Titanium is very chemically reactive and therefore, has a tendency to weld to the cutting tool during machining thus, leading to premature tool failure (Ezugwu and Wang, 1997). Its low thermal conductivity increases the temperature at the tool-work interface thus, affecting the tool life adversely.

Additionally, its high strength maintained at elevated temperature further impairs the machinability. Owing to all these problems, it is very difficult to machine titanium and its alloys by conventional machining processes and moreover, by conventionally used tool materials. In the last few decades, there have been great advancements in the developments of cutting tools, including coated carbides, ceramics and cubic boron nitride and polycrystalline diamond. However, none of these newer developments had successful application in the machining of titanium and its alloys with conventional processes due to their peculiar characteristics. Straight tungsten carbide cutting tools have proven their superiority in almost all machining processes of titanium alloys, but still there is a great scope for improvement in machining efficiency.

Non-traditional machining methods such as Electric Discharge Machining (EDM) and Laser Beam Machining (LBM) has been applied to the machining of titanium and its alloys during recent times but even these established processes have their limitations; particularly in machining of small and deep holes in titanium and its alloys. With EDM process, one problem is that the debris in machining gap cannot be eliminated easily, and the machining status is unstable during the process (Lin and Yan, 2000). Another reason is that titanium has a low heat conduction efficiency and high tenacity. LBM can be applied for machining of titanium, but even this process has its own problems in forming pear shaped holes and tapering of holes, holes with straight profile are difficult to obtain.

USM can be suitable for machining titanium and its alloys due to the following characteristics Kazantsev et al. (1973). Wan sheng et al. (2002) have investigated the effect of ultrasonic vibration introduction in EDM process to machine micro holes in titanium alloy; concluding an increase in MRR as well as the process stability along with reduction in arcing phenomenon. When applied to machining of titanium alloy, the combined EDM-USM process has been found to demonstrate better performance in terms of improved MRR, discharging efficiency and reduced thickness of the recast layer (Wansheng et al., 2002).

Lin and Yan (2000) have also shown a similar result; the introduction of ultrasonic vibration into deep hole EDM of titanium alloy can improve the machining quality and efficiency distinctly. Singh and Khamba (2006) have investigated the machining characteristics of titanium and its alloy (Ti-6Al-4V) using USM process. They have reported optimum MRR and TWR with boron carbide as abrasive material with grit size 220 and Stainless steel as tool material. The surface finish has been reported to be better than that obtained while machining brittle materials such as ceramics.

Kornaraiah and Reddy investigated the influence of tool material properties i.e. hardness 011 the material removal rate 111 USM of glass. Results showed that the MRR increased with an increase in the hardness of the tool material. The different tool materials were arranged in the increasing order of superiority as mild steelctitanium < stainless steel < silver steel < niamonic-80 A < thoriated tungsten. The tool materials used were found to undergo a significantly different amount of work-hardening, which contributed to the variation in their machining performance. Neppiras using other tool materials gave the following ranking: copper < stainless steel < silver steel < mild steel < brass < tungsten carbide. Kumar and Khamba reported achievement of higher material removal rates using a high carbon steel tool, which had higher hardness in comparison to other tools used for the experimentation. Tools with diamond tips have been shown to have good material removal characteristics.

PROCEDURE OF CHEMICAL-ASSISTED ULTRASONIC MACHINING

In the process of the USM, materials are removed by microchipping or erosion with the abrasive particles. When glasses are dipped in the Hydrofluoric Acid (HF) solution the total chemical reaction can be described as:

$$SiO_2 + 6\,HF \longrightarrow H_2SiF_6 + 2\,H_2O$$

In the conventional USM, the tip of the tool vibrates at low amplitude (2–50μm) and high frequency (20 kHz), which transmits a high velocity to the fine abrasive grains between the tool and the surface of the workpiece. The indentation of a material surface by the abrasives will cause local deformation and initiate cracks. The initiation and propagation of median and lateral cracks contribute to the material removal process the workpiece used in present study is soda glass.

In chemical-assisted ultrasonic machining, the propagation of impact energy in the lateral direction is limited because the linking forces between the molecules are weakened. Alternatively, in the median direction, the transmitted energy increases and results in deep median cracks. Therefore, the crater size of a single impulse of an abrasive is reduced and the removal rate can be increased.

EXPERIMENTAL METHODS

From the literature survey undertaken regarding the application of USM for titanium and its alloys, it is evident that use of USM as a machining process for titanium has not been explored to a great extent. Moreover, the power rating of USM as a factor has not been reported by any investigator up to the best knowledge of the author. Hence, power rating of the ultrasonic machine was selected as a process parameter in this study.

In all, three factors were selected for experimentation – tool material; with two levels: High carbon steel and titanium alloy, grit size of abrasive and power rating of the ultrasonic machine. High carbon steel (1095) and titanium alloy (ASTM Grade-V) were selected as tool materials because they possess a wide spectrum of mechanical and physical properties, which could be of significance in USM of titanium. The chemical composition and few important mechanical properties of both tool materials are given in Tables 1 and 2, respectively. Both tools were prepared as solid cylindrical type with diameter 8 mm. The response factors to be studied were fixed as: MRR of titanium work piece, TWR of both the tools used and surface roughness of the machined surface.

To study the influence of power rating of the ultrasonic machine and grit size of the abrasive material, a pilot experimentation was performed using both tools (of HCS, titanium alloy) and different levels of power rating (from 100 to 500 W) with equal intervals of 100 W and different grit sizes (100–600). Experiments were performed with Sonic Mill-AP 500 W set up manufactured by Sonic Mill, Albuquerque. Aluminium oxide was used as an abrasive material for preparing the slurry with a concentration of 25%. Three grit sizes of 220, 320 and 500 were selected for final experimentation as they represent a wide range of average particle size (16–64 microns) and also exhibit strong influence on the variation in machining performance as observed in pilot experimentation. Power levels beyond 400 W could not be selected as the machining status was highly unstable after crossing this value. Moreover, the machining performance was very low for power rating less than 100 W. Hence, four power levels were finalised for the experimentation: 100, 200, 300 and 400 W.

Chemical composition (by weight %) of HCS (1095 series)			
C	*Mn*	*Residual*	*Fe*
1.01	0.35	0.3	balance

Table 1 Chemical composition and important properties of Tool material (HCS).

Chemical composition (by weight %) of titanium alloy (ASTM Grade V)							
O	*N*	*C*	*H*	*Fe*	*Al*	*V*	*Ti*
0.20	0.05	0.08	0.015	0.40	6.02	4.27	balance

Table 2 Chemical composition and important properties of Tool material (Titanium alloy).

The ultrasonic drilling Machine used for the experimentation consisted of an ultrasonic spindle kit; a constant pressure feed system and slurry flow system. The maximum power input to the machine was 500 W. Figure 2 shows the static USM set up used for the experimentation.

a) Front view

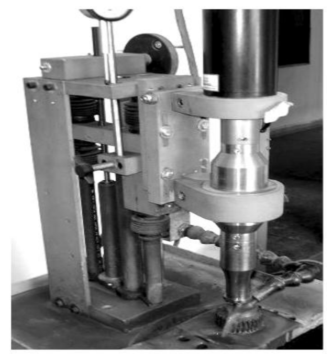
b) Side view

Figure 2 Ultrasonic machining set-up.

The ultrasonic spindle kit comprises an ultrasonic spindle mounted with cylindrical horn, a power supply unit that converts 50 Hz electrical supply to high frequency 20 kHz output. This high frequency electric signal is applied to a piezoelectric transducer positioned in the spindle. The function of this transducer is to convert the applied electrical signal into mechanical vibrations. The amplitude of vibration was in range of 25.3-25.8 μm with a frequency of 20 kHz +/- 200 Hz. The static load for feed rate was fixed at 1.636 Kg and slurry flow was maintained at 36.4 X 103 mm3/min.

There are several approaches to design the experiments such as full factorial designs, fractional factorials, Latin square designs and taguchi's robust design of experiments technique. The identification of all the significant two-way interactions between the different factors cannot be realised effectively by using techniques such as fractional factorials and taguchi's robust design methodology (Astakhov, 2004). Moreover, if any crucial factor is missed at the time of experimentation or any particular combination of the selected factors is not put into trial, sometimes the results obtained might just be inadequate from the point of view of optimisation. Full factorial designs usually result in more experimentation requirements and hence more time and resources consumption in performing it but at the same time, have been reported to provide best accuracy in design and subsequent analysis of experiments (Hicks and Turner, 1999). Hence, this approach was used in designing and analysing the experimental runs.

Each experiment was replicated twice to take the inherent variability of the process into consideration.

CONCLUSION

This work presents the identification of process parameters for USM process that put a significant effect on the machining performance of the process for titanium as work material and subsequently, the most significant levels for each parameter undertaken in the study. ANOVA was performed on the response variables data produced from the experimentation which was designed by using full factorials approach. The significance of all the three parameters studied was conformed by ANOVA results. For MRR and TWR, all the three parameters were found to be significant for their main effects.

Two-way interactions among tool and power rating, tool and grit size and grit size-power rating were also significant for MRR and TWR. For surface roughness, grit size of the abrasive slurry was the only factor found significant. None of the two-factor interactions were found to have any significance for surface roughness.

USM is a very random process. Even minor fluctu slurry concentration can affect the response to considerable extent. Hence, a large volume of the slurry must be used to minimize the effect of variations in the input parameters. Also, the tool may crack if slurry flow rate is inadequate.

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