ULTRASONIC MACHINING

[1] Bhushan.A. Aher, [2] Viraj.D. Ghodke, [3] Jasraj.N. Ahirrao

[1,2,3]*Mechanical, B.V.C.O.E.&R. I, Anjenari, Nashik, University of Pune (India)*

ABSTRACT

Abstract Ultrasonic machining (USM) has immense potential for machining hard and brittle materials such as ceramics, bio-ceramics and glasses, etc. irrespective of electrical conductivity of the workpiece material. Alumina (Al2O3) is very hard and brittle bio-ceramic material and highly biocompatible. It is very difficult to machine by any conventional machining process. For this reason, ultrasonic machining is applied for these bio-ceramic materials. Stepped whole generation on the alumina implant is required for proper fitting in our chewing gum. This paper presents the study on the influences of ultrasonic machining process parameters such as abrasive grain size, power rating and tool feed rate on generated stepped hole profile. The material removal rate and accuracy of the job profile such as over cut of larger diameter (OLD) hole and over cut of smaller diameter (OSD) of the stepped hole profile have been studied. Based on experimental results, the influences of abrasive grain size, slurry concentration and power rating have been studied through graphical representation of the results. The experimental investigations carried out for determining the influence of USM process parameters will provide effective guideline to select parametric settings for achieving maximum material removal rate and desired job profile accuracy on stepped hole drilling operation on alumina.

Keywords: Ultrasonic Machining; Alumina; material removal rate; over cut of larger diameter hole; over cut of smaller diameter hole and stepped hole

I. INTRODUCTION

Hard solids are invariably stiff, strength and wear resistant. On the other hand, hard solids typically exhibit statistically variable brittle fracture and high sensitivity to machining damage. When loaded with tensile stresses, hard solids pass from elastic to fracture behavior and invariably fail by crack extension. Thus, hard solids are usually brittle, i.e., they have small capacity to convert elastic energy into plastic deformation at room temperature (Dieter, 1981)

Brittle and hard solids can be classified in four groups: minerals, polycrystalline ceramic aggregates (traditional and advanced), single crystals and amorphous glasses. Minerals are frequently used as raw materials in the production of a large range of products such as abrasives, gemstones, metals and alloys, single crystals synthetically produced on a commercial scale, etc. Traditional ceramics and glasses are extensively used to manufacture many products currently used in daily life. Advanced ceramics have been widely adopted as functional as well as structural engineering materials (Chiang et al. 1997). Functional ceramics and single crystals are extensively used in the production of electric, electronic, magnetic and optical components for high performance systems such as transducers, resonators, actuators and sensors (Fraden, 1996). The past two decades have seen a tremendous resurgence in the use of advanced ceramics in structural applications such as roller and sliding bearings, adiabatic diesel engines, cutting tools, etc.

Conventional forming and sintering processes of ceramic powders do not necessarily give the high dimensional accuracy and the good surface quality required for functional and structural components. Similarly, the functional devices built with single crystals frequently show monolithic structures with complexes shapes that cannot be achieved during the process of crystal growth. Thus, precision machining technologies have been developed for the manufacture of cost-effective and quality-assured precision parts produced by brittle and hard solids. Several machining techniques can be mentioned like diamond turning, ion and electron-beam machining, laser-beam machining and abrasive machining processes (Snoyes 1986, Nakazawa 1994).

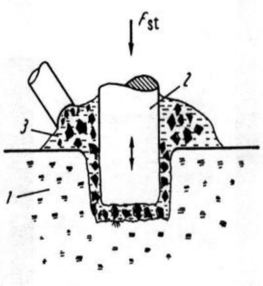
Although Brazil is one of the most important suppliers of raw materials to produce functional and structural components for high performance systems, fundamental and applied research connected with the machining of brittle and hard materials are still incipient. On the other hand, the Brazilian commercial balance is usually troubled by mass importation of optical and electronic devices build with advanced ceramics and single crystals. In addition, it is expected that industries installed in Brazil dealing with automotive, aircraft and agricultural machinery will increase their activities in the coming years. If so, an increasing amount of functional and structural components made by advanced materials will be also expected. Under these circumstances, efforts to investigate the machinability of brittle and hard solids by precision manufacturing processes would contribute to the development of a network of domestic suppliers for advanced materials and devices.

Literature

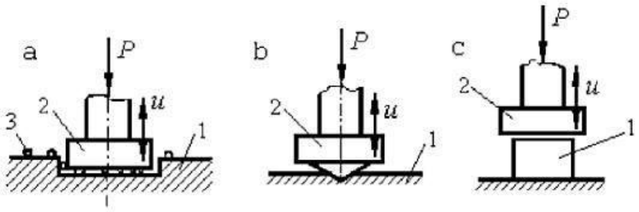
II. ULTRASONIC PROCESS:

Ultrasonic machining (USM) is the removal of material by the abrading action of grit-loaded liquid slurry circulating between the workpiece and a tool vibrating perpendicular to the workface at a frequency above the audible range. Ultrasonic machining, also known as ultrasonic impact grinding, is a machining operation in which an abrasive slurry freely flows between the workpiece and a vibrating tool. It differs from most other machining operations because very little heat is produced. The tool never contacts the workpiece and as a result the grinding pressure is rarely more, which makes this operation perfect for machining extremely hard and brittle materials, such as glass, sapphire, ruby, diamond, and ceramics.

Diagram of ultrasonic cutting process. 1) Workpiece; 2) tool; 3) abrasive suspension.



The working process of an ultrasonic machine is performed when its tool interacts with the workpiece or the medium to be treated. The tool is subjected to vibration in a specific direction, frequency and intensity. The vibration is produced by a transducer and is transmitted to the tool using a vibration system, often with a change in direction and amplitude. The construction of the machine is dependent on the process being performed by its tool.



The above figure shows the ultrasonic erosion process used to machine hard, brittle materials. The workpiece 1 is placed under the face of the tool 2 which is subjected to high frequency vibration perpendicular to the surface being machined. Abrasive slurry is conveyed to the working zone between the face of the tool and the surface being machined. The tool moves towards the workpiece and is subjected to a static driving force P. repetitive impact of the tool on the grains of the abrasive material, falling from the slurry onto the surface to be treated , lead to the fracture of the workpiece material and to the creation of a cavity with the shape mirror formed of the tool. The abrasive particles are propelled or hammered against the workpiece by the transmitted vibrations of the tool. The particles then microscopically erode or "chip away" at the workpiece

Tool materials used :-

Material	Chemical Composition	Crystalline Structure	Density (g/cm^3)	*E* (GPa)	*H* (GPa)	K_{Ic} (MPam$^{1/2}$)
Alumina	Al_2O_3	FCC/polycristalline	4.0	210 - 380	14 – 20	3 - 5
Ferrite	-	- / polycristalline	-	~180	6.8	1
LiF	LiF	FCC/single-crystal	2.43	54.6	0.92 ± 0.03	1.5
Quartz	SiO_2	Trigonal/single-crystal	2.65	78.3	15.0 ± 1.0	0.53 ± 0.01
Soda-lime glass	SiO_2+Na_2O+CaO	Amorphous	2.5	69	5.8 ± 0.5	0.48 ± 0.05
Zirconia	ZrO_2	Tetragonal/polycristalline	5.8	140 - 210	10 – 12	8 - 10

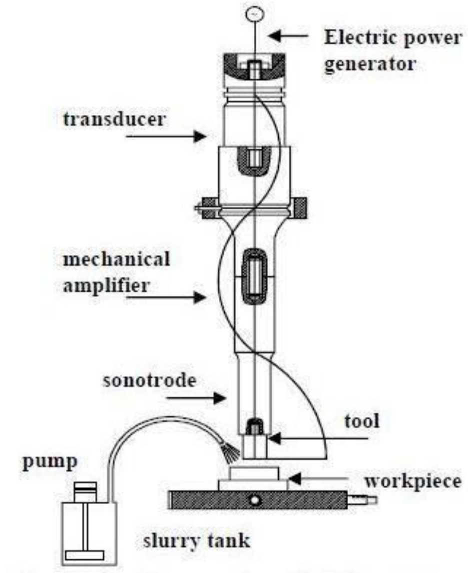
Generally, the tool oscillates at a high frequency (about 20,000 cps) in an abrasive slurry. The high speed oscillations of the tool drive the abrasive grain across a small gap of about 0.02-0.10mm against the workpiece

III.MACHINE UNIT FOR ULTRASONIC MACHINING

The below figure schematically depicts the major components of a typical ultrasonic machining setup. The vibration exciter, a magnetostrictive transducer, is fixed to the body of the acoustic head using the shoulder and the thin walled cup . The winding of the transducer is supplied with an alternating current, at ultrasonic frequency, by the generator

The alternating magnetic field induced by the current in the core of the transducer, which is made from magnetostrictive material, is transformed into mechanical vibration in the core. Its main elements are an electromagnet and a stack of nickel plates. The high frequency power supply activates the stack of magnetostrictive material which produces the vibratory motion of the tool. The tool amplitude of this vibration is usually inadequate for cutting purposes, and hence the tool is connected to the transducer by means of a concentrator which is simply a convergent wave guide to produce the desired amplitude at the tool end. The waveguide or concentrator 6 transmits this vibration to the tool 7. The concentrator takes the form of a bar with a variable cross section. It is specially designed to transmit vibration from the transducer, to the tool, with an increase in the amplitude. The selection of frequency and amplitude is governed by practical considerations.

The workpiece 10 is placed under the tool, on a plate 8, in a tray 9, within an abrasive slurry. The ďodLJ of the aĐoustiĐ head is adjusted to the ďase's guides ϲϲ aŶd is suďjeĐted to a statiĐ force P which drives the tool in the direction necessary to machine the workpiece



Tool holder :-

The tool holder transfers the vibrations and, therefore, it must have adequate fatigue strength. With a good tool design, an amplitude gain of 6 over the stack can be obtained. Generally, the shape of tool holder is cylindrical, or a modified cone with the centre of mass of the tool on the centre line of the tool holder. It should be free from nicks, scratches and tool marks to reduce fatigue failures caused by the reversal of stresses.

Tool materials and tool size :-

The tool material employed in USM should be tough and ductile. However, metals like aluminum, give very short life. Low-carbon steel and stainless steels give superior performance. The qualitative relationship between the material removal rate and lambda i.e. workpiece/tool hardness.

Long tool causes overstressing of the tool. Most of the USM tools are less than 25 mm long. In practice the slenderness ratio of the tool should not exceed 20. The under sizing of the tool depends coupon the grain size of the abrasive. It is sufficient if the tool size is equal to the hole size minus twice the size of the abrasives.

 ISBN: 978-81-932074-7-5

Trancducers :-

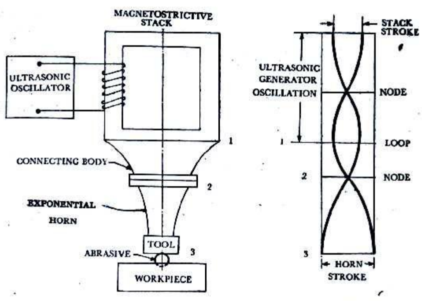
The ultrasonic vibrations are produced by the transducer. The transducer is driven by suitable signal generator followed by power amplifier. The transducer for US M works on the following principle

- Piezoelectric effect
- Magnetostrictive effect
- Electrostrictive effect

IV.PARAMETERS OF ULTRASONIC MACHINING

The ultrasonic vibration machining method is an efficient cutting technique for difficult-to- machine materials. It is found that the USM mechanism is influenced by these important parameters.

- Amplitude of tool oscillation
- Frequency of tool oscillation
- Tool material
- Type of abrasive
- Grain size or grit size of the abrasives
- Feed force
- Contact area of the tool
- Volume concentration of abrasive in water slurry
- Ratio of workpiece hardness to tool hardness; $ʃ=\sigma_W/\sigma_t$

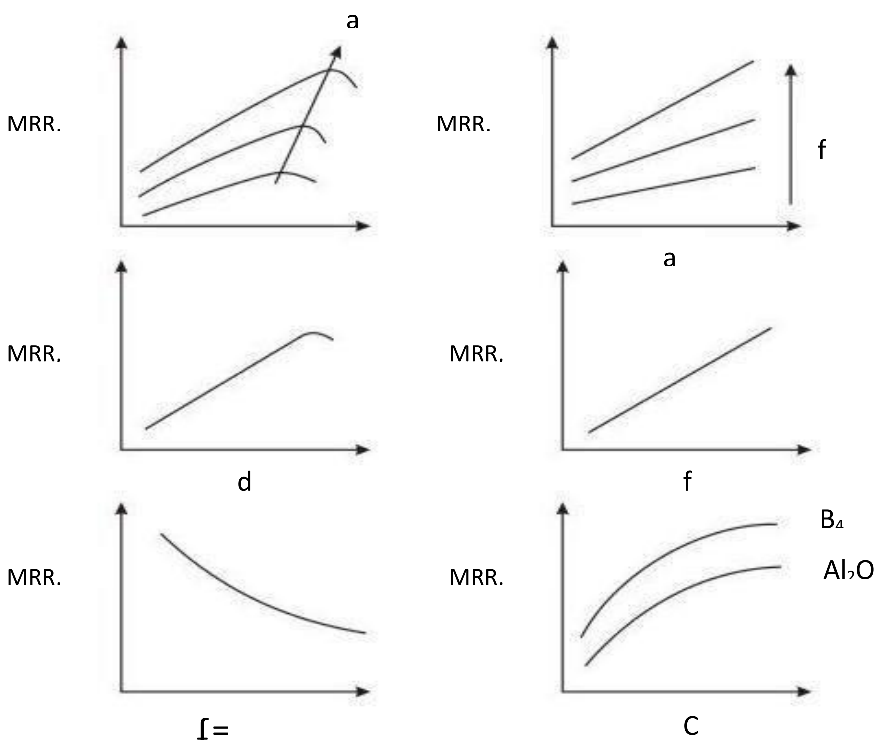


(a) SCHEME (b) STROKE MAGNIFICATION

Physical parameters	
Abrasive	Boron carbide, aluminium oxide and silicon carbide
Grit size(d_0)	100 – 800
Frequency of vibration (f)	19 – 25 kHz
Amplitude of vibration (a)	15 - 50 µm
Tool material	Soft steel titanium alloy
Wear ratio	Tungsten 1.5:1 and glass 100:1
Gap overcut	0.02-0.1 mm

V.MATERIAL REMOVAL RATE

USM can be applied to machine nearly all materials; however it is not economical to use USM for materials of hardness less than 50 HRC. Generally the workpiece materials are of stainless steel, cobalt-base heat-resistant steels, germanium, glass, ceramic, carbide, quartz and semiconductors. It is highly useful in the machining of materials that cannot be machined by any conventional machining process that are ceramic and glass.



5.1.Advantages :-

- A nearly limitless number of feature shapes—including round, square and odd- shaped thru-holes and cavities of varying depths, as well as OD-ID features—can be machined with high quality and consistency.
- Aspect ratios as high as 25-to-1 are possible, depending on the material type and feature size.
- The machining of parts with preexisting machined features or metallization is possible without affecting the integrity of the preexisting features or surface finish of the workpiece.
- USM machined surfaces exhibit a good surface integrity and the compressive stress induced in the top layer enhances the fatigue strength of the workpiece.
- The quality of an ultrasonic cut provides reduced stress and a lower likelihood of fractures that might lead to device or application failure over the life of the product

5.2 Disadvantages :-

*Ultrasonic machines have a relatively **low mrr.** Material removal rates are quite low, usually less than 50 mm3/min.

*The abrasive slurry also "machines" the tool itself, thus causing **high rate of tool wear** which in turn makes it very difficult to hold close tolerances.

*The slurry may wear the wall of the machined hole as it passes back towards the surface, which limits the accuracy, particularly for small holes.

*The machining area and the depth of cut are quite restricted

VI. CONCLUSION

In the above literature an effort has been made to familiarize with the basic layouts of the common Ultrasonic Machining setup, the various elements that constitute the overall build, and the basic parameters on which the machining characteristics depend.

Preliminary USM experiments carried out pointed out the various regions of improvement in the experimental setup.. The slurry concentration could be varied to find out the effect on the parameter. Different materials can be used for a given abrasive of varying size to find out the best option for machining a given workpiece. The effects of tool vibration frequency, tool vibration amplitude and feed force along with the other process parameters in the USM method were studied theoretically.

The overall ultrasonic machining process is studied and an effort is made to carry out rigorous experiments in order to reach at the optimal values that could result in the required improvement in machining characteristics mandatory for smooth operation of the setup and satisfactory results

REFERENCE

[1]. Effect of machining parameters in ultrasonic vibration cutting - Chandra Nath, M. Rahman - Department of Mechanical Engineering, National University of Singapore, 9 Engineering Drive 1, Singapore–117576, Singapore

[2]. Integrated Modeling of the Ultrasonic/Sonic Drill/Corer – Procedure and Analysis Results – Mircea

Badescu, Xiaoqi Bao, Yoseph Bar-Cohen, Zensheu Chang, Stewart Sherrit - JPL/Caltech, (MS 67-119), 4800 Oak Grove Drive, Pasadena, CA 91109-8099

[3]. A Comparative Study on Ultrasonic Machining of Hard and Brittle Materials - P. L. Guzzo and A. H. Shinohara - Departamento de Engenharia Mecânica Universidade Federal de Pernambuco Cidade Universitária & A. A. Raslan - Faculdade de Engenharia Mecânica Universidade Federal de Uberlândia Campus Sta. Mônica

[4]. L. Balamuth, Ultrasonic assistance to conventional metal removal,Ultrasonics (1966) 125–130.

[5]. Microultrasonic Machining by the Application of Workpiece Vibration - Kai Egashira, Takahisa Masuzawa - Institute of Industrial Science, University of Tokyo, Tokyo, Japan

[6]. Vibration Velocity Limitation of Transducer Using Titanium-Based Hydrothermal Lead Zirconate Titanate Thick Film - Takefumi KANDA, Yutaka KOBAYASHI, Minoru Kuribayashi KUROSAWA and Toshiro HIGUCHI

[7]. M. Zhou, X.J. Wang, B.K.A. Ngoi, J.G.K. Gan, Brittle-ductile transition in the diamond cutting of glasses with the aid of ultrasonic vibration, Journal of Materials Processing Technology 121 (2002)243–251.

[8]. C. Nath, M. Rahman, S.S.K. Andrew, A study on ultrasonic vibration cutting of low alloy steel, Journal of Materials Processing Technology 192–193 (2007) 159–165.

[9]. J.-D. Kim, E.-S. Lee, A study of the ultrasonic-vibration cutting of carbon-fiber reinforced plastics, Journal of Materials Processing Technology