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Parametric Studies on Profile Accuracy of Square Stepped Hole Generated on Zirconia by USM Process

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Abstract

Zirconia (ZrO2) is a highly biocompatible ceramic material with good fracture strength property that allows application in biomedical engineering. Generating square stepped hole on zirconia bio-ceramic with desired quality is very much difficult. Ultrasonic drilling is used nowadays for both conductive and nonmetallic materials; preferably those with low ductility and high hardness above 40HRC, e.g., inorganic glasses, silicon nitride, zirconia, etc.. Keeping in-view of the objectives of the present research work, the experimental observations and studies have been planned for generating of square stepped hole on zirconia bio-ceramics using ultrasonic machining and also conducting fruitful research analysis for deriving effective research findings. The effects of different ultrasonic machining process parameters such as abrasive grain diameter, abrasive slurry concentration, power rating and tool feed rate on various machining criteria i.e. flat to flat overcut (FFOC), corner to corner overcut (CCOC) and diametrical overcut (DOC) of square stepped hole on zirconia bio-ceramics have been studied. Some graphs have been plotted for showing the relationship between process parameters and responses. From those graph, it are clearly shown for achieving the better profile accuracy i.e. flat to flat overcut (FFOC), corner to corner overcut (CCOC) and diametrical overcut (DOC) of square stepped hole, the lower value of abrasive grain diameter, abrasive slurry concentration, power rating and tool feed rate are preferred.

Keywords: ultrasonic machining, bioceramic, flat to flat overcut, corner to corner overcut, diametrical overcut.

1. INTRODUCTION

Advanced ceramics are familiar for their outstanding properties like high stiffness, high hardness, high thermal shock resistance, high corrosion resistance and good creep resistance. Those materials can be cut efficiently by non-conventional processes based on direct utilization of various forms of energy, such as ultrasonic machining (USM), electro-discharge machining, electron-beam machining and electro-chemical machining, etc. USM is used widely in the machining of high-performance composites, ceramics, quartz and graphite etc1, 2 & 3]. Ultrasonic machining (USM) is one of the most effective methods for machining hard and brittle materials such as ceramic, quartz, and glass for the aerospace, electronics, optics, automotive industries and medical field. Production of complex shapes on such materials is still more difficult using conventional methods [4, 5]. Ultrasonic machine does not thermally damage the workpiece or introduce significant levels of residual stress, which is important for the survival of brittle materials service [6, 7]. It has been observed that any increase in the amount of work energy imparted to the ceramics in terms of the amplitude of tool tip, static load applied and size of the abrasive would result in an increase in the material removal rate [8, 9]. It was found that low-impact force caused only structural disintegration and particle dislocation in experimental simulation of the process mechanics in an attempt to analyze the material removal mechanism during machining of ceramic (Al2O3). The high-impact force contributed to cone cracks and subsequent crater damage [10. 11].

However, many aspects of ultrasonic machining process such as generating square stepped hole, array of hole and complexities in shape generation etc. are still not investigated. Therefore, an attempt has been made to further explore the fabricating square stepped hole on zirconia bio-ceramic material using ultrasonic machining process. Keeping in-view of the objectives of the present research work, the experimental observations and studies have been planned for conducting fruitful research analysis for deriving effective research findings for generating of square stepped hole on zirconia bio-ceramics using ultrasonic machining. The effects of different ultrasonic machining process parameters such as abrasive grain diameter, abrasive slurry concentration, power rating and tool feed rate on various machining criteria i.e. flat to flat overcut (FFOC), corner to corner overcut (CCOC) and diametrical overcut (DOC) of square stepped hole on zirconia bio-ceramics have been studied. Graphical representation of the machining process parameters and process responses in terms of FFOC, CCOC, DOC have been considered for understanding the correlations between the inputs and output characteristics

2. EXPERIMENTATION

Experimental set-up used in this research investigation was "AP-1000" Sonic-Mill ultrasonic machine with the frequency of vibration 20 kHz and amplitude of vibration 25 μm. During ultrasonic machining, the workpiece was flat shaped zirconia of 58.5 mm length, 58.5 mm breadth and 5.1 mm thick. The cylindrical shaped stainless steel (SS304) rod was taken for making the tool and square stepped shape was generated at end tip of the tool. Then the tool was silver-brazed on the hexagonal bolt. Fig.1 shows the schematic diagram of Ultrasonic machining set-up. The photographic view of the developed tool is shown in Fig. 2 (a). The photographic views of square stepped hole generation on zirconia workpiece after machining are also shown in Fig. 2 (b). The five different abrasive grain diameters of 14 μm, 24 μm, 34 μm, 44 μm and 64 μm is selected for whole experimentation. The machining was performed by ultrasonic machine at five different power ratings

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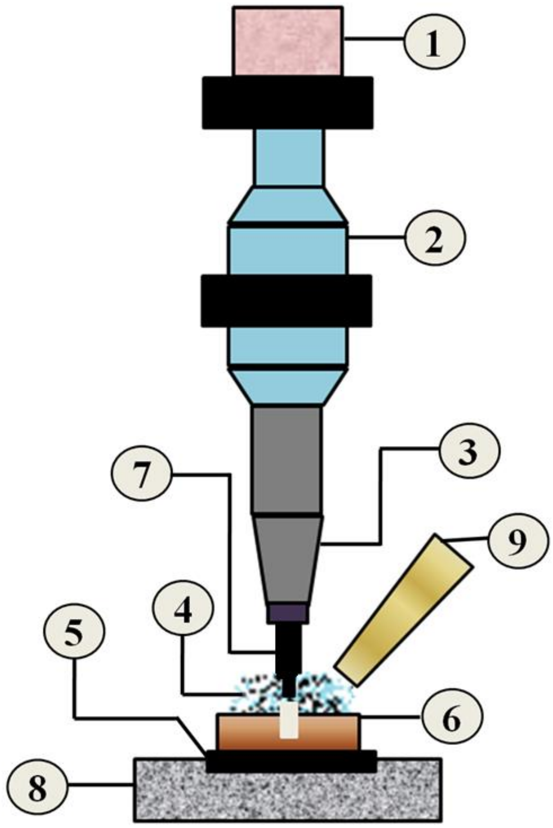
of 300 W, 350 W, 400 W, 450 W and 500 W and tool feed rate varies from 0.84 to 1.32 mm/min. The slurry concentration was varied from 30% to 50% and slurry temperature at 27˚C (room temperature).



1) TRANSDUCER; 2) COUPLER; 3) HORN; 4) ABRASIVE SLURRY MIXED WITH WATER; 5) MAGNETIC FIXTURE; 6) WORKPIECE; 7) TOOL; 8) BASE; 9) SLURRY PIPE

Fig.1 The schematic diagram of USM set-up

3. MEASUREMENT OF RESPONSES

Flat to flat overcut (FFOC), corner to corner overcut (CCOC) and diametrical overcut (DOC) of square stepped hole are selected as responses for USM. The measurement procedure is described here under.

3.1 Flat to flat overcut (FFOC) of square stepped hole

The flat to flat overcut (FFOC) has been calculated by measuring the distance of a two parallel edge of the square flat surface. The absolute value of flat to flat surfaces of square stepped hole of workpiece and the corresponding flat to flat of square stepped shape of the tool is taken. Then deviation is calculated. The flat to flat overcut (FFOC) of square stepped hole has been evaluated using the following relation:

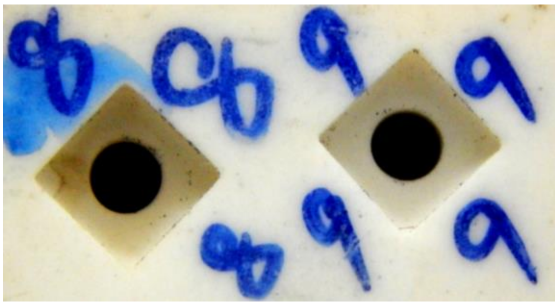
$$FFOC = \frac{1}{n}\sum_{i=0}^{n}\lceil(F_{wi} - F_{ti})\rceil \qquad (1)$$

Where n is the number of linear measurement across flat surfaces of the hole, Fwi is i^{th} distance across flats of the square stepped hole and F_{ti} is i^{th} distance across flat of the square stepped shape of the tool.

3.2 Corner to corner overcut (CCOC) of square stepped hole

The Corner to corner overcut (CCOC) has been calculated by measuring the distance of diagonal of the square flat surface.

(a)



(b)

Fig. 2 (a) Developed square stepped tool for USM. (b)Square stepped hole on zirconia workpiece after machining

The absolute value of corner to corner of square stepped hole of workpiece and the corresponding corner to corner of square stepped shape of the tool is taken. Then deviation is calculated. The corner to corner overcut (CCOC) of square stepped hole has been evaluated using the following relation:

$$CCOC = \frac{1}{n}\sum_{i=0}^{n}\lceil(C_{wi} - C_{ti})\rceil \qquad (2)$$

Where n is the number of linear measurement across flat surfaces of the hole, Cwi is i^{th} distance across flats of the square stepped hole and C_{ti} is i^{th} distance across flat of the square stepped shape of the tool.

3.3 Diametrical overcut (DOC) of square stepped hole

The diametrical overcut (DOC) of square stepped hole was evaluated using the following relation:

$$\boldsymbol{DOC = \frac{1}{n}\sum_{i=1}^{n}\lceil(D_{wi} - D_{ti})\rceil} \qquad (3)$$

Where n is the number of measurement, D_{wi} is diameter of the square stepped hole of the workpiece and D_{ti} is the diameter of the tool for i^{th} observation.

4. BASIC INFLUENCES OF PROCESS PARAMETERS ON RESPONSES OF ULTRASONIC MACHINING OF SQUARE STEPPED HOLE FABRICATION ON ZIRCONIA

The effects of major process variables, such as the abrasive grain diameter, abrasive slurry concentration, power rating and tool feed rate, on the responses, i.e. flat to flat overcut (FFOC), corner to corner overcut (CCOC) and diametrical overcut (DOC) of square stepped hole on zirconia bio-ceramics have been analyzed for obtaining the machining characteristics of USM operation using various plotted graph.

4.1 Influences of abrasive grain diameter on FFOC, CCOC and DOC of square stepped hole

Fig. 3 shows the effect of abrasive grain diameter on flat to flat overcut (FFOC), corner to corner overcut (CCOC) and diametrical overcut (DOC) of square stepped hole on zirconia bio-ceramics. While abrasive slurry concentration of 40 %, power rating of 400 W and tool feed rate of 1.08 mm/min was constant.

From the graph, it is observed that fine abrasive grain produces hole with low overcut i.e. OSD and also found minimum flat to flat overcut (FFOC), corner to corner overcut (CCOC) of square hole. Average larger grain diameter is 64 micron and average smaller grain diameter is 16 micron. So that the area of average larger grain diameter is very high compare to the average smaller grain diameter. The contact surface area is less when the fine and smaller abrasive grain diameter is used. So that diametrical overcut of smaller hole generation by USM is less. So that low overcut i.e. OSD, minimum flat to flat overcut (FFOC), corner to corner overcut (CCOC) of square hole is achieved by low value of abrasive grain diameter.

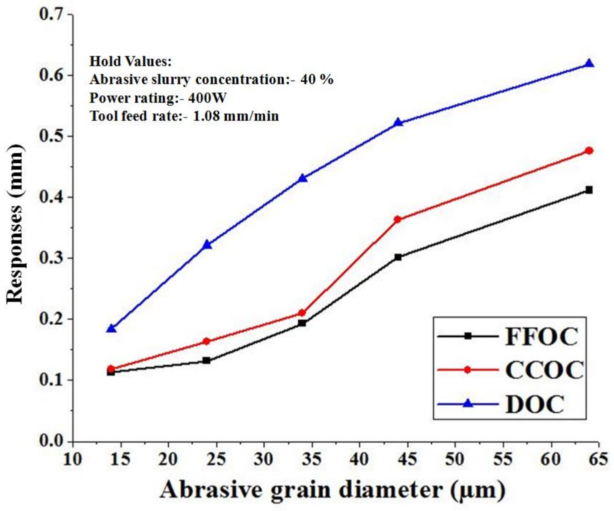


Fig. 3 Effect of abrasive grain diameter on FFOC for square stepped hole generation

4.2 Influences of abrasive slurry concentration on FFOC, CCOC and DOC of square stepped hole

Fig. 4 shows the effect of abrasive slurry concentration on flat to flat overcut (FFOC), corner to corner overcut (CCOC) and diametrical overcut (DOC) of square stepped hole on zirconia bio-ceramics. While abrasive grain diameter of 34 µm, power rating of 400 W and tool feed rate of 1.08 mm/min was constant.

If slurry concentration is low then profile accuracy value is good. When abrasive slurry concentration is very low, then total mass of abrasive in the working zone is low so hammering force is very small. If abrasive slurry concentration is high, the density of the slurry is high. So that, more material is eroded from the workpiece due to erosion mechaism. For this reason more material removed. For this reason lower FFOC, CCOC and DOC value is achived using of low abrasive slurry concentration.

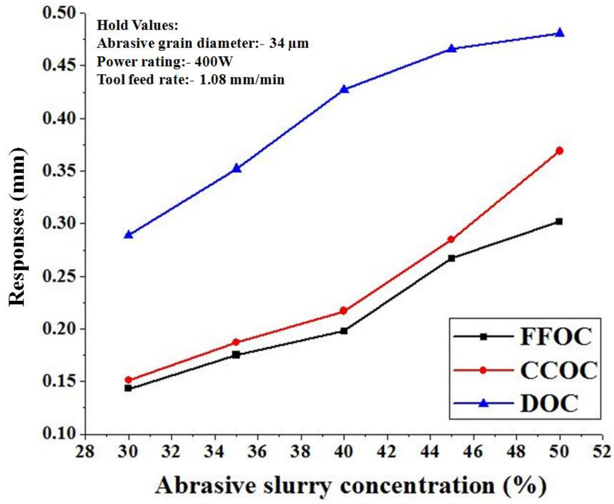


Fig. 4 Effect of abrasive slurry concentration on FFOC for square stepped hole generation

4.3 Influences of power rating on FFOC, CCOC and DOC of square stepped hole

Fig. 5 exhibits the effect of power rating on flat to flat overcut (FFOC), corner to corner overcut (CCOC) and diametrical overcut (DOC) of square stepped hole on zirconia bio-ceramics. While abrasive grain diameter of 34 µm, abrasive slurry concentration of 40 % respectively and tool feed rate of 1.08 mm/min was constant.

From the graph, it is clearly observed that with the increase in power rating, the FFOC, CCOC and DOC values are increased. Actually high value of power rating means the tool vibrates with high power and abrasive particle strikes on the surface of the workpiece with high energy. For this reason the material removes from the workpiece at faster rate. So the flat to flat overcut (FFOC), corner to corner overcut (CCOC) and diametrical overcut are increased. So that for achieving low FFOC, CCOC and DOC lower value of power rating is preferred.

Fig. 6 shows that effect on FFOC, CCOC and DOC with varying tool feed rate. While abrasive grain diameter of 34 µm, abrasive slurry concentration of 40 % respectively and power rating of 400 W was constant.

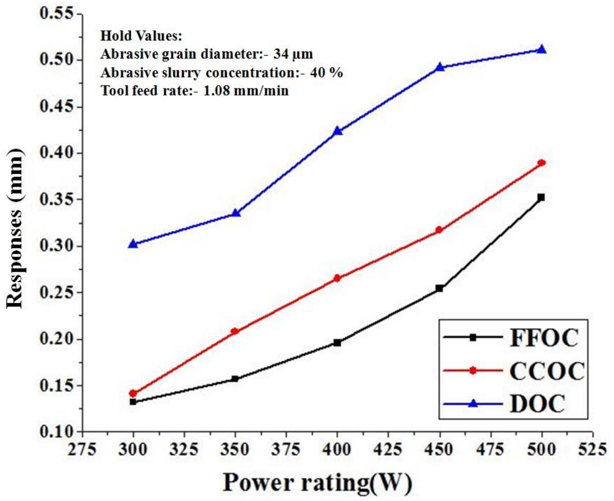


Fig. 5 Effect of power rating on FFOC for square stepped hole generation

4.4 Influences of tool feed rate on FFOC, CCOC and DOC of square stepped hole

From the graph, it is obtained that higher value of tool feed rate gives maximum FFOC, CCOC and DOC. With higher value of applied tool feed rate, more material is removed by the action of the abrasive particles just below the tip of the tool. Therefore diametrical overcut increases with increase in applied tool feed rate. Low value of tool feed rate is preferred to achieve low FFOC, CCOC and DOC of square stepped hole.

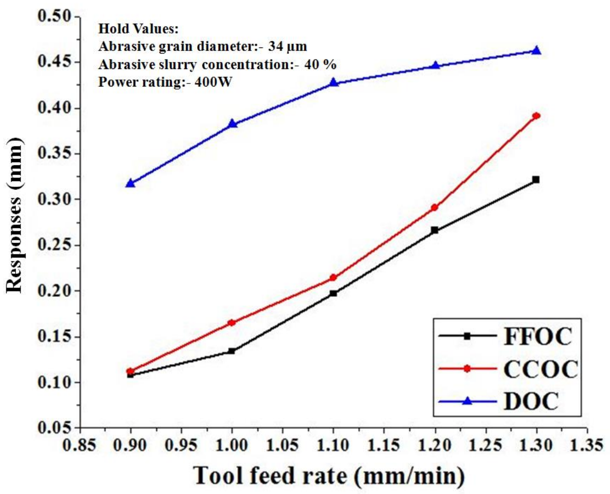


Fig. 6 Effect of tool feed rate on FFOC for square stepped hole generation

5. CONCLUSIONS

It is concluded that the ultrasonic machining (USM) process can be effectively utilized for fabricating square stepped hole with higher accuracy on bio-ceramics i.e. zirconia. In ultrasonic machining of bio-ceramics, abrasive grain diameter, power rating and tool feed rate are the influencing parameters for controlling flat to flat overcut (FFOC), corner to corner overcut (CCOC) and diametrical overcut (DOC) of square stepped hole on zirconia bio-ceramics. For achieving the better machining accuracy i.e. difference of flat to flat distance (FFD) of square hole, flat to flat overcut (FFOC), corner to corner overcut (CCOC) and diametrical overcut (DOC) of square stepped hole, the lower abrasive grain diameter, abrasive slurry concentration, power rating and tool feed rate is preferred.

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