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Parametric Study of Micro-hole Drilling in Glass using Ultrasonic Machining

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Abstract

Glasses have extensive applications in the fabrication of micro-components because of their exceptional mechanical properties. Micro-machining of glass to the required tolerance without any structural damage is a challenging task. Ultrasonic machining is a non-traditional machining process which can machine micro features in very hard and brittle materials without any heat generation. In this work, using ultrasonic machining, micro-hole drilling has been performed on a glass slide. Machinability study is carried out by analyzing the performance measures like material removal rate, tool wear rate, overcut, and circularity error, with respect to the controlled parameters such as feed rate, abrasive grit size and concentration of abrasives in the slurry. An increase in material removal rate, tool wear rate, and overcut has been observed with increase in grit size and slurry concentration; whereas the same decreases with the increase in feed rate. The circularity error has been found minimum at a higher feed rate, slurry concentration, and lower grit size. The holes drilled in glass by ultrasonic machining process have been found to be precise and accurate.

Keywords: Ultrasonic Machining, Feed Rate, Slurry Concentration, Grit Size, Material Removal Rate, Tool Wear Rate, Circularity Error.

1. INTRODUCTION

There is an increasing need for micro components and products in various industries such as electronics, optics, medicine, biotechnology, automotive, communications, and aeronautics. Various micro-manufacturing processes have been developed to produce components with features in the range of a few hundred micrometers. In USM the material is removed by the continuous hammering of abrasive particles having very high hardness. Therefore, a shaped tool material having lower hardness than work material can also be used, as there is no direct contact. When proper process conditions are chosen in USM, features with good dimensional accuracy and surface finish can be generated with high efficiency. Another important advantage of USM is that it does not significantly bring in residual stresses and surface damage to the machined surface since the material removal is not thermally induced. Ultrasonic machining (USM) is used for machining hard and brittle materials to complex shapes with good accuracy and reasonable surface finish.

The production accuracy for ultrasonically drilled holes is affected by the continuous wear of the abrasive particles in the slurry and by tool wear. The effects of certain important parameters such as static load, machining time, types of abrasives, and grit size were taken to conduct the experiments. It has been concluded that the machining accuracy depends to a large extent on the abrasive grit size and to a lesser extent on the amplitude of vibration and the static load. Finer abrasives resulted in reduced oversize and increased accuracy of the holes of machined workpiece [1]. Experiments have been conducted on different work materials –glass, porcelain, ferrite, alumina using various tools- titanium, and stainless steel. The surface roughness of different workpieces was analyzed with respect to the hardness of the tool material and abrasive used. The results showed that surface roughness decreases with the decrease in the grain size and harder tool material gives low surface roughness [2]. When performing drilling operation, USM can produce holes as small as 76 µm in diameter [3].

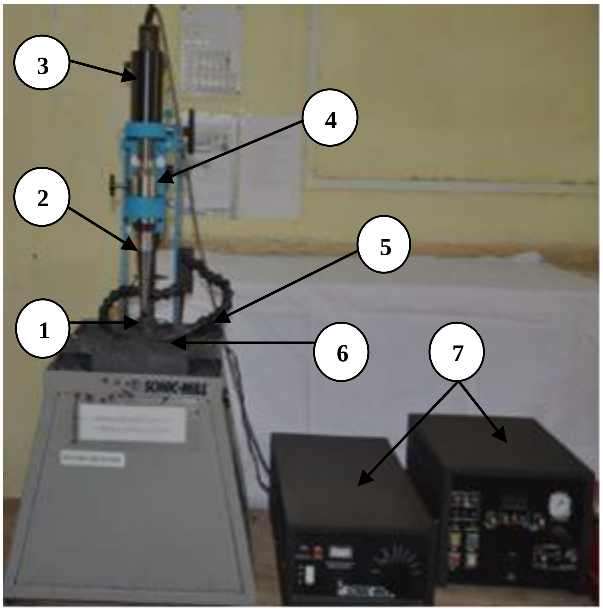

Fig.1. Ultrasonic Machining Setup: 1. Cutting tool, 2. Horn, 3. Transducer, 4. Acoustic head, 5. Abrasive Flow Pipe, 6. Magnetic plate, 7. Control unit

The best tolerance that can be obtained practically in ultrasonic drilling is of the order of ±25 µm; however, with special considerations given to slurry circulation and abrasive selection, tolerances of the order of ±10 µm can be achieved [4]. Holes can be easily drilled in the workpiece; however, the depth to diameter ratio is limited to 3:1 [5]. When optimum flushing techniques are used, hole-depth capabilities can be extended to 150 µm with an aspect ratio up to 40:1 [6-9]. However, effective machining rate is reduced for machining of workpiece thickness more than 12.7 mm, due to inefficient slurry flow through the cutting gap [10]. Penetration rates, ranging from 0.025–2.5mm/min can be obtained depending upon the shape

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being machined, input parameter settings and work material properties [11]. Surface finish is generally governed by abrasive particle size [12]. The better surface finish has been observed by using finer abrasive particle size [13]. Because USM is a non-thermal and non-electrical process, the work material properties remain unaltered [14].

2. METHODOLOGY

In this current work, a set of combinations of the process parameters are considered to observe the influence on the output responses. The thickness of the workpiece (Glass) is 1.33 mm and the tool is used is having the diameter 550 µm. In this case, feed rate (µm/s), grit size (Mesh no.) and slurry concentration (%) have been chosen as input variables, and the responses that have been evaluated are volumetric material removal rate (mm3/min), directional tool wear rate (µm/s), overcut (µm) and circularity error (µm). To conduct the experiments Taguchi L8 orthogonal array has been chosen. The experimental sequence has been followed as mentioned in Table 1. Every experiment has been conducted two times and the average output is calculated by the following procedure.

- Material removal rate has been calculated by considering the ratio of volumetric work material removal to the machining time.

- The tool wear rate (TWR) has been evaluated by directional reduction in tool length per unit time. This is calculated by measuring the difference in initial length and final length of the tool per unit machining time.

- The overcut is a measure of the difference between the radius of the drilled hole and radius of the tool.

- The circularity error is defined as the radial distance between the circumscribing circle and the inscribing circle which contains the profile of the irregular surface of the hole.

Microscopic images of the holes machined on glass have been taken using metallurgical optical microscope. The images for calculating the tool wear as well as the circularity of the hole have also been taken and analyzed using the optical microscope and its inbuilt measurement software. After analysis of the image, the output responses have been calculated. The variations of output responses against the controlled parameters feed rate, grit size of abrasive and the slurry concentration have been shown by graph plots (Fig. 2-3 and Fig. 5-6).

3. RESULTS AND DISCUSSIONS

The results in the form of average output responses, which have been observed after experimental analysis, are listed in Table 1. The Error bar graph has been shown in Figure 4. The maximum average error percentage is observed for material removal rate (11.69%), followed by circularity error (10.96%) and tool wear rate (10.56%), and the least for overcut (5.60%). With the increase in feed rate from 40 µm/s to 60 µm/s, the MRR increases from 0.0152mm3/min to 0.0161mm3/min because at higher fed rate tool progresses at higher speed, resulting in lower machining time (Fig. 2). But it decreases with the decrease in grit size (increase in grit number) because smaller abrasive particles creates to lower indentation volume leads to minimal material removal. The maximum material removal rate is observed to be 0.0187mm3/min at mesh number 220. MRR has also been found to increase with the increase in slurry concentration from 35% to 50% because of increase in the concentration of abrasives per unit volume of slurry. At 50% slurry concentration the material removal rate is 0.0224mm3/min.

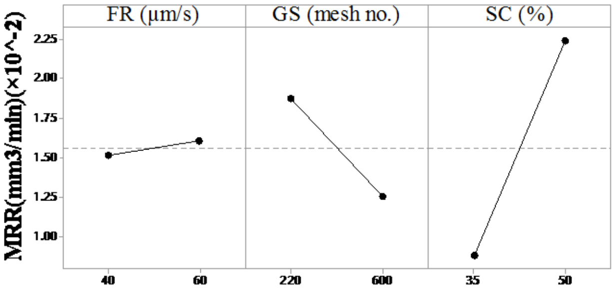

Fig.2. Variation of MRR

From Figure 3, it is clear that, as the feed rate increases the tool wear rate (TWR) is almost constant. With the decrease in grit size from 220 mesh to 600 mesh, tool wear rate decreases and it has been found to be maximum (0.3915µm/s) for 220 mesh. This is due to the finer abrasive particles indents at the tool surface and creates less indentation volume. But with the increase in slurry concentration the TWR increases, because the slurry carries more abrasive particles leads to more number of indentation. For 20% and 50% slurry concentration, the TWR is 0.264µm/s and 0.451µm/s respectively.

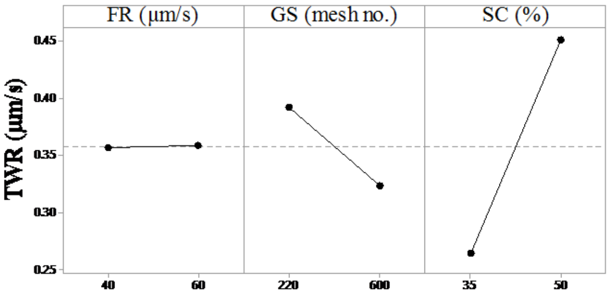

Fig.3. Variation of TWR

Figure 5 shows the variation of overcut for different controlled parameters. The overcut increases with the increase in feed rate because of the high rate of tool penetration promoting more chipping of the work material. The minimum overcut is observed to be 196µm for fed rate 40µm/s. With the decrease in grit size, the overcut has been found to decreasing from 209.1µm to 192.8µm because of lower particle size reduces the gap between the hole surface and the rod surface. It has also been found to increase from 163.4µm to 238.5µm with the increase in slurry concentration from 35% to 50%. This is due to higher abrasive particles removes more material from the workpiece.

The circularity error increases with the increase in fed rate from 4.1µm to 5µm as shown in Fig. 6. this is due to at lower feed rate the abrasive particles gets sufficient time to remove the burs. Whereas with the increase in mesh number the circularity error decreases because finer abrasive particles polishes the drilled hole surface. The minimum Circularity error is found to be 3.9µm for mesh number 600. With the increase in slurry concentration, the circularity error increases from 4.4µm to 4.8µm because a higher number of abrasive particles are indenting the work material.

Table 1: Experimental conditions and average output responses

Sl.No	F.R(μm/s)	G.S(mesh no.)	S.C(%)	MRR(mm3/min)(×10-2)	TWR(μm/s)	O.C(μm)	C.E(μm)
1	40	220	35	0.62	0.211	143.5	5.0
2	40	600	50	2.88	0.555	255.5	5.0
3	60	220	50	1.08	0.326	165.0	3.0
4	60	600	35	1.48	0.333	222.0	3.5
5	40	220	35	0.69	0.205	167.0	5.5
6	40	600	50	3.29	0.595	270.5	5.5
7	60	220	50	1.12	0.314	178.0	4.0
8	60	600	35	1.32	0.320	206.0	5.0

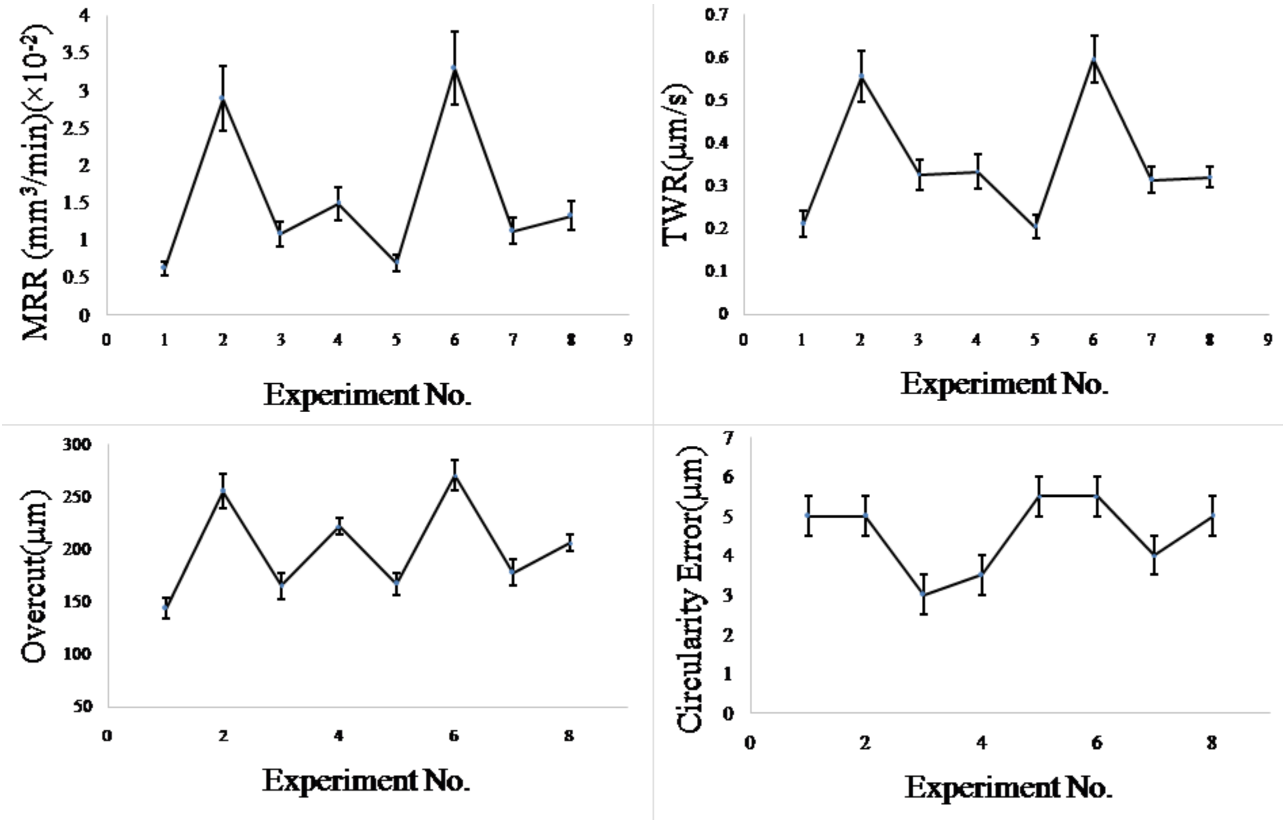

Fig.4. Error bar graph of performance measures for different experiment number.

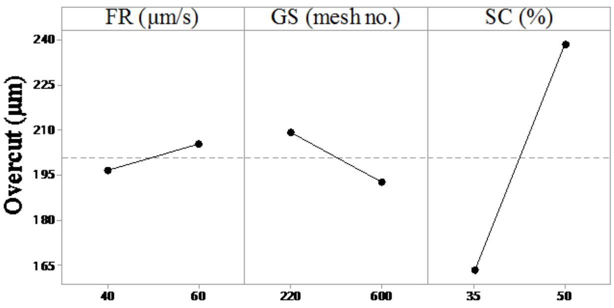

Fig.5- Variation of Overcut

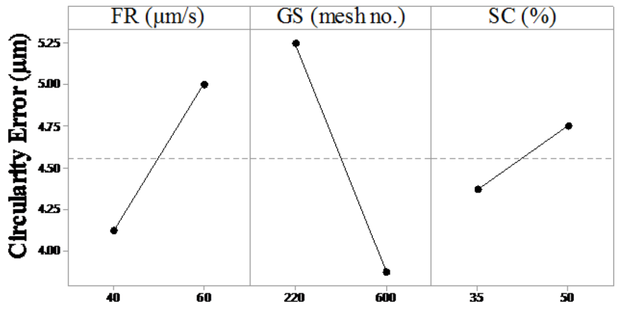

Fig.6- Variation of Circularity Error

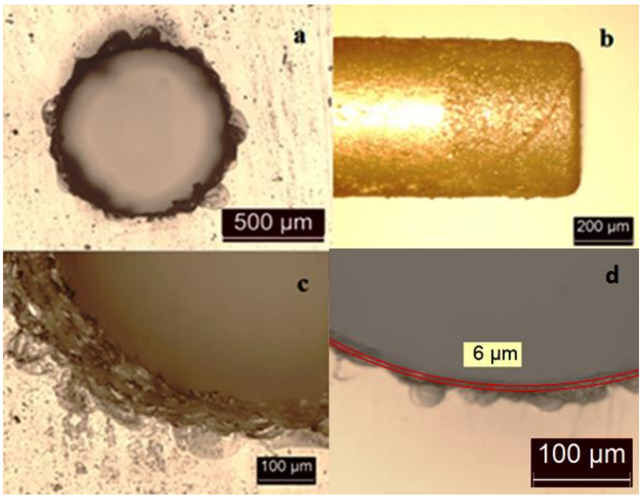

Fig.7- Microscopic image: a) typical micro hole drilled on the glass, b) the stainless steel tool after the experiment, c) angular view showing the inner wall surface of the drilled hole, d) circularity error of the produced curved surface.

7 CONCLUSIONS

Micro ultrasonic machining is found suitable for micromachining of glass. It has been observed that all the performance measures increases with the increase in feed rate and slurry concentration but decreases with the increase in mesh number (decrease in particle size). The average overcut and circularity error has been found to be 200.94 µm and 4.563 µm respectively during the machining process. The best parametric condition has been found with feed rate 60 µm/s, slurry concentration 50% and grit size 220 (60 µm) giving higher MRR, and minimal TWR, overcut and circularity error. This preliminary study has been done to exploit the various machining conditions with the aim of achieving high production rate with better accuracy.

Abbreviations

CE- Circularity Error	SC- Slurry Concentration
CUSM- Chemical USM	SR- Surface Roughness
FR- Feed Rate	SS- Stainless Steel
GS- Grit Size	TWR- Tool Wear Rate
MRR- Material Removal Rate	USD- Ultrasonic Drilling
OC- Overcut	USM- Ultrasonic Machining
RUSM-Rotary USM	

References

[1] M. Adithan, and V. C. Venkatesh, Production Accuracy of Holes In Ultrasonic Drilling, Wear, 1976, 40(3): 309–318.

[2] M. Komaraiah, M.A. Manan, P.N. Reddy, and S. Victor, Investigation of surface roughness and accuracy in ultrasonic machining, Precision Engineering, 1988, 10(2): 59-65.

[3] T.B Thoe, D.K Aspinwall, M.L.H Wise, The effect of operating parameters on ultrasonic contour machining. Proc. 12th Annual Conference of the Irish Manufacturing Committee, Cork, Ireland, Sep., 1995, 305–312.

[4] D.C Kennedy, R.J. Grieve, Ultrasonic machining—A review, The Production Engineer, 1975, 54(9): 481–486.

[5] S.R. Ghabrial, Trends towards improving the surfaces produced by modern processes, Wear, 1986, 109 (1–4): 113–118.

[6] S.R Ghabrial, S.M Saleh, A Kohail, A. Moison, Problems associated with electro-discharge machined, electro-chemically machined and ultrasonically machined surfaces, Wear, 1982, 83: 275–283.

[7] L. Koops, Investigation into the influence of the wear of abrasive powder on the technological indices of ultrasonic machining, Annals of the CIRP, 1964, 13(3): 151–157.

[8] M.S Koval Chenko, A.V. Paustovskii, V.A. Perevyazko, Influence of properties of abrasive materials on the effectiveness of ultrasonic machining of ceramics, Powder Metallurgy and Metal, Ceramics, 1986, 25: 560–562.

[9] D. Kremer, New developments in ultrasonic machining, SME Technical Paper, 1991, 91–522: 13.

[10] M.M Barash, D. Watanapongse, On the effect of ambient pressure on the rate of material removal in ultrasonic machining, InternationalJournalofMechanicalSciences,1970,12:775–779.

[11] A.I. Markov, Kinematics of the dimensional ultrasonic machining method, Machines and Tooling, 1959, 30(10): 28–31.

[12] H. Dam, P. Quist, M. Schreiber, Productivity, surface quality and tolerances in ultrasonic machining of ceramics, Journal of Materials Processing Technology, 1995, 51(1–4): 358–368.

[13] A. Bhattacharya, New Technology, The Institution of Engineers (I), Calcutta, 1973, 12–17.

[14] M.A Moreland, Ultrasonic Advantages revealed in the hole story, Creative Manufacturing Engineering Program, Society of Manufacturing Engineers, 1987, 1–7.