Full Factorial Experiments to Investigate Effect of Ultrasonic Machining Parameters on MRR in Blanking of Glass

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Abstract— Ultrasonic machining is employed frequently for machining of brittle materials like glass, ceramics etc. Production of blanks by machining glass is required for wide variety of optical and other applicaitons. In this work, a full factorial experiment is designed to study the effect of process parameters on ultrasonic blanking of glass. The control parameters chosen are amplitude, pressure and thickness of the glass sheet being machined. Three levels of each of these parameters are selected giving 33 = 27 trials. The material removal rate is measured as response parameter. A velocity transformer with tool integral to the lower end is designed with annular cutting edge to increase the efficiency in cutting. Silicon Carbide abrasive particles are used with water as the abrasive slurry. The material removal rate is found to increase with increase in amplitude and pressure but decreases with increase in thickness of the work piece. ANOVA is carried out for the experimental results.

Key words: Factorial Experiments, Investigate Effect, Ultrasonic Machining

I. Introduction

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 [1]. Ultrasonic machining offers a solution to the expanding need for machining brittle materials such as single crystals, glasses and polycrystalline ceramics, and for increasing complex operations to provide intricate shapes and workpiece profiles. This machining process is non-thermal, non-chemical, creates no change in the microstructure, chemical or physical properties of the workpiece and offers virtually stress-free machined surfaces. It is therefore used extensively in machining hard and brittle materials that are difficult to cut by other conventional methods [2]. Generation of holes in glass is required in variety of applications like optical microscopes, measurement optics etc. In order to produce these components, ultrasonic machining is a viable alternative. In this paper, the ultrasonic machining parameters affecting the machining response such as amplitude, pressure and thickness of work are varied for an experimental evaluation of their effect on machining performance parameters namely material removal rate (MRR) while blanking of glass.

II. Experimental Plan

A full factorial design of experiment with replication is implemented with three major control factors – amplitude, pressure and thickness of the glass sheet being cut. The values selected for the low, medium and high level for each of the control parameters is mentioned below in Table I. The amplitude is varied in terms of percentage of amplitude delivered at full power by the converter.

Amplitude (A)	Pressure (P)	Glass Sheet Thickness (T)
A1 = 70%	P1 = 0.5 bar	t1 =1 mm
A2 = 80%	P2 = 1 bar	t2 =1.2 mm
A3 = 90%	P3 = 1.5 bar	t3 = 1.4 mm

Table I: Parameters and Their Levels.

Ultrasonic sonotrode is designed and manufactured with integrated tool. The design of tool is carried out on the basis of the phenomenon of sound propagation in solids. The amplitude of propagated sound wave is inversely proportional to the cross-sectional area. The recommended amplitude for USM machining is in the range of 20 to 60 microns. An integrated sonotrode and tool design is selected. The shape of the tool is obtained at the end of the sonotrode itself. The amplitude of vibration produced by converter is 10 micron which is doubled by the silver booster. Hence an approximate gain of 3 is selected for the sonotrode. The design of the sonotrode is carried out using CARD (Computer Aided Resonator Design) software. The cutting edge of the blanking tool is so formed that a chamfer is generated on the outer side to allow the removal of abrasives removed material from the interface and permit a blank to be produced with least taper effect.

III. Experimental procedure

The detailed procedure followed for ultrasonic drilling is described as under:

1) Take the thickness of glass sheet as per parameter setting in DOE and measure weight.
2) Melt the mounting wax in beaker and pour it in petri-dish. Put one 8mm diameter aluminium washer in petri-dish to prevent end chipping.
3) Place the glass sheet having aluminium foil attached at its bottom, when the wax starts getting hard. Allow 15 min for curing.
4) Prepare slurry having 27% concentration of abrasives by volume in water
5) Securely tighten the sonotrode placing grease at mating face of booster and horn to prevent coupling losses.
6) Make buzzer circuit and join one end at horn and another with aluminum foil under glass sheet in petridish as shown in Fig. 1.

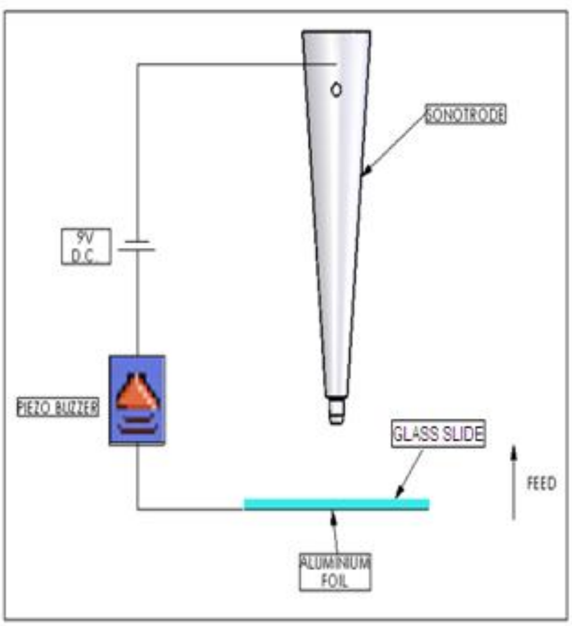

Fig. 1. Buzzer Circuit

7) Start slurry circulation and adjust the flow with flow control valve.
8) Set the amplitude of vibrations, pressure as per parameter for designed experiment.
9) Start sonotrode (horn) vibrations using foot switch.
10) Start machining holding petri-dish in hand in presence of abrasive slurry. Also record machining time using stopwatch.
11) Machining is completed when buzzer makes the sound.
12) Switch off slurry pump and remove the blank from inside of horn using compressed air.
13) Clean the blank by washing it in Acetone.
14) To remove workpiece from petri-dish, heat the petri-dish a little, and remove the glass slide. Remove aluminum foil contract under it. Wash and clean wax using.
15) Measure the weight of cut blank and slide.

The material removed on weight basis is obtained by subtracting the sum of mass of blank and mass of slug from the mass of glass sheet before machining. The MRR is then obtained in terms of volumetric material removal rate by taking density of glass as 2.5 gm/cc. The weight loss method of MRR calculation gives the actual material removed during cutting

IV. RESULTS & DISCUSSION

Analysis of variance for MRR obtained as a result of the experiments is carried out using MINITAB software. Results are represented in Table 2 for MRR. Fig. 2 shows the main effects of control variables on MRR and Fig. 3 shows the interaction effect of control variables on MRR

Factor	**DoF**	**Seq. Sum of Squares (Seq. SS)**	**Adj Sum of Squares (Adj. SS)**	**Mean Square Value MSV= Adj. SS/DF**	**F= MSV /MSVe**	**P**
T	2	0.037881	0.037881	0.01894	41.78	0
A	2	0.028997	0.028997	0.014499	31.98	0
P	2	0.011714	0.011714	0.005857	12.92	0
T*A	4	0.010354	0.010354	0.002589	5.71	0.002
T*P	4	0.003077	0.003077	0.000769	1.7	0.18
A*P	4	0.001279	0.001279	0.00032	0.71	0.595
T*A*P	8	0.001142	0.001142	0.000143	0.32	0.953
Error	27	0.01224	0.01224	0.000453		
Total	53	0.106683				

Table II: Anova for Mrr Using Adjusted Ss.

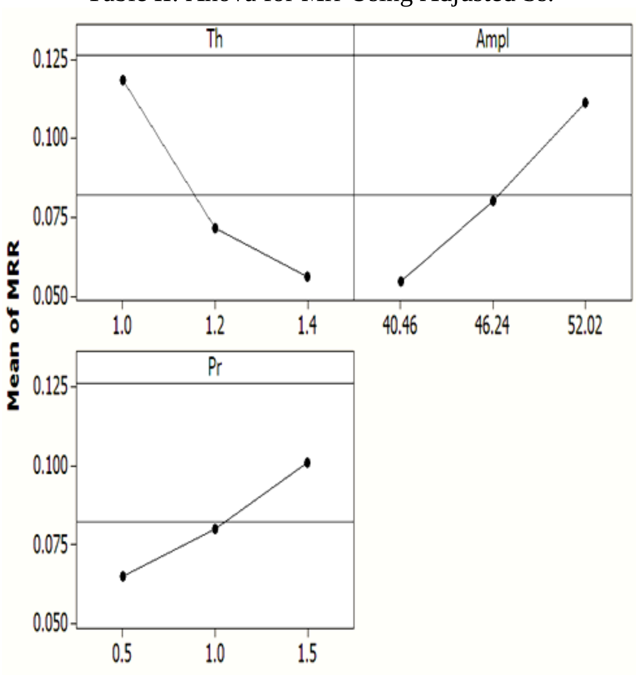

Fig. 2: Main Effect Plot: Data means for MRR.

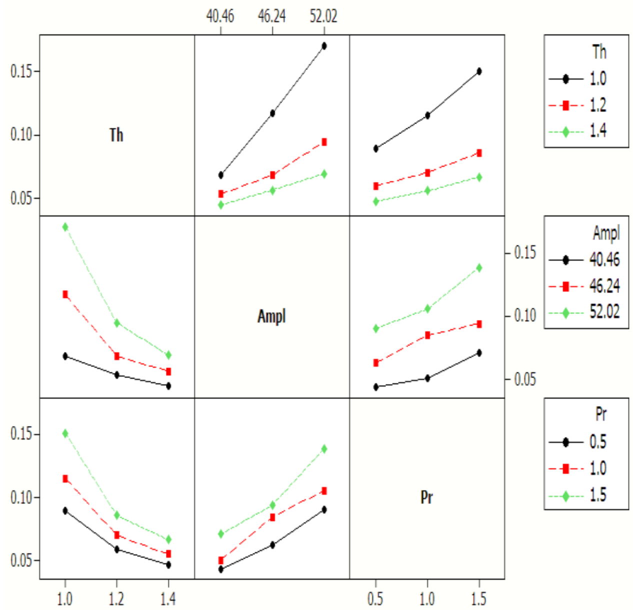

Fig. 3: Interaction Effect Plot: Data means for MRR.

From the results for ANOVA of Data Means for MRR listed in Table II and main effects plot shown in Fig. 2, it is observed that amplitude is the second most significantly affecting factor for MRR. Thickness is found to be the most significant factor in blanking. The interaction between thickness and amplitude is also found to be statistically significant based on the ANOVA Table II with corresponding p-value lesser than 0.05.

The MRR increases with increase in amplitude for all levels of thickness and pressure as seen in Fig. 3. The nature of increase is observed to be non-linear with an increasing rate in most of the cases. It is observed that the range and variation in MRR from lowest level to highest level of amplitude considerably reduces for the higher value of thickness. This indicates that the dominance of amplitude in increasing the MRR is higher at lower thickness values and reduces at the higher values of thickness. The increase in MRR with increase in amplitude can be attributed to the higher momentum imparted to the abrasive particles before striking the workpiece at higher amplitudes which increases the energy with which the abrasive particles collide with the work surface increasing the size of the micro-crack or micro-crater created by each impact. This in turn increases the MRR

From the results for ANOVA of Data Means for MRR listed in Table II and main effects plot shown in Fig. 2, it is seen that pressure shows least significant effect on the MRR of all the control variables selected for experimentation. The MRR shows a general tendency of increasing non-linearly with increase in pressure for all levels of amplitude as seen in Fig. 3 with increasing rate except for the medium level of amplitude at low thickness where the rate of increase flattens beyond the medium pressure level. Because of the lesser significance of pressure in terms of MRR, it is observed that the range and variation in MRR from lowest level of pressure to highest level of pressure is reducing considerably with thickness. The increase in pressure increases the force with which the abrasive particles hit the workpiece surface causing an increase in the impact generated at the work surface which causes greater size of cracks and faster propagation of these cracks. This leads to increase in the MRR with increase in pressure.

The thickness of the workpiece is found to be most significantly affecting the MRR out of all the control variables. From the results for ANOVA of Data Means for MRR listed in Table II and main effects plot shown in Fig. 2, the F-value and p-value show that thickness affects the MRR more significantly than pressure and amplitude with a nonlinear reduction in MRR at a decreasing rate as the work thickness increases. From Fig. 3, it is clearly seen that there is steep reduction in MRR for all levels of pressure and amplitude except for the low amplitude and low pressure combination for low and medium thickness values. This shows that the dominance of other factors, namely, amplitude and pressure is less in terms of their effect on the MRR. The interaction between thickness and amplitude is found statistically significant having p-value less than 0.05, which also indicates the true capturing of the phenomena in the ANOVA. With the increase in the thickness of the work, the energy to be applied to the abrasives to penetrate to the full depth would also increase which would in turn require larger amplitudes for maintaining machining rate and hence this interaction is important to sustained ultrasonic machining with increase in the thickness of the workpiece. With increase in thickness the friction between the abrasive particles and side surfaces of the work as well as the returning abrasive particles and debris increases substantially which leads to sharp decrease in MRR. Also, the increase in work thickness causes more lateral transfer of ultrasonic energy into the work and reduces effective cutting as the depth of machining increases.

V. CONCLUSION

The following major conclusions can be drawn from the efforts to study the effect of amplitude, pressure and thickness of glass sheet during ultrasonic drilling process.

1) The MRR increases non-linearly with increase in amplitude and pressure and decreases non-linearly with increase in thickness.
2) Statistically the significance of effect of these parameters is found to be in order of thickness, amplitude and lastly pressure. Interaction between thickness and amplitude and thickness and pressure is also found significant.
3) The ultrasonic blanking of glass requires careful design of sonotrode and tool.

REFERENCES

[1] Y. M. Chiang, D. Birnie III, W. D. Kingery, “Physical Ceramics”, The MIT Series in Materials Science and Engineering, Edited Journal, Wiley and Sons, Inc., New York, USA, pp 522, 1997
[2] P. L. Guzzo, A. H. Shinohara, and A. A. Raslan, “A Comparative Study on Ultrasonic Machining of Hard and Brittle Materials”, Presented at COBEF 2003 – II Brazilian Manufacturing Congress, Uberlândia, MG. Brazil, , pp 57-61, 18-21 May, 2003..
[3] R. K. Springbone, Non-Traditional Machining Processes, American Society of Tool and Manufacturing Engineers, Dearborn, Michigan, 1967.