I J M S E
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8(1) 2017 : January-June • pp. 7-11

STUDY THE EFFECT OF ABRASIVE (AL_2O_3 & SIC) IN ULTRASONIC MACHINING OF PLAIN GLASS

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Abstract: Ultrasonic machining (USM) is an efficient and economical means of precision machining of glass or ceramic materials. In USM, the material is removed by the repeated impact of the abrasive particles on the workpiece surface However, because of its complexity, the mechanism of the material removal process is still in infancy stage. In present study, the tool performance is evaluated by measuring uniformity of vibration amplitude of the working surface and the stress developed during loading condition. Desired amplitude on the tool was studied by von-misses stress model. Experimental results of mixed abrasive slurry (in 1:1 ratio)were compared with different abrasives. Significant improvement in material removal rate with better surface integrity was noticed with mixed abrasive slurry along with decreased machining load.

Keywords: Ultrasonic machining; von-misses stress model; Abrasive slurry; material removal rate

1. INRTODUCTION

Glass is one of the most difficult to cut functional material [1]. The conventional fabrication methods for glass materials include diamond turning, electrochemical machining, ultrasonic machining, wet/dry etching and laser ablation processing etc are used in industries [2]. Ultrasonic machining (USM) helps to remove material with the impact motion of ultrasonic-vibrated abrasive particles [3]. The material removal rate of ultrasonic machining is determined by the vibration amplitude, the machining load and the size of the abrasive particles. However, despite the added advantages, USM has proved to be low material removal process. In the present study, USM process was modeled by Von-Misses stress model displacement amplitude to ascertain effect of amplitude on tool. It is indicated that amplitude plays an important role in machining [4]. The ultrasonic machine tool was optimized based on the results of the dynamic analysis and experimental data. Mixed abrasive slurry is used in present study. To get mixed abrasive slurry effect, aluminum oxide and silicon carbide was mixed in 1:1 ratio by weight in the water carrying medium. Detailed experimentation was carried out to investigate machining mechanism.

2. PRINCIPLE OF USM TOOL MODELING

Tool is the key component of ultrasonic machining. The horn of USM is required to produce the sufficient amplitude vibration. In order to have the maximum amplitude of vibration (resonance), the length of the horn (concentrator) is made multiples of one-half the wavelengths of sound. The shape of the acoustic horn controls the final amplitude [5]. Amplitude transformation or gain is achieved by reducing the cross section along the length of the tool [6]. The performance of the tool and horn is usually assessed by the amplification factor or 'gain' that can be achieved at the tool end. The gain '$\breve{G}$' is defined by the ratio of output amplitude (A_2) to input amplitude (A_1)

$$\breve{G} = A_2/A_1$$

The basic requirement for a gain is, when the amplitude factor 'Ğ' > 1. For the cylindrical tool the gain in amplitude is '1' as it is of uniform cross section.

3. MECHANISM OF MIXED SLURRY ULTRASONIC MACHINING

In USM process, material is removed by micro chipping or erosion with the abrasive particles. The tip of the USM tool vibrates at low amplitude (2.5-55 μm) and high frequency (20 kHz–60 kHz), which transmits a high velocity to the fine abrasive grains between the tool and the surface of the workpiece. The chemical composition of the workpiece, the grit size of abrasive particles and the static load affect the characteristics of ultrasonic machining [7]. During ultrasonic machining, the indentation of a material surface by the abrasive will cause local deformation and initiate cracks. Figure 1show the initiation and propagation of medium and lateral cracks, which contributes to the material removal process [8]. However, in mixed abrasive slurry, the different abrasive particles gives the different strength values; e.g Silicon Carbide gives more strength as compare to Aluminum Oxide [9]. Both abrasives give individual impact energy in the lateral direction to workpiece [10], [11]. The propagation of impact energy in the lateral direction is limited because the linking forces between the molecules are weakened [12]. Alternatively, in the median direction, the transmitted energy increases and as a result deep median cracks are developed [13]. Therefore, the crater size of a single impulse abrasive is reduced along with increased material removal rate [14].

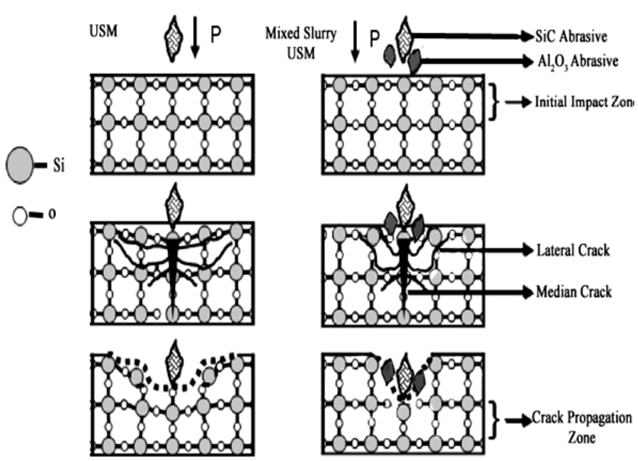


Figure 1: Mechanism of USM and Mixed Slurry USM

4. FINITE ELEMENT ANALYSIS OF THE USM TOOL

The equation of motion for USM tool is given by following equation:

$$M\ddot{x} + C\dot{x} + Kx = 0 \quad (1)$$

Where M, C and K represent mass, damping and stiffness matrix respectively and $\ddot{x}$, $\dot{x}$ and x represent the acceleration, velocity and displacement of the vibrating body. Neglecting the damping of the tool in air, the equation of motion can be written as;

$$M\ddot{x} + Kx = 0 \quad (2)$$

The model properties of the ultrasonic machine tool are determined by the solution of Eigen value problem given by following equation:

$$K - \omega_i^2 M\phi_i = 0 \quad (3)$$

Where ϕ_i = i^{th} eigenvector (mode shape) and ω_i^2 = natural frequency of the i^{th} mode shape.

Solving the Eigen value problem for the tool profile, gives the natural frequency and the Eigen vector gives the model shape. The length of the tool is decided by the material being used to fabricate the tool. Ideally, tools are made of materials that are strong and have good acoustical properties [8]. In the present study, High carbon high chromium 'D2' alloy steel (Table 1) is used for the fabrication of the tool. The machining frequency (f) and wavelength (λ/2) were selected as 30khz and 140mm based on literature review

Table 1
Material Properties of Alloy Steel (High Carbon High Chromium D2 Steel)

Alloy Steel (High carbon, High Chromium steel D2)	
Density	7.8gm/cm^3
Hardness (Vicker's) HRB	168
Ultimate Tensile Strength	765 MPa
Yield Strength	529 MPa
Young's Modulus	84.2 GPa
Poisson Ratio	0.321
Specific Heat Capacity	0.359 Kj/Kg°C
Thermal Conductivity	4.5 W/mK

5. 3D TOOL MODEL

A 3D tool model (owing to displacement in the actual ultrasonic machining) with a suitable element is shown in Fig. 2. The tool was meshed using 6589 tetrahedral. Model extraction is carried out in the frequency range of 20kHz-30 kHz. Mode shape is extracted in the given frequency range with pre-stress result turned on. The natural frequency of the longitudinal mode obtained in the modal analysis is 28- 504 Hz.

6. EXPERIMENTATION

In the present study, a commercial ultrasonic machine (20-30 kHz and 1500 W) manufactured by Sonic Mill, USA (shown in Fig. 3) has been used. The Table 2 shows the machining parameters for experimentation.

Table 2
Machining Parameters For Experimentation

Factor	*Levels*		
	Level 1	*Level 2*	*Level 3*
Concentration	20	30	–
Abrasive	Al_2O_3	SiC	(Al_2O_3 + SiC) in ration 1:1
Power Rate	20	40	60
Grit Size	280	400	600

In order to conduct the experiments, Taguchi L18 mixed orthogonal array was used. MINITAB software was used to analyze result. The surface roughness was measured by perthometer (model SJ400 manufactured by Mitutoyo Company Japan) and the Rockwell hardness was measured by Rockwell hardness tester.

Fig. 4 shows the comparison of machining load between the USM and the mixed slurry USM. Fig. 4(a) shows that in the normal USM, the machining load over 0.1gf (threshold value) frequency occurs during the process. When load exceeds the threshold value, the machining process is stopped for some time, but in case of mixed USM, the machining load goes beyond the threshold value. When the tool penetrates the smooth and hard surface of the glass, the machining load decreases gradually and there is an increase in material removal rate. Under the given machining conditions and same process parameters, the process becomes more stable and faster. Fig. 5 shows the graphical representation

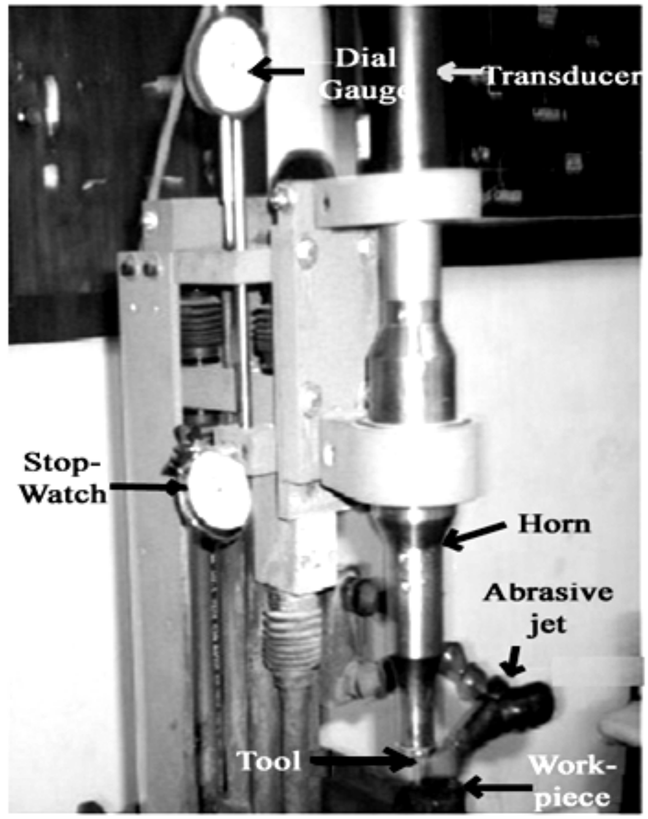
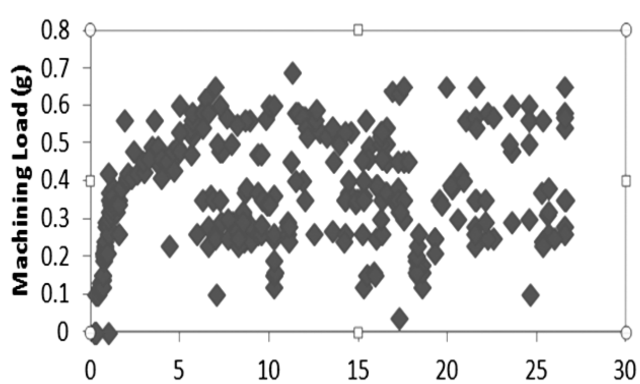


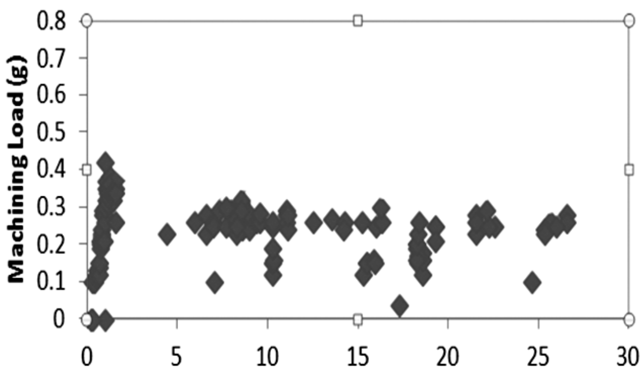
Figure 2: Ultrasonic Machine (Sonic Mill, USA)

of the measured depths with respect to machining. When the mixed slurry is used, the machining rate is enhanced by 26-34%, in comparison to silicon carbide and aluminum oxide.

Experimental results indicate that Al_2O_3 gives poor micro hardness, while mixed slurry reveals better hardness. Optical image (Fig. 6) of the holes machined with different abrasives reveals smoother profile is obtained with mixed abrasives USM, However, the diameter enlargement occurs in the Al_2O_3, SiC and Al_2O_3 + SiC slurry USM because of the secondary abrasive circulation.



[a] Non mixed abrasive Ultrasonic Machining



(b) Mixed abrasive Slurry Ultrasonic Machining

Figure 3: Comparison of machining load by (a) non mixed abrasive USM and (b) Mixed slurry USM

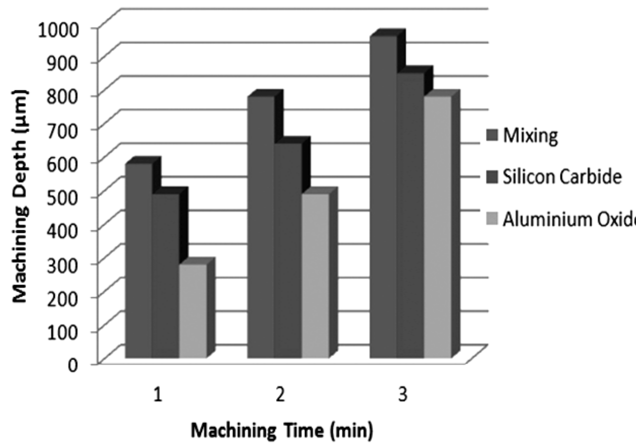
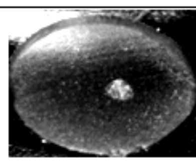
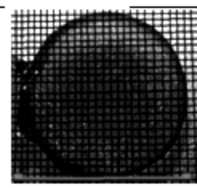
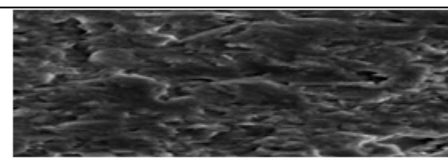
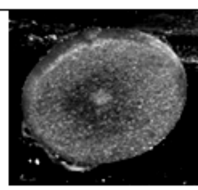
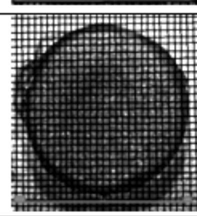
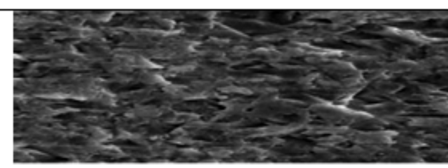
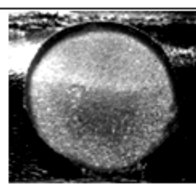
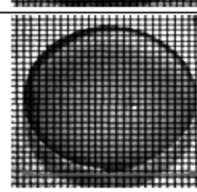
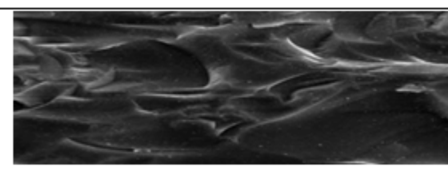


Figure 4: Machining depths with respect to machining time.

Fig. 6 shows that holes machines with mixed abrasive slurry also propagate fewer cracks, which is also evident from SEM images of the machined holes.

Slurry Type	Machining Image	Optical Image	SEM Image
Al_2O_3 Slurry			
SiC Slurry			
Mixing (Al_2O_3 + SiC) Slurry			

7. CONCLUSION

USM has been found to be a promising machining technique for obtaining desired dimensional accuracy and intricacy from hard and tough glass materials. Abrasive Powder mixing into the slurry of USM is one of the innovative developments that ensure better machining rates at desired surface quality. Within the range of parameters selected for the present work the following conclusions are drawn:

1. The use of mixed slurry reduced the tool wear rate of alloy steel (D2 steel) tool.
2. Mixed slurry USM give the better micro hardness as compare to SiC and Al_2O_3, i.e. 79.52 HRB, 72.51 HRB and 68.59 HRB respectively.
3. Mixed slurry USM provides the maximum material removal rate.
4. Minimum cracks are generated by the machining of Mixed Slurry USM as compared to the other.

REFERENCES

[1] H. Hocheng& C.C Hsu, "Preliminary study of ultrasonic drilling of fiber reinforce plastic", Journal of Material Processing Technology, Vol. 48, 1995, pp. 255–266

[2] Q.H Zhang, J.H Zhang, Z.X Jia & J.L Sun, "Material-removal-rate analysis in the ultrasonic machining of engineering ceramics", Journal of Material Processing Technology, Vol. 88, 1999, pp. 180–184.

[3] A.B.E. Khairy, "Assessment of some dynamic parameters for the ultrasonic machining process", Wear, Vol. 137, 1990, pp. 187–198.

[4] D.A Wang, W.Y Chuang, K. Hsu & H.T Pham, "Design of a Bezier-profile horn for high displacement amplification", Ultrasonics, Vol. 51, 2011, pp. 148–156.

[5] T.C Lee & C.W Chan, "Mechanism of the ultrasonic machining of ceramic composites", Journal of Material Processing Technology, Vol. 71, 1997, pp. 195–201.

[6] J.P Choi, B.H Jeon & B.H Kim, "Chemical assisted ultrasonic machining of glass", Journal of Material Processing Technology, 2007, Vol. 191, pp. 153-156

[7] T.B Thoe, D.K Aspinwall & M.L.H Wise, "Review on ultrasonic machining", International Journal of Machine Tools Manufacturing, Vol. 38, 1998, pp. 239–255.

[8] P.C Pandey & H.S Shan, "Modern Machining Processes", Tata McGraw-Hill Publishing Company, New Delhi. 1980, pp. 79–80.

[9] R. Singh& J.S Khamba, "Taguchi technique for modeling material removal rate in ultrasonic machining of titanium" Material Science and Engineering, Vol. 21, 2007, pp.365–369.

[10] R. Singh & J.S Khamba, "Comparison of slurry effect on machining characteristics of titanium in ultrasonic drilling", Journal of Material Processing Technology, Vol. 32, 2008, pp. 200–205.

[11] J.A Mc-Geough, "Advanced methods of machining", 1st Edition, Chapman and Hall, London.1988.

[12] C. Nath, G.C. Lim and H.Y Zheng, "Influence of the material removal mechanisms on hole integrity in ultrasonic machining of structural ceramics", Ultrasonics, Vol. 29, 2012 pp. 605–613.

[13] H. Hocheng & K.L Kuo, "Fundamental study of ultrasonic polishing of mold steel", International Journal Machine Tools Manufacturing, Vol. 2, 2012, pp. 7–13.

[14] H.E.L. Hofy, "Advanced machining processes. Non-traditional and Hybrid machining processes", 2nd Edition, McGraw-Hill, Egypt. 2010, pp. 5–6.