Micro drilling of glass by ECDM

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Key words : Electrochemical discharge machining, Glass microdrilling, Spark generation

1. Introduction

Drilling micro holes is a regular process in micro machining. EDM and ECM[1] offer very good results. But their drawback is only applicable to conductive materials.

Recently many non-conventional methods have been studied to machine nonconductive materials. Ultrasonic machining (USM) offers to obtain micro holes but its disadvantages are tool wears and micro cracks of workpieces. Laser beam machining (LBM) can make very high aspect ratio holes but the surfaces of holes are rough due to heat effect.

Electrochemical discharge machining (ECDM) was first reported by Kurafuji and Suda[2] for drilling a micro hole on glass. It is an alternative method which overcomes drawbacks of USM and LBM. ECDM allows to machine different kinds of structures with a small surface roughness. The experimental system is rather simple. Tool wear in ECDM is negligible. And ECDM can be applied in mass production.

In this paper, machining conditions of sub 100 μm diameter hole drilling on soda lime glass by ECDM are studied. The effect of electrolyte concentration, voltage, pulse on-time and pulse off-time is investigated.

2. Fundamentals and mechanism of ECDM

ECDM is based on electrolysis. A ECDM cell consists of a platinum electrode as the anode and a tungsten carbide electrode as the cathode (machining tool). The surface area of the cathode is much smaller in size than that of the anode. As a voltage is applied between two electrodes immersed in the electrolyte (KOH, NaOH), electrolysis reactions occur at both electrodes.

At the anode:

$$4OH^- \rightarrow 2H_2O + O_2 \uparrow + 4e^-$$

At the cathode:

$$2H_2O + 2e^- \rightarrow 2OH^- + H_2 \uparrow$$

The higher voltage is, the more hydrogen bubbles are created. When the voltage approaches the critical voltage, the tool is completely covered by hydrogen bubbles. And sparks are generated in the gap of the cathode and the electrolyte due to the breakdown of the insulating layer of hydrogen bubbles. Workpieces are machined by thermal energy of sparks.

3. Experimental system

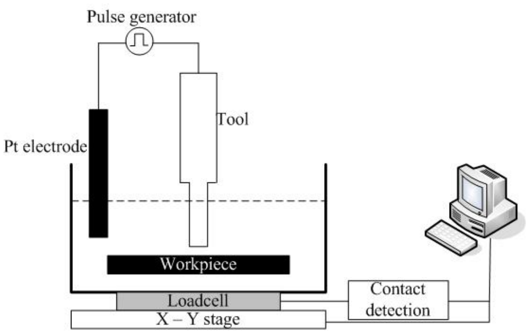


Fig. 1 Schematic of ECDM experimental system

The experimental system is shown in fig. 1. It consists of an electrochemical cell (tool as the cathode, platinum electrode as the anode and KOH solution as the electrolyte), a pulse generator, X-Y-Z stages, and a loadcell to detect mechanical contacts of the tool and the workpiece. The workpiece is 15 mm x 15 mm soda lime with 150 μm thickness. The tool material is tungsten carbide. The tool is machined by WEDG[3]. Platinum is used as the anode because of its stability in the oxidation environment. The rotation speed of the tool is 300 rpm.

4. Machining characteristics

4.1 The effect of concentration

The concentration of the electrolyte influences the machining quality. Experiments in this part were carried out to examine the effect of the KOH solution concentration. The voltage pulse (pulse on-time 1 ms and pulse off-time 2 ms) and the 33 μm diameter tool are used. The diameters of hole entrances, hole exits and the machining time are shown in fig. 2 and fig. 3.

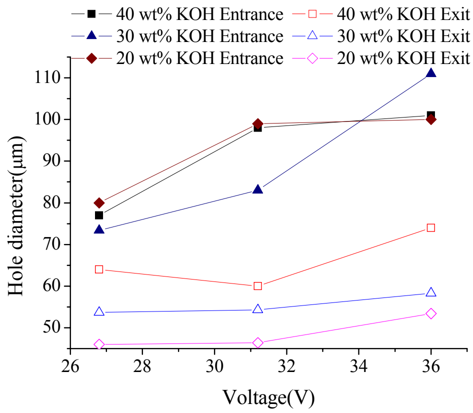


Fig. 2 Diameters of hole entrances and hole exits

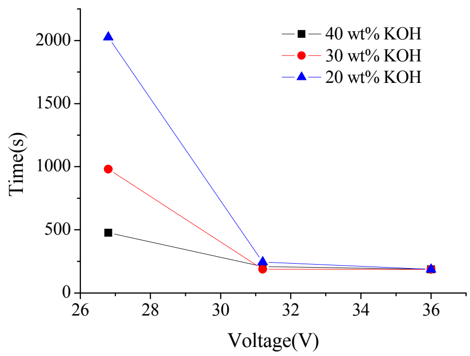
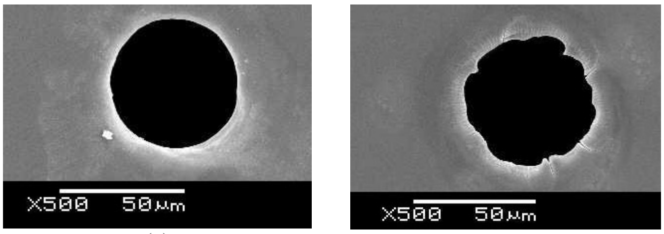


Fig. 3 Machining time according to concentration

The machining rate and machining gap increase as the voltage increases. When the voltage is smaller than 26.8 V, around a depth of 100 μm the tool cannot penetrate into the workpieces any more because the spark energy is too small. The through holes cannot be machined. The machining gap at a concentration of 30 wt% and a voltage of 26.8 V is the smallest one. And the machining time at this condition is also acceptable. These values of voltage and concentration are the optimal conditions for micro drilling by

ECDM.

As voltage increases, not only machining gaps but also micro cracks increase at hole exits. Fig. 4 shows hole entrances and hole exits drilled in the 30 wt% KOH. At a voltage of 26.8 V, thermal cracks cannot be seen in the entrance and exit. But at a voltage of 31.2 V the thermal cracks are very clear at the hole exits.



(a) (b)

Fig. 4 (a) hole exit at 26.8 V; (b) hole exit at 31.2 V

4.2 The effect of electrolyte

Preferable electrolytes are the KOH solution and the NaOH solution. Fig. 3 shows holes drilled in the KOH solution and the NaOH solution respectively with a voltage of 30 V, the tool diameter 20 µm.

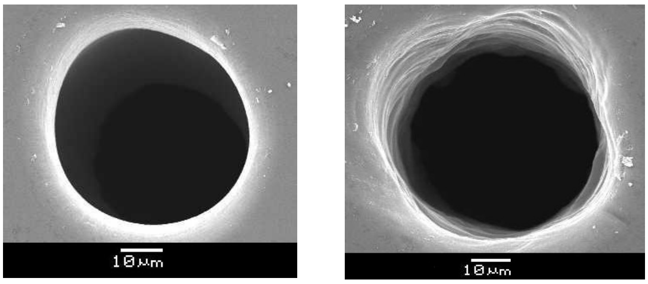


Fig. 5 Micro holes drilled in the KOH solution (left) and NaOH solution (right)

In ECDM, sparks occur in the hydrogen layer. The thinner this layer is, the smaller machining gaps are. The thickness of the hydrogen layer is dependent on the wettability[4]. Increasing the wettability makes the hydrogen bubbles to be flatter; the layer thickness is reduced. At the same concentration, the wettability of the KOH solution is higher than that of the NaOH solution. Therefore, the quality of holes drilled by the KOH solution is better.

4.3 The effect of pulse off-time

In ECDM, materials are removed by thermal energy. The heat affected zone (HAZ) always exists. It creates raw surfaces and thermal cracks. As DC voltage applied in ECDM drilling, HAZ cannot be reduced because sparks occur continuously. If a voltage pulse is applied, the sparks are only available during pulse on-time. Therefore, HAZ is small and good surface holes are obtained. The millisecond range is the optimal frequency for ECDM.[5] In this part, the duty ratio of the voltage pulse is investigated. Experiments were carried out at a constant value of the pulse on-time of 1 ms. Fig. 6 shows the variance of the hole diameter and machining time according to the values of pulse off-time.

When DC voltage is applied, the machining time is small but the machining gap is very large. The pulse off-time of 1 ms offers a small machining gap and an acceptable machining time. If the pulse-off time is over 4 ms, through holes are not obtained because the thermal energy is not enough to remove workpiece materials when the tool penetrates deeply in the workpiece.

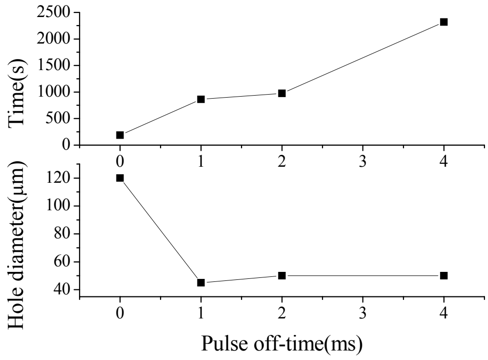


Fig. 6 Machining time and hole diameter according to pulse off-time

5. Application

Micro holes on glass materials are very basic parts in MEMS. Fig. 7 shows a typical application, micro hole array machined on

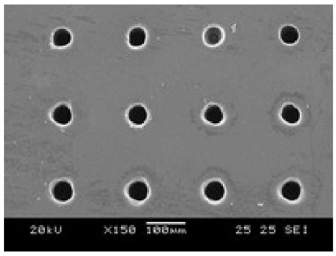


Fig. 7 Micro hole array on Soda lime glass

Soda lime glass with 150 µm thickness. Hole diameters are 70 µm. This method can be also applied in machining holes in micro channels or in printed circuit boards.

6. Conclusion

In this paper, the micro drilling of glass by ECDM was studied. The influences of the voltage, the concentration, the electrolyte, and the pulse-off time were investigated. 30 wt% KOH solution, 26.8 V voltage pulse, 1 ms pulse time-on and 1 ms pulse-off time are the optimal machining conditions. Using these machining conditions, sub-100 µm diameter holes in 150 µm thick glass can be obtained easily by a simple machining system.

References

1. S.H. Ahn, S.H. Ryu, D.K. Choi, C.N. Chu, "Electro-chemical micro drilling using ultra short pulses," Precision Engineering, **28**, 129–134, 2004.
2. H. Kurafuji, K. Suda, Electrical discharge drilling of glass, CIRP Ann., **16**, 415-419, 1965.
3. T. Masuzawa, M. Fujino, and K. Kobayashi, "Wire Electro-Discharge Grinding for Micro-Machining," *CIRP Ann.*, **34(1)**, 431–434, 1985.
4. R. Wuthrich et al, "Physical principles and miniaturization of spark assisted chemical engraving(SACE)," Journal of Micromechanics and MicroEngineering, **15**, 268-275, 2005
5. D.J. Kim, Y.M. Ahn, S.H. Lee, Y.K. Kim, "Voltage pulse frequency and duty ratio effects in an electrochemical discharge microdrilling process of Pyrex glass," International Journal of Machine Tools & Manufacture, **46**, 1064-1067, 2006.