Improving the material removal rate during SACE glass micro-drilling

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Abstract

Spark assisted chemical engraving (SACE) is a non-traditional micro-machining technology for machining non-conductive materials, specifically glass [1]. It is based on electrical discharge generation which results in high temperature glass etching. The chemical attack forms a complex which is believed to block the machining progress especially at high depths where flushing the hole is more difficult. In this work, two methods, mechanical and chemical, are investigated to prevent this material from accumulating in the machining zone.

1 Introduction

During machining a gas film is repeatedly formed around the tool-electrode. High energy discharges are generated through this film causing accelerated glass etching, where it is known that the machining zone temperature reaches 500-600ºC [2-5]. The attack of the glass by the OH radicals, provided by the electrolytic solution, leads to the formation of sodium silicate (Na_2SiO_3) based on the following reaction:

$$SiO_2 + 2NaOH \rightarrow Na_2SiO_3 + H_2O$$

It is believed that this product causes a decrease in the material removal rate due to its solidification where it accumulates below the tool-electrode. In this paper, experiments to remove the Na_2SiO_3 from the machining zone through two methods: mechanical and chemical are reported. To remove the sodium silicate from the hole mechanically, tool rotation is added. In order to make the evacuation process more efficient, a helical micro-drill bit is used. The drill bit is rotated in both directions, clockwise (CW) and counter-clockwise (CCW). The CCW rotation brings material into the hole whereas the CW rotation removes material from the hole.

The possibility of enhancing the mechanical drilling procedure chemically is investigated by using ammoniacal solution with different ammonia concentrations.

Ammonia is well known for its ability to form water soluble compounds or complexes with metalloids such as silicone and its compounds (silicates) [6,7]. Hence, it is expected that the silicate compounds produced during etching will be dissolved in the solution due to their reaction with ammonia.

2 Experimental

The machine is composed of a machine head (incorporating a spindle and a force sensor) and a processing cell. The glass work-piece is fixed inside a processing cell (filled with electrolyte) while the machine head incorporates the tool-electrode. To allow alignment of the tool and the work-piece the system is mounted on an XYZ stage.

Drilling is done using the constant velocity-feed mode, where the tool is moved towards the glass work-piece at a constant feed-rate. The machining voltage is 30V and the tool rotational speed is 1000rpm. The tool diameters are 500µm for the cylindrical tool and 570µm for the helical micro drill bit (PCB drill number 74). The electrolyte solutions used are a 30wt%NaOH and a 30wt% NaOH-ammonium hydroxide (100:5 in volume) solution.

The holes' surface textures are examined using an optical microscope () and then compared to those obtained by drilling under standard conditions.

The efficiency of both strategies towards micro-drilling enhancement is based on examining the depth at which forces start to appear. This depth will be referred to as the "initial depth".

3 Results and Discussion

Results show that the initial depth is shifted from around 100µm to 500µm when machining with a rotating helical drill bit instead of a stationary cylindrical tool. Depending on the drill bit rotational direction, different initial depths result. For low tool feed-rates (below 10µm/s) this effect could hardly be seen where for CCW rotation initial depth was around 570µm as compared to 540µm in case of CW rotation. As the tool feed-rate is increased (30µm/s), a more pronounced difference in the initial depth, based on the direction of rotation, occurs (120 and 75mu for CCW and CW respectively).

This is explained by the fact that for low tool feed-rates drilling is already efficient due to the more time allowed for hole flushing and heating. As a result, the tool rotational direction does not greatly influence the machining efficiency for low tool feed-rates. However, for high feed-rates, CCW rotation improves the drilling performance due to the forced electrolyte flow into the hole which evacuates the formed complexes. Since CW rotation results in removing the material from the hole, the material being the formed complexes as well as the molten electrolyte, the initial forces appear earlier compared to CCW rotation. However, no difference could be observed in the surface texture based on the rotation direction.

The addition of ammonia to the electrolyte proved to enhance the machining performance in case a cylindrical rotating tool is used. The initial depth is increased by 40mu for a tool feed of 5mu/s. Figure1 shows the surface texture obtained for both cases: pure 30wt%NaOH (a) and with ammonium hydroxide (100:5 in volume) added (b).

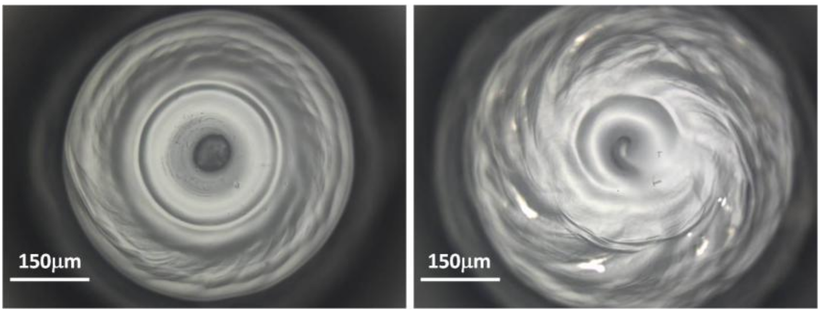

Figure 1: The different surface texture of the bottom of the hole resulting from machining with different electrolytic solutions: a) 30wt%NaOH and b) 30wt%NaOH with ammonium hydroxide (5:100 in volume). Both holes are machined using a 500µm diameter cylindrical tool, 30V, 5µm/s tool feed-rate and 1000rpm rotational speed.

The addition of ammonia clearly changed the hole surface texture. Further investigation is required to identify the resulting mechanisms due to addition of ammonia to the electrolyte, and the consequential effects on the machining process itself.

4 Conclusion

In this work it is demonstrated that the tool rotational direction affects the machining efficiency. In case electrolyte is forced to enter the micro-hole, forces appear later than in the case where the electrolyte is pulled out of the hole. Further, the addition of ammonia to the electrolyte proved to delay the force appearance and to influence the surface texture by probably dissolving the complex formed during machining. These results indicate that it is already difficult to evacuate this complex from the machining zone under standard operating conditions (NaOH electrolyte). Further investigation is required in this domain.

The results of this work will open a new way to enhance the material removal rate by finding adequate chemical compound to dissolve the complex formed during machining.

Acknowledgement

The authors would like to thank FQRNT and Posalux SA for funding this research.

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