Analysis of surface and subsurface damage of micro-ground Bk7 glass using on machine fabricated PCD micro-tool

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Abstract

This paper presents the research results of the morphology of subsurface damage (SSD) in BK7 glass ground with on- machine fabricated PCD micro tool. Grinding generated damages during this process are assessed and characterized using bonding interface sectioning technique combined with field emission scanning electron microscopy (FESEM). Both the damage depth and surface roughness are found to be influenced by the depth of cut, and spindle speed. In addition to this, two major type of grinding damage have been identified likely chipping damage and micro-cracking damage. Lateral, median and cone cracks are found to be existed in the sub-surface. As long as the cutting points are unloaded and residue can escape; the material is removed in a combined brittle and ductile mode. When the cutting surface is loaded with residue, the tool work piece interface temperature becomes so high that the material is removed by plastic flow. Hence the surface is polished with fine debris. Unfortunately, as this surface cools down, thermal quenching produces a network of crack. Although the machined surface seems to be show ductile mode of cutting behaviour even at higher material removal, analysis of subsurface damage shows that the material removal is a combined effect of grain dislodgement, micro-cracking and plastic deformation. These results provide valuable insight into the grinding damage induced due to the properties of glass as well as process parameters.

1 Introduction

As the quality of advanced glass and ceramics has dramatically improved with the modern manufacturing techniques, the bulk defects are significantly reduced in terms of their size and numbers. Hence, the primary source to introduce damage into glass and ceramics materials is grinding or other machining process. Due to low fracture toughness compared to metal and alloys, glass and ceramics are very sensitive to cracking and other damage. Hence, ground work pieces are always left with such damage as cracks, pulverization layers, and a limited amount of plastic deformation which resulted from hard and brittle nature of work pieces [1-6]. Grinding also induces surface residual stresses that may affect the strength and fatigue life. The residual surface and subsurface damage may seriously alter the surface properties and cause strength degradation or even a catastrophic failure of the glass and ceramics components. Literature shows that damage induced by conventional grinding has been assessed and characterizes using large grinding wheel in case of ceramics material (silicon nitride, alumina, and silicon carbide) mostly, for glass material using on machine fabricated micro-grinding PCD tool, the room is still left for further research. Hence, in the following study, subsurface damage is investigated on Bk7 glass. This paper presents important observation and measurement results of subsurface damage of the BK7 glass ground with micro-PCD tool which was prepared using micro block-electro discharge machining.

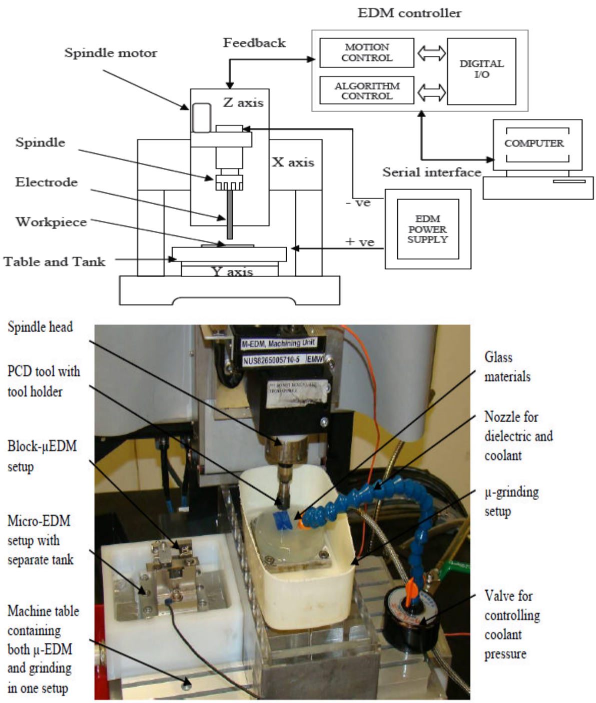
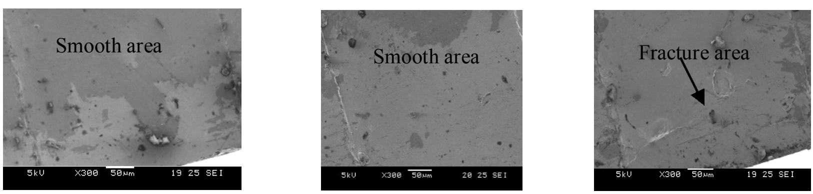
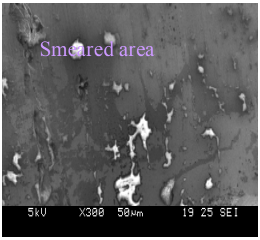


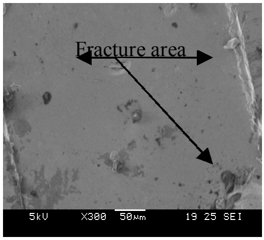
Fig.1: Schematic diagram and real picture of the setup with multi-purpose miniature machine tool.



(a)Depth of cut=2µm (b) Depth of cut=5 µm (c) Depth of cut =10µm



(d) Depth of cut =15



(e) Depth of cut =20µm

Fig. 2: Ground surface characteristics of BK7 glass for varying depth of cut.

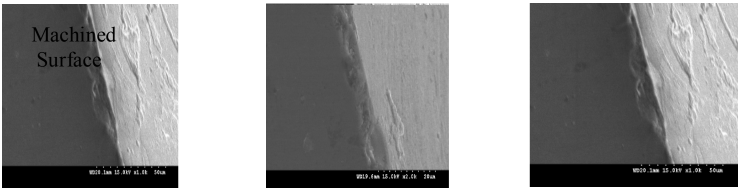
2. Experimental Details

A multi-purpose miniature machine tool, developed for high-precision micro-machining at National University of Singapore (NUS), is used for conducting both the block-µEDM and micro grinding experiments shown in Fig.1. Commercially available PCD tool containing 0.5 micron grain size was shaped by micro-EDM using capacitance of 100pF and voltage of 100V. Micro-grinding was carried out on 2 mm length. The spindle speed of 2000 and 2500 rpm were used. The feed rate was taken as 25µm/min while performing the effect of depth of cut. A bonded interface sectioning technique was used to examine the grinding induced sub-surface damage. The specimens were separated after grinding by melting the glue and were cleaned with acetone in an ultrasonic bath. Then the specimens are etched with 1% weight HF solution in distilled water for 30 seconds in order to remove any damage created during parting the surfaces[7]. The polished surfaces were gold coated for FESEM examination.

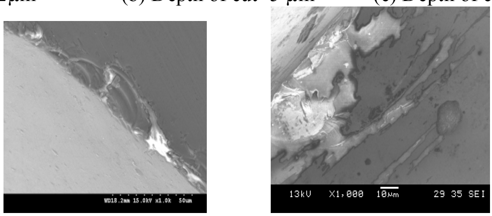
3. Results and Discussion

3.1Ground surface characteristics

Typical FESEM micro-graphs of the ground BK7 glass are shown in Fig.2. It is found that ground surface consists of four different areas (a) the smooth area; (b) the fracture area; (c) the smeared area; (d) the Ploughing striations. Debris is also found to be existed in some cases. The smeared products and fine debris that cover the ground surface are generated when the material removed from surface is trapped between the grinding tool and work pieces and is crushed against the surface. Ploughing or grinding marks can also be observed on the surfaces ground while using small feed rate. Pores can be occasionally seen on the ground surface. The pores usually resulted from the pulling off the grain particles. This pull out is clearly associate with the surface cracking. The white areas found on the Fig.2 (d) are cleavage facets parallel to the ground surface. When small depth of cut is used, side wall looks so smooth and straight; on the other hand, higher depth of cut makes the side wall surface irregular and rough. At low rate of material removal, the cutting points on the tool remove and expel the material from the machined surface in an efficient manner. At high rates of material removal however debris is not expelled efficiently and the debris generated from the cut must pass between the tool and machined surface. The temperature generated during high material removal also account for the surface degradation.



(a)Depth of cut=2μm (b) Depth of cut=5 μm (c) Depth of cut =10μm

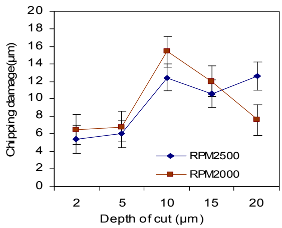


(d)Depth of cut =10μm (e) Depth of cut =15 μm

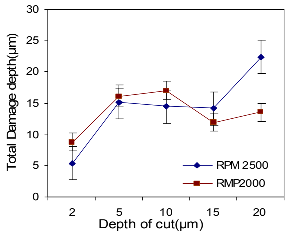
Fig.3: Sub-surface damage of Bk7 glass during micro-grinding varying depth of cut using spindle speed of 2500 rpm.

3.2. Grinding induced subsurface damage

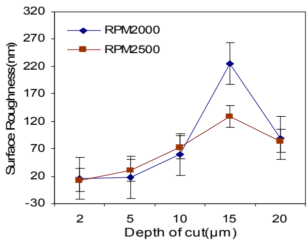
The damaged layer found right underneath the machined surfaces seems likely to be generated by means of chipping manner. As shown in Fig.3, grain dislodgement seems to be contributing largely to the induction of this type of chipping layer. During micro-grinding process, the contact of an individual diamond particle with the glass work piece might produce this damage zone which contains distributed grain-boundary micro-cracks. The dislodgement of individual grains resulting from the grain-boundary micro fractures consequently contributes to this damage layer. This fact might reveal that the chipping layers might be introduced by this grain dislodgements phenomenon. In order to determine the total damage, it would be interesting to combine together both the modes of damage known as total damage which contains both chipping and cracking layer. The depths of total damage layer measured from the FESEM images were plotted in Fig.4. It is noticed that chipping damage grows with the increase of depth of cut. With the further increase of depth of cut it shows jig jag trend of decreasing and increasing afterward. Chipping damage for higher depth of cut seems to be more overwhelming and it might cover the total damage layer too. This fact can be explained as follows. As the depth of cut increases during grinding, the local contact force also tend to increase and the number of contacting particles would also increase which leads to the possible removal of a segment of material containing a number of individual grains, rather than dislodgements of individual grain only. While removing this segment material, chipping damage no longer depends on the depth of cut, which might be the reason of further reduction of chipping damage layer even with the increasing depth of cut[8].It is also found from the graph that with the increasing value of depth of cut the total damage depth also starts increasing initially. Then further increment of depth results in a dropping of total damage layer then finally again tends to increase. This trend is similar for both the spindle speed. As like chipping layer, it is also noticed that the lower spindle contributes to higher depth of damage than higher one.



(a)



(b)



(c)

Fig. 4: Effect of depth of cut on the chipping layer thickness total damage depth and roughness.

3.3 Subsurface crack configuration

In the cross section image shown in Fig. 5 the median and lateral cracks are found to be existed. These median cracks are perpendicular to the glass surface largely contribute to deeper the subsurface damage and potentially to some material removal thorough the interaction with the other cracks. The size of the median crack found from the FESEM image is nearly o.5 µm to 1.0 µm. Lateral cracks were initiated and propagated by the residual stresses only close to the plastic deformation. By their geometry it is clear that the formation of lateral cracks will largely lead to the material removal and will contribute significantly to the observed surface roughness. The size of the lateral crack was found to be nearly 1 µm. Hertzian cracks are cone crack that will also contribute largely to the deeper sub surface damage and also the removal of some material through the interaction of some others cracks as well. From Fig.5 (b), the size of this category crack has been found to be nearly more than 2 µm. Hertzan crack arising at the edge of the compressed region followed by a conical propagation of the crack in material. Increasing the loading further generated the second third and additional similar cracks. Combined with the grain dislodgment evidence obtained from previous Fig., it is inferred that material removal of this glass is dominated by brittle fracture either by dislodgement or lateral cracking. As seen from Fig.5 (a), the pores are apparently visible because of the pulling off of the glass particles. These pores can be a reason of crack expansion and deepen the damage layer.

3.4 Analysis of surface roughness

It can be seen from the Fig.4 (c) that surface roughness increases initially with the increase of depth of cut and then decreases with the increases of depth of cut. This increased depth of cut would normally lead to the greater grinding force and thus worsen the surface finish. In other words, surface roughness value was supposed to be increased. The elevated temperature in grinding zone due to the increased depth of cut might explain the contradictory result of surface roughness. The increase of depth of cut makes the coolant penetration difficult into grinding zone and thus reduces the cooling effects. Thus might cause a local temperature elevation in the grinding zone, consequently soften the work pieces surface and thus promoting ductile mode cutting or reduce the brittle mode cutting. As a result a slightly improved surface finish is evident in the Fig.4 (c) even with the further increment of depth of cut[9]. It can also be noticed that higher level of spindle speed also improved the surface roughness slightly. This surface roughness value shows the significant agreement with the grinding damage value for different value of depth of cut.

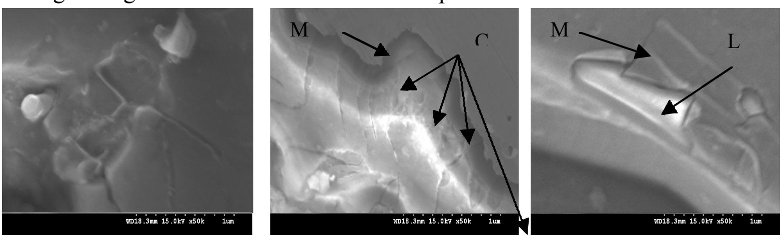


Fig.5: Micro-crack observed from the subsurface layer of BK7 glass. (M-median crack, L-Lateral, C-cone crack)

4. Conclusion

Details knowledge for surface micro-grinding of BK7 glass by on machine fabricated PCD tool has been investigated in this study. The following conclusion can be drawn from the above studies.

- Ground surface consists of four different areas (a) the smooth area; (b) the fracture area; (c) the smeared area; (d) the ploughing striations.
- It is noticed that chipping damage grows with the increase of depth of cut. With the further increase of depth of cut it shows jig jag trend of decreasing and increasing afterward. Total damage also shows the same trends along with the change of depth of cut. Depth of cut 2 µm is found to be providing lowest grinding damage.

- Grinding induced subsurface crack exhibit different configuration likely median lateral and cone. These crack size is nearly below to above 1µm. Subsurface cracks may exist under those ground surface which look even fracture or damage free by the microscopic observation.
- It can be seen that surface roughness increases initially with the increase of depth of cut and the decreases with the increases of depth of cut. This trend of surface roughness also shows good agreement with sub–surface damage, although this surface roughness cannot reveal the morphology of sub-surface damage.

5. References

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