Theoretical and Experimental Study of Single Grain Grinding of Fused Silica Glass

Tianyi Sui[1, a], Bin Lin[1,b *], Zhongchen Cao[1c], Feifei Zhao[1,d] and Yunhua Su[1,e]

[1] Key Laboratory of Advanced Ceramics and Machining Technology of Ministry of Education, Tianjin University, Tianjin, China

[a]suity@tju.edu.cn, [b]tdlinbin@126.com, [c]charles.zc.cao@hotmail.com, [c]zhaofeifei760521 @163.com, [d]suyunhua@tju.edu.cn

Keywords: Fused silica glass, Single grain grinding, Indentation model, Surface topography.

Abstract. Fused silica glass is widely used in many important area as optical component, such as aerospace, biomedicine and chemical production. However, the rupture and smash during the machining process caused by low fracture toughness of the material limited its machining efficiency. In this paper, the grinding force and surface topography of fused silica glass was studied by single grain scratching test. It was found that the smash and exfoliation happened on low grinding speed and caused wide scratch while smooth surface generated at high grinding speed.

Introduction

With the high transparency, optical homogeneity and chemical stability, the fused silica glass was applied in many important area such and used as the material for large aperture optical component. However, traditional machining method could not meet with the high surface quality requirement because of the high hardness and fracture fragility and low facture toughness of the material. At the same time, the material strength are close to its elastic limit, so the component will breaking easily when the load excess its own elastic limit, the crack and the pit made from the machining process would influence the quality of the component significantly. Therefore, it is important to study the grinding mechanism of fused silica[1-3]. Griffith studied the mechanism of crack growth and gave out the criterion for it[4]. Mott and Roberts investigated the kinetic equation of dynamic fracture problem[5-8]. Kirchner reported that the movement of grinding particle in real grinding process and simulated the normal tangential component of the surface elastic stress field[9,10]. Warnecke found the grinding result was closely related to the removal mechanism of the material[11]. Thonggoom found the brittle fracture happened after serval times of scratching[12]. Keep in view of the previous work reviewed above, it is important to study the grinding mechanism for optical glass to improve the surface quality and processing efficiency. In our research, the cup wheel grinding model of hard and brittle material was built, the grinding process of fused silica glass was analyzed by finite element simulation. The grinding force and surface topography of fused silica glass was studied by single grain scratching test. It was found that the smash and exfoliation happened on low grinding speed and caused wide scratch while smooth surface generated at high grinding speed. The grinding force by experiment meets well with the result from grinding model.

Experimental section

The diamond tool for single grain grinding test was designed and shown in Fig. 1. The tool arbor was made by 40 Cr and the tool bit is made by aluminum alloy. Four abrasive particles were added and the rotating diameter is 18mm. Kistler 9257B three-dimensional dynamometer was used in the experiment and the grinding force was recorded in x, y and z direction. The fused silica tested in the experiment has the diameter of 200 mm, the density is 2530kg/m3, the shear modulus is 0.15 GPa and the extension strength is 150 MPa. In order to simulate the liner velocity of the single grain on grinding wheel, the rotating speed was set between 5000-20000 r/min

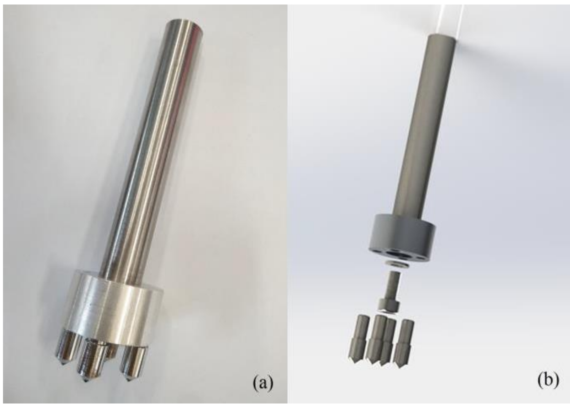


Fig. 1 The diamond tool for single grain grinding test: a) the picture of the diamond tool, b) the component diagram of the diamond tool.

The Kistler dynamometer was fixed on the platform of the machine tool and the fused silica glass was fixed on the dynamometer. The planeness was adjusted to less than 1 μm before the experiment. The rotating speed was set at 5000, 8000, 12000, 15000 and 18000 r/min and the grinding depth was set at 2, 5, 8, 10 and 15 μm. The fused silica glass was examined by NANOVEA-ST400 three dimensional non-contact surface profilometer and HPCCD30 ultra depth field optical microscope after the experiment.

Fig.2 The experimental device

Result and discussion

The normal force and tangential force of the grinding test was recorded and shown in Fig. 3. It could be found that both the normal force and tangential force decreased with the increase of the rotating speed, with the larger grinding depth, the normal force and the tangential force increased dramatically. When the rotating speed exceed 12000r/min, the influence of grinding depth and rotating speed on the grinding force became weak, which meets well with the high speed grinding theory.

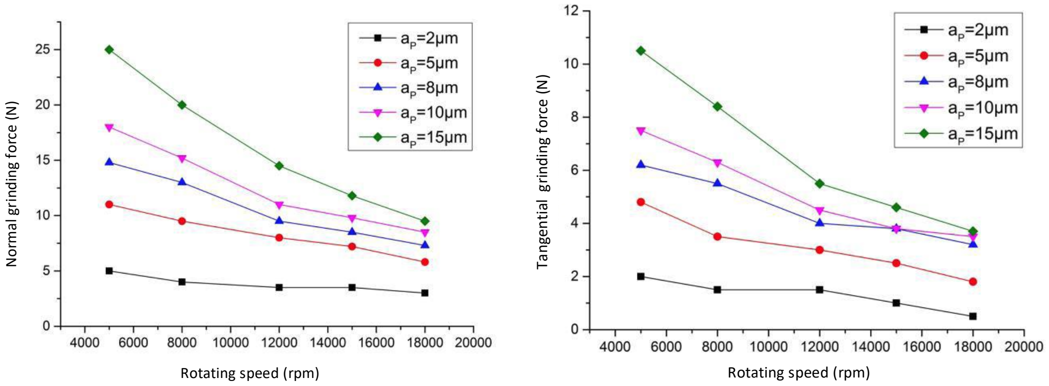
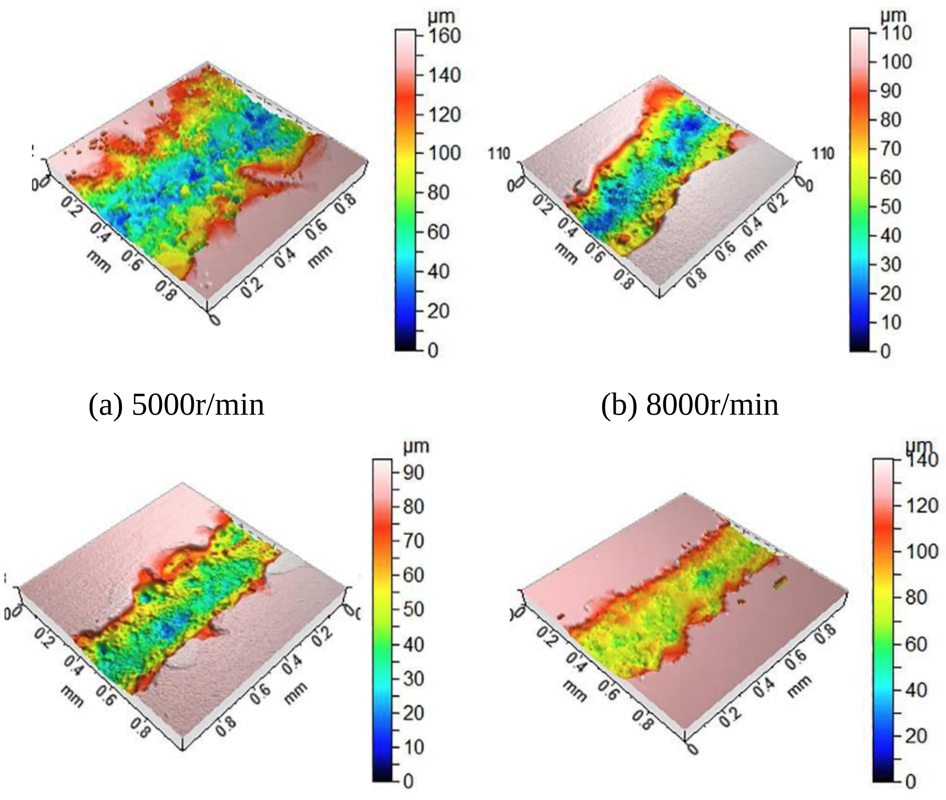


Fig. 3 The Normal and tangential force of the grinding experiment with different rotating speed

The surface of fused silica glass after grinding was characterized by NANOVEA ST300 3D topography with the area of 1mm*1mm, the scanning frequency was set at 1000 Hz and the step was 5 μm. It could be found that when rotating speed is at 5000r/min, lot of cracking and breaking happened at the edge of the scratch. With the increase of the rotating speed, the edge of the scratch became smooth and the surface quality became much better than that of low speed. That could be due to the higher energy and higher grinding force that lead to cracking and breaking when rotating speed is at lower state.

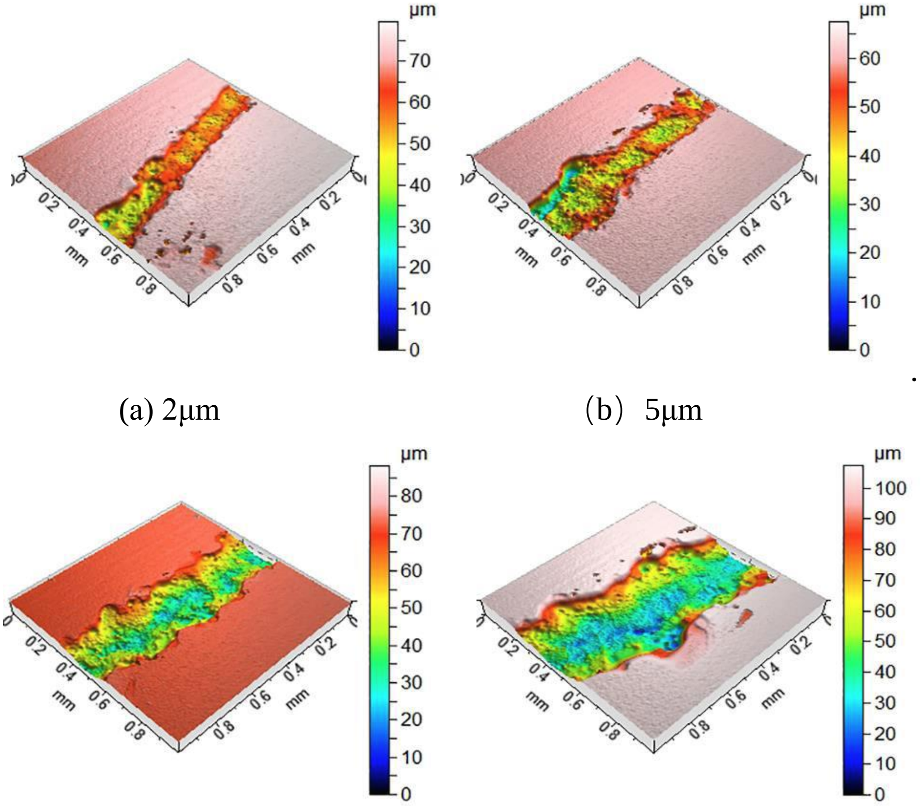


(a) 5000r/min (b) 8000r/min

(c) 12000r/min (d)18000r/min

Fig. 4 The 3D topography of fused silica glass surface with different grinding wheel speeds

Fig. 5 showed the surface of fused silica glass when grinding with different grinding depth. It could be found that the grinding depth didn't show strong influence on the surface quality. When increasing the grinding depth, the increase of the grinding force is mainly due to the increase of the cutting layer thickness.



(a) 2μm (b) 5μm

(a) 8μm (b) 15μm

Fig.5 The 3D topography of fused silica glass surface with different grinding depth

Conclusions

In this paper, the fused silica glass was tested by single grain grinding experiment. The grinding force was recorded and the grinding surface of fused silica glass was examined. It was found that with the increase of the rotating speed and grinding depth of the single grain, both the normal force and the tangential force increased dramatically. When the rotating speed is higher than 12000r/min, the influence of rotating speed on grinding force became weak. More cracking and breaking happened with lower rotating speed, which maybe due to the higher energy and grinding force at low speed. The grinding depth didn't effect the surface quality of fused silica glass significantly.

References

[1] Jun Li. The critical processing technology of ultra-precision machining of hard and brittle materials. Graduate University of the Chinese Academy of Sciences, 2007

[2] Ohmori H, Katahira K, Naruse T, et al. Microscopic grinding effects on fabrication of ultra-fine micro tools. CIRP Annals, 2007, 56(1): 569-572.

[3] Ong N S, Venkatesh V C. Semi-ductile grinding and polishing of Pyrex glass. Journal of

Materials Processing Technology, 1998, 83(1): 261-266.
[4] Griffith A A. VI. The phenomena of rupture and flow in solids [J]. Philtransroysoca, 1920.
[5] Jp B. Some kinetic considerations of the Griffith criterion of fracture-I: eqns of motion at constant deformation. Journal of the Mechanics and Physics of Solids, 1960.

[6]Berry J P. Some kinetic considerations of the Griffith criterion for fracture-II: equations of motion at constant deformation. Journal of the Mechanics & Physics of Solids, 1960, 8(3): 194-206.
[7] Roberts D K, Wells A A. The velocity of brittle fracture. Engineering, 1954.
[8] Mott N F. Slip at grain boundaries and grain growth in metals [J]. Proceedings of the Physical Society, 1948, 60(4): 391-394.
[9] Kirchner H P. Damage penetration at elongated machining grooves in hot-pressed Si3N4. Journal of the American Ceramic Society, 2010, 67(2): 127-132.

[10] Kirchner H P. Comparison of single‐point and multipoint grinding damage in glass. Journal of the American Ceramic Society, 2010, 67(5): 347-353.
[11] Warnecke G, Shäfer L, Eichgrün K, et al. Appendix - manufacturing of ceramic components. Handbook of Ceramic Grinding & Polishing, 1999: 443-471.
[12] Thonggoom R, Funkenbusch P D. Transition in material removal behavior during repeated scratching of optical glasses. Journal of Materials Science, 2005, 40(16): 4279-4286.