Optimizing the Grinding Parameters on the CNC Milling Machine for Best Glass Edge Quality

Xiaoyu Li1,*, Minbo Wang1, Liangbao Jiang1,*, Jiaxi Liu1, Jiaming Li1, and Yue Yan1,*

1Beijing Institute of Aeronautical Materials, Beijing 100095, China
* Corresponding author: lixiaoyu621@126.com; liangbaojiang@hotmail.com; yue.yan@biam.ac.cn

Abstract. The effects of different grinding parameters on the glass edge quality and bending strength were investigated, including wheel speed, feeding rate, wheel mesh and wheel shape. The results show that bending strength and Weibull modulus increase with the increasing of wheel speed and then decrease. The grinding feeding rate has a similar influence on the bending strength and Weibull modulus. There is an optimal matching relationship between glass strength and grinding wheel speed as well as feeding rate. The bending strength and Weibull modulus increase with the increasing of wheel mesh. Taper cup wheel is more suitable to obtain a more smoother glass edge and stronger glass.

1. Introduction
Grinding is an important fundamental process in glass fabrication. The edge of glass should be grinded after cutting to remove defects and avoid safety hazards. The grinding parameters including the feeding rate, wheel speed, wheel mesh and wheel shape have different influence on the glass edge quality [1]. Subsurface damages induced by grinding strongly influence the mechanical strength of glasses. To improve the edge quality, adopting right grinding parameters are required. Researchers and manufacturers have made a lot of effort to machine glasses with low surface roughness and subsurface damage [2]. The glass edge can be free of defects with a proper grinding parameter. Thus, it is meaningful to investigate the optimum grinding parameters.

In this paper, we take the aluminosilicate glass as research object, aiming at researching the influence of different grinding parameters on the glass edge quality and bending strength. The influence of the feeding rate, wheel speed, wheel mesh and wheel shape are investigated. The edge quality and bending strength of the glass after grinding with different parameters are researched to estimate the grinding effect.

2. Experimental procedure
An aluminosilicate glass produced by Aureavia Hi-tech Company (Chongqing, China) was used in this study. The size of the glass specimens was 120mm×20mm×1.8mm. The samples were divided into three groups, to investigate the influence of feeding rate, wheel speed and wheel mesh on the glass edge quality, separately. The grinding parameters of the three groups were shown in Table 1.

| Group | Wheel speed (r/min) | Feeding rate (mm/min) | Wheel mesh | Wheel shape |
|-------|---------------------|-----------------------|------------|-------------|
| 1     | 25000               | 1200                  | 800        | Tapered Wheel |

Table 1. Grinding parameters of three groups
An CNC Milling Machine (LDKW-2520) produced by Lidu Glass Machinery Company was used. The edge morphology was observed with an optical microscopy (ESPEC-VMS-2515H) and the fracture surface was observed with an electron microscope (Tescan Vega 3 SBH). The bending strength was obtained using an Instron universal testing machine. Fifteen specimens were tested for each condition using a displacement-controlled method with a cross head speed of 5mm/min. The load at failure was used to calculate the strength of the specimen. Subsequently, the strength distributions were analyzed using a Weibull approach [3].

3. Results and discussions

Figure 1 shows the glass edge morphology and the fracture surface dependence of wheel speed. It can be seen that the roughness of the glass edges and the fracture surfaces both decreases and then increases with the increasing of wheel speed. According to the literatures [4], the grinding of glass would change from brittle to ductile mode with the increase of wheel speed which may lead to a smoother surface. However, With the further increase of grinding wheel speed, the normal component of the cutting force increases. There is almost only rubbing and extruding from wheel on the glass surface, and almost no material removal. At the same time, the increase of grinding wheel speed can lead to the excessive surface temperature of glass, which will further soften the glass chip and adhesion to the grinding wheel. The pile up of the glass chip on the grinding wheel which will lead to the increase of the roughness.

![Fig. 1 Edge quality dependence of wheel speed](image)

(a), (b), (c) are surface images and (d), (e), (f) are edge images
Fig. 2 Cumulative fracture probability (P) as a function of MOR ($\sigma_b$) and Weibull plots for glasses ground with different wheel speed. The straight lines are the Weibull fitting results.

Figure 2 (a) shows the cumulative fracture probability (P) as a function of MOR ($\sigma_b$). It can be seen that the samples ground with a wheel speed of 40000 r/min show a higher MOR. Figure 2 (b) shows the Weibull modulus with different grinding wheel speed. The Weibull modulus is also higher when the grinding wheel speed is 40000 r/min. These mechanical results are in accordance with the roughness results. The cutting force in the process of glass grinding is the combination of the pressure of grinding wheel on the glass and the shear force between grinding wheel and glass edge. The pressure can produce longitudinal cracks, which can reduce the strength of the glass. The shear force can produce lateral cracks, which can remove materials. The relationship between the pressure and the length of longitudinal cracks can be expressed by formula 1 [5], in which E stands for Young’s modulus, H is hardness, Kc is stress intensity factor, $\kappa$, $\alpha$ and $\psi$ are constants related to the properties of grinding wheel.

$$c_m = \kappa^{\frac{1}{\psi}} \left( \frac{E}{H} \right)^{\frac{2(1-\nu)}{\psi}} \left( \cot \psi \right)^{\frac{1}{\psi}} \left( \frac{P}{K_c} \right)^{\frac{1}{2}}$$  

The grinding mode is brittle with a smaller wheel speed, and cracks are easy to form in brittle mode which leads to a lower glass strength. With the increasing of wheel speed, the grinding mode would change into ductile mode. However, the further increase of wheel speed can lead to the increase of pressure, which will produce longer longitudinal cracks according to formula 1. Therefore, there is an optimal matching relationship between glass strength and grinding wheel speed.

Fig. 3 Edge quality dependence of feeding rate: (a), (b), (c) are surface images and (d), (e), (f) are edge images
Figure 3 shows the glass edge morphology and the fracture surface dependence of feeding rate. It can be seen that the roughness of the glass edges and the fracture surfaces both decreases and then increases with the increasing of feeding rate. Figure 4 (a) and (b) shows MOR and Weibull modulus of glass samples grinded with different feeding rate. The glasses grinded with a feeding rate of 1200 mm/min shows highest strength and Weibull modulus, and these results are in accordance with the roughness results.

Fig. 4 Cumulative fracture probability (P) as a function of MOR ($\sigma_b$) and Weibull plots for glasses grinded with different feeding rate. The straight lines are the Weibull fitting results.

Figure 5 shows the glass edge morphology and the fracture surface dependence of wheel mesh. It can be seen that the roughness of the glass edges and the fracture surfaces both decreases with the increasing of wheel mesh. Figure 6 (a) and (b) shows MOR and Weibull modulus of glass samples grinded with different wheel mesh. The strength and Weibull modulus both increase with the increasing of wheel mesh.

Fig. 5 Edge quality dependence of wheel mesh: (a), (b), (c) are surface images and (d), (e), (f) are edge images

Fig. 6 Cumulative fracture probability (P) as a function of MOR ($\sigma_b$) and Weibull plots for glasses grinded with different wheel mesh. The dash lines are the Weibull fitting results
Figure 7 shows the glass edge morphology and the fracture surface dependence of wheel shape. From figure 7, the roughness of the glass edges ground with taper cup wheel is much smoother than that with tapered wheel. Figure 8 shows the schematic diagram of the basic principle ground with tapered wheel and taper cup wheel, separately. It can be seen from figure 8 that the contact area between the tapered wheel and glass is much smaller than that of taper cup wheel and glass. Large contact area is helpful for uniform force on glass section and better grinding effect. In addition, the maximum grinding depth of taper cup wheel is 0.37mm, which is less than that of tapered wheel (0.4mm). The grinding force increases with the increase of cutting depth. Larger grinding force of tapered wheel also leads to larger roughness.

Figure 9 (a) and (b) shows MOR and Weibull modulus of glass samples ground with different wheel shape. The strength and Weibull modulus of glasses ground with taper cup wheel is higher than that grounded with tapered wheel, and this result is in consistent with the roughness results.
Fig. 9 Cumulative fracture probability (P) as a function of MOR ($\sigma_b$) and Weibull plots for chemically tempered aluminosilicate glasses with tapered and taper cup wheel grinding, respectively. The dash lines are the Weibull fitting results.

4. Summary

The influence of different grinding parameters on the glass edge quality and mechanical properties were investigated, including the feeding rate, the wheel speed and wheel mesh. The results show that the bending strength and Weibull modulus of the glass both increase and then decrease with the increasing of wheel speed. The change of the bending strength and Weibull modulus of the glass with feeding rate shows the same trend as the change with wheel speed. The mechanical properties of the chemically strengthened glasses increase with the increasing of wheel mesh, and this result is in consistent with the roughness results. Taper cup wheel is more suitable to obtain a more smoother glass edge and stronger glass. There is an optimal matching relationship between glass strength and grinding parameters.

References

[1] Reddy M M, Gorin A, Abou-El-Hossein K A. Predictive Surface Roughness Model for End Milling of Machinable Glass Ceramic[J]. Iop Conference, 2011, 17:012002.

[2] Chen Jiang, Jipeng Xu, Chunhua Wang. Experimental investigation of subsurface damage of optical glass in precision grinding using a brittle material removal fraction[J]. The International Journal of Advanced Manufacturing Technology, 2017.

[3] W. Weibull, A statistical distribution function of wide applicability, presented to the American society of mechanical engineers, J. Appl. Mech. 23(1951) 981-997.

[4] Zhong Z W. Ductile or Partial Ductile Mode Machining of Brittle Materials[J]. International Journal of Advanced Manufacturing Technology, 2003, 21(8):579-585.

[5] Li Y, Zheng N, Li H, et al. Morphology and distribution of subsurface damage in optical fused silica parts: Bound-abrasive grinding[J]. Applied Surface Science, 2011, 257(6):2066-2073.