Proceedings of Asia International Conference on Tribology 2018, pp. 131-133, September 2018

Velocity-dependent wear behaviors of a phosphate glass

Hongtu He, Liang Yang, Yafeng Zhang, Jiaxin Yu*

Key Laboratory of Testing Technology for Manufacturing Process, Southwest University of Science and Technology, Mianyang 621010, China.

*Corresponding e-mail: yujiaxin@swust.edu.cn

Keywords: Glass; adhesive wear; tribochemical wear

ABSTRACT – The velocity-dependent wear behaviors of a phosphate laser glass were investigated by a reciprocating sliding tribometer in dry and humid air. The experimental results show that, with increase in sliding velocity, the wear volume of phosphate glass increases in dry air but decreases in humid air. Adhesive wear occurs easily in the high velocity sliding due to the friction-induced high temperature. Under low velocity, the absorbed water film between the contact asperities forms more easily, and the tribochemical reaction is more sufficient, which assists the material removal of phosphate glass.

1. INTRODUCTION

As an ideal energy gain medium, phosphate laser glass is widely used in high power laser systems [1], while it needs to achieve high surface processing quality. Velocity is an important parameter in the glass surface machining, which could determine the surface quality of glass. The essence of glass surface machining is the material removal caused by the local shear and friction between machining tool and glass under a given velocity. So, exploring the effect of velocity on the material removal by tribology is very useful to understand the role of the machining velocity in the glass surface processing.

Some previous researches described different damage modes of glass surface under various sliding velocities, but rarely relate to the velocity-dependent damage mechanism. For example, Bandyopadhyay et al. [2] found that the wear rate of glass decreased with increase in velocity in scratch damage investigation of soda lime glass, but the related mechanism was not discussed. Phosphate glass has poor thermal conductivity and water resistance, so sliding velocity would affect the frictional temperature and water molecules adsorption at interface, when it is worn in a humid air. That would further affect the tribochemical reaction and material removal efficiency, but the specific effect mechanism is still unclear.

2. METHODOLOGY

The glass sample is polished N31 Nd-doped phosphate laser glass slide, provided by Shanghai Daheng Optics and Fine Mechanics Co., Ltd., China. In this investigation, all the friction and wear tests were performed on a universal ball-on-flat tribometer. Tests were performed through reciprocating sliding in the humid air. The friction pair is alumina ceramic balls with radius of 2 mm. The normal load is 2 N, number of cycles is 50, and the velocity is set to vary from 0.25 to 7.5 mm/s. After the test, the images of wear tracks were obtained by optical microscopy. Then, the three-dimensional morphology of wear tracks was analyzed by a white light scanning profilometry. Finally, the chemical composition of the wear debris under various velocities was detected by Raman spectra.

3. RESULTS AND DISCUSSION

Figure 1 shows the characteristic profile line of wear tracks in phosphate laser glass under various sliding velocities. In dry air, the typical wear width and depth are 80 μm and 0.04 μm under a sliding velocity of 0.2 mm/s. As the velocity gradually increases to 7.5 mm/s, the typical wear width and depth increase to 190 μm and 0.09 μm. While in humid air, the typical wear width and depth are 150 μm and 0.43 μm under a sliding velocity of 0.2 mm/s. As the velocity gradually increases to 7.5 mm/s, the typical wear width and depth decreases to 70 μm and 0.07 μm.

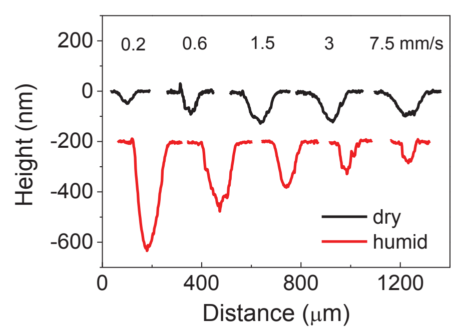

Figure 1 Profile lines of wear tracks in phosphate glass under various sliding velocities in dry and humid air.

The increase in sliding velocity can induce an increase in the frictional temperature of the contact surfaces, causing local softening of the contact asperities of glass, and then affects the wear mode of glass. Equation (1) gives the estimation of the local temperature rise of contact asperities caused by friction [3]:

$$\Delta T = \frac{\mu p v}{4a\left(k_1 + k_2\right)} \quad (1)$$

Where μ is the friction coefficient, v is the sliding velocity, p is the normal load, a is the radius of actual contact area of frictional surfaces, and k_1 and k_2 are the thermal coefficients of two friction pairs. Since the actual contact radius of asperities can not be accurately measured, assuming the contact radius of asperities in this study is 100 ~ 200 nm, the local temperature rise will change from 7.7 ~ 15.4 K to 223.4 ~ 446.8 K when the velocity increases from 0.25 to 7.5 mm/s. The true radius of contact asperities should be much smaller than the current hypothetical value, so the local temperature rise in the case of high-velocity friction will be further significantly increased. It easily reaches the glass transition temperature, resulting in softening of the contact asperities and then leading to adhesive wear.

Figure 2 shows the variation of wear volume of phosphate glass with sliding velocity. As the velocity increases from 0.25 mm/s to 7.5 mm/s, the wear volume of glass sharply decreases from 1.8×10^5 μm^3 to 0.15×10^5 μm^3 in humid air, while the wear volume increases from 0.1×10^5 μm^3 to 0.45×10^5 μm^3 in dry air.

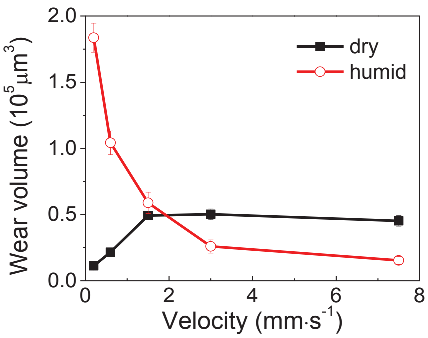

Figure 2 The wear volume of phosphate laser glass as a function of sliding velocity in dry and humid air.

When a phosphate glass is exposed in a humid air, the water film adsorbed on the surface will cause the deliquescence (hydrolysis) of glass, and the related chemical reaction can be described by Equation (2) [4]:

$$\text{P-O-P}+H_2O\rightarrow\text{P-OH}+\text{OH-P} \quad (2)$$

The above hydrolysis reaction will be exacerbated when the tensile stress or shear stress acts on the glass surface, which can be explained by stress corrosion theory. In reciprocating friction of glass in humid air, due to the continuous effect of shear stress, stress corrosion will further promote the materials removal of glass. Under high velocity sliding, the interface water bridge is difficult to form and is easily damaged due to the rapid relative movement between the contact asperities. As a result, the water molecules participating in the hydrolysis decreased, and the corresponding tribochemical wear is weakened. In addition, under high velocity sliding, due to the significant increase of friction temperature in the contact area, the interface adsorption water film forms more difficultly, which further reduces the possibility of hydrolysis and tribochemical wear. On the contrary, under low velocity sliding, the residence time of water molecules at the contact interface is longer, the hydrolysis and tribochemical wear is more sufficient, which assists the material removal of glass. As a result, the material removal (wear) of phosphate glass is more serious in low velocity sliding friction.

In order to confirm the occurrence of tribochemical reaction under various sliding velocities, the chemical composition of wear debris of phosphate glass under low velocity (0.25 mm/s) and high velocity (7.5 mm/s) were analyzed by Raman spectroscopy, and they were compared to that of original surface. As shown in Figure 3, under three conditions, the intensity of peak at 3100 cm^{-1} (typical OH stretching vibration peak) [5] showed significant differences. It is very weak in the wear debris of original surface. The peak intensity increased slightly under high velocity sliding, which indicates that more OH groups were found in glass wear debris after rubbing under high velocity sliding. The more OH groups possibly came from the P-OH bond, which implied hydrolysis of P-O-P network may take place to a certain extent. The peak intensity at 3100 cm^{-1} under low velocity sliding increased significantly, indicating P-OH groups increase sharply in the debris after rubbing under low velocity sliding, so the hydrolysis reaction was more serious under low velocity sliding. It further confirms that more sufficient hydrolysis under low velocity exacerbates the tribochemical wear, which results in larger wear volume of phosphate glass in humid air.

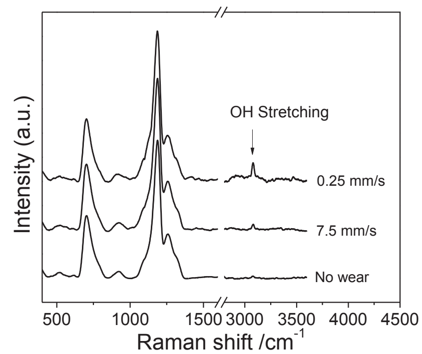

Figure 3 Raman spectra of the wear debris in phosphate laser glass after wear testing in humid air.

4. CONCLUSION

Compared to low velocity sliding, adhesive wear occurs easily in the high velocity sliding in phosphate glass due to the friction-induced high temperature.

The wear volume of phosphate glass decreases with increase in sliding velocity in humid air, because the tribochemical reaction is more sufficient under low velocity sliding, which assists the material removal of phosphate glass.

ACKNOWLEGEMENT

The authors are grateful for the financial support from the National Natural Science Foundation of China (No. 51575462 and No. 51605401)

REFERENCES

[1] Hu, L. L., & Jiang, Z. H. (2005). Research progress of phosphate laser glass. *Bulletin of the Chinese Ceramic Society*, *24*(5), 125-129.

[2] Bandyopadhyay, P., Dey, A., Mandal, A. K., Dey, N., Roy, S., & Mukhopadhyay, A. K. (2012). Effect of scratching speed on deformation of soda–lime–silica glass. *Applied Physics A, 107*(3), 685-690.

[3] Kim, D. W., & Kim, K. W. (2013). Effects of sliding velocity and normal load on friction and wear characteristics of multi-layered diamond-like

carbon (DLC) coating prepared by reactive sputtering. *Wear, 297*(1-2), 722-730.

[4] Yu, J. X., Jian, Q. Y., Yuan, W. F., Gu, B., Ji, F., & Huang, W. (2014). Further damage induced by water in micro-indentations in phosphate laser glass. *Applied Surface Science, 292*, 267-77.

[5] Carey, D. M., & Korenowski, G. M. (1998). Measurement of the Raman spectrum of liquid water. *Journal of Chemical Physics, 108*(7), 2669-2675.