

Effect of the Temperature on the Friction-Wear Properties of Poly(ether ketone) with a Cardo Group

Nong Tian, Fengyuan Yan, Weimin Liu

State Key Laboratory of Solid Lubrication, Lanzhou Institute of Chemical Physics, Chinese Academy of Science, Lanzhou, Gansu 73000, China

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ABSTRACT: We studied the effect of temperature on the friction-wear properties of poly(ether ketone) with a cardo group (PEK-C) with a XuanWu-3 pin-disc friction-and-wear tester. Testing conditions such as the temperature obviously affected the friction and wear behavior of PEK-C. As the ambient temperature increased, the wear of PEK-C increased, and there was a maximum value of the friction coefficient of PEK-C at a certain temperature. This phenom-

enon could be attributed to the effect of an adhesive-elastic property of PEK-C. Scanning electron microscopy revealed that the size and shape of the wear debris of PEK-C varied as the temperature varied. The main mechanism behind the different tribological characteristics lay in the variations of the physical state on the friction surface of PEK-C due to the increasing surface temperature of PEK-C. © 2004 Wiley Periodicals, Inc. *J Appl Polym Sci* 93: 696–699, 2004

INTRODUCTION

Testing conditions, such as the speed, load, and temperature, obviously affect the friction and wear behavior of a polymer.^{1–5} There are many practical applied conditions for tribological materials, and so the relationship of the testing conditions and friction-wear properties is one focus. Because of the inherent characteristics of a polymer, it is sensitive to the speed, load, and temperature. The state of a polymer changes under three kinds of testing conditions. In this article, the effects of temperature on the tribological behavior of poly(ether ketone) with a cardo group (PEK-C) are mainly examined in an attempt to explore the friction-wear mechanisms.

EXPERIMENTAL

PEK-C (Fig. 1) was produced by the Changchun Institute of Applied Chemistry (Changchun, China). PEK-C powder was heated at a rate of $5^{\circ}\text{C min}^{-1}$ from room temperature to the maximum temperature of 320°C . The pressure was held at 10 MPa for 30 min, and then the powder was cooled to room temperature. PEK-C used for the tests was formed into shapes at high temperatures and was then processed into pin samples with a diameter of 5 mm and a length of 18 mm.

A stainless steel (1Cr18Ni9Ti) disc with a diameter of 45 mm and a thickness of 8 mm was chosen as one

of the mating materials of the sliding system. The surface roughness of the disc was $0.45\mu\text{m}$.

The friction and wear tests were conducted on a XuanWu-3 model pin-disc friction-and-wear tester at room temperature or an elevated temperature in the ambient atmosphere. A contact schematic diagram of the frictional couple is shown in Figure 2; it consisted of a single pin sample of PEK-C and a stainless steel disc rotating at a selected speed against this pin. The friction track diameter of the pin on the disc was 25 mm. Before each test, the stainless steel (1Cr18Ni9Ti) disc and PEK-C pin ($\phi 5\text{ mm} \times 18\text{ mm}$) were polished with no. 900 water-abrasive paper. Then, the surfaces of the stainless steel disc and PEK-C pin were cleaned with cotton dipped in acetone and then dried in air. Sliding was performed under ambient conditions over a period of 120 min at a sliding speed of 0.39 m/s and a load of 39.2 N at different temperatures. The friction coefficients were obtained through the calculation of the friction torque measured with a loaded cell sensor. The wear rate was measured by the weight loss of PEK-C. In this work, three to five samples were tested under each condition; the friction coefficient and wear rate were the average values of three replicate test results.

Finally, the morphologies of the debris and worn surfaces of PEK-C and transfer films of PEK-C formed on the surfaces of steel rings were observed with a JSM 5600LV scanning electron microscope.

RESULTS AND DISCUSSION

Figure 2 shows the variation of the friction coefficient with the ambient temperature for PEK-C. The friction coefficient of PEK-C first increased with increasing

Correspondence to: N. Tian (tnqy@sina.com).

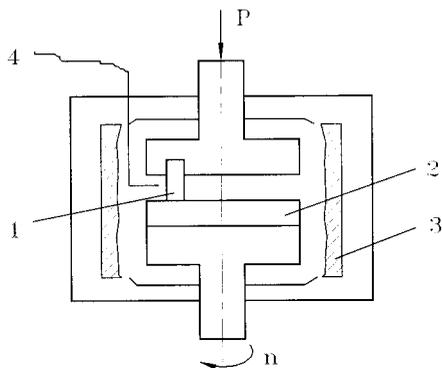


Figure 1 Structural schematic diagram of the XuanWu-3 friction-wear tester: (1) sample, (2) couple, (3) heating oven, and (4) thermocouple.

ambient temperature but soon afterward decreased as the ambient temperature increased further. There existed a maximum value of the friction coefficient of PEK-C at a certain temperature. The friction coefficient of PEK-C increased from 0.26 to 0.76 (the maximum value) as the ambient temperature rose from 20 to 172°C, and then it decreased as the ambient temperature increased further; when the ambient temperature was 200°C, the friction coefficient of PEK-C was 0.28.

The polymer showed different physical states under different temperatures. In the glassy state, the molecular segment of the polymer was frozen, and the deformation of the polymer under an external force was small. In the viscous elastic state, the molecular segment of the polymer was likely to move, and deformation was possible under an external force. In the viscous flow state, the molecular main chain could move freely, and the polymer displayed melting flow under an external force. When the ambient temperature was relatively low, PEK-C was in the glassy state, the thermal motion of the PEK-C molecule was weak, the deformation of the friction force was relatively small, and so the corresponding friction coefficient

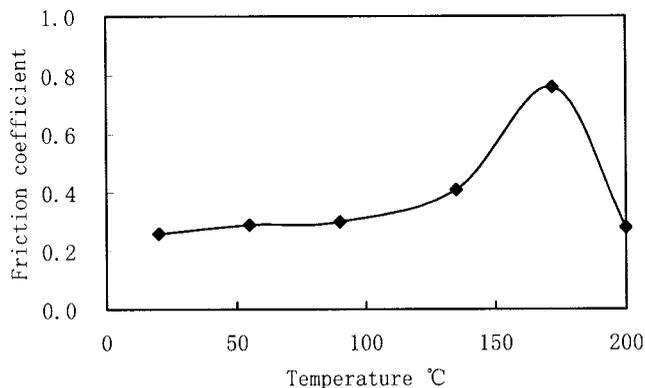


Figure 2 Friction coefficient of PEK-C as a function of the ambient temperature. Sliding was performed under ambient conditions over a period of 120 min at a sliding speed of 0.39 m/s and a load of 39.2 N at various temperatures.

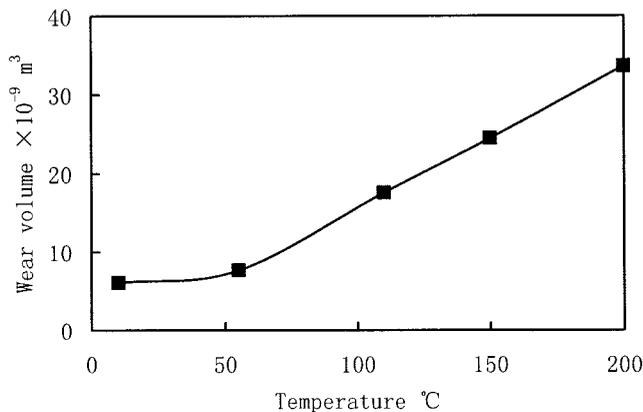


Figure 3 Wear volume of PEK-C as a function of the ambient temperature. Sliding was performed under ambient conditions over a period of 120 min at a sliding speed of 0.39 m/s and a load of 39.2 N at various temperatures.

was relatively low. As the ambient temperature gradually increased, the thermal motion of the PEK-C molecule gradually increased, PEK-C changed from the glassy state to the viscous elastic state, the deformation of the friction force increased gradually, and the corresponding friction coefficient rose. When the ambient temperature increased further, because the polymer was a bad conductor of heat, under the joint action of the ambient temperature, load, and frictional force, a lot of heat accumulated on the surface of PEK-C; therefore, the surface temperature rose, the thermal motion of the PEK-C molecule was aggravated, PEK-C changed from the viscous elastic state to the viscous flow state, a micromelt of the surface took place, the deformation of the friction force decreased, and the corresponding friction coefficient decreased gradually.

Figure 3 shows the variation of the wear volume with the ambient temperature for PEK-C. As the ambient temperature increased, the wear of PEK-C increased continuously. When the ambient temperature was higher than 150°C, the wear of PEK-C became severe. Under the condition of the contract form of the friction-wear test, with polymer sliding on the counterpart, the shear force mainly affected the polymer surface and counterpart surface as well as the polymer surface and polymer subsurface. When the ambient temperature was relatively low, the thermal motion of the PEK-C molecule was weak, it was not easy to slide between the polymer surface and polymer subsurface, the shear force mainly affected the polymer surface and counterpart surface, and so the wear volume of PEK-C was relatively low. As the ambient temperature increased gradually, the thermal motion of the PEK-C molecule increased gradually, the frictional surface started intensifying, it was easy to slide between the polymer surface and polymer subsurface, the shear force simultaneously affected the two interfaces, and so the wear volume of PEK-C started increasing. When the ambient temperature increased further, the softened layer of the frictional sur-

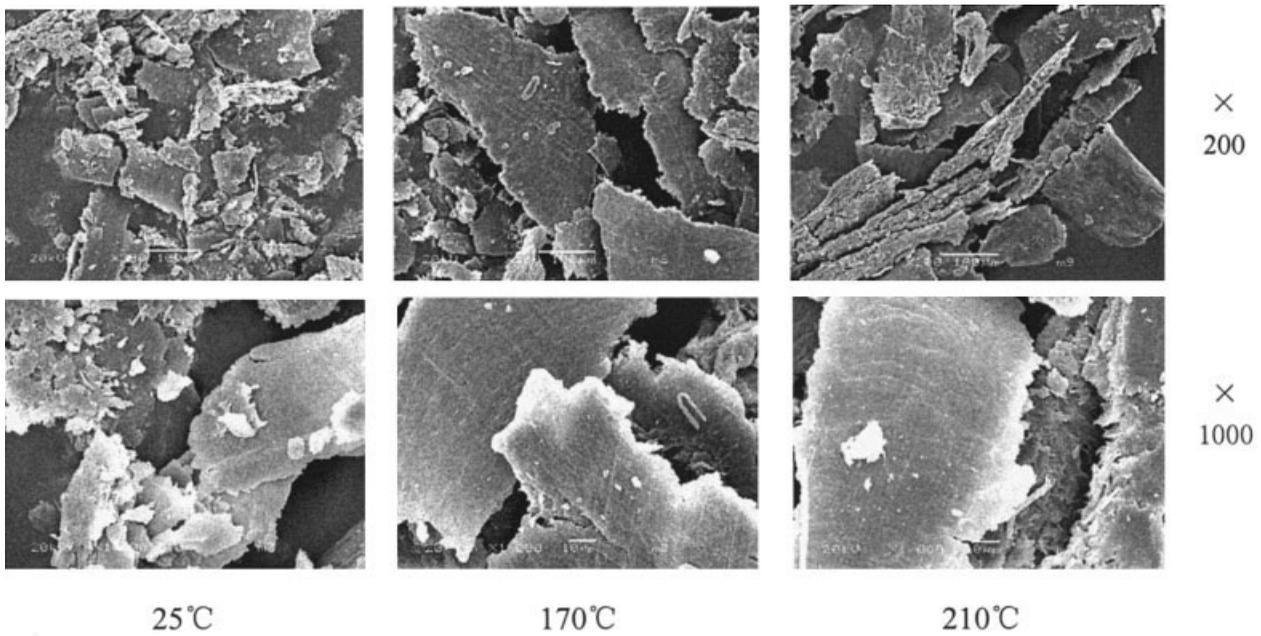


Figure 4 SEM micrographs of wear debris of PEK-C at different temperatures.

face enlarged further and was accompanied by a micro-melt of the PEK-C surface, the action force between the polymer surface and polymer subsurface was smaller than the action force between the polymer surface and counterpart surface, the shear force mainly affected the polymer surface and polymer subsurface, and so the wear volume of PEK-C increased sharply.

Figure 4 shows scanning electron microscopy (SEM) micrographs of the wear debris of PEK-C at ambient temperatures of 25, 170, and 210°C. There were obvious differences in the wear debris of PEK-C at the

different temperatures. When the ambient temperature was 25°C, the wear debris of PEK-C was relatively small and flakey. When the ambient temperature was 170°C, the wear debris of PEK-C was relatively large and flakey. When the ambient temperature was 210°C, there were two kinds of wear debris of PEK-C: one was relatively large and flakey, and the other was relatively long and stripe-shaped.

We think that the polymer surface was not easy to deform when the ambient temperature was relatively low; some relatively small microconvexities were

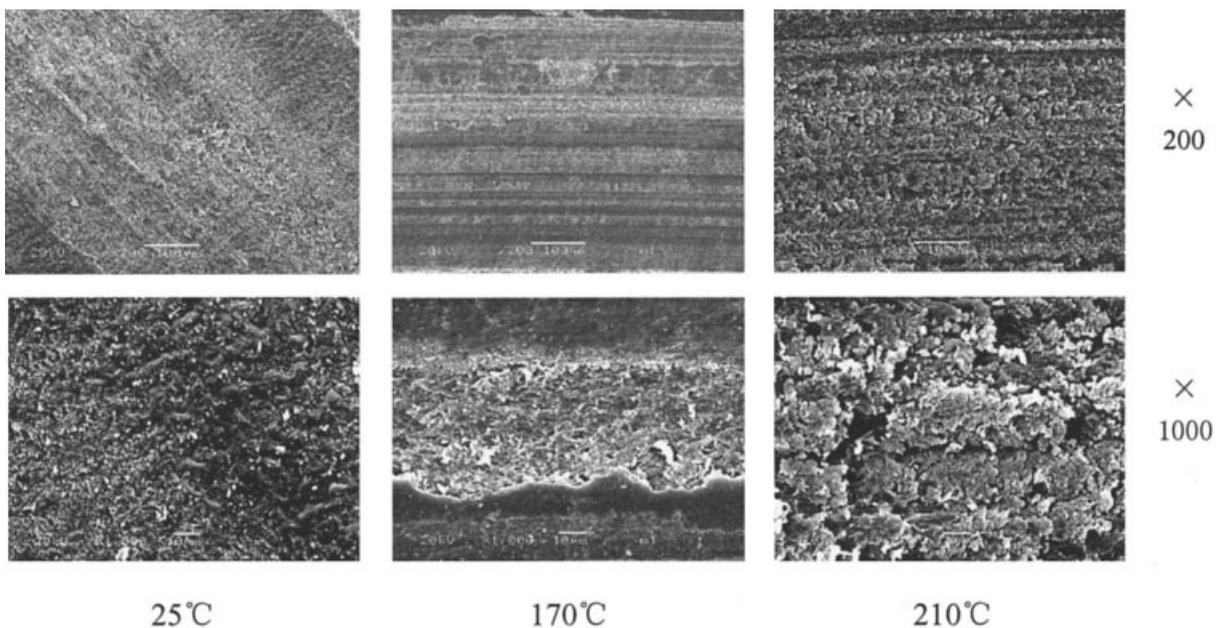


Figure 5 SEM micrographs of the worn surface of PEK-C at different temperatures.

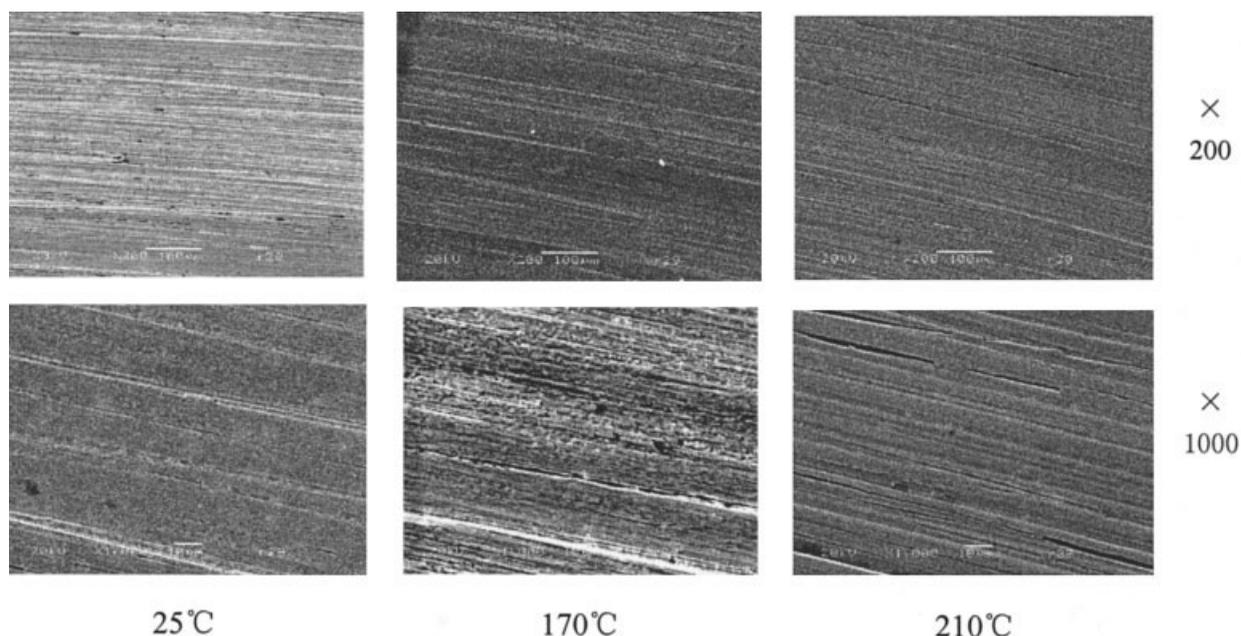


Figure 6 SEM micrographs of the worn surface of a PEK-C couple at different temperatures.

sheared by the frictional force, and so the size of the wear debris of PEK-C was relatively small. As the ambient temperature increased gradually, the deformation capability of the polymer improved, and microconvexities were planished after being deformed under a joint action of the ambient temperature and load. The wear debris of PEK-C was not sheared easily from the polymer bulk only one time, the microconvexities disengaged the bulk after repetitious extrusion, and so the wear debris of PEK-C was relatively large and flakey. When the ambient temperature increased further, the shear force mainly affected the polymer surface and polymer subsurface, the wear debris sheared easily, and so the wear debris of PEK-C was large and flakey. In addition, a micromelt of the polymer surface possibly resulted in the emergence of long and stripe-shaped wear debris.

Figure 5 shows SEM micrographs of the worn surface of PEK-C at ambient temperatures of 25, 170, and 210°C. There were almost no any nicks on the wear scar of the PEK-C block, and the worn surface was very smooth at 25°C. Obvious ploughed marks appeared on the wear scar of the PEK-C block, and some parts of the ploughed marks were wide and deep, so the worn surface appeared to be relatively coarse. When the ambient temperature was 210°C, there were no obvious ploughed marks on the wear scar of PEK-C, and the worn surface was relatively smooth. This corresponded to the friction coefficient of PEK-C obviously decreasing at that temperature.

The transfer films were formed on the stainless steel disc surfaces by the stainless steel discs being run against the PEK-C pin (Fig. 6). A relatively uniform and coherent transfer film was formed on the counterpart steel disc by the steel disc being run against the

PEK-C pin, and the counterpart surface of PEK-C was relatively smooth at the ambient temperature of 25°C. When the ambient temperature was 170°C, the transfer film that formed on the counterpart steel disc was not uniform and coherent, and the counterpart surface of PEK-C was relatively coarse. This corresponded to the very high friction coefficient of PEK-C at that temperature. When the ambient temperature was 210°C, a relatively uniform and coherent transfer film was formed on the counterpart steel disc, and the counterpart surface of PEK-C was also relatively smooth. This corresponded to the friction coefficient of PEK-C obviously decreasing at that temperature.

CONCLUSIONS

The testing conditions, such as the ambient temperature, obviously affected the friction and wear behavior of PEK-C. As the ambient temperature increased, the wear of PEK-C increased, and there was a maximum value of the friction coefficient of PEK-C at a certain temperature.

The SEM results revealed that the size and shape of the wear debris of PEK-C varied as the temperature varied. The main mechanism behind the different tribological characteristics lay in the variations of the physical state on the friction surface of PEK-C due to the increasing surface temperature of PEK-C.

References

1. Blanchet, T. A.; Kennedy, F. E. *Wear* 1992, 153, 229.
2. Lu, Z. P.; Friedrich, K. *Wear* 1995, 181, 624.
3. King, R. B. *Wear* 1979, 56, 37.
4. Cong, P. H.; Li, T. S.; Liu, X. J.; et al. *J Mater Sci* 2000, 35, 2597.
5. Cong, P. H.; Li, T. S.; Liu, X. J.; et al. *Tribology (China)* 1997, 17, 220.