Tribological Properties of Micron Silicon Carbide Filled Poly(ether ether ketone)

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ABSTRACT: The composite of poly(ether ether ketone) (PEEK) filled with micron silicon carbide (SiC) with different filler proportions was prepared by compression molding. The friction and wear properties of the composite were investigated at ambient conditions on a block on ring machine by running a plain carbon steel (AISI 1045 steel) ring against the composite block. The morphologies of the worn composite surfaces and the transfer film on the counterpart steel ring were examined with scanning electron microscopy and electron probe microanalysis. The results showed that the friction and wear of PEEK was slightly reduced at a filler proportion of micron SiC of 2.5–5.0 wt %. Abrasive wear was dominant for the PEEK composite; this was especially so at higher filler proportion. Meanwhile, abrasion and transfer to the composite surface of the counterpart steel ring were also observed. © 1999 John Wiley & Sons, Inc. J Appl Polym Sci 74: 2611–2615, 1999

Key words: poly(ether ether ketone); micron SiC; filler; tribological properties; wear mechanism

INTRODUCTION

Poly(ether ether ketone) (PEEK) and its composites are becoming more widely used as bearing and slider materials under severe conditions. Therefore, the friction and wear properties of PEEK and its composites are of greater interest and importance, which in turn encourages related research and development efforts.[1–4] It has been found that the incorporation of some appropriate reinforcing agents into PEEK has a beneficial effect on its strength and tribological properties. Briscoe et al.[5] described the friction and wear of PEEK-poly(tetrafluoroethylene) blends over a wide composition range under several testing conditions. Friedrich[6] reported that short glass fibers slightly improved the wear resistance of PEEK and carbon fibers were superior to glass fibers in enhancing the wear resistance. Bahadur and Gong[7] investigated the action of various copper compounds as fillers on the tribological behavior of PEEK and revealed that CuS and CuF_2 filler were very effective in reducing the wear of PEEK when sliding occurred against steel surfaces. Our previous work[8] indicated that nanometer Si_3N_4 filler was very effective in reducing the friction coefficient and wear rate of PEEK.

Silicon carbide (SiC) has excellent mechanical and physical properties such as high hardness, high corrosion resistance, and high thermal conductivity. This is why it has great potential for use in tribological applications. Accordingly, micron SiC was selected as the filler for PEEK to investigate its effect on the friction and wear properties of PEEK. We believed that the work

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would be helpful for providing guidance to the tribological application of PEEK.

EXPERIMENTAL

PEEK powder with a diameter of about 100 μm was provided by Jilin University of China. The micron SiC powder (<75 μm) was supplied by Shanghai Institute of Ceramics (Chinese Academy of Sciences). The polymer powder was fully mixed with the micron SiC filler by dispersing them both in alcohol with an ultrasonic bath for about 15 min. Then the mixture was dried at 110°C for 6 h to remove the alcohol and moisture. The dried mixture was then compressed and heated to 340°C in a mold at a rate of 10°C/min. The pressure was held at 5 MPa at a temperature below 320°C. For the rest of the heating cycle the pressure was raised to 15 MPa to ensure good compactness of the resultant composite specimens. The mixture was held at 340°C for 8 min and then cooled to 100°C in the mold.

The friction and wear tests were conducted on an M-200 model friction and wear tester. The contact schematic diagram of the frictional couple is shown in Figure 1. During the test the friction force between the test block and the counterpart steel ring was recorded with a torque shaft equipped with strain gauges. Sliding was performed under ambient conditions over a period of 1.5 h at a sliding speed of 0.445 m/s. The ambient temperature was about 20°C and the relative humidity was 50 ± 5%. Before each test the plain carbon steel ring (HRC 48–50) and the PEEK or its composite blocks were all abraded with no. 900 water-abrasive paper. Then the steel ring and PEEK or its composite blocks were cleaned with acetone and dried. At the end of each test the wear weight loss of the composite block was determined accurately to 10^{-8} kg with a high precision analysis balance. Three replicate friction and wear tests were carried out for each specimen to minimize data scattering, and the average of the three replicate test results are reported in this work. The deviation of the friction and wear test data was 15%. After testing, the morphologies of the worn composite surfaces and the transfer films on the counterpart steel surface were observed with a Jeol-1200EX scanning electron microscope (SEM) and an EPM-810Q electron probe microanalyzer (EPMA).

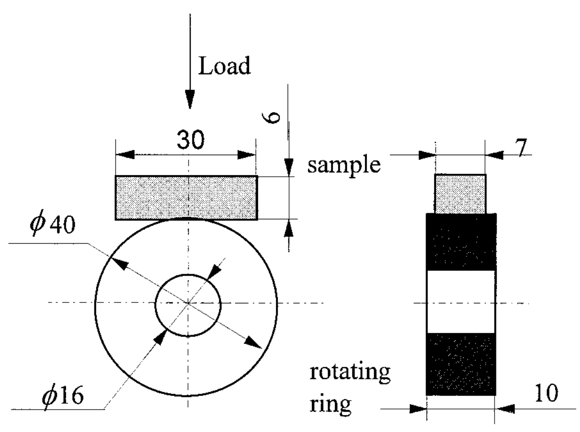

Figure 1 The contact schematic diagram for the frictional couples on the MM-200 wear tester.

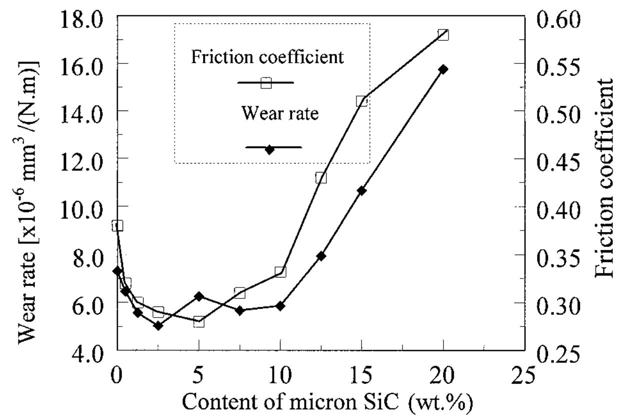

Figure 2 Effect of the content of micron SiC on the friction coefficient and wear rate of the filled PEEK composite (load, 196 N; sliding velocity, 0.445 m/s).

RESULTS

Friction and Wear Properties

Figure 2 shows the friction coefficient and wear rate of micron SiC filled PEEK as a function of SiC content. The friction coefficient decreased at a filler content below 5.0 wt %. Above the filler content of 5.0 wt % the friction coefficient increased with increasing SiC content. Especially at a filler content above 10.0 wt %, the friction coefficient nearly linearly increased with increasing SiC content and was even higher compared to unfilled PEEK. In the meantime the PEEK composite of lower SiC content (below 10.0 wt %) had a slightly decreased wear rate than unfilled PEEK. Above a filler content of 10.0 wt % the wear rate increased linearly with increasing SiC

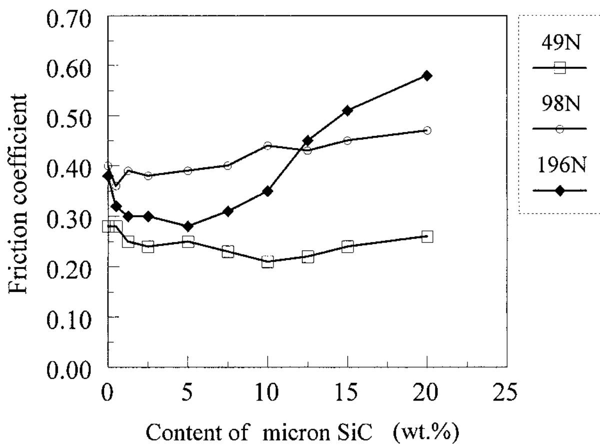

Figure 3 The friction coefficient under various loads as a function of the micron SiC content in the filled PEEK (sliding velocity, 0.445 m/s).

content and was much higher than that of unfilled PEEK. In combination with the friction coefficient and wear rate, it is rational to recommend the optimal SiC content in the PEEK composite as 2.5–5.0 wt %.

Figures 3 and 4 show the effect of load on the friction coefficient and wear rate of PEEK composites. We found that the friction coefficient under a lower load changed slightly with an increase of the filler content. The lowest friction coefficient was obtained at a load of 49 N. The wear rate of the composites under various loads decreased slightly as the content of SiC was below 10.0 wt %. Above a filler content of 10.0 wt % the wear rate increased to some extent with increasing SiC content. The lowest wear rate was also obtained under a load of 49 N.

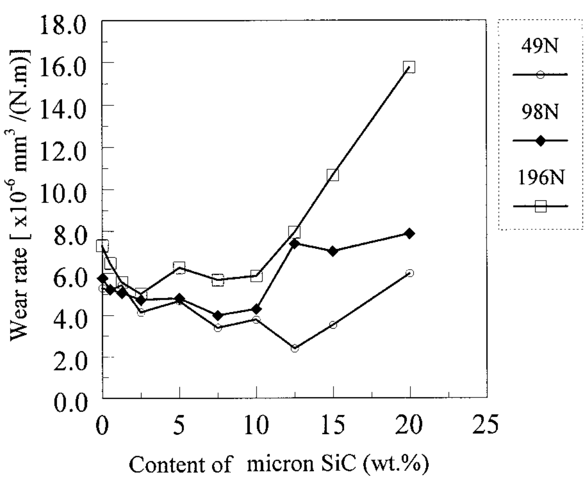

Figure 4 The wear rate under various loads as a function of the micron SiC content in the filled PEEK (sliding velocity, 0.445 m/s).

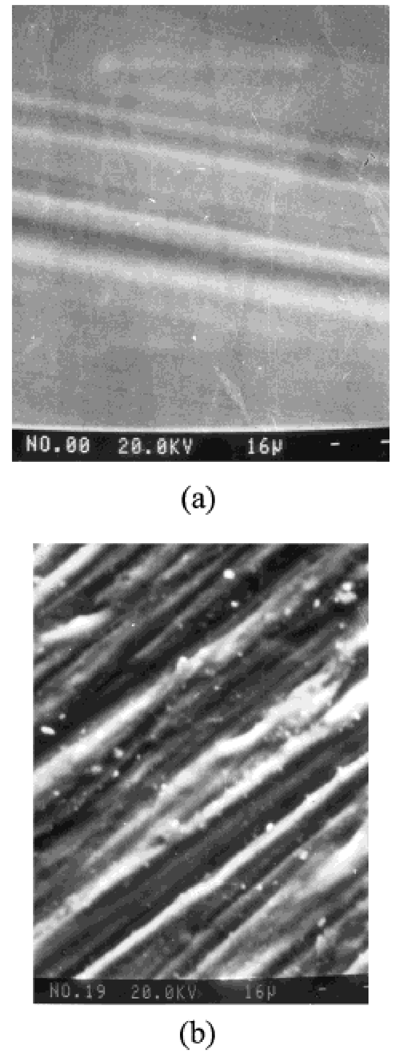

Figure 5 SEM micrographs of the worn surfaces of (a) unfilled PEEK and (b) PEEK-SiC composite (load, 196 N; sliding velocity, 0445 m/s; test duration, 90 min).

SEM and EPMA Observation of Worn Composite Surface and Transfer Film on Counterpart Steel Surface

Figure 5 shows the SEM micrographs of the worn surfaces of unfilled PEEK and the PEEK-2.5 wt % SiC composite sliding against the AISI 1045 steel ring under the same test conditions. The worn surface of the unfilled PEEK shows some signs of scuffing and adhesion while that of the PEEK-SiC composite has obvious signs of scuffing, plastic deformation, and adhesion. The severe plastic de-

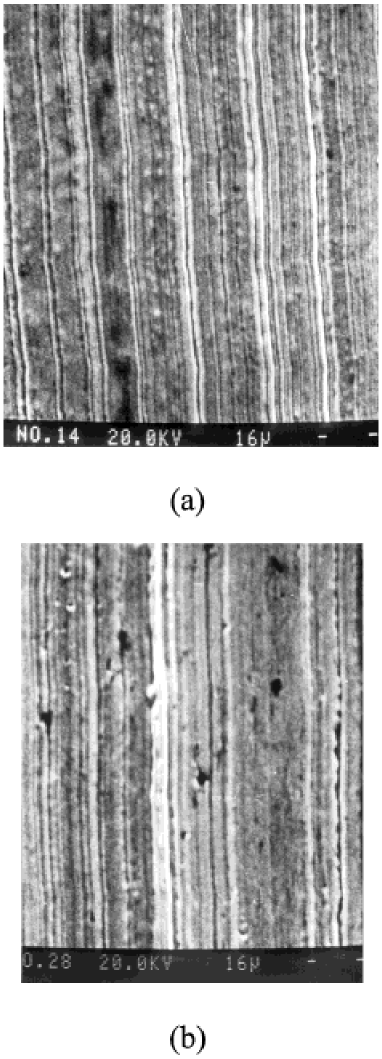

Figure 6 SEM micrographs of the transfer films (a) against unfilled PEEK and (b) against PEEK-2.5 wt % SiC (same conditions as in Fig. 5).

formation in the worn PEEK-SiC composite surface could be attributed to the abrasive action of the SiC particles during the friction process. And the difference in the worn surface morphologies of the unfilled PEEK and PEEK-SiC composite should be attributed to the action of the SiC filler because the two materials were tested at the same conditions. Subsequently, it can be concluded that the SiC particle filler in the PEEK brought about the abrasion action to the composite friction surface. Interestingly, the SEM morphologies of the corresponding transfer films in Figure 6 demonstrate that the transfer film on the steel counterpart against the PEEK-SiC composite is somewhat thinner and nonuniform compared to that against the unfilled PEEK. This observation also indicates that the SiC particle filler acted as an abrasive to abrade the transfer film, similar to what was observed for the worn PEEK-SiC composite surface. The adhesion and transfer for the frictional couples is also demonstrated by the typical element distributions in the worn composite surface and in the transfer films. As shown in Figure 7, the existence of Fe in the worn composite surface and the detection of Si in the counterpart steel surface indicate that the transfer of counterpart iron onto the composite surface and the transfer of SiC in the composite onto the counterpart steel surface both occurred during the friction process. Accordingly, the dominant wear mechanisms for PEEK-SiC against

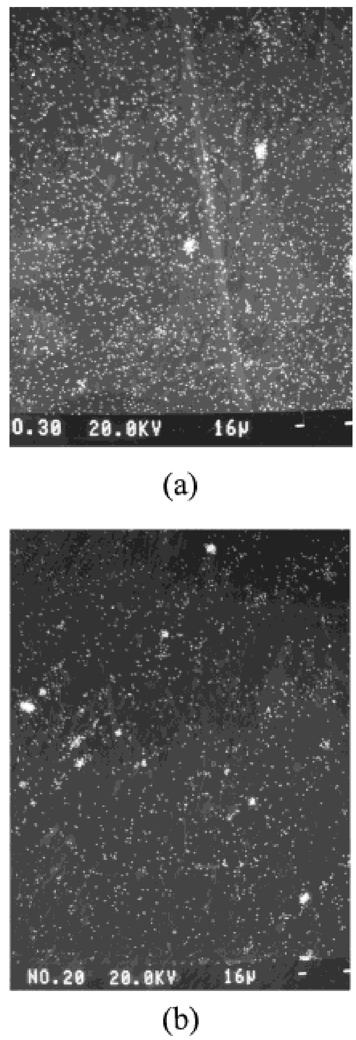

Figure 7 The distributions of (a) the Si element in the counterpart worn steel surface and (b) the Fe element in the worn composite surface (same conditions as in Fig. 5).

steel are abrasive and adhesion wear and plastic deformation. Those for unfilled PEEK are adhesion and scuffing.

CONCLUSIONS

The tribological properties of micron SiC filled PEEK sliding against a plain carbon steel ring were investigated under ambient dry conditions. We found that a low content of micron SiC (below 7.5 wt %) in PEEK slightly reduced the friction and wear of the PEEK composite. In combination with the friction coefficient and wear rate, the optimal content of micron SiC in the filled PEEK was suggested as 2.5–5.0 wt %. The dominant wear mechanisms for the PEEK-SiC composite were scuffing, plastic deformation, and adhesion; those for unfilled PEEK were scuffing and adhesion. And the difference in the worn surface morphologies and wear mechanisms of the unfilled PEEK and PEEK-SiC composite was attributed to the action of the SiC filler.

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