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EFFECTS OF BLENDING PROPORTION ON TRIBOLOGICAL PROPERTIES OF PI/UHMWPE COMPOSITES UNDER RECIPROCATING SLIDING CONDITION

TRACK OR CATEGORY

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AUTHORS AND INSTITUTIONS

Song Chen, Haitao Duan*, Jian Li
State Key Laboratory of Special Surface Protection Materials and Application Technology, Wuhan Research Institute of Materials Protection, Wuhan 430030, Hubei, China
* Corresponding author. E-mail:duanhaitao2007@163.com, Tel: +86-027-83641630.

INTRODUCTION

Due to the low friction, good self-lubricating performance, excellent chemical stability and impact toughness, ultra-high molecular weight polyethylene (UHMWPE) has been widely used in tribological applications [1-3]. However, pure UHMWPE has low thermal deflection temperature (about 78.9°C at 0.46MPa, 46.1°C at 1.8MPa, ASTM D648), which limits its application at high temperature [4]. Conventional approach to overcome such drawbacks of pure UHMWPE is to blend UHMWPE with highly heat-resistant ceramic materials. By using above-mentioned materials as fillers, the UHMWPE-based composites exhibit improved heat resistance. Unfortunately, ceramic materials are inclined to retain their solid form in the process of fabrication, so they have low interfacial compatibility with UHMWPE. Polyimide (PI) is a good class of polymers to blend with UHMWPE, as it produces composites with high thermal degradation temperature, and has better compatibility than ceramic materials. However, available literature on the fabrication and properties of PI/UHMWPE composites is still rather lacking. In this study, hot-press molding was used to fabricate PI/UHMWPE composites. A reciprocating ball-on-flat contact tribometer was then used to investigate the tribological properties of the molded composites. This study presents an attempt to fabricate new composites with excellent tribological properties when used at an environment with a temperature beyond the thermal deflection temperature of UHMWPE.

EXPERIMENTAL DETAILS

Dry sliding wear tests with a reciprocating ball-on-flat contact tribometer (Rtec Instrument, USA) under working environment temperature of 100°C were conducted. The specimen was moved back and forth repetitively under a stationary ball. The experimental parameters were arranged as shown in Table 1. Prior to wear test, the polished specimens were ultrasonically cleaned in ethyl alcohol bath and then dried for 24 hours in a drying oven with constant temperature set at 25°C. The reciprocating stroke was constantly set at 8 mm running with a frequency of 6 Hz. An analog-to-digital converter was used to measure friction coefficient which was stored and recorded in a personal computer. After sliding experiments a JSM-6510LV scanning electron microscope (SEM, JEOL, Japan) and a MICRLMEASUER2 confocal scanning optical microscope (Sciences et Techniques Industrielles de la Lumière, France) were used to scan the changes of micro-topography of the specimen surfaces.

Table 1. Experimental parameters of dry sliding wear tests

Ball specimens			Flat specimens			Sliding speed (m/s)	Sliding time (s)	Force (N)
Material	Size (mm)	Roughness (nm)	Material	Size (mm)	Roughness (nm)			
GCr15	φ6.4	300~600	Composites	20×10×7	100~230	0.048	1800	50

RESULTS AND DISCUSSION

The friction coefficients of the composite/GCr15 sliding pairs with different blending proportion are plotted as a function of test time in Fig. 1(a). To investigate the influence of blending proportion on the friction coefficient, mean values of friction coefficients after a run-in period (normally in the range of 550~1750s) are therefore calculated, which are then plotted as a function of PI content in Fig. 1(b). The plots show the decrease in friction coefficients of composites/GCr15 with the increase in the 0~50% PI. However, the friction coefficient tends to increase again as the proportion of PI is increased beyond 50%. The composite with 50% PI is the best to reduce friction coefficient, and its friction coefficient has reduced 43.1% compared to pure UHMWPE.

On the basis of the molecular-mechanical theory of dry sliding friction of polymeric materials, the friction force is defined as the sum of the tangential resistance caused by mechanical engagement and the deformation ability of molecule chains under a shear force [5]. Hence, the results in Fig. 1(b) can be explained by: (i) the increase in PI content from 0~50% enhance its surface hardness and heat resistance – its flat surface to be indented by GCr15 ball only constituting with shallow indentations and subsequently causing relatively lower friction coefficient; (ii) the increase in the content of PI beyond 50% increase the rigid chemical groups in the composites – reducing the deformation ability of molecular chains to sustain shear force taking place and thus resulting in large friction coefficient between the sliding pairs; and (iii) the competitive mechanism of the above two factors cause the first reduction and then increase in friction coefficient.

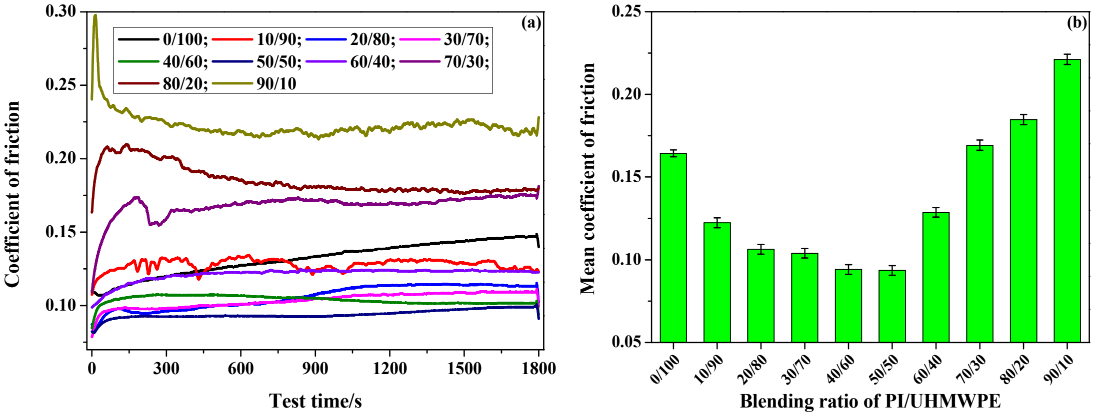

Fig. 1. Friction coefficients of composite/GCr15 sliding pairs: (a) friction coefficient against test time; (b) mean friction coefficient against blending proportion.

Fig. 2 shows the optical micrographs of wear scar on the post-test PI/UHMWPE composite surfaces with different PI content. The strip shape of wear scratches for the mass percentage of PI below 50% tends to conform to the penetrating depth of GCr15 ball. However, the boat shape of PI/UHMWPE surface with PI content above 60% is likely caused by the collateral loss during sliding. There exist two stages with the increase of PI mass fraction. The first stage mainly consists of the specimens having PI content below 50%. The abraded depth, width and abraded volume loss in the first stage decrease at a lower rate. In the second stage, the specimens with PI content beyond 50% show higher abrasion. The composite filled with 50% PI is the best to reduce wear rate. By measuring the change values, it is found that the abraded depth, abraded width and abraded volume loss have reduced 54.7%, 26.4% and 66.7% as compared to pure UHMWPE, respectively.

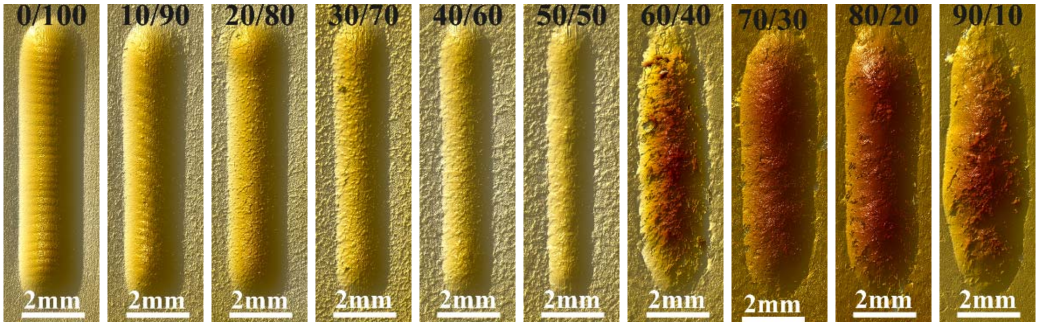

Fig. 2. Optical micrographs of wear scratches on PI/UHMWPE surfaces.

SEM images, with magnification of 100×, of the worn surfaces of the PI/UHMWPE composites with various PI content are illustrated in Fig. 3. For those composites with PI content below 10%, their worn surfaces show sights of plastic deformation and viscoelastic flow, indicating the main wear mechanism to be adhesive in nature. For those composites with PI content in between 30~50%, only few worn traces are observed on the worn surfaces which still looked mirror-like smooth and clean, suggesting low wear rate taking place with the composites having PI content in the range of 30~50%. For the composites with PI content beyond 70%, fatigue micro-cracks are identified on the worn surfaces and such cracks grew with the increase of PI content, implying the main wear mechanism to be fatigue mode.

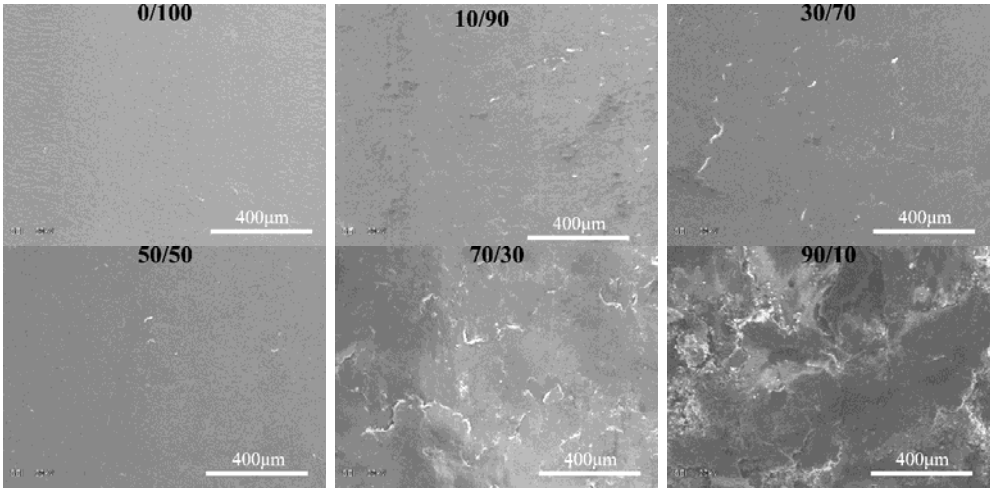

Fig. 3. SEM images of the worn surfaces for PI/UHMWPE composites.

CONCLUSIONS

In this study, tribological properties of PI modified UHMWPE composites were studied with a reciprocating ball-on-flat contact tribometer. Results show that:

(a) The friction coefficients of composites/GCr15 decrease with the increase in the 0~50% PI. However, the friction coefficient tends to increase again as the proportion of PI is increased beyond 50%. The composite with 50% PI is the best to reduce friction coefficient, and its friction coefficient has reduced 43.1% compared to pure UHMWPE.

(b) The abraded depth, width and abraded volume loss of the specimens having PI content below 50% decrease at a lower rate with the increase of the PI content, while the specimens with PI content beyond 50% show higher abrasion. The composite filled with 50% PI is the best to reduce wear rate, its abraded depth, abraded width and abraded volume loss have reduced 54.7%, 26.4% and 66.7% as compared to pure UHMWPE, respectively.

(c) The worn surfaces of those composites with PI content below 10% show sights of plastic deformation and viscoelastic flow, indicating the main wear mechanism to be adhesive in nature. Low wear rate has taken place with the composites having PI content in the range of 30~50%. For the composites with PI content beyond 70%, fatigue micro-cracks are identified on the worn surfaces and such cracks grew with the increase of PI content, implying the main wear mechanism to be fatigue mode.

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KEYWORDS

Polyimide; UHMWPE; Friction; Wear