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Friction and wear of fiber reinforced polyimide composites

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ABSTRACT

In the present work friction and wear of polyimides reinforced by carbon, glass and aramid fibers were studied and comparatively evaluated under dry sliding against sandpaper and steel rig as well as under three-body abrasive conditions. The worn surfaces of the composites were examined by scanning electron microscopy to reveal mechanisms of materials damage. Wear mechanisms are found to be dependent on test conditions. It was proven that reinforcements affect tribological properties of the polyimide composites to a great extent. The best performance under tests conditions was shown by inorganic fibers reinforced composites due to the effective sharing of the load between surfaces in contact. Brittle glass fibers have not contributed into improvement in wear resistance under three-body abrasive conditions due to insufficient support from polyimide matrix.

1. Introduction

Polymers are extensively used in mechanical engineering as structural and tribo-materials because of their outstanding properties, such as high strength, light weight, excellent thermal stability, combined with wear and solvent resistance. These excellent properties widely broaden the applications in automotive, aerospace and electronic industries [1–5]. The development of lightweight composites, especially polymeric composites reinforced by fibers, has been of paramount importance over decades. Carbon, glass and aramid fibers have been widely employed as the reinforcements in polymer matrix [6–12]. Carbon fibers reinforced polymer composites exhibit higher modulus, lower coefficient of friction and better wear resistance as compared to a neat polymer when tested against smooth steel surfaces [13]. Glass fiber reinforced materials possess high mechanical strength and demonstrate excellent wear resistance. Moreover, glass fibers are widely available and quite inexpensive [14]. Organic aramid fibers have received special attention because of their high tensile strength and elastic modulus combined with good thermal and radiation resistance as well as low specific density [15–17].

One of the most important characteristics of the materials is their wear resistance in wide variety of possible applications. Polymer matrix composites have been extensively evaluated as tribomaterials [18–22]. Particularly, three-body abrasive wear has been widely studied using a sand feeder to introduce silica particles into a sliding contact zone of frictional pair [21,22]. The performance of polymers sliding against hard and smooth counterface is determined by the transfer ability and buildup of a polymer film. Efficiency of materials in reducing friction and wear depends on the molecular polymer structure and counterface type [23]. However, only few publications are available on the comparison of the tribological properties of composites under dry sliding and abrasive wear conditions [24–26].

Three types of polyimide composites reinforced by different fibers and unfilled base polyimide were prepared using a hot press molding technique. The main objective of the present work was comparative critical evaluation of friction and wear behavior of the materials under dry sliding against silicon carbide sandpaper and steel ring; as well as under three-body abrasive condition against rubber wheel to study the effect of reinforcements on tribological performance and wear mechanisms of the polyimide based composites.

2. Experimental

2.1. Materials

Polyimide (PI) YS-20 grade powder (Shanghai Synthetic Resin Institute, China) of particles size <75 μm and specific density of 1.4 g cm^{-3} was used for composites fabrication by means of a hot press molding technique, which is the most common technique for the sintering of PI composites. Fixed volume content of the fibers of 15 vol% was chosen according to [27]. The mixtures were

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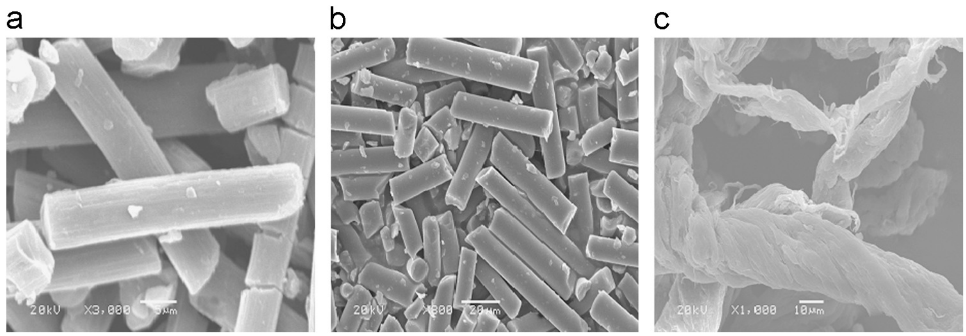

Fig. 1. SEM images of the reinforcements: (a) carbon fibers, (b) glass fibers, (c) aramid fibers.

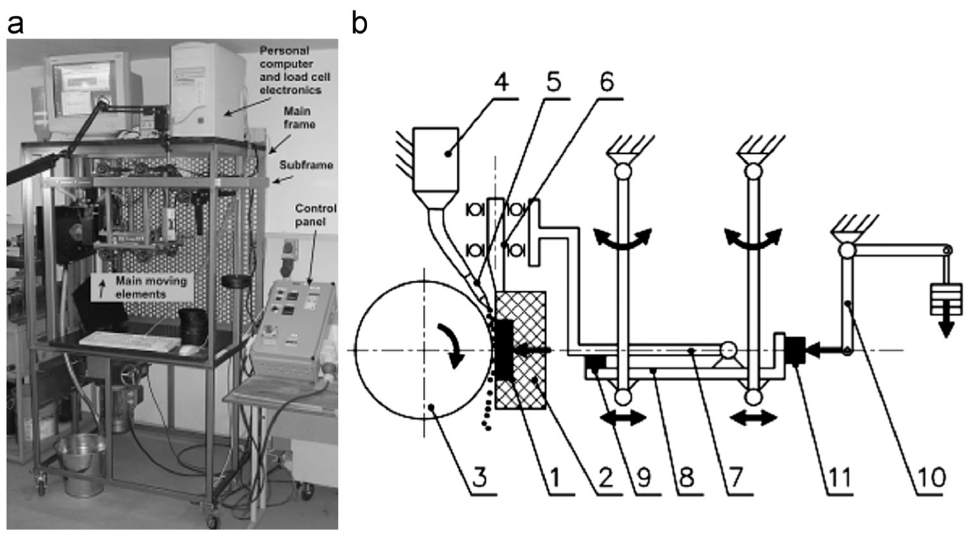

Fig. 2. (a) Photograph of Multifunctional modular tribosystem; (b) main moving elements of the MMT system: 1: sample; 2: holder; 3: wheel; 4: bunker; 5: nozzle; 6: ball bearings; 7: suspension; 8: platform; 9 and 11: sensors; 10: load system.

compressed and heated up to 380° C in a mold with intermittent deflation. The pressure was held at 20 MPa for 60 min to allow full compression sintering. At the end of each run of compression sintering the processed specimens were cooled on air in a stove and cut into preset sizes for testing.

The carbon fibers (Nantong Senyou Carbon Fiber Co., Ltd., China) with length of 20–50 μm and the diameter 7 μm; the glass fibers (Nanjing Institute of Glass Fiber Research and Design, China) of 10 μm in diameter and 10:1 aspect ratio; as well as the aramid fibers (Shanghai Ruiyan Trading Co., Ltd., China) with length ranged between 75 and 125 μm and diameter of about 25 μm were imbedded into the polymer matrix as reinforcements. Representative scanning electron micrographs of the reinforcements are shown in Fig. 1.

2.2. Experimental details

2.2.1. Dry friction against steel ring

A multifunctional modular tribosystem (MMTS), as shown in Fig. 2 [28], was employed for materials testing under dry friction against steel ring similar to ASTM G137-97. Friction and wear behavior of the composites rotating against a GCrl5 steel ring of 85 mm in diameter and 10 mm in width were evaluated on a block-on-ring tribometer at a tangential speed of 1 m s^{-1} and a load of 30 N at room temperature. The size of the test sample was 5 mm × 15 mm × 25 mm. The chemical composition of a counterpart was as following: C 0.95–1.05 wt%, Si 0.15–0.35 wt%, Mn 0.25–0.45 wt%, P ≤ 0.025 wt%, S ≤ 0.025 wt%, Cr 1.40–1.65 wt%, and Fe balance. A bulk hardness of HRC 65 ± 5 has been specified by supplier. Before each test, the steel ring and the block were thoroughly cleaned with cotton dipped in acetone.

The MMTS consists of a main frame, three sub-frames, base plates, personal computer, electronics to record sensor (cell) signals, control panel with motor frequency controller, programmable disc shaft tachometer/counter enabling stopping after required number of rotations and main moving elements (Fig. 2a). The principals of work and details are described elsewhere [29].

The sliding process can be generally divided into two stages: a running-in stage and a steady wear stage. In the most cases the sliding behavior in the steady stage is of a special concern, since it determines component durability. The values of the COF and wear rates refer to the mean values in the steady stage, and each result is an average value of at least three repeated tests.

The wear loss ΔV of the specimen was calculated as following:

$$\Delta V\left[\frac{\pi(R/2)^2}{180}\ \arcsin\ \frac{b}{R}-\frac{b\sqrt{(R/2)^2-(b/2)^2}}{2}\right]B \tag{1}$$

Where ΔV is the wear volume loss (mm^3), R is the diameter of the ring (85 mm), b is the length of the wear trace (mm), B is the width of the wear trace (10 mm). The specific wear rate K (mm^3 N^{-1} m^{-1}) was calculated using value of the volume loss:

$$K=\frac{\Delta V}{PL} \tag{2}$$

where P is the applied load (N), and L is the sliding distance (m).