

Experimental investigation on tribological behavior of several polymer materials under reciprocating sliding and fretting wear conditions



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ABSTRACT

This work comparatively studied the friction and wear behaviors of the six polymers (UHMWPE, PTFE, Phenolic, PHBA, PEEK and PI) under reciprocating sliding and fretting wear conditions. Hopefully, the results could contribute to provide some guidance for use and selection of materials. By investigating their friction and wear values, the morphologies of the worn surfaces and microstructures, the corresponding wear mechanisms under the two wear modes were analyzed in detail. It was also discussed the relationship between the microstructure and tribology performances of materials. The results showed that the sliding wear resistance of material was different with its fretting wear resistance. Fretting wear resistance increased orderly: PTFE < UHMWPE < PHBA < PI < PEEK < Phenolic.

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1. Introduction

Compared to the traditional metal and ceramic materials, high-performance polymer materials have shown some excellent properties, such as lightweight, flexibility, excellent corrosion resistance, good processability and low cost, which make them an obvious choice for replacing metallic and ceramic components [1–3]. Nowadays, polymeric materials are increasingly used in various assemblies or equipment such as gears, bearings, joints, seals, food conveyor, semiconductor, car elements etc. under dry, steam and chemical environment [4–6]. Ensuring a good match of the polymer materials under applied conditions is critical for the durability and reliability of components [7]. When these polymeric components inevitably experience relative movement for a long time, wear is considered to be one of the most common factors in material loss and failure. In the last decades, the friction and wear behaviors of polymers attract extensive interests from both academia and industry [8]. But this is a tough thing because the wear performances are not only dependent on the material properties but also the contact conditions, and can't be predicated from the well-established laws [9,10].

The linearly reciprocating sliding wear and fretting wear are two common fundamental wear modes. According to ASTM G133–2005, the direction of the relative motion between reciprocating

sliding surfaces reverses in a periodic fashion. While fretting wear can be defined as small amplitude oscillatory motions between two solid surfaces in contact [11]. It differs from the sliding wear in two aspects: (1) very low relative displacement between the contact surfaces (range typically between 10 and 100 μm [12]), and (2) most parts of the wear debris are trapped in the contact zone [13,14]. The very small oscillatory movements between interfaces cause cracks to nucleate and grow with repeated motion, leading to premature catastrophic failures [14,15]. To prevent fretting damage, fretting wear has been widely studied for more than fifty years [12]. Most researchers have focused on fretting behaviors of metals rather than polymers. But application of fretting theories of metals to polymers has been challenging and little fundamental knowledge exists [16]. Moreover, polymers are easily extruded out of the contacting region at high load even at very small displacement due to their pliability; therefore it is a difficult thing to distinguish the fretting wear from the case of reciprocating sliding [17]. This makes it harder to study the fretting wear properties of polymers.

With the increasing use of polymers in a wide variety of engineering applications, it is necessary to study their own unique response to fretting wear [16]. Just a few of works are carried out to investigate the tribological behaviors of polymers under the fretting wear conditions [14]. Among the studies of fretting wear of polymers, most researchers have been marking continuous efforts to improve their fretting wear resistances by filling various fibers and solid lubrications. For example, the fretting wear behaviors of PEEK was improved by filling with nanometer Al_2O_3 and

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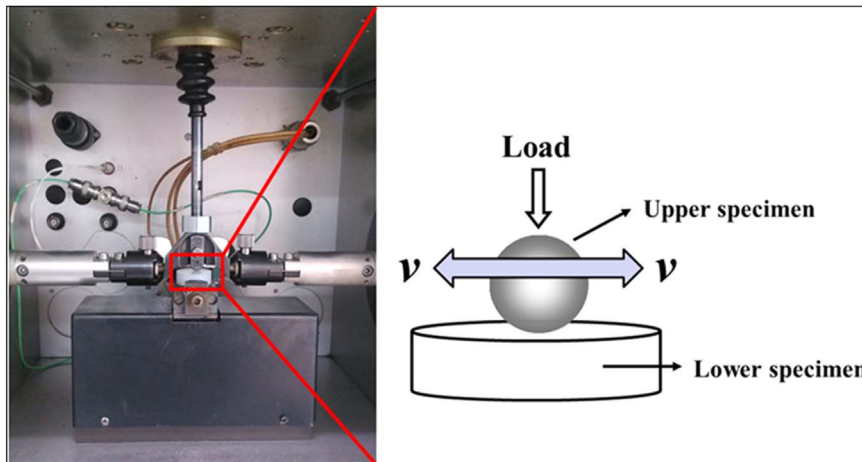


Fig. 1. The contact schematic of the frictional couple [39].

Table 1
Some properties of the six polymer materials.

Material	ρ^{exp} (g cm^{-3})	ρ^{rel} (g cm^{-3})	T_g ($^{\circ}\text{C}$)	T_m ($^{\circ}\text{C}$)	Hardness (Shore (D))
UHMWPE	0.930	0.930	–	136.5	67
PTFE	2.16	2.165	–	328.0	61
Phenolic	1.20	1.219	–	–	92
PHBA	1.45	1.417	–	–	83
PEEK	1.32	1.312	148.8	340.0	88
PI	1.38	1.369	240.6	–	85

SiO_2 [18]. ZnO and Ag nanoparticles can synergistically improve the fretting wear behavior of UHMWPE [6]. Polyamide 12 reinforced by the optimum concentration of short carbon fibers and PTFE has an excellent wear performance in adhesive and fretting wear modes [19]. Fillers boosted the tribo-performance of a pure polymer, however, at the cost of worsening the performance [19,20]. In order to obtain a clear relationship between the tribological behaviors and the structures and the properties, it is necessary to choose the pure polymers. Only Guo and Luo investigated the fretting wear resistance for twelve unfilled plastics, and found that the wear damages were related to the heat resistance of materials and the frictional heat produced during fretting [14,21]. It is a well-accepted fact that no single polymer material performs the best or worst in all wear modes [20]. So it is important to know the tribological behaviors of the materials in various wear conditions during the process of the material selection. Unfortunately, less is reported on the systematic studies on wear behavior of materials in different wear situations, especially in the case of reciprocating sliding wear and linearly fretting wear [20]. This means the different performances of polymers under the two wear modes are not clear. This clearly shows the necessity to study the tribological behaviors of the unfilled polymers under the two wear modes.

In this research, ultra-high molecular weight polyethylene (UHMWPE), polytetrafluoroethylene (PTFE), phenolic resin (Phenolic or PR), poly (phenyl p-hydroxybenzoate) (PHBA), polyetheretherketone (PEEK) and polyimide (PI), the six polymer materials were chosen because of their wide use in various environments. The tribological measurements were conducted on the six polymer materials to compare their reciprocating sliding and fretting wear behaviors. The tests have been performed using an oscillating reciprocating friction and wear tester. By comparing their friction and wear values, the morphologies of the worn surfaces and microstructures, the corresponding wear mechanisms of materials at the two test conditions were analyzed in

detail. In addition, the relationships between microstructures and tribology performances of materials have been discussed. Hopefully, the findings reported here will help to provide some guidance for use and selection of polymer materials which is more suitable for the reciprocating sliding or fretting wear conditions.

2. Materials and methods

2.1. Materials

Commercial GUR 4150 UHMWPE powders (Ticona Co., USA) were used in the present study. It was in the form of white powder with an average molecular weight of $9.2 \times 10^6 \text{ g mol}^{-1}$ and a density of 0.93 g cm^{-3} . PTFE powders (the average particle size of $25 \mu\text{m}$ and the density of 2.16 g cm^{-3}) were supplied by Shanghai 3 F New Materials Co., Ltd (China). Phenolic powders (FB88#, the density of 1.70 g cm^{-3}) were purchased from Bengbu Tianyu High Temperature Resin Material Co., Ltd (China). PHBA powders with a particle size of $10\text{--}21 \mu\text{m}$ and density of 1.45 g cm^{-3} were obtained from Zhonghao Chenguang Research Institute of Chemical Industry (China). PEEK powders (VESTAKEEP 4000 FP, the average particle size of $65 \mu\text{m}$ and the density of 1.32 g cm^{-3}) were procured from Degussa Co., Ltd (Germany). PI powders (YS-20, the average particle size of $30 \mu\text{m}$ and the density of 1.38 g cm^{-3}) were supplied by Shanghai Research Institute of Synthetic Resins (China).

2.2. Preparation of materials

A hot compression molding technique was utilized to prepare the specimens of UHMWPE, Phenolic, PHBA, PEEK and PI. UHMWPE powders were filled into a mould and sintered at the pressure of 10 MPa and temperature of $200 \text{ }^{\circ}\text{C}$ for 30 min in a stove. Phenolic powders were heated to $180 \text{ }^{\circ}\text{C}$ and kept this temperature for 75 min while the pressure was held at 15 MPa. The PHBA was sintered at the pressure of 20 MPa and temperature of $380 \text{ }^{\circ}\text{C}$ for 30 min. PEEK powders were compressed and heated to $367 \text{ }^{\circ}\text{C}$ in a mould. While the pressure was held at 3 MPa for 100 min in order to full compression sintering. And the PI was maintained at $375 \text{ }^{\circ}\text{C}$ and kept this temperature for 30 min under the pressure of 15 MPa. At the end of each sintering process, the target specimen was naturally cooled to room temperature. While PTFE powders were filled into a mould at room temperature and compressed at the pressure of 30 MPa for 10 min, and then followed by sintering in a stove at $380 \text{ }^{\circ}\text{C}$ for 3 h.

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