



## Short Communication

## Exploring the influence of counterpart materials on tribological behaviors of epoxy composites



Huimin Qi<sup>a,b</sup>, Ga Zhang<sup>a,\*</sup>, Bernd Wetzel<sup>c</sup>, Werner Österle<sup>d</sup>, Tingmei Wang<sup>a</sup>,  
Qihua Wang<sup>a</sup>

<sup>a</sup> State Key Laboratory of Solid Lubrication, Lanzhou Institute of Chemical Physics, Chinese Academy of Sciences, Lanzhou 730000, China

<sup>b</sup> University of Chinese Academy of Sciences, Beijing 100049, China

<sup>c</sup> Institute for Composite Materials (IVW), University of Kaiserslautern, 67663 Kaiserslautern, Germany

<sup>d</sup> Federal Institute for Materials Research and Testing (BAM), 12205 Berlin, Germany

## ARTICLE INFO

## Article history:

Received 3 May 2016

Received in revised form

9 August 2016

Accepted 12 August 2016

Available online 13 August 2016

## Keywords:

Counterpart materials

Transfer film

Epoxy composites

Nanoparticles

## ABSTRACT

The dependence of the friction and wear of epoxy (EP) composites materials on counterpart materials, such as standard bearing steel, medium carbon steel and chrome-plating (Cr), was investigated. The conventional composite filled with short carbon fiber (SCF) and graphite shows the highest tribological performance when rubbing against Cr, whereas, the hybrid nanocomposite (EP filled with SCF, graphite and silica nanoparticles) exhibits the lowest friction and wear when sliding against the standard bearing steel. The role of nanoparticles in the tribological performance is distinctly different when sliding against with various counterpart materials. It is demonstrated that counterpart materials exert an important influence on material transfer, tribo-oxidation and mechanical mixing of wear products, resulting in the different formation mechanisms of transfer film.

© 2016 Elsevier Ltd. All rights reserved.

## 1. Introduction

Polymer-metal sliding pairs are being widely utilized in industry as important tribo-engineering components, not only for ease in manufacture, but also for their potentially excellent tribological performance in engineered forms [1–4]. Great efforts have been dedicated in the last decades to the tribological mechanisms of polymer-based materials [5–8]. Series of high-performance composites were successfully developed under specific application conditions, e.g. pv factors (pressure × velocity) and temperatures.

In general, one believes that high-performance composites exhibit great abrasion resistance. Moreover, in-situ formation of lubricating transfer film on the steel counterface is identified to be a key factor dominating the friction and wear of polymeric materials [7,9]. Herein, reinforcing fillers, e.g. carbon, glass and aramid fibers, are added into polymer matrix to enhance its load carrying capability and abrasion resistance. Short carbon fibers (SCF) possess high strength, modulus and low expansion coefficient and therefore they have been widely used in polymer matrix as reinforcements [10–12]. However, it is hard to develop low friction and high anti-wear polymer composites only with SCF. In

order to increase the applicability of SCF reinforced composites, it is imperative to seek for effective ways to further improve their friction and wear behaviors. As we all know, layer structured solid lubricants are apt to transfer to the counterface and thereby, lead to the formation of a lubricating transfer film [13,14], which can improve the friction-reducing and anti-wear ability of SCF reinforced composites effectively.

In addition, it was demonstrated that the incorporation of ceramic nanoparticles into polymer matrix and fiber reinforced polymer composites resulted in the generation of a “high quality” transfer film [15–17]. Harris et al. [8] recently reported that when polymer polytetrafluoroethylene (PTFE)/nano-aluminum oxide (Al<sub>2</sub>O<sub>3</sub>) composites was slid against 304 stainless steel counterbody, broken PTFE chains underwent a series of reactions and chelated to both the metal surface and the alumina filler particles. Our recent work [2,18] revealed that when hybrid nanocomposites filled with both silica (SiO<sub>2</sub>) nanoparticles and carbon fibers (CF) were slid against bearing steel, a silica-based transfer film was obtained. Based on comprehensive characterizations of the nanostructures of the transfer films, we proposed that mechanical mixing of wear products and tribo-sintering of nanoparticles are the main mechanisms governing the transfer film formation [2,18]. It was manifested that nanoparticles and the conventional fillers, i.e. SCF and solid lubricants, play a synergetic role in enhancing the tribological performance of polymer [11–14].

It should be noted that the tribological behavior of polymer-

\* Corresponding author.

E-mail address: [gzhang@licp.cas.cn](mailto:gzhang@licp.cas.cn) (G. Zhang).

metal sliding pair is a system property and is not only related to the polymer but also to counterpart materials. Better understanding of the friction mechanisms of polymers sliding against different counterpart materials is beneficial to design perfect matching friction pairs. In particular, physical interactions and tribo-chemical reactions occurred on the sliding interface play an important role in the structure of the transfer film [8,16,19]. Bahadur et al. and Gao investigated how polyphenylene sulfide (PPS) and PTFE react with fillers and counterpart steels, respectively [16,19]. Chen et al. reported that different grades of steel resulted in various tribological behaviors of polyamide 66 composites when subjected to rolling–sliding contact [20]. Therefore we believe that besides the structure of polymeric materials, the property of counterparts can exert an important influence on the interface behavior of the sliding pair. Nevertheless, majority of investigations on the tribological behaviors of polymer composites focus on the effects of composites' structures and running conditions. To the best knowledge of the authors, in most of reported works only bearing steel, stainless steel and carbon steels were used as counterpart materials. However, few studies directly investigated the effect of counterpart materials on the tribological mechanisms of polymer composites [21–25].

In fact, various counterpart materials were utilized in reality, design of best matching tribo-pairs becomes important. Standard bearing steel and medium carbon steel are widely used counterpart materials rubbing with polymer composites in various applications [20–23]. Moreover, in order to inhibit severe tribo-oxidation of steel counterparts, chromium coatings were electro-deposited on the surface of counterparts sliding against polymeric materials. It is deemed that the distinct chemical compositions of the counterpart materials can exert a role on tribo-chemical reactions, and thereby affect transfer film formation. However, the lack of a solid understanding on the influencing mechanisms of the counterpart materials can become a hurdle for optimizing the performance of the matching pairs. It is therefore of both fundamental and practical interests to explore the mechanism how counterpart materials affect transfer film formation and tribological behaviors of polymer composites.

In this work, the friction and wear properties of conventional epoxy (EP) composite materials (EP filled with SCF and graphite) as well as hybrid nanocomposite (EP filled with silica nanoparticles, SCF and graphite) when being slid against standard bearing steel, medium carbon steel and chrome-plating were compared. The structures of transfer films formed on the surfaces of the three different counterparts were analyzed and the influencing mechanisms of counterpart materials on the tribological performance of EP composites were explored. Most importantly, this work extends the current research on tribology of epoxy composites and it can provide theoretical guides for designing polymer-metal sliding pairs by simultaneously considering both the polymer and metallic materials.

## 2. Experimental

### 2.1. Material preparation

Diglycidyl ether of bisphenol A epoxy resin (DER331, DOW) and Cycloaliphatic amine hardener (HY 2954, Huntsman) used as curing agent were utilized for preparing EP composites. The SiO<sub>2</sub> nanoparticles were supplied as colloidal silica masterbatch (Nanopox F400, Evonik) and in-situ synthesized with the diameter of 20 nm. Polyacrylonitrile (PAN)-based short carbon fibers (SCF) were added into EP resin used as reinforcing fillers (Tenax, A-385). The diameter and length of the SCF are 7 μm and 40–70 μm, respectively (Fig. S1a). Graphite (RGC39TS, Superior Graphite)

**Table 1**  
Abbreviated forms and specific compositions of polymer specimens used (vol%).

Abbreviated form	EP	SCF	Graphite (Gr)	SiO <sub>2</sub>
EP/SCF/Gr	82	10	8	0
EP/SCF/Gr/ SiO <sub>2</sub>	77	10	8	5

particles were used as solid lubricant and have an average size of 4 μm (Fig. S1b). Graphite flake has a layer structure and the carbons in the same layer are combined by covalent bond to form hexagons, while intermolecular forces exist between layers, which are beneficial to slip during sliding process. The SiO<sub>2</sub> masterbatch was diluted with EP resin, and then required amounts of milled carbon fibers and graphite flakes were mixed in the resin using a vacuum dissolver (Dispermat, VMA-Getzmann). After being blended with the curing agent, the mixture was cured at 70 °C for 8 h, followed by 8 h at 120 °C. The abbreviated forms and the composition of EP composites were listed in Table 1.

### 2.2. Tribological tests

Dry friction tests were performed at room temperature using a Pin-On-Disc test rig (POD, Wazau, Germany). The testing species had a dimension of 4 × 4 × 12 mm<sup>3</sup> and the contact surface against a stationary counterface was 4 × 4 mm<sup>2</sup>. The diameter of the wear track was 33 mm and the schematic diagram of POD was shown in Fig. S2. During the tests, three different metallic counterparts i.e. 100Cr6 (EN 10,084-1998, widely used standard bearing steel), St50-2 (DIN 17,100, medium carbon steel, non-alloy steels for general structural applications), and Cr were used. Cr was obtained by chromium electroplating on the surface of 100Cr6 at Lanzhou Flight Control Co., Ltd., China with the plating thickness of 20 μm and the average deposition rate of the Cr coating 8.33 nm/s. During the electroplating process, 100Cr6 was used as the cathode and pure chrome plate was used as anode. The chemical equations for chromium electroplating were shown in Fig. S3. The compositions of 100Cr6, St50-2 and Cr were listed in Table 2. The Martens Hardness was measured by Shimadzu DUH-202 with the pressure of 1000 mN and the hardness of 100Cr6, St50-2 and Cr is 6870, 2311 and 6192, respectively. The metallic counterfaces were finished by mechanical grinding and the average roughness, *R<sub>a</sub>*, was controlled at about 0.30 μm. The disks were cleaned with acetone in an ultrasonic bath before tests.

Each test lasted 20 h, allowing the system to reach a steady friction and wear process. The sliding velocity was fixed at 1 m/s, and the contact pressures were 1 MPa and 3 MPa, respectively. The friction coefficients were measured online by a torque sensor. At least three specimens were tested under each condition to calculate the average friction coefficient and wear rate. The specific wear rate *W<sub>s</sub>* (mm<sup>3</sup>/Nm) was defined as material volume loss per load (*N*) and per sliding distance (*m*), calculated from the volume loss using the following equation:

$$W_s = \Delta M / (\rho \cdot F \cdot L) \quad (\text{m}^3/\text{Nm}) \quad (1)$$

where  $\rho$  was the density of polymer composite, *F* was normal load applied on polymer specimens (64 *N*), and *L* was total sliding distance (*m*). The worn surfaces of polymer composites and transfer films formed on the disks' surfaces were inspected with a Field Emission Scanning Electron Microscope (FE-SEM, Zeiss, Germany). The elemental compositions of the transfer films were analyzed by using an Energy Dispersive X-Ray Spectroscopy (EDX) instrumented onto the FE-SEM.

Download English Version:

<https://daneshyari.com/en/article/614081>

Download Persian Version:

<https://daneshyari.com/article/614081>

[Daneshyari.com](https://daneshyari.com)