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Study on the friction and wear properties of glass fabric composites filled with nano- and micro-particles under different conditions

Feng-Hua Su[a,b], Zhao-Zhu Zhang[a,*], Wei-Min Liu[a]

[a] *State Key Laboratory of Solid Lubrication, Lanzhou Institute of Chemical Physics, Chinese Academy of Sciences, Lanzhou 730000, PR China*
[b] *Graduate School of the Chinese Academy of Sciences, China*

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Abstract

The glass fabric composites filled with the particulates of polytetrafluoroethylene (PTFE), micro-sized MoS_2, nano-TiO_2, and nano-$CaCO_3$, respectively, were prepared by dip-coating of the glass fabric in a phenolic resin containing the particulates to be incorporated and the successive curing. The friction and wear behaviors of the resulting glass fabric composites sliding against AISI-1045 steel in a pin-on-disk configuration at various temperatures were evaluated on a Xuanwu-III high temperature friction and wear tester. The morphologies of the worn surfaces of the filled glass fabric composites and the counterpart steel pins were analyzed by means of scanning electron microscopy, and the elemental distribution of *F* on the worn surface of the counterpart steel was determined by means of energy dispersive X-ray analysis (EDXA). It was found that PTFE and nano-TiO_2 particulates as the fillers contributed to significantly improve the friction-reducing and anti-wear properties of the glass fabric composites, but nano-$CaCO_3$ and micro-MoS_2 as the fillers were harmful to the friction and wear behavior of the glass fabric composites. The friction and wear properties of the glass fabric composites filled with the particulate fillers were closely dependent on the environmental temperature and the wear rates of the composites at elevated temperature above 200 °C were much larger than that below 150 °C, which was attributed to the degradation and decomposition of the adhesive resin at excessively elevated temperature. The bonding strengths between the interfaces of the glass fabric, the adhesive resin, and the incorporated particulates varied with the types of the particulate fillers, which largely accounted for the differences in the tribological properties of the glass fabric composites filled with different fillers. Moreover, the transferred layers of varied features formed on the counterpart steel pins also partly accounted for the different friction and wear behaviors of the unfilled glass fabric and the composites. In a practical viewpoint, 10% PTFE-filled glass fabric composite could be suitable to tribological applications at moderately elevated temperature.

Keywords: Glass fabric composite; Solid lubricant; Nanoparticulates; Filler; Friction and wear behavior

1. Introduction

Polymers and their composites form a very important class of tribo-engineering materials [1–4]. It has been found that many inorganic particulate fillers are effective to modify the physical and mechanical properties and hence to reduce the wear of the polymers as well. The modification and wear-reducing effects of the inorganic particulate fillers are highly dependent on the formation and characteristics of the transfer films generated on the counterface surface by way of the mechanical and tribochemical interactions among the polymer matrices, the fillers, the counterface metal, and the atmospheric oxygen, during the sliding process [5]. Moreover, it has also been extensively reported that the reinforcement of various matrices by fibers functions to increase the wear-resistance significantly [6–8]. For example, glass fiber has been attracting much attention in the modification and reinforcement of polytetrafluoroethylene (PTFE), owing to the good thermal stability and relatively low cost [12,13]. However, glass fiber as the reinforcing agent is usually insufficient to increase the wear-resistance of many polymers, since it is liable to brittle fracture during the sliding process and hence to cause severe scuffing of the polymeric matrix [13]. This

* Corresponding author. Tel.: + 86 931 4968098; fax.: +86 931 4968098.
E-mail address: zzzhang@ns.lzb.ac.cn (Z.-Z. Zhang).

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shortcoming of the glass fiber could be overcome to some extent by introducing glass fabric of increased load-carrying capacity [14]. Unfortunately, the use of glass fabric in bearing industry is still limited owing to the unsatisfactory wear-resistance and load-carrying capacity. Therefore, it is imperative to seek for the effective ways to decrease the brittleness of the glass fabric and glass fibers, so as to increase its applicability in the bearing industry where the integration and multi-functionalization of the bearings made of various composites are of particular interest [15]. Various surface modification techniques, such as surface chemical modification, surface physical modification, painting, and coating, have been tried to modify the glass fabric in this respect [9–11]. With this perspective in mind, we selected solid lubricants PTFE and MoS_2, and inorganic nano-TiO_2 and nano-$CaCO_3$ widely used as fillers [16] to fill the glass fabric in the presence of phenolic adhesive resin, so as to endow the glass fabric with good self-lubricity and increased mechanical strengths and wear-resistance.

This article deals with the preparation of the glass fabric composites modified with various solid lubricant particulates and inorganic nano-particles. The friction and wear behaviors of the composites and their dependence on the environmental temperature are also investigated. The present work is expected to broad the application of glass fabric composites in dry-sliding bearings.

2. Experimental

The glass fabric was provided by Nanjing Academy of Glass Fibers in China. The adhesive resin (204 phenolic adhesive) was provided by Shanghai Xingguang Chemical Plant of China. Irradiated PTFE powders (<20 μm) were provided by Lanzhou Irradiation Center of China. Nano-TiO_2 (20–30 nm) and nano-$CaCO_3$ (30–50 nm) were prepared at our lab. MoS_2 particulates (<38 μm) were produced by Shanghai Colloid Chemical Plant of China. The glass fabric was dipped in acetone for 24 h and then boiled in distilled water for 10 min, followed by cleaning with acetone in an ultrasonic bath. The surface of the 1Cr18Ni9Ti stainless steel disk (diameter 22.5 mm) to be coated with the fabric composite was polished with $280^{\#}$ and $350^{\#}$ sand paper to a surface roughness of $R_a = 0.45$ μm. The solid lubricant particulates and the nanoparticles were evenly dispersed in the adhesive at proper mass fractions with the assistance of magnetically stirring and ultrasonic stirring. Then the glass fabric was immersed in the mixed adhesive to allow the coating by the adhesive mixture. The immersing of the glass fabric in the mixed adhesive and the successive drying of the coated glass fabric around 60 °C were repeated until the adhesive was used up and the glass fabric composite about 400–450 μm thick was obtained. Finally, the glass fabric composites were affixed on the stainless steel surface using the phenolic resin adhesive and cured at 180 °C for 2 h. The contents (mass fraction) of micro-MoS_2 and nano-$CaCO_3$ in the glass fabric composites were fixed as 10 and 3%, respectively, according to a series of screening tests.

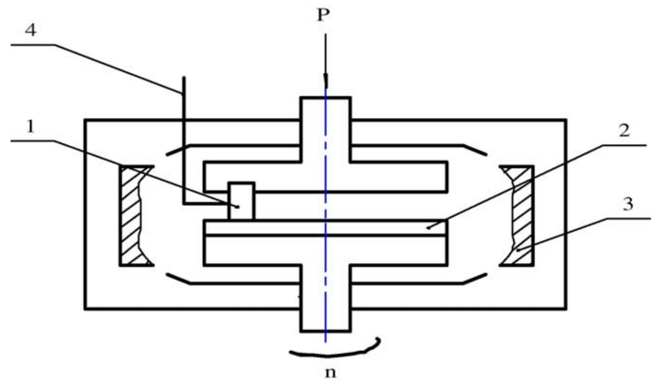

Fig. 1. The picture of pin-on-disk friction and wear tester. P—applied load; 1—the counterpart pin (diameter 3 mm); 2—the disk specimen; 3—electric furnace; 4-themocouple.

The friction and wear behavior of the glass fabric composites supported on the stainless steel sliding against AISI-1045 steel pin of a diameter 3mm at various temperatures were evaluated on a Xuanwu-III test rig as shown in Fig. 1. Prior to the tests, the pin was sequentially polished with $350^{\#}$, $700^{\#}$, and $900^{\#}$ sand paper, to a surface roughness $R_a = 0.15$ μm, and then cleaned with acetone. The sliding was performed under ambient condition at a sliding speed of 0.252 m/s, a normal load within 156.8–313.6 N, a temperature of 25–240 °C, and over a period of 2 h, except for otherwise indication. At the end of each test, the disk was cleaned and dried, then its wear volume loss (V) was obtained by measuring the wear scar area and depth on a micrometer (±0.001 mm). The wear rate was obtained from dividing the wear volume loss by the normal load and sliding distance. The friction coefficients were obtained from the frictional torque measured by a load cell sensor. Three replicate friction and wear tests were carried out for each specimen to minimize data scattering and the averages of the three replicate test results are reported in this work (The relative errors to measure the friction coefficient and wear volume loss are ±10 and ±5%, respectively). The morphologies of the worn composite surfaces and the transfer films on the counterpart steel pin surface were analyzed on a JSM-5600LV scanning electron microscope (SEM) equipped with an energy dispersive X-ray analyzer (EDXA).

3. Results and discussion

3.1. The friction and wear behaviors of the glass fabric composites

The friction coefficients and wear rates of the glass fabric composites reinforced with different fillers sliding against the AISI-1045 steel pin at room temperature and 150 °C are comparatively shown in Fig. 2. It is seen that the glass fabric composites filled with irradiated PTFE show the best