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Tribological behavior of hybrid PTFE/Kevlar fabric composites with nano-Si_3N_4 and submicron size WS_2 fillers

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ABSTRACT

Hybrid PTFE/Kevlar fabric composite specimens were prepared with nano-Si_3N_4 and/or submicron size WS_2 as fillers. The tribological behaviors of these composites were studied. The morphologies of the worn surface, transfer film and debris were analyzed by means of scanning electron microscopy. In addition, an energy-dispersive X-ray spectrometer was used for analysis of the elemental distribution and content in the transfer film. The results indicate that single nano-Si_3N_4 fillers can effectively reduce the wear rate of composites, but they do not reduce the friction coefficient. Hybrid Si_3N_4 and WS_2 fillers can significantly reduce the wear rate and friction coefficient of composites.

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1. Introduction

Fabric composites play an important role in materials and mechanical engineering, not only for their ease in manufacturing and low unit cost but also for their potentially excellent tribological performance in engineered forms; therefore, they are very attractive materials for use as advanced bearing liner materials. Hybrid PTFE/Kevlar fabric composites, which are woven out of PTFE and Kevlar fibers, are one of the most popularly used bearing liner materials. The good lubrication of the PTFE fiber side was used as the friction surface, and the Kevlar fiber side, with its good mechanical properties, was used as the binding surface [1–3]. However, it is well known that PTFE fibers exhibit a high wear rate in the pristine form; as a result, hybrid PTFE/Kevlar fabric composites would also not satisfy most of the tribological requirements. Therefore, a modification is necessary to improve the tribological properties of hybrid PTFE/Kevlar fabric composites.

Many researchers have developed polymer-based nanocomposites for tribological applications [4–8]. Li et al. filled PTFE with nanoparticles of ZnO and found that using nanometer ZnO powders as a filler in PTFE changed the microstructure of PTFE and prevented the destruction of PTFE banded structures during the friction process [9]. Sawyer et al. studied the wear and friction properties of nano-alumina-filled PTFE composites and found that at filler concentrations of 20 wt%, the wear resistance improved by 600 × [10]. Sebastian et al. studied the tribological behavior of polyphenylensulfide composites filled with short carbon fibers and/or carbon nanotubes. They found that due to the fast formation of a groove-filling transfer film on the counterpart, these composites exhibited an excellent tribological property [8]. Wang et al. filled polyetheretherketone (PEEK) with various weight fractions of nano-Si_3N_4 and found that nano-Si_3N_4 particles could significantly improve the wear resistance and reduce the friction coefficient. This improvement was closely related to the improved characteristics of the transfer film [11]. Chang et al. observed the tribological properties of polyamide composites filled with TiO_2 nanoparticles, short carbon fibers, and graphite flakes. It was found that nano-TiO_2 could effectively reduce the frictional coefficient and wear rate. One mechanism of the remarkable improvement of the tribological properties of the composites was the positive rolling effect of nanoparticles between the material pairs [12,13].

Recently, some research on nanoparticle-filled fabric composites revealed their significant potential in producing materials with good comprehensive friction properties [14–19]. Professor Zhang and his coworkers at the Lanzhou Institute of Chemical Physics have performed a significant amount of work in the area of fabric composites filled with nanoparticles. Su et al. investigated the tribological properties of nano-TiO_2 and nano-ZnO-filled hybrid glass/PTFE fabric composites, and the results indicated that the incorporation of TiO_2 and ZnO nanoparticles could significantly improve the wear resistance of the composites [14–17]. Zhang et al. studied the influence of nano-TiO_2 and nano-SiO_2 on the tribological behavior of hybrid PTFE/Kevlar fabric/phenolic composites. The incorporation of TiO_2 or SiO_2 nanoparticles was found to reduce the wear rate of the fabric composite at elevated temperatures, but it did not have an important influence on the wear resistance of the composites at room temperature.

Nanoparticles can be effective in reducing the wear rate of fabric composites, and in some cases, the coefficient of friction can also be reduced. However, in practice, fabric composites filled with

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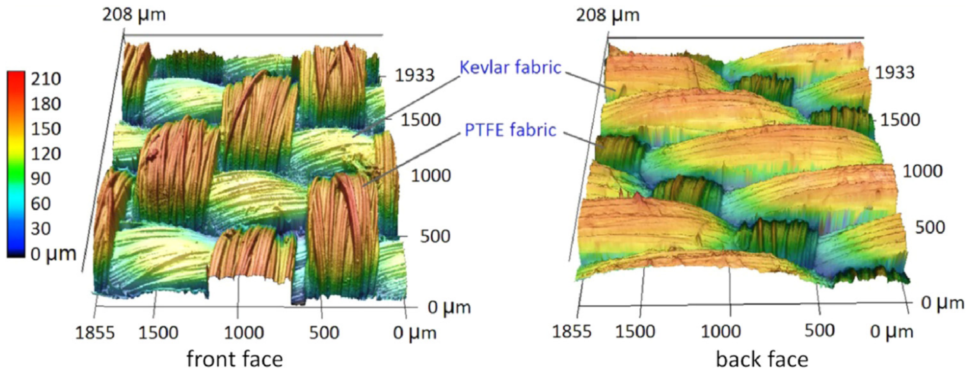

Fig. 1. Image of the PTFE/Kevlar fabric.

Table 1
Properties of nano-Si_3N_4 and submicron size WS_2.

Materials	Si_3N_4	WS_2
Grain size (nm)	80–100	600
Purity (%)	99.9	99.9
Specific surface area (m²/g)	71.0	3.2
Tap density (g/cm^3)	1.14	2.04
Bulk density (g/cm^3)	0.49	0.44

only nano-fillers still do not meet the practical requirements, due to their relatively high friction coefficient. Thus, a combination of various functional fillers is required. Unfortunately, few studies have been performed to investigate such combinations. This paper therefore focuses on the study of the tribological behavior of hybrid PTFE/Kevlar fabric composites with a combination of nano-Si_3N_4 and submicron size WS_2 fillers.

2. Experimental section

2.1. Materials and specimen preparation

The PTFE/Kevlar fabric used in this study was woven from PTFE fibers and Kevlar fibers, and a picture of the fabric is shown in Fig. 1. As shown in Fig. 1, the two sides of the fabric have different proportions of PTFE and Kevlar. The front face was rich in PTFE fiber and was always used as a friction surface. The back face was rich in Kevlar fiber and was used as a binding surface. In this way, the low friction of PTFE and high strength of Kevlar were combined to a great extent [1]. The fillers used in this study are commercially available, and the material properties are listed in Table 1.

Due to the very small diameter of nano-Si_3N_4, nano-Si_3N_4 has a much higher surface area-to-volume ratio than do larger-sized particles, and their surface energy is high. Thus, the adhesive force between the nanoparticles is strong, and the particles are easily agglomerated [14]. To prevent agglomeration of the particles, ultrasonic vibration was used to disperse the nano-Si_3N_4 and submicron size WS_2 particles in a modified polyimide resin. The hybrid PTFE/Kevlar fabrics were ultrasonically cleaned in an acetone bath for 1 h, boiled 30 min in distilled water, dried in an oven at 80 °C for 1 h, and then the dried hybrid PTFE/Kevlar fabrics were weighed by a precision balance (accuracy: 0.1 mg). The fillers were mixed uniformly with modified polyimide adhesive resin at the proper mass fractions with the assistance of ultrasonic stirring. Afterwards, the hybrid PTFE/Kevlar fabrics were immersed in the mixed adhesive containing the fillers. Subsequently, the immersed PTFE/Kevlar fabrics were dried in a nitrogen-purged environment at a rate of 50 °C/h to 130 °C, where they were held for 1 h.

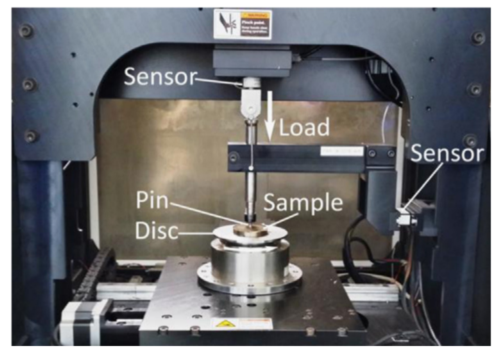

Fig. 2. The schematics of the test assembly.

The specimens were then cooled at a rate of 50 °C/h back to room temperature. After this, the specimens were weighed and the relative mass fraction of fabrics was calculated. The immersion was repeated several times until the relative mass fraction of fabrics was 70 ± 5%. And then, a laboratory press was used to consolidate the fabrics under pressure of 5 MPa at 210 °C for 30 min. Finally, the filled PTFE/Kevlar fabric composites (which were composed of the PTFE/Kevlar fabric, the adhesive resin, and the fillers) and unfilled PTFE/Kevlar fabric composites were affixed onto the 440c stainless steel using the modified polyimide adhesive resin and then cured at 210 °C for 15 min under pressure of 0.2–0.3 MPa.

2.2. Tribological test

Tribological tests were performed using a pin-on-disc tribometer (RTEC MFT-5000, made in the USA) under dry friction conditions. All of the experiments were performed under laboratory conditions (temperature, T=25 °C, relative humidity ~50%). Fig. 2 shows the schematics of the test assembly. In the pin-on-disc tester, a stationary steel pin slid against a rotating steel disc that was affixed with the PTFE/Kevlar fabric composite specimens. The flat-ended bearing steel pin (diameter of 3.3 mm) was secured to the load arm with a chuck. The distance between the center of the pin and the center of the disc was 16 mm. The pin remained over the disc with two degrees of freedom: the vertical one for normal load application by direct contact with the disc and the horizontal one for friction measurement.

The sliding was performed under dry friction conditions at a sliding speed of 1 m/s and at a normal load of 513 N (60 MPa), and the sliding distance used was 1.8 km. For self-lubricating fabric composites these contact pressures are typical for industrial applications. The normal load and friction force were measured by normal force sensor (range: 50–5000 N, resolution: 0.25 N) and friction force sensor (range: 1–100 N, resolution: 0.005 N), and the frequency of sampling is 1000 Hz. The friction coefficient μ of the

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