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Effect of MWCNTs-GO hybrids on tribological performance of hybrid PTFE/Nomex fabric/phenolic composite

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ABSTRACT

Filler reinforcing is an effective way of improving the tribological performance of fabric composites. However, the interface stability between fillers and the polymer matrix is critical for filler reinforced composites. To address this problem, hybrids of MWCNTs and graphene oxide (GO) are developed to improve the mechanical and tribological performances of hybrid PTFE/Nomex fabric/phenolic composite. Pin-on-disk wear tests show that the wear rates of hybrid fillers filled fabric/phenolic composites are significantly reduced, when hybrid filler of 1 wt% MWCNTs and 2 wt% GO is employed. We also investigated the effect of filler content on the mechanical and tribological property of the fabric composites. The wear mechanisms of the composites are discussed based on the characterizations.

1. Introduction

Polymers possess many advantages, i.e. lightweight, ease of manufacturing, excellent corrosion-resistance and self-lubricating effect, etc., which enable polymers and polymer composites to be desirable materials for frictional components, such as bears, gears, piston rings and soft seals, etc. [1–3]. Among polymer composites produced, fabric reinforced polymer composites exhibit enhanced mechanical strength in both longitudinal and transverse directions of the fabric and possess the ability of conforming to curve surfaces without wrinkling, compared with other polymer composites [4]. Accordingly, fabric reinforced polymer composites have recently generated immense commercial and academic interests because of their wide applicability in the fields of aircraft, aviation, high-speed railway, automobile, and so on [5–7].

However, on account of the dissatisfying antiwear property of polymer matrix, it is usually essential to introduce fillers into the polymer matrix for enhancing the antiwear performance of fabric reinforced polymer composites [8,9]. Compared with single filler reinforcement, hybrid fillers are more and more widely applied in respect that the synergetic effect of hybrid fillers is much more beneficial to improve the mechanical and tribological properties of polymer composites [10–14]. For example, it was reported that the synergistic effect from nano-TiO_2 and graphite resulted in improved tribological performance of epoxy matrix composites [12]. Wang et al. [13] found that the incorporation of attapulgite-graphene oxide hybrids into epoxy composites contributed greatly to the thermal and mechanical reinforcements of the composites. Yan et al. [14] fabricated bismaleimide composite filled with the hybrid nanoparticles composed of reduced graphene oxide and MoS_2 nanosheets. Comparatively, the fabricated composite displayed distinctly improved the mechanical and tribological properties. Moreover, hybrid of carbon nanotube-graphene oxide/graphene was also reported to be effective in enhancing the mechanical and thermal properties of polymer composites [15,16]. However, aside from the reported studies regarding to hybrid fillers, scarcely any researchers attempt to improve the mechanical and tribological performances of fabric reinforced polymer composites by incorporating MWCNTs-GO hybrids into the polymer matrix.

In this study, we combine the two ultrastrong materials, namely

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one-dimensional CNTs and two-dimensional GO nanoplatelets, into MWCNTs-GO hybrids and then employ them as novel hybrid fillers for hybrid PTFE/Nomex fabric/phenolic composite. Wear tests show that the incorporation of hybrid fillers, especially the hybrid of 1 wt % MWCNTs and 2 wt% GO, contribute to the improved antiwear property of the fabric composite. We also investigated the mechanical and tribological properties of varied MWCNTs-GO hybrids reinforced hybrid PTFE/Nomex fabric composites. Based on the characterizations, the probable reasons for the reinforcement are discussed. This study is hoped to extend the application of fabric composites.

2. Experimental

2.1. Materials

The satin weave hybrid PTFE/Nomex fabric (volume fraction of PTFE to Nomex: 1:3) is woven out of PTFE fibers (fineness: 400 Denier) and Nomex fibers (fineness: 200 Denier) purchased from DuPont Plant. The adhesive resin (204 phenolic resin) is provided by Shanghai Xing-guang Chemical Plant, China. The graphite (diameter < 38 μm) is provided by Lanshu Graphite Plant, China. Pristine MWCNTs (diameter:8–15 nm, length:50 μm) is purchased from Nanjing Xianfeng Nano Material Co. Ltd., China. The rest of the chemicals are all of analytical grade and used as received.

2.2. Preparation of graphene oxide and oxidized MWCNTs

Typically, graphene oxide is synthesized from natural graphite powder by a modified Hummers method [17,18]. The detailed process of the preparation can be found in our former study [19].

To prepare oxidized MWCNTs, 0.5 g MWCNTs is firstly immersed in piranha solution in 50 °C for 12 h (H_2SO_4 and 30 wt% H_2O_2 in a 3:2 vol ratio) [20] and then washed with distilled water and ethanol until the pH is near 7. After drying in an oven at 60 °C for 3 h, the powder of oxidized MWCNTs is acquired.

2.3. Preparation of hybrid fabric/phenolic composites

The hybrid PTFE/Nomex fabric is cleaned with petroleum ether and ethanol sequentially in Soxhlet extractor and then dried in an oven at 50 °C. The adhesive solution is prepared by mixing the adhesive with the mixed solvent of acetone, ethanol, and ethyl acetate with the volume ratio of 1:1:1. Subsequently, the pristine hybrid fabric is immersed in the adhesive solution filled with varied contents of MWCNTs and GO. After several cycles of immersion and coating, the mass fraction of the hybrid PTFE/Nomex fabric in the fabric/resin composite reach to about 70 ± 5%. Finally, the prepregs are cut into pieces and adhered onto the AISI-1045 steel (size of Φ 45 mm × 8 mm, surface roughness of 0.45 μm) using 204 phenolic resin and then cured at 180 °C for 2 h. The fabricated fabric composites are designated according to Table 1.

Table 1
Designation of the fabricated fabric composites.

Material (Designation)	Filler in the resin (wt%)	
	GO	MWCNTs
Composite A	0	0
Composite B	2	0
Composite C	2	1
Composite D	1	1
Composite E	1	2
Composite F	2	2
Composite G	0	2

2.4. Friction and wear test

The Xuanwu-III pin-on-disk tribometer (see Fig. 1) is applied to investigate the tribological properties of hybrid PTFE/Nomex fabric/phenolic composite. In this pin-on-disk tester, a stationary AISI-1045 steel pin (2 mm in diameter) cylindrical in shape is employed to slide against fabric composite specimen. Prior to each test, the pin is polished with 350, 700, and 900 grade water-proof abrasive papers sequentially to a roughness of 999 ± 73 nm and then cleaned with acetone. The sliding wear tests are performed for 2 h in ambient condition. At the end of each test, the corresponding wear volume loss (V) of the composite is obtained by measuring the depth of the wear scar on a micrometer (resolution: 0.001 mm). The wear performance is expressed by wear rate (ω, $m^3\ (N\ m)^{-1}$) as follows: $\omega = V^*(PL)^{-1}$, where V is the wear volume loss in m^3, P is the load in Newton and L is the sliding distance in meter. Each experiment for per sample is carried out three times and the average value is used.

The average surface roughness (Ra) of the pin is characterized by a MicroXAM-3D surface Profiler (ADE shift, America). Morphology and microstructure of MWCNTs, GO and the hybrid is investigated by FEI Tecnai F30 transmission electron microscopy (TEM). Bruker IFS66/S Fourier transform infrared (FTIR) spectrometer is employed to investigate the microstructure of oxided MWCNTs. The MH-5-VM Vickers hardness tester was used to determine the hardness of the composite. The morphology of the worn surfaces of the composites is analyzed on a JSM-5600LV scanning electron microscope (SEM).

3. Results and discussion

3.1. FTIR analysis and TEM analysis

The FTIR spectra of pristine and oxidized MWCNTs are shown in Fig. 2. It can be seen that new peaks are found in the spectrum of oxidized MWCNTs. Typically, the absorption band of oxidized MWCNTs at 3400 cm^{-1} is attributed to C–OH. The peak positioned at 1621 cm^{-1} is attributed to C=O stretching vibrations from carbonyl and carboxylic groups. Furthermore, the stretching vibrations of C–O can be found at 1300–1000 cm^{-1}. The results indicate that oxidized MWCNTs were successfully prepared.

The TEM images of GO nanosheets, oxidized MWCNTs, and the hybrid of oxidized MWCNTs and GO are shown in Fig. 3. In Fig. 3a the graphitic lattice of GO nanosheets is clearly illustrated. And the microstructure of oxidized MWCNTs can be seen in Fig. 3b. For the hybrid of GO nanosheets and oxidized MWCNTs (see Fig. 3c), it is shown that most of the oxidized MWCNTs attached onto GO

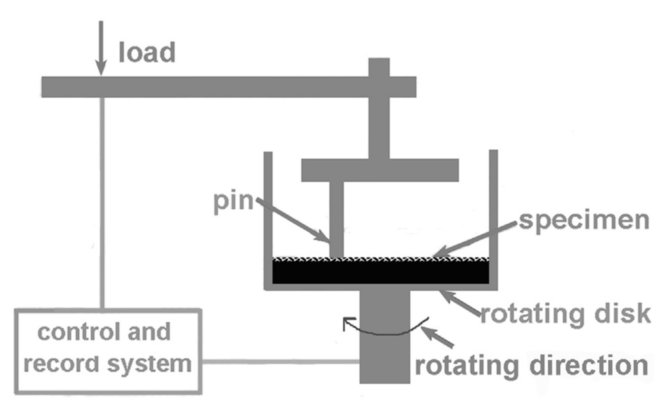

Fig. 1. Schematic diagram of the pin-on-disc wear tester.