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TiB_2 reinforced hybrid-fabric composites with enhanced thermal and mechanical properties for high-temperature tribological applications

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ABSTRACT

Titanium boride (TiB_2) particles with different sizes were introduced into the hybrid Nomex/PTFE fabric composites to explore the high-temperature tribological properties. The thermal, mechanical and tribological properties of the filled fabric composites were investigated. Results showed that the presence of TiB_2 improved the thermal and mechanical properties obviously. High-temperature friction and wear tests also proved that the anti-wear ability of TiB_2 filled fabric composites was enhanced sharply without sacrificing the friction coefficients. Meanwhile, the effects of fillers content and size, applied load and temperature on tribological properties and wear mechanisms were also investigated. XRD and XPS were employed to analyze the worn surfaces and demonstrate the fabrication of tribofilm composed of TiO_2 and B_2O_3, which played a vital role in the excellent tribological behaviors.

1. Introduction

Fabric-reinforced resin matrix composites are increasingly being utilized for automobiles construction, aviation, pressure vessels and self-lubrication liners in place of traditional polymer, metallic and ceramic materials due to their higher specific strength, self-lubrication and excellent performance tailorability [1–3]. Among various fabrics investigated, hybrid Nomex/PTFE fabric is regarded as a kind of ideal material for self-lubrication liners, as it combines the high strength of Nomex fibers with the self-lubrication of PTFE fibers [4,5]. Regarding resin matrix, phenolic resin is preferred for resin adhesive in friction materials for decades, owning to its low cost, satisfying wetting capability with most ingredients and good combination of mechanical and tribological properties [6]. However, phenolic resin is often blamed for various frictional heat induced problems, especially the decline phenomenon in the elevated temperature condition due to its poor thermal resistance [7]. Accordingly, seeking a way to improve high-temperature tribological properties of the phenolic-matrix fabric composites is very meaningful and necessary.

Recently, embedding hard phase in the tough resin adhesives has been proved as an effective way to improve the tribological properties of polymer composites, such as SiO_2, TiO_2, MoS_2 and carbon nanomaterials [8–11]. Note that although much progress has been made, limited researches focus on the high-temperature tribological properties of polymer matrix composites, especially in terms of phenolic composites. In high-temperature condition, polymer matrix commonly suffers from softening, deformation or even thermo-oxidative degradation, resulting in presenting relatively weak anti-wear and load-carrying capacity [12]. In order to develop polymer composites that are wear resistant but also preserve the low friction coefficient in high-temperature environment, careful consideration must be given to the concentration of fillers that are used. The role of the filler is to improve the load-carrying capacity of matrix, increase thermal conductivity and promote the formation of a transfer film [13].

Among rigid reinforcing particles, TiB_2, exhibiting outstanding properties, such as ultrahigh hardness, melting point, effective thermal conductivity and high wear resistance, has emerged as an excellent reinforcement. Thus, it can be logically deduced that TiB_2, acting as filler, can effectively improve the properties of filled composites. Such as, Zhang et al. utilized micron-size TiB_2 particles to reinforce Inconel 625 produced by selective laser melting and found exceptional microhardness of the composite was obtained [14]. LÜ et al. observed that

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yield stress and tensile strength of Al-4.5 Cu alloy were improved by 85% and 46%, respectively, due to the in-situ incorporation of 5 vol% TiB_2 particulate [15]. Ito et al. modified the sintering behavior and thermoelectric performance of Y-doped $SrTiO_3$ by addition of TiB_2 [16]. Most importantly, TiB_2/Al metal matrix composites presented a very low friction coefficient in a wide volume ratio of TiB_2 and Al [17,18]. The TiB_2 left on the composite surface was oxidized to TiO_2 and B_2O_3 followed by the generation of H_3BO_3 leading to the low friction coefficient [19,20]. Nevertheless, most of the publications are focusing attention on metal or alloy composites, and there are rare studies concerning the effects of TiB_2 on the mechanical and tribological properties of polymer composites.

Herein, TiB_2 particles were introduced into the polymer composites to explore the tribological properties for the first time. To explore how the presence of TiB_2 affected the high-temperature tribological properties of filled hybrid-fabric phenolic composites, friction and wear tests were performed on the Pin-on-disk type high-temperature tribological tester. Thereinto, the thermal stability, thermal conductivity, hardness and tensile strength of filled fabric composites were measured by TGA, thermal conductivity analyzer, Rockwell apparatus and universal materials testing machine, respectively. Furthermore, X-ray diffraction (XRD) and X-ray photoelectron spectroscopy (XPS) were also employed to recognize the possible chemical reaction during the process of high-temperature friction. Besides, work in progress at this paper found that the tribological properties, thermal and mechanical properties of the filled fabric composites largely depended on the size of fillers. An attempt has also been made to correlate the high-temperature tribological properties of fabric phenolic composites with thermal, mechanical properties and tribo-chemical reactions.

2. Experimental section

2.1. Materials

The hybrid Nomex/PTFE fabric, which was knitted out of Nomex fibers and PTFE fibers supplied by DuPont Plant, was satin-weave with the volume fraction of Nomex to PTFE: 3:1. The phenolic resin adhesive was obtained from Xing-guang Chemical Reagent Co. Ltd, China. Titanium boride (TiB_2) particles with average sizes of 4 μm and 47 μm were separately provided by Meryer Chemical Technology Co. Ltd and Alfa Aesar (China) Chemicals Co. Ltd. The morphologies and XRD results of different sizes of TiB_2 particles were shown in Fig. 1. The rest chemicals were all of analytical grade and used as received.

2.2. Specimen preparation

The hybrid Nomex/PTFE fabric was cleaned by Soxhlet extractor with petroleum ether and ethanol sequentially and dried at 50 °C. Then the pre-calculated amounts of two kinds of TiB_2 particles at mass fractions of 2.0%, 4.0%, 6.0%, 8.0% and 10.0% were added into phenolic resin respectively. The obtained TiB_2/phenolic resin composites were diluted with the mixed solvent $V_{acetone}$: $V_{ethanol}$: $V_{ethyl\ acetate}$ = 1:1:1 and the fillers in resin were mixed evenly with the aid of ultrasonic. Subsequently, the hybrid-fabrics, having been treated by air-plasma with the power of 100 W for 10 min, were immersed immediately in above-mentioned TiB_2/phenolic resin adhesive solution. Repetitive immersions and dryings of the hybrid Nomex/PTFE fabrics were performed until the mass fraction of hybrid-fabrics reached to about 70–75% in the composites. The SEM images of the microstructure for hybrid Nomex/PTFE fabric phenolic composites at different filler content were shown in Fig. 2. Finally, the received prepregs were affixed onto the AISI-1045 steel disks utilizing phenolic resin as adhesive and then cured at 180 °C for 120 min under a certain pressure. In the following text, the unfilled hybrid-fabric composite, 6 wt% small size TiB_2 (S-TiB_2) filled hybrid-fabric composite and 6 wt% large size TiB_2 (L-TiB_2) filled hybrid-fabric composite were abbreviated as composite A, composite B and composite C, respectively.

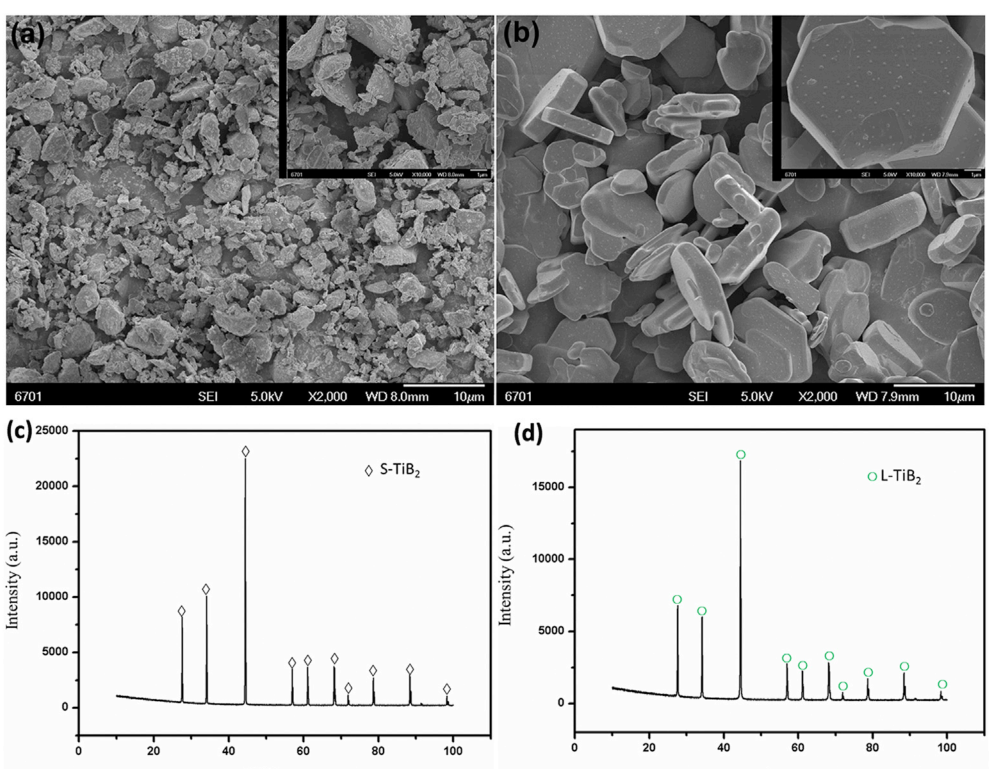

Fig. 1. Micro morphologies and XRD results of S-TiB_2 particles (a, c) and L-TiB_2 particles (b, d).