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Influence of air-plasma treatment and hexagonal boron nitride as filler on the high temperature tribological behaviors of hybrid PTFE/Nomex fabric/phenolic composite

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ABSTRACT

In this work, we investigated the effect of air-plasma treatment on the bonding strength of hybrid PTFE/Nomex fabric and mechanical strength of PTFE and Nomex fibers. Besides, we employed hexagonal boron nitride (h-BN) as high-temperature lubricant and incorporated it into the hybrid fabric/phenolic composite. The high-temperature tribological performances of the fabric composite were evaluated on a pin-on-disk tribometer. The results indicated that the air-plasma treated hybrid PTFE/Nomex fabric composites filled with 6 wt% h-BN exhibited outstanding tribological properties. The results of the morphology study of the fabric composites support the results of the wear test and the corresponding wear mechanisms of the composites were discussed based on the characterizations.

1. Introduction

Fabric reinforced polymer composites play an important role in materials and mechanical engineering, due to their light weight, ease of fabrication, excellent specific strength, corrosion resistance, design flexibility, self-lubricating properties, lower friction coefficient, and wear rate as compared to their metal-based counterparts [1–4]. Therefore, they are very attractive materials for used as advanced bearing liner materials. Hybrid PTFE/Nomex fabric composite, which are woven out of PTFE and Nomex fibers, was one of the most widely used ones owing to their excellent properties [5,6]. The good lubrication of the PTFE fiber side was used as the friction surface, and the Nomex fiber side, with its good mechanical properties, was used as the binding surface [7–9]. However, the PTFE fibers had a high wear rate in the pristine form and Nomex fibers exhibited poor adhesion to other materials because of a relatively smooth and inert surface. Therefore, the modification of hybrid PTFE/Nomex fabric is necessary to improve the tribological properties of hybrid fabric composites.

To improve the tribological properties of the hybrid fabric composites, surface modification of fabric and filler reinforcing have demonstrated to be the effective ways. Plasma treatment has been well-proven technique to modify the chemical and physical structures of fiber surface layers, to enhance fiber–matrix bonding strength without influencing their bulk mechanical properties. It improves fiber–matrix adhesion largely by introducing polar or excited groups that can form strong bonds between the fiber and the matrix, and sometimes by roughening the surface of fibers to increase mechanical interlocks between the fiber and the matrix [10,11]. Tiwari et al. found that the

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inert nature of carbon fabric could be improved with cold nitrogen plasma treatment and the abrasive wear performance significant enhancement [10]. Zhang et al. studied the tribological behavior of air-plasma treated Kevlar fabric reinforced phenolic composites. They found that due to the enhancement the adhesion between the Kevlar fabric and the phenolic adhesive, these composites exhibited excellent tribological property [12]. Furthermore, nanoparticles can be effective in reducing the wear rate and friction coefficient of fabric composites due to the positive rolling effect of nanoparticles between the rubbing surfaces [13–15]. In order to meet the high-temperature tribological performance, however, the nanoparticles should possess the ability to improving the thermal stability of the polymer matrix. One of the suitable candidates, also known as white graphite, is hexagonal boron nitride (h-BN) [16,17]. h-BN has a lamellar crystalline structure, which provides excellent lubricating properties. Furthermore, it has outstanding properties, such as a high thermal conductivity, a low thermal expansion, a good thermal shock resistance, a high electrical resistance, a low dielectric constant, and microwave transparency [18–20]. Hence, h-BN is expected to be an ideal solid lubricant to improve the high-temperature tribological properties of fabric composites.

The purpose of this paper is to systemically investigate the effect of the air-plasma treatment and h-BN content on the tribological properties of hybrid PTFE/Nomex fabric/phenolic composite under high-temperature. Air-plasma treatment was demonstrated beneficial for improvement adhesion strength of hybrid PTFE/Nomex fabric composite as indicated by the increased surface roughness and surface activity supported by SEM, FTIR and XPS studies, respectively. Furthermore, wear tests showed that the tribological properties of 6 wt% h-BN reinforced air-plasma treated hybrid fabric/phenolic composites were optimized under high-temperature, when compared with others. This study is hoped to extend the application of fabric composite under high-temperature.

2. Experimental

2.1. Materials

The satin weave hybrid PTFE/Nomex fabric (volume fraction of PTFE to Nomex:1:3) was woven out of PTFE fibers (fineness:400 Denier) and Nomex fibers (fineness: 200 Denier) purchased from DuPont Plant. The adhesive resin (204 phenolic resin) was provided by Shanghai Xing-guang Chemical Plant, China and h-BN by Shinuorui Company, China. The rest of chemicals were all of analytical grade and used as received.

2.2. Preparation of hybrid fabric/phenolic composites

The hybrid PTFE/Nomex fabric was cleaned with petroleum ether and ethanol sequentially in Soxhlet extractor and then dried in an oven at 50 °C. The adhesive solution was prepared by mixing the adhesive with the mixed solvent of acetone, ethanol, and ethylacetate with the volume ratio of 1:1:1. Subsequently, the air-plasma treatment hybrid fabric (100 W, 10 min) was immersed in the adhesive solution with the content of h-BN between 0 wt% and 8 wt%. After several cycles of immersion and coating, the mass fraction of the hybrid PTFE/Nomex fabric in the fabric/resin composite reached to about 75 ± 5%. Finally, the prepregs were cut into pieces and adhered onto the AISI-1045 steel (size of φ 45 mm φ 8 mm, surface roughness of 0.45 μm) using 204 phenolic resin and then cured at 180 °C for 2 h. In the following text, 6 wt% h-BN reinforced air-plasma treated hybrid fabric composite was designated as composite A, unfilled air-plasma treated fabric composite was designates as composite B, 6 wt% h-BN reinforced untreated fabric composite was designated as composite C, and unfilled untreated fabric composite was designated as composite D.

2.3. Friction and wear test

The friction and wear behavior of hybrid fabric composites was investigated using a Xuanwu-III pin-on-disk friction and wear tester (Fig. 1). The pin-on-disk tester consisted of loading a stationary pin sliding against a rotating disk which was affixed with the hybrid fabric/phenolic composites. The flat-ended AISI-1045 pin (diameter 2 mm) was fixed to the load arm with a chuck. The distance between the center of the pin and axis was freedom: a vertical one, which allowed normal load application by direct contact with the disk, and a horizontal one, for friction measurement. Prior to each test, the pin was polished with 350, 700, and 900 grade water-proof abrasive papers sequentially to a surface roughness Ra = 0.15 μm and then cleaned with acetone. The sliding was performed at high temperature environments (210–300 °C), with the applied loads in the range of 188–282 N and speed of 0.26 m/s. At the end of each test, the corresponding wear volume loss (V) of the composite was obtained by measuring the depth of the wear scar on a micrometer (resolution: 0.001 mm). The wear performance was expressed by wear rate (ω, $m^3 (N\,m)^{-1}$) as follows: $\omega = V/(PL)$, where V is the wear volume loss in m^3, P is the load in Newton and L is the sliding distance in meter. The friction coefficient was the ratio of the measured friction force and load. It was measured from

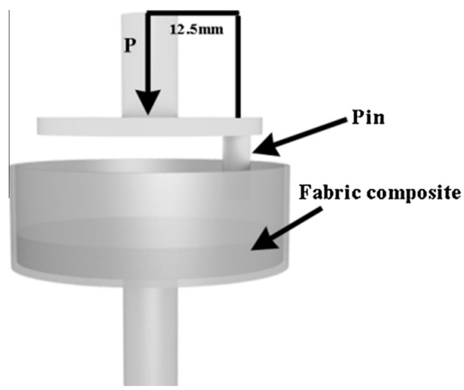

Fig. 1. Schematic diagram of the pin-on-disk wear tester.