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Tribological properties of hybrid PTFE/Kevlar fabric composite in vacuum

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ABSTRACT

The dry sliding tribological properties of hybrid PTFE/Kevlar fabric composite were investigated under ambient and different vacuums, loads, sliding velocities, and temperatures. The results showed that hybrid PTFE/Kevlar fabric composite displayed lower friction coefficient in vacuum than that in ambient and satisfactory antiwear performance in low vacuum and middle vacuum, but poor antiwear performance in high vacuum. In vacuum, the friction coefficient and wear rates decrease with the increasing of sliding velocities, loads and temperature within a certain range. But the higher temperature of 60 °C detriments the friction coefficient and wear rate. Textile structure also has an obvious influence on the antiwear performance. The main wear mechanism in vacuum including plastic deformation, microcutting, fatigue damage and abrasive wear.

1. Introduction

The high reliability and long life of key active components used in spacecraft are generally depended on the mechanical and tribological properties of lubricating materials. In space environment, the friction and wear behaviors of lubricating materials are different from that in atmospheric environment for the effect of vacuum, temperature, radiation and so on. Exploitation of tribological materials used in dry sliding bearings or bushings under such extreme conditions is a valuable subject for spacecraft development [1,2].

Polymer composites have been employed typically as the lubricating materials of dry sliding components due to these advantages, such as self-lubricating ability, light weight, excellent antiwear performance, and dimensional stability [3,4]. For polymer composites working under vacuum environment, it is a problem for the transfer of friction heat on the interface due to the poor thermal conductivity of polymer and the lack of heat transfer medium (air). The generation of friction heat or a higher environmental temperature easily lead to plastic deformation and adhesion happening on the contact surface of soft matrix [5]. So, it is important to study and understand the individual or synergistic effect of space environment on the friction and wear performance of tribo-materials. Zheng et al. [6] found that the friction coefficients of Polyimide-based composites increased slightly with sliding velocity in vacuum which is opposite in air. Theiler et al. [7] studied the friction and wear behavior of PEEK composites filled with carbon fibers, PTFE, and graphite or MoS_2 in vacuum environment in the temperature range between −80 °C and +20 °C. Yuan et al. [8] investigated the friction and wear properties of PTFE coatings under vacuum conditions. It was shown that the friction coefficients of the PTFE coatings first increase and then decrease with the increase of sliding velocity, but decrease with the increase of load under vacuum conditions. While the wear first decreases then increases either with the sliding speed or load increasing under vacuum conditions.

It is well known that PTFE exhibits low friction coefficient but poor abrasion resistance [9–11]. While Kevlar fiber is characterized by high elastic modulus and strength, and good wear-resistant [12,13]. Hybrid PTFE/Kevlar fabric composites have better antifriction and wear-resistant performance due to the integration of PTFE fibers and Kevlar fibers. The tribological behaviors and mechanisms of hybrid PTFE/Kevlar fabric composite under dry sliding conditions in atmospheric environment have comprehensively studied. Qi et al. [14,15] discussed the role of textile structure in the friction and wear properties of hybrid PTFE/Kevlar fabric composite. Huang et al. [16] investigated the friction and wear behaviors of hybrid PTFE/Kevlar fabric composite filled with the particulates of polyphenylene sulfide (PPS). It was shown that the tribological properties of hybrid PTFE/Kevlar fabric composite

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Table 1
Physical properties and used conditions of the 204 phenolic resin.

Parameter	Curing temperature	Continuous operating temperature	Shear strength	Curing pressure	Curing time
Property	180 °C	–70 to 200 °C	≥ 15 MPa (R. T.)	0.1–0.2 MPa	2 h

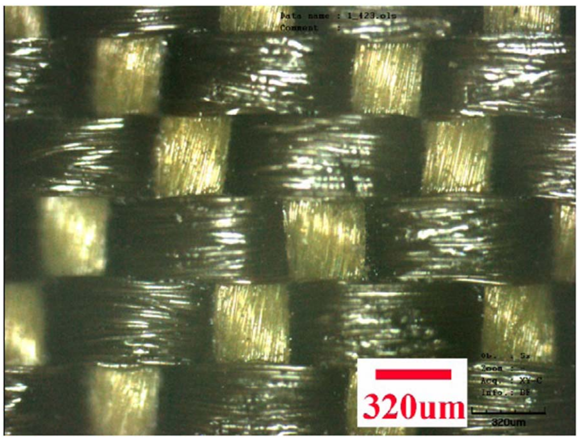

Fig. 1. CSLM micrograph of hybrid PTFE/Kevlar fabric composite.

were improved by enhancing the interfacial adhesion between fibers and the resin matrix with filling PPS particulates. Zhang et al. [17,18] found that the optimized cryo-treatment and plasma treatment of hybrid PTFE/Kevlar fabric can improve the wear resistance of fabric/phenolic composite. In their research [19], the effects of filling nanoparticles TiO_2 and SiO_2 on the sliding wear performance of hybrid PTFE/Kevlar fabric/phenolic composites were studied. The results indicated that 5 wt% TiO_2 nanoparticles were effective in reducing wear of hybrid PTFE/Kevlar fabric/phenolic composite at elevated temperatures while SiO_2 nanoparticles increased wear. Combining the effect of air-plasma treatment and lubricant filling, PFW (Polyfluorowax) filled air-plasma treated PTFE/Nomex fabric composite exhibited enhanced tribological properties [20].

To the author's knowledge there is few data in the open literature for tribological performance of hybrid PTFE/Kevlar fabric composite under vacuum conditions. In this paper, the friction and wear behaviors and mechanisms of hybrid PTFE/Kevlar fabric composite under vacuum conditions were systematically investigated with ring-on-plate contact form. It is expected that this study may be helpful to extend the application of hybrid PTFE/Kevlar fabric composite in aerospace fields.

2. Experimental

2.1. Materials and specimen preparation

The hybrid PTFE/Kevlar fabric (broken twill weave) was weaved out of PTFE fibers and Kevlar-49 fibers (Du pont, USA). The warp yarn was Kevlar and the weft yarn was PTFE. The properties of 204 phenolic adhesive resin (Shanghai Xinguang Chemical Plant, China) are listed in Table 1.

The hybrid PTFE/Kevlar fabrics were dipped in acetone for 12 h, cleaned in the acetone solution, boiled 20 min in distilled water, and then dried in the oven at 80 °C for 1 h. Then, the hybrid PTFE/Kevlar fabrics were immersed in the phenolic resin and treated by ultrasonic oscillation for 3 h. A glass rod was used to roll on the PTFE/Kevlar fabric and to ensure that no bubbles were present on the fabric surface to make the resin fully saturate the fabric and uniformly cover the fabric surface. Subsequently, the fabric was once again dried in the drying oven at 110 °C for 1 h. A series of test specimens are fabricated from the hybrid PTFE/Kevlar composite (as shown in Fig. 1) tube. The relative mass fraction of resin was about 20 ± 5%.

2.2. Friction and wear test

The friction and wear behaviors of hybrid PTFE/Kevlar fabric composite were performed on a ring-on-plate wear testing apparatus (Vacuum Wear Tester) under vacuum conditions (10^3–10^{-5} Pa). Illustration of the wear testing apparatus was shown in Fig. 2. A steel ring, the outer diameter 33 mm, the inner diameter 27 mm, was used sliding against with a steel plate on which hybrid PTFE/Kevlar fabric composite (circular with the diameter 38 mm) was bonded as the friction face. The pre-treatment approaches of the ring and plate specimens were listed as follows. The plate specimen was polished with 150# and 400# water sandpaper. The steel ring was polished with 600#, 800# and 1200# water sandpaper (surface roughness Ra is about 0.15 μm). Both ring and plate specimens are cleaned for 15 min in alcohol using ultrasonic cleaner. Then, hybrid PTFE/Kevlar fabric composite was bonded on the surface of the plate specimen with a small amount of the phenolic adhesive resin and cured at 180 °C for 2 h under the contact pressure 0.2 MPa. During starting of the test, the load was applied through the ring against the plate, on which hybrid PTFE/Kevlar fabric composite was bonded. The ring was kept stationary and the plate rotated a certain period of time under a prescribed set of working conditions. The wear tests were performed at different vacuums (10^3–10^{-5} Pa), loads (4–15 MPa), sliding velocities (0.3–0.6 m/s), and temperatures (−30 °C to 60 °C). At the end of each test, the wear volume loss was obtained by measuring the wear depth of hybrid PTFE/Kevlar fabric composite with a micrometer (resolution 0.001 mm) and the worn surface appearance was observed by CLSM (Confocal Laser Scanning Microscopy). The

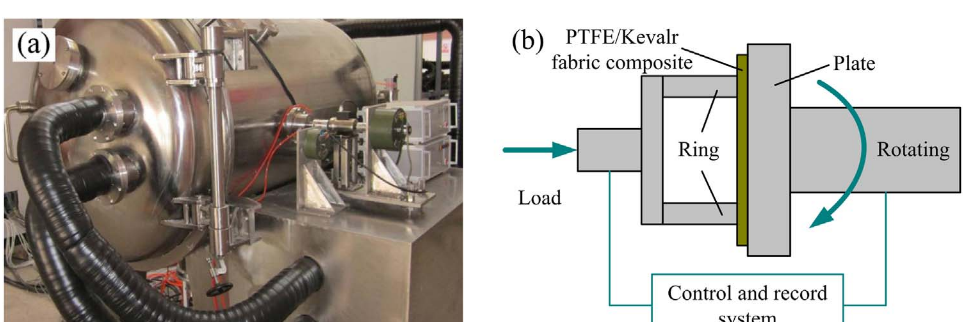

Fig. 2. (a) Illustration of Vacuum Wear Tester; (b) Schematic of the contact form of frictional pair.