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Effects of rare earth treatment on tribological properties of self-lubricating spherical plain bearings☆

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ABSTRACT

The effects of the rare earth treatment on the friction, wear, and bonding behavior of polymeric, self-lubricating spherical plain bearing materials were investigated. The materials of interest consisted of woven Kevlar (TM) and poly-tetrafluoroethylene (PTFE) fibers. An oscillating wear tester, operating at angles of $\pm 10^{\circ}$, four different frequencies, and a constant load, was used to test assembled bearings at room temperature. Worn surface morphologies of the liners were investigated by scanning electron microscopy (SEM) and energy dispersive spectrometry (EDS). Compared with bearings without rare earth treatment, the bonding qualities between the binder and the surrounding steel housing, and the wear resistance of the treated bearings were both greatly improved. Contact surface morphology indicates that the treated bearing liners experienced only slight amounts of adhesive wear while those without the treatment seemed to wear more by abrasion. Overall, rare earth treatments served both to improve bonding quality of the bearing liner and improve their tribological properties.

1. Introduction

PTFE fiber can be used as the liner of the spherical plain bearing because of low friction coefficient, excellent corrosion resistance and other advantages. But the application scope of PTFE fiber, as self-lubricating liner, is restricted owing to the huge wear rate [1–4]. To this end, some researchers carried out a large number of research works about hybrid self-lubricating materials made of some functional fibric and PTFE fabric to advance wear property of PTFE [5,6]. The Kevlar fiber with PTFE fabric knitting has been widely used to improve the wear resistance, mechanical properties and dimensional stability due to the high tensile strength and high elastic modulus [7]. However, the woven liner of Kevlar and PTFE fabric exhibits poor adhesion to adhesive resin due to its chemically inert surface, which leads to poor interface binding force between the liner and the adhesive, thus affect the tribological performance of the self-lubricating liner. There are many reports related to the approaches used to modify the fiber surface [8–11]. Among those approaches, rare earth treatment seemed to be a simple and interesting method [12,13]. It is well known that rare earth can be widely used in electronics, metallurgy, and chemical engineering, etc. The rare earth elements have unique chemical properties and strong activity and the rare earth atom shows larger effective nuclear charge because its 4f electron is weakly bonded for the nuclear, which can affect the properties of the materials [14]. Rare earth atom is a typical hard ion and has strong complex ability and strong ionic bond between the atomic coordination. Therefore, rare earth treatment can improve the interfacial adhesion force of the composite material and its tribological properties [15,16]. In this paper, in order to improve the bonding quality of liner and the tribological properties of the self-lubricating spherical plain bearing, the liners were treated with the rare earth and the influences of the rare earth treatment on bonding quality and tribological properties of self-lubricating spherical plain bearing are investigated.

2. Experiments

2.1. Test preparation

The basic dimensions of a test spherical plain bearing are shown as follows: outer ring diameter Φ35 mm, outer ring width 12 mm, inner ring diameter Φ20 mm, inner ring width 16 mm, ball diameter Φ29 mm. The materials of inner and outer ring were made of GCrl5 steel and the liner was the mixed woven material of the Kevlar and PTFE fiber. The one rich in PTFE fiber was used as a friction surface while the other rich in Kevlar fiber was used as a binding surface in Fig. 1. The mixed woven liner was treated by the rare earth before bonding, and the detailed steps were shown as follows: (1) the liner was immersed in acetone solution for 10–14 h at room temperature, then was dried in the 60–80 °C oven for 10–20 min. (2) The liner of the acetone treatment was

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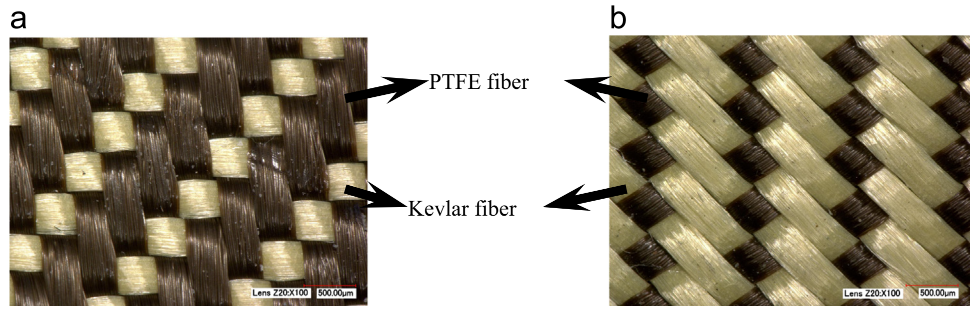

Fig. 1. The structure of woven PTFE and Kevlar fibers. (a) The surface rich in PTFE fibers; (b) the surface rich in Kevlar fibers.

immersed in rare-earth modifier solution for 2–3 h, and then they were dried in the 80–120 °C oven for 20–30 min. The components of the rare earth modifier solution mainly included lanthanum chloride ($LaCl_3$ 0.3%), deionized water (H_2O 99.2%), ammonium chloride (NH_4Cl 0.2%), nitric acid (HNO_3 0.1%) and urea (CON_2H_4 0.2%). The adhesive was bi-component enhanced phenolic adhesive resin (204 phenolic adhesive) purchased from Shanghai Xinguang Chemical Plant of China. The dried liner was glued on the inner surface of outer ring, and then they were placed in calorstat oven at the temperature of 100 °C for 4 h after fixing the inner ring. Finally, the friction and wear test specimens can be obtained.

2.2. Test apparatus

Bonding quality was estimated by the liner peel strength. The self-made peel fixtures were used to fix the peel sample which was gripped in the Instron5944 electronic universal material test machine, then the two fixtures were away from the liner at a certain speed and the liner was peeled down from the outer ring of the bearing. The peel test diagram is shown in Fig. 2.

The bonding force and displacement information were collected and stored with the sensor and data acquisition system. The peel strength data were calculated with the data processing software. The specific calculation formula of the peel strength σ is shown as follows:

$$\sigma = C \times \frac{S}{LB}$$

where C is the load of the unit highly in the peeling curve, N/mm; S is the area of the peeling curve, mm^2; L is the length of the bottom line in the peeling curve, mm; B is the width of the peeling sample, mm.

The tests of the tribological properties were conducted with the testing machine which was a self-made friction and wear tester for spherical plain bearing shown in Fig. 3. By using a torque sensor, a lever indicator and a thermocouple, changes of the friction torque, wear loss and friction temperature were detected. The test conditions were as follows: (1) oscillating frequencies were 2.0 Hz, 2.5 Hz, 3.0 Hz, 3.5 Hz; (2) the oscillation range was $\pm 10°$; (3) the applied pressure on the bearing was 52 MPa (applied load 12.5 kN); (4) tests were done at room temperature. After mounting the bearing in the test machine and after a static load was applied for 15 min, the torque sensor and wear testing sensor were activated and the test was run for 25,000 oscillating cycles. Finally, the wear surface morphologies of the liners were analyzed by the scanning electron microscopy (SEM) and energy dispersive spectrometer (EDS).

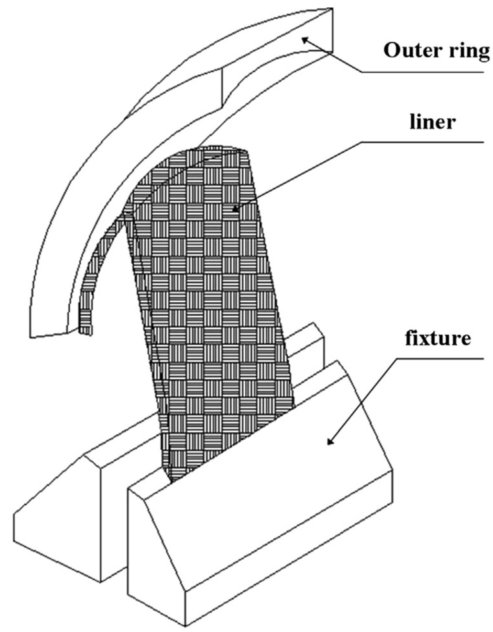

Fig. 2. The diagram of peel strength test.

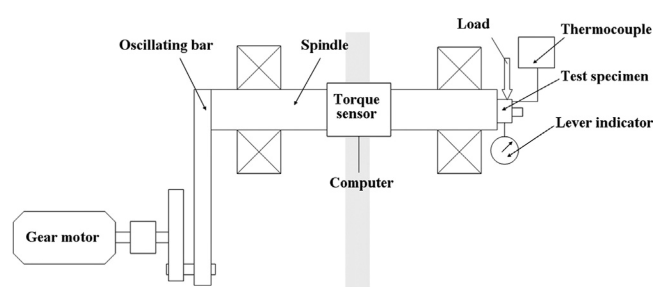

Fig. 3. Schematic diagram of a spherical plain bearing testing machine.

3. Results and discussion

3.1. The liner bonding quality

Based on the bonding quality test aerospace standard SAE-AS81820 of the spherical plain bearings in USA [17], the test program is as follows: the peeling angle is 104.32–178.87°. The peeling speed is 19 mm/min and the acquisition interval is 2 ms. The adhesion degrees of the liners were examined before peeling and 90% tightly adherent must be ensured. The reliabilities of the liners were examined after peeling and the situation of the unbonded area equal to 25% of the outer ring width should not be allowed. The results are shown in Table 1.

It can be seen from the Table 1 that the peel strength of the test bearings is all higher than the value of 0.357 N/mm which is obtained with the formula in the standard SAE-AS81820, so the peel strength of all test bearings can meet the standard requirements. However, the peel strength of liner treated with the rare earth is two times as large as the untreated liner which can be seen obviously from the Table 1. It shows that the bonding quality