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Effects of weft density on the friction and wear properties of self-lubricating fabric liners for journal bearings under heavy load conditions

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ABSTRACT

To improve the sliding friction and wear properties of the fabric self-lubricating liner for journal bearings, conventional and reinforced liners were prepared to investigate the influence of weft density on the friction and wear properties of the liner under heavy load conditions using the self-lubricating liner performance assessment tester. The tribological results showed that the weft density significantly affects the tribological properties of the fabric self-lubricating liner under heavy load conditions. Both the conventional and reinforced liners possess preferably friction and wear properties at the weft density range of 300–350 roots per 10 cm and the reinforced liner shows better friction and wear properties than the conventional liner.

1. Introduction

The application of functional fiber and functional fabric has widely increased owing to their excellent impact properties, stretch properties, friction and wear performance and knitting property. They are widely employed in the fields of aerospace, marine/offshore industries and ground transportation [1], as well as in ballistic impact protection systems [2]. As a type of functional fabric composite, the fabric self-lubricating liner is composed of fiber fabric, resin, fillers and other materials and is applied in cases that require antifriction and wearable materials [3]. Because of its structure and material characteristics, the liner is characterized by its ability to bear heavy loads, long service life, flexibility and non-lubricating property [4]. The self-lubricating liner is undoubtedly the key factor in the service performance of spherical plain bearings [5].

The fabric, as the matrix of the fabric self-lubricating liner, mainly provides self-lubricating material which has a very significant effect on the mechanical behavior and the tribological properties of liner. Technically, the fabric properties are closely related to warp, weft density and count. In the study by Akgun [6], the change in the weave pattern from plain to satin shows opposite effect on the percentage reflectance/surface roughness and the fabric balance. Meanwhile, the weft density also significantly influenced the percentage reflectance, fabric balance and surface roughness. Researchers have also discovered that the shrinkage of the warp density and the cross point between warp and weft yarns is enhanced by the increase in picking density, which could improve the spreading effect of the applied stress and the friction force between yarns [7]. Moreover, the relationship between the flexural properties of the composites and the fiber content was also studied [8].

Weft density is one of the most important parameters weaving. Ref. [9] showed that the effect of weave type on the skewness drops with the increase in the weft density. In fact, the free spaces among the floats, the float length and the shearing rigidity of fabric are all related to weft density. As the weft density increases and the weft yarn becomes thicker, the drape coefficient of woven fabrics increases [10].

In the present study, conventional and reinforced liners for journal bearings were prepared. The influence of weft densities on the tribological properties of the liners under heavy load conditions was investigated. As a result, an ideal weft density range in which both the conventional and reinforced fabric self-lubricating liners possess preferable friction and wear properties was obtained. The discussions on the mechanism of the weft density that affects the properties of the liner are presented. Our work is aimed at contributing to the improvement in the tribological properties of the fabric self-lubricating liner as well as the service life of self-lubricating spherical plain bearings.

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2. Preparation of the fabric self-lubricating liner

2.1. Fabrication of the liner

The fabric was woven with PTFE fiber and aramid fiber (Kevlar 49). The PTFE fiber used in weft direction was supplied by Shanghai Lingqiao Environment Protecting Equipment Works Co., Ltd., which was manufactured using thin-film cutting technology. The aramid Kevlar fiber was supplied by DuPont, U. S. The resin used was modified phenolic resin that supplied Shanghai Xinguang Chemical Co., Ltd. The properties of the two fibers and the resin are listed in Tables 1–3, respectively.

The fabric used in the experiments was fabricated by Y200S Electronic Sample Loom (NanTong SanSi Electromechanical Science & Technology Co. Ltd., China). Two types of liners were prepared, namely, the conventional liner in the weave pattern of plain and the HZ-1 reinforced liner in the weave pattern with one-third broken twill. Both liner types were woven with a warp density of 290 roots per 10 cm and a weft density range of 200–450 roots per 10 cm with an interval of 50 roots per 10 cm. After soaking in acetone for 24 h, the woven fabric was boiled in distilled water for 15 min. Then the pretreated fabric was dried at 80 °C in an oven for 1 h and soaked in phenolic-acetal resin. After treatment by ultrasonic cleaning oscillation for 3 h, a glass rod was used to roll on the liner 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. The fabric liner was completely fabricated after this step. Fig. 1 shows the confocal laser scanning microscopy (CLSM, OLYMPU, OLS3100, Japan) photographs of the liner.

2.2. Tribological tests

Sliding friction experiments were carried out under laboratory condition using the self-lubricating liner performance assessment tester. Fig. 2 shows the structure diagrams of the tester. The experimental parameters listed in Table 4 are within low velocity and heavy load conditions.

The free-body diagram of the motion elements is shown in Fig. 3, where M (N mm) is the friction torque applied on the shaft, $\overline{F}$ is the simplified friction force and F (N) is the load applied on the bush. Before the derivation of the friction coefficient equation, two hypotheses are made: (a) the shaft motion is uniform and (b) the friction force of the liner concentrates on the bottom spot. According to the balance of torque applied on the shaft, Eq. (1) is obtained:

$$M = \overline{F}D \tag{1}$$

where D (mm) is the shaft diameter. Based on the friction eqation, Eq. (2) is obtained:

$$\overline{F} = \mu F \tag{2}$$

Combining Eqs. (1) and (2), the friction coefficient μ can be calculated by Eq. (3):

$$\mu = \frac{M}{DF} \tag{3}$$

In the derivation of Eq. (3) several hypothesises are made so that error between the calculated value and actual results is exist. However, all the friction experiments are conducted under the same condition, which makes the friction coefficient calculated by Eq. (3) a creditable principle to evaluate the antifriction property of different fabric liners.

The wear loss of the liner in experiment can be measured online using the self-lubricating liner performance assessment tester, and the line wear rate K can be obtained by Eq. (4) [11, 12]. Each experiment was repeated three times to ensure the reliability and accuracy of the data.

$$K = \frac{h}{PN} \tag{4}$$

where P (MPa) is the pressure, h (mm) is the line wear loss of the liner and N (s) is the cycle time of whole experiment.

3. Results and discussion

3.1. Friction coefficient

Fig. 4 shows the friction coefficients of the conventional and HZ-1 reinforced fabric self-lubricating liners with different weft densities under different loads. When the weft density is relatively small, the friction coefficients of both conventional and HZ-1 reinforced fabric self-lubricating liners decrease with the increase of the weft density. When the weft density is 300 roots per 10 cm or 350 roots per 10 cm, a minimal value of the frictional coefficient is achieved. However, with the increase of weft density (> 350 roots per 10 cm), the frictional coefficient increases. By taking all factors into account, a low fabric weft density indicates a low PTFE fiber content and results in the difficulty of the formation of enough lubricating film due to the lack of lubricating material during the friction process, which results in a higher friction coefficient. By contrast, when the fabric weft density is very high, the reinforcing material content in the liner decreases, which causes poor abrasive resistance of the liner. In this case, the PTFE lubricating film will nearly be consumed away in a short period;

Table 1
Physical characteristics of PTFE fiber.

Parameter	Liner density	Density	Tenacity	Shrinkage factor	Working temperature
Property	400 den	2.0 g/cm^3	> 0.7 (CN · dtex^{-1})[a]	< 2%	– 190–260 °C

[a] CN · dtex^{-1}: weight (g) of a bundle of fiber per 10,000 m.

Table 2
Physical characteristics of Kevlar49 fiber.

Parameter	Liner density	Toughness	Density	Elongation after fracture	Tensile modulus	Decomposition temperature	Moisture content
Property	400 den	215 CN · Tex^{-1}	1.45 g/cm^3	3.3%	125.0 GPa	500 °C	4.5%

Table 3
Physical properties and used conditions of the resin.

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