Study on the Tribological Characteristics of Solid Lubricants Embedded Tin-Bronze Bearings

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ABSTRACT: The friction and wear characteristics of graphite, MoS_2, and PTFE embedded tin-bronze bearings were studied using a pin-on-disc tester. The results indicated that solid lubricants decreased and stabilized the friction coefficient, and decreased the wear rate by two to three orders of magnitude. When the content of solid lubricants, PTFE mixed with graphite, was 20–40%, the performance of the solid lubricants embedded bearing (SLEB) was the best. Wear scar was analyzed by means of X-ray diffraction (XRD), Auger electron spectroscopy (AES), and scanning electron microscopy (SEM). The results show that the transfer films of solid lubricants reduce adhesion between the SLEBs and the mating material, and the wear mechanism of SLEBs changes to fatigue and adhesive wear. The main reason for fatigue wear is microcracks expanding at Pb points in SLEBs. © 2001 John Wiley & Sons, Inc. J Appl Polym Sci 80: 2394–2399, 2001

Key words: PTFE; graphite; MoS_2; embedded bearing; tribological properties; adhesive wear; fatigue wear

INTRODUCTION

Embedded bearings are self-lubricating bearings in which solid lubricants are embedded into base metals. The base metals support load and the solid lubricants supply lubrication. Embedded bearings could be used in many forms of specified bearings because metals and solid lubricants could be selected extensively. Embedded bearings have many advantages, such as a wide range of size and shape and a wide range of performing conditions, e.g., high-load, low speed, reciprocating, high temperature, waving, and irradiation environments.[1–5]

Solid lubricants embedded tin-bronze bearings (SLEBs) have been applied for years in developed countries, and there are some papers about their application.[1–6] However, very little is known about the tribological characteristics and wear mechanism of SLEBs.[1,6–8] The purpose of this study is to investigate the effect of the content of graphite, MoS_2, and PTFE on the friction and wear properties of SLEBs, and to discuss the wear mechanism by means of analyzing wear scar and solid lubricants transfer films.

EXPERIMENTAL

Materials

Graphite, MoS_2, or PTFE (the compositions are given in Table I) were mixed homogeneously, and

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Table I Composition of Solid Lubricants

	Graphite	MoS_2	PTFE	$BaSO_4$	Phenolic
A1	※	—	—	—	※ 2
A2	※	—	—	※ 1	※ 2
A3	※	※ 1	—	—	※ 2
B1	—	※	—	—	※ 2
C1	—	—	※	—	—
C2	※ 1	—	※	—	—

※ 1—filler; ※ 2—binder.

were hot pressed to form solid lubricants pillars. The base metal was cast tin-bronze (ZQSn5-5-5). Different quantities of solid lubricants pillars were embedded into the friction surface of the base metal. After curing, the friction surface of SLEBs was $\phi 42 \times \phi 36$ mm, and the surface roughness, *Ra,* was 2.6–3.3 μm.

The mating material was 45 steel cylinder (ϕ12 mm) with a hardness of HRC 45–50, a width of friction end-face of 8 mm, and surface roughness, *Ra,* was 0.26–0.53 μm.

Friction and Wear Test

A pin-on-disc wear tester was used in this study. In order to improve contact between the rubbing pairs, one-pin contact was modified into three-pin contact, and a self-aligning apparatus was added to the chucking appliance. A schematic diagram of the modified tester is shown in Figure 1. Experimental conditions were room temperature, dry friction, specific load of 5 MPa, sliding velocity of 0.16 m/s, and testing time of 8 h.

SLEBs and mating material were cleaned with acetone prior to the commencement of the experiments. The friction coefficient was calculated by moment of friction force, which was detected by a BLK-50 load sensor, whereas wear was determined by micrometer with an accuracy of 0.001 mm. All data in the paper are the average values of three repeated tests.

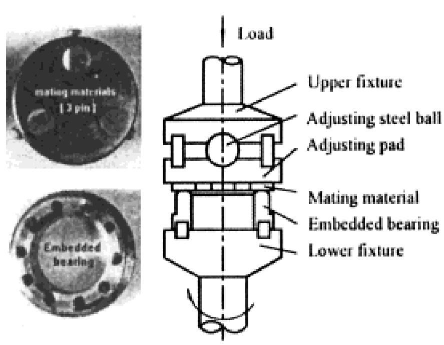

Figure 1 Schematic diagram of the modified tester.

Analysis Instruments

The composition of transfer films on the friction surface was analyzed by scanning electron microscopy (SEM) (JEM-1200EX/9100EDAX, Japan Electron Optics Co., Ltd) and XRD (D/MAX-IIIB, Japan Rigaku Dennki Co.). Transfer matter bonded to base metal was analyzed by AES (PHI-550, America Perkin-Elmer).

RESULTS AND DISCUSSION

The Effect of Solid Lubricants

Friction Coefficient

From Figure 2 it can be seen that, compared with tin-bronze (indicated as ZQ), the friction coefficient of all kinds of SLEBs decreased. PTFE was the best solid lubricant to decrease the friction coefficient, and the friction coefficient of PTFE-filled SLEB was around 0.13. The friction coefficients of MoS_2 and graphite-filled SLEBs was 0.14 and 0.08–0.20, respectively. Concerning the stability of the friction coefficient, PTFE as solid lubricant was better than that of MoS_2, and graphite was the worst. When PTFE mixed with graphite was used as solid lubricant, the tribological performance of SLEBs was improved further.

Wear

Wear of some kinds of SLEBs is given in Figure 3. The results indicate that, compared with tin-bronze, the wear rate of the SLEBs decreased obviously, the wear rate of PTFE-filled SLEB decreased by two to three orders of magnitude and

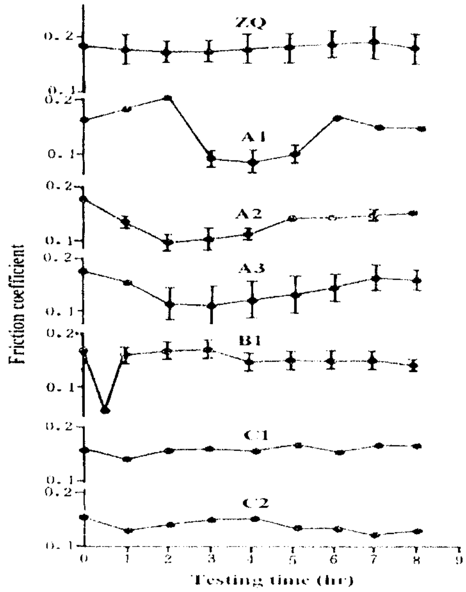

Figure 2 Friction coefficient as a function of SLEBs.

reached 2×10^{-6} mm/(Nm), and the wear rate of MoS_2 or graphite-filled SLEBs decreased by one order of magnitude only. Compared with single composition solid lubricant, PTFE mixed with graphite gave a better lubricating effect.

Effect of Solid Lubricants Content

Figures 4 and 5 show the effect of solid lubricants content on the friction and wear behaviors of SLEB C2.

Friction Coefficient

As shown in Figure 4, when the content of solid lubricant was less than 20% (area fraction), the friction coefficient of SLEB decreased as the content of solid lubricant increased. If the content of solid lubricant was more than 20%, the friction coefficient tended to be stable. This indicates that

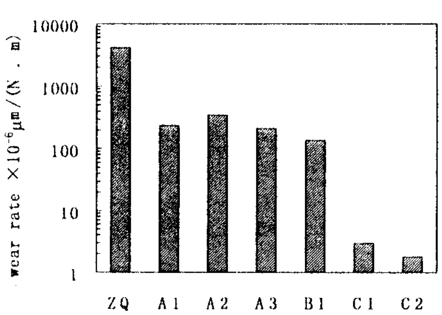

Figure 3 Wear rate of the SLEBs.

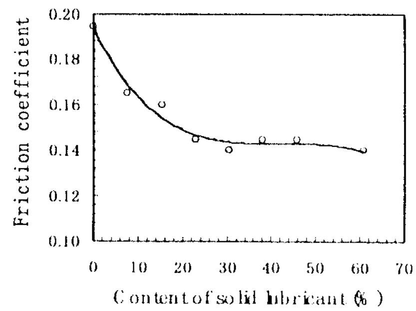

Figure 4 Friction coefficient as a function of solid lubricants content of the SLEBs.

the lubricating effect of solid lubricants on SLEBs is limited.

Wear Property

Figure 5 shows the wear rate as a function of solid lubricant content of the SLEBs. When the content of solid lubricant was 8%, wear rate of bearing decreased by three orders of magnitude, and it decreased continuously as the content of solid lubricant increased. However, wear rate of the SLEB increased as the content of lubricant increased when the lubricant was more than 30%. The wear rate of 60% lubricant-filled SLEB was two times that of the 30% lubricant-filled SLEB.

All of these results show that, to improve friction and wear properties of bearings, content of solid lubricants should be in a suitable range, i.e., 20–40%. When the solid lubricants proportion is more than 30%, a decrease in wear resistance is observed, because of the reduction in load supporting capacity of the base metal.

Antifriction, Antiwear Mechanism of Solid Lubricants

Chemical composition of the different SLEBs was analyzed by means of XRD (CuKα, 50 kV, 150

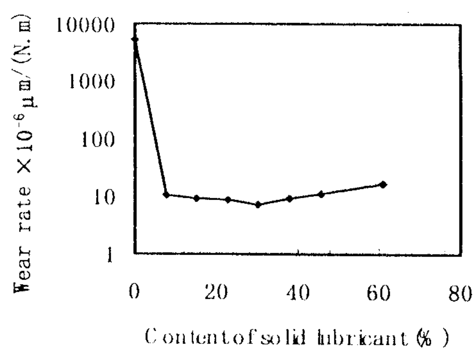

Figure 5 Wear rate as a function of solid lubricants content of the SLEBs.

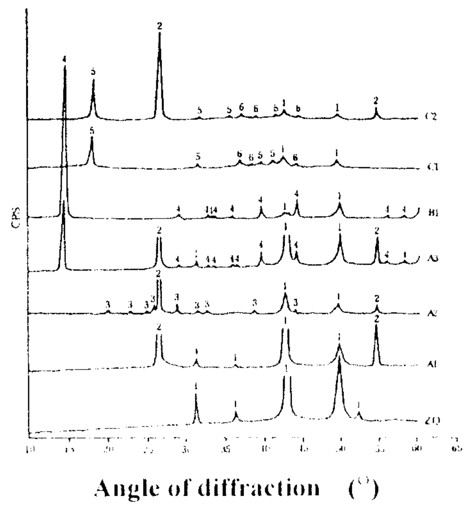

Figure 6 X-ray diffraction spectrum of friction surface of the SLEBs. (1) Cu; (2) Graphite; (3) $BaSO_4$; (4) MoS_2; (5) PTFE; (6) Fe_3O_4.

mA, scanning speed 5°/min). The result is given in Figure 6.

From Figure 6, it can be seen that many diffraction peaks appeared on the friction surface of the SLEBs. Besides the strong diffraction peak of Cu, there were diffraction peaks of solid lubricants. This result illustrates that solid lubricants form a transfer film during the rubbing process. Antiwear property of the SLEBs is improved because of the formation of solid lubricants transfer films during the friction process, the transfer films reduce contact between the rubbing pairs directly. Different kinds of solid lubricants caused different tribological results, which are related to composition of solid lubricants as well as the bonding strength of transfer films on the friction surface.[8]

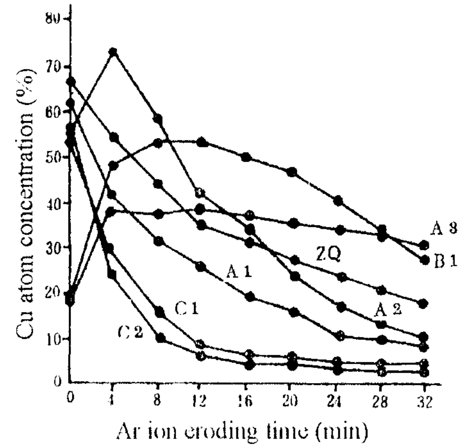

Figure 7 AES depth profile of Cu atoms on friction surface of the mating materials.

In order to clarify antifriction and antiwear mechanisms of the SLEBs, adhesive strength of some transfer films was detected by AES.

Depth distribution of the Cu atoms on the mating material's surface rubbed against different SLEBs is given in Figure 7. Cu atoms on mating materials which rubbed against C1 and C2 (solid lubricants were mainly PTFE) were removed easily by Ar+; for A1, A2 (solid lubricants were mainly graphite), and ZQ, Cu atoms were not removed easily. MoS_2 caused Cu atoms to increase on the mating material (A3, B1). The order of adhesive quantity of Cu atoms on mating materials is in good agreement with tribological properties of the SLEBs. The less the adhesive quantity of Cu atoms on mating materials (rubbed against C1, C2), the lower and more stable the friction coefficient, and the better the antiwear property. This means that tribological characteristics of SLEBs could be presupposed

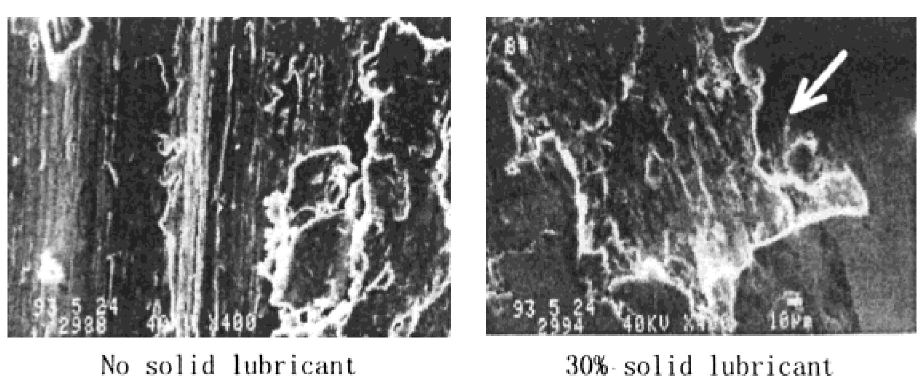

Figure 8 SEM micrograph of tin-bronze bearing and SLEB.

Table II Components of Worn Surfaces of the SLEBs

Sample	Position	Composition (wt %)			
		Cu	Pb	Sn	Zn
No solid lubricant	Original surface	87.19	4.50	3.25	5.06
	Plow groove	87.66	4.39	3.29	4.66
30% solid lubricant	Smooth surface	89.04	3.51	2.99	4.46
	Worn pit	79.72	12.76	3.05	4.47

qualitatively by observing the adhesive strength of Cu atoms on the mating materials.

To conclude, transfer films of solid lubricants between the SLEBs and the mating materials prevent or reduce adhesion of the base metal Cu to the mating materials, and decrease adhesive wear of the rubbing pairs. The qualities (including uniformity of transfer matter and adhesive strength) of transfer films play a main role in determining tribological properties of SLEBs.

Failure Mechanism of SLEBs

The friction surface of tin-bronze bearing had wear grooves and scratch marks. The friction surface of the SLEBs was smoother, but there were some porphyritic pits with an area of about a square millimeter.

Wear scar of the tin-bronze bearing and 30% lubricant-filled SLEB were observed by means of SEM; the result is shown in Figure 8. The former showed plastic deformation, furrow, and serious adhesive wear; the latter showed slight adhesive wear and some porphyritic wear pits. These characteristics indicate that solid lubricants reduce adhesive wear of the SLEBs, but lead to fatigue wear.

In order to investigate the formation mechanisms of wear pits, original surface, wear groove, and porphyritic pits were analyzed by EDAX; the result is given in Table II. It was found that Pb content on the original surface, plow groove of the tin-bronze bearing, and the smooth surface of the SLEB did not obviously vary, but Pb content on the porphyritic pits was one to two times that found on the smooth friction surface of the SLEB. This is important evidence that eq. Pb content increase on porphyritic pits leads to fatigue wear.

Figure 9 shows fatigue wear mechanism of SLEBs. From metallographic analysis,[9] it is known that Pb atoms disperse in Cu alloy as fine particles [Fig. 9(a)]. During the rubbing process, solid lubricant transfers to the base metal surface, then forms transfer films [Fig. 9(b)]. Transfer films reduce adhesive wear between the SLEB and the mating material,[6–8] and the surface of the SLEB becomes antiwear. Under periodic friction shearing stress, microcracks emerge easily at Pb points [Fig. 9(c)].[10] Several microcracks expand and connect to each other, leading to fatigue wear [Fig. 9(d)], and the material peels off as wear debris [Fig. 9(e)].

The reason for the Pb content increase on the porphyritic pits is that Pb fine particles connected at different depth scales that formed the debris; therefore, Pb could be detected simultaneously in certain ranges of depth.

CONCLUSIONS

1. All the tested solid lubricants could improve tribological performance of SLEBs under dry friction conditions. Among the selected solid lubricants in this paper, PTFE mixed with graphite showed the best performance.

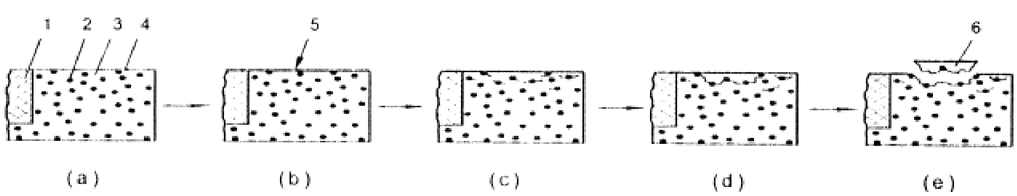

Figure 9 Schematic diagram of fatigue wear of the SLEBs (1) solid lubricants; (2) Pb; (3) copper alloy; (4) friction surface; (5) transfer film; (6) worn debris.

2. When the content of solid lubricants was 20–40%, the friction coefficient of PTFE mixed with graphite-filled SLEB decreased to around 0.13, and wear rate was reduced by three orders of magnitude.
3. The tribological properties of the SLEBs were determined by well-distribution transfer films of solid lubricants on the rubbing pairs. PTFE and graphite transfer films prevented or reduced adhesion of base metal Cu to the mating materials, and decreased adhesive wear of the rubbing pairs.
4. Under periodic friction shearing stress, microcracks formed in tin-bronze base metal, which led to fatigue wear of the SLEB.

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REFERENCES

1. Tada, H. In Teaching material, No. 304th Study Group of Japan Mechanical Society, Tokyo, 1969, 1.
2. Catalogue of Oiles Co., Ltd., 1982.
3. Li, T. S. Solid Lubrication (China) 1989, 9, 69.
4. Abe, W. Lubrication (Japan) 1981, 26; 316.
5. Akaoka, J. Lubrication (Japan) 1980, 25, 224.
6. Li, W. L.; Li, T. S.; Tao, J. Solid Lubrication (China) 1991, 11, 35.
7. Tao, J.; Li, T. S.; Li, W. L. Solid Lubrication (China) 1991, 11, 120.
8. Tao, J.; Li, T. S.; Shen, W. C.; Xu, J. F. Tribology (China) 1993, 13, 317.
9. Metallographic Spectrum of Metal Materials; Jiangsu Province Science and Technology Press: Nanjing Automobile Manufacturer, Nanjing, 1979, 126.
10. Gao, C. Q.; Liu, J. J. Adhesive Wear and Fatigue Wear of Materials; Mechanical Industry Press: 1989; 280.