Tribological properties of the two embedded solid lubricant composites at heavy loads

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The 20 wt.% short glass fiber and 5 wt.% graphite reinforced polytetrafluoroethylene (PTFE) composite was prepared as the embedded solid lubricant, and the 40Cr steel and C86300 bronze were used as the backing material. The sliding tests were carried out on an oscillating tibometer under a contact pressure of 80 MPa and oscillating frequency of 0.14 Hz conditions at air. The results showed that the steel-based embedded solid lubricant composite against a 38CrMoAlA steel shaft exhibited low coefficient of friction and good wear resistance compared with the brass-based one. The major differences in tribological properties for the two composites arise from the different nature of 40Cr steel and C86300 bronze. The thermal softening of C86300 bronze occurs due to frictional heating leading to temperature rise and its strength drops rapidly in contrast to 40Cr steel. The present work is believed to be helpful for understanding of friction and wear behavior of different self-lubricating composites under heavy loading conditions.

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1. Introduction

Polymer and composites especially fiber-reinforced composite, form a very important class of tribo-materials and are used where components are supposed to run without external lubricants [1]. In recent years, several new solid lubricants and modern lubrication concepts have been developed to achieve better lubricity and longer wear life in demanding triboligical applications. Most of the traditional solid lubricants were prepared combining with metal in order to improve the operating durability and mechanical performance under severe conditions. Metal-based embedded composites are an important mode of self-lubricating materials and wildly used as gearings in metallurgy machine, mining apparatus and sluice system.

Several laboratory fundamental investigations on the solid lubricating composites and dry bearings have been done. Seong Su Kim et al. [2] reported that the seizure problem of metallic journal bearing materials could be solved by using hybrid composite journal bearing. Endo [3] studied a series of engineering plastics bearings and found that there were remarkable effects of thermal properties of materials and the experimental conditions on the wear of dry bearings. Tao and Li [4] embedded PTFE-graphite composites into bronze bearings in various embedded area, and had pointed out that the transfer film formed by the inserted solid lubricants was dominant in the sliding process. Xiang et al. [5] reported that metal–plastic transverse section (SBP) composite exhibited low and stable coefficient of friction, outstanding thermal conductivity, and is suitable as bearing material at dry sliding.

Nevertheless, in a comprehensive and practical sense, the major problems of designing polymer bearings are the decision of optimal dimensions and choice of material for a long life and for obtaining lower friction losses [6, 7]. Limited studies have been concerned with the wear life of embedded solid lubricating composites especially under heavy load conditions. Hence, this is an area of considerable current research interest, where new embedded composite materials are being sought to exploit the properties of proper backing metals and suitable solid lubricants. The purpose of this work is to investigate the effect of C86300 bronze and 40Cr steel as the backing metals on the wear life and tribological properties of embedded self-lubricating composites under severe loading conditions, respectively. The PTFE composite including short glass fiber and graphite is prepared as the solid lubricant.

2. Experimetnal

Table 1. The physical and mechanical properties of the backing metals.

Properties	Metals	
	40Cr Steel(AISI 5140)	Bronze(C86300)
Density (g.cm^{-3})	7.82	7.7
Hardness (HB)	207	225
Young's modulus (GPa)	210	105
Tensile strength(MPa)	980	820
Yield point (MPa)	785	460
Elongation	9%	18%
Linear expansion coefficient (20～200℃) (μm/m.K)	12	22

The 40Cr steel (AISI 5140) sleeve was heated to 860 ℃, held 9 min, cooled in oil followed by tempering at 550 ℃. The solid lubricant composing of PTFE, 20 wt% shot glass fiber and 5 wt% graphite powders was made by compression molding. The bearing of 40Cr steel-based (SBC) and bronze-based composites (BBC) were prepared by mechanical machining, thus holes at a certain depth with the bearings were obtained by drilling, then pins of PTFE composite of diameter about 7.8 mm were embedded into the holes tightly by means of epoxy resin adhesive at an embedded surface area ratio of 30%. The physical properties of backing materials are listed in table 1, while the morphology of the embedded bearings sample of 54 mm long, 55 mm in external diameter and 65 mm in internal diameter is shown in Fig.1 after finishing.

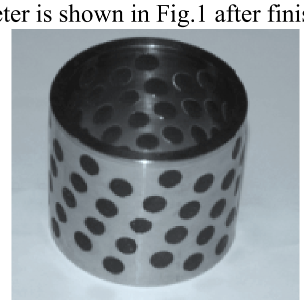


Fig. 1. Photograph of the embedded solid lubricating composite.

Under room temperature and relative humidity of 60±5%, the friction and wear behavior of the embedded steel-based and bronze-based composites were examined on a NH-100 heavy-loading tribometer designed for this work at a load of 236 KN (nominal pressure of 80 MPa), an oscillation frequency of 0.14 Hz. The 38CrMoAlA (AISI 6470E) steel was employed as shaft material with a surface hardness of HRC70 after nitriding at 600 ℃. Fig.2 represents the contact schematic diagram of the frictional pair. In this test, YD-21 dynamic resistance strain instrument was used to measure the friction coefficient. Simultaneously, the surface temperature of the testing samples was detected. In order to understand the details of the wear mechanisms operating on the PTFE solid lubricant, a QunTa200 scanning electron microscope (SEM) was used to probe the morphologies of worn surface.

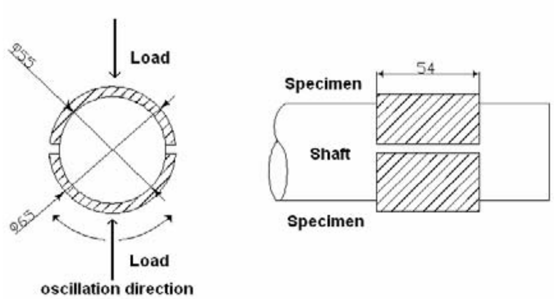


Fig.2. Contact schematic diagram of the frictional pair.

3. Results and disscusion

3.1 Tribological behavior of embedded solid lubricating composites

The variation of friction coefficient with test time is shown in Fig.3. For 40Cr steel-based composite, the friction coefficient decreased to a certain value from the beginning of the test and maintained that value for a long period. Dissimilarly, the friction coefficient obtained on the study of bronze-based composite increased slightly with the test process after initial decreased to a certain degree. Moreover, the coefficient of friction of SBC is about 1/2 of that BBC exhibits in the test. This is understandable that friction coefficient start with a running-in period followed by steady-state period for PTFE polymer. It is believed that within running-in period, rough and discontinuous transfer film operating on the surface of SBC, then the continuous composite film covers the surface leading to lower friction coefficient values. The increase of friction coefficient values of BBC is attributed to the failure of solid lubricating film under heavy loading conditions.

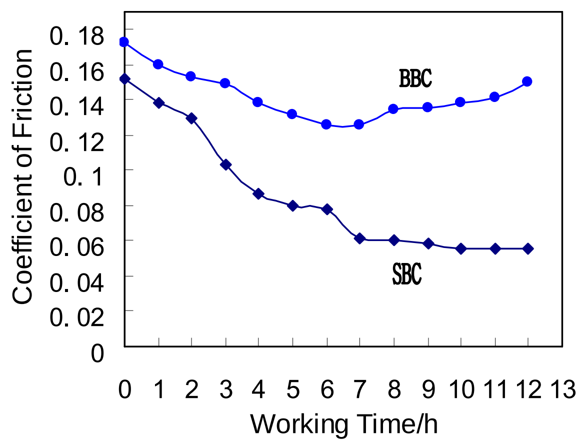


Fig. 3. Friction coefficient of SBC and BBC as a function of working time.

The temperature of the worn surface of specimens as a function of testing time is shown in Fig.4. The temperature is one of the most significant factors which reflect the working of the transfer film. Attention should be paid to the fact that the temperature of SBC is up to 120 ℃ and a stable trend exhibits in the steady-state period. However, the contact surface temperature of BBC increases rapidly and exceeds 145 ℃ to some extent.

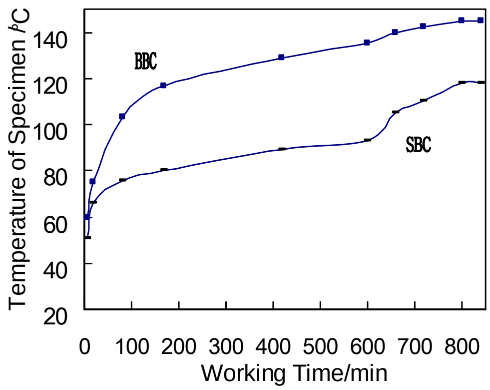


Fig. 4. Variation of temperature of the two specimens with working time.

Fig. 5 shows the wear depth as a function of oscillation time. It is clear from the graph that the wear depth of BBC was increased linearly with the working time. And the lubricative invalidation occurred on the interface between the friction pairs via macroscopical observation. However, the SBC exhibited excellent wear resistance even the value of oscillation time was over 10^5 under the pressure of 80 MPa.

At high loads, the elastic deformation at the point of contact between PTFE composite and the counterface is so great that individual asperities on the contacting surfaces are 'ironed out'. This is responsible for the formation of transfer thin films occurring on the interface. And the formation and behavior of the films are critical in the wear of dry bearings lubricated by means of polymers solid lubricants. Deformation and adhesion are two main wear mechanisms in the contacting of polymer and hard metals [8]. The method of improving the compressive strength of PTFE composites is to employ the metals as backing body. Indeed, the differences of wear life and tribological performance in SBC and BBC result from the different properties of backing metals at high load. When the temperature of metals especially nonferrous metals is increasing due to friction, several effects will occur: their mechanical properties will change, coefficient of linear expansion will alter, and phase transformations may take place. All these will influence their loading capacity under the high pressure in this test. It is obvious from Table 1 that the linear expansion coefficient of bronze was higher than that of 40Cr steel at working temperature. In this case, the dissipation of frictional work generates enough local heat to raise the temperature at the interface, and therefore the bronze loses its shear strength. Accordingly, bronze can not operate well under high load. This is in agreement with the reports obtained by Huchings [9]. At high load thermal softening of the bronze occurs, resulting in an increase in the rate of severe wear. On the contrary, the 40Cr steel shows no significant change in friction with temperature over this range, since its mechanical properties do not alter markedly. Hence, hard backing steel exhibits good anti-deformation resistance and reinforces the solid lubricant at heavy load. The transfer film can operate stably during the test.

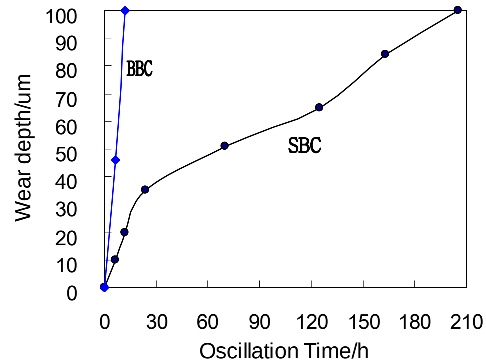
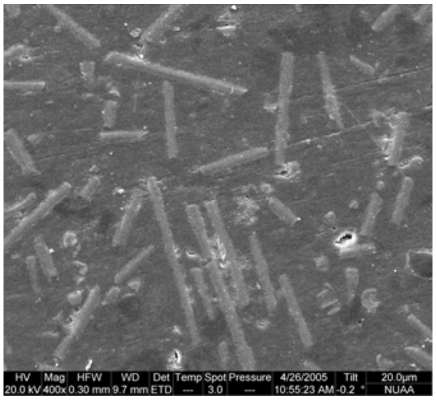


Fig. 5. Experimental curves for wear depth of SBC and BBC with oscillation time.

3.2 Analysis of worn surface and discussion

Fig.6 (a) and (b) showed microscopic morphology of the worn surface for PTFE composite and 40Cr steel sleeve, respectively. A detailed study of the embedded self-lubricating composite against hard shaft steel suggests the following sequence of events. The wear mechanism of PTFE is dominated by plastic deformation, an important factor in determining the wear rate is the plastic groove volume removed. Short glass fiber (SGF) possesses high strength and high clash modulus, and the load action on the composites is mainly borne by glass fiber, thus, the friction behavior of the PTFE composite is mainly determined by SGF. A micrograph Fig.6 (a) shows broken pieces of glass fiber debonding from the polymer pin surface. SGF distributed dispersedly in the PTFE matrix and prevented the deformation of the polymer. Meanwhile, long scars were found on the worn surface of PTFE composite. The reason is that abrasion occurs on the interface by peeling off of the SGF. And abrasion is one of the main wear regime of the reinforced PTFE composite. In addition, it is hypothesized that the glass fibers tend to polish the counterface, resulting in a uniform transfer film and low wear rate [10]. Subsequently, a continuous lubricating transfer film over the surface of steel as shown in Fig.6 (b) is observed clearly. There are two main reasons responsible for this phenomenon. Firstly, the application of 40Cr steel as the undertaker improved the dimensional stability of SBC. Accordingly, it was observed that the PTFE composite film band got denser at the middle of the composite. On the contrary, uninterrupted transfer film was not found on the surface of BBC. Moreover, graphite is very effective in reducing the wear and friction of the composite owing to its lamellar structure. Graphite powder is helpful in the formation of the transfer film and prohibits PTFE from flaking off because of the perfect adhesive property of graphite.



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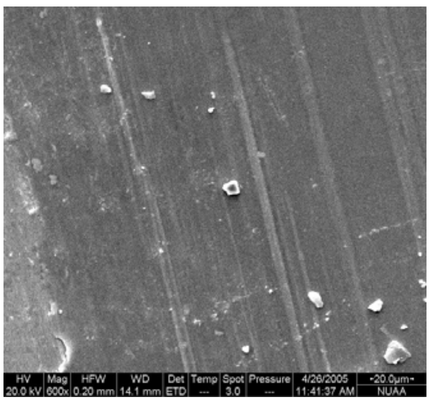

b

Fig. 6. SEM photographs of worn surface of SBC under dry lubrication conditions. (a) Worn surface of PTFE composite. (b) Transfer film on the surface of steel.

4. Conclusions

Based on the experimental and analytical results of dry friction and wear test presented above, the following observations and conclusions were made:

Under ambient conditions, 40Cr steel based embedded composite exhibited good wear resistance and long service life at a high pressure of 80 MPa.

The transfer film was formed efficiently on the surface of the backing steel by reinforced PTFE composite lubricant.

The mechanical properties of backing metals were important factors against the wear of metal-based embedded solid lubricating composites at high load. The failure of bronze-based composite resulted from the thermal soften of the bronze with the increase of the contact temperature.

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