Study on the ultimate load carrying capacity of journal bearings with different materials and surface treating processes

Hulin Li¹,*, Yanzhen Wang² and Zhongwei Yin³

¹, ³ School of design, Shanghai Jiao Tong University, Shanghai, China
² CSSC 708 Research Institute, Shanghai, China

Email: gslhl@126.com; merinawang@163.com; yinzw@163.com

Abstract. The ultimate load carrying capacity of journal bearings with different materials and surface treatment processes was studied in the present work. The load carrying capacity and backside temperature of bearing were examined using a bearing fatigue test machine (Glacier Vandervel, made in UK). The results showed that the copper-based sputtering bearing has the highest ultimate bearing capacity and the fatigue strength reaches 131.3 MPa. The bearing capacity of copper-based electroplated bearings is 99.7 MPa, which is lower than that of copper-based sputtering bearings. The bearing capacity of high tin aluminum alloy is obviously higher than that of white alloy bearing, and the bearing capacity of the two bearings is 72.7 MPa and 36.3 MPa, respectively. Finally, the mechanisms of fatigue failure of the bearings were analyzed.

Keywords: ultimate load carrying capacity, sputtering bearing, electroplating bearing, Aluminium-based alloy bearing, tin-based alloy bearing

1. Introduction

As one of the most important component of diesel engines, oil-lubricated journal bearings are designed to convert the reciprocating motion of pistons into the rotary motion of the crankshaft[1]. It is critical for the stable operation of diesel engines that the bearing material has excellent load carrying and tribological behavior. Bearing material is generally required to have good embedability, conformability, seizure resistance, and most importantly excellent tribological performance under oil-lubricated conditions [2-4].

The load carrying capacity and tribological behavior of journal bearings materials have been investigated by many related studies. Bican and Savaskan [5] studied the wear behaviors of Al–25Zn–
3Cu–3Si alloy using a block-on-disc machine and compared with the performance of 60/40 brass and SAE 65 bronze, the results showed that the Al–25Zn–3Cu–3Si alloy showed the best wear resistance. Kumar et al [6] studied the friction and wear characteristics of Cu–Sn alloy reinforced with molybdenum disulfide (MoS2) fabricated by a powder metallurgy route. The results showed that the wear rate of composites is the lowest when MoS2 content is 7 wt%. Miguel et al [7] studied the effect of spraying process on tribological behavior of bronze–alumina composite coatings by ball on disc dry sliding tests, and the results showed that the wear rate of composites was significantly reduced by Al2O3 particles.

The load carrying capacity and tribological behaviors between different bearing materials vary greatly. Until now, some research studied the load carrying capacity and frictional behavior of journal bearing under static load, but the performances under actual dynamic load are unclear. Thus, this paper focuses on the bearing capacity and operating characteristics of four kinds of bearing (sputtering AlSn20Cu bearing, electroplating AlSn20Cu bearing, AlSn40Cu alloy bearing and ZSnSb8Cu4 alloy bearing) under dynamic load to provide technical support for the practical application of these kinds of bearings.

2. Experimental section

2.1 Materials and specimen preparation

In the experiment, the ultimate load carrying capacity of four kinds of bearing prepared by different matrix materials and surface treating processes were tested. The shaft was made of 42CrMo steel and the bearings were made of bimetal composite or three-layer metal composite. The copper-based sputtering bearing is composed of 10# steel back, CuPb22Sn2 alloy substrate layer and AlSn20Cu alloy sputtering layer, which is abbreviated as CBAS-Bearing in this paper. The copper-based electroplating bearing is composed of 10# steel back, CuPb22Sn2 alloy substrate layer and PbSn18Cu2 alloy electroplating layer, which is abbreviated as CBPE-Bearing in this paper. The high tin aluminum alloy bearing is composed of 10# steel back, AlSn40Cu alloy substrate layer, which is abbreviated as HTAB-Bearing in this paper. The tin-based bearing is composed of 10# steel back, ZSnSb8Cu4 alloy substrate layer, which is abbreviated as TB-Bearing in this paper.

2.2 Ultimate load carrying capacity test

![Figure 1. The schematics of the test assembly](image1)

![Figure 2. Test load curve](image2)

Ultimate load carrying capacity tests of bearings were performed using a bearing fatigue strength test machine (Glacier Vandervel, made in UK), as shown in Fig. 1. Each test runs for 20 hours, and then checks the damage of bearing. If the bearing passes the test (no damage visible to the naked
eyes), add one level load (7.0 MPa) to continue the test. Repeat the above operation until the bearing is fatigue damaged or wear out. The previous level load when the bearing is damaged is determined as the ultimate load carrying capacity of the bearing. The test shaft diameter is 52.7$\pm$0.013 mm, bearing outer diameter is 56.426 mm, bearing thickness is 1.825$\pm$0.006 mm, and bearing width is 29.5 mm. For the ultimate load carrying capacity tests, the rotational speed is 3000 r/min and the running time is 20 hours (3.6$\times$10$^6$ cycles) for each test. As shown in Fig. 2, the loading frequency is 50 Hz and sampling frequency is 1000 Hz.

3. Results and discussion

Fig. 3 shows the variation of the backside temperature of bearings with load and time. As shown in Fig.3, the backside temperature of bearings for different material and surface treatment processes increases first and then remains basically unchanged. In addition, for all the bearings the backside temperature increases with the increase of load. As can be seen from Fig. 3a and Fig. 3b, under the almost same load conditions, the backside temperature of bearings with electroplating layer is significantly lower than that of bearings with sputtering layer. The possible reasons are that the hardness and the friction coefficient of PbSn18Cu2 electroplated coating are lower than that of AlSn20Cu sputtering coating.

**Figure 3.** Backside temperature of bearings vs. load and time (a: CBAS-Bearing; b: CBPE-Bearing; c: HTAB-Bearing; d: TB-Bearing)

![Figure 3. Backside temperature of bearings vs. load and time](image)

**Figure 4.** Worn surface of CBAS-Bearing

**Figure 5.** Worn surface of HTAB-Bearing

Fig. 4 shows the digital camera photo of worn surface of CBAS-Bearing under different loads. The results showed that, as the increase of load, the wear zone develops from the end surfaces of the bearing toward the middle plane of the bearing and the wear damage increases gradually. The AlSn20Cu sputtering layer on the bearing surface is completely worn off when the load is increased to 122 MPa.
However, the CuPb22Sn2 alloy substrate layer of CBAS-Bearing is still in the good condition. Therefore, the main failure mode of CBAS-Bearing is the abrasion wear of sputtered coating.

Fig. 5 shows the digital camera photo of worn surface of HTAB-Bearing under different loads. The results showed that the wear of AlSn40Cu alloy bearing is not significant when the load increases to 68 MPa. The main reason is that the lubrication film between the bearing and the shaft is thick when the load is small, thereby avoiding the direct contact of the bearing and shaft. However, when the load increases to 75 MPa, fatigue flaking off as shown in Fig. 5f appears on the worn surface of AlSn40Cu alloy layer. Therefore, the failure of the HTAB-Bearing is mainly due to the fatigue failure caused by the test load approaching the material's fatigue limit.

![Figure 6. Worn surface of CBPE-Bearing](image6)

![Figure 7. Worn surface of TB-Bearing](image7)

Fig. 6 shows the digital camera photo of worn surface of CBPE-Bearing under different loads. The results showed that the wear of PbSn18Cu2 electroplated coating aggravates as the increase of load. The PbSn18Cu2 electroplated layer is completely worn through when the load increases to 109 MPa. Like the CBAS-Bearing, the CuPb22Sn2 alloy substrate layer of CBPE-Bearing is also intact, which indicates that the main failure mode of CBPE-Bearing, like that of CBAS-Bearing, is the abrasion wear of the coating.

Fig. 7 shows the digital camera photo of worn surface of TB-Bearing under different loads. The results showed that the abrasion wear of ZSnSb8Cu4 alloy substrate layer increases with the increase of load. As we all know, the hardness and wear resistance of TB-Bearing are much worse than those of CBAS-Bearing, CBPE-Bearing and HTAB-Bearing. The wear of TB-Bearing is not serious because of the small load and the thick oil film between bearing and shaft. However, it can be seen from the Fig.3d that when the test load is increased to 41MPa, the fatigue is happened. Therefore, same as the HTAB-Bearing, the main failure mode of TB-Bearing is fatigue damage of based alloy layer.

![Figure 8. Average fatigue load and backside temperature of bearing](image8)

Fig. 8 shows the average fatigue load and the corresponding backside temperature of bearing with different materials and processing technology. The results showed that the average fatigue load (average
value of 3 tests) of CBAS-Bearing, CBPE-Bearing, HTAB-Bearing and TB-Bearing is 131.3 MPa, 99.7 MPa, 72.7 MPa and 66.3 MPa, respectively, and the corresponding backside temperature of bearing is 123.8 °C, 110.2 °C, 101.5 °C and 92.3 °C, respectively. It can be seen from the figure that with the increase of the test load the temperature of the bearing is increased. When the experimental load increased to 27 MPa the backside temperature of TB-Bearing is over 90 °C, which is close to the maximum working temperature of white alloy. Therefore, the bearing capacity will be adversely affected.

4. Conclusion

The ultimate load carrying capacity of journal bearings with different matrix materials and surface treating methods are studied using a bearing fatigue strength test machine in the present work. The following conclusions can be drawn: (1) The copper-based sputtering bearing has the best bearing capacity, and the ultimate bearing capacity reaches 131.3 MPa. (2) Surface treatment has a significant effect on the wear resistance of the bearing, the wear resistance of sputtering coating is better than that of electroplating coating. (3) The main failure form of CBAS-Bearing and CBPE-Bearing is abrasion wear of sputtered or electroplated coating, while the failure form of HTAB-Bearing and TB-Bearing is fatigue of alloy layer.

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