Contrast Research about Performance of PA1010 and HPb59-1 Isolator in Heavy Slewing Bearing

Chuanhui Huang, Lei Zhang* and Bin Song
Department of mechanical Engineering, Xuzhou University of Technology, Xuzhou, China

*Corresponding author e-mail: triple-stone@foxmail.com

Abstract. The performance of heavy slewing bearing isolator materials PA1010 and HPb59-1 mating for bearing steel GCr15 was investigated through experiments in this paper. The effects of applied load, sliding speed and lubricant on friction coefficient and wear loss of PA1010 and HPb59-1 were discussed. The damage mechanism and failure law of PA1010 and HPb59-1 isolators were analysed. The results show that the friction coefficient of PA1010 is lower than that of HPb59-1 and the wear loss of PA1010 is higher than HPb59-1. The influence of rotational speed on the tribological properties of HPb59-1 is obviously higher than that of PA1010. At the low sliding speed, the wear loss of these two materials changes more significantly with the change of load. The influence of coupling pair surface roughness on the tribological properties of PA1010 is significantly higher than that of HPb59-1. When the surface roughness of coupling steel ring increases from 0.2μm to 0.4μm, the growth rate of friction coefficient of PA1010 is 274.1% higher than that of HPb59-1, and the growth rate of wear loss is 25.5% higher than HPb59-1.

1. Introduction

Isolator is one of the important basic parts of various bearings, which is used to separate and fix the relative position between the rolling elements and reduce the mutual friction between rolling elements. Its comprehensive performance has an important impact on the service reliability and life of bearing products [1,2]. At present, the common structural forms of isolators mainly include the frame type, fancy type, ball type and special-shaped type. The commonly used materials are the plastic, brass, bronze and steel, among which the nylon PA1010 and lead brass HPb59-1 are the most widely used in industry [3,4].

PA1010 has a small pressure fluctuation, low specific gravity, good compliance, and can withstand certain plastic deformation, so it is widely used in engineering [5-8]. However, compared with other engineering plastics, its hardness is higher. Sometimes it will cause the noise at run time. The wear mechanism of PA1010 is mainly the plastic deformation, ploughing and fatigue delamination. The wear loss is closely related to the applied load, which is due to the influence of applied load on its transfer to the wear surface of the coupling part and the film formation [9-11]. The mechanical strength, hardness and wear resistance of PA1010 can be significantly improved by adding the proper fillers to PA1010 [12-15]. The brass of HPb59-1 has high strength and hardness, good machinability and mechanical properties, which can withstand the hot and cold pressure processing. Because of its good corrosion stability and wear resistance, it is widely used in high-speed precision cylindrical roller bearings and thrust angular contact ball bearings [16]. On the basis of HPb59-1, the maximum speed...
allowed by the material can be significantly increased by adding some alloy elements, such as Ni, Mn, Fe and Al [17,18].

Isolator is not only affected by the friction force, tension, centrifugal force and inertia force, but also by the chemical action of the lubricant and its additive, aging product and coolant. Therefore, the material selection and structure design of isolator is one of the key technologies of the bearing design and manufacture. In this paper, the tribological behaviors of PA1010, HPb59-1 against the bearing steel GCr15 were investigated by the wear experiments. The friction and wear mechanism was discussed, and the damage mechanism and failure law of PA1010 and HPb59-1 isolators were analyzed. The purpose of this study is to provide the experimental and theoretical reference for the mechanical design of isolator.

2. Friction and wear test

The friction and wear experiment was carried out on M-2000 testing machine. Fig.1 shows the contact diagram of upper and lower samples for sliding wear. The samples of PA1010 and HPb59-1 isolators were processed into a cuboid of 20mm×10mm×8mm. The roughness (Ra) of the wear surface was about 0.8μm after being polished with 800μm sandpaper. Before the experiment, the samples were cleaned with absolute ethanol and dried at 80°C for 1.0h. The GCr15 steel sample was machined into a circular ring with the dimensions of 40mm in outer diameter, 16mm in inner diameter and 10mm in thickness. The hardness after quenching was about 63HRC. Three kinds of surface roughness (Ra), such as 0.2μm, 0.3μm and 0.4μm, were obtained by grinding and polishing the cylindrical surface with different particle size sandpapers. The rough texture morphologies of outer circle surface obtained by three-dimensional optical topography instrument (Rtec MFP-D) are shown in Fig.2. Before the wear tests, the samples were cleaned with the acetone solution and dried at 80°C for 1.0h.

![Figure 1. Contact diagram of upper and lower samples for sliding wear](image1)

![Figure 2. 3D surface topographies of metal counterparts with different surface roughness](image2)

The rotating speed of steel ring was 200rpm and 400rpm, and the load was set to 200N, 400N and 600N respectively. The experimental time was 20minutes. The lubrication condition was the No.2 lithium base grease commonly used for the bearings. The friction force was collected by the computer data system, which was converted into the friction coefficient of K according to the following formula.

$$K = \frac{F}{P}$$

Where $F$ is the friction force, N. $P$ is the contact load, N. After the experiment, PA1010 and HPb59-1 samples were taken off to measure the wear width of test surface. The wear surface morphologies of PA1010 and HPb59-1 samples were observed by SEM (INSPECTS50).
3. Results and discussion

Fig. 3 shows the variation of friction coefficient and wear loss of PA1010 and HPb59-1 with the increase of applied loads. It can be seen that the friction coefficient of PA1010 is lower than that of HPb59-1. The average ratio of PA1010 and HPb59-1 is about 1:1.16 under the same load. With the increase of applied load, the friction coefficients of these two materials decrease slightly, but remain basically unchanged. When the test speed increased from 200 rpm to 400 rpm, the friction coefficients of PA1010 and HPb59-1 increase by 12.8% and 19.0% respectively. The wear loss of PA1010 is obviously higher than that of HPb59-1, which reveals that its wear resistance is not as good as that of HPb59-1. The average ratio of PA1010 and HPb59-1 is about 2.51:1 under the same load. With the increase of applied load, the wear loss increases gradually. When the load increases from 200N to 600N, the wear loss of PA1010 and HPb59-1 increases by 140.7% and 158.8% respectively. The specific increment of wear loss for these two materials is shown in Fig. 4. It can be seen that the increment at 200 rpm is higher than that at 400 rpm, which indicates that the wear loss of two materials changes more significantly with the change of applied load at low speed. Under the same load, the wear loss of PA1010 at 400rpm is increased by 38.5% compared with that at 200rpm. While the wear loss of HPb59-1 is increased by 91.7%, which is about 2.4 times of PA1010. This result means that the effect of experimental speed on the tribological properties of HPb59-1 is significantly higher than that of PA1010.

Figure 3. Friction coefficient and wear in cases of different load and revolving speed

Figure 4. Increment of wear of PA1010 and HPb59-1 in cases of different revolving speed

Fig. 5 shows the friction coefficient and wear loss of PA1010 and HPb59-1 under different surface roughness and load. It can be seen that the friction coefficient and wear loss increase with the increase of the surface roughness of friction ring. When the surface roughness increases from 0.2μm to 0.4μm, the friction coefficient of PA1010 increases by 45.9% (200N), 50.0% (400N) and 50.0% (600N), and the wear loss increases by 270.7% (200N), 54.2% (400N) and 101.1% (600N), respectively. The friction coefficient of HPb59-1 increases by 15.4% (200N), 18.2% (400N) and 9.1% (600N), and the wear loss increases by 188.2% (200N), 53.2% (400N) and 77.5% (600N), respectively. Compared with HPb59-1, the friction coefficient of PA1010 is increased by 274.1% and the wear rate is 25.5% higher than that of HPb59-1, which indicates that the tribological properties of PA1010 are significantly affected by the surface roughness of coupling pairs. Although the wear loss of PA1010 is
obviously higher than that of HPb59-1, the difference becomes smaller and smaller with the increase of surface roughness. The wear loss of PA1010 is obviously higher than that of HPb59-1, but the difference between them becomes much smaller with the increase of surface roughness.

![Figure 5. Friction coefficient and wear in cases of different surface roughness of matching materials and load](image)

Figure 6. Worn surface microscopic morphology of PA1010 and HPb59-1

The typical wear morphologies of PA1010 and HPb59-1 are shown in Fig.6. It can be seen that the wear surfaces of two materials show obvious abrasive wear characteristics. Under the same experimental conditions, the wear degree of HPb59-1 is much less than that of PA1010, because the strength and hardness of HPb59-1 are much higher than PA1010. Compared with metal materials, PA1010 is a kind of polymer material with a low elastic modulus and high viscoelasticity. When there exit some micro-convex bodies on the surface of coupling metal, the surface of PA1010 will be cut off and resulted in the strong ploughing effect. The surface layer of PA1010 is quickly cut off to form the wear debris. Moreover, under the continuous rolling of coupling parts, the edge of ploughing on PA1010 surface cracked to form the piece spalling. This phenomenon is more obvious with the increase of surface roughness of couple part. Compared with Fig.6(a) and Fig.6(b), it can be seen that the ploughing phenomenon on wear surface of PA1010 is obviously serious at the surface roughness of 0.4μm. Therefore, the friction and wear properties of PA1010 are significantly affected by the
surface roughness of coupling pair, which is higher than that of HPb59-1. The strength and hardness of HPb59-1 are higher than that of PA1010, so it will not crack when the plastic deformation occurs. The good compliance and embedded possession make the wear debris formed by ploughing effect be rolled into the wear surface, so the wear surface of HPb59-1 is smoother than that of PA1010.

Assuming that the shape of rough peak is a semi-cylinder, the embedded area of rough peak is composed of the cylindrical surface (shear surface) and the end face (ploughing surface), as shown in Fig. 7. In sliding motion, the shear occurs on the cylindrical surface, where is the area of adhesion effect. The end face is the area of ploughing effect, in which the hard peak pushes the isolator material to cause the cutting effect. The friction force on interface is composed of the shear force and ploughing force. Shear force proportional to the loss factor of the material is the intermolecular force, which is caused by the continuous formation and destruction of adhesion between PA1010, HPb59-1 and the surface of coupling steel rings. The ploughing force mainly occurs on the end face. It is the energy dissipation caused by the failure of PA1010 and HPb59-1 materials due to the micro convex sliding. With the increase of sliding speed, the number of adhesion points per unit time on shear surface and the material ploughed off in unit time on the end face increase at the same time. All of these lead to the increase of friction power consumption. At this time, the load does not change, so the friction coefficient increases with the sliding speed. The higher sliding speed makes the friction heat increase during the sliding process. The result of the temperature rise in friction area is that the adhesion effect is more likely to occur on the cylinder surface, which makes the proportion of wear caused by the shear effect increase in the total wear amount. As GCr15 steel and HPb59-1 are both metals, it is easier to form adhesion points between on wear surface (compared with GCr15-PA1010). Therefore, the wear increment of HPb59-1 is significantly higher than that of PA1010 with the increase of relative sliding speed. With the increase of the surface roughness of coupling steel ring, GCr15 roughness peak is pressed deeper on wear surface of PA1010 and HPb59-1. The hardness of PA1010 is significantly lower than that of HPb59-1, and the indentation is deeper under the same load. So the ploughing effect on the end face and adhesion effect on the cylindrical surface are more severe. As a result, the effect of surface roughness of coupling pair on the tribological properties of PA1010 is significantly higher than that of HPb59-1.

**Figure 7.** Friction model of ploughing effect

### 4. Conclusions

1. The friction coefficient of PA1010 is lower than that of HPb59-1 and the wear loss of PA1010 is higher than HPb59-1. The influence of rotational speed on the tribological properties of HPb59-1 is obviously higher than that of PA1010. At the low sliding speed, the wear loss of these two materials changes more significantly with the change of load.

2. The influence of coupling pair surface roughness on the tribological properties of PA1010 is significantly higher than that of HPb59-1. When the surface roughness of coupling steel ring increases from 0.2μm to 0.4μm, the growth rate of friction coefficient of PA1010 is 274.1% higher than that of HPb59-1, and the growth rate of wear loss is 25.5% higher than HPb59-1.
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References

[1] S. Zupan, I. Prebil, Carry angle and carrying capacity of a large single row ball bearing as a function of geometry parameters of the rolling contact and the supporting structure stiffness, Mechanism and Machine Theory, 10(2001)36 1087-1103.
[2] Niraj Makhecha, Ravi C Patel, A review on optimization of dynamic load carrying capacity of deep groove ball bearing using teaching-learning based optimization technique, International Journal for Scientific Research & Development, 3(2015)5 447-452.
[3] Li Yunfeng, Jiang Di, Strength check of a three-row roller slewing bearing based on a mixed finite element model, Proceedings of the Institution of Mechanical Engineers, Part C: Journal of Mechanical Engineering Science, 231(2017) 18 3393-3400.
[4] Kania, Ludwik, Modelling of rollers in calculation of slewing bearing with the use of finite elements, Mechanism and Machine Theory, 41(2006)11 1359-1376.
[5] Lu Hongbo, Zhang Xingyuan, Investigation of MWS relaxation in nylon 1010 using dielectric relaxation spectroscopy, Journal of Macromolecular Science, Part B Physics, 45B(2006)5 933-944.
[6] Zhang Jiamin, Zhu Mingyi, Lian Zhaoxun, Improvement on impact strength of the nylon 1010 injection products with inlay, Advanced Materials Research, 242(2011) 1137-1140.
[7] Zhang Hongmei, Lu Xianbo, Zhang Yong. Synergistic effects of rare earth oxides on intumescent flame retardancy of Nylon 1010/ethylene-vinyl-acetate rubber thermoplastic elastomers, Journal of Polymer Research, 22(2015)2 1-10.
[8] Huang Chuanhui, Wang Shibo, Liu Liguo. Experimental study on the mechanical properties of metal oxides filled PA1010 composites, Key Engineering Materials, 358(2007) 1346-1349.
[9] Jia Xian, Ling Xiaomei, Characteristics and mechanism of abrasive wear for thermoplastic polymers, Journal of University of Science and Technology Beijing, Mineral Metallurgy Materials, 10(2003)5 44-47.
[10] Ge Shirong, Huang Chuanhui, The rolling contact fatigue wear of nylon composites filled with metal-oxides, Key Engineering Materials, 358(2007) 860-863.
[11] Han Dongtai, Yang Yong, Wang Lijun, Experimental investigation of friction thermal effect of semi metallic nylon 1010 composites, Journal of Engineering Thermophysics, 34(2013)3 509-512.
[12] Wang Junxiang, Gu Mingyuan, Bai Songhao, Ge Shirong, Investigation of the influence of MoS2 filler on the tribological properties of carbon fiber reinforced nylon 1010 composites, Wear, 255(2003)6 774-779.
[13] Wang Shibo, Tribological properties of nylon 1010 composites filled with zinc oxide whisker in rolling friction with traction, Industrial Lubrication and Tribology, 64(2012)3 164-170.
[14] Wang Junxiang, Gu Mingyuan, Wear properties and mechanisms of nylon and carbon-fiber-reinforced nylon in dry and wet conditions, Journal of Applied Polymer Science, 94(2004)2 789-795.
[15] Wang Shibo, Ge Shirong, Zhang Dekun, Comparison of tribological behavior of nylon composites filled with zinc oxide particles and whiskers, Wear, 266(2009)1 248-254.
[16] Laumann S., Jisa R., Deinhofer G., Franek F, Tribological properties of brass materials and their application for cages in rolling bearings, Tribology-Materials, Surfaces and Interfaces, 8(2014)1 35-40.
[17] Ünlü Bekir Sadik, Atik Enver, Evaluation of effect of alloy elements in copper based CuSn10 and CuZn30 bearings on tribological and mechanical properties, Journal of Alloys and Compounds, 489(2010)1 262-268.
[18] Saruhan Hamit, Saridemir Suat, Erkan O’mer, The effect of full annular rub on the rotating machinery system considering different rub materials and shaft running speeds, UPB Scientific Bulletin, Series D: Mechanical Engineering, 75(2013)4 197-210.