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Tribological behaviors of UHMWPE composites with different counter surface morphologies

Yanzhen Wang, Zhongwei Yin*, Hulin Li and Gengyuan Gao
State Key Laboratory of Mechanical System and Vibration, Shanghai Jiao Tong University, Shanghai, China
* Corresponding author. e-mail address: yinzw1972@163.com

Abstract. The influence of counter surface morphologies on hybrid glass fiber (GF) and carbon fiber (CF) filled ultrahigh molecular weight polyethylene (UHMWPE) were studied under various contact pressure and sliding speed against GCr15 steel in dry condition. The goals were to investigate the tribological behavior of GF/CF/UHMWPE composite as a kind of water lubricated journal bearing material. The friction and wear behavior of composites were examined using a pin-on-disc tribometer. The morphologies of the worn surface were examined by scanning electron microscopy (SEM) and laser 3D micro-imaging and profile measurement. Generally, the wear rate and friction coefficient of composites increase as the increment of counter surface roughness. The friction coefficient increases firstly and then decrease with an increase in sliding speed and contact pressure for counterface with Ra=0.2 and 3.5 μm, while the friction coefficient decreased for counterface with Ra=0.6 μm.

1. Introduction

Water-lubricated journal bearings are drawing increasing attention due to its environmental friendliness, low cost, and low friction coefficient. They have been widely used in shipbuilding and industrial equipment [1, 2]. UHMWPE is an advanced engineering plastic with ultra-low water absorption, excellent chemical stability, and high impact strength, these advantages making it potentially suitable for application in water-lubricated journal bearings [3, 4]. The study of tribological behavior of bearing materials in different counter surface morphology is crucial for the simulation of bearing operation. At present, it is lack of relevant research on how the counter surface morphology influence the performance of UHMWPE composites. Therefore, it is necessary to study the performance of UHMWPE composites in different counter surface morphology and operation condition.

Research have suggested that counter surface morphology plays a critical role in the occurrence of different wear mechanisms, which are intrinsically connected to the friction coefficient values [5-9].

El-Domiaty et al. [10] investigated the wear characteristics of UHMWPE, the results showed that the wear rate of polyethylene (PE) increased with surface roughness. Blanchet et al. studied the coupled effects of nano-filler content and counter surface roughness on polytetrafluoroethylene (PTFE). The results showed that the wear rate at different counter roughness are affected by nano-fillers contents. Wang et al. [11] studied the tribological behaviors of five composites in seawater, and the results showed that the wear rate of composites in seawater increased sharply for the surface roughness of the counterface increases largely owing to the corrosion of seawater.

Operate conditions also have significant influence on the friction and wear performance of UHMWPE composites. Sumer et al. [12] studied the friction and wear performance of pure polyetheretherketone (PEEK) and 30 wt% glass fiber reinforced PEEK in different contact pressure and sliding speed. The results showed that the friction coefficient and wear rate of PEEK and PEEK composites increase slightly with the increment of pressure. Besides, the friction coefficient decrease while the wear rate increase with an increase in sliding speed. Srinath et al. [13] studied the sliding wear behavior of polyamide 6-clay nanocomposites at different contact pressure. The results showed that the specific wear rate increase as the increase of normal pressure, while the change of friction coefficient with normal pressure varies with filler content.

UHMWPE is a potential material for the application in water lubrication. Therefore, it is necessary to fully study the performance of UHMWPE composites with various counter surface roughness and working condition to provide basis for the application in bearing. Thus, this study is proposed to study the performance of 12.5 wt.% GF and 12.5 wt.% CF filled UHMWPE sliding against GCr15 steel in dry condition with various counter surface roughness, sliding speed and contact pressure.

2. Material and methods

2.1 Materials

12.5 wt.% E-glass fiber (average diameter of 10 μm, the length to radius ratio 4, density 2.25 g/cm^3) and 12.5 wt.% PAN-based carbon fiber (average diameter of 7 μm, the length to radius ratio 4, >95% carbon content, density of 1.75 g/cm^3) were filled in UHMWPE powders (average particle size 40 μm, molecular weight 3 000 000, density 0.94 g/cm^3). The molding method of composites was first cold pressing and sintering, then hot-pressing. These manufactured composites were machined to pins with 8 mm diameter and 20 mm long. The disc material was GCr15 (AISI 52100 steel) with the hardness of HRC62. The dimension of the disc was 50 mm diameter and 8 mm long.

Three types of surface morphology were processed to investigate its influence on tribological behavior. They are grinding-finishing (Ra=0.2 $\pm$ 0.05), grinding (Ra=0.6 $\pm$ 0.1), and grinding -sandblasting-finishing (Ra=3.5$\pm$0.1). The measured roughness characteristics of metal disc were shown in Table 1, where R_p is the maximum height of the profile above the mean line within the assessment length, R_v the maximum depth of the profile below the mean line within the assessment length, R_z the average maximum height, R_q root mean square roughness, R_c the average height of profile, R_a the arithmetic mean roughness of the profile [5, 14]. The values in Table 1 were an average of three measurements. The arithmetic mean roughness R_a was used to describe roughness of counterface. All the samples were cleaned with mixed solution (acetone and ethanol 1:1) before tests.

Table 1. The roughness characteristics of the metal disc before tests (units: μm; I, II, III: group number of surface roughness).

Number	R_p	R_v	R_z	R_c	R_a	R_q
I	0.37	0.82	1.19	0.62	0.14	0.20
II	1.38	1.88	3.26	2.03	0.51	0.64
III	6.73	9.59	16.32	12.98	3.43	4.14

2.2 Tribological test

A pin-on-disc tribometer (MFT-5000, RTEC, San Jose, CA) was used for friction and wear tests. The schematic diagram of the test configuration was shown in Fig.1. The tribological test was conducted according to standard ASTM G99 [15]. The experiments were performed under the temperature of 22 ^{o}C, and relative humidity 50±5%. The surface of the GF/CF/UHMWPE composite pins was examined by scanning electron microscope (SEM) after tests. The worn surfaces of steel disc were tested by the laser microscopic measurement apparatus with a repeated accuracy of 0.012 μm (Keyence, Osaka, Japan). The test conditions of friction coefficient are shown in Table 2, and the specific wear rates are tested using sliding speed of 0.2 m/s and pressure of 5.0 MPa.

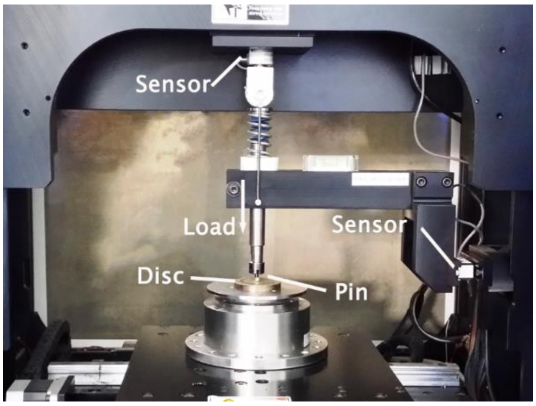

Figure 1. The schematics of the test configuration.

The wear of the polymer pins was determined by measuring their mass loss, which was subsequently converted to their volume loss using the densities of the composites. The specific wear rate of composite was determined using the following equation:

$$W=\frac{\Delta V}{F_N \times L} \quad [\mathrm{mm}^3/(\mathrm{Nm})]$$

where W is the specific wear rate, ΔV the volume loss, F_N the normal load, and L the sliding distance.

Table 2. Experimental conditions.

Parameters	Value
Specific pressure (MPa)	1.0, 2.0, 3.0, 4.0, 5.0
Speed (m/s)	0.2, 0.4, 0.6, 0.8, 1.0
Pin material	12.5 wt%GF+12.5wt%CF+UHMWPE

Disc material	GCr15
Operating temperature (°C)	22
Relative humidity	50 ± 5 %

3. Results and discussion

Fig. 2a shows the relation between the friction coefficient and sliding speed using a pressure of 2.5 MPa in dry condition for GF/CF/UHMWPE composites with a counterface roughness R_a of 0.2, 0.6 and 3.5 μm. For counterface roughness R_a of 0.2 μm and 3.5 μm, the friction coefficients first increased and then decreased with an increase in sliding speed. While for a counterface roughness R_a of 0.6 μm, the friction coefficients decreased with an increase in sliding speed. With an increase in counterface roughness from R_a=0.2 to R_a=0.35 μm, the friction coefficient increases slightly for rough counterface conducive to the transfer of GF/CF/UHMWPE to disc surface and the transfer film has excellent antifriction properties.

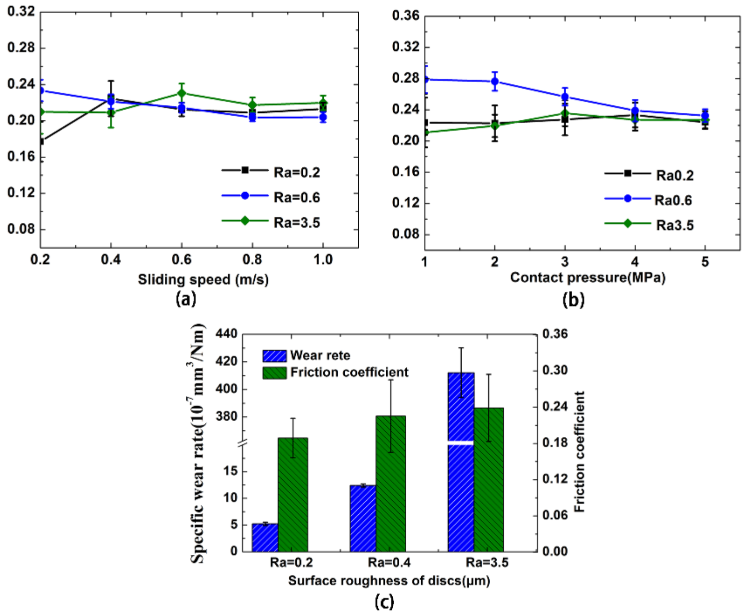

Figure 2. Friction coefficients and specific wear rate of GF/CF/UHMWPE composites.

Fig. 2b shows the relation between the friction coefficient and contact pressure using a sliding speed of 0.2 m/s in dry condition with counterface roughness R_a of 0.2, 0.6 and 3.5 μm. For counterface roughness R_a of 0.2 μm and 3.5 μm, the friction coefficients first increased and then decreased with an increase in contact pressure. While for counterface roughness R_a of 0.6 μm, the friction coefficient decreased with contact pressure increasing from 1.0 MPa to 5.0 MPa.

Fig. 2c shows the specific wear rates and friction coefficient of GF/CF/UHMWPE composites using contact pressure 5.0 MPa and sliding speed of 0.2 m/s. It demonstrates that the wear rate of composites with counterface roughness R_a=0.2 μm is the lowest with the value of 5.23×10^{-7} mm^3/Nm, followed by that of counterface roughness R_a=0.6 μm with a value of 12.4×10^{-7} mm^3/Nm and that of counterface roughness R_a=3.5 μm with a value of 412.1×10^{-7} mm^3/Nm. Thus it can be concluded that the specific wear rate increase with an increase in counterface roughness. The friction coefficient increases only slightly as counterface roughness increase from R_a=0.2 to R_a=3.5 μm. This means that the rough surface accelerates the transfer of composites, which decrease the friction coefficient but increase the wear rate of composites.

Fig. 3 shows the SEM micrographs of the worn surfaces of GF/CF/UHMWPE composites after specific wear rate experiments. Each composite pin was sprayed with a gold coating to obtain electrical conductivity. As shown in Fig.3 (a) and (A), the worn surface of GF/CF/UHMWPE after sliding against counterface with R_a of 0.2 exhibited many scratches which indicated the remarkable abrasive wear. The worn surface of GF/CF/UHMWPE after sliding against counterface with R_a of 0.6 (Fig.3 (b) and (B)) was smooth with some spalling fiber on the surface. Besides, the worn surface also showed abundant conjunct fiber in the matrix, resulting in the anti-wear properties of GF/CF/UHMWPE composites. The worn surface of GF/CF/UHMWPE after sliding against counterface with R_a of 3.5 (Fig.3 (c) and (C)) exhibited serious exfoliation of matrix, which resulted in the sharp increase in wear rate. For GF/CF/UHMWPE composites sliding against different counterface morphologies (R_a=0.2, 0.6, and 3.5 μm), all of the worn surface showed bulges of glass fibers and carbon fibers. The abundant fiber bulges reduced the contact area, which resulted in the anti-friction properties of GF/CF/UHMWPE composites.

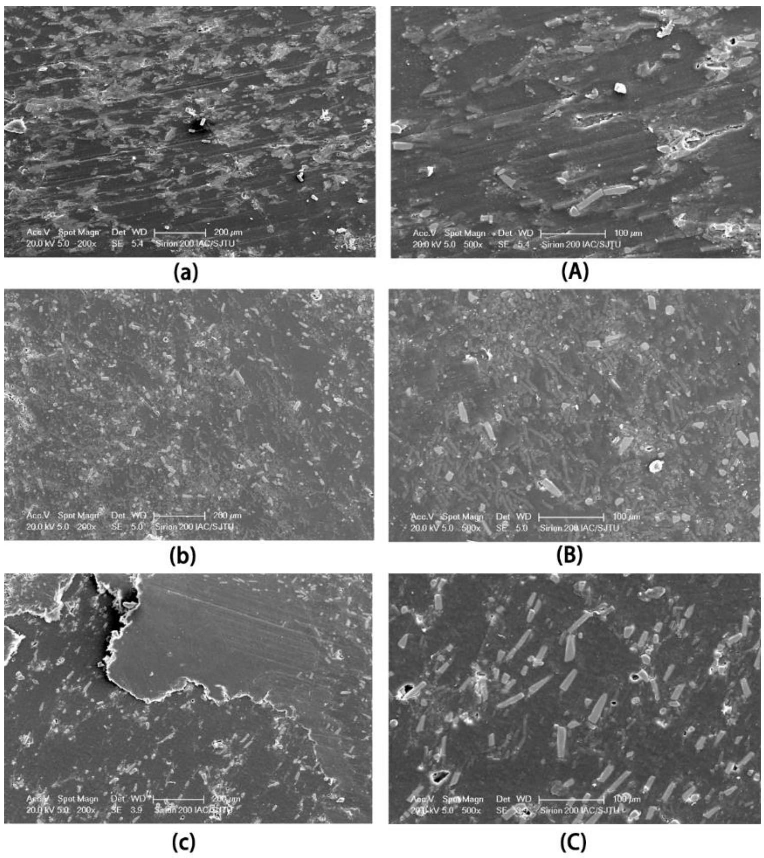

Figure 3. Scanning electron microscopy (SEM) images of worn surfaces of GF/CFUHMWPE composites (a, surface of GF/CF/UHMWPE after test using R_a=0.2 μm; A, enlarged view of a; b, surface of GF/CF/UHMWPE after test using R_a=0.6 μm; B, enlarged view of b; c, surface of

GF/CF/UHMWPE after test using R_a=3.5 μm; C, enlarged view of c).

Fig.4 shows the digital camera photo of disc after tests and the 3D and profile views. As shown in Fig.4 a-c, the worn surfaces of discs with R_a=0.2 μm had little transferred GF/CF/UHMWPE composites, and worn surfaces of discs with R_a=0.6 μm had a certain amount of transferred GF/CF/UHMWPE composites. While the worn surface of discs with R_a=3.5 μm had a thick layer of GF/CF/UHMWPE transfer film. It indicated that the rougher the disc surface, the more conducive to the transfer of GF/CF/UHMWPE composites. And the formation of transfer films reduced the friction coefficient further.

As shown in Fig.4 A-D, the morphology of worn surface of discs with R_a=0.2 μm and R_a=0.6 μm had little difference before and after tests, while the morphology of worn surface of discs with R_a=3.5 μm had obvious characteristic of smear. It suggested that the formation of transfer film for the rough counterface (R_a=3.5 μm) decreased the surface roughness values and friction coefficient.

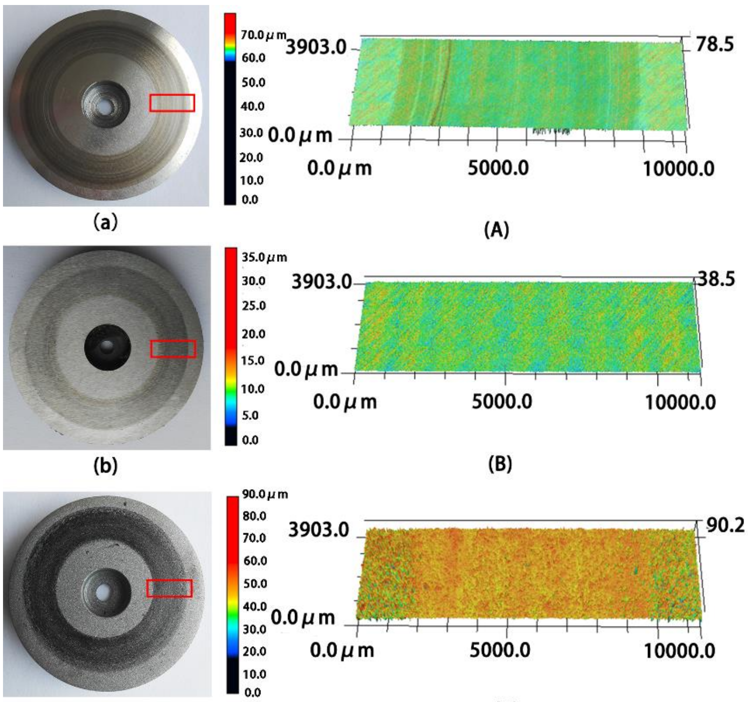

Figure 4. Surface of discs after tests (a, digital camera photo of disc with R_a=0.2 μm; A, 3D and profile views of a; b, digital camera photo of disc with R_a=0.6 μm; B, 3D and profile views of b; c, digital camera photo of disc with R_a=3.5 μm; C, 3D and profile views of c;).

4. Conclusion

In this work, the tribology behaviors of 12.5wt.% glass fiber and 12.5 wt.% carbon fiber filled UHMWPE sliding against GCr15 steel under dry friction at different counter surface morphology were studied. The following conclusions can be drawn:

a. It was found that the tribological behaviors of 12.5 wt.% GF and 12.5 wt.% CF filled UHMWPE were significantly influenced by counter surface morphology. The wear rate of GF/CF/UHMWPE composites increases with an increase in counter surface roughness, while the increase in friction coefficient is not obvious for the formation of transfer film.

b. Sliding speed has an important influence on the tribological behavior of GF/CF/UHMWPE composites. With an increase in sliding speed, the friction coefficient first increased and then decreases for Ra=0.2 and 3.5 μm, while the friction coefficient decreases for Ra=0.6 μm.

c. Also, contact pressure has an important influence on the tribological behavior of GF/CF/UHMWPE composites. With an increase in contact pressure, the friction coefficient first increased and then decreases for R_a=0.2 and 3.5 μm, while the friction coefficient decreases for R_a=0.6 μm.

d. It indicated that the rougher the disc surface, the more conducive for the transfer of GF/CF/UHMWPE composites. And the formation of transfer films reduced the friction coefficient but increased the wear rate of composites.

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Reference

[1] Santos E. N., Blanco C. J. C., Macêdo E. N., Maneschy C. E. A. and Quaresma J. N. N. 2012 *Tribol Int* **52**, 161.
[2] Pai R. and Hargreaves D. J. 2012, 347.
[3] Wang J., Yan F. and Xue Q. 2009 *Tribol Lett* **35**, 85.
[4] Xiong D. and Ge S. 2001 *Wear* **2001**, 242.
[5] Golchin A., Friedrich K., Noll A. and Prakash B. 2015 *Tribol Int* **88**, 209.
[6] Golchin A., Nguyen T. D., De Baets P., Glavatskih S. and Prakash B. 2013 *Proc IMechE Part J: J Engineering Tribology* **228**, 371.
[7] Quaglini V., Dubini P., Ferroni D. and Poggi C. 2009 *Mater Design* **30**, 1650.
[8] Barrett T S S. G. W., Batchelor A W. 1992 *Wear* **153**, 331.
[9] Stupak P R K. J. H., Donovan J A 1990 *Wear* **141**, 73.
[10] El-Domiaty A., El-Fadaly M. and Nassef A. E. 2002 *J Mater Eng Perform* **2002**, 577.
[11] Wang J., Yan F. and Xue Q. 2009 *Science Bulletin* **54**, 4541.
[12] Sumer M., Unal H. and Mimaroglu A. 2008 *Wear* **265**, 1061.
[13] Srinath G. and Gnanamoorthy R. 2007 *Compos Sci Technol* **67**, 399.
[14] Gadelmawla E S K. M. M., Maksoud T M A, et al. 2002 *J Mater Process Tech* **123**, 133.
[15] ASTM 2010 *Annual Book of ASTM Standards* **3**, 1.