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Study on influence of Koch snowflake surface texture on tribological performance for marine water-lubricated bearings

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ABSTRACT

The ultra-high molecular weight polyethylene (UHMWPE) has become one of the most popular and reliable material for water-lubricated bearings in recent years. In this study, three kinds of new Koch snowflake textures were designed on the surface of the UHMWPE to try to decrease friction and prolong the service life of the bearings. The wear process of the UHMWPE/QSn7-0.2 rubbing pair was analyzed using a specially designed tester under water-lubricated conditions. The analysis results demonstrated the testing velocity and load significantly affected the friction coefficient of the UHMWPE specimens. The UHMWPE specimen without texture-treatment had higher friction coefficient than that of the textured UHMWPE specimens at high velocity, where the maximum rate of increase was 35.2% at the velocity of 350r/min compared with non-texture. The dominant wear mechanism was abrasive wear and slight adhesive wear for the non-texture UHMWPE sample, and the wear mechanism of textured samples was slight abrasive wear. The wear performance of the UHMWPE with composite texture was superior to that of other textures, which was mainly attributed to the micro hydrodynamic bearing effect and stepped bearing effect. As a result, the findings of this work can provide experimental foundation for texture design and optimization on UHMWPE surfaces for better service of the marine water-lubricated bearings.

1. Introduction

Currently the development of environmentally-friendly ship has attracted considerable attentions in the global ship industry [1]. One of the serious concerns in marine pollution is the oil spilling. Thousand tons of lubricant oil leaked from the marine stern bearings have flowed into the sea every year [1]. To prevent marine pollution, the traditional oil lubrication method is gradually replaced by the water lubrication. The oil spilling problem can be well solved by the water-lubricated stern bearings owing to its environmental friendly property [2]. Since the ultra-high molecular weight polyethylene (UHMWPE) possesses excellent physical-mechanical properties (e.g., high relative molecular weight, high fatigue resistance, high abrasion resistance, high impact resistance and low temperature resistance), and most importantly, it is environmental friendly, UHMWPE has become a preferable choice to traditional plastics for water-lubricated stern bearings [3–5].

However, as the water viscosity is much smaller than oil viscosity, the load carrying capacity of water-lubricated bearing is lower, which caused water-lubricated bearing to be boundary and mixed lubrication state, especially under the operating conditions of start-up, closing down, low-speed and heavy-duty. In addition, the local warming in the UHMWPE may give rise to adhesion phenomenon and friction noise [6]. Although the UHMWPE has been applied in the water-lubricated bearings, how to improve these aforementioned problems still remain to be discovered. In the latest publication [7], the surface texture technology has been proven to be effective for improving the friction property of bearings by creating the additional micro hydrodynamic bearings effect and storing wear particles. Previous researches [8–12] have investigated the effect of texture on cylinder liner surface. It was found that the texture can help to store lubricating oil so as to amplify the fluid lubrication effect. Meanwhile, texture also can prolong the service life of the cylinder through accommodating wear particles that generated in the process of friction [8,13], and the improvement effects on friction properties rely on the shape, density, depth of the textures, as well as operating velocity and loading of the cylinder-liner pair [10]. Biomimetic-based surface texture design has gradually attracted

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attention in recent years, and it has been applied in friction performance improvement [14,15]. For instance, based on the shark epidermis bionic groove structure was applied in ship, aircraft and swimsuit reduction and resistance [16–18]. Barthlott and Neinhuis [19] examined over 200 kinds of hydrophobic surfaces of plants, they discovered that the micro-nano surface texture played an important role in the hydrophobicity of biomaterials. Some superhydrophobic surfaces can be applied in many fields, such as oil/water separation, self-cleaning and photo-controlled reversible wettability [20]. Thus, it can be noticed that the surface texture design based on bionic principle is an effective way to improve the friction performance and other properties [21,22]. However, to the best of our knowledge, the surface texture has not been applied in the marine water-lubricated stern bearings.

In order to address the surface texture design of marine water-lubricated bearings, this paper proposes a new surface texture design of the UHMWPE surfaces based on Koch snowflake fractal structure. As well known, the snowflake rubs with air but eventually keeps its shape on the ground. This observation indicates the snowflake finally falling to the ground has the least friction resistance with air, this phenomenon is mainly attributed to the convergence effect. In addition, Uiddin [23] analyzed the similar texture by numerical simulation method, he concluded that Koch snowflake texture with appropriate dimensions can improve friction properties by increasing the triangular effect, but the conclusion lacked the experimental verification. Hence, it is reasonable to design the Koch snowflake surface texture to enhance the micro hydrodynamic bearing effects under water-lubricated condition to improve lubrication because water can future enhance the convergence and triangular effects. Additionally, it has been widely proved that the texture of pits has excellent effect to improve friction properties. In order to further explore the texture friction properties of the Koch snowflake, this paper also designs a composite surface texture which is intersected by the cross arrangement of the pits and the Koch snowflakes. In the experiments, three types of Koch snowflake surface textures were designed on the UHMWPE surface to investigate the influence on friction properties of UHMWPE-based water-lubricated bearings. The influence mechanism and friction improvement of the new texture on the marine water-lubricated bearings was analyzed by experimental data.

2. Method and materials

2.1. Preparation of UHMWPE materials and surface textures

Because marine stern shaft sleeve is mostly the copper & copper alloy, to simulate the stern tube bearing condition, QSn7-0.2 copper and UHMWPE discs were used as the rubbing pair in the experimental tests (see Fig. 1). The inner and outer diameters of the UHMWPE and QSn7-0.2 specimens were 18 mm and 30 mm, respectively. The contact area of UHMWPE-QSn7-0.2 pair was 452.16 mm^2. The QSn7-0.2 copper disc was polished using the polishing machine before test. The surface roughness *(Sa)* and surface kurtosis (*Sku*) of the UHMWPE were measured using laser-interference profilometer (LI-3, Huazhong University of Science and Technology, China) before test, was 0.04 ± 0.01 μm. The molecular weight of UHMWPE was 1.4×10^6. The lubricant media used in the test was distilled water. Table 1 shows the major mechanical properties of the specimens, and Table 2 describes the element contents of the QSn7-0.2.

Table 1
Important mechanical properties of UHMWPE and QSn7-0.2 at room temperature.

Test samples	Hardness	Mass density (g/cm^3)	Tensile strength (MPa)	Yield strength (MPa)
UHMWPE	65 HRA	0.94	44.1	17
QSn7-0.2	≥70 HB	8.8	≥355	≥170

Table 2
Main element proportions of QSn7-0.2

Cu	Zn	Sn	Ni	Al	Pb	Impurity
90–92%	0.3%	6.0–8.0%	0.2%	0.01%	0.02%	0.15%

Koch snowflake texture was prepared on the UHMWPE surface through precision CNC machine, and the motion trail of lathe tool was accurately controlled to guarantee the texture size. Fig. 2 depicts the schematic diagram of the three Koch snowflake textures in the experiments. The first type contained 8 snowflakes, the second had 16 snowflakes, and the third was the combination of 8 snowflakes and 16 circle-patterns, all patterns were evenly distributed on the contact surface. Based on the results of Ibatan [7], the area of the three types of textures accounted for 9.2%, 18.4% and 12.0% of the UHMWPE surface area. Due to the size of lathe tool, in this study the side length of the Koch snowflake and the depth of all textures were set up to 1 mm to ensure the accuracy of the Koch snowflake texture.

2.2. Test facility and sliding friction test

All experimental tests were conducted on the CBZ-1 tribo-tester, as shown in Fig. 3. The UHMWPE specimen was fixed below the QSn7-0.2 specimen. The QSn7-0.2 specimen was fixed to a rotor and can rotate relative to the UHMWPE surface.

The first set of experiments were used to investigate the influence of different velocities on the friction properties of different Koch snowflake texture samples. Based on the rules and regulations of Lloyd,s Register, the nominal bearing pressure for water lubricated bearings is less than 0.55 MPa [24], so the load, i.e., 0.4 MPa (181 N) was added to the UHMWPE-QSn7-0.2 rubbing pairs in the experiments, and their

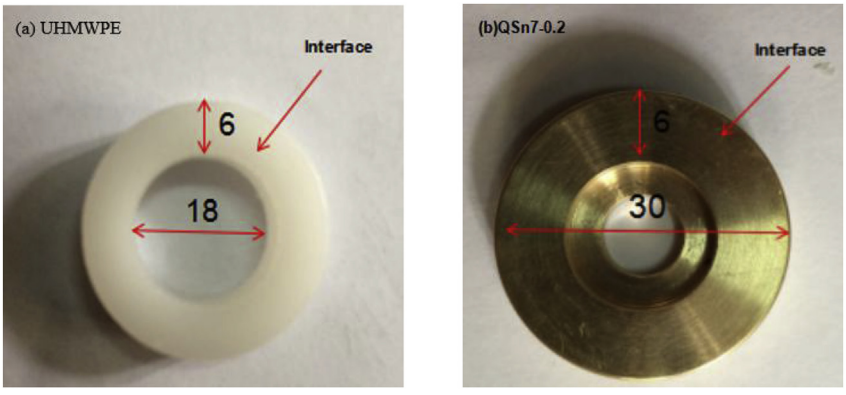

Fig. 1. Images of the test samples: (a) UHMWPE specimen, and (b) QSn7-0.2 specimen.

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