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Optimization of the surface texture for silicon carbide sliding in water

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Abstract

Surface texturing has been recognized as an effective means to improve the tribological performances of sliding surfaces. Usually, generation additional hydrodynamic pressure to increase the load carrying capacity is regarded as the most significant effect of surface texture. In the case of silicon carbide sliding against identical material in water, the experimental results indicate that surface texture is also helpful to improve the running-in progress to smooth the contact surfaces, showing another reason to result in low friction. Based on the consideration of enhancing the generation of hydrodynamic pressure and improving running-in progress, a surface texture pattern, which was combined with large (circle, 350 μm in diameter) and small (rectangular, 40 μm in length) dimples, was designed to maximize the texture effect on the load carrying capacity of SiC surfaces sliding in water. The friction coefficient of such textured surface was evaluated and compared with that of untextured and those only with large or small dimples only. The friction reduction mechanisms of the patterns with different dimples in size are discussed.

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Keywords: Surface texturing; SiC; Water lubrication; Running-in

1. Introduction

The surface texture, such as artificial micro-grooves or micro-dimples fabricated on the contact surfaces has proven to be effective to improve the tribological performances of sliding [1–6]. These discoveries have induced many successful applications of surface texture on golf ball, engine cylinder [7,8], sliding bearing and mechanical seal [9,10], slider and disk of hard disk driver [11,12], etc.

Many studies show that the benefits of surface texture could be obtained from boundary to hydrodynamic conditions. The friction reduction mechanisms of surface texture depend on contact conditions, materials and lubricants. Briefly, the mechanisms proposed include: decreasing contact area to reduce stiction [13]; trapping debris to prevent severe wear on the surfaces [2]; acting as reservoirs to provide lubricant to the contacting surfaces to prevent seizure [14], and generating hydrodynamic pressure to increase the load carrying capacity [15], etc.

Generally, to generate additional hydrodynamic pressure is considered as the most significant effect of surface texture under full fluid lubrication condition, so that it has attracted much more focusing historically and presently [15,16]. The main principle is that each feature acts as a hydrodynamic micro-bearing while fluid is driven and flowing over the textured surface. The pressure increased in the converging region could be greater than that of pressure decreased in diverging region of the texture since cavitations happen there. Therefore, this asymmetric hydrodynamic pressure distribution generates additional load carrying capacity for sliding surfaces. Usually, micro-grooves or micro-dimples are designed evenly distributed on the surface. The dimensions and area ratio of the texture are considered as important parameters related to the generation of hydrodynamic pressure. Recently, Etsion and co-workers have used partially textured surface to emphasize the hydrodynamic effect, showing a new attempt to optimize the surface texture design through its layout or distribution [17].

The specialty of silicon carbide (SiC) is the tribochemical reactions while it slides against identical material in water. These reactions take place during sliding with the aid of friction, remove the asperities on the surface by resolving it into

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water as silica gel [18]. After the research longer than 15 years, although scientists are still arguing on if the silica gel will contribute to the lubrication by changing the viscosity of water or not [19,20], there is no doubt that the tribochemical reactions make the establishment of full fluid lubrication easily by smoothing the contacting surfaces significantly.

Generating hydrodynamic pressure is still assumed as the main contribution of the texture in the case of SiC sliding in water. Author's previous work has demonstrated the effects of dimensions and area ratio of micro-dimples on the load carrying capacity of SiC sliding in water by experiments [21]. By the best texture pattern reported in ref. [21], which has evenly distributed dimples with diameter of 350 μm, depth around 3.2 μm and area ratio of 4.9%, the load carrying capacity has been increased more than two times.

Besides hydrodynamic effect, the texture on the surface of SiC is also helpful for the progress of running-in process [22]. Experimental results have shown that with same running-in process, the surface with texture become smoother than that of untextured surface. This is attributed to better supply of water from dimples to satisfy the need of tribochemical reactions.

Therefore, the objective of this research is to improve the load carrying capacity of SiC sliding in water by optimizing the surface texture, obtaining the texture effects not only on hydrodynamic pressure generation, but also on running-in process promotion.

2. Experimental

2.1. Texture design

As reported in ref. [21], the pattern with the dimple diameter of 350 μm, area ratio of 4.9% and depth about 3.2 μm showed the best results, which increased the load carrying capacity more than two times over untextured surface. The main reason was supposed to be its ability to generate hydrodynamic pressure. Since it was the pattern with sparsely distributed dimples (the pitch between dimples is 1.4 mm), it was decided to combine a pattern with densely distributed fine dimples to the pattern above to provide better water supply to the contacting area. We hope to obtain the benefits of both the hydrodynamic pressure generation and the running-in progress promotion. Fig. 1 shows three different patterns used in this experiment. Pattern (a) is the best pattern reported in ref. [21], which only has the dimples of 350 μm in diameter. Pattern (b) only has the small square dimples with the side length of 40 μm. Pattern (c) is the pattern combined with (a) and (b). Because pattern (b) has a large number of small dimples, using the shape of square instead of circle could significantly save the computing time for the generation of photo mask used for lithography process.

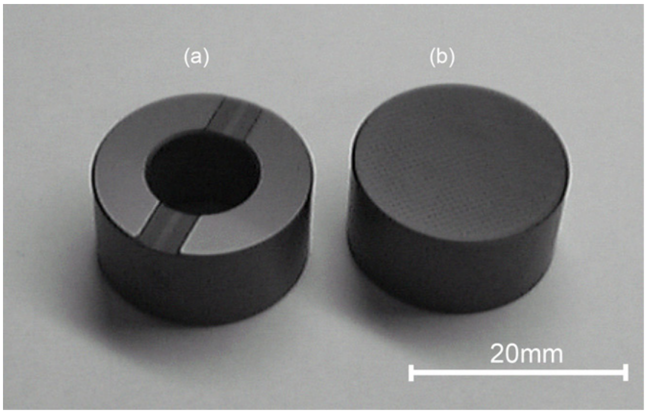

Fig. 2. Specimens: (a) ring (upper specimen) and (b) disk (lower specimen).

2.2. Specimens

The friction tests were carried out between the flat surfaces of a ring [Fig. 2(a), upper specimen] and a disk [Fig. 2(b), lower specimen]. Both the ring and disk were made of SiC sintered after CIP process. The mechanical properties of the material are listed in Table 1. The centre hole of the ring was used for water supply. Two grooves were made on the flat surface of the ring to guide water from the centre hole to the contact surfaces. The contact area of the ring and disk during test is about 1.9 cm^2.

Both the flat surfaces of upper and lower specimens were ground and polished to a roughness Ra of around 0.02 μm. And then, the dimple patterns shown in Fig. 1 were fabricated on the flat surface of the disk by lithography and reactive ion etching (RIE).

The detail process of texture fabrication shown in Fig. 3 contains the following steps:

(a) The surface of SiC disk was cleaned with standard cleaning procedure.
(b) A Cr film of approximately 1 μm was coated on the cleaned SiC surface by sputtering as a protection film during RIE.

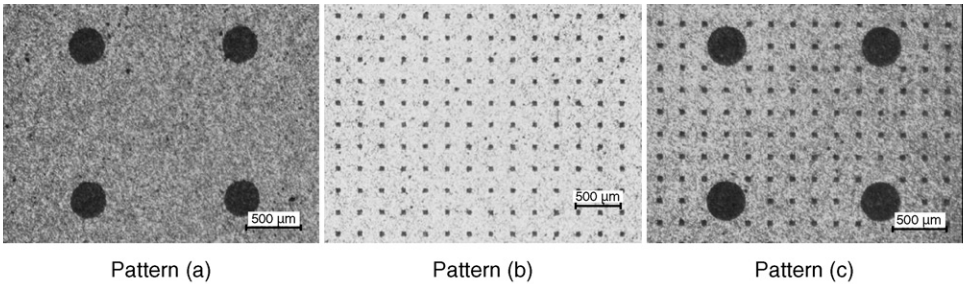

Fig. 1. Three patterns of surface texture used in this experiment: (a) large dimples only; (b) small dimples only; and (c) large dimples mixed with small dimples.