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Preliminary investigation of the effect of dimple size on friction in line contacts

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ABSTRACT

The scale of surface texture is becoming an important issue of surface texture design, particularly for the condition of low speed and high load. Experiments were carried out to investigate the effect of dimple size on friction under line contact condition. The patterns of dimples distributed as square array were fabricated on the surface of brass disks. Each pattern has the same area density of 7%, the same depth over diameter ratio h/d of 0.03, and dimple diameter d varying from 20 to 60 μm. The frictional tests of the brass disk sliding against a stationary cylindrical surface of bearing roller were conducted. It was found that the pattern with dimple diameter of 20 μm presented the effect of friction reduction. For the further understanding of the effect of dimple size under line contact condition, numerical simulations were also carried out to evaluate the hydrodynamic pressure within the contact of cylindrical and plane surfaces. The effects of dimple size and radius of the cylinder on the load carrying capacity were evaluated and discussed.

1. Introduction

Through eons of life evaluation, biological surfaces exhibit appealing and enigmatic properties for specific purposes. The longitudinal ribs on shark skin reduce drag and friction force dramatically. The micro- and nano-structures on lotus leaves represent self-cleaning surfaces to avoid fluid-dynamic deterioration by the agglomeration of dirt [1,2]. These nature facts remind people that a smooth surface is not always the best. The discovery that scored or marked golf ball flies farther inspired people to develop modern golf ball which is coated with dimpled enamel. However, this kind of approach could not be always successful without comprehensive understanding of the mechanisms, just as that developing aircraft needs mathematical expressions from aerodynamics rather than just watching the flight of bird.

The surface texture, such as micro-dimples or grooves, has been a well known approach to improve tribological performances of sliding surfaces. Reserving lubricant to prevent seizure should be the earliest understanding of the lubricating mechanism of surface texture. Hence, the cross hatch by horning has been successfully used for cylinder liner of combustion engine so far [3]. In the 1960s, Hamilton et al. indicated that micro-irregularities are able to generate the additional hydrodynamic pressure to increase the load carrying capacity of the surfaces [4]. This theory has been well accepted, and micro-hydrodynamic effect is regarded as the most dominant effect of surface texture at the condition of high speed and low load. At this condition, the texture design concept is mainly according to fluid dynamics [5–10], and there is an optimal depth over diameter ratio similar to the case of step bearing.

At the "dry" contact condition, it is known the surface texture could trap wear debris to prevent further abrasive wear [11], and decreases the contact area to reduce the adhesive force between the disk and the slider of magnetic storage devices [12].

The condition with low speed and high load is complicated because full film lubrication could not be established easily. A part of the surface is in contact so that the friction was determined by how surface texture influences boundary lubrication [13], EHL, lubricant reservoir [14], and so on. Currently, lot of research works concentrated on this field. Dimples with the depth in nano-scale were reported to be effective for friction reduction at low speed and high load conditions [15]. The reason has been well explained by EHL experiments [16–18], which showed that a significant increase in lubricant film thickness is induced by a shallow micro-cavity in the elastohydrodynamic lubrication regime. However, beside the depth issue, it is still unclear what kind of surface texture is good for high load situation, and some results even conflicted. Wakuda et al. carried out the friction tests of line contact between steel cylinder and dimpled Si_3N_4 ceramic plate [19]. His results suggested that the dimples with the diameter larger than Hertz contact width resulted in lower friction coefficient. Wang et al. proposed the method of virtual texturing to optimize the design of surface texture; the results suggested that the lubrication transitions from a highly hydrodynamic state

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in the case of several large size dimples to a mixed state in the case of many small size dimples [20]. Meanwhile, Pettersson et al. conducted the friction tests between a bearing steel ball and textured silicon wafer [21]. She presented a figure which separated the surface patterns into two groups. One is the patterns resulted in low friction and no measurable wear, the other is the features resulted in high friction and severe wear. It is difficult to have a simple parameter to identify the difference of the patterns in these two groups. But, the image is that the features which caused low friction are smaller than that which caused high friction. Costa et al. investigated the influence of patterns of various shapes of depressions on lubrication film thickness by the reciprocating sliding of patterned plane steel surfaces against cylindrical counter bodies [22]. It is found that textured planes with features much larger than the elastic contact width obtained film thickness smaller than those of untextured specimen. So, smaller or larger, it is still disputable which is better for friction reduction in case of high contact pressure such as line contact.

This paper attempts to study the surface texture effect at the condition of line contact, particularly the issue of dimple size effect. Experiments were carried out to investigate the dimple size effect on the friction between cylindrical and plane surfaces. In order to understand the experimental results, numerical simulations based on micro-hydrodynamic effect were conducted to analyze the influence of dimple size and cylindrical radius on the load carrying capacity of the surfaces.

2. Experimental

2.1. Specimens and surface texturing

Cylindrical and plane specimens were used to perform sliding tests at line contact condition. The roller of SKF thrust rolling bearing 81208 was used as the cylinder. It has diameter of 9 mm and length of 8 mm. Fig. 1 shows the optical microscope image of the cylindrical surface.

Brass disks with diameter of 62.5 mm and thickness of 6 mm were used as the plane specimens. The disks were first ground and polished using Buehler® standard procedure to obtain the surface roughness of *Ra* around 0.03 μm. Photolithographic technique was used to fabricate a photoresist mask on the surface of brass disk with a specific surface pattern of dimples. Then, the uncovered surface was electrolytic etched in 1 M NaCl solution with about 0.2 A DC current at room temperature. The depth of the depression was determined by etching time. After photoresist was removed by solvent, the disk surface was with the pattern of dimples and ready for test. Fig. 2 shows the optical microscope images of dimple patterns fabricated in this research. The dimples are arranged as a square array on the surface of each brass disk. The specific parameters of each pattern are listed in Table 1.

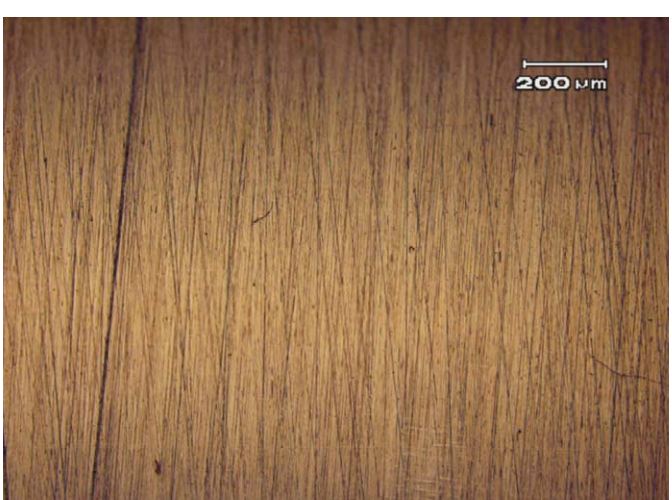

Fig. 1. Optical microscope image of the cylinder surface.

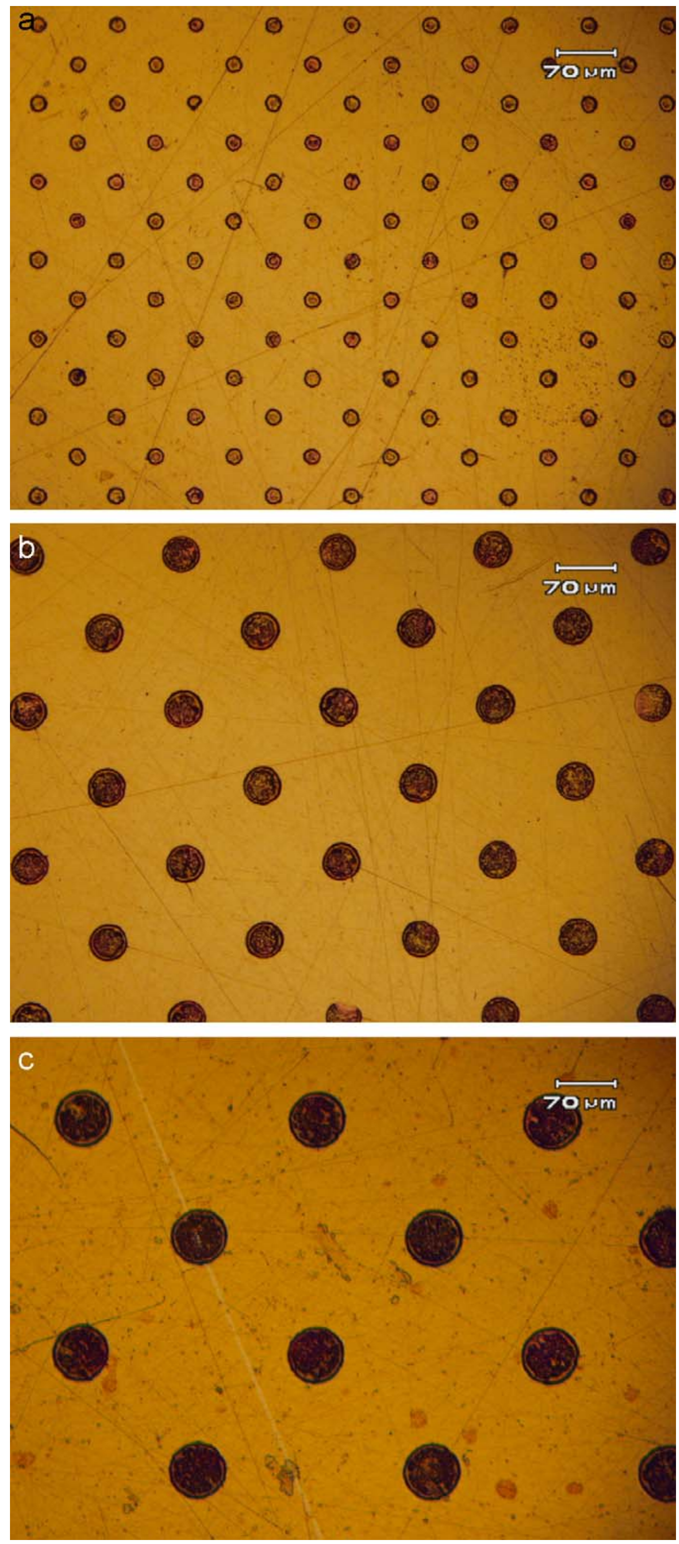

Fig. 2. Optical images of the patterns on the surface of brass disks. (a) $d = 20\,\mu m$, (b) $d = 40\,\mu m$ and (c) $d = 60\,\mu m$.