Experimental investigation of effect of the surface texture configuration on hydrodynamic performance under oil lubricated rotating condition

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Abstract. A series of experiments is conducted to investigate the hydrodynamic performance of samples with different surface texture configurations. Two kinds of dimple texture configurations are designed: circumferential radiation distributed partial textured sample and equal distance distributed fully textured sample. The none textured sample is taken as a contrast one. In the test, gap between tested specimen and the geometric probe is set at 20 µm. By changing the rotating speed of the geometric robe, the load-carrying capacity measured is constantly changing. It is found that the load-carrying capacity is strongly influenced by the surface texture configuration and the operation condition.

1. Introduction
The Surface texture is a generally accepted technology to improve the friction performance of mechanical components[1], especially enhance the lubrication performance of the mutual moving surfaces in the hydraulic system[2, 3]. The vast majority of research about surface texture accepts that the generation of an additional hydrodynamic lift force is the most dominant effect which can enhance hydrodynamic lubrication[4-6]. Besides that surface texture could been seen as “lubricant reservoirs”[7], providing lubricant if necessary, and “wear debris container”, minimizing third-body abrasion[8].

Researchers pay attention to the theoretical modeling of surface texture[2, 9-13]. Mao[2] has analyzed the hydrodynamic performance of surface texture used in hydraulic cylinder based on Reynolds equation. Uddin [12] used the numerical model to analyze and optimize the texture shape in order to get an optimal texture shape with the lowest friction coefficient on a certain operating condition. Sahlin[13] adopted 2D CFD modeling to investigate the internal factor that the depth and the width of a single texture affected hydrodynamic performance. The flow type and the Reynolds number had been taken into account. The aforementioned researches concentrated on a single texture or a fully textured surface. Etsion[14-16] and his study group have conducted a series investigation on the partial laser surface texture. They claimed that in some case partial texture performer better than the full texture. Yu[17] studied how the texture types, the texture configurations and the rheological parameters of the lubricant grease affected the load-carrying capacity, friction and friction coefficient.
of the bearings. Chen[18] experimentally investigated the influence of the texture type and the operating condition on the hydrodynamic effect.

However, most researchers investigated the hydrodynamic performance of partial textured surface under lubricated rotating condition by compare the texture type or the texture size. Limited investigation analyze the distinction between the unregular partial texture and the regular fully texture. In this paper, circumferential radiation distributed partial texture and equal distance distributed fully texture are adopted to evaluate the hydrodynamic performance of surface texture under oil lubricated rotating condition.

2. Experimental details

2.1. Experimental apparatus, textured samples and lubricants

Some text. Experiments were conducted on a rotational rheometer (AR2000ex, TA Instruments.) under adequate lubrication. The instrument was allowed to control rotating speed of the shaft and gap between the test specimen and the geometric measuring probe.

The scheme of experimental apparatus is shown in Fig.1 (a). The upper one of the co-acting parts was the geometric measurement probe, which is a stainless circular plate with the diameter of 40 mm.

Test sample was fixed on a lubricant reservoir. The micro-dimples were fabricated on the surface of test sample. Two kinds of textured sample were adopted in tests.

One is a partial dimple textured sample, as shown in Fig.1 (b). The texture region is an annular region with the inner radius ($R_1$) of 17.45 mm and the external radius ($R_2$) of 29.3 mm. Micro-dimples radially distributed in the texture region. There were six micro dimples distributed along the radius with the same interval, which is about 400 μm. And the angle (alphabet $\alpha$ in Fig.1 (b)) of circumferential circular sector texture unit was 5°. That’s to say, there were 72 micro-dimples equally distributed along the peripheral direction.

And another one is a fully dimple textured sample, shown in Fig.1 (c). Texture region was fully covered with micro-dimples. The distance between the adjacent micro-dimples was 400 μm.

![Fig.1 Scheme of experimental apparatus: (a) test configuration; (b) partial textured sample; (c) fully textured sample](image)

All the micro-dimples were in the same geometric size (the diameter is 400 μm, the depth is 15 μm). Disc-on-disc tests were performed in unidirectional rotating slide under adequate lubrication. The mating pairs were lubricated by lubricant (density at 15 °C is 0.87 kg/L, dynamic viscosity at -20 °C is 5.4 Pa . s).
2.2. Experimental procedure
Test was conducted with a constant gap (10 µm). Test duration was 30 min. Rotating speeds of 15, 30, 45, 60, 75 and 90 rev/min increased in a stepwise after running for 5 min. That’s to say, each rotating speed operated for 5 min. During the test, the normal force, is seen as load-carrying capacity, might be measured at intervals of 15 seconds, which means 20 sampling times have been adopted in each test.

All the tests were evaluated in air atmosphere with a constant room temperature of 25° and a constant relative humidity of 45%. Each test was repeated 3 times.

3. Results and discussion
3.1. Morphology of sample
The surface morphology of the micro-dimple textured sample was shown in Fig.2, which was detected a three dimensional optical surface profiler (Contour GT-X, Bruker, USA). Fig.2 (a) presented 2D optical surface profiler of the fully textured sample at low magnification. It obviously displayed the distance between adjacent micro-dimples was about 400 µm, either horizontally or vertically. Fig.2 (b) and Fig.2 (c) presented 2D optical surface profiler and 3D optical surface profiler of a single micro-dimple. The profiles showed that the diameter of micro-dimple was 400 µm and the depth was 15 µm.

![Fig.2 Surface morphology of the micro-dimple textured sample: (a) 2D optical surface profiler at low magnification; (b) 2D optical surface profiler of a single micro-dimple; (c) 3D optical surface of a single micro-dimple](image)

3.2. Effect of rotating speed
Fig.3 (a) showed that load-carrying capacity of partial textured sample under different rotating speeds. As the gap between sample and the probe was set at 20 µm and remained the same during the test. As could be seen the load-carrying capacity almost remained stable at about 0.5 N when the rotating speed \( \omega = 30 \) rad/s. But when the rotating speed \( \omega \) was 60 rad/s, the load-carrying capacity would slightly increase in the first 3 sampling points and then tend to be stable at about 2.5 N. Similar situation was occurred to the case of 90 rad/s. The load-carrying capacity would increase in the first 4 sampling points and then increase in a quite small scope around 5 N.

Fig.3 (b) showed that load-carrying capacity of fully textured sample under different rotating speeds. As could be seen the load-carrying capacity almost remained stable at about 0.3 N when the rotating speed \( \omega = 30 \) rad/s. But when the rotating speed \( \omega \) was 60 rad/s, the load-carrying capacity would stay at 0.35 N in the first 9 sampling points and then rapidly increase to 2.8 N. Similar situation was occurred to the case of 90 rad/s. The load-carrying capacity would increase in the first 5 sampling points and then rapidly increase to 1.8 N.
In the case of partial textured sample, the rotating system didn’t reach the steady state in the beginning of the test. While the system had become stabilized, the load-carrying capacity translated to be stable. However, in the case of fully textured sample, because of the existence of regular textures, it had a steady load-carrying capacity at the beginning, regardless of the rotating speeds. That is fully textured surface had a positive effect on reducing the difference caused by rotating speed under conformal contact condition. But with the increment of test time the effect mentioned above started failure and eventually settled in one value. What’s more, the faster the rotating speed was, the shorter the time maintained the effect was.

3.3. Effect of surface texture pattern
On the base of the previous study and analysis, the values measured in the beginning (about 5 values) in each test wouldn’t be taken into account in the next analysis and comparison of tests. Fig.4 revealed the difference among load-carrying capacity of three samples (partial textured sample, fully textured one and none textured one). It was obvious that in the case of none textured sample the load-carrying capacity increased linearly with the rotating speed. And for partial textured sample, by and large the load-carrying capacity was increasing with the rotating speed. But at low rotating speed (15, 30 and 45 rad/s) the load-carrying capacity was less than the case of none textured sample while at high speed (60, 75 and 90 rad/s) it was superior to the case of none textured sample. What’s more, the higher the rotating speed the more partial textured sample had the advantage. For fully textured sample, the load-carrying capacity performed distinctly different tendency. At low rotating speed (15, 30 and 45 rad/s) the load-carrying capacity was inferior to the cases of none textured sample and fully textured sample. At rotating speed of 60 or 75 rad/s, it had an advantage. But it manifested decrease at rotating speed of 90 rad/s and the value was about 1.6 N. For none textured sample and partial textured sample, values were about 2.9 N and 5.1 N, respectively.

![Fig.3 Load-carrying capacity of samples under different rotating speeds: (a) partial textured sample; (b) fully textured sample](image)
The load-carrying capacity was affected by the fluid mechanics of hydrodynamic lubrication between the two parallel surfaces. As been investigated in the literature [1. Minimize friction of lubricated laser-microtextured-surfaces by tuningmicroholes depth, 2. Two-Dimensional CFD-Analysis of Micro-Patterned Surfaces in Hydrodynamic Lubrication], the geometric size of surface texture and the operating condition had a significant influence on the hydrodynamic effect. And almost the vast majority research had conducted the investigation based on the hypothesis that the hydrodynamic effect was simple superposition of single texture effects. However, just as been studied in this paper, the hydrodynamic lift force of the partial textured surface was superior to that of the fully one. The internal reason might be that the spread pattern of the partial textured surface played a positive role in the fluid radial motion.

4. Conclusions
In this study, we have experimentally investigated the hydrodynamic effect of two kinds of textured surfaces under rotating lubricated condition. In most cases the partial textured sample has shown a better hydrodynamic performance than that of the fully one. Especially when the rotating speed is 90 rad/s, the load-carrying capacity of the partial textured sample exceeds 2 times of the load-carrying capacity of the fully one. So if surface texture technology has been introduced in the mating pairs, besides the geometric size of textures, the operating condition should be considered in conjunction with the texture pattern. In the case that dimple depth is 15 μm and the gap between the mating surfaces is 20 μm, the partial surface texture is more suggested.

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