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The effect of surface texturing on reducing the friction and wear of steel under lubricated sliding contact

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ABSTRACT

Surface texturing is a widely used approach to improve the load capacity, the wear resistance, and the friction coefficient of tribological mechanical components. This study experimentally investigates the effect of surface texturing on reducing friction and wear. A numerical model of the load carrying capacity of multi-dimples is developed to analyze the relevant mechanism, and the effect of surface texturing on different dimple area fractions is evaluated to determine the optimal dimple pattern. The results show that surface texturing is important for reducing friction and wear. Changes in dimple area fraction can dramatically reduce friction and wear. The results indicate a 5% optimal dimple area fraction can generate the greatest hydrodynamic pressure compared with other fractions and can reduce friction and wear up to 38% and 72%, respectively. The theoretical model and the experimental results are found to be closely correlated. The generation of hydrodynamic pressure, the function of micro-trap for wear debris and the micro-reservoirs for lubricant retention are the main causes for the reduction in the friction and wear of the surface texturing.

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1. Introduction

Because approximately 40% of total energy losses result from engine friction and wear loss, friction and wear must be reduced to improve fuel consumption [1]. Surface texturing is an emerging effective method for improving the tribological performance of the mechanical components [2,3].

Since 1960s, Hamilton et al. [4] proposed the idea that surface texturing in the form of micro asperities acted as micro hydrodynamic bearings between two parallel surfaces, subsequent studies have investigated the hydrodynamic effect of surface texture. It has been shown that the selective micro-texture is effective for generating additional load capacity under hydrodynamic lubrication conditions and the cavitation is the main reason of this phenomenon [5–8]. Generally, the pressure increases in the converging film regions, while it decreases in the diverging film regions. The cavity generated in diverging film regions truncates the negative pressure and additional load capacity or positive pressure is generated by texture between contact surfaces [3,9,10], the schematic is shown in Fig. 1 [4,11].

Today, various forms and geometric features of surface texturing for tribological applications are carried out widely and various texturing techniques are also employed in these studies including machining, photoetching, etching techniques, ion beam texturing, and laser texturing [12,13]. According to the literature, the introduction of texturing may trap wear debris, thus reducing the ploughing and deformation components of friction [9,14], and may also act as a micro-reservoir for lubricants, thus reducing the friction and increasing the lifetime of the sliding contacts [15–17]. The effect of surface texturing on reducing friction and wear was depended considerably on the shape, size, density, and pattern of dimples [18,12,19,20]. For example, the experimental work by Etsion and Sher [19] indicated that partial LST piston rings could consume up to 4% less fuel compared with non-textured conventional barrel-shaped rings. Wang's study suggested that pattern mixed with the large dimples (350 μm) and small dimples (40 μm) could result in higher critical load over that with small or large dimples only, and three times greater than that of untextured surface [20]. The previous studies also show that it existed an optimum texturing parameter for maximum load carrying capacity and minimum friction coefficient for different shape surface texturing, and the ranges of the optimum texturing parameter were varied in deferent operation conditions [8,10].

Most studies of surface texturing have focused on the experimental aspect, and recently, theoretical research has received more attention. This study experimentally investigates the effect of surface texturing on reducing the friction and wear of a steel surface. A numerical model of the load carrying capacity of multi-dimples is developed to analyze the mechanism

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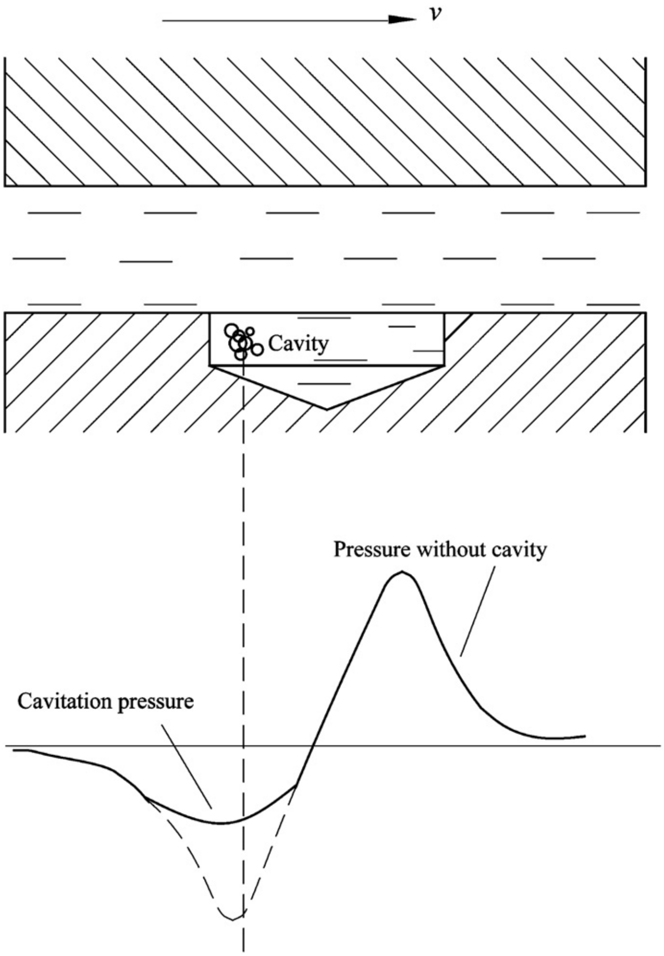

Fig. 1. Schematic of positive pressure sourced from cavitation.

responsible for reducing friction and wear with surface texturing, and the effect of surface texturing with several dimple area fractions is evaluated to determine the optimal dimple pattern.

2. Experimental details

2.1. Sample preparation

In this study, two different hardness materials which are commonly used in the tribological mechanical components were employed in the test and the chemical composition is shown in Table 1. The high alloy steel with a hardness of HRC 62 was chosen as the upper specimen for better wear resistance and the medium carbon steel with a hardness of HRC 20 was chosen as the lower textured specimen to study the friction and wear reduction effect of the surface texturing. The two flat steel specimens were fixed and slid against each other; this process is shown schematically in Fig. 2.

All lower steel samples were firstly lapped to achieve a surface roughness of 0.04 μm RMS and were then textured to the regular arrays of cylindrical dimples using a miniature engraving machine. Each dimple cell was an axisymmetric cylindrical segment with a diameter d ($d = 300\ \mu m$, $500\ \mu m$, and $700\ \mu m$), and depth h_1 ($h_1 = 50\ \mu m$) and was located in the center of an imaginary square cell with length l ($l = 2$ mm) (as shown in Fig. 3). Following previous studies [21,22], three dimple area fractions (2%, 5%, and 10%) that are varied by changing the diameter of each dimple were chosen and were defined as the following:

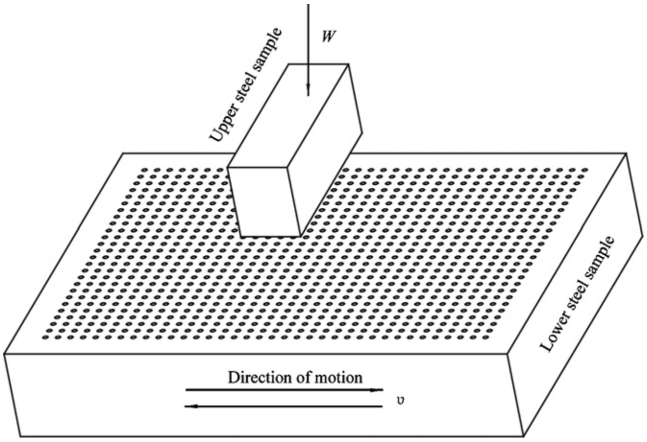

Fig. 2. Schematic of the friction and wear test.

$$S_p = \frac{\pi d^2}{4l^2} (\%) \tag{1}$$

After being fabricated with the texture, the samples were deburred, cleaned by ultrasonication in acetone and deionized water for 2 h, and dried with flowing air to keep the surface conditions as constant as possible. A non-textured sample was also measured for comparison. Four sets of samples were used in the tests, and each set was tested once.

2.2. Friction and wear measurements

Friction and wear tests were performed using a multi-functional tribometer (UMT, CETR, Campbell, CA, USA) under linear reciprocating motion and full lubrication. The tests were conducted at a normal load of 150 N (corresponding to a nominal contact pressures of 8.3 MPa), a frequency of 6 Hz and a stroke length of 20 mm (resulting in an average sliding speed of 0.24 m/s) in a laboratory atmosphere (25 °C, RH 55%). A lubricant with a dynamic viscosity of 0.04678 Pa s and a density of 850 kg/m^3 was used.

To ensure full contact with the mating surface, running-in was performed for all samples before tests [23]. In the running-in process, the normal load was gradually increased in increments of approximately 50 N, at a velocity of 120 mm/s. When the friction force stabilized, it indicated that the running-in had finished. Then, the friction and wear tests were performed. The normal load and the friction force were measured with a stress sensor and the data were digitized and were collected on a personal computer. The average data of the friction signal were calculated, and the friction coefficient was obtained.

To study the effect of the surface texturing on reducing wear, the wear debris in lubricant should be separated and collected after the tests. The separation and collection of the wear debris proceeded as follows: after a 7 h test, the wear debris and the lubricant were

Table 1
Chemical composition of the samples (wt%).

	C	Si	Mn	Cr	S	P
Upper sample (high alloy steel)	2.16	0.27	0.35	11.62	0.021	0.012
Lower sample (medium carbon steel)	0.45	0.23	0.66	0.15	0.025	0.008

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