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The effect of laser surface texturing on transitions in lubrication regimes during unidirectional sliding contact[☆]

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Abstract

Laser surface texturing (LST) is an emerging effective method for improving the tribological performance of friction units lubricated with oil. In LST technology, a pulsating laser beam is used to create thousands of arranged microdimples on a surface by a material ablation process. These dimples generate hydrodynamic pressure between oil-lubricated parallel sliding surfaces. The impact of LST on lubricating-regime transitions was investigated in this study. Tribological experiments were conducted with a pin-on-disk apparatus at sliding speeds in the range of 0.015–0.75 m/s and nominal contact pressures that ranged from 0.16 to 1.6 MPa. Two oils with different viscosities (54.8 and 124.7 cSt at 40 °C) were used as lubricants. The test results showed that laser texturing expanded the contact parameters in terms of load and speed for hydrodynamic lubrication, as indicated by friction transitions on the Stribeck curve. The beneficial effects of laser surface texturing are more pronounced at higher speeds and loads and with higher viscosity oil.

Keywords: Laser surface texturing; Friction; Machine element; Lubrication regime; Hydrodynamics; Lambda ratio; Microdimpling

1. Introduction

The need to reduce friction and the amount of wear on machine element components involved in sliding contact is ever present. The efficiency, reliability, and durability of such components depend on the friction that occurs at the sliding contact interface. In addition, there is always the desire to increase the load capacity or the power density of machine elements, which of course will lead to higher severity of surface interaction. Both the need to reduce friction and the desire to increase load capacity require effective lubrication strategy for sliding surfaces.

Surface lubrication involves many aspects of the physical and chemical properties of the surface material and the lubricant. The viscosity of the lubricant and some of its other rheological properties determine the thickness of the lubricant fluid film. A thicker lubricant fluid film leads to better lubrication. Similarly, the roughness of the contacting surfaces has a major impact on the friction and wear behavior of lubricated surfaces. In general, smoother surfaces are better for fluid film lubrication. Indeed, the effects of lubricant film thickness and surface roughness on lubrication are combined in the so-called λ ratio parameter, defined as the ratio of the lubricant fluid film thickness to the composite surface roughness of contacting surfaces. The higher the λ ratio, the more effective the fluid lubrication mechanism; and very low values of λ indicate higher severity of interaction between asperities on contacting surfaces. Of course, higher friction and wear are expected under the relatively severe contact conditions of low λ values.

In recent years it has been shown that the presence of artificially created microfeatures can significantly affect friction and wear behavior of lubricated surfaces. For instance, 'undulated' surfaces created by machining of 50–800-μm-deep and about 20–500-μm-wide periodic grooves on the surface of a titanium alloy disc were shown to reduce friction in lubricated reciprocating contact when compared to nonundulated surfaces [1]. The friction reduction was attributed to the trapping of wear debris in the groove, thereby eliminating the 'plowing' contribution

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to friction. In the mechanical seal community, it has been recognized that micro surface patterns, such as radial taper, hydropads, lobes, and grooves can exert beneficial effects on the lubrication of mechanical seals. With this recognition, Etsion et al. [2,3] recently developed a method to texture seal surfaces with a laser. The process, known as laser surface texturing (LST), involves creation of an array of microdimples on the seal surface by a material ablation process with a pulsating laser beam.

Laser surface texturing (LST) was shown both analytically and experimentally to enhance hydrodynamic and hydrostatic lubrication of mechanical seals. The result is a significant improvement in the load capacity, wear resistance, and friction coefficient of mechanical seals [2,3]. The LST mechanical seals have been successfully field tested, and showed a substantial reduction in wear and surface damage when compared with untextured seal surfaces.

With the excellent results in seal applications, LST technology is now being considered and evaluated for other tribological applications, especially those that involve conformal contacts. Analysis of lubrication mechanisms and optimization of LST for piston–ring and cylinder–liner contact interface has been conducted [4]. This analysis showed that the dimple area density and the dimple diameter-to-depth ratio are important parameters for this application. Experimental results from conformal reciprocating sliding contact tests showed that LST reduced the friction coefficient by 30–40% when compared with an untextured surface under flooded adequate-lubrication conditions [5]. The results were consistent with analytical predictions. Under starved-lubrication, LST also provided beneficial results in terms of friction reduction and increase in load capacity before seizure. It is assumed that the dimples act as an oil reservoir. It was, however, observed that, when the dimples are relatively deep or when the oil viscosity is relatively high, LST may be detrimental to tribological performance under starved-lubrication conditions.

In view of the promise, and perhaps some limitations of the new LST technology for applications on various lubricated tribological components, it will be very useful to assess the impact of LST on lubrication regime transition. Such an assessment could provide a guideline and better understanding of the application of LST to various tribological components. This paper presents our experimental investigation of the effect of LST on lubrication regime transitions.

2. Experimental details

Friction tests were conducted with a pin-on-disk friction machine in unidirectional sliding. The ‘pin’ was a 9.55-mm-diameter hardened 52100 steel ball with a nominal hardness of 60 HRC. Inasmuch as the LST technology was developed and, so far, optimized for conformal contacts, a flat contact area was created on the ball sample by first sliding the ball against a flat sample that contained a series of SiC abrasive papers, ending with very fine, 4000-grit paper. The final flat area created on the ball is 4.7 mm in diameter; its surface roughness is 0.01 μm R_a. The disc samples, 50 mm in diameter and 10 mm thick, are made from hardened H-13 steel with 60 R_c hardness. Fig. 1a–c, respectively, shows a schematic diagram of the contact configuration, and pictures of the test machine and pin specimen used for friction testing.

Disc samples with various surface preparations were used for frictional tests. Table 1 lists the characteristics of the tested discs, which are identified with numbers 1–6.

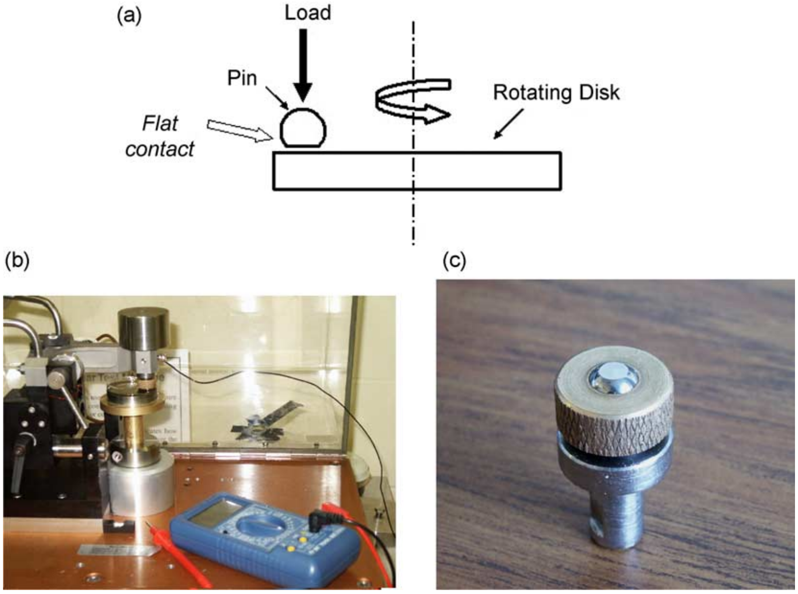

Fig. 1. (a) Schematic diagram of contact configuration; (b) picture of pin-on-disc test rig; and (c) picture of ball specimen with flat contact area.