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Friction and wear behavior analysis of the stainless steel surface fabricated by laser texturing underwater

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ABSTRACT

Laser surface texturing is an advanced technology to reducing the friction between two contact surfaces in relative motion. Experiments both underwater and in the air were performed to evaluate the influence of processing environment on the machining quality. Processing parameters including water depth, pulse width and repetition rate significantly influence the morphology of micro dimples. It is found that thermal effect of laser can be suppressed in the water. Meanwhile, recoil pressure of water evaporation could increase the depth of generated micro dimples. Results of the friction and wear tests show that the friction coefficient of laser textured surface is greatly reduced at high sliding speed and heavy load situations where micro-dimples act as micro-bearings, lubricant and debris reservoirs.

1. Introduction

Friction and wear exist between two components which are in the relative motion. It not only consumes much energy but also is an important cause of mechanical parts' failure. Adoption of anti-wear materials and reducing the roughness of contact surfaces as much as possible are all limited by technical skills and cost. Improving the friction condition between the contact surfaces is a urgent need to save the raw material and raise the operation efficiency for the entire mechanical system [1].

Producing periodically arrayed structures on the surface, i.e. surface texturing, is confirmed to be an effective way to reduce the friction and wear for the lubricated contacts [2]. The mechanism is that textures on the contact surface act as micro-bearings producing hydrodynamic pressures which provide load support. Meanwhile, textures could also retain oil and debris and hence, reduce the wear. A number of surface texturing techniques, such as electro-chemical micro-machining (ECM) [3], abrasive jet machining (AJM) [4], pellet-pressing (PP) [5], electric discharge texturing (EDT) [6], laser surface texturing (LST) [7], have been put forward. Compared with other methods, LST could produce microstructures in designed distribution on target surface through laser ablation of material. It can be applied to almost all kinds of materials including difficult-to-machine metal, ceramic material and polymer materials.

Laser surface texturing has been successfully applied in the cases where serious friction occurs like mechanical seal and piston ring [8]. Etsion et al. [9] applied LST on piston ring and established a numerical model to study the effect of micro-dimples on the tribological behavior in reciprocating motion. It was found that the diameter-to -depth ration and density of micro-dimples are the main parameters affecting the friction performance of textured surface. By optimized texturing design, the friction can be reduced by 30%. Rapoport [10] conducted laser texturing experiments on stainless steel surface using nanosecond pulsed laser. In addition to laser induced micro pit, laser texturing also generates a bulge which consists of resolidified material around the pit. Experimental results show that best lubricating condition can be obtained when half of the bulge is worn out. At harsh friction conditions, bulges can prevent quick worn out of the surface texture. However, due to the thermal effect of laser, large amount of molten material and residual thermal stress may lead to micro-cracks on the machined surface. In the real service environment, high alternating tensile stress in dynamic oil film may promote the propagation of micro-cracks and causes the fatigue failure of friction pair. Heat affected zone induced by thermal diffusion surrounding the laser processing area is often harmful for the machining quality improvement in almost all types of laser machining, generating recast layer in laser drilling [11] and cutting, reducing the residual strength of heat sensitive material [12], etc. Underwater or water-assisted laser processing methods have been studied to resolve the problem in the subtractive machining, such as etching and cutting [13]. Due to the water cooling, it was found that processing underwater could produce a better cutting quality than in the air and avoid debris re-deposition. Therefore

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processing environment has a big impact on the material response. Water environment may also be useful to restrict the harmful thermal effect in laser surface structure.

In the presented paper, laser surface texturing experiments both in the air and underwater were performed. The aim of this work is to investigate the effect of processing environment on the laser texturing quality. Relation of processing parameters with the morphology of surface texture is studied. Then the friction performance of textured surface is compared with the non-textured surface at the same running conditions.

2. Experiment set up

2.1. Laser texturing

Fig. 1 is the experiment set up schematic of laser texturing underwater. The system consists of laser source, focusing head, water container and moving platform. An wavelength 1070 nm YLR-150/1500-QCW-AC fiber laser manufactured by IPG photonics was adopted as the laser source. In the pulsed mode, the maximum output power is 1500 W with $\pm$0.5% stability. The range of laser pulse width is from 0.2 to 20 ms. Stainless samples (austenitic steel, HB=170) with the size 50 mm × 50 mm × 10 mm (x, y, z) are immersed in the water container which is fixed on the platform moving at the x–y plane. The used water is deionized water at the environment temperature (about 300 K). All the virgin steel samples are polished and have a roughness of 0.1 μm Ra. Texture with uniform micro-dimples is manufactured on the surface of stainless steel plates. During the machining, the height of focusing head is kept constant and the focus plane is placed on the upper surface of the steel sample. Diameter of the laser spot is about 200 μm. Laser texturing experiments both underwater and in the air are performed. Manufacturing of one dimple is realized by one or multiple laser pulses ablation. The main parameters involved in the process are water depth above the sample surface h, peak power p, pulses repetition F, pulse length τ and pulses number n. Morphology of micro-dimples is observed by a ZEISS® confocal microscopy and characterized with a KEYENCE® 3D surface profiler. The magnification of confocal microscopy is 150 × with 0.16 μm resolution. The minimum resolution of 3D surface profiler is 0.05 μm. Measurement range at the x–y plane is 100 × 100 mm. The laser induced dimple usually presents a volcanic vent shape as shown in Fig. 2. There is a bulge consisting of resolidified molten metal around the ablation pit. The shape of dimple is characterized by ablation depth, bulge height, inner diameter and outer diameter. The laser parameters have an obvious impact on the morphology of resulting dimples. When keeping peak power as constant, pulse length determines the single pulse energy and hence the ablation depth of a single pulse. Pulses number applied in the same location affects the total depth of one dimple. Repetition rate F is the reciprocal of time interval between two consecutive laser pulses. If repetition rate is too big, there is not enough cooling time before the upcoming laser pulse, generating more molten material.

In order to investigate the effect of processing parameters on the texture, single factor parametric analysis, i.e. tuning one parameter with other parameters unchanged, considering four

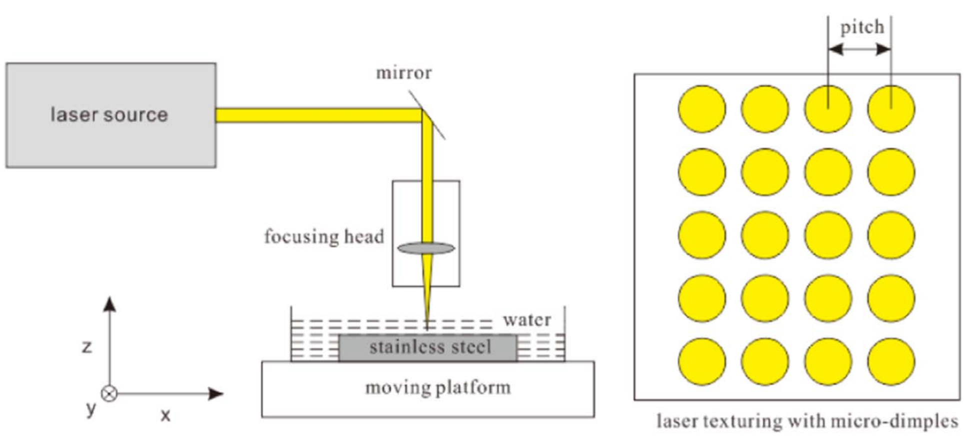

Fig. 1. Schematic of laser texturing underwater.

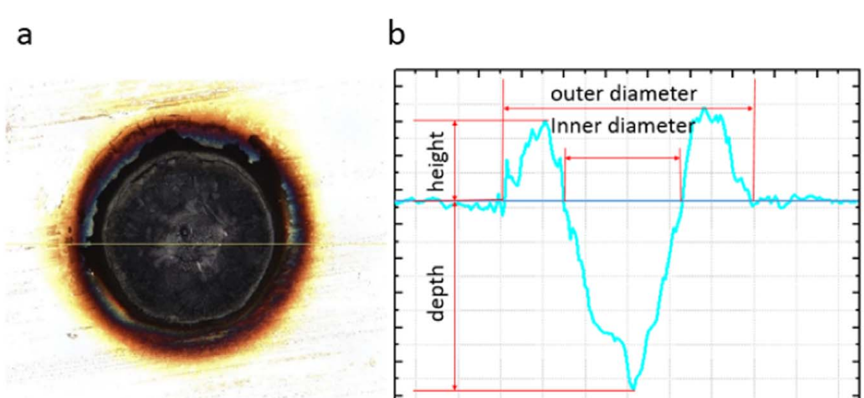

Fig. 2. Cross section of a laser induced dimple.