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Effects of laser shock peening and groove spacing on the wear behavior of non-smooth surface fabricated by laser surface texturing

K.Y. Luo[a,b], C.Y. Wang[b], Y.M. Li[a], M. Luo[b], S. Huang[b], X.J. Hua[b], J.Z. Lu[a,b,*]

[a] Key Laboratory of Modern Agricultural Equipment and Technology (Jiangsu University), Ministry of Education, Zhenjiang 212013, PR China
[b] School of Mechanical Engineering, Jiangsu University, Zhenjiang 212013, PR China

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ABSTRACT

The friction coefficient and wear resistance of non-smooth surface with different conditions are studied in this work. First, the effects of groove spacing on the friction behavior and wear resistance of the non-smooth surface are investigated. Second, the effects of massive laser shock peening (LSP) impact on the dry sliding wear performance of the non-smooth surface manufactured by laser surface texture (LST) are evaluated. In addition, the worn surfaces and typical microstructure in the top surface layer of all samples were characterized by field emission scanning electron microscope (SEM) with an EDS elemental analysis and transmission electron microscopy (TEM). The influence process of groove spacing and LSP on the friction behavior and wear resistance of T9 tool steel are also analyzed and discussed.

1. Introduction

Laser surface texturing (LST) is an emerging novel method for creating non-smooth surface on the contact surface of the work piece, and this surface engineering process is used to improve tribological characteristics of metallic materials [1,2]. Tool steels, commonly used for manufacturing molds, dies and other components that are subjected to extremely high load in almost all industry sectors and agricultural machinery. These steels require high wear and corrosion resistance, either for cold or hot work applications. Recently, some researchers have demonstrated that LST is used to manufacture non-smooth surface to significantly improve wear characteristics and to enhance the fatigue resistance of mold parts. LST was employed to fabricate biomimetic non-smooth surfaces of metallic materials, including medium carbon steel [3], carbon steel AISI 1045 [4], and 3Cr2W8V steel [5]. The non-smooth surface has higher microhardness and better wear-resistance, and sizes of non-smooth units and laser parameters are important factors that affect the thermal fatigue resistance of biomimetic non-smooth surfaces. LST has many advantages, such as non-contact, good flexibility, and high spatial resolution, but tensile residual stress and shrinkage cavity are also generated by the thermal effect during LST process.

Laser shock peening (LSP) is a novel surface treatment process for improving the fatigue durability, wear performance, and other mechanical properties of metallic materials because of its high-pressure (GPa–TPa), ultra-fast (several tens of nanoseconds), ultra-high strain-rate (more than $10^7\ s^{-1}$) and high-energy laser pulses (each pulse of energy several tens of joules) used in this process [6–8]. Moreover, LSP is better as a post processing method to improve mechanical properties of the surface layer because it creates compressive residual stress with a depth of more than 1 mm. In actual engineering applications, multiple locations of the metallic workpiece were usually treated in a massive parallel mode to accomplish uniform surface properties across the entire sample surface, which is massive LSP impact. Bionic non-smooth surfaces of stainless steel 0Cr18Ni9 were fabricated by laser multiple processing (LMP), i.e., LST and subsequent LSP, and results showed that LSP induced surface microhardness and compressive residual stress [9]. However, the above investigation did not involve in the effects of LSP on the friction coefficient and wear resistance of a non-smooth surface fabricated by LST.

The friction coefficient and the wear resistance of non-smooth surface with different conditions were investigated. The effects of groove spacing and groove depth on the performances of non-smooth surface were highlighted. Furthermore, the influence process of groove spacing and LSP on wear behavior of a non-smooth surface with LST treatment were discussed and analyzed. In addition, the grain microstructure of T9 tool steel before and after

* Corresponding authors at: School of Mechanical Engineering, Xuefu Road301, Jiangsu University, Zhenjiang City, Jiangsu Province 212013, China.
Tel.: +86 511 88797198; fax: +86 511 88780352.
E-mail addresses: jzlu@mail.ujs.edu.cn, blueesky2005@163.com (J.Z. Lu).

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Table 1
The chemical composition of T9 tool steel (Atomic Percent).

Composition	C	Si	Mn	S	P	Cr	Ni	Cu	Fe
Content	0.85–0.94	≤0.35	≤0.40	≤0.030	≤0.035	≤0.25	≤0.25	≤0.25	Balance

LSP was characterized. These topics can provide some important insights into the fabrication of a non-smooth surface.

2. Experimental procedures

2.1. Specimen preparation and processing parameters

The substrate material is a T9 tool steel, and its chemical composition is listed in Table 1. The as-received substrate was cut into rectangular-shaped samples with a dimension of 20 mm × 20 mm × 3 mm (length × width × thickness). Prior to LST, these samples were polished with SiC sandpaper in different grades of roughness (from 150 no. to 1200 no.) to ensure uniform finishing, and subsequently cleaned with acetone and deionized water. The LST process was conducted in air using a DPSS Q-CW Nd:YAG laser with configuration parameters of 15 W TEM00 laser output power, 70 ns pulse duration, 1 kHz repetition-rate, 1064 nm wavelength and 100 μm beam diameter.

The configuration and geometry and the photograph of non-smooth surface for the specimens used for the tribological test are shown in Fig. 1. The texture of two intersectional and perpendicular grooves was formed by laser processing in the specimen surface. The groove spacing *l* between two grooves, the groove width *d*, and the groove depth *h* can be schematically illustrated in Fig. 1(a). The above-mentioned parameters, including *l*, *d* and *h*, are changeable and can be used to investigate the effects of these parameters on the wear performance of non-smooth surface.

The specimen denotations, the groove parameters and the specimen number of all LST treated (LSTed) specimens are listed in Table 2. The spacing *l* between two grooves varied from 100 μm to 1000 μm. The groove depths of 5, 10 and 15 μm were chosen. Eight specimens for each kind of LSTed specimen existed, four of which were treated by massive LSP impact (LMPed). The specimen denotations, the groove parameters and the specimen number of all LMPed specimens are listed in Table 3.

Massive LSP impact was carried out using a Q-switched Nd:YAG laser system in Laser Technology Institute at Jiangsu University. The laser wavelength is 1064 nm, and the pulse width is 10 ns with top-hat shape, and the laser spot diameter is 2 mm. The pulse energy of laser beam was 12 J and the repetition-rate is 5 Hz. During massive LSP impact treatment, all specimens were initially submerged into a water bath, and a uniform water layer of 1 mm was used as the transparent confining layer. 86 type black paint with a thickness of 100 μm was coated on the sample surfaces as an ablation medium for plasma initiation to protect the sample surface from thermal damage, and its chemical composition was 5C–21.2C_2H_4O–16.83$C_{10}H_9O_7SNa$–13.18$(C_2H_5O)_4Si$–2.1NaOH–water (wt.%). The laser beam was kept perpendicular to the specimen surface, and the overlapping rate between two adjacent round spots was 50% in both transverse and longitudinal directions to ensure that no blind area existed at the shocked region. During massive LSP impact, the one direction of both groove directions was overlapping treated, and then laser beam was shifted at an half of the laser spot diameter along the other direction. Next, repeat the first step. Until the whole surface was treat by massive LSP impact. We defined the above process as laser multiple process (LMP), i.e., laser surface texture (LST) and subsequent laser shock peening (LSP), which was a novel surface treatment process.

2.2. Wear and frictions tests

A uni-directional ball-on-disk sliding wear tester (Microphotonics, Tribometer TRBH, MT/60/NI) was used to perform the dry sliding wear tests, in which the frictional coefficient can be determined at a precision of ±0.005. The hardened 404 steel ball (*Ra* < 0.1 m, hardness 653 HV, and diameter of 9.5 mm) was used as a pin on plate samples at a rotation diameter of 7 mm and 200 cycles/min for 15 min (sliding distance 66 m) in air at room temperature (25 °C). The width, length, and depth of the worn track can be measured by a universal tool-measuring microscope to calculate the volume of wear loss. During the dry sliding wear test, 30 N loads were used. Prior to the wear tests, the disks were weighed by a scale with a measurement range from 0 g to 100 g and an accuracy grade of 0.1 mg. After wear testing, the disks were cleaned by acetone and deionized water, and then weighed again to calculate the abrasion loss.

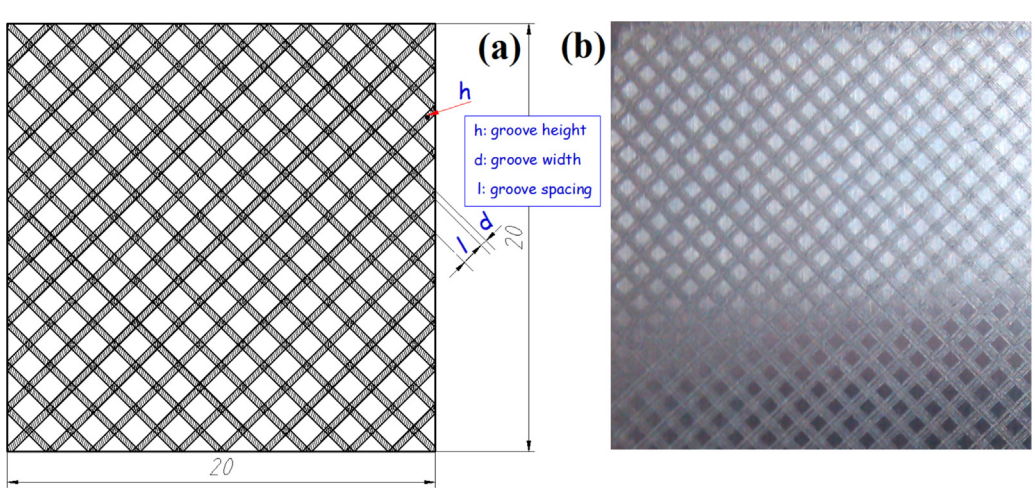

Fig. 1. (a) The configuration and geometry, and (b) the photograph of non-smooth surface for the specimens used for tribological test.