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Influence of Laser Shock Texturing on W9 Steel Surface Friction Property

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Abstract: To improve surface friction property of high speed steel, micro-dent arrays on W9Mo3Cr4V surface were produced by laser shock processing. Friction test was conducted on smooth surface and texturing surface and effect of surface texturing density on friction property was studied. The results show that, under the same condition, friction coefficient of textured surface is lower than smooth surface with dent area density less than 6%, wear mass loss, width and depth of wear scar are smaller; Wear resistance of the surface is the best and the friction coefficient is the smallest when dent area density is 2.2%; Friction coefficient, wear mass loss, width and depth of wear scar increase correspondingly as density of dent area increases when dent area density is more than 2.2%. Abrasive wear and adhesive wear, oxidative wear appear in the wear process. Reasonable control of geometric parameters of surface texturing induced by laser shock processing is helpful to improve friction performance.

1. Introduction

High speed steel has high strength, toughness and good heat resistance. It commonly used in manufacture of complex tools, such as lathe tools, milling cutters, drills, taps, etc. [1,2]. Wear is the main failure mode of high speed steel cutting tools in machining process. High speed steel tools should have good friction properties to ensure the stability of cutting force and the surface quality of workpiece as the key basic parts and it should also have good wear resistance to guarantee the dimensional accuracy of workpiece and tool life.

At present, there are several ways to improve wear resistance and service life of cutting tools. New green cutting technology was used to reduce tool wear by cooling and lubricating in the cutting process, such as Minimum Quantity Lubrication (MQL), spray cooling, liquid nitrogen cooling, low temperature air cooling cutting, water vapor cooling cutting technology [3,4]. Coating technology [5]combines the characteristics of high strength, toughness of matrix, high hardness and wear resistance of coating. It can improve the wear resistance of the tool without reducing its toughness. But coating technology has some shortcomings, including complex process, high requirements for equipment, long period, high production cost, etc. With higher demand of tool cutting performance, the requirements for coating material are increasingly hasher. Kawasegi N[6] designed micro- and nano-grooves textures on the tool rake by laser processing, and used the tool in turning experiments of aluminum alloys. Results show that surface textures produced beneficial lubricating film on the surface of tool, which effectively reduced the friction. However, laser thermal effect acted in the process they used. It can have a detrimental residual tensile stress which destroys the integrity of the material surface for the effect of ablation and vaporization on material. New idea to solve the problem appears with development of Laser Shock Processing (LSP). It avoids material surface ablation because surface deformation caused by laser shock is force effect. Furthermore, the microstructure refining, improvement of surface hardness and beneficial distribution of residual compressive stress induced by laser shock process can significantly improve the wear resistance of tool surfaces. Therefore, laser shock texturing on high speed steel tools for reshaping and modification can improve antifriction and antiwear properties, and increase the service life of the tools.

So far there has been little research on improvement of friction property and wear resistance of high speed steel material treated by LSP. In this paper, different micro-dent arrays were produced on W9Mo3Cr4V surface by LSP, and friction properties of textured surface was studied. The results provide good guidance for later research on improving wear resistance of cutting tools by LSP.

2. Experiments

2.1. Specimen preparation.

The material of specimens is high speed steel W9Mo3Cr4V. The specimens were cut into rectangular shape with dimensions 20 mm × 20 mm × 4 mm (length × width × height). Before laser shock experiment, the specimen surface was polished to a mirror finish with different SiC abrasive papers (from 600# to 1200#), and surface roughness was up to 0.05μm. Finally the treated surface was cleaned by anhydrous alcohol.

2.2. Experiment of laser shock texture.

The experiments were performed using a Spitlight2000 Nd: YAG pulse laser. Wavelength adopted in laser shock texture is 1064 nm. K9 glass with thickness of 4 mm acts as confinement layer. Aluminum foil with thickness of 100 μm produced by 3M Co., Ltd. was adopted as the absorbing material.

In order to study the influence of dent arrays distribution on friction and wear experiment, spot diameter were 1.2 mm, 1.4 mm, 1.6mm and 1.8 mm, and center distance of dent were 0.5 mm, 1 mm, 1.5mm under the same laser energy of 800 mJ. The treated area size was 10 mm×8 mm (length×width). The texture parameters and specimen number are presented in Table 1.

Table 1. Experiment parameters of laser shock.

Specimen no.	Spot diameter (mm)	Center distance (mm)	Specimen no.	Spot diameter (mm)	Center distance (mm)
1	1.2	1.5	4	1.4	1
2	1.2	1	5	1.6	1
3	1.2	0.5	6	1.8	1

2.3. Friction test.

The specimens were cleaned by anhydrous alcohol after laser processing to remove surface residual impurities. Dry friction tests were conducted using a ball-on-disc configuration on a UMT-2 type friction wear testing machine produced by CETR Company. The upper specimen was a GCr15 steel ball with diameter 9.5 mm, and the lower specimen was sample treated by laser shock texturing. The diameter of the wear track was 6 mm. The tests were carried out with a load of 20 N, rotation speed of 100 r/min and time 20 min.

3. Results and discussion

3.1. Morphology of the micro-dent.

LEXT OLS4000 3D laser scanning confocal microscope was used to measure the morphology of micro-dents after laser shock. Figure.1 is the morphology of the micro dents. The micro-dents of different locations on the specimen were measured. To obtain the average value of dent diameter and depth, based on the assumption that ***d*** is the diameter of the dent and ***l*** is the side length of the micro-dent unit (see figure. 1b), then the dent area density can be calculated as follow:

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

Table 2 shows the parameters of texturing in detail.

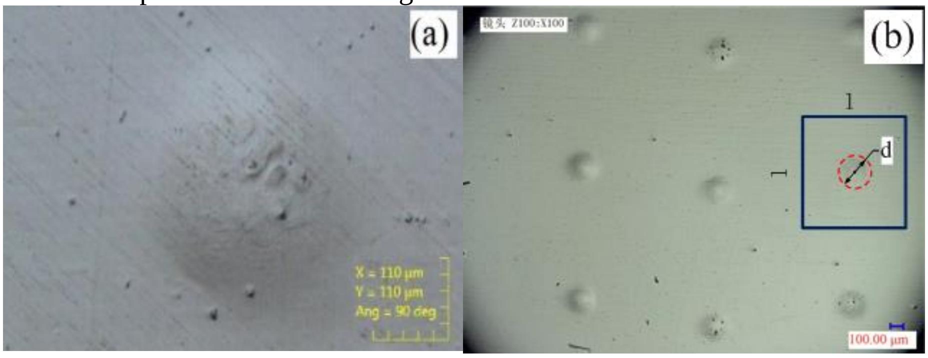

Figure. 1. The morphology of the micro dent (a) single dent (b) micro-dent arrays.

Table 2. Parameters of texturing.

Specimen no.	Diameter of dent (μm)	Depth of dent (μm)	Dent area density (%)	Specimen no.	Diameter of dent (μm)	Depth of dent (μm)	Dent area density (%)
1	247.875	4.216	2.20%	4	270.101	3.701	5.70%
2	247.875	4.216	4.90%	5	292.372	3.414	6.60%
3	247.875	4.216	19.60%	6	324.864	3.016	8.00%

3.2. Analysis of friction coefficient.

Figure. 2a shows the friction coefficient curves of smooth specimen and specimens with different distances of dent center, with laser energy of 800 mJ and spot diameter of 1.2 mm. It can be seen that the friction coefficient of textured specimen with dent center distance 0.5 mm is higher than the smooth surface. The friction coefficients of textured surfaces are less than smooth surface, and decrease with the increase of dent center distance from 0.5 mm to 1.5 mm. The friction coefficient is the minimum when the dents center distance is 1.5 mm. Figure. 2b shows the friction coefficient curves of textured specimens with different spot diameters with laser energy of 800 mJ and dent center distance of 1 mm. It can be seen that the friction coefficient gradually increases as the spot diameter from 1.2 mm to 1.8 mm, the friction coefficient does not increase significantly when the spot diameter increases from 1.4 mm to 1.8 mm.

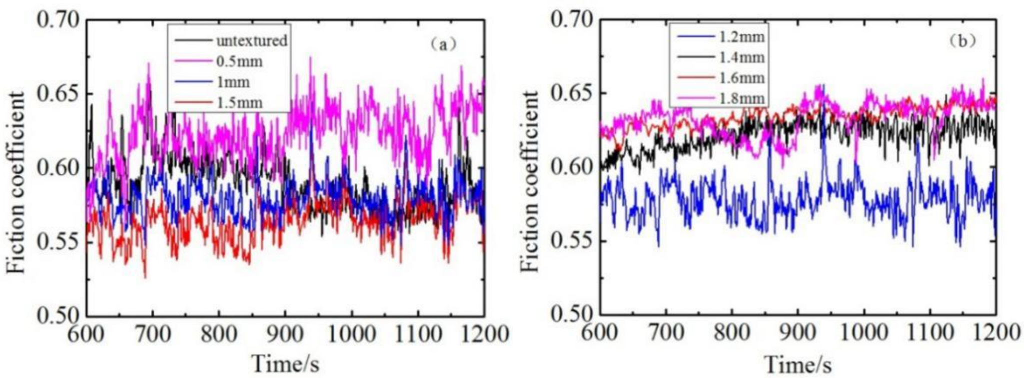

Figure. 2. Change of friction coefficient with time (a) different distances of dent center (b) different spot diameter.

Figure. 3 shows the friction coefficient curves with different dent area densities under laser energy of 800 mJ, and laser spot diameter is 1.2 mm, 1.4 mm, 1.6 mm, 1.8mm and dent center distance is 0.5 mm, 1 mm, 1.5 mm. It can be seen that the friction coefficient of textured surface with dent area density less than 6% is lower than smooth surface. Friction coefficient is the smallest when the dent area density is 2.2%. With the increase of dent area density from 2.2% to 6.6%, the friction coefficients increase rapidly, then an inflection point appears when the dent area density is close to 7.5%. When the dent area density increases continuously from 7.5% to 19.6%, the increments of friction coefficients is not obvious. Analysis suggests that the textured surface has the ability of capturing abrasive particles to a certain extent and play an important part of reducing furrow effect, so the friction coefficients are reduced. While the dent area density increases, the friction coefficients also increase. The reason is that the increase of dents number makes the surface roughness increased, and the effect of capturing abrasive particles and reducing furrow is less than the frictional resistance effect caused by micro dents, so friction coefficient increases. The distance between adjacent dents is large as the dent area density is small. The larger proportion of smooth area and dents area makes lower friction torque [7, 8], so the friction coefficients decrease.

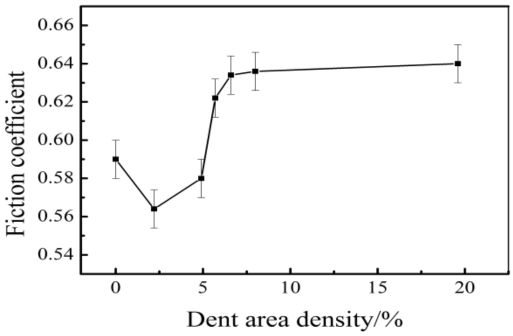

Figure. 3. Change of friction coefficient with dent area density.

3.3. Analyses of wear loss.

Evaluation indexes of wear loss are mainly wear mass loss, bulk worn loss and linear wear loss. Due to the uniform density of material, wear mass loss is chosen to evaluate the wear resistance of material in this experiment. Wear mass loss is the mass difference before and after wear test. In order to reduce errors caused by manual measurement, each specimen cleaned by ultrasonic and dried, was measured repeatedly for 3 times before and after weighing. Figure. 4 shows the wear mass loss of specimens with different dent densities measured by electronic balance (precision of 0.1 mg).

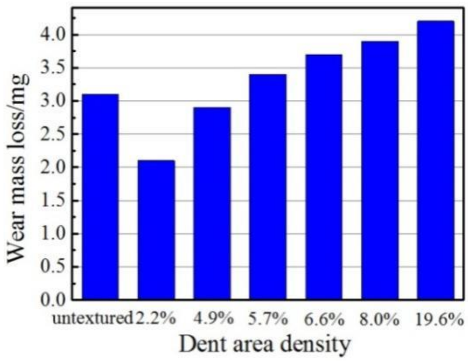

Figure. 4. Wear mass loss under different dent area density.

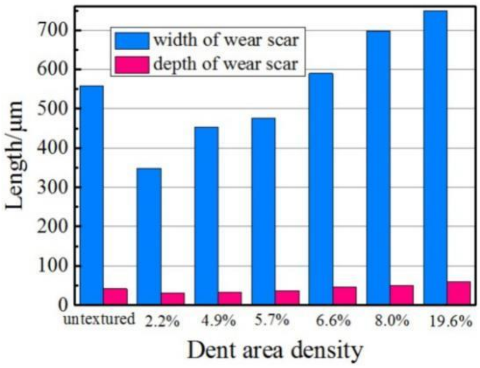

Figure. 5. Width and depth of wear scar under different dent area densities.

It can be seen from Figure. 4, the wear mass loss is consistent with friction coefficient under dry fiction. When the dent area density is less than 4.9%, the wear mass losses of textured specimens are less than smooth specimen’s. The wear mass loss increases correspondingly as density of dent area increases.

By measuring the width and depth of wear scar to estimate the bulk worn loss, it can be also used as the evaluation index of wear loss. The width and depth of wear scar were measured by laser scanning confocal microscope. Figure. 5 shows the widths and depths of wear scars with different dent area densities.

The widths and depths of wear scars are less than smooth surface's when the dent area density is less than 5.7%, which is inconsistent with change of the friction coefficient and wear mass loss. By analysis that smooth specimens exist serious adhesive wear during the process of wear, and abrasive dust adhere to both sides of wear scar under the squeezing action of steel ball, resulting in too large measured values of smooth specimen's wear scar. The width and depth of wear scar decrease correspondingly as density of dent area decreases.

It is inferred that the dents capture abrasive particles during the wear process when the dent area density is low, then abrasive wear reduces. On the other hand, residual compressive stress is produced in the treated area by laser shock, leading to improvement of hardness and wear resistance. However, when the dent area density increases to some extend, the contact area of friction pair is reduced. The average contact stress also increases, which becomes the main factors affecting antiwear properties of material surface, so the wear rate increases.

3.4. Analyses of worn surfaces.

Figure. 6a shows the wear trace micrographs of textured specimen which was not cleaned after the dry friction experiment. It can be seen clearly that micro dent is covered with abrasive dust, indicating that the dents have ability of capturing abrasive dust in the process of friction. To a certain extent, it is good for reducing abrasive wear, thus reducing the surface wear. Brown rust appeared inside the wear trace. Analysis suggests that high temperature was produced in the process of friction, and the material is more susceptible to oxidation. Figure. 6b shows the serious adherent phenomenon on the both sides of wear trace. This is because steel ball squeeze material towards two sides during the motion, resulting in accumulation and adhesion of abrasive dust. From the both figures, we can see a number of parallel furrows were formed along the direction of sliding on the worn surface, which is caused by abrasive wear. Abrasive wear is that the material on the surface is pushed to the front of the steel ball, or the surface material is pushed to the both sides of motion direction, and therefore the hard particles which fell from surface produced furrows on the surface of material under the force [9].

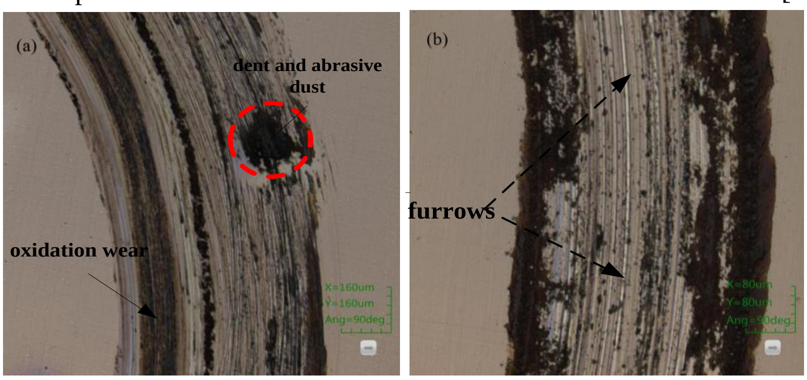

Figure. 6. Micrographs of wear trace (a) wear race of textured specimen (b) wear race of untextured specimen.

4. Conclusions

Influence of the dent area densities on the properties of friction and wear were explored corresponding to different dent center distance and spot diameter. Some important conclusions can be drawn as follows.

The tribological properties of high speed steel W9Mo3Cr4V treated by laser shock peening are affected by dent area density. The friction coefficients of textured surfaces with dent area densities less than 6% are lower than smooth surface, and exists a best optimum value of dent area density with the least friction coefficient. Friction coefficient increases rapidly with the increasing dent area density when the dent area density is more than the best value. Increments of friction coefficients are not obvious when the dent area density is more than the value of inflection point.

Wear mass losses of textured surfaces are less than the smooth surface's when the dent area densities are less than 4.9%. Wear mass losses increase gradually with the increasing dent area densities. When the dent area densities are less than 5.7%, the width and depth of wear scars are less than the smooth surface's. The results of wear losses are consistent with friction coefficients under dry fiction.

Abrasive wear and adhesive wear, oxidative wear appear in the wear process. The micro dents have the ability of capturing abrasive dust. Reasonable control of geometric parameters of surface texturing induced by laser shock processing is helpful to improve friction performance.

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