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Fabrication of the laser textured nickel surface and its tribological property under the water lubrication

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Abstract
Friction is one of the main causes of mechanical component failure and material waste. It is known from the friction theory that changing the roughness of the surface of the material can change the friction property of the material. Laser surface texturing is a good method for constructing a rough surface. In the experiment, the texture of the circular pits with different areal densities was constructed on the nickel surface. The coefficient of friction of the circular pit under the water-lubricated friction condition was kept at about 0.17, while the untreated metal nickel under the same conditions exceeds 0.65. The circular pit texture improves the frictional properties of the nickel surface.

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I. Introduction
Friction is one of the main causes of mechanical component failure, resulting in a large amount of energy consumption and material waste. The surface texture technology is used to prepare regular geometric shapes such as pits, convex hulls, stripes and meshes on the surface of the material, which can reduce material wear and improve the surface wear resistance of the material. Methods of fabricating texture on the surface of the material include laser processing, surface shot peening, electrical discharge machining, machining, and the like. Laser processing technology is highly efficient, clean and easy to control, and has been widely used in the surface texture preparation. For example, the application of the laser technology to prepare a textured surface on the HD hot work die steel has improved wear resistance by more than 2 times. A convex-clad, stripe-like and grid-like surface is prepared on the surface of the brake rotor of gray cast iron, which has excellent wear resistance and is more than 50% longer than the normal brake hub under the actual working conditions.

Fine grooves and convex hulls are laser-machined on the surface of 65Mn spring steel rolls, and the life of the textured rolls is 2-3 times that of the ordinary rolls. The surface of the 45 steel was laser-machined with pits, grooves and other textures, and the friction and wear tests were carried out under the conditions of the cam/roller conditions of the internal combustion engine. The experimental results show that the tribological properties of the surface of the laser micro-textured sample is improved. Bonse fabricated the laser-induced periodic surface structures on stainless steel and titanium alloy surfaces upon irradiation with multiple femtosecond laser pulses, finally find that for specific conditions when compared to the non-irradiated one, on the titanium alloy a significant reduction of the friction coefficient by a factor of more than two was observed on the laser-irradiated surface. Many experts and scholars have performed laser processing on the surface of many...
FIG. 1. The scheme of the laser scanning processing to fabricate the circular pit texture.

FIG. 2. The effect of the processing parameters on the depth and diameter of the pit (a) power (b) speed (c) number (d) frequency (e) areal density.

In this paper, the coating material nickel commonly used in engineering is taken as experimental material. The pulsed laser is used to process the pit texture on the surface of the test piece. The wear and tear morphology were observed by the disc-disk grinding method, and the friction and wear characteristics of the pit texture surface were studied by comparing with the surface of the common specimen.

II. EXPERIMENT

In order to improve the friction property of the nickel surface, the rough nickel surface with round pit texture is first prepared, and then the friction law is explored.

(1) Material pretreatment

The purity of nickel is 99.5%, and it is polished to the specular gloss by the 800#, 1000#, 1500# sandpaper, and then ultrasonically treated with the acetone solution, absolute materials, and also found that its friction performance has been greatly improved.13–15
ethanol and deionized water for 10 minutes, then dried with the compressed air to remove the surface impurities.

(2) Processing texture

The laser source is a YLP-SD20L (Sanda Laser) fiber nanosecond pulse laser with a center wavelength $\lambda$ of 1064 nm, a repetition frequency $f$ of 20-80 kHz, an output beam quality factor of $M^2 < 1.5$, and a maximum power of 20 W. The scanning galvanometer with a 110 mm focal length lens controls the movement of the laser in the plane, and the spot size after focusing is $\phi$ less than 20$\mu$m. The scheme of the laser scanning processing is shown in Fig. 1.

In order to study the influence of laser parameters on the circular pit texture, we can control the size of the pit to achieve the target parameters (the diameter and depth of the pit texture), by changing the laser speed, the processing time, the laser power, the laser frequency and the areal density (the ratio of the surface area of the pit to the original surface area). The results are shown in Fig. 2. As the number of processing and the laser power increases, the depth of the pit gradually increases. As the laser speed increases, the depth of the pit gradually decreases. As the laser repetition frequency increases, the pit depth first increases and then decreases. The variation of the areal density has little effect on the depth of the pit, since the diameter of the pit is independent of the laser parameters and is only related to the shape of the texture.

From the above rules, a circular pit with a diameter of 100$\mu$m and a depth of 10$\mu$m was experimentally processed. The laser parameters were set with the scanning speed of 1000 mm/s, the number of processing of 1, and the repetition frequency of 60 kHz. The other parameters were fixed, the pitch of the pits was changed to set different areal densities, and the effects of different areal densities on the wetting properties of the metal were investigated experimentally.
(3) Post-treatment of materials

After the laser processing, it was immersed in petroleum ether for half an hour (to ensure that surface impurities are removed more thoroughly), and then ultrasonically treated with acetone solution, absolute ethanol, deionized water for 10 min, and dried with compressed air to remove surface impurities and oil stains, and then left in the air for two weeks.

(4) Friction test

Friction experiments were carried out by using the MM-W1B vertical universal friction and wear tester. The changes of the friction coefficient of the samples before and after the laser texturing were compared and analyzed: the disk-disk-type grinding method was used with the load of 10N, the time of 20min and the rotation speed of 400r/min in normal temperature. During the experiment, the test piece did not move, and the upper test piece was rotated. As shown in Fig. 3. The lubricant was water. The test was repeated at least 3 times in each group. The friction coefficient during the experiment was directly derived from the computer.

The circular crater having a diameter of 100μm and a depth of 10μm was tested for friction properties at the surface densities of 0%, 30%, 40%, 50% and 60%. Observed by the white light interferometer (ZYGONexView), under the experimental conditions, the shape of the pit texture is the most regular and the material removal is the most thorough. As shown in Fig. 4, the textured center material with a diameter of 200 μm and a depth of 10 μm is not completely removed.

III. RESULTS AND DISCUSSION

The surface morphology of the nickel pitted texture sample was observed by the scanning electron microscopy (TESCAN LYRA3 FEG-SEM/FIB). As shown in Fig. 5(a), the areal density was 60% and the magnification was 1000 times. The nickel surface was observed by a white light interferometer. The three-dimensional shape of the structure, as shown in Fig. 5(b), has an areal density of 40%. The surface is a single circular pit, and no protrusions and micro-nano structures are formed.

Due to the irradiation of the laser, the sample forms a regular circular pit structure. Laser irradiation removes the material of the illuminated area, resulting in a regularly arranged circular concave structure, which increases the surface roughness of the nickel.

In order to study the effect of the texture of the pits with different areal densities on the surface friction coefficient of the nickel, the coefficient of friction of the pits with a diameter of 100μm and a depth of 10μm at 0%, 30%, 40%, 50% and 60% is tested. Changing the spacing of the pits to set different areal densities, the friction coefficient measured under the condition of room temperature with the load of 10N, the rotation speed of 400r/min, the experiment time of 20min and the lubrication with water. As shown in Fig. 6. After the laser texturing, the friction coefficient of nickel surface is obviously reduced, and it decreases with the increase of areal density. It is the smallest when the areal density is 60%, which is 0.17, far less than the unprocessed surface of 0.65.

The surface morphology of the specimen under the friction test of the pit was observed by the scanning electron microscopy (SEM). The Fig. 7(a) shows the surface wear morphology of the specimen corresponding to the non-textured surface, and the Fig. 7(b) shows

![Fig. 6. The friction coefficients of the nickel surface on different areal density.](image)

![Fig. 7. The topography of the nickel surface with pit texture after the friction test](image)
the surface wear morphology of the areal density 60%. The corresponding surface of the test piece is worn, and the depth of the pit is 10μm. It can be observed from the figure that the circular pit of the friction zone has been smoothed compared with the non-textured wear surface. It can be seen from the Fig. 6, that the friction coefficient after the smoothing is gradually increased to a stable state. The rolling condition on the surface of the test piece was improved, and the degree of the adhesive wear was reduced.

The laser prepared surface pit texture did change the friction coefficient of the nickel. The rough surface increases the actual contact area of the liquid and liquid, reduces the actual contact area of the solid, changes the contact performance between the friction pairs, reduces the formation probability of the adhesive joints, and reduces the adhesive wear. The texture can form a function of storing lubricant. When the water film on the surface is thinned and destroyed, the water in the groove can be supplemented, and a secondary lubrication effect is generated. The metal surface always has a certain thickness during the friction process. The continuous water film is beneficial to the formation of fluid dynamic pressure lubrication, improving the load-carrying capacity and reducing the frictional resistance, thereby avoiding the occurrence of the boundary lubrication or even the dry friction. Because of the surface texture, the liquid has a dynamic pressure effect, the liquid pressure in the texture zone is high, the distance between the friction pairs is increased, and the actual contact of the two friction pairs is reduced. The research by Rapoport and Kovalchenko also confirmed this. The pit texture also captures the wear debris generated by wear and prevents severe wear. The study by Pugno also shows that the laser interacts with the metal, which also increases the hardness of the surface, and the support and protection of the hard spots on the edge of the laser pit improves the tribological property.

IV. CONCLUSION

Using a nanosecond pulsed laser to construct pits texture of different areal densities on the nickel surface, with the diameter of 100μm and the depth of 10μm, which reduces the friction coefficient of the nickel surface from 0.65 to 0.17.

1. The texture can store the lubricant. During the rubbing process, the water film on the surface is gradually thinned, and the water in the pits can be used as a supplement to make a continuous water film with a certain thickness on the metal surface. It is beneficial to form fluid dynamic pressure lubrication and reduce frictional resistance, thereby avoiding the boundary lubrication or even the dry friction;
2. The interaction of the laser with the metal increases the hardness of the metal surface, thereby improving the tribological properties;
3. The surface texture increases the contact area of the liquid and the liquid, and the actual contact area of the friction pair is reduced, thereby reducing the friction;
4. The surface texture can capture the debris generated during the friction process, which reduces the pear groove effect and prevents the occurrence of the severe wear;
5. The method is simple and economical. It provides new ideas for improving the tribological properties of nickel and its alloys.

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REFERENCES

1. A. Kovalchenko, O. Ajaşi, A. Erdemir et al., “Friction and wear behavior of laser textured surface under lubricated initial point contact,” Wear 271(9-10), 1719–1725 (2011).
2. D. Z. Segu, S. G. Choi, J. hyouk Choi et al., “The effect of multi-scale laser textured surface on lubrication regime,” Appl. Surf. Sci. 270, 58–63 (2013).
3. D. Braun, C. Greiner, J. Schneider et al., “Efficiency of laser surface texturing in the reduction of friction under mixed lubrication,” Tribology International 77, 142–147 (2014).
4. M. Scargari, F. P. Mezzapesa, G. Carbone et al., “Friction properties of lubricated laser-microtextured-surfaces: An experimental study from boundary-to-hydrodynamic-lubrication,” Tribology Letters 49(1), 117–125 (2015).
5. B. Kim, Y. H. Chae, and H. S. Choi, “Effects of surface texturing on the frictional behavior of cast iron surfaces,” Tribology International 70, 128–135 (2014).
6. M. Scargari, F. P. Mezzapesa, G. Carbone et al., “Minimize friction of lubricated laser-microtextured-surfaces by tuning microholes depth,” Tribology International 75, 123–127 (2014).
7. S. C. Vlădescu, S. Medina, A. V. Olver et al., “Lubricant film thickness and friction force measurements in a laser surface textured reciprocating line contact simulating the piston ring–liner pairing,” Tribology International 98, 317–329 (2016).
8. W. C. Xiu, S. Yang, L. Chen et al., “Study on wear resistance of bionic non-smooth shape on hot work die steel surface,” Industry and Technology Forum 2013(22), 72–73.
9. H. Zhou, Brake drum with bionic non-smooth surface: CN1644950[P], 2005.
10. Y. C. Qi, C. Y. Ma, Y. Peng et al., “Study on wear resistance of laser engraved bionic non-smooth form on roll surface,” Application Laser 26(1), 1–4 (2006).
11. W. Tang, Y. Zhou, H. Zhu et al., “The effect of surface texturing on reducing the friction and wear of steel under lubricated sliding contact,” Applied Surface Science 273, 199–204 (2013).
12. J. Bonse, K. Koter, M. Hartelt et al., “Femtosecond laser-induced periodic surface structures on steel and titanium alloy for tribological applications,” Applied Physics A 117(1), 103–110 (2014).
13. J. Huang, S. Wei, L. Zhang et al., “Fabricating the superhydrophobic nickel and improving its antifriction performance by the laser surface texturing,” Materials 12(7), 1155 (2019).
14. R. Bathe, V. S. Krishna, S. K. Nikumb et al., “Laser surface texturing of gray cast iron for improving tribological behavior,” Applied Physics A 117(1), 117–123 (2014).
15. J. Bonse, S. Kirner, M. Griepentrog et al., “Femtosecond laser texturing of surfaces for tribological applications,” Materials 11(5), 801 (2018).
16. J. Huang, S. Wei, L. Zhang et al., “Fabricating the superhydrophobic nickel and improving its antifriction performance by the laser surface texturing,” Materials 12(7), 1155 (2019).
17. D. Z. Segu, S. G. Choi, J. hyouk Choi et al., “The effect of multi-scale laser textured surface on lubrication regime,” Appl. Surf. Sci. 270, 58–63 (2013).
18. S. P. Mishra and A. A. Polycarpou, “Tribological studies of unpolished laser surface textures under starved lubrication conditions for use in air-conditioning and refrigeration compressors,” Tribology International 44(12), 1890–1901 (2011).
19 L. M. Vilhena, B. Podgornik, J. Vižintin et al., “Influence of texturing parameters and contact conditions on tribological behaviour of laser textured surfaces,” Meccanica 46(3), 567–575 (2011).

20 D. He, S. Zheng, J. Pu et al., “Improving tribological properties of titanium alloys by combining laser surface texturing and diamond-like carbon film,” Tribology International 82, 20–27 (2015).

21 W. Tang, Y. Zhou, H. Zhu et al., “The effect of surface texturing on reducing the friction and wear of steel under lubricated sliding contact,” Applied Surface Science 273, 199–204 (2013).

22 L. Rapoport, A. Moshkovich, V. Perfilyev et al., “Wear life and adhesion of solid lubricant films on laser-textured steel surfaces,” Wear 267(5-8), 1203–1207 (2009).

23 A. Kovalchenko, O. Ajayi, A. Erdemir et al., “The effect of laser surface texturing on transitions in lubrication regimes during unidirectional sliding contact,” Tribology International 38(3), 219–225 (2005).

24 N. Pugno, “Increasing nanohardness and reducing friction of nitride steel by laser surface texturing,” Tribology International 42(5), 699–705 (2009).