Study on Surface Micro-texture of Characterization and Laser Processing on 45 Steel

Suqin Jiang¹, Hongguang Xu², Zhenfei Jiang¹*, Ruixue Li¹, Bokui Li¹, Xu Pei¹ and Zhaomei Xu¹

¹Faculty of Mechanical and Material Engineering, Huaiyin Institute of Technology, Huaian, China
²Faculty of Transportation Engineering, Huaiyin Institute of Technology, Huaian, China

*Corresponding author e-mail: m18751289305@163.com

Abstract. The mechanism of laser surface micro-texture on friction characteristics of 45 steel surface was studied. The micro-texture was characterized and measured by 3D geometric parameters. The orthogonal experiment method was used to optimize the laser processing parameters. The friction and wear experiments were performed on the smooth samples and textured samples. The results show that micro-texture with reasonable size is conducive to reduce friction and drag. This has certain reference and theoretical basis for the study of the relationship between surface geometry and service performance.

1. Introduction
Recent studies have shown that artificially processing micro-textures on the surface of friction surfaces is beneficial to reduce friction and drag [1-2]. At present, micro-texture morphology of certain rules can be obtained by laser, electric spark, etching, machining and other methods. Domestic and foreign scholars such as Kummel, Salama, and Tang Liping have applied the micro-texture to the friction surfaces of ceramic cutting tools, bearings, and heavy-duty gears, respectively, and found that pits and cross-textured textures can improve the wear resistance and prolong the service life of the parts [3-5]. The micro-texture on the surface of the friction pair belongs to micro-fabrication, and it can utilize the high energy density and high directivity of the laser to shape and sculpt the micro-morphology on the surface of the solid material. The use of laser to design micro-texture on the surface of friction pairs has advantages beyond other surface modeling methods. In this paper, the micro-texture surface morphology characteristics and laser processing technology is studied, and the relationship between surface geometry characteristics and service performance is explored. It is
necessary to design and manufacture the matching micro-geometry for the lubrication friction performance requirements.

2. Characterization and measurement of geometric parameter of surface micro-texture

Because of the influence of texture and surface roughness on tribological properties during machining, with the appearance of micro-machining, the usual roughness Ra, Rz and other expression methods can not fully characterize the part surface geometry.

Some studies [4] show that the shape of different micro-textures can play a role in friction reduction and drag reduction, as well as the width, depth, and distribution of geometric features on the surface have a significant impact for the friction characteristics. In order to objectively and reasonably evaluate the influence of micro-texture on tribological properties in friction and wear experiments, the three-dimensional of laser micro-texture is characterized in this paper. The width, depth, ratio of depth to diameter and area occupancy of the micro-texture are selected as the three-dimensional surface morphology parameters.

Geometrical parameters were measured by Micro XAM 3D non-contact profiler. When the laser micro-texture processing completed, all samples were ultrasonically cleaned with anhydrous alcohol for 30 minutes, and then the samples were dried and graded. The 3D topography and 2D dimensional cross-section profile of the textured texture measured by the surface profiler are shown in Figure 1 and Figure 2, respectively.

![Figure 1. 3D topography measurement chart of micro-texture.](image1)

![Figure 2. X,Y cross-section profile of micro-texture.](image2)

3. Optimization of laser micro-texture process parameters

3.1. Laser micro-texture experiment

The diode-pumped UV laser processing system was used for laser micro-texture processing. The Nd:YVO4 was selected as the medium for pump to produce pulsed laser. The output wavelength is 355 nm, which has low light damage and high efficiency in laser processing. The laser mode is TEM00, pulsed laser, and the output wavelength is 1064 nm. With the help of auxiliary blowing system of the processing system, most of the slag in the processing can be removed and metal recasting can be reduced. The test specimens, which were quenched and then tempered, were 45 steel bars with a diameter of 15mm. The surface was sanded with metallographic sandpaper and then polished. The roughness is about 1.6 µm. The sample was ultrasonically cleaned and dried.
3.2. Optimization of laser processing parameters

In order to obtain a more ideal micro-texture geometric surface parameter depth-to-radius ratio and area occupancy rate, a fixed angle of 135° is set for the mesh pattern, and the laser energy is adjusted to the best value to match the operating frequency. Processing parameters choose spacing and scanning speed in turn. Table 1 shows the orthogonal experimental design of 45-steel textured reticulate micro-texture by laser processing.

Table 1. The orthogonal experimental design of 45-steel textured reticulate micro-texture by laser.

| Level | Angle (°) | Spacing (A) (mm) | Scanning speed (B) (mm / s) |
|-------|-----------|------------------|-----------------------------|
| 1     | 135       | 300              | 1.0                         |
| 2     | 135       | 450              | 1.5                         |
| 3     | 135       | 600              | 2.0                         |

3.3. Friction and wear characteristics experiment

Taking the quality loss of laser texture specimen after friction and wear test as optimization objective, the influence of micro-textures with different geometrical parameters on friction properties of materials was studied. The friction and wear test is based on UMT-2 multi-functional biological friction and wear testing machine. The test chooses φ4 mm stainless steel ball as friction pair. The friction and wear test conditions are suggested as follow: loading 0.8 kg, rotation speed 300 r/mm, friction time 30 min, room temperature, SAE20/W40 lubricating oil, 3 repeated tests for each sample. To ensure that the interface is always in an oil-rich state, oil is added every 10 minutes during the experiment. The results of friction test for each group of samples before and after texture are shown in Table 2, the depth to width ratio and area occupancy of each group by different process parameters are counted, and the wear lose is obtained by before and after the frictional test. To analyze the effect of texture on friction performance, the wear loss of smooth specimen after friction test is in the tenth scheme.

Table 2. The result of friction test for each group of samples before and after texture.

| Sample scheme | Process parameters | Characterization | Wear lose (g) |
|---------------|--------------------|------------------|---------------|
|               | A | B | Width (μm) | Depth (μm) | Depth to width ratio | Area occupancy | |
| 1             | 1 | 1 | 56    | 5    | 0.08 | 13.33 | 0.0006 |
| 2             | 1 | 2 | 58    | 6    | 0.10 | 16.00 | 0.0005 |
| 3             | 1 | 3 | 60    | 8    | 0.13 | 21.33 | 0.0011 |
| 4             | 2 | 1 | 67    | 6    | 0.09 | 10.67 | 0.0003 |
| 5             | 2 | 2 | 69    | 7    | 0.10 | 12.44 | 0.0002 |
| 6             | 2 | 3 | 70    | 9    | 0.13 | 16.00 | 0.0010 |
| 7             | 3 | 1 | 80    | 5    | 0.06 | 6.67  | 0.0007 |
| 8             | 3 | 2 | 81    | 6    | 0.07 | 8.00  | 0.0005 |
| 9             | 3 | 3 | 83    | 12   | 0.14 | 10.67 | 0.0012 |
| 10            | 3 | 3 | 83    | 12   | 0.14 | 10.67 | 0.0009 |
4. Result and discussion results and analysis of experiment

4.1. The analysis of friction characteristics of micro-texture surface

It can be seen from the table 3, the wear loss of textured surface is significantly smaller than that of smooth surface, this implies that surface micro-texture does reduce friction and wear loss. Under the netlike structure of 135°, the wear loss of textures with a pitch of 450 μm and a speed of 1.5 mm/s are less than other spicing.

Figure 3 shows the results of friction coefficient of smooth specimens and textured specimens with different line spacing. Compared with the smooth surface specimens, the friction coefficient of the sample with micro-texture is smaller. The surface of the groove can play a role in oil storage and friction reduction under the state of lubrication. When the distance between the groove becomes larger from 300-600um, the friction factor decreases first and then increases, which is slightly smaller than 0.15 of the smooth specimens. The reasons may be that the line spacing is too small, and the surface slot area occupancy rate is too large, resulting in the reduction of surface integrity; line spacing is too large, the area occupancy of the slot is reduced, the continuity of the oil film is reduced and the carrying capacity is reduced. Pettersson [6] have also pointed out that the surface friction coefficient of grooved or textured surface is smaller than that of the smooth surface against surface contact friction pairs of cast iron specimens and curved shape of friction has less fluctuations. It can be obtained from the comparison that the effect of reduce friction and wear loss is best when the distance is 450 μm, and the minimum friction coefficient is about 0.11.

![Figure 3. Friction coefficient of textured specimen and smooth specimen.](image)

4.2 Analysis of optimization results of orthogonal test

4.2.1 Analysis of influence of process parameters on wear resistance. Due to the defects in the material surface during the processing and the friction coefficient of the material itself, the scanning speed and mesh spacing have no reference to the data of the friction coefficient. The influence of the two factors of scanning speed and mesh spacing on the wear loss should be analyzed emphatically.

Select the Minitab tool to perform orthogonal analysis of the experimental data in Table 2. Figure 4 is a graph of the mean effect of scanning speed and mesh spacing on wear loss. It can be found that the
scanning speed had a greater effect on the wear loss than the mesh spacing. Figure 5 shows the interaction diagram of wear loss, as well as the average wear loss is shown in Table 3. It can be seen from the image that the minimum loss of network texture is mesh spacing 450 μm and the scanning speed is 1.5 mm/s. In order to verify the conclusion, it need to analyze the mean variance. The average variance analysis of wear loss is shown in Table 4. According to the mean main effect diagram and the average variance of the wear loss interaction diagram, the proposed scheme A2B2 was selected. Therefore, from the point of view of wear loss, the optimum scheme is mesh spacing 450 μm and the scanning speed is 1.5 mm/s. According to the result of prediction analysis, the best laser processing parameter combination is A2B2.

Figure 4. The main effects of speed and spacing of reticulate pattern for mean of wear loss.  
Figure 5. The diagram of interaction effects of parameters.

Table 3. Abrasion quality average response table.

| Level | Mesh spacing | Speed |
|-------|--------------|-------|
| 1     | 0.000733     | 0.000533 |
| 2     | 0.000633     | 0.000400 |
| 3     | 0.000667     | 0.001100 |
| Delta | 0.000100     | 0.000700 |
| Rank  | 2            | 1      |

Table 4. Analysis of the mean variance of the wear loss.

| Source            | Degree of freedom | Seq SS | Adj SS | Adj MS | F     | P     |
|-------------------|-------------------|--------|--------|--------|-------|-------|
| Mesh spacing      | 2                 | 0.000000 | 0.000000 | 0.000000 | 0.21  | 0.822 |
| Scanning speed    | 2                 | 0.000001 | 0.0000001 | 0.000000 | 10.97 | 0.024 |
| Residual error    | 4                 | 0.000000 | 0.000000 | 0.000000 |       |       |
| Total             | 8                 | 0.0000001 |        |        |       |       |

4.2.2 Analysis of relationship between surface characteristic parameters and wear resistance. The depth to width ratio is used as a reference factor to describe the three-dimensional surface features, but it is not enough to represent the specific conditions of the three-dimensional micro-texture surface. Therefore, the influence of the area occupation rate of micro-texture on the wear resistance must also be considered. In order to analyze the relationship between surface feature parameters and wear resistance, the single factor analysis was performed on the depth to width ratio and area occupancy measured in Table 2 respectively.

According to the data from Table 2, when the ratio of micro-texture depth to diameter is 0.1014, and the area occupancy is 0.1244, the loss mass of the sample is the smallest. The ratio of depth to
diameter and area occupancy are too large or too small have little effect on friction reduction of parts. This is because the micro-texture makes the original smooth, flat parts of the friction pair surface formed a regular uneven rubbing pattern, play a role in storing lubricant. This texture size is too small and oil storage effect is not obvious. However, if the texture size is too large, the oil storage space will easily be destroyed and the surface friction resistance will be increased.

5. Conclusions
(1) Laser micro-texture acts as a storage lubricant for the surface of parts associated with lubrication and friction to form dynamic pressure lubrication, which can reduce friction and wear properties.
(2) Through orthogonal test, the optimized process parameters are obtained. When the texture pattern pitch is 450µm and the laser scanning speed is 1.5mm/s, the friction reduction performance is the best. At this time, the micro-texture depth ratio is about 0.1014, and the area occupancy rate is 12.44%.
(3) The evaluation of the three-dimensional geometrical characteristics of micro-textures requires a comprehensive consideration of the effect of the ratio of the depth to the diameter and the area occupancy on the friction and wear characteristics.

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