Study on Friction and Wear Behaviors of Micro Texture Shape and Its Modified Surface

Xu Rui, Wang Yipu, Liu Haixu, Qi Wanting, Wang Zhankui and Su Jianxiu*

School of Mechanical and Electrical Engineering, Henan Institute of Science and Technology, Xinxiang, 453003, P.R.China

*E-mail: dlutsu2004@126.com

Abstract. The 304 stainless steel has good mechanical properties and is widely used in industrial manufacturing. In this paper, take 304 stainless steel as the substrate material, the five micro texture shapes, such as groove array, square column array, circular pit array, regular hexagon column array and trapezoid column array, on the surface of 304 stainless steel were carved by nanosecond laser engraving machine under the same parameters, and then were immersed in 0.5mol/l perfluorodecyl trimethoxysilane ethanol solution at 45 ℃ for 5 hours. Five type super-hydrophobic surfaces were obtained. A series of friction and wear experiments were conducted out and the influence of different micro texture on the friction and wear to the 304 stainless steel surface was analyzed. The results show that the square column array has the best friction and wear resistance, and its friction coefficient is 0.16, which is the lowest in all other micro texture shapes. It can be used as a reference for improving the friction and wear resistance of metal surface.

1. Introduction

In the instrument, equipment and mechanical system, the friction and wear behaviors of the surfaces which contact and move with each other will directly affect the service life, working efficiency, bearing capacity and safety factor of the whole instrument or system. According to statistics, about 80% of parts damage is caused by friction and wear of various forms [1], and the economic loss of mechanical parts directly caused by friction and wear reaches hundreds of billions Yuan every year. In recent years, researchers have found that the surface texture can significantly improve the friction performance of part surface, and it has been used in the production and manufacturing, such as the mechanical seals, the cylinder and piston rings, the cutting tools and dies, etc. [2]. The design idea of surface texture comes from the non-smooth surface which is common in nature. The ordered micro/nano structure on the lotus leaf surface has high super-hydrophobic property and reduces the friction and wear [3,4]. It is a research hotspot to modify, shape and control the surface of friction pair by advanced means. The method making micro texture on part surface can significantly improve the friction characteristics of the contact surface. The geometric parameters of the micro texture on the surface affect or even determine the friction properties of the object surface. The use of surface texture has a long history. For example, the scratch on the sliding bearing bush, the stripe with 45 ° inclination on the cylinder wall of the engine, and the shallow pit on the golf ball are all effective means to reduce the friction. With the development of modern processing technology such as laser and MEMS, it is possible to accurately process the micro/nano scale surface texture on different material surfaces, which has expanded a new space for the application of surface texture [5].
Surface texture has been studied and applied in the field of Tribology for a long time [6,7], but there are few studies on surface friction and wear by the surface modification based on micro texture. In recent years, it is one of the research focuses in the field of surface engineering to produce micro/nanostructures on the surface of materials by laser processing. Micro/nanosecond laser processing has attracted more and more attention because of its cheap equipment, fast processing speed and no environmental pollution [8, 9].

The 304 stainless steel has good mechanical properties and is widely used in industrial manufacturing. In this paper, take the 304 stainless steel as the substrate and different micro texture shapes, such as groove array, square column array, circular pit array, regular hexagon column array and trapezoid column array, on the surface of 304 stainless steel were carved by nanosecond laser engraving machine under the same parameters. Then it is modified using perfluorosilane to drop the surface energy and to study the effect of micro texture shape on the friction and wear behaviors of the surface.

2. Experiment

2.1. Experimental materials
Take the 304 stainless steel as the sample with the thickness 1mm and size 10mm×10mm, and it was purchased from Shenzhen Ruikai Mould Co., Ltd. The chemical reagents used were 1H, 1H, 2H, 2H-Perfluorodecyl trimethoxysilane purchased from Qufu Jiaye Chemical Co., Ltd. The ethanol with purity 97% will be used in experiments.

2.2. Experimental instruments and equipment
There are some experimental instruments and equipment used in in experiments, such as the high-speed laser engraving machine with the type KN120, the optical contact angle measuring instrument with the type TST-200H, ball-disk friction and wear tester with the type Ms-t300, the scanning electron microscope with the type S-400N made by Hitachi Co., Ltd of Japan, the ultrasonic cleaning machine, and so on.

2.3. Experimental steps
Before experiments, all samples was polished using the sandpaper with 800-mesh and to make the surface of the stainless steel uniform and smooth with the surface roughness about Ra 0.2µm. Firstly, the five micro texture shapes of the square column array, the circular pit array, the regular hexagon column array, the trapezoid column array and the groove array on the surface of samples were carved by nanosecond laser engraving machine. The carving power is 12W, carving speed is 300mm/s and the carving frequency is 20 KHz. The shape of the micro texture is shown in Table 1 and Fig.1 below. Secondly, place the samples carved into the ultrasonic cleaner for 10 minutes, then take them out and blow dry with a hair dryer. Finally, put these samples in the solution with 0.5 mol/l perfluorodecyl trimethoxysilane ethanol at 45℃for 5 hours, and then take out the samples modified and wash them with alcohol, and then let them dry naturally in the laboratory. These dried samples were used for another test and analysis next.

Table 1. Micro texture shape of stainless steel surface.

| Number | 1 | 2 | 3 | 4 | 5 |
|--------|---|---|---|---|---|
| micro texture Shape | Square column array | Circular pit array | Regular hexagon column array | Trapezoid column array | Groove array |

3. Experimental results and discussion

3.1. Experimental methods and results
Take these samples on the contact angle measuring instrument to measure the contact angle with the 4μl water droplets, and 5 data of water contact angle (WCA) on the surface of each sample were measured respectively and take the average value. The friction and wear characteristics of no micro texture (smooth) surface and micro texture surface were studied by using the ball disk friction and wear tester. The Al₂O₃ ceramic ball with diameter of 3mm and hardness of 1650HV was selected as the wearing part. The test parameters, such as the pressure was set 1N, the rotational speed was set 100r/min, the relative humidity was 20-30%, and the temperature was set 28℃. Before testing, all the surfaces will be cleaned. After the experiment, the surface morphology was observed by SEM. Table 2 and Fig.2 show the friction coefficients of different micro texture shapes with modified surfaces and without modified surfaces, Fig.3 is the SEM image of the modified surface with different micro texture shapes after friction and wear testing.

Figure 1. Micro texture shapes of stainless steel surface measured by the scanning electron microscope (a) The surface without micro texture, (b) the square column array, (c) the circular pit array, (d) the regular hexagon column array, (e) the trapezoid column array, (f) the groove array.

| Surface shape                  | No micro texture | Square column array | Circular pit array | Regular hexagon column array | Trapezoid column array | Groove array |
|-------------------------------|------------------|---------------------|--------------------|-------------------------------|------------------------|--------------|
| without modified surface      | 0.429            | 0.284               | 0.410              | 0.550                         | 0.371                  | 0.501        |
| modified surface              | 0.202            | 0.160               | 0.329              | 0.348                         | 0.267                  | 0.346        |

3.2. Discussion
It can be seen from table 2 and Fig.2 that the friction coefficient of the surface modified with the square column array shape is only 0.16, which is minimum in that of other surfaces. The largest friction coefficient tested is the regular hexagon column array shape without surface modification and the value is 0.55. It can be seen from table 2 that the friction coefficient of the surface modified is smaller than that of without surface modification, this is because that there is a layer of super hydrophobic film on the modified surface, which can play a role of lubrication, so the friction coefficient of the surface modified will be reduced. However, it can be seen from table 2 and Fig.2 that the influence of different micro texture shapes on the friction coefficient is different. The surface friction coefficient of square column array and trapezoid column array is smaller than that of no micro texture surface without modification, but in modification surfaces, the surface friction coefficient of the Regular hexagon column array, the circular pit array, the groove array and the trapezoid column
array is higher than that of no micro texture surface. It is fully explained that it is very important of surface modification in wear reduction, which also provides a new way to reduce friction and increase friction on the surface. From Fig. 3, it can be seen that the contact scratches on the no texture surface, the square column array surface and trapezoid array surface after modification is relatively larger than that of the circular pit array surface, the groove array surface and the regular hexagon column array surface. So the friction coefficient with the no texture surface, the square column array surface and trapezoid array surface is relatively small. In addition, the surface with micro texture has some space for storing debris. In the process of relative movement, it can store debris and avoid secondary friction and wear.

![Figure 2](image)

**Figure 2.** Friction coefficients of each sample measured by the friction and wear tester
(a) The surface without micro texture, (b) the square column array, (c) the circular pit array, (d) the regular hexagon column array, (e) the trapezoid column array, (f) the groove array.

4. **Summary**

In this paper, take the 304 stainless steel as the substrate material, the five micro texture shapes, such as groove array, square column array, circular pit array, regular hexagon column array and trapezoid column array, on the surface of 304 stainless steel were carved. According to experimental results and analysis, it can be concluded as follows.

The friction coefficient of the surface modified with the square column array shape is only 0.16, which is minimum in that of other surfaces. The largest friction coefficient tested is the regular hexagon column array shape without surface modification and the value is 0.55. It fully shows that the
surface with the square column array shape and modified in the solution with 0.5 mol/l perfluorodecyl trimethoxysilane ethanol can improve the friction and wear performance.

Figure 3. SEM of friction and wear on different shape surfaces with modification

The friction coefficient of the surface modified is smaller than that of without surface modification, it is fully explained that it is very important of surface modification in wear reduction, which also provides a new way to reduce friction and increase friction on the surface.

In addition, the surface with micro texture has some space for storing debris. In the process of relative movement, it can store debris and avoid secondary friction and wear.

These results can provide a reference for improving the friction and wear performance of metal surface.

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