IOP Conf. Series: Materials Science and Engineering **758** (2020) 012088 doi:10.1088/1757-899X/758/1/012088

Testing research on friction and wear performance of microstructure surface of unfolding wheel for bearing steel ball detection

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Abstract. The unfolding wheel of AVIKO series steel ball surface quality automatic detector is expensive and easy to wear, which seriously restricts its application and development. In this paper, the wear reason and motion form of the unfolding wheel are analyzed, the unfolding contact model is simplified reasonably, and the corresponding experimental equipment and scheme are designed. The microstructures with different shape parameters are machined on the test pieces surface by laser machining technology, and the theoretical calculation formula for the weight of wear is obtained through friction and wear tests and data fitting. The test results show that compared with the smooth test piece, the test pieces with microstructure surface can increase the friction coefficient and reduce the degree of wear, and the diamond microstructure has the best effect on reducing the wear weight. The fitted formula provides theoretical and experimental basis for the follow-up research and the design of microstructure parameters of unfolding wheel.

1. Introduction

Steel ball is an important rotating part of rolling bearing, the quality of the steel ball will directly affect the bearing precision and life. In addition to the geometric accuracy, dimensional accuracy, material and heat treatment, another important index for evaluating the quality of steel balls is surface quality [1]. The steel ball and the unfolding wheel are both smooth surfaces, which are easy to slip in the unfolding process, and the contact collision and movement form cause the unfolding wheel to easily wear and failure. It has been shown that microstructure surface can improve the friction and wear properties of materials[2]. Tatsuya Sugihara et al. [3] machine microstructures on the carbide milling cutters and find that the wear of the blade surface is reduced and the cutting performance is improved. Miao Jiazhi et al. [4] find that the cylinder liner with the microstructure surface can reduce the friction coefficient by 41.83%, and increase by 33.68% compared to the smooth surface, it is determined by the microstructure parameters. Qi Ye et al. [5] conclude that the microstructure can alleviate the stress concentration in the contact area and reduce the wear within a certain range of areal density through the ring-block linear contact friction and wear test. Based on the above research, the microstructure is applied to the surface of the unfolding wheel, and its friction and wear properties are studied by tests.

2. Unfolding principle and simplified contact model

The unfolding mechanism of AVIKO series steel ball surface quality automatic detector is mainly composed of driving wheel, unfolding wheel and supporting wheel. When the steel ball is unfolded, driven by the motor, the driving wheel rotates around the fixed axis x_3, and at the same time drives the

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steel ball to rotate around the axis x_1. The rotating steel ball drives the unfolding wheel to rotate around the axis x_2. At the same time, under the function of the unfolding wheel with special geometry, the steel ball rotates around the axis z_1, realizing the full surface unfolded of the steel ball. In order to facilitate the test, after considering the friction and contact form between the unfolding wheel and the steel ball, the contact is simplified to the model shown in Fig. 1.

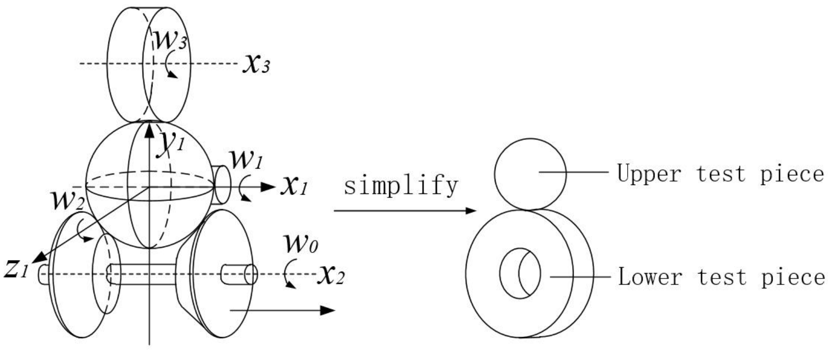

Figure 1. Unfolding principle and simplified contact model

3. Test

3.1. Test pieces preparation

The material of the upper test piece used in the test is GCr15, with a diameter of 12.7mm and a hardness of HRC62~65. The material of the lower test piece is T10A, and the hardness reaches HRC51~56. As shown in Fig. 2, the circular, square, and diamond pit microstructures are processed on the peripheral surface of the lower test pieces by the laser marking machine, and the pits depth is all 50μm. Table 1 shows the microstructure parameters of different test pieces.

Figure 2. Lower test piece with circular microstructures

Table 1. Microstructure parameters of different lower test pieces

Number	Shape	Single size(μm)	Area(μm^2)
0	Smooth	none	none
1	Circular	100(diameter)	7850
2	Circular	150(diameter)	17663
3	Circular	200(diameter)	31415
4	Square	88.6(side length)	7850
5	Square	132.9(side length)	17663
6	Square	177.2(side length)	31415
7	Diamond	164.9/95.2(long/short axis)	7850
8	Diamond	246.9/148.5(long/short axis)	17663
9	Diamond	329.8/195.4(long/short axis)	31415

3.2. Test equipment and conditions

As shown in Fig. 3, this test uses a specially constructed point contact friction and wear tester on cylindrical surface microstructures, which is mainly composed of a friction and wear test device, a friction performance detection device and a screw adjusting device. The friction and wear test device designed according to the simplified contact model realizes contact and friction between the upper and lower test pieces; The friction performance detection device measures the friction force between the upper and lower test pieces by the S-shaped sensor and the force transmission rod. The screw adjusting device is used to adjust the steel ball to the proper point contact position on the surface of the lower test pieces. S-shaped sensor measures the friction force every 0.1 seconds, and transmits the measured data to the computer through the serial port in real time. Table 2 shows the test conditions.

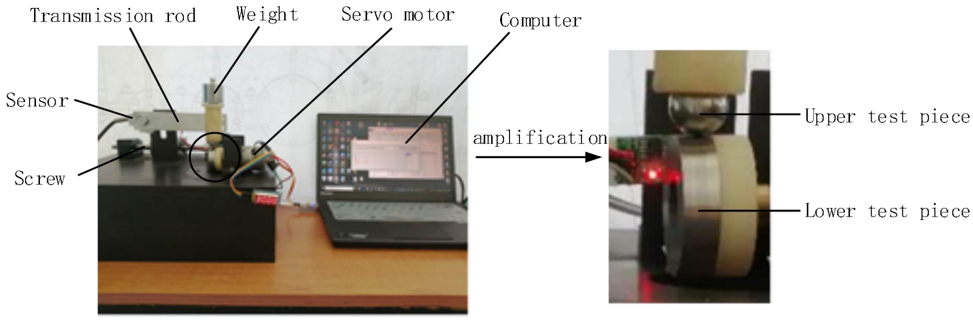

Figure 3. Cylindrical surface microstructure point contact friction and wear tester

Table 2. Conditions of friction and wear test

Temperature(°C)	Motor speed(r/min)	Time(min)	load(N)	Friction conditions
30	1400r/min	120	2/3	Dry friction

In the test, the weight loss of the lower test pieces is used to evaluate the wear resistance, the smaller the wear weight, the better the wear resistance. BSM220.4 electronic analytical balance is used to measure the weight of the lower test pieces before and after wear tests, and the measurement accuracy is 0.1mg. Before weighing, use the ultrasonic cleaner to clean for 20min and blow dry to avoid the interference of environmental humidity and debris on the weight.

3.3. Test results and analysis

3.3.1 Friction coefficient: In the process of test, the points that sudden increase of friction force due to the influence of human behavior should be removed. After sorting and converting a large number of measured friction force data under 2N load, the partial friction coefficient fluctuation curve as shown in Fig. 4 is obtained (The figure shows the friction coefficient of No. 3 test piece). Although the friction coefficient fluctuates, it generally tends to be a stable value. After calculating the average value, the friction coefficients of all test pieces are filled in table 3.

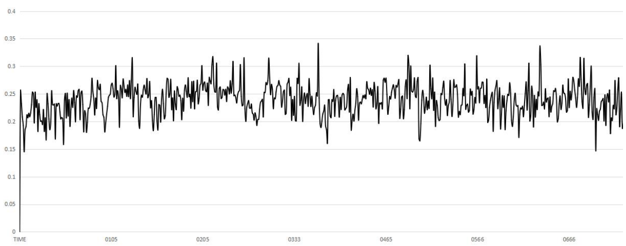

Figure 4. Partial friction coefficient fluctuation curve of No.3 test piece

Table 3. Friction coefficient of different test pieces

Shape / Area(μm^2)	Circular	Square	Diamond	Smooth
7850	0.22	0.27	0.27	
17663	0.23	0.22	0.25	0.18
31415	0.25	0.24	0.26	

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The data in table 3 are classified and extracted according to the friction coefficients of the circular, square, and diamond microstructures under different areas, and connected into lines to obtain the chart shown in Fig. 5. It can be seen that compared with smooth test piece, all the test pieces with microstructures can increase the surface friction coefficient. This is because the microstructures change the surface morphology of the test pieces, increase the roughness of the surface of the friction pair, and reduce the contact area between the upper and lower test pieces. As a result, the normal pressure increases, so the friction force increases. The friction coefficient is related to the shape and area of the microstructures. Among the three shapes of microstructures, the diamond microstructure has the best friction enhancement effect, but the relationship between the microstructure area and the friction coefficient is not obvious.

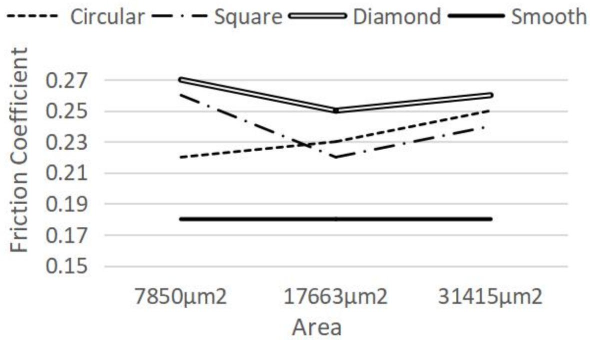

Figure 5. Friction coefficient of different microstructures shapes under different areas

3.3.2 Wear weight: In order to quantify the shapes of the microstructures, the ratio of S/d^2 is adopted to represent the shape parameters of the microstructures. S is the area of the microstructures, d is the distance between the longest two points on the pits surface, d is the diameter in the circle, the diagonal in the square, and the long axis in the diamond. According to the microstructure area classification, the wear weight of ten group of test pieces are listed in table 4.

Table 4. Wear weight of different microstructure test pieces

Area (μm^2)	Number	Shape	Shape parameter	Wear weight（g）	
				2N	3N
7850	1	Circular	0.785	0.0057	0.0061
	4	Square	0.502	0.0045	0.0055
	7	Diamond	0.289	0.0041	0.0044
17663	2	Circular	0.785	0.0052	0.0050
	5	Square	0.502	0.0036	0.0040
	8	Diamond	0.289	0.0025	0.0028
31415	3	Circular	0.785	0.0042	0.0045
	6	Square	0.502	0.0023	0.0027
	9	Diamond	0.289	0.0017	0.0022
none	0	none	/	0.0156	0.0162

By converting the wear weight data in table 4 into the Fig. 6, it can be seen that no matter what the load, the wear weight of microstructure test pieces is lower than that of smooth test piece, and the wear weight decreases with the increase of microstructure area. This is because the laser processing technology can increase the surface hardness, harden the edges of the microstructure pits, and improve the wear resistance. In addition, the wear debris formed in the friction process is filled into the pits, which effectively reduces the wear of the abrasive particles. The larger the area of the micro pits, the larger the size of the contained abrasive particles, and the more the abrasive particles. Among the three kinds of microstructure shapes, no matter which area, the wear weight of diamond microstructure test pieces are lower than that of other test pieces, so diamond microstructure has the best wear resistance.

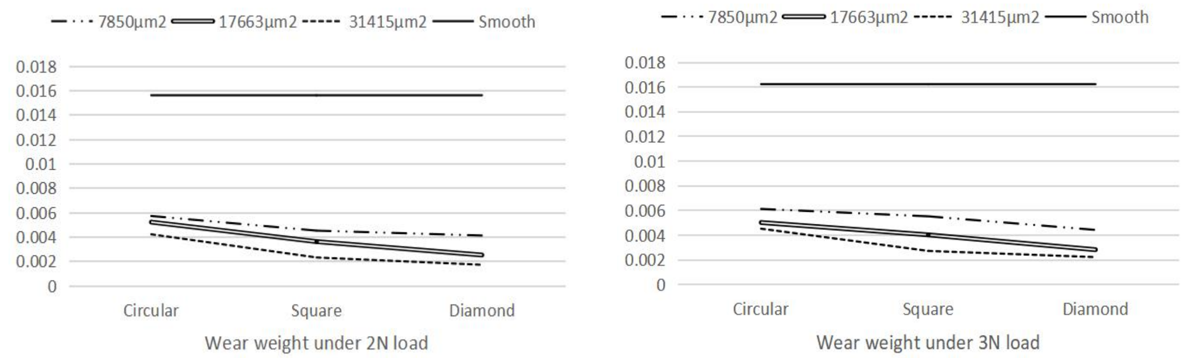

Figure 6. Wear weight of microstructure test pieces under different load

3.4. Fitting formula of wear weight
A total of 18 sets of data in table 4 are fitted to obtain the function formula of the wear weight W under the influence of three variable of the microstructure area S, the applied load N and the microstructure shapes X:

$$W = -8.599 * 10^{-8} S + 0.004 N + 0.005 X + 0.002 \tag{1}$$

The goodness index of fitting is $R^2=0.9595$, close to 1, which shows that there is a good correlation between the fitting results and the test data, so it can be used to calculate the wear weight of microstructures surface in the test.

4. Conclusions
1. The circular, square and diamond microstructures are machined by laser technology on the circumferential surface of the lower test pieces. Three kinds of microstructure areas are designed for each shape, and the friction and wear tests are carried out respectively. The results show that, compared with the smooth test piece, the microstructure test pieces can increase the friction coefficient and reduce the wear weight. Therefore, the application of microstructures to the surface of unfolding wheel can achieve the purpose of increasing friction and reducing wear.
2. With the increase of microstructure area, the weight of wear decreases. By comparison, diamond microstructure has the best effect on increasing friction and reducing wear, followed by square.
3. The fitted wear weight calculation formula can be used to calculate the wear weight under the influence of microstructure shapes, load and microstructure area, which can provide reference for the follow-up theoretical research.

References
[1] Zhao Gang, Wang Baoyi, Ma Songxuan. Theoretical analysis of meridian unfolding mechanismin in Aviko K steel ball appearance inspection machine. Journal of Sichuan University. 1997, 34(5): 635-639.
[2] Zeng Yawei, Chen Liyu, Yang Xiaming. State of surface texturing for improving friction performance. Tool technology. 2016, 50(5): 3-7.
[3] Tatsuya Sugihara, Toshiyuki Enomoto. Crater and flank wear resistance of cutting tools having micro textured surfaces. Precision Engineering. 2013, (37): 888-896.
[4] Miao Jiazhi, Guo Zhiwei, Yuan Chengqing. Effect of textured surface on the friction performance of cylinder liner-piston ring system in the internal combustion engine. Journal of tribology. 2017, (4): 465-471.
[5] Qi Ye, Chang Qiuying, Wang Bin, et al. Research on tribological behaviors of laser surface textures under dry sliding. Journal of China Ordnance. 2015, 36(2): 200-205.

Acknowledgments
This study is supported by the Natural Science Foundation of Heilongjiang Province of China. Roller Surface Microstructure and its Dry Friction and Wear Mechanism for Bearing Steel Ball Defect Detection (No.E2017052)