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Influence of Micro Cold Pressing on Surface Wear ability of Mold Steel

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Abstract

Both traditional grinding and micro cold pressing are conducted to compare the micro surface morphologies of cold work mold steel specimen. Surface roughness, hardness and surface morphologies are analyzed under varying feeds of ball end cutter in Y direction and Z direction in MCP. The friction coefficients and wear rates of two types of specimen under oil lubrication are obtained through friction and wear test. After micro cold pressing, hardness increases from 0.11 to 0.099, with surface roughness reduced from 5.496μmto 1.871μm and wear rate reduced from 0.0506μm to 0.0153μm (Wear rate is measured in Z direction). The study shows that during micro cold pressing the ball end cutter flattens wear scar, which reduces surface roughness. Surface roughness is related to DY and DZ. Under fixed DZ, reduction in DY leads to an increase in flatness of specimen surface. Since work hardening takes place during micro cold pressing, surface hardness of specimen has improved with the greatest increment at 169.6HV.Grooved surface morphology is obtained by micro cold pressing. The depth of groove is related to DY and DZ. When DZ is fixed, depth of groove is smaller when DY is 0.05mm than that when DY is 0.1mm. Under fixed DY, the depth of groove increases with the increase of DZ. Surface quality (including surface roughness, roughness and surface morphology) affects friction coefficient and wear rate. Reasonable surface quality not only decreases friction coefficient but also decreases wear rate. Friction coefficient can be reduced by 10% while wear rate can be reduced by 69.76%.

Keywords*: Micro cold pressing, surface morphology, friction coefficient, wear loss.*

1. Introduction

Manufacturing, which represents comprehensive national power and technology level, is based on the development of mold industry. The value of products produced with dies are worth is dozens of times higher than cost of dies. With the intensifying competition in automotive industry, it is predicted update of automotives during the twelfth five-year plan will push forward an automotive die market worth 12 to 16 billion [1]. Therefore, the die industry, which directly affects the competitiveness of automotive products, has displayed its great prospect. In the friction pair comprised of die, the workpieces and their interface, the friction characteristics have a critical effect on product quality, productivity, die capacity and service life. There has been an urgent need for decrease in frictional wear so as to improve product quality, productivity and reduce manufacturing cost [2-4]. All friction surfaces are consisted of micro peaks and valleys. The geometric characteristics play a significant role in frictional wear and lubrication in mixed lubrication and dry friction. The structure of metal surface varies with different processing conditions. There is a great difference between the mechanical properties between surface material and base material. The strengthening degree,

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micro toughness and residual stress of surface metal has an important effect on frictional wear [5]. Factors influencing die wear ability include die material, lubrication condition, surface morphology, surface finish, hardness and working condition, *etc*.

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2. Friction and Wear Test

2.1. Specimen Material and Specification

Cold work mold steel Cr12MoV is selected as specimen material, whose harness increases to HV700 after quenching. Traditional grinding is applied, with axial feed at 5 mm/s and rotational speed of grinding wheel at 1000 n/min. The surface roughness Sa is around 5.5 μm. Micro cold pressing is conducted with CNC machine and specimens with size of 30 mm*10 mm*10 mm are obtained by cutting.

2.2. Specimen Preparation Technique

Two types of specimens are used in the experiment. All of the material are processed by grinding, but some of the specimens after grinding are further processed by micro cold pressing (see Figure 1). During micro cold pressing process, the specimen is oil lubricated and a ball end cutter with a diameter of 10 mm. Feed in Y direction and Z direction are variable with fixed feed of 800 n/min in X direction. Feed in Y direction and Z direction are denoted as DY and DZ respectively. Specimen number, DY and DZ are displayed in Table 1.

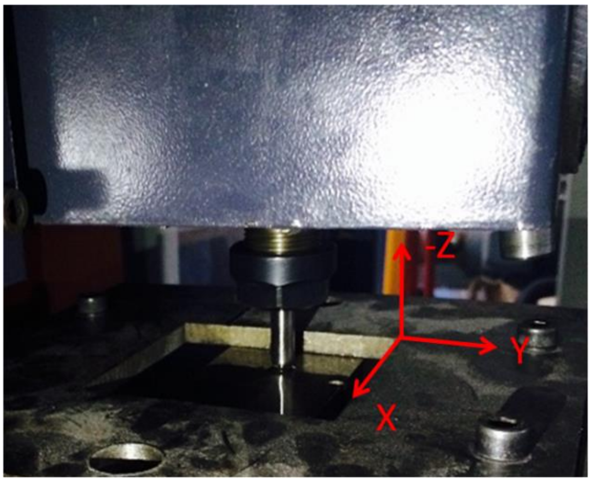


Figure 1. Surface Treatment of Specimen

Table 1. Specimen Number

Number	D_Y (mm)	D_Z(mm)
NO.0	0	0
NO.1	0.05	0.1
NO.2	0.05	0.2
NO.3	0.05	0.3
NO.4	0.05	0.2(twice feed)
NO.5	0.05	0.3(three times feed)
NO.6	0.1	0.1
NO.7	0.1	0.3
NO.8	0.1	0. 2(twice feed)
NO.9	0.1	0.3(three times feed)

2.3. Friction and Wear Test

The friction and wear test is carried out on RTEC highly-integrated multifunctional friction and wear tester. The tester can be used to study various materials, film membrane, coverage, modified layers, bulk materials, solid or liquid lubricating layer, mechanical characteristics, frictional characteristics of lubricating oil and lubricant and actual working condition. It can switch between different test modes, like spinning ball disk or pin disk mode, high-speed reciprocating mode and Timken ring block mode. It measures frictional force, loading force, online wear depth and online three-dimensional morphology (wear depth, width, volume, roughness and *etc.*)in the meantime. Sensers adopt an interchangeable modular organization, which enables a wide-range test ranging from low load to high load. During a friction and wear test, the specimen platform moves in X direction and Y direction and spins around Z axis, which realizes a compound motion.

Two specimens are needed in the test. The upper specimen is a pin made of GCr15 with a diameter of 6 mm and harness of HRC 65. The lower specimen is made according to No.0 to No.9 in Table 1. Each time the motor spindle rotates, the upper specimen and lower specimen move in a straight line relative to each other twice. The frequency is 8 HZ under a loading force of 150 N and the friction lasts for 15 minutes. Oil lubrication is applied between the two specimens, which mean plenty lubricating oil is applied to the friction surface of lower specimen during the test. The lubricating oil used is Hasitai No.5 engine oil made in Shanghai, China. Figure 2 shows the procedure of the test.

3. Results and Analysis

3.1. Effects of Micro Cold Pressing On Surface Roughness and Hardness

Table 2 displays surface roughness and hardness of specimens. Results demonstrate that surface roughness of specimens decreases remarkably after micro cold pressing while hardness increases. When micro cold pressing is applied, ball end cutter flattens wear scars caused by grinding on specimen surface by cutting peaks and filling valleys. On the other hand, hardness increases mainly because work hardening during micro cold pressing. Plastic forming of surface structure leads to compression of lattice, enhancement of micro harness and strengthening of surface [6].

Table 2. Surface Roughness and Hardness of Specimen Surface

Specimen number	NO.0	NO.1	NO.2	NO.3	NO.4	NO.5	NO.6	NO.7	NO.8	NO.9
Surface roughness (μm)	5.496	2.228	2.226	1.871	2.844	2.61	2.899	2.958	3.7	4.976
Hardness(*HV*)	704	871.7	785.6	824.6	805.4	810.5	815.9	757.4	847.5	873.6

Figure 3 illustrates the relation between surface roughness and feed. Under fixed DZ, surface roughness is smaller when DY is 0.05μm than that when DY is 0.1μm. It indicates that smaller DY results in flatter specimen surface. The smaller DY is, the more times the ball end cutter has to move in the same zone, which reduces the appearance of peaks and valleys on the specimen surface. When DY and DZ are the same, one time feed in Z direction results in smaller surface roughness compared to many times feed. Therefore, many times feed is adverse for obtaining small surface roughness. Many times feed means applying micro cold pressing to the same zone several times, butrepeated micro cold pressing causes wrinkling on the specimen surface. A reasonable control of DY, DZ and feed times can effectively improve surface quality of specimen.

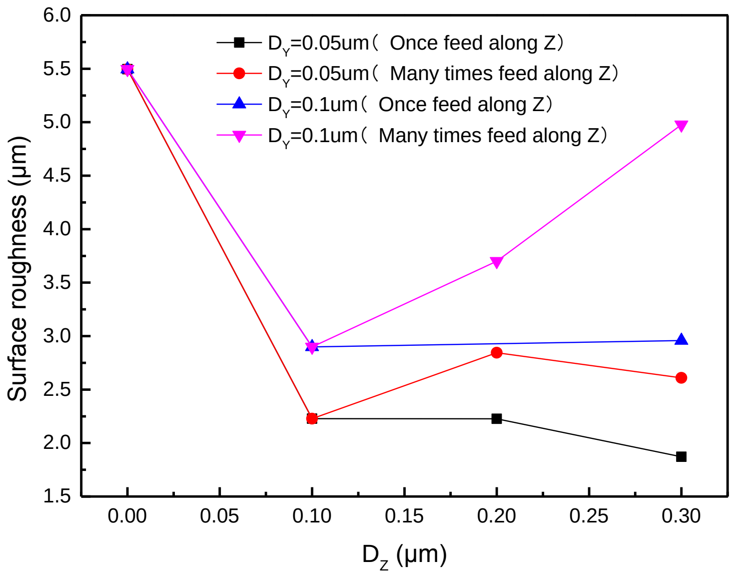


Figure 3. Relation between Surface Roughness and Feed

Figure 4 shows the matrix structure and Figure 5 show the sectional microstructure of each specimen. The comparison between matrix structure and sectional microstructure indicates that grinding does not contribute to significant structural changes on specimen surface while micro cold pressing results in remarkable structural changes on the surface. After micro cold pressing, slip occurs frequently compared to the original matrix structure. Slip is the main deformation mechanism during micro cold pressing. The more frequently slip occurs, the more distinct work hardening is and the thicker the work-hardening layer is(see Figure 4 and Figure 5). Work hardening is the result of the increasing resistance of dislocation movement with the accumulation of deformation [6]. The thickness of work-hardening layer has a direct impact on the plastic deformation on the surface [7]. The greater the deformation is, the thicker the work-hardening layer is. Under fixed DY, the thickness of work-hardening layer increases with the increase of DZ. The work-hardening layer of No.3 is thicker than that of No.2. When DY and DZ are the same, many times feed in Z direction leads to a thicker work-hardening layer than once feed. The work-hardening layer of No.4 is thicker than that of No.2 while the layer of No.5 is thicker than that of No.3.

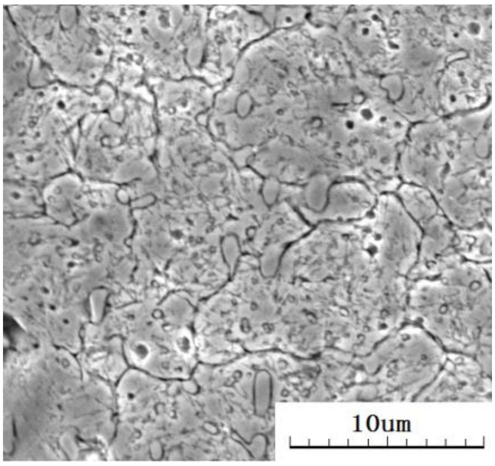
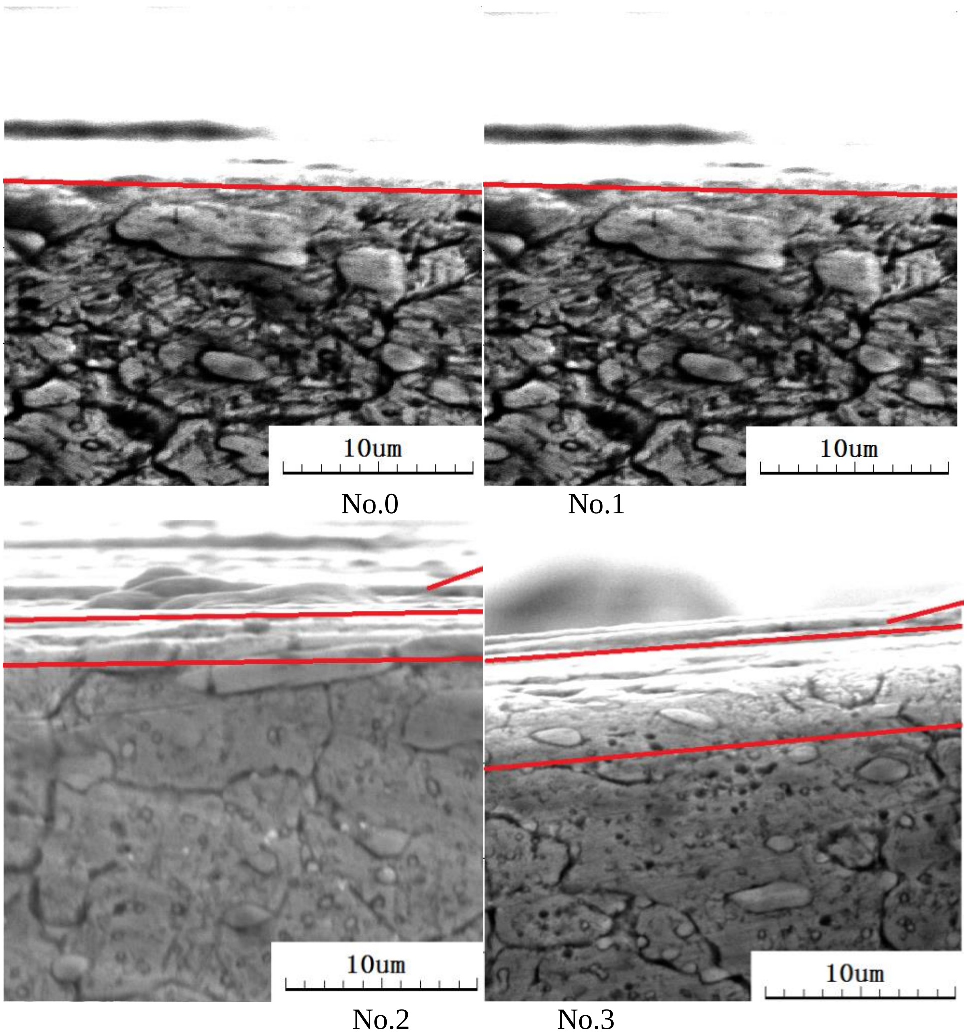


Figure 4. Matrixstructure



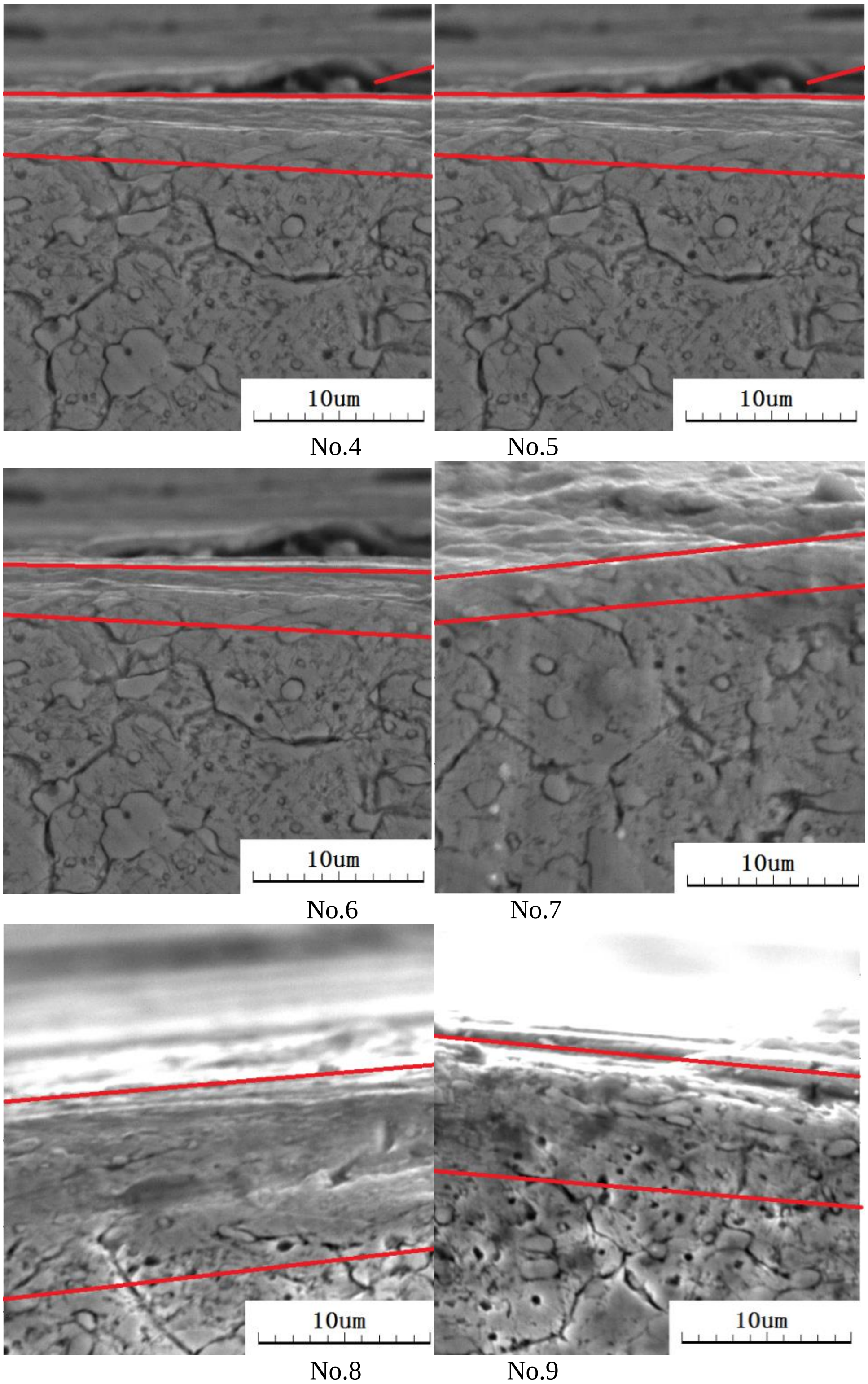
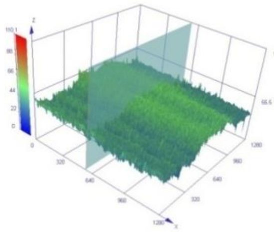
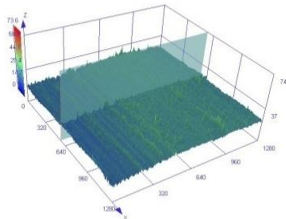
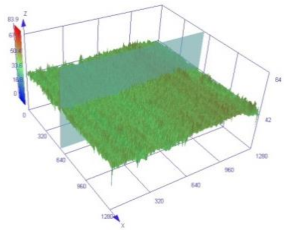
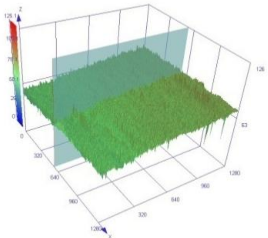
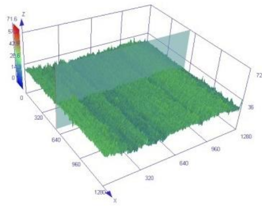
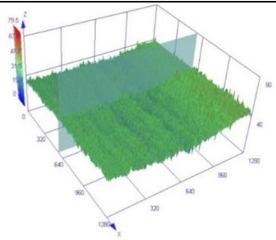
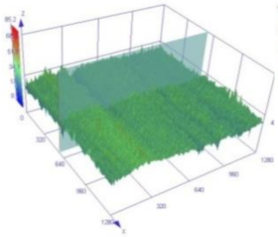
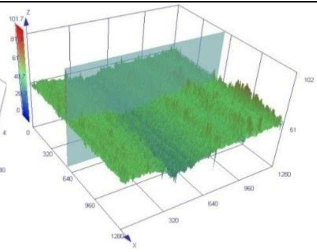
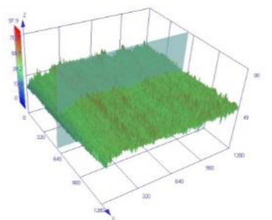


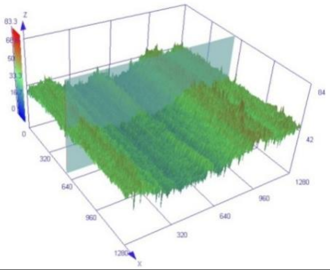
Figure 5. Sectional Microstructure of Each Specimen

3.2 Influence of Micro Cold Pressing On Surface Morphology of Specimen

Table 3 displays surface morphology of each specimen. Figure 6 illustrates sectional height of specimen. The curve of sectional height is obtained using a microscope whose magnification is 10. To precisely portrait surface morphology of specimens after micro cold pressing, filtering is applied to the sectional curve in order to get the 2-dimensional curve of surface morphology. To represent surface morphology quantitively, sectional height amplitude, which is the difference between maximum and minimum (calculated as d0-d9), is adopted to characterize the image. Table 4 represents the sectional height amplitude of each specimen. The grooved scar, which is cause by ball end cutter during micro cold pressing, is distinctly shown in Figure 6. Compared with wear scar of No.0, the depth of wear scar is much shallower after micro cold pressing. Figure 7 demonstrates the relation between sectional height amplitude and feed. Figure 6 and Figure 7 illustrates that the depth and distribution of grooved scar is relative to the magnitude of DY and DZ. To be specific, the depth of wear scar is smaller when DY is 0.05 than that when DY is 0.1. With fixed DY, the depth of scar increases with the increase of DZ. Therefore, reasonable control of DY and DZ will lead to a uniform distribution of grooved scar across the surface.

Table 3. Surface Morphology of Specimens

Specimen number	NO.0	NO.1	NO.2
Surfaces morphology			
Specimen number	NO.3	NO.4	NO.5
Surfaces morphology			
Specimen number	NO.6	NO.7	NO.8
Surfaces morphology			
Specimen number	NO.9		

Surfaces morpholog y	

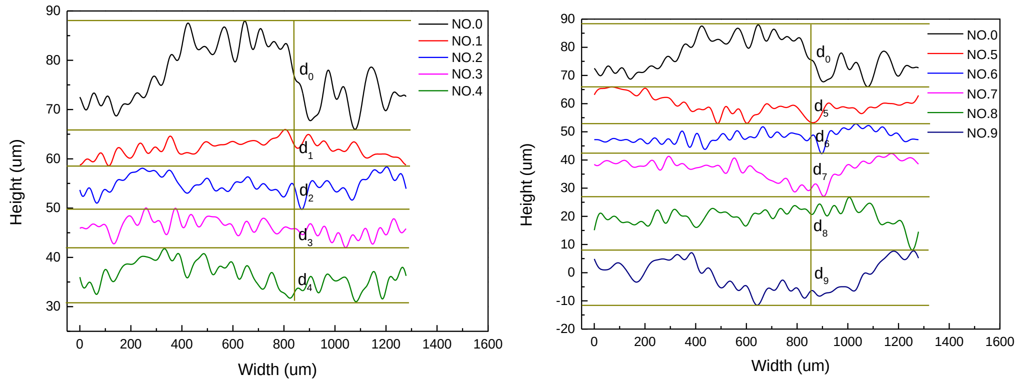


Figure 6. Sectional Heights of Specimens

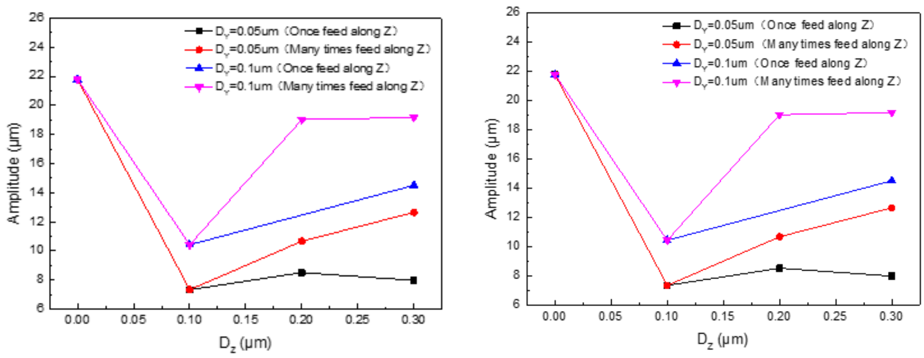


Figure 7. The Amplitude and DZ

Table 4. The Sectional Height Amplitude

Nomuber	d_0	d_1	d_2	d_3	d_4	d_5	d_6	d_7	d_8	d_9
sectional height amplitude (μm)	21.77	7.34	10.67	7.98	8.52	12.65	10.43	14.51	19.02	19.17

3.3. Influence of Micro Cold Pressing On Friction Coefficient on Specimen Surface

Figure8 shows the friction coefficient curve of specimens. Friction coefficient is much bigger at the beginning of friction test than in a steady state, because at the instant of beginning the friction is close to static friction whose coefficient is far bigger than kinetic friction coefficient. All specimens after micro cold pressing has a smaller friction coefficient than specimen No.0 without micro cold pressing. In addition, the friction coefficient curve of specimens No.1 to No.9 is smoother than that of specimen No.0. It is easier for specimens after micro cold pressing to get into a static stage. While it takes 320s for specimen No.0, it takes only 160s for No.4 to get into a static stage, which saves as much as half time of the former. Figure 9 illustrates the relation between friction coefficient and sectional height amplitude. With the increase of sectional height amplitude, friction coefficient decreases first and then increases again. There exists an optimum value on the curve.

Three reasons contribute to the phenomenon above. Firstly, surface roughness of specimens decrease a lot after micro cold pressing. Secondly, surface hardness rises at certain degree after micro cold pressing. Within certain limits, the decrease of surface roughness directly reduces the resistance to slip. The increase of hardness decreases plastic deformation during friction and further decreases frictional resistance to slip[8]. Thirdly, a reasonable depth of grooved scar forms surface texture which can store lubricant and accumulate tiny wear particles. Thus, abrasive wear and furrow are effectively prevented. With lubricant oil, surface texture is more likely to form hydrodynamic lubrication which can improve bearing capacity and frictional characteristics of the surface [9-11]. Under oil lubrication or mixed lubrication, micro holes or micro grooved texture can serve as micro hydrodynamic bearings so as to exert additional hydrodynamic pressure. Under starved lubrication, as the friction continues, lubricant oil stored in grooves can form oil film for the friction pair and decrease friction coefficient [12-13].

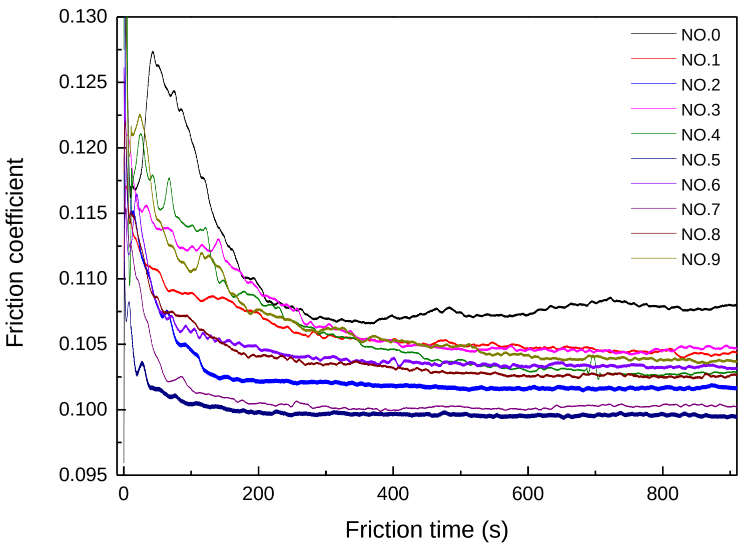


Figure 8. Friction Coefficient Curves of Specimens

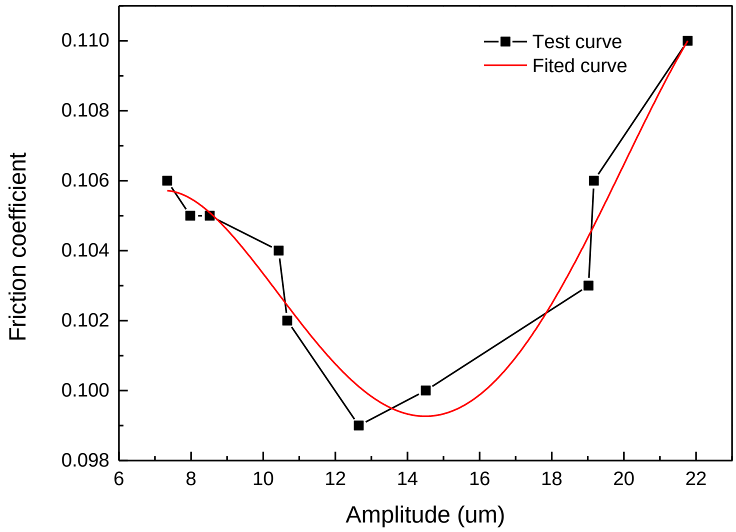


Figure 9. The Relation between Friction Coefficient and Sectional Height Amplitude

3.4. Influence of Micro Cold Pressing On Surface Wear Rate

In this work, wear rate is represented by changes in Z coordinate, denoted by ΔZ_n (displacement vertical to the friction surface) where n denotes specimen number. Wear rate decline Δ, which represents the difference of wear rate before and after micro cold pressing.

$$\Delta = \frac{\Delta Z_0 - \Delta Z_n}{\Delta Z_0} \times 100\% \quad (1)$$

Table 5 shows the wear rate and wear rate decline of specimens.

Table 5. Wear Rate and Wear Rate Decline of Specimens

Specimen number	0	1	2	3	4	5	6	7	8	9
ΔZ_n (μm)	0.0506	0.0343	0.0447	0.0385	0.0426	0.0153	0.0317	0.0792	0.0414	0.0959
Δ	0	32.21%	11.66%	23.91%	15.81%	69.76%	37.35%	-56.52%	18.18%	-89.53%

Figure 10 illustrates the relation between wear rate and feed in Z direction. Compared with specimen without micro cold pressing, most of specimens get a decrease in wear rate but the opposite condition also exists. Micro cold pressing results in work hardening on the specimen surface and smoothens the surface. Moreover, residual stress on specimen surface also changes and mainly exists in the form of compressive stress. Therefore, micro cold pressing decrease friction coefficient and wear rate to a certain degree but not all micro cold pressing lead to the decrease of wear rate. When DY is 0.1mm and DZ is 0.3mm, the wear rate is greater after micro cold pressing than without micro cold pressing regardless of the feed times in Z direction when DZ is 0.3mm.

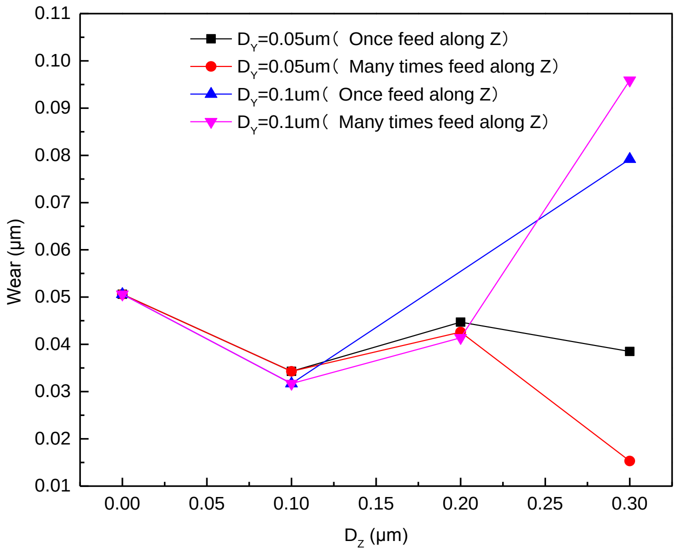


Figure 10. The Relation between Wear Rate and DZ

A comprehensive analysis of Figure 5 and table 4 demonstrates that although No.3 is superior to No.6 in terms of surface roughness and hardness, but the grooved scar in No.6 is more distinct than that in No.3. In addition, the sectional height amplitude of No.6 is greater than that of No.3 because the former is more advantageous for storing abrasive dust and reducing abrasive wear. Hence, the wear rate of No.6 is smaller than that of No.3. The wear rates of No.9 and No.7 is greater than No.0, because grooved scar of No.9 is wider and deeper which leads to its weakness in both number and size of peaks. During friction, oil films between peaks are more likely to be pierced and have a vulnerable stability. Moreover, metal directly contacts with each other when the oil film disappears so that a greater adhesion force is generated and wear rate increases [14-15]. The weakness of surface peaks results in high contact pressure when friction occurs, which significantly increases plastic deformation and wear rate. Grooves of large size appear in the smooth areas of No.7 specimen surface. Therefore, the peaks are far away from each other, which lead to instable friction where sudden changes in pressure often come into being at peaks or valleys and causes great impact and increased wear rate.

Above all, a reasonable control of surface roughness, hardness and surface morphology by controlling DY and DZ can reduce wear rate of specimen.

4. Conclusion

(1)Reasonable micro cold pressing can achieve smooth specimen surface. Micro cold pressing causes work hardening, which increases hardness and quality of specimen surface. After micro cold pressing, hardness increases from 0.11 to 0.099, with surface roughness reduced from 5.496μmto 1.871μm.

(2) Micro cold pressing results in grooved surface morphology with certain depth. The distribution of grooves are related to feed in Y and Z direction, denoted by DY and DZ. When DZ is fixed, depth of groove is smaller when DY is 0.05mm than that when DY is 0.1mm. Under fixed DY, the depth of groove increases with the increase of DZ.

(3)A reasonable control of surface roughness, hardness and morphology by controlling DY and DZ can effectively decrease friction coefficient by 10% at most.

(4)A reasonable control of surface roughness, hardness and morphology by controlling DY and DZ can effectively decrease wear rate by 69.76% at most.

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