# Effects of Composite surface modification on the tribological characteristics of Cylinder Liner-Piston Ring

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**Key words:**Cylinder liner-piston ring, Surface texture, Friction coefficient, Surface nitriding

**Abstract:** Three kinds pit array on the surface of cylinder liner were prepared by using laser device, the diameter were 250μm, 350μm and 400μm respectively. Then, the textured surface was nitriding treated by using nitriding salt bath device. The friction coefficient of the piston ring and the three kinds of surface composite modification cylinder liner was detected by computer controlled friction and wear testing machine. The friction and wear characteristics of cylinder liner piston ring were discussed under different contact pressure and rotational speed. The result showed that the friction and wear properties of cylinder liner - piston ring can be enhanced through the lubrication state improved of the surface texture. The friction coefficient of the composite treated sample was decreased and the fluctuation is small. At te same time, the texture was not destroyed. The friction and wear properties of the samples with different diameters texture were affected by the change of the friction surface and the rotating speed. The wear resistance of the cylinder with the diameter of 400μm is the best.

## Introduction

The cylinder liner-piston ring is one of the most important friction pairs of internal combustion engines, and its advantages and disadvantages of tribology performance impact the entire performance of internal combustion engines directly. It will reduce the output power of internal combustion engines and shorten service life of internal combustion engines when operating conditions are changed. Furthermore, it will generate major failure such as scuffing of cylinder bore and shut down internal combustion engines when the friction pair operating conditions deteriorating further, which directly affect the engine's normal work. Therefore, the study of this friction pair to reduce friction loss and improve tribology performance of the cylinder liner and piston ring plays important significance[1]. In order to improve the frictional wear performance of the cylinder liner-piston ring, it mainly adopts surface strengthening treatment, such as chromeplate, spraying finishing, nitridation, chemical composite plating and laser strengthening technology, etc., except for changing texture and optimizing structural shape [2]. Jiang An had studied the influences of the cast iron piston ring before and after nitridation on the cylinder liner-piston ring friction performance by using a friction wear testing machine[3]. The results showed that nitriding improved the stability and abrasive resistance of the cylinder liner-piston ring friction pair. The surface texture technology has been widely applied in improving frictional wear performance of materials after more than ten years development. There are several technologys can be used to prepare surface texture. Among them, the laser processing technology is widely applied due to its excellent focusing performance, easy automatic control, no pollution, low energy consumption, and unique material functional mechanism. The laser honing technology utilizes laser beam with a certain energy density to form an oil way and cavity that store and transport lubricating oil. It can optimize matching and continuousness and have a certain density, width, depth, angle and shape on the working surface of artifacts. Moreover, it has acquired a remarkable result in the aspect of improving surface abrasive resistance [4, 5]. Pattersson U.[6] applied the method of laser processing to conduct surface texture on the surface of piston ring and carry out the test of tribology. Finally, it acquired a remarkable effect of reducing 25% of friction. Liu Yijing[7] utilized Micro ECM process technology to fabricate micro-sized surface texture with four different diameters and 5 different depths on the real piston skin surface. Teh results show that surface texture shows up a better antifriction effect in the friction process of piston/cylinder liner. The surface texture has the diameter of 250μm and depth of 5μm and can reduce 37.8% of friction of samples with texture under the conditions of 200N load and rotate speed of 200r/min.Differing from previous studies, this paper simulates working environment of cylinder liner-piston ring by conducting surface texture of cylinder liner and nitriding combined treatment, carries out in-depth study on frictional wear mechanism and influence factors, and inspects influences of sliding speed and load fluctuation on friction performance in the relative movement process of cylinder liner-piston ring.

## The Experiment

The upper sample is directly fetched from Practical application Cr-Mo-Cu piston ring. The material is Cr-Mo-Cu alloy cast iron. The basic size of piston ring isz102mm×5mm. Its chemical components are shown in Table 1. The under sample is alloy boron cast iron cylinder liner. The basic size of cylinder liner is ø102mm×10mm. The chemical components are shown in Table 2.

Tab.1 Chemical composition of piston sample(wt％)

| C | S | Si | Mn | P | Cr | Mo | Cu | Fe |
|---|---|---|---|---|---|---|---|---|
| 3.0-3.3 | ≤0.1 | 2.0-2.4 | 0.8-1.2 | 0.35-0.65 | 0.4-0.75 | 0.6-0.85 | 0.8-1.2 | the others |

Tab.2 Chemical composition of cylinder liner sample(wt％)

| C | Si | Mn | P | S | Cr | Mo | Cu | B | Fe |
|---|---|---|---|---|---|---|---|---|---|
| 2.8-3.2 | 1.8-2.0 | 0.8-1.0 | ≤0.15 | ≤0.1 | 0.2-0.4 | 0.4-0.7 | 0.6-0.8 | 0.03-0.06 | the others |

The 300W Nd: YAG millisecond pulse laser was used to prepare surface texture samples. The processing speed is 100mm/s, the current is 120A, frequency is 10HZ, and pulse width is 2.5ms. The cylinder liner surface texture of the below sample applies 3 kinds of point pit diameters. The sample A has the dimple diameter of 250μm. Tangential hole pitch is 400μm, radial hole pitch is 800μm. B is dimple diameter is 350μm, tangential hole pitch is 450μm, radial hole pitch is 850μm. C is dimple diameter is 400μm, tangential hole pitch is 500μm, and radial hole pitch is 850μm.

The MRTR friction testing machine was used to conduct friction-wear test in order to study the situation of the modified friction pair when the load and velocity were changed in the reciprocating motion. The test can be completed in three stages in line with the test scheme design. The first stage detected influences of different surface texture on friction performance under the state of normal temperature, the same rotate speed and load. The second stage detected influences of different loads on friction performance on the same texture surface in the same rotate speed and normal temperature. The three stage detected influences of different rotate speeds on friction performance in the same texture surface under the condition of the same normal temperature and the load. The upper sample of the tester was piston ring and under sample was cylinder liner. Loads in the experiment were 19.6N, 24.5N, and 29.4N. The rotate speed in the experiment respectively choosed 100r/min, 150r/min and 200r/min with 3.5h test time. The automatic record time interval of friction coefficient in the experiment process was 10s. The oil supply and environmental temperature of lubricating oil in the experiment were kept in the same state. The surface morphology of cylinder liner was detected by using YM-200 electron microscope. The sample surface hardness before and after nitriding utilized MICRO-586 Vickers microhardness tester to test.

## Result and Analysis

### Changes of Sample Surface after Nitrding Treatment

The experiment adopted salt bath nitriding furnace to conduct nitriding treatment on the texture surface and cylinder liner matrix. The samples were installed in the nitriding furnace after coarse grinding, fine grinding and ultrasonic cleaning. The nitriding salt was specialized low-temperature nitriding salt and the test was conducted for 3h under 430℃. The MICRO-786 Vickers microhardness tester was adopted to test surface hardness after surface nitriding treatment. The test data of surface microhardness of 1-2 samples are shown in Table 3.

Table 2 Micro-hardness of sample surface ($HV_{0.1}$ Load1000g)

| Sample | Test 1 | Test 2 | Test 3 | Test 4 | Test 5 | Test 6 | Test 7 | Test 8 | Mean value |
|---|---|---|---|---|---|---|---|---|---|
| Non-nitriding | 304.58 | 242.29 | 270.39 | 295.87 | 236.10 | 228.41 | 296.72 | 286.61 | 270.12 |
| Nitriding | 495.59 | 580.91 | 558.17 | 532.60 | 562.62 | 538.83 | 550.62 | 549.54 | 546.11 |

It can be observed from Table 3 that sample microhardness after nitriding is higher nearly 50% than non-nitriding samples. Thus, it can be observed that nitriding treatment improved the hardness of cylinder liner surface Obviously because the infiltration of N element permeated and the formation of compact structure Iron nitride on the surface of cylinder surface. the compact structure Iron nitride can reduce surface pore and improve consistency. The improvement of hardness promoted the improvement of cylinder linear abrasive resistance. This is beneficial to improve service life of cylinder linear.

### The Change of Friction Coefficient

The friction coefficient curve of different diameter surface texture under 150r/min of rotate speed and 24.5N load is shown in Figure 1. The friction coefficient of the original surface is the biggest and the changing range is 0.018-0.022 according to the changing curve of friction coefficient. The nitriding point 400μm pit diameter has the minimum friction coefficient. The changing range is 0.012-0.015. The oil film on the friction surface was difficult to form on the surface of sample with 250μm diameter due to a little lubricating oil can be stored. Therefore, the friction coefficient has no big change, which Similar to untextured surface. The friction coefficient of non-nitriding and non-texture surface has larger fluctuation, while nitriding texture samples have slower fluctuation. It indicated that the surface texture plaied a huge influence on the oil film in the formation stage. With the continuousness of a friction test, the sample with the 350μm of point pit stores more lubricating oil and generates permanent influences, so as to reduce friction coefficient constantly.

The figure 2 is the friction coefficient curve under different loads. It can be observed that friction coefficient of the sample in Group A has the obvious downtrend before 1000s under the lubricating condition of 19.6N. And it enters into the stable state when the friction coefficient is 0.0135. The changing range is 0.011-0.016. The friction coefficient of the sample in Group B is relatively stable, and changing range is 0.013-0.014. The friction coefficient of the sample in Group C is dropped obviously with the increase of time and it is kept in stability in the range of 0.009-0.012 after 6000s. The initial friction coefficient of samples in both Group A and Group C has relatively larger fluctuation, while the sample in the group B has slower fluctuation, which indicated that surface texture plaied a larger influence on the oil film formationin in the formation stage of the oil film. With the continuous friction behaviors, The pit in the sample of Group C stored more lubricating oil and plaied a permanent influence, so as to reduce friction coefficient constantly. The friction coefficient of the sample in Group C has stable fluctuation and kept in the range of 0.012-0.014 under 24.5N because of the oil film on the sample surface can be generated more rapidly with the increase of load. The sample in Group B performed better friction property than the sample in Group A. The friction coefficient of the sample in the Group A keeped stable. The friction coefficient of the sample in Group B showed the trend to decline dramatically with the continuous frictional wear. Ultimately, the friction coefficient had the consistent tendency with the sample in Group C. Under the 29.4N load, there is boundary lubricating state, and samples in both Group B and Group C similarly perform better friction performance in the initial stage of friction. However, with the increase of friction time, friction coefficient increases gradually and performs the similar friction performance with the sample in Group B, because friction pair surface on the boundary lubricating state appears more peak contact. Thus, it can be observed from the above-mentioned experiment that the effective oil reserve on the friction surface plays a huge influence on the long-term persistent friction behaviors. The samples in both Group B and Group C improve the lubricating state since the oil reserve and oil film thickness of friction surface plays a positive role. Particularly for the sample in Group C, it can extend the service life of lubricating oil within a certain working period and increase lubricating effects.

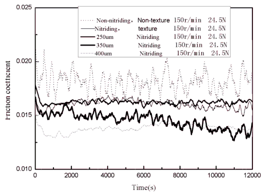


Fig. 1 Friction coefficient under same load and rotating speed

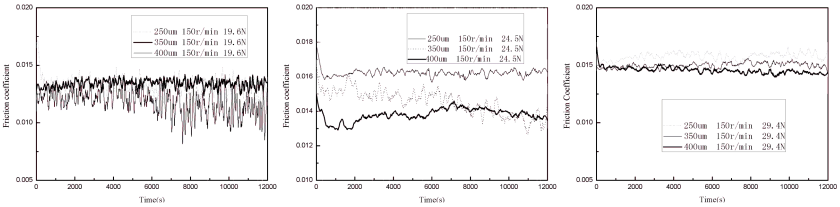


Fig. 2 Friction coefficient of different friction pairs under different loads

It can be observed from Figure 3 that the friction coefficient with lower speed is larger under the same load situation. With the increase of speed, the friction coefficient is smaller obviously. The reason of this phenomenon is that the friction pair locates in the state of boundary lubrication under low speed and locates in the state of mixed lubrication under high speed. The friction coefficient between the rotate speed of 150r/min and 200r/min is smaller. Thus, it can be found that if the speed continues to rise and lubricating state doesn’t change, fluid shearing thinking effect for causing friction coefficient results in too low lubricating oil viscosity, and friction coefficient gradually goes up with it.

Fig3 Friction coefficient curves of the different friction pairs under different speed

## The Texture Wear Morphology

The wear surface morphology of surface texture cylinder liner under different loads is showen in Figure 4, Figure 5, and Figure 6. It can be seen that the three piston samples under different loads appear obvious grinding crack. The furrow on the surface of cylinder liner in both Group B and Group C was shallower under 19.6N. The furrow quantity, width and depth on the wear surface of piston increased slightly with the increase of loads. The sample in Group A also appeared more grinding cracks and abrasion was more serious than the rest loading morphology under 19.6N. On the other hand, when the sample in Group A is kept in the low load, it is difficult for surface lubricating oil to form an oil film. The wear of the sample in Group C was more serious than the rest of two morphologies. The wear furrow was deeper and appeared obvious stripping. The sample in Group B appeared deeper furrow and extended cracks to the deep side gradually under 29.4N. The wear is the most serious in three groups. The sample in Group C has the small surface wear. It can be observed that the crack appeared in wear area of Group A was deeper and longer than the sample in Group C.

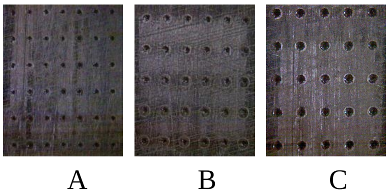


Fig. 4 Load19.6N rotational speed of 150 r/min different texture surface wear morphology

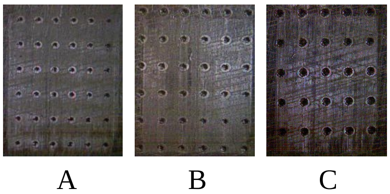


Fig.5 Load 24.5N, rotational speed of 150 r/min different texture surface wear morphology

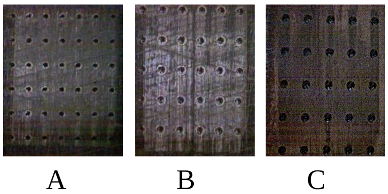
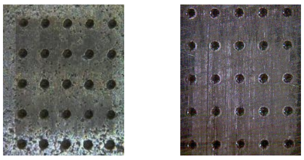


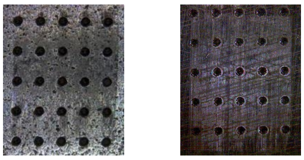
Fig.6 Load 29.4N, rotational speed of 150 r/min different texture surface wear morphology

The wear surface morphology of the different cylinder liner was shown in Figure 7, Figure 8 and Figure 9. It can be observed from the figure that the wear surface of non-nitriding cylinder liner and nitriding cylinder liner presented the abrasive wear property. The surface furrow of nitriding cylinder liner is thinner and shallower, while the surface furrow of non-nitriding cylinder liner is deeper and broader. There were obvious stripping phenomenon appeared on the surface of non-nitriding point pin surface. As for surface nitriding cylinder liner, because nitriding surface has larger hardness, so it only can protect point pin of cylinder liner sleeve structure, make it better improve abrasive resistance, reduce abrasion loss and lower friction coefficient.



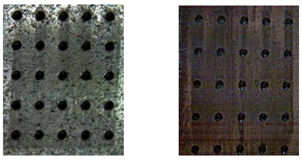
（a）Nitriding（b）Non-nitriding

Fig. 7 Morphology of cylinder liner of 150 r/min, 19.6N, ø400μm



（a）Nitriding（b）Non-nitriding

Fig 8 Morphology of cylinder liner of 150 r/min, 24.5N, ø400μm



（a）Nitriding（b）Non-nitriding

Fig 9 Morphology of cylinder liner of 150 r/min, 29.4N, ø400μm

## Conclusions

(1) The surface texture can play the role on improving abrasive resistance, enhancing bearing ability, and reducing friction coefficient under Lubrication condition. The diameter of surface texture had an important influence on the piston frictional performance. The surface texture with 400μm diameter can perform good friction property under the conditions of different rotate speeds and loads.

(2) The friction coefficient of the samples reduced obviously with the increase of speed under all test loading condition. Moreover, the load is larger, and the friction coefficient is lower. The friction coefficient of 19.6N load was higher than the loads of 24.5N and 29.4N, respectively.

(3) The surface point pit can play a role of oil reservoirs to reduce the usage amount of lubricating oil and shorten the formation time of lubricating films, so as to reduce the wear of the friction pair and reduce the friction coefficient effectively. The nitriding treatment can improve the hardness of cylinder liner surface matrix metal, further improve the function of oil storage, control the number of grinding particles effectively, and reduce the effect of abrasive wear.

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