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EXPERIMENTAL RESEARCH ON THE TRIBOLOGICAL PERFORMANCE OF LASER TEXTURED CYLINDER LINER

TRACK OR CATEGORY
Engine & Drive Train I

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INTRODUCTION

As the core component of Internal Combustion Engine(ICE), Cylinder Liner-Piston Ring(CL-PR) system has significant effects on the engine running-in process, fiction and wear performance, fuel and lubricating oil consumption[1,2]. With the development of surface science, surface texturing technology that uses micro-nano processing means has been applied on mechanical surface finishing[3]. The hydrodynamic effects generated by micro structures such as grooves and pockets could improve the film bearing capacity, and the textures can be regularly displayed on the surfaces. Due to these advantages, surface textures have much potential in improving the ring/liner tribological performance[4]. Recent years, researchers around the world have done a lot of useful work on ring/liner texturing[5,6]. Also, various texturing methods like mechanical processing, electrochemical machining and optical manufacture were developed[7]. Especially the Laser Surface Texturing(LST) method, has become a research hotspot because of it's advantages in high-efficiency, low-pollution, flexible and controllable processing[8].

In this research, the LST method was utilized to process the typical micro-dimples on cylinder liner, and the segment samples of CL-PR was made for reciprocating test on friction testing machine, then the anti-friction effects of surface textures under different lubrication states will be clarified.

MAIN BODY

1. Experimental setup

In our previous work, LST has been applied to processing micro-dimples on cylinder liner and piston ring successfully in ICE[9, 10]. The LST equipment adopts the acoustic-optical Q-switched Nd:YAG laser, and the wavelength of output laser is 532nm. By combining rotary machining method with a single laser pulse repetitively shocking at the same point, the dimple textures can bu processed on liner. Through changing the laser pulse energy, number of shocking times and step size, the micro-dimples with different diameters, depths, area ratios and array modes can be textured on liner surface. Using the above LST technology, the designed micro-dimples(diameter 50μm, depth 8μm and area ratio 0.1) were textured on the liner surface in this study.

The friction testing rig and the CL-PR samples are shown in figure 1 and figure 2. The main body of the rig is MFT-5000 friction and wear testing machine. It consists of the reciprocating drive module, oil sump, heating chamber, loading and friction measuring mechanism, and fixtures. The upper sample is compression ring segment held by the upper fixture and bears the normal load exerted by loading mechanism. Meanwhile, the lower sample is liner segment(plateau-honed and laser textured liners) held by the lower fixture and does linear reciprocating motion during the friction test process. The segment samples of cylinder liner and piston ring used in the friction test are cut from the production ring/liner pair. The diameter and axial width of compression ring is 73mm and1.5mm, and the length of the ring segment is about 20mm. The diameter of liner is 73mm, and the length and width of the liner segment are about 40mm and 15mm, respectively. Under the reciprocating motion, the relative sliding speed of ring/liner pair is zero at the two dead centers of stroke, while at the middle position of stroke, the sliding speed is the largest. In this way, the reciprocating motion of ring on liner can be simulated, and the instantaneous friction force of CL-PR will be measured by the force sensor.

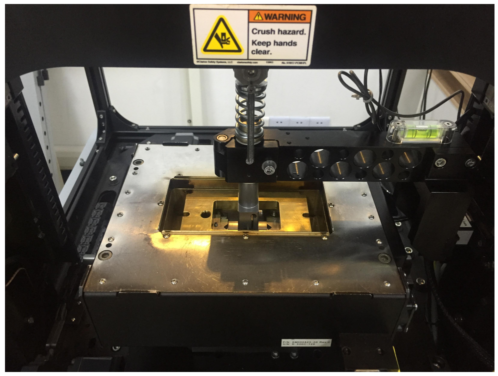

Figure 1. Reciprocating friction testing rig of cylinder liner-piston ring

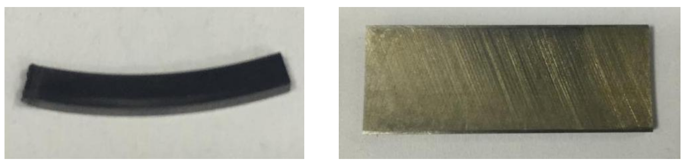

Figure 2. Piston ring sample(left) and cylinder liner sample(right)

When the engine is running, the velocity and the external load of piston ring varies under a working cycle. To simulate the different lubrication conditions between ring/liner pair due to the variations of bearing coefficient, the oil viscosity can be adjusted by changing the oil temperature under the constant load and speed of the friction and wear testing machine[11]. Since the liner segment was immersed in the lubricating oil, there exists a certain amount of lubricant between CL-PR pair during the test. The testing condition is as follows: the reciprocating stroke is 24mm, the reciprocating frequency is 5Hz and the normal load is 6-135N according to the actual pressure 0.4-9MPa on compression ring. When the oil temperature is controlled within 5±1℃, the lubrication state of CL-PR is dominated by hydrodynamic lubrication; while the oil temperature is controlled within 100±5℃, the lubrication state of CL-PR is dominated by mixed lubrication.

2. Results and analysis

Figure 3 illustrates the frictional performance comparison between plateau-honed liner and laser textured liner under low temperature oil bath dominated by hydrodynamic lubrication state. Figure 3(a) displays the ring/liner friction changing curves under the normal load of 100N on compression ring. The horizontal ordinate crank angle in this figure corresponds to different positions of ring segment on liner sample: 0° and 180° are the two dead centers, 90° is the middle position of the stroke. It can be seen that the instantaneous friction force of CL-PR changes with the crank angle. When the ring moves from one dead center to another dead center on liner, the friction force drops at first till the middle position of stroke. Then it rises, and the peak value occur around the dead center. Under the testing condition, the friction force of laser textured cylinder liner-piston ring is lower than that of plateau-honed cylinder liner-piston ring during the whole reciprocating cycle. Especially around the dead centers, the friction gap between the two ring/liner pairs is larger.

Also, the average friction coefficients of the ring/liner reciprocating motion is analyzed. As displayed in figure 3(b), with the external load on compression ring rising from 6N to 135N, the average friction coefficient of CL-PR within a working cycle shows a downward trend. For the plateau-honed liner and laser textured liner, the average friction coefficients decrease by 52.5% and 56.9% respectively when the load increases from 6N to 135N. In addition, under the loads 6N, 12N, 24N, 60N, 100N and 135N, the coefficients of laser textured liner drop by 18.6%, 24.9%, 29%, 37.6%, 34.1% and 33.2% respectively in comparison with these of plateau-honed liner. The results demonstrate that under hydrodynamic lubrication state, laser texturing micro-dimples on liner surface can effectively reduce the friction force of

CL-PR within a wide range of external load on ring, which is helpful for controlling the engine frictional loss and improving it's mechanical efficiency.

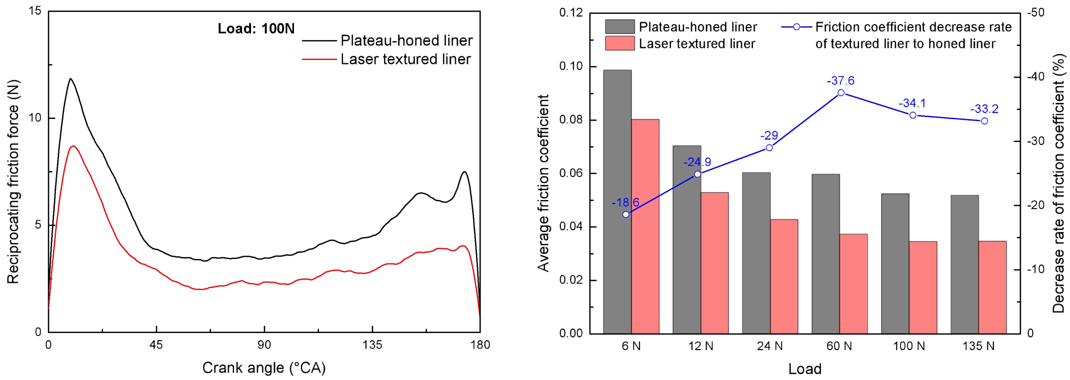

Figure 3. Frictional performance comparison between plateau-honed liner and laser textured liner under hydrodynamic lubrication: (a) friction forces under 100N, (b) average friction coefficients under 6-135N

Figure 4 illustrates the frictional performance comparison between plateau-honed liner and laser textured liner under high temperature oil bath dominated by mixed lubrication state. As shown in figure 4(a), the friction force peak values all occur around the dead centers, while the valley values all appear near the middle position of the stroke. In addition, the tribological properties of plateau-honed liner and laser textured liner are different under the mixed lubrication state between CL-PR pair. At the load of 100N, the friction force of laser textured liner and plateau-honed liner are very close around the dead centers; while within the crank angle 70°-120°, the force of laser textured liner is lower than that of plateau-honed liner. For example, at the position of 100° crank angle, the instantaneous friction force of laser textured liner reduces by approximately 6.6% in comparison with that of plateau-honed liner. In addition, the average friction coefficients of the ring/liner reciprocating motion is compared in figure 4(b). Similar to the results under hydrodynamic lubrication state, the average friction coefficient of CL-PR under mixed lubrication state shows a downward trend as well with the rising external load on compression ring. When the load grows from 6N to 135N, the average friction coefficients of the plateau-honed liner-piston ring and laser textured liner-piston ring decrease by 22.6% and 20.4%, respectively. Compared with average friction coefficients of the plateau-honed liner/ring pair under the loads 6N, 12N, 24N, 60N, 100N and 135N, the coefficients of laser textured liner/ring pair drop by 6.1%, 5.0%, 1.9%, 1.8%, 2.6% and 3.6%, respectively. This indicates that even under the mixed lubrication state, liner surface textures can still help to reduce the friction force of CL-PR at different loads.

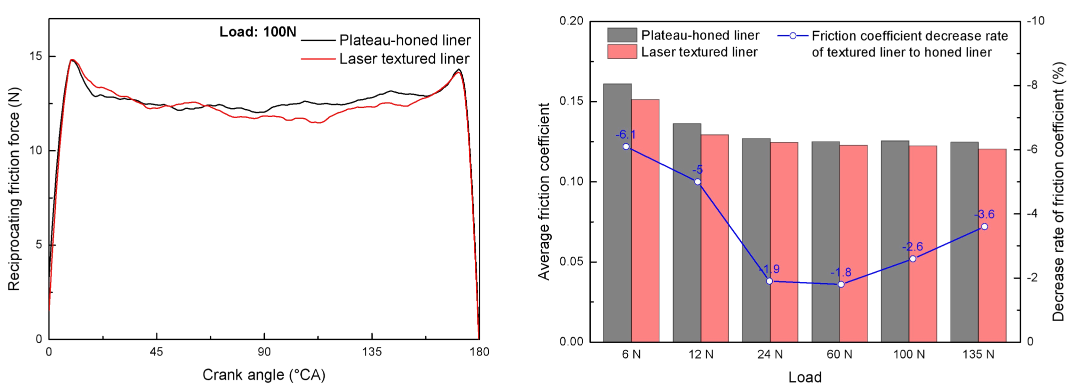

Figure 4. Frictional performance comparison between plateau-honed liner and laser textured liner under mixed lubrication: (a) friction forces under 100N, (b) average friction coefficients under 6-135N

From the above testing results and analysis, it can be drawn that laser texturing micro-dimples on cylinder liner with appropriate design is conducive to improving the engine mechanical efficiency and has the potential in reducing the fuel consumption when the engine is running

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KEYWORDS
Engine, Cylinder liner-piston ring, Laser surface texturing, Lubrication