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Wall-wetting Effects on the Tribological Performance of Cylinder liner-piston ring in Diesel Engines

TRACK OR CATEGORY

Lubrication Fundamentals IV – Novel Additives

AUTHORS AND INSTITUTIONS

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INTRODUCTION

Many kinds of advanced fuel injection technologies (high-pressure injection, early injection, and retarded injection etc.) are applied to improve the in-cylinder combustion process by optimizing the fuel atomization and oil gas mixture[1,2]. But the fuel impinging on the cylinder liner will dilute the lubricating oil, causing negative effects on the physical and chemical properties of the lubricants, especially on its kinetic viscosity[3]. Subsequently, the viscosity changes will influence the lubrication oil film between Cylinder Liner-Piston Ring (CL-PR), thus affecting the tribological properties of the CL-PR pair. In this paper, an experiment was conducted at first to investigate the lubricant viscosity changing with the percentage of fuel mixed in lube oil. Then based on the experiment results, a mixed lubrication model was built to simulate the tribological properties changes of CL-PR in a diesel engine.

MAIN BODY

1. Experimental study of the wall-wetting effects on lubricant viscosity

The wall-wetting ratio is defined as the ratio of mixed diesel volume to the diesel plus lubricant volume. With increasing the diesel mixed in lubricating oil, the wall-wetting ratio rises from 0 to 50%. When the ratio is under 10%, the step is set to be 1% to investigate the sensibility of lubricant viscosity to the ratio changes. When the ratio is over 10%, the step is 5%. The grade of lubricating oil selected is SAE 15W-40, its kinetic viscosity is around 15.64 mm^2/s at 100℃, while the viscosity of the diesel used is approximately 2.53 mm^2/s at 100℃.

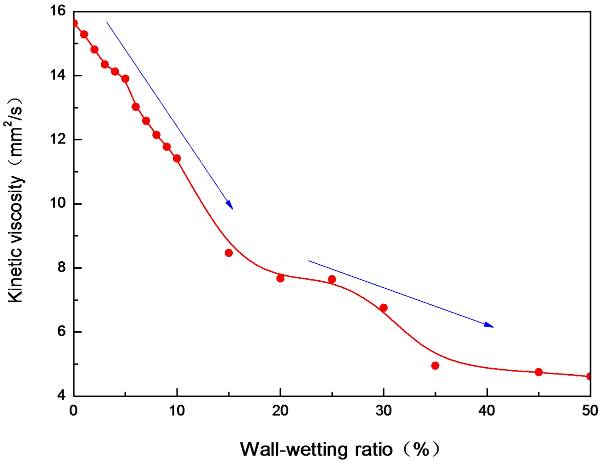

Figure 1. Lubricant viscosity changes with the wall-wetting ratio

The lubricant viscosity changes with the wall-wetting ratio is shown in figure 1. With the growth of wall-wetting ratio, i.e., more diesel mixing in the lubricating oil, the viscosity drops rapidly at first and then tends to be relatively stable. It declines by 45.8% when the ratio rises from 0 to 15%, and by only 24.7% when the ratio rises from 15% to 50%, in compraison with the viscosity of pure lubricating oil at 100℃. This indicates that a small quantity of diesel mixing in lubricating oil will have a significant effect on the viscosity, but when the wall-wetting ratio increases to a higher level, this effect will be weaker.

2. Numerical research on tribological properties of ring/liner pair

In the CL-PR system, fluid lubrication, mixed lubrication and boundary lubrication all exist. When in mixed or boundary lubrication, both film pressure and asperity force should be considered. In this study, a mixed lubrication model is built to investigate the tribological properties of CL-PR changing with the wall-wetting ratio. It is based on the classical Reynolds Equation, and composed of film thickness equation, load equilibrium equation and the Asperity Equation presented by Greenwood and Tripp[4]. To take surface roughness into consideration, the pressure and shear flow factors proposed by Patir and Cheng[5] are introduced. More detailed information of this model can be found in our previous work[6].

The simulation was based on a 2.8L 4-cylinder diesel engine and its operating condition was under the speed of 1450 r/min and 25% load rate. To investigate the ring/liner frictional performance under different wall-wetting ratio, the viscosity values adopted are from the experimental results above.

Figure 2 shows the oil film thickness ratios between CL-PR under different wall-wetting ratios. With the increase of wall-wetting ratio, the oil film thickness ratio decreases, which means the lubrication oil film between liner and ring surface becomes thinner. During the expansion stroke from 0° Crank Angle(CA) to 180° CA, the film thickness of 50% wall-wetting ratio declines most by 43.9% in comparison with that of 0% wall-wetting ratio. In a whole working cycle, fluid lubrication, mixed lubrication and boundary lubrication all occur between ring/liner pair. So the eigenvalues H=4 (marked by green dash line) and H=1 (marked by black dash line in the enlarged view) are set to distinguish mixed lubrication and boundary lubrication respectively.

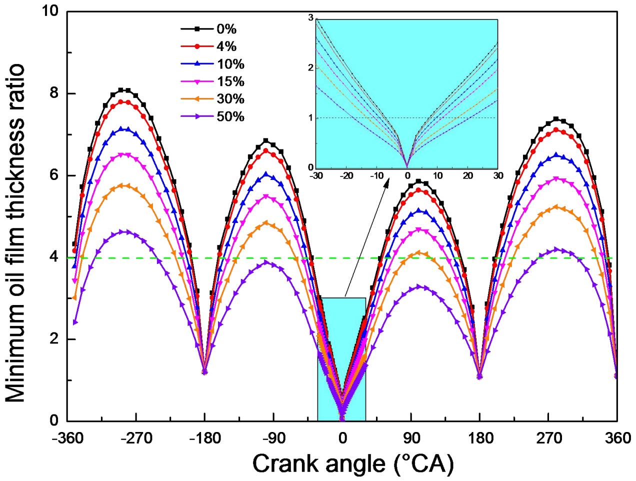

Figure 2. Lubrication oil film thickness ratios under different wall-wetting ratios

Figure 3 shows the dimensionless asperity pressure changing with the wall-wetting ratio around Fired Top Dead Center(FTDC). Between the interval of [-30° CA , 30° CA], the asperity pressure grows at first and peaks at FTDC, then it shows a downward trend. With the wall-wetting ratio rising from 0% to 50%, the asperity pressure increases. Especially at the FTDC, the peak asperity pressure increases by 14.8% in comparison with that of 0% wall-wetting ratio. With the piston moving towards FTDC, the film thickness decreases, causing the asperity contact area to increase. In this circumstance, the external load of piston ring is mainly born by asperity supporting force rather than film pressure. When the wall-wetting ratio rises from 0 to 50%, the proportion of asperity pressure occupying total loads extends from nearly 64.2% to 76.3%.

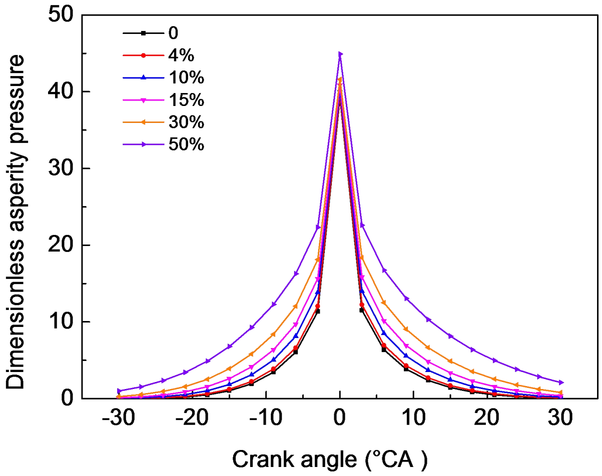

Figure 3. Dimensionless asperity pressure around FTDC

Figure 4(a), (b) illustrates the dimensionless friction force changing with the wall-wetting ratio, and (b) is the enlarged view of boundary lubrication region from -12° CA to 12° CA. In the middle position of each stroke where fluid or mixed lubrication dominates, the friction force decreases when wall-wetting ratio increases from 0 to 15%. But after the ratio rises to 50%, the friction force grows slightly. On the other hand, the friction force variation around the FTDC is totally different. In the interval of [-10° CA, 10° CA], it monotonically increases with wall-wetting ratio rising from 0 to 50%. This phenomenon may result from the combined effects of lubricant viscosity and working condition changes. As more fuel is mixed in the lubricating oil, the viscosity declines, causing fluid shear stress to decrease. Thus, the total friction force is significantly influenced because it equals to the sum of fluid and asperity friction force, which all vary with the crank angle. In the middle position of each stroke, effect of fluid friction changes is primary, which decreases with wall-wetting ratio. Whereas, when the piston approaches FTDC, the lubrication regime transits from mixed lubrication to boundary lubrication, making asperity friction become the main factor in total friction force, which increases with wall-wetting ratio.

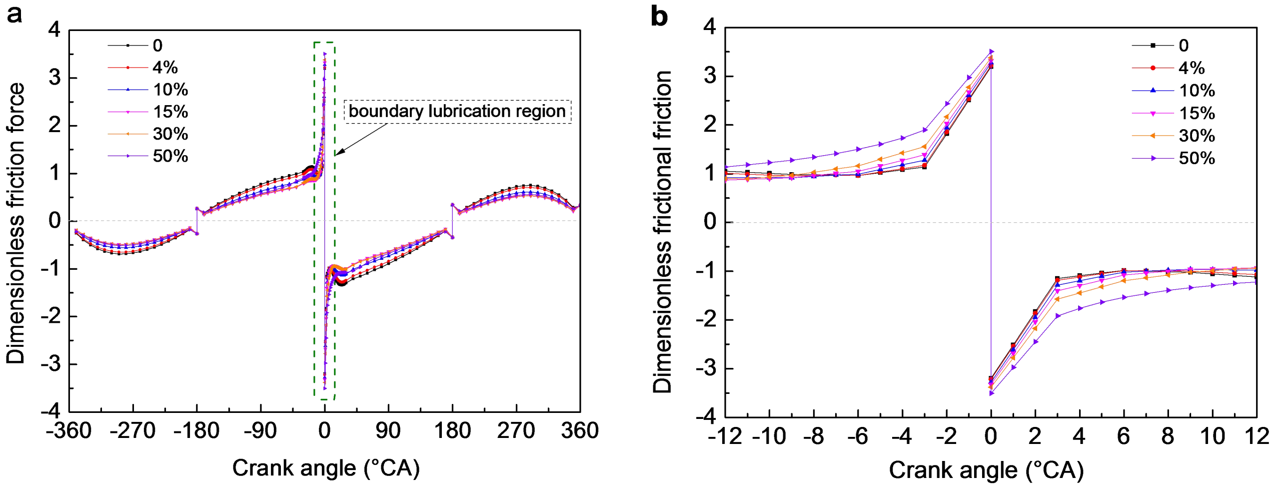

Figure 4 Dimensionless friction force under different wall-wetting ratios: (a) over a working cycle; (b) in boundary lubrication region around the FTDC

To clarify the frictional loss of CL-PR changing with the percentage of diesel mixed in lubricating oil, the dimensionless average frictional powers are calculated under different wall-wetting ratios. As shown in figure 5, with the wall-wetting ratio rising to 4%, 10% and 15%, the average frictional power drops by 5.5%, 17.8% and 28.4% compared to 0% wall-wetting ratio. The lowest power loss occurs at 15%, after that it grows till 50% wall-wetting ratio. The reason for these results is that friction power is proportional to the friction force which fluctuates over a working cycle. In the middle position of each stroke, the power of low wall-wetting ratio is larger, while around the FTDC, the power of high wall-wetting ratio is larger. Thus, the average frictional power shows the specific changing trend described above, and finally the total frictional losses under different wall-wetting ratios show the same varying trend.

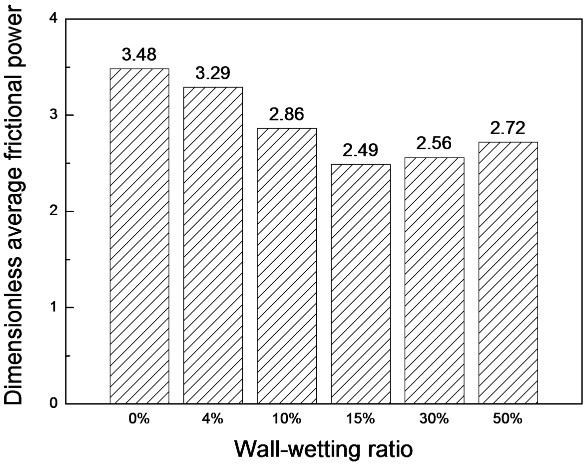

Figure 5. Dimensionless average frictional powers under different wall-wetting ratios

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KEYWORDS

Wall-wetting, Cylinder liner-piston ring, Viscosity, Mixed lubrication, Friction