

Analysis of Piston Friction in Internal Combustion Engine

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ABSTRACT

The purpose of this study is to analyze the piston skirt friction reduction effect of a diamond-like carbon (DLC)-coated wrist pin. The floating liner method and elasto-hydrodynamic lubrication (EHL) simulation were used to analyze piston skirt friction. The experimental results showed that a DLC-coated wrist pin reduced cylinder liner friction, and that this reduction was particularly large at low engine speeds and large pin offset conditions. Friction was particularly reduced at around the top and bottom dead center positions (TDC and BDC). EHL simulation confirmed that a DLC-coated wrist pin affects the piston motion and reduces the contact pressure between the piston skirt and cylinder liner.

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1. INTRODUCTION

Improving the fuel efficiency of vehicle engines is particularly important from the standpoint of reducing CO₂ emissions. One important way of improving fuel efficiency is to reduce engine friction loss. As shown in [Figure 1](#), reducing piston and rings friction losses is an effective way of achieving this aim since the piston and rings are responsible for 30% to 40% of the friction loss in an engine.

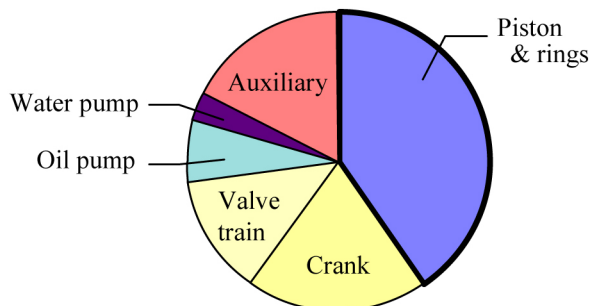


Figure 1. Ratio of piston friction loss in a Toyota representative 2 liter, inline 4-cylinder, gasoline engine.

Diamond-like carbon (DLC) is gaining attention as a highly wear-resistant low-friction material. Consequently, it is being adopted in an increasingly large number of sliding engine parts, such as in the injection system [1], valve lifters [2], piston rings [3], wrist pins, and so on [4]. Assuming that a DLC-coated wrist pin would have an effect on the piston skirt, this study analyzed the friction reduction mechanism of a DLC-coated wrist pin.

2. BACKGROUND AND AIMS OF STUDY

Hayashi et al. [5] and Higasa et al. [6] analyzed wrist pin friction in previous studies. Suhara et al. also focused on the wrist pin and developed a pin boss frictional force measurement rig. This research investigated the effects of engine speed and load on pin friction, and examined the lubrication regime of the pin based on these results [7]. Other research has also examined piston skirt friction. For example, Watanabe et al. analyzed the effects of piston motion on friction [8]. However, there is no published research into the effects of wrist pin friction characteristics on the piston motion and piston skirt friction. Therefore, this study aimed to identify these effects by measuring piston friction using the floating liner method and by elasto-hydrodynamic lubrication (EHL) simulation.

3. TEST ENGINE

Piston friction was measured using a naturally aspirated, spark-ignited 0.5-liter single-cylinder engine. Table 1 shows the specifications of the test engine.

Table 1. Specifications of test engine.

Number of cylinders	Single
Displacement (L)	0.5
Bore/stroke	86/86
Intake system	Naturally aspirated
Fuel system	Port injection

Figure 2 shows the configuration of the test engine. The engine was configured based on the floating liner method. The cylinder liner is supported by 3-component force transducers, thereby enabling measurement of the frictional force between the piston and cylinder. 3-component force transducers hold a liner tight compared to other floating liner methods, which leads to higher accuracy of friction measurement even when thrust force is loaded on the liner. According to Ito et al., the standardized deviation for measurements through disassembling and assembling was 0.92% [9].

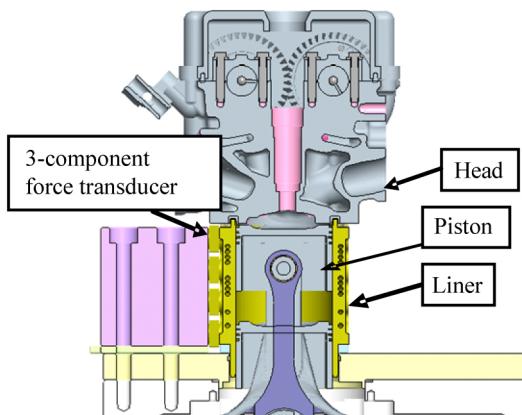


Figure 2. Configuration of test engine.

4. TEST CONDITIONS

4.1. Engine Operating Conditions

Table 2 shows the engine operating conditions. Conditions with a close correlation to actual vehicle driving conditions were selected for the test. The engine load was set to an indicated mean effective pressure (IMEP) of 650 kPa. The lubricant and coolant temperatures were both set to 80°C and four engine speeds were set from 800 rpm to 2,000 rpm.

Table 2. Operating conditions.

Engine speed (rpm)	800, 1,200, 1,600, 2,000
Load (IMEP) (kPa)	650
Oil temp. (deg C)	80
Coolant temp. (deg C)	80

4.2. Specifications of Piston and Wrist Pin

Tables 3 and 4 show the specifications of the piston and the wrist pin. Two different pin offsets were set to change the piston motion. The friction coefficients for two types of pins were confirmed using a ring-on-block test machine, and that of the DLC-coated wrist pin was 0.05, which is approximately one-third of the level of an uncoated pin.

Table 3. Specifications of piston.

Nominal diameter (mm)		86
Base material		Al
Resin coating on skirt	Binder	PA
	Solid lubricant	MoS ₂
		Graphite
		PTFE
Amount of pin-offset (mm)		0, 0.65

Table 4. Specifications of wrist pin.

Base material	Steel
Length (mm)	58
Diameter (mm)	24
Coating/friction coefficient	DLC: 0.05, no coating: 0.15

5. TEST RESULTS

5.1. Effect of DLC-Coated Wrist Pin on Friction Loss

Figure 3 shows the reduction in friction mean effective pressure (FMEP) at each engine speed when a DLC-coated wrist pin was used. Measurement results here were averaged over 120 cycles per condition. The reduction effect is calculated by subtracting the FMEP obtained with a DLC-coated wrist-pin from the FMEP obtained with an uncoated pin. The reduction effect shown here does not include the friction loss on the wrist pin.

When the pin offset was set to 0.65 mm, the friction loss reduction effect was more pronounced at lower engine speeds. With an offset of 0 mm, the results found that no major reduction in friction loss occurred and that engine speed did not affect the results.