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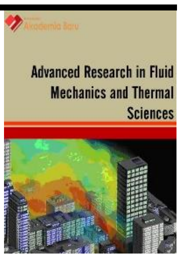

Custom Cylinder Liner-Piston Ring Combination on Pin-on-Disc for Lubricant Characteristic Study

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ABSTRACT

Tribology test can be conducted through several options of tribometer and most of the piston ring study was made using a reciprocating machine to replicate the actual engine mechanism. This study was to evaluate the lubricant characteristic of the coefficient of friction and wear rate using custom rig made for the pin-on-disc machine. The custom rig was designed to increase the contact surface between the piston ring and disc under rotational motion. The test was conducted under increasing speed (100, 200 and 300 rpm) and load (1, 2, 3, 5 kg). Results show the same increasing trending on wear rate while decreasing trend on the coefficient of friction for both speed and load test. Those consistent results are influenced by the good lubricant properties as well as proper design of piston ring holder.

1. Introduction

Recent developments towards green technology had delivered responsive feedback from researchers to invent and develop new technology in addition to reduce current environmental issues and the dependant on natural resources. The issues include the used of petroleum crude oil as our lubricant resources which are on the verge of extinction and contribute to many environmental pollutions. One of the many products made from petroleum oil is the engine oil or lubricant oil. Past research had shown a pattern of lubricant development made from greener and sustainable resources derived from the vegetable oil. Those researchers had highlighted the benefits of vegetable oil as lubricant in terms of its properties [1] and characteristics [2], easy of producing [3], cost-effectiveness [4], environment-friendly [5]. By the advantage of one of the largest palm oil manufacturers in the world, the number of research using palm based-oil for lubricant resources in Southeast Asia is growing fast with the development of lubricant from crude palm oil products to the advance modification of crude palm oil and its by-product.

Lubricants are primarily used to reduced friction stress between two moving surfaces. As the applications of lubricants had widespread, its functionality is followed as an antiwear, antioxidant,

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rust and corrosion inhibitor. hydraulic and brake fluids, compress oil, gear oil, and engine oil. In a machining operation, conducted under high-speed motion creates higher friction between workpiece and tool from direct close contacts such as cutting operation lead to the increase in local heat which overheats the tool causing the lost in temper and hardness. This can be avoided by applying such lubricant as friction reducer as well as a cooling agent to the cutting operation. Meanwhile, in the vehicle aspect, the lubricant is applied as engine oil to lubricate the function of the reciprocating piston engine and piston ring mechanism in an internal combustion engine.

A number of studies had been done to test the properties, behavior, and performance of engine oil [6-8]; namely, from petroleum resources and renewable resources using several methods of testing such as cold forward extrusion [9-11], Four-ball [12-15], Pin-on-disc (POD) [16,17] and other tribological test [18-22] while a focus test of engine oil study for piston and piston ring are usually conducted using cylinder liner machine [23-25] to compensate the reciprocating motion as well as the advantages to use actual material. Grabon *et al.,* [26] study the friction force behavior of grey cast iron piston ring and cylinder liner with oil pocket. The surface roughness difference on cylinder liner surfaces due to the variation of honing setting was studied and found that the R_v corresponds to the material fraction of the surface layer while R_p to the oil retention volume [27]. A tribology study also made by using a material cut from cylinder liner honed while the counter–specimen was made special from chromium-coated steel C45 to evaluate the Sq parameters of one-process and two-process surfaces [26]. However, the same advantages are available with the Pin-on-Disc machine which only a few studies had to recognize its ability to test fluid and lubricant at a different and custom arrangement. Razak *et al.,* [28] has made a new approach to the comparative study for the Hyaluronan oil and palm based-oil using hip implant mechanism on POD machine. Previously, a test conducted with Pin-on-Disc machine consisted of a pin being hold by the pin holder and a disc with rotating motion. As to test for a specific material, the pin and disc are fabricated to its specification needed according to the test requirements. Then the research expands using POD to focus on the specific concept testing. In this study, a lubricant test had been conducted to replicate the actual material of the piston engine and piston ring using modified POD machine. The study was conducted to observe the suitability and compatibility of the POD machine as the piston ring and piston engine lubricant tester.

2. Methodology

2.1 Lubricants

The palm based-oil used in this experiment was the refined, bleach and deodorized (RBD) Palm Kernel Oil (PKO) supplied by Keck Seng (M) Sdn Bhd Malaysia. It appears as a semi-solid form at room temperature and needs to be heated as a liquid at 27.5°C before entering the POD machine. Commercial engine oil used in this study was the Mineral oil (SAE 40) bought from a local manufacturer. The lubricant oil was supplied at a constant flow rate to the piston ring and the disc during the 1 hour test for each experiment.

2.2 Pin and The Disc

The piston ring samples were bought from RIKEN and oil ring has been used as a tested ring. Piston ring holder was fabricated to firmly hold the piston ring during the sliding test. Piston ring holder was made in two different rig version (Rig 1 and Rig 2) to accommodate the increasing applied load during the experiments. Both of piston ring holder designed to hold 1 piece of piston ring at a time and able to have contact with the rotating disc at almost ¼ of its surface. Both of piston ring design was shown in Figure 1 as the 3D model and 2D drawing. POD machine was modeled to hold a test for a pin-type test and a disc. For this experiment, the disc was fabricated using alloyed white cast-iron with hardness treatment at HRB 87 to replicate standard engine block material. The disc was fabricated with a quarter-circle curve to have a larger contact surface during the sliding test with the piston ring as illustrated in Figure 2. The assembly of the overall POD machine arrangement for the test is shown in Figure 3.

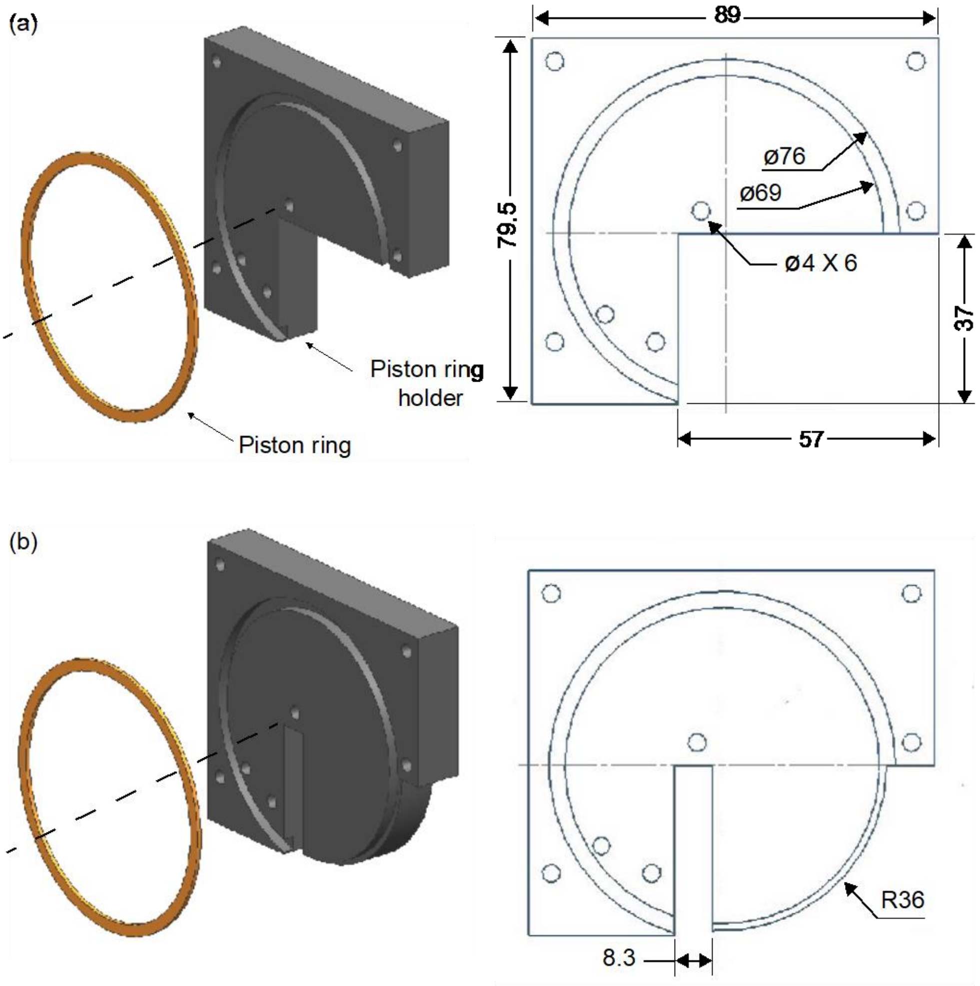


Fig. 1. 3D model and 2D drawing for piston ring holder design (a) rig 1 (b) rig 2

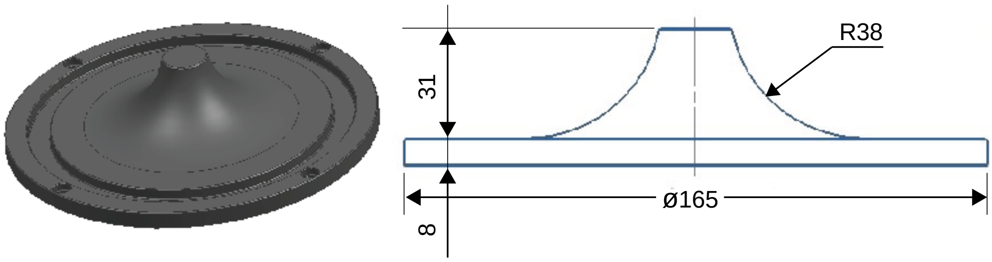


Fig. 2. 3D model and 2D drawing for cast iron disc design

2.3 Experiments

A custom pin-on-disc friction-measuring device was designed to measure the coefficient of friction (CoF) and the wear rate (WR). The average value of the coefficient of friction and wear rate was obtained from using the wear and friction sensor on the tribometer tester. The first parameter tested on normal loads were varied in three values of 1, 2 and 3 kg at a sliding velocity of 300 rpm and second parameter tested on normal speeds were varied in three values 100, 200 and 300 rpm at a constant load of 1kg. The experiments were conducted under continuous oil supply from the POD oil tank at a rate of 0.83 ml/s. All experiments were followed according to the ASTM G-99 standards procedures.

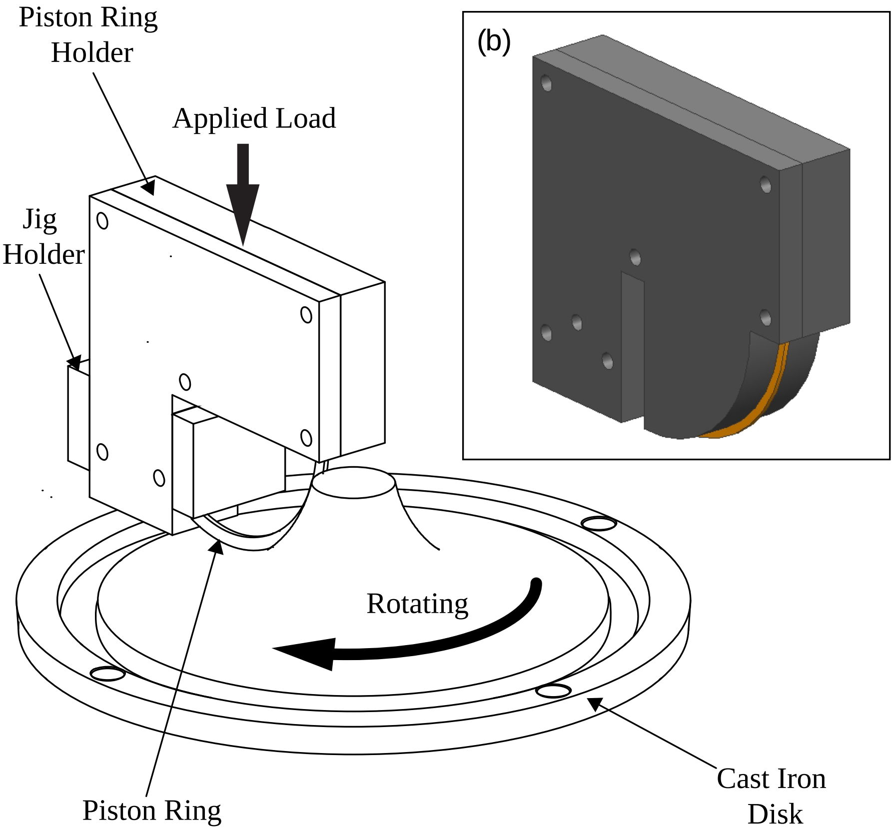


Fig. 3. Custom Pin-on-Disc Rig 1 design assembly for piston ring and the cast iron disc and (b) Piston ring holder using Rig 2 assembly

3. Results

3.1 The Effect of Increasing Rotating Speeds

This section discusses the effects of CoF and WR on the piston ring tested at increased speeds with the constant applied load (1 kg) using the custom rig. Sliding speed plays an important role in deciding the effects to the CoF and WR value. The sliding speed influenced the frequencies of contact between the piston ring and rotating disc. Higher speeds mean that more contact was made between both surfaces and could change the behavior of lubricant properties reacts to the specific condition. As depicted in Figure 4(a), the wear rate increased as the speeds been increases which shows that more material has been grind and loss due to the increase in frequent contact with RBD PKO recorded lower value compared to SAE 40 at 100 and 200 rpm. At 300 rpm speed, a significant increase in wear rate was recorded. This phenomenon was due to the higher speed affecting the effectiveness of lubricant distribution to the contact surfaces. At a higher speed, lubricant supplied reaches the contact point of piston ring and disc and get dispersed aside to the non-contact area in which the contact surface should be fully lubricated.

The same theory could be applied to the reducing trend of CoF value when speed increases. When speed been increased, the number of rubbing or contact surface between the piston ring and cast iron disc were a directly proportional increased. Due to this condition, the contact surface is been grind more frequent at a constant load which results in the good surface finish as in Figure 6(a) while reducing the CoF value. This can be seen in Figure 4(b) where all lubricants recorded reduce CoF value when speed is increased.

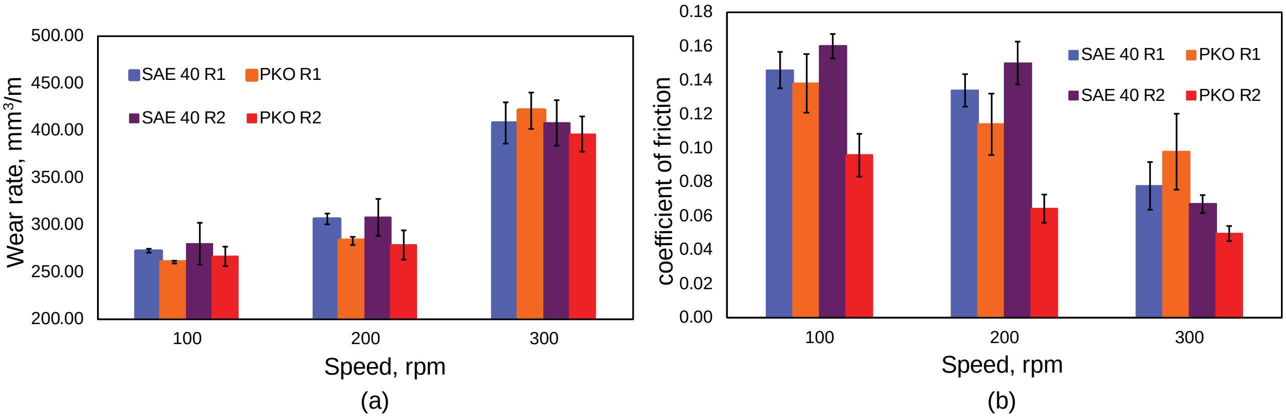


Fig. 4. The effect of increased rotating disc speeds on (a) wear rate and (b) CoF for both Rig 1 and Rig 2

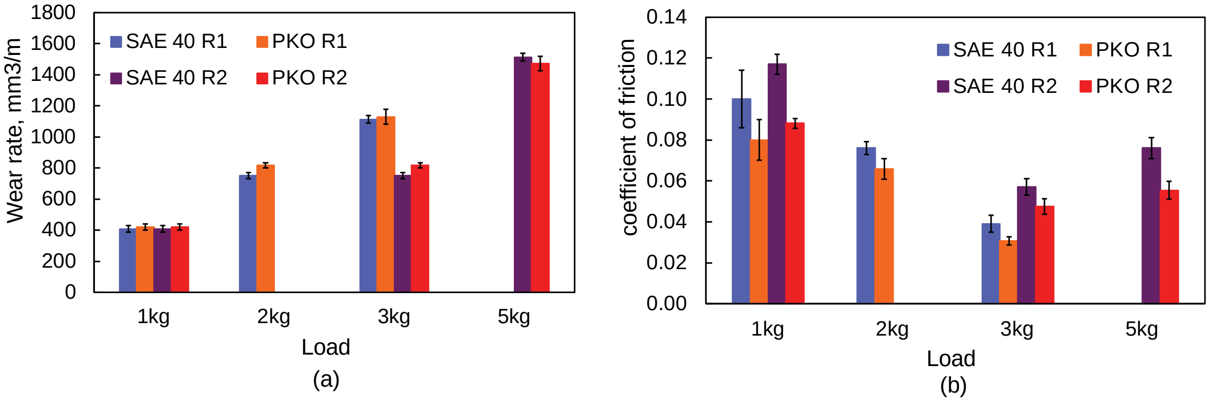
In terms of reproducibility and repeatability of data gained from the experiments, the newly fabricated rig using a POD machine was able to produce stable results on both CoF and WR data. There is not much difference between Rig 1 and Rig 2 recorded for wear rate in both lubricant used and only RBD PKO recorded reduced in CoF value from Rig 1 to Rig 2. Rig 1 holds the piston ring free at the contact area in which can contribute to a certain smaller vibration and increase in friction resistance at rotating direction during sliding contact with the disc and small particles from wear losses. With using Rig 2, the piston ring held firm across the contact area of the piston ring and allow the lubricant to be distributed at a stable rate and performing the lubricity action properly. Referring to the properties in Table 1, it is shown that RBD PKO had a much lower viscosity than mineral oil. Lower viscosity has much more penetration opportunity to the gap left between the piston ring and the disc while knowing that the load applied is consistent, so the gap is consistent. This allows the advantage of palm oil constant viscosity properties [29] to steadily filling the gap to provide enough film layer protection between contact surfaces hence reducing the CoF at increasing speed. The data gained from both rig (Rig 1 and Rig 2) recorded a smaller error in standard deviation to the average value. The ability to deliver a stable and consistent speed provided by the POD machine in addition to the firm holder of piston ring design during the experiment helps in producing reliable data for CoF and WR.

Table 1
Physiochemical properties of lubricant samples

	Kinematic viscosity		
Lubricant sample	40°C (cSt)	100°C(cSt)	VI
Mineral oil	114	29.4	294
RBD PKO	18.2	10.5	608

3.2 The Effect of Increasing Applied Loads

The experiment at increasing applied loads was held at 1, 2, 3 kg (Rig 1) and 1, 3, 5 kg (Rig 2) for a constant speed of 300 rpm. By increasing the applied load at higher speed influenced the shear stress increment on the contact surfaces as well as resulting in more material losses from the sliding motion. As depicted in Figure 5(a) wear rate versus load graph, the wear rate consistently increases from 1 to 5 kg applied load. Higher wear rate is a sign that more material losses occur during sliding contact between the piston ring and the disc. Those material losses in small particles are trapped in the lubricant are been carried back to the contact area from the rotational motion and act as third body abrasion to increase more wear. When the load applied is high in addition to the higher speed, it increases the temperature at the point contact which can cause adhesive wear to occur and increase wear. At 3 kg load, Rig 2 recorded a decrease value of wear rate for both lubricants. From the observation, it is explained that at 3 kg load using Rig 1, the piston ring starts to show a little bending on the piston ring at rotation direction which causes the contact area occurs at the edge of piston ring and increase the friction-resistant as well as the CoF value. Meanwhile, by using Rig 2, the piston ring condition was held firm and consistent without any bending and additional load (5 kg) can be applied during the test.



(a)

(b)

Fig. 5. The effect of increased rotating disc loads on (a) wear rate and (b) CoF for both Rig 1 and Rig 2

Even though wear rate results show an increment with increase load, CoF value recorded contrary reduce trending throughout the increased load from 1 to 3 kg. High applied load with constant speed produce a coarser surface finish with deeper grooves that act as an oil reservoir and allowing the lubricant to flow easily to the contact area to smoother the sliding contact between the piston ring and the disc. The study made by Grabon *et al.,* [26] shows that a dimpled textured on cylinder liner act as oil pocket to help to reduce the friction force. This is also supported by the research of partially surface texturing the flat piston ring at a ratio of B/W = 0.6 that results in 25% lower friction [23]. Due to this reasoning, the CoF can be reduced. However, at 5 kg load, the CoF is slightly increased due to the increase in contact area temperature. Lubricant is absorbed into the piston ring and weakens the metal surfaces, while with high temperature, the weaken surface melted and creating bigger debris as in Figure 6(b) that trapped between the contact surfaces those increase CoF. Others findings suggested that insufficient amount of lubricant on the contact surface causing the rupture of metal asperities by the friction force hence increase the WR and CoF [30].

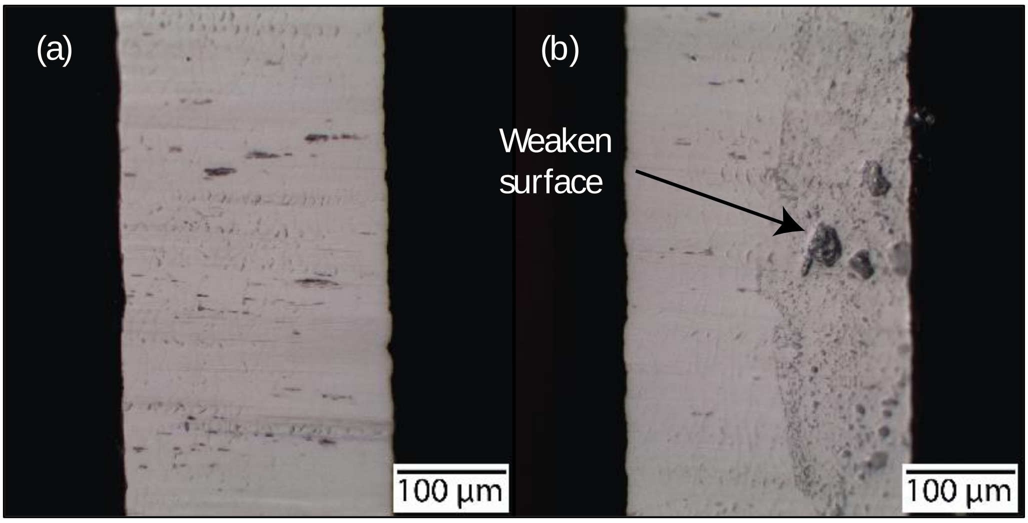


Fig. 6. Wear surfaces on (a) varied speed test and (b) 5 kg load test

4. Conclusions

The experimental study was conducted to observe the suitability and compatibility of testing the piston ring and disc under lubrication condition using custom rig in a POD machine. The piston ring holder designed in two types to accommodate higher load test. Results show that CoF and WR value was consistent with smaller error of standard deviation during the experiment with variation of increasing speed and load. The advantages of a POD machine to provide continuous and stable speed during the experiment contribute to a consistent result gain on a custom rig design. The piston ring holder design also plays important roles to firmly hold the piston ring on the machine and gives more contact surfaces between the piston ring and disc to test the tribology parameters.

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