Tribological Performance of Palm Kernel Oil at Various Load Using Pin-on-Disk Tribotester

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ABSTRACT

Vegetables oil are known as an oil resources that is renewable, non-toxic and biodegradable compared to the petroleum oil. This properties brings the researcher to study on vegetable oil as a substitute resources for an application such as lubricants. In this study, the tribological properties of Palm Kernel Oil was studied by evaluating the wear and friction characteristics of aluminium (A1100) pin lubricated with different types of oils and tested using pin on disc machine in compliance with the ASTM G99 standard. The two oils used are Palm Kernel Oil and commercial semi-synthetic engine oil. The material for spherical ended pin is aluminium A1100 while material for steel disc is SKD-11. For each test, load are varied at 1 kg, 3 kg and 5 kg. The duration of each test located is 1 hour and the linear speed of the rotating disc are kept constant at 1.5 m/s. A fixed amount of 2.5 ml of lubricant is applied to the disc. From the analysis, the coefficient of friction obtained by palm kernel oil is better than semi-synthetic engine oil. However, the value of wear scar resulted from palm kernel oil is larger than semi-synthetic engine oil. Additional additives are needed to improve the wear scar of pin lubricated by Palm Kernel Oil in the future.

Keywords: *Coefficient of Friction, Pin-On-Disc, Palm Kernel Oil, Lubrication, Wear.*

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Introduction

Generally, tribology deals with the technology of lubrication, control of friction and prevention of wear of surfaces having relative motion under load. Thus, it is very important to modern machinery recently which involve sliding and rolling surfaces.

Nowadays, lubricant play a very important role in engines and machines which are mainly used to reduce the friction and wear between two contacting surfaces. It can performs a variety of functions such as protect metal surfaces against corrosion, acts as a heat transfer agent, flushes out contaminants, absorbs shock and act as a seal against dirt, dust and water [1]. By providing a protective film between two sliding solid bodies, it can reduce the frictional force, amount of wear and the degree of surface adhesion.

Numerous studies using pin on disc tribotester have been carried out to determine the wear behaviour of the two sliding bodies with using certain types of lubricants. Coefficient of friction, COF commonly used because it can be analyse to determine the performance of the lubricants which being tested. Furthermore, by measuring the volume loss from the pin on disk experiment, it also allow us to calculate the wear rate of the material. From the previous research, we can see that the value of coefficient of friction, COF is influenced by several factors such as normal load, rotating speed, temperature and surface roughness of the tested materials.

Yunus et al. [2] have explained that palm oil is mainly composed of unsaturated fatty acid, triglycerides and non-glycerides substance. The high amount of unsaturated fatty acids in the palm oil will create high strength lubricant film and act as boundary lubricant. This is also influenced by the fact that the molecular weight of palm oil is more consistent than mineral oil. Then, Masjuki et al. [3] stated that the unsaturated fatty acid in palm oil contains thicker molecular layers, which will be subsequently prevent direct metal to metal contact. Besides that, palm oil also had the ability to form a thin film by chemical absorption of fatty acid onto the interface. This phenomenon is called soap film, where it reduces direct metal to metal contact and avoids severe wear [4][5].

Most of lubricating oils used today are based on mineral oil which being extracted from petroleum oil. Although this oil is very useful and widely used, it is also an environmental hazard due to their toxicity and non-biodegradability. Because of growing attention to the environmental issues, the industry has been trying to formulate biodegradable lubricants with can be used to substitute the usage of petroleum based oils as lubricants. Today, vegetable oils are being considered for their suitability as industrial lubricant. This is because vegetable-based lubricants are much more biodegradable than petroleum based lubricant oils.

A review by [6] are showing that vegetable oils produce highest value of biodegradability after being test by relatively primary biodegradation screening test, CEC-L-33-A-94. The parameter measured from this test is the loss of hydrocarbon infrared bands at 2930cm^{-1}. This results showing that biodegradability of vegetable oils are much better than mineral oils which are being used widely today.

Experimental Methodology

Apparatus

In the present investigation, the pin-on-disk had been used to study both wear and coefficient of friction. The pin-on-disk test is commonly used in a comparative test in which the controlled wear is performed on the samples to study. The volume loss allows the calculation of the wear rate of the material. In this method, a pin is clamped firmly against a rotating disk linked to a certain dead weight with a beam and two pulleys.

In this experiment, the test lubricant was not pumped and flowed throughout the experiment time. 5ml of test lubricant was used. To make sure the test lubricant did not flow out due to the centrifugal force while the disk rotated, a groove with 10mm width and 5mm depth was provided in the rotating disk. The flat-end pin surface, which was used as a specimen was touched onto the horizontal surface of the groove at the beginning of the experiment.

A linear voltage differential transformer (LVDT) sensor was used to read the wear rate. The grooved-disk is cleaned before experiment using acetone. The surface roughness was recorded according to the parameter set up by researcher. Figure 1 shows the arrangement of the grooved-disk and the hemispherical-ended pin.

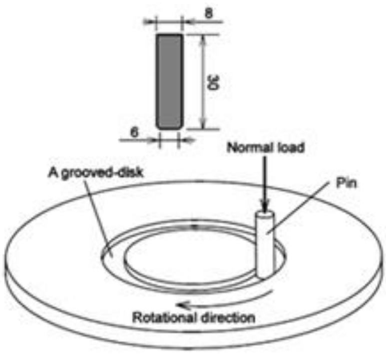

Figure 1: The grooved-disc and hemispherical ended pin

Specimen Material and Lubricants

The grooved-disk is made from SKD-11 steel while the material for the hemispherical ended pin were made from aluminium, A1100. Pin samples were prepared as 6mm in diameter. The surface roughness of the pin was measured using a surface roughness profiler which consisted of a stylus detector to determine the pattern of the pin surface. After the completion of each test, a sandpaper was used to smoothen back the surface of the disc for the next experiment. Palm kernel oil and commercial semi-synthetic engine oil were used as the test lubricating oils, with the same volume of 2.5ml. The test lubricants were dripped onto the specific location before the experiment, as shown in Figure 1.

Experimental Setup

The experiments were conducted according to ASTM G99. The principle of sliding was using a cantilever loaded pin against the horizontal rotating grooved disk in a lubricant oil bath. All the tests were carried out at room temperature, 22± 2 °C. In this experiment, 1 kg, 3 kg and 5 kg of the normal loads were applied, and the rotating time was one hour. The disc rotating speed are kept constant at 1.5 m/s. The masses of the pins were measured before and after each test, and the weight losses were recorded. The surface finishes of the pins were measured before and after the experiment.

Wear and Friction Evaluation

The frictional force between the pin and rotating disk during the test was measured by using a load cell attached at the side of the pin-holding lever arm and the values were recorded. The coefficient of friction was calculated simply by dividing the frictional force value with the corresponding axial load based on the Eq. (1).

Coefficient of friction, COF = (Frictional force, F)/ (Normal Load, N) (1)

Coefficient of friction would show its prominent function in the determination of transmission efficiencies through moving mating components. LVDT sensor which was directly connected to a display monitor detected the wear rate of the pin. Less resistance contributes to higher efficiency. Therefore, in terms of lubricant, less friction and wear is desirable.

Weight Loss Evaluation

The pins were firstly weighed using an electronic balance with an accuracy of 0.1 mg. Each pin was measured three times to obtain an average value and reduce the impact of possible measurement errors in the calculation. After the experiment, the pin was cleaned with acetone and the weights of the pin were recorded again. The difference of pin mass before and after the experiment would be used to evaluate the wear rate of the specimen

Result and Discussion

Coefficient of Friction, COF

To study the anti-friction behaviour of palm oil, several experiments were conducted using different loads, which were 1 kg, 3 kg and 5 kg with 1.5m/s of sliding speed. The duration of the experiment was one hour (3600 seconds). The anti-friction behaviour of palm kernel oil (PK) was compared with the anti-friction behaviour of semi-synthetic engine oil (SSEO). Frictional force obtained directly from the experiment using LVDT sensor was converted into the friction coefficient value according to Eq. 1. The relation between coefficient of friction and normal load is illustrated in Figure 2.

From the graph, x-axis represents the value of coefficient of friction for each experiment. Generally, both oils shows small decrement in value of COF through the load increment. For SSEO, the value of COF for 1kg of load is 0.039, slightly decrease to 0.037 for 3 kg and 0.036 for 5kg. Because of only small changes of COF, it can be said that the amount of load applied only cause small changes towards the value of COF for SSEO.

The value of COF for PK oil then initially at 0.036 for 1kg, decrease to 0.031 for 3kg and finally decrease a little to 0.026 for 5 kg. Based on that values, we can say that the increasing amount of load applied give significant effects towards the value of COF for PK oil. Sapawe et al. [12] also found that COF values decreases when load increases in the study of Palm Olein at varied load with hemispherical pin and grooved disk.

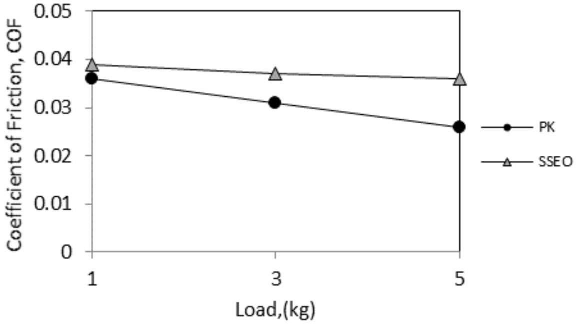

Figure 2: COF for PK oil and SSEO

The value of COF is decreasing due to the load increment. This result is consistent with the result obtained by Al-Samarai et al. [7]. It can be said that a large quantity of wear debris are believed to be responsible for the decrease in friction with the increase in normal load. Wear debris produced will interact with the metal surface and will act as protective layer to overcome high frictional force and metal to metal direct contact and resulted to the lower value of COF. After that, PK oil exhibits lower value of COF. Based on Fox et al. [10], PK oil have a very small value of COF. This is due to the composition of PK oil itself which is made up from unsaturated fatty acid, triglycerides, and non-glycerides substance. The triglyceride structure of vegetable oils provides qualities desirable in a lubricant. Long, polar fatty acid chains provide high strength lubricant films that interact strongly with metallic surfaces, reducing the friction resulted.

Then, vegetable oils are particularly effective as boundary lubricants as the high polarity of the entire base oil allows strong interactions with the lubricated surfaces. Boundary lubrication performance is affected by attraction of the lubricant molecules to the surface and also by possible reaction with the surface. This has been confirmed that the palm oil had the ability to form a thin film by chemical absorption of fatty acid onto the interface [4, 5]. This phenomena is called soap film, where it reduces direct metal to metal contact and lowered the value of COF resulted in the experiment.

Wear Scar Diameter, WSD

Based on Figure 3, we can see in general for both types of oils as the load increase, the WSD for both lubricant also increased. We can say that WSD is directly proportional to the load applied. Then, we also can see that WSD for PK oil is larger than SSEO. Basically, the value of WSD is related with the value of wear as we discussed before. When the value of wear increase, the value of WSD will also increase.

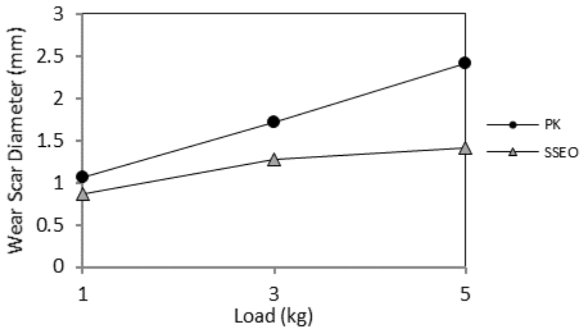

Figure 3: WSD for PK oil and SSEO

The value of WSD is directly proportional to the load applied. When the value of wear increase, the value of WSD will also increase. Besides that, WSD at higher load is greater than lower load because the amount of pressure acting on the disc at higher load applied is larger. Then, wear rate also will be faster due to that amount of pressure. Nuraliza et al. [8] found that ploughing effect and inclusion of wear debris will affect the wear rate. In term of wear protection, SSEO exhibits slightly better performance than PK oil due to the weakness of PK oil towards oxidation. Fox et al. [9] said that the oxidation stability of the fatty acids present in the system may also have an impact on the wear at higher temperatures. If the fatty acids are unable to resist oxidation at the higher temperatures any protective layer would quickly degrade, resulting in a rapid increase in wear. The layer could be continually replenished, but would just as quickly degrade again.

Weight Loss of Pins

The pin was weighed before and after the experiment to know the difference of pin mass loss after the experiment. The results are shown in Figure 4. In general, SSEO exhibits better performance than PK oil in term of weight loss. This is because weight loss of pin resulted from SSEO is clearly lower than PK oil for all amount of load applied.

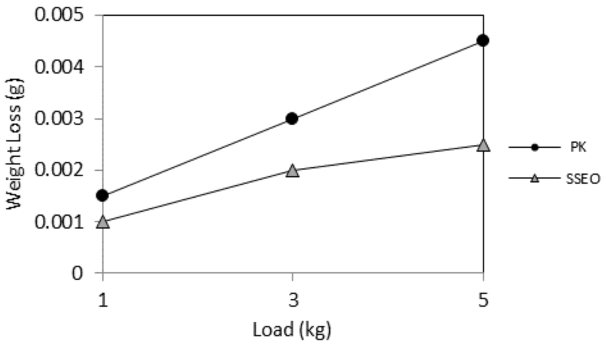

Figure 4: Weight loss for PK oil and SSEO

Weight loss of pin are increase with the load increment. Based on Al-Samarai et al. [7] studies, an increase in the load leads to increased wear and loss of the metal. The initial rubbing duration breaks the surface layers, which cleans and smoothens the surfaces and increases the strength of the connections and contact between the surfaces. The friction force due to the tillage effect between the surfaces increases the temperature between them. This effect results in adhesion and increases the deformation at the surface layers, leading to further loss of the metal.

Surfaces Roughness of Pins

Surface roughness is one of the most essential parameters in determining the wear rate and friction coefficient and it helps to summarize the behaviour of lubrication effect during the sliding time of mating components. The surface roughness analysis is done by inspecting the surface roughness of aluminium pin (A1100). This analysis was carried out in order to determine the relationship between the surface roughness and the load applied. From the Figure 5, we can see in general the value of roughness for PK oil are lower than SSEO. The value of surface roughness for palm kernel are in the range of 0.022 µm up to 0.037 µm while the range for SSEO is 0.042 µm up to 0.050 µm. It can be identified that the value of surface roughness for PK oil is lower than SSEO.

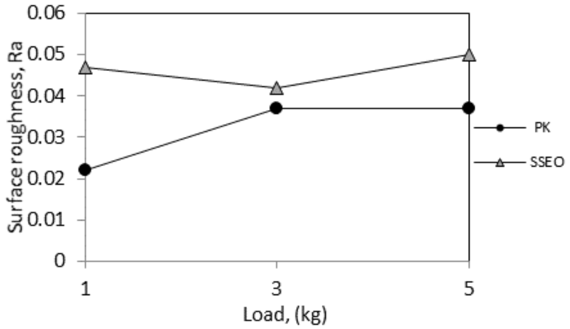

Figure 5: Surfaces roughness for PK oil and SSEO

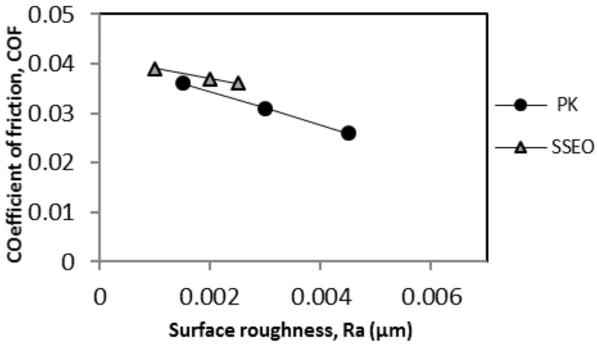

Figure 6: COF vs surfaces roughness of the pins

Figure 6 above shows the graph of COF against surface roughness of the pin after an hour experiment runtime. It can be seen that as a surface roughness increases, the value of COF decreases. According to Barret et al. [11], friction is consequently much higher for a very smooth surface. Basically, friction is caused by the microscopic contact between two objects. For two smooth surfaces with low roughness value, the area of contact between them is actually higher, hence resulted to more friction. Because of that, the adhesion of two smooth surfaces is better and hence more friction is produced when relative motion is present. In contrast, rough surfaces will have less area of contact and lead to less friction was produced during sliding action.

Wear Worn Surface

High power CCD microscope also used to capture the micrograph of the worn surface. The images were captured at different magnification levels to get the sharpest image. This will be useful in determining the characteristics of wear on the pin lubricated with different oils. Figure 7 and 8 shows micrographs of pin worn surface at different magnification levels for both types of oils. Based on the picture taken by high-profile CCD microscope, we can see clearly surface finish of SSEO are having larger and uneven pattern as compared to PK oil. It can be said that PK oil produced smoother surface as compared to SSEO.

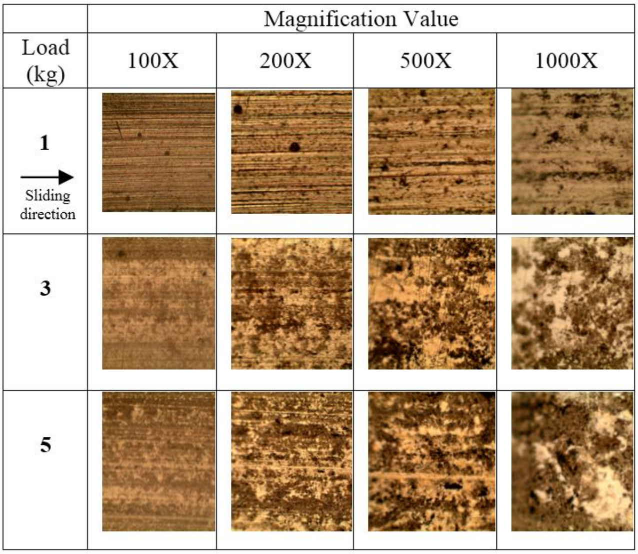

Figure 7: Micrographs of pin worn surface at different magnification levels for PK oil

The most types of wear occurred throughout this experiment is abrasive wear. This is because as we can see from the CCD high power micrograph picture in Figure 7, there is no severe wear, plastic deformation or delamination occur. Based on worn surface observation, PK oil produced smoother surface as compared to SSEO. The large uneven and irregular pattern exhibits by SSEO prove that SSEO produced quite coarse surface as compared to PK oil. The results can be attributed as the larger value of COF for SSEO as compared to PK oil.

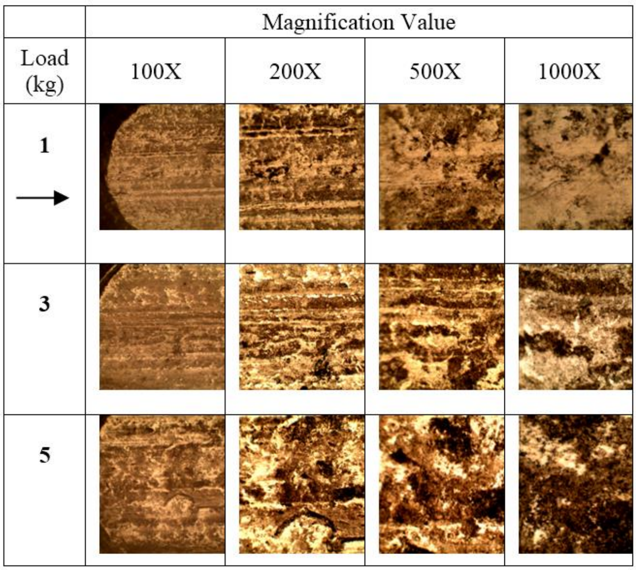

Figure 8: Micrographs of pin worn surface at different magnification levels for SSEO oil

Conclusion

The tribological behaviour of PK oil had been evaluated using pin-on-disk tribotester. All the results of PK oil were compared mutually with the results obtained by SSEO. As the normal load increase, the value of coefficient are decrease. The coefficient of friction produced by the pin lubricated with palm kernel, PK oil is found to be lower than semi-synthetic engine oil, SSEO. The value of wear scar diameter and weight loss are increasing with normal load increment. In this case, SSEO exhibits slightly better wear protection due to lower value of WSD and weight loss.

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