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TRIBOLOGICAL PROPERTIES OF POTENTIAL BIO-BASED LUBRICANTS FROM RBD PALM STEARIN AND PALM FATTY ACID DISTILLATE

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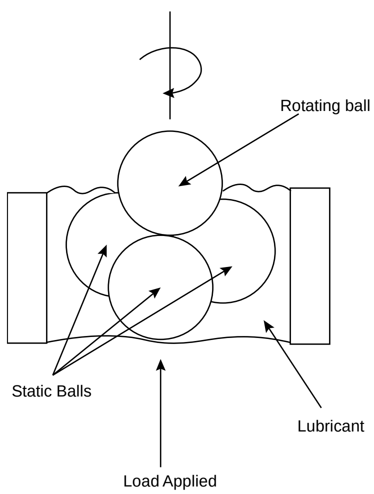
Graphical abstract



FOURBALL TRIBOTESTER BALL ASSEMBLY

Abstract

Palm-based oil properties, which consist of long fatty acid chains, have the potential to replace current mineral oils. Recent studies have shown that palm-based oil has comparable lubricating properties to those of commercial engine oil. However, several palm oil products yet to be discover as lubricants such as RBD Palm Stearin (RBD PS) and Palm Fatty Acid Distillate (PFAD) due to its solid form properties. In this study, both RBD PS and PFAD has been tested for the suitability as lubricant in the tribological experiments consists of anti-wear test and extreme pressure test according to ASTM standards of D4172 B and 2783 respectively. In ASTM D4172 B, test has been conducted with 40kg load and 1200 rpm speed at 75°C in duration of 60 minutes while in ASTM 2783 the temperature and speed are remain constant at 45°C and 1760 rpm in duration of 10 minutes with increasing loads until failure detected. Mineral Oil (MO) has been used as a direct comparison between commercial engine oil and bio-based palm oil. Results shows PFAD has recorded lowest average coefficient of friction (COF), wear scar diameter (WSD) and surface roughness at 0.038, 433µm and 0.188µm in anti-wear test. In the extreme pressure test, RBD PS shows the earliest failure of 4mm wear scar diameter at 126kg followed by palm fatty acid distillate and mineral oil at 130kg and 146kg load.

Keywords: Bio-based lubricants, wear, coefficient of friction, surface roughness, extreme pressure

1.0 INTRODUCTION

Mineral and petroleum oil are widely used as resources of lubricant oil. However, these resources are toxic, non-biodegradability, not environment friendly and depleted over time. Approximately 85% of lubricants that being used around the world are mineral-based oils [1]. According to Campanella *et al*. [2] and Shahabuddin *et al*. [3], mineral oil lubricants contain many kinds of additives such as antioxidant, anti-wear, detergents, dispersants, anti-foams, extreme pressure agents, friction modifiers and viscosity improvers. Some of these additives are toxic [4, 5] and harmful to human health, wildlife and environment [6]. Due to the environmental concern, the research towards finding the alternative based-oil for lubricants becomes very demanding nowadays. One of the potential solutions for substitution of mineral oils are by using vegetable oil, due to its renewable and high in biodegradability characteristics. However, vegetable oils without additives are not well performed compared to mineral oils in anti-wear and friction [7, 8] scuffing load capacity [9] and fatigue resistance [10].

The study of vegetable oils suitability as a lubricant was conducted by Golshokouh *et al.* [11, 12] comparing tribological performances between palm fatty acid distillate and commercial engine oil at different speeds and comparing oil performance between jatropha oil and commercial engine oil at different temperatures. Malaysia is one of the world's largest palm oil manufacturers; it has the advantage of producing palm oil-based lubricant in large quantities at a lower cost. It is assumed that one hectare of palm trees can produce almost 10 times as much oil as other sources of vegetable oil [13]. Lubricant creates a thin layer that reduces friction and protects parts from wear. Friction defines the efficiency and reliability of various machinery components, e.g. in automotive engines. It is estimated that approximately 20–25 percent of the energy generated by combustion is lost to frictional dissipation [14]. This wear causes up to 80–95 percent of failures and damage to surfaces [15].

The needs of renewable resources to replace current petroleum based oil are very important and palm based oil has the potential to fulfill the objective. RBD Palm Stearin and PFAD are among several products processed from palm fruit in which the usage capacity is low compared to Palm Olein. The fact that both RBD PS and PFAD are not widely been tested as a lubricant is because they exist in a solid form which is different physical form of liquid for lubricant. RBD Palm Stearin has been studied in metal flow extrusion [16] and at various applied load [17]. Meanwhile Aiman and Syahrullai [18] blended the semi synthetic oil with palm oil to test the performance using fourball machine. Palm olein also has been used in the study of plastic deformation by plane extrusion and compared with parrafinic oil [19]. In this study, the performance of RBD Palm Stearin and PFAD has been tested in the tribological experiments includes the findings in coefficient of friction, wear and surface roughness. The experiments conducted follows according to ASTM standards ASTM D4172 for anti-wear test and ASTM 2783 for extreme pressure test. Mineral oil has been added into the experiments specimen as a direct performance comparison.

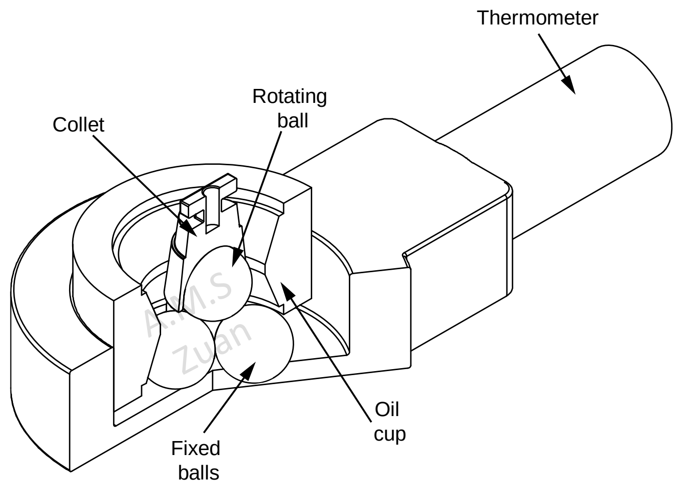


Figure 1 Fourball tribotester ball assembly

2.0 METHODOLOGY

2.1 Experimental Apparatus

Four-ball tribotester machine was used in this project to run both Anti-Wear test and Extreme Pressure test. Figure 1 shows the schematic diagram of four-ball tribotester main components such as oil cup assembly, collet and ball bearings. The test was conducted using a ball bearing with a diameter of 12.7 mm composed of chrome alloy steel, made from AISI E-52100 with grade 25 extra polished and have a Rockwell C hardness of 64 to 66. One ball bearing is moving rotationally at certain speed is in contact with three stationary ball bearings which immersed in the tested lubricant under a certain load.

2.2 Lubricants

The testing lubricants used are RBD Palm Stearin, PFAD and Mineral Oil. Palm Stearin is the solid fraction obtained by the fractionation of palm oil after crystallization at a controlled temperature, whereas PFAD undergo physical refining with degumming, pre-bleaching, deacidification and deodorization process. Both RBD Palm Stearin and PFAD need to be heated to its melting point since they are existed in the solid form at room temperature. Table 1 shows the properties of RBD PS and PFAD.

2.3 Experimental Procedure

In Anti-Wear test, the experiment was done according to ASTM D 4172. The top bearing rotates against three stationary ball bearings at constant load, speed and temperature of 40 kg, 1200 rpm and 75°C for duration of 60 minutes for each test. In Extreme Pressure test, the top bearing rotates at constant speed and temperature of 1760 rpm and 45°C for duration of 10 seconds for each. It will be repeated with various load started at 80kg until the tested lubricant reach the failure state. The EP Test was done according to the ASTM D 2783.

The coefficient of friction value was determined to evaluate the performance of lubricant. The coefficient of friction was measured based on the average of frictional force. The coefficient of friction indicates the transmission efficiency of the moving components. Higher in efficiency means less resistance to the moving parts, hence in terms of lubricity, less friction is desirable.

The lubricant performance was also determined from the mean wear scar diameter. Wear scar diameter was measured from the three pieces fixed balls using charge couple device (CCD) microscope to capture the photomicrograph. Generally, the bigger the wear scar diameter means the more severe the wear.

3.0 RESULTS AND DISCUSSION

3.1 Anti-Wear Test

In the Anti-Wear test, all lubricants have been tested under constant load of 40kg, speed of 1200rpm temperature of 75 °C and 60 minutes time according to the ASTM standards. This test has been replicated for 3 times to observed the consistencies of the data taken for each tribology parameters includes coefficient of friction, wear scar diameter and surface roughness. Data plotted in Figure 2 shows the COF for all lubricants tested through 60 minutes test. All lubricants shows a slight increases in the early experiment period of 600 seconds before become stable. Lowest COF recorded by PFAD while highest by mineral oil. The average COF recorded for mineral oil is 0.101, RBD PS is 0.069 and PFAD is 0.036. The differences of COF performance between mineral oil and PFAD was around 35.6% while RBD PS was at 68.3%. The performance of the RBD Palm Stearin is consistently better than that of mineral oil, but it remains less efficient than the palm fatty acid distillate.

With respects to the viscosity in previous research it was been reported that palm oil has a constant viscosity, which maintains a stable shear rate [20]. Specific density and viscosity has a significant effect on friction and wear rate. The specific density and viscosity has been measured up to 55 °C (Table 1). At 75 °C reaction time, palm based oil manage to maintain the viscosity resulted in lower friction and wear value compared to mineral oil. Study made by Ing *et al*. [21] claimed that the viscosity is influences by temperature where at higher temperature the fluidity and dilution of oil will increases which lead to thinner viscosity.

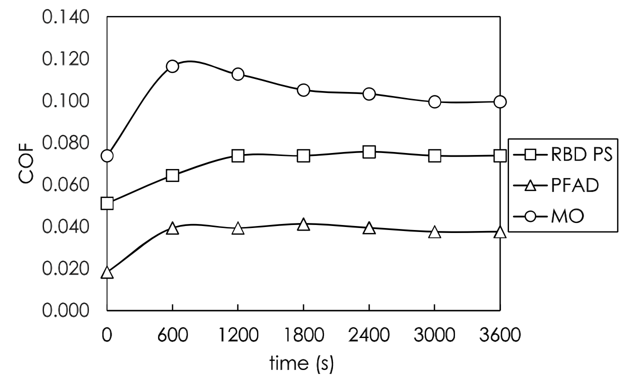


Figure 2 COF vs time for all tested lubricants at normal load

Table 1 Properties of tested lubricants

	Melting Point (°C)	Density g/ml	Viscosity MPa.s
RBD Palm Stearin	44	0.891	23.8
PFAD	50	0.887	30
Mineral Oil	-	0.878	63.21

As in Figure 3, Mineral Oil has recorded highest wear scar with average of 0.496µm compared to RBD palm stearin and palm fatty acid distillate with average wear scar diameter 0.317µm and 0.470µm respectively. Without any additives been added into the oil, palm based oil can still perform lower wear scar diameter than mineral oil which consist of strong anti-wear additives that could form two layers, physical layer (physiosorbed) and chemical layer (chemosorbed). In another research, castor oil found to be less efficient in wear scar diameter compared to mineral oil [22]. Farhanah and Bahak [23] also study the effect of temperature rise using different type of mineral oil and found that oil thin film became thinner at higher temperature and reduces the metal to metal contact hence increase wear scar diameter. Palm fatty acid distillate only differ from mineral oil by 5% in average value of wear scar. Higher content of fatty acid can contribute to the increase of wear since the fatty acid will absorbed and weaken the metal surface. The increase of shear strength on the balls surfaces are due to the adsorbed oil and chemical attack effect by the fatty acid present in vegetable oil [24].

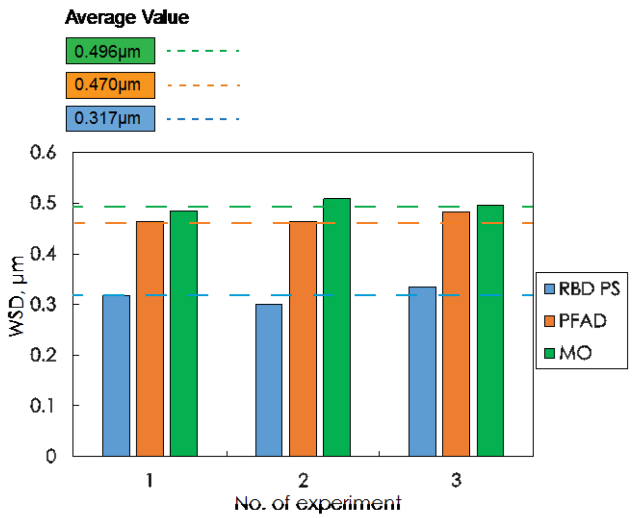


Figure 3 Wear scar diameter for all tested lubricants at normal load

However, as surface roughness results been recorded, it was found that mineral oil performs better than RBD palm stearin and slightly higher than palm fatty acid distillate. The average value of surface roughness for RBD palm stearin, mineral oil and palm fatty acid distillate are 0.317, 0.282 and 0.223 respectively as in Figure 4. RBD palm stearin recorded highest surface roughness value even though its wear scar data shows lowest compared to the others oil.

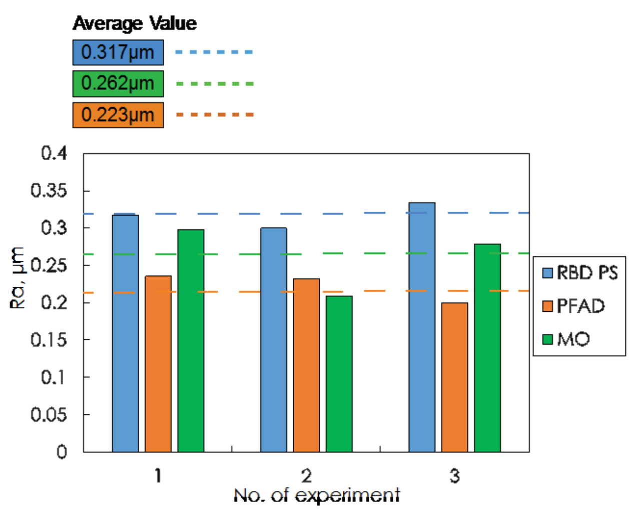


Figure 4 Surface roughness for all tested lubricants at normal load

3.2 Extreme Pressure Test

As engine development are growing fast to fulfil the end user requirement, the capabilities of the engines need to be enhance to deliver more power [25]. With this, modern engines will have a very high load during post firing expansion strokes bringing the studies of extreme pressure into important part. According to the ASTM standards for extreme pressure test, the lubricants tested are considered fail its lubrication properties once its reach a wear scar diameter of 4mm. Therefore, in this studies, all lubricants are tested for their lubricant limitation at rising loads in search of maximum load that could be applied according to ASTM 2783.

As load increases, mineral oil can maintain the COF value while both RBD palm stearin and palm fatty acid distillate shows an increment pattern. At 130kg, while mineral oil maintaining its low COF at 0.157, RBD palm stearin and palm fatty acid distillate recorded higher value at 0.755 and 0.748. Only after 130kg, mineral oil starts to shows a dramatic increase where the reading at 146kg loads was 1.036 as shown in Figure 5.

To determine the maximum load of each lubricants tested before reaching the limit of 4mm wear scar, the loads during testing has been increase at increment of 20kg per test. It can be seen in Figure 6 that as loads increases the wear scar also increases for all lubricants tested where for palm based oil, RBD palm stearin and palm fatty acid distillate shows a significant increase compared to mineral oil. At 80kg load, palm fatty acid distillate already shows a higher value of 2220μm wear scar diameter followed by 2780μm at 100kg before fail at 4mm wear scar diameter at 130kg. RBD palm stearin and mineral oil recorded lower reading of wear scar diameter at 80kg by 627μm and 420μm respectively. However as loads increase to 100kg, RBD palm stearin recorded wear scar of 2600μm and failed at 126kg slightly lower than palm fatty acid distillate. At 126kg and 130kg where both RBD palm stearin and palm fatty acid distillate reach 4mm wear scar diameter and failed, mineral oil only recorded a wear scar of 1290μm and 1440μm which is around 65% lower. Mineral oil only reach 4mm wear scar at 146kg load. Commercial mineral oil has been develop with an extra additives such as antioxidant to provide longer protection from oxidation process that lead to an increases of wear rate [26].

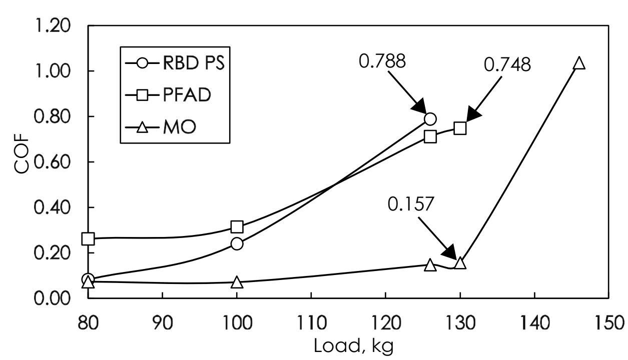


Figure 5 COF for extreme pressure test

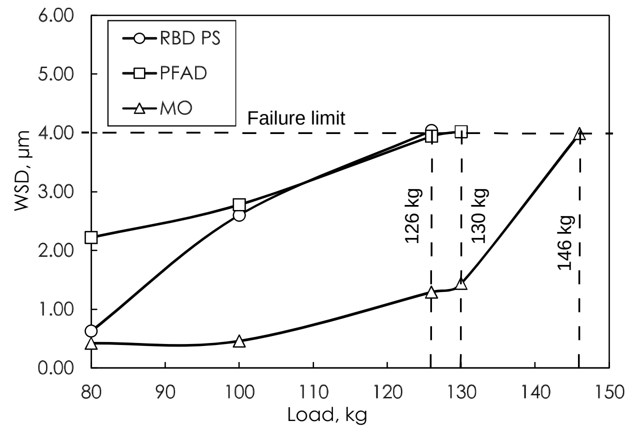


Figure 6 Lubricants failed at 4mm wear scar diameter

The average values of the arithmetic surface roughness R_a has been measured for each lubricants tested in the extreme pressure test and recorded in Figure 7. After load increased at 130kg, palm fatty acid distillate shows higher surface roughness value at 1.207µm followed by mineral oil, 0.99µm and RBD palm stearin, 0.022µm. Eventhough RBD palm stearin has recorded a higher wear scar diameter as loads increases, the surface roughness performance is stable at lower value of average 0.041µm. This proves that RBD palm stearin can protect the contact surface of metal from severe wear compared to others tested lubricants.

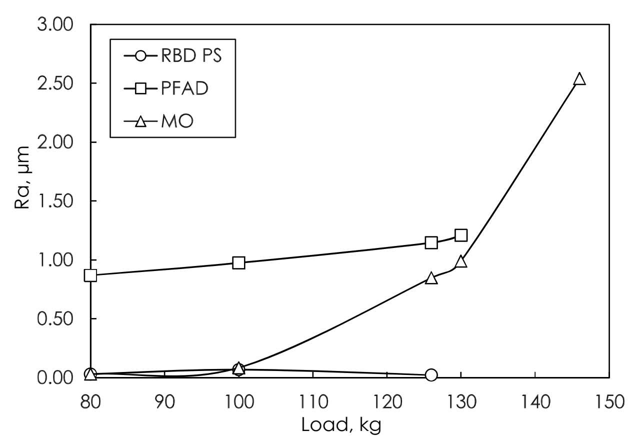


Figure 7 Surface roughness for extreme pressure test

4.0 CONCLUSION

The investigation on tribological behavior of RBD palm stearin and palm fatty acid distillate was completely obtained using fourball tribotester. The result was compared mutually with mineral oil as lubricants. The viscosity of lubricant is directly proportional to the lubricant temperature. The friction coefficient obtained lubricated with palm fatty acid distillate and RBD palm stearin is better than mineral oil for at static loads but after loads increases, mineral oil performed better. The results for wear scar diameter also shows the similar outcome where at static load of 40kg in anti-wear test, palm based oil are better than mineral oil and vise-versa at increasing load. RBD palm stearin reach the 4mm wear scar failure limit earliest at 126kg followed by palm fatty acid distillate and mineral oil at 130kg and 146kg load. The free unsaturated fatty acids play an important role in reducing friction coefficient and wear. The mineral oil also shows the ability to reduce wear at increasing loads because it is formulated with the additives thus increase the anti-wear performance. RBD palm stearin gives the lowest value of R_a in the extreme pressure test. This concluded that bio-based oil from palm oil such as RBD PS and PFAD has a potential to replace or substituting the commercial petroleum based oil.

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