



## Tribological behaviour of refined bleached and deodorized palm olein in different loads using a four-ball tribotester

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### KEYWORDS

Palm olein;  
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**Abstract** Vegetable oil is one of the bio-oils that have been promoted to replace petroleum-based products due to its eco-friendly characteristics. Palm oil has high productivity rate, and so it could fulfil the demand for a bio-lubricant. In this paper, the influence of the normal load on friction and wear performance were investigated for a RBD palm olein and compared with paraffinic mineral oil using four-ball tribotester. The normal load was varied from 30 kg to 60 kg. All experimental works were conforming to ASTM D 4172. The results exhibited that the RBD palm olein has lower coefficient of friction compared to paraffinic mineral oil. However, the wear scar of ball bearings lubricated with RBD palm olein showed larger diameter compared to paraffinic mineral oil. As a conclusion, RBD palm olein has better performance compared to paraffinic mineral oil in terms of capability to reduce friction.

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### 1. Introduction

The development of lubricant is not only based on the properties of the lubricant itself. The parameters, such as speeds, load and temperature at the surface, require scientists to study and understand the changes occurring in the bulk materials when the surfaces of the materials are moving relatively to each other. Joseph et al. [1] state that in order to understand the effects on friction and wear, researchers must also understand the reactions between the materials and the fluid present between the two moving surfaces [1]. Lubricants play a very important role in minimising the wear in a mechanical system so that the system can operate for the extended period. On the other hand, Michael et al. [2] proposed that developing lubricants that can be used in engineering systems without replenishment is very

important for increasing the functional lifetime of mechanical components [2]. Apart from that, additives are usually mixed into the base oil to improve its performance. Joseph et al. [1] stated that the number and amount of additives present depend on the application [1]. They are selected to enhance the base oil performance so that the combination will meet the system requirements.

Starting in the early 19th century, engineers and researchers found an effective solution to increase the production of petroleum. This has led to the production of low-priced petroleum-based lubricants, which brought into society the greenhouse effect and the issue of global warming. The increase of worldwide concerns about health, the environment and limited petroleum resources has promoted the use of biodegradable products. Special attention has been paid to protecting the environment against pollution caused by the petroleum-based lubricants. Delgado et al. [3] conducted a survey which found out that nearly 12 million tons of lubricant wastes were deposited into the environment every year [3]. As a result of increasing awareness of ecological pollution, biodegradable oil products are becoming an important alternative to conventional lubricants. Animal fat and vegetable oil are considered as substitutes for mineral-based oil as a lubricant. Nosonovsky [4] found out that vegetable oils were used in the construction of

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monuments in ancient Egypt. Based on this statement, the usage of vegetable oil as a lubricant in the industrial sector is not an impossible work [4].

The advantages of choosing vegetable oil rather than lubricants from other sources are the fact that they are biodegradable and are less toxic when compared to petroleum-based oil. They are easy to produce and form a renewable source. In addition, when Kalin and Vizintin [5] investigated the tribological behaviour of the two moving metals using biodegradable oil compared to mineral oil, they showed that the vegetable oils possess even a better lubricating ability than the current mineral or synthetic oils because they contain a large amount of unsaturated and polar ester groups components that favourably affected the conditions during reciprocating sliding [5]. Furthermore, the long-chain fatty acids present in vegetable oil have better intrinsic boundary lubricant properties. Vegetable oils show good lubricating abilities because they give rise to the low coefficients of friction. However, many researchers report that even when the coefficient of friction is low with vegetable oil as the boundary lubricant, the wear rate is high. Bowden and Tabor [6] investigated the chemical attack on the surface by the fatty acid present in the vegetable oil [6]. They found out that the metallic soap film is rubbed away during sliding, and producing the non-reactive detergents increases wear.

Several researchers have tested palm oil for engineering applications. Bari et al. [7] included palm oil as a potential fuel in diesel engines [7], Wan Nik et al. [8] studied the potential of palm oil as hydraulic fluid [8], and Syahrullail and his colleagues investigated the characteristics of palm oil as a metal forming lubricant [9,10]. The research on palm oil as lubricant can be categorized into four (4) major groups, which (1) uses 100% palm oil as a test lubricant [11,12], (2) uses palm oil emulsion [13,14] and (3) uses palm oil with additive [15,16] and (4) uses palm oil as an additive [17]. All of them found out that palm oil showed satisfactory results and has a bright future to be used widely in engineering applications. However, some factors such as the oxidation of vegetable oil must be taken into consideration. In the early 1990s, the Palm Oil Research Institute of Malaysia – PORIM (presently known as Malaysian Palm Oil Board – MPOB) successfully converted crude palm oil into palm oil methyl ester. PORIM used the trans-esterification method, which shortens the molecular chain in the palm oil to twenty molecules from about fifty seven, reducing the palm oil viscosity and making it less polluting. According to Maleque and Masjuki [12], the trans-esterification also improved the thermal stability of palm oil [12]. In the previous studies, researchers used various vegetable-oil-based lubricants and additives, but there are very limited references that used Refined, Bleached and Deodorized (RBD) palm olein as the base lubricant or additive.

This study is to investigate the coefficient of friction and wear performance of RBD palm olein using a four-ball tribotester. The RBD palm olein is a refined palm oil product that is liquid at room temperature. The comparison lubricant is additive-free paraffinic mineral oil. The experiments were conducted under various normal loads. The results demonstrate that RBD palm olein shows lower coefficient of friction compared to paraffinic mineral oil for all normal loads applied. However, ball bearings that lubricated with RBD palm olein shows larger wear scar area compared to those lubricated with paraffinic mineral oil.



Figure 1: Four-ball tribotester machine.

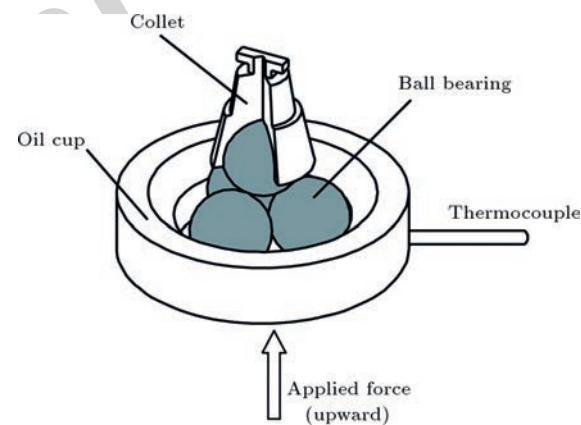


Figure 2: The schematic diagram of four-ball tribotester.

## 2. Experimental method

### 2.1. Apparatus

The research for this study used a four-ball wear tester. The four-ball wear machine was first described by Boerlage [18] as already having acquired the status of an established institution in the fundamental investigation of characteristics of the lubricants. This instrument uses four balls, three balls at the bottom and one ball on the top. The three-bottom balls are held firmly in a ball pot containing the lubricant being tested and pressed against the top ball. The top ball is made to rotate at the desired speed while the bottom three balls are pressed against it.

Figure 1 shows a four-ball tribotester machine, and the important components are the oil cup assembly, collect, and ball bearings, as shown in Figure 2. The surfaces of the components were cleaned with acetone before conducting each test.

Table 1: Composition of palm olein [19].

Fatty acid	C-atoms	Saturation	Percentage (%)
Myristic acid	14	Saturated	1
Palmitic acid	16	Saturated	43
Stearic acid	18	Saturated	5
Oleic acid	18	Mono-unsaturated	39
Linoleic acid	18	Poly-unsaturated	11
Others	–	–	1

## 2.2. Materials

The standard balls used in this experiment are made from AISI E-52100 chrome alloy steel, with the following specifications: diameter 12.7 mm; extra polish (EP) grade 25; hardness 64–66 HRC (Rockwell C Hardness). Four new balls were used for each test. Each time before starting a new test, the balls were cleaned with acetone and wiped dry using a fresh lint-free industrial wipe.

## 2.3. Lubricants

The lubricants used for this experiment were RBD palm olein and paraffinic mineral oil. Palm oil industry is one of the biggest agricultural industries in Malaysia. Since a few decades ago, through institutions such as Malaysian Palm Oil Board (MPOB), Malaysia has successfully developed methods to refine palm oil. One of the products is RBD palm olein. RBD is an abbreviation of refined, bleached and deodorised, which means that this oil has gone through a purifying process to vanish the unnecessary fatty acid and odour. Then, it has also gone through fractionation process to extract the palm olein. Palm olein is the liquid fraction obtained from the fractionation of palm oil after crystallization at a controlled temperature. This research used a standard grade of RBD palm olein, which Pantzaris has incorporated in the Malaysian Standard [19] as MS 816:1991. In this study, RBD palm olein was chosen because of its refined condition and the composition of oleic acid that seemingly could help in reducing the friction. The composition of palm olein is shown in Table 1.

The results obtained from experiments using RBD palm olein were compared with the results from the experiment which used paraffinic mineral oil. From the chemical bonding point of view, palm olein has a straight chain. This molecule chain is similar to the molecule chain in paraffinic mineral oil. To make sure the comparison is fair enough, an almost similar viscosity of paraffinic mineral oil was chosen. Besides that, almost all the lubricants in industrial are made based on paraffinic mineral oil. Another type of oil is naphthenic mineral oil. This type of oil has a benzene ring that is normally contributed to high resistance, which could provide high load or friction coefficient. Each trial tested 10 ml of the lubricant.

## 2.4. Test procedures

To set up the steel balls, the ball pot and the steel balls were thoroughly cleaned using acetone and wiped dry using a fresh lint free industrial wipe. No trace of solvent should have remained when the lubricant was introduced and the parts were assembled.

The steel ball bearings were placed into the ball pot assembly and the assembly was tightened using a torque wrench in order to prevent the bottom steel balls from moving during the experiment. The top, spinning ball was locked inside the

collector and tightened onto the spindle, then the test lubricant was introduced into the ball pot assembly. The researcher observed that the oil level filled all the voids in the test cup assembly. The assembled ball pot components were installed onto the non-friction disc in the four-ball machine and the test load was applied slowly to avoid shock loading. Next, the lubricant being tested was heated to 75 °C by the tribotester's built-in heater. When the set temperature was reached, the researcher would start the drive motor which had been set to drive the top ball at a desired speed. After one hour, the heater was turned off and the oil cup assembly was removed from the machine. The test oil was drained off from the oil cup and the ball bearings were wiped using a fresh lint free industrial wipe.

An oil cup with three fixed ball bearings was put under a specific CCD microscope. Using image capture software, the wear scar on the ball bearings surface was captured and the diameter of the wear scar was measured using specific measurement software.

## 2.5. Friction evaluation

From the four-ball tribotester machine, the friction torque was recorded using specific data acquisition system. The friction torque for all test lubricants increased rapidly at the beginning of the test. After 5–10 min, the friction torque data became a steady-state condition. The average of friction torque at the steady state condition was recorded and the friction coefficient, as calculated according to IP-239, is expressed as follows:

$$\mu = \frac{T\sqrt{6}}{3Wr}, \quad (1)$$

where  $\mu$  is the friction coefficient,  $T$  is the frictional torque in kg mm,  $W$  is the applied load in kg and  $r$  is the distance from the centre of the contact surface on the lower balls to the axis of rotation, which was determined to be 3.67 mm. The same calculation method was used by Thorp [20] and Ing et al. [11]. The frictional torque data was recorded by the computer, which calculated the friction coefficient automatically.

## 3. Result and discussion

### 3.1. Density and dynamic viscosity

The density of fluids is defined as the unit of mass per volume. A laboratory experiment had been carried out to measure the density of RBD palm olein and paraffinic mineral oil using a hydrometer. Dynamic viscosity is a measure of the resistance of a fluid which is deformed by either the shear stress or the tensile stress of the fluids. It is also known as the internal friction of the fluids.

A viscometer was used to measure the viscosity for both lubricants. To evaluate fluidity, the viscometer rotor was immersed into the lubricants and turned for a certain period of time. The viscometer has a spindle that rotates with a certain speed. After inserting the spindle into the lubricant, the speed of the spindle resisted the fluidity or viscosity of the lubricant and the viscosity could be calculated. As shown in Table 2, the viscosity of both lubricants decreases as the temperature of the lubricants increases. This indicates that the fluidity of the lubricant also increases as the temperature increases. The more fluid the lubricant is, the easier it is for the particles in the fluids to move. Hence, the temperature of the fluids also influences the viscosity of the fluids.

Table 2: Properties for RBD palm olein and paraffinic mineral oil.

Parameter	RBD palm olein	Paraffinic mineral oil	Test method
Density at 25 °C, kg/m <sup>3</sup>	915.5	848.0	ASTM D1298-85(90)
Dynamic viscosity at 40 °C, mPa s	34.8	31.6	ASTM D445-94
Dynamic viscosity at 75 °C, mPa s	17.5	18.6	ASTM D445-94
Dynamic viscosity at 100 °C, mPa s	13.2	14.1	ASTM D445-94

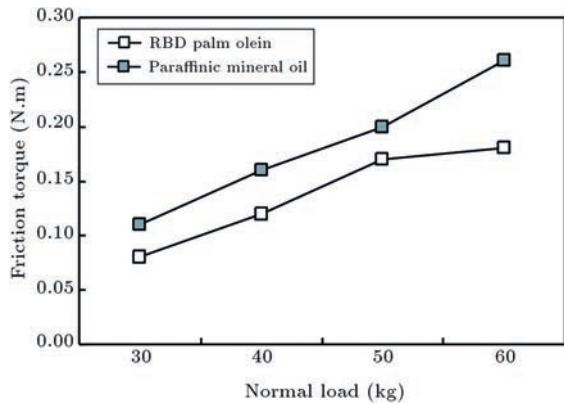


Figure 3: Friction torque for RBD palm olein and paraffinic mineral oil for various normal load.

### 3.2. The effects of normal load on friction

To study the friction performance of RBD palm olein under different normal loads, experiments were conducted varying the normal loads at 30, 40, 50 and 60 kg, and keeping the rotational speed at 1200 rpm and the bulk oil temperature at 75 °C for one hour.

The results of the friction torque tests were plotted and are illustrated in Figure 3. The friction torque results of RBD palm olein were compared mutually with the paraffinic mineral oil. The friction torque for both lubricants showed similar trends from the normal load tests at 30–50 kg; the friction torque obtained increased proportionately to the increment of normal load. When the normal load was increased to 60 kg, however, the friction torque obtained from the RBD palm olein experiment remained at about 0.17 N m, while the friction torque obtained from the paraffinic mineral oil increased by almost 0.25 N m.

RBD palm olein contains fatty acids that help the lubricant molecules to stick on the ball bearing surface very well and maintain the lubricant layer. The presence of thin lubricant films of lubricant between the ball bearing surfaces minimized the material transfer and adhesion of the two surfaces. This makes RBD palm olein have lower friction torque compared to paraffinic mineral oil.

The coefficients of friction for RBD palm olein and paraffinic mineral oil under each experimental condition were calculated and plotted as shown in Figure 4. An increment of normal load slightly increases the coefficient of friction. In average, RBD palm olein and paraffinic mineral oil have a coefficient of friction of 0.07 and 0.09, respectively.

### 3.3. The effects of normal load on wear scar

The wear scar diameters of the three bottom ball bearings were measured using a special microscope and the mean values

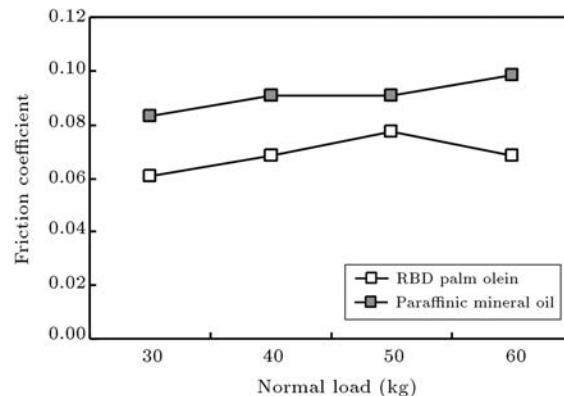


Figure 4: Friction coefficients for RBD palm olein and paraffinic mineral oil for various normal loads.

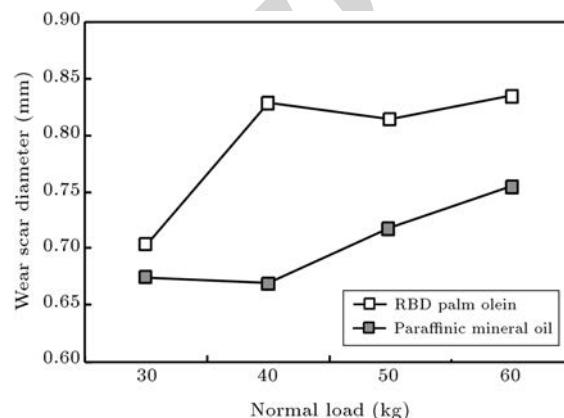


Figure 5: Wear scar diameter for RBD palm olein and paraffinic mineral oil for various normal loads.

were calculated. Figure 5 shows the mean value of the Mean Wear Scar Diameter (MWSD) for each normal load. The figure shows clearly that the MWSD increases gradually with an increase in the normal load.

The MWSD for ball bearings lubricated with the RBD palm olein was higher than the ball bearings lubricated with the paraffinic mineral oil under all experimental conditions. For the RBD palm olein at 30 kg normal load, the MWSD was 0.7 mm. At the normal load of 40–60 kg, the RBD palm olein was able to retain the value of MWSD at about 0.8–0.84 mm. The interaction between the lubricant and the metal surfaces, and the reduction in the pressure caused the value of MWSD to increase. A similar result was found by Bhattacharya et al. [21]. The increment of the mean wear scar diameter was also caused by chemical attack on the rubbing surfaces by the fatty acid in the RBD palm olein [6].

For the paraffinic mineral oil, at the normal load of 30 kg and 40 kg, there were no obvious increments of the MWSD; the value was around 0.68 mm. Starting from the normal load of 50 kg, the MWSD of ball bearings lubricated with paraffinic mineral oil started to increase gradually. The MWSD at a normal load of 60 kg was 0.75 mm.

### 3.4. Wear worn surface characteristics

Figure 6 shows micrographs of wear-worn surfaces produced after the one-hour tests lubricated with the RBD palm olein and paraffinic mineral oil under different applied loads.

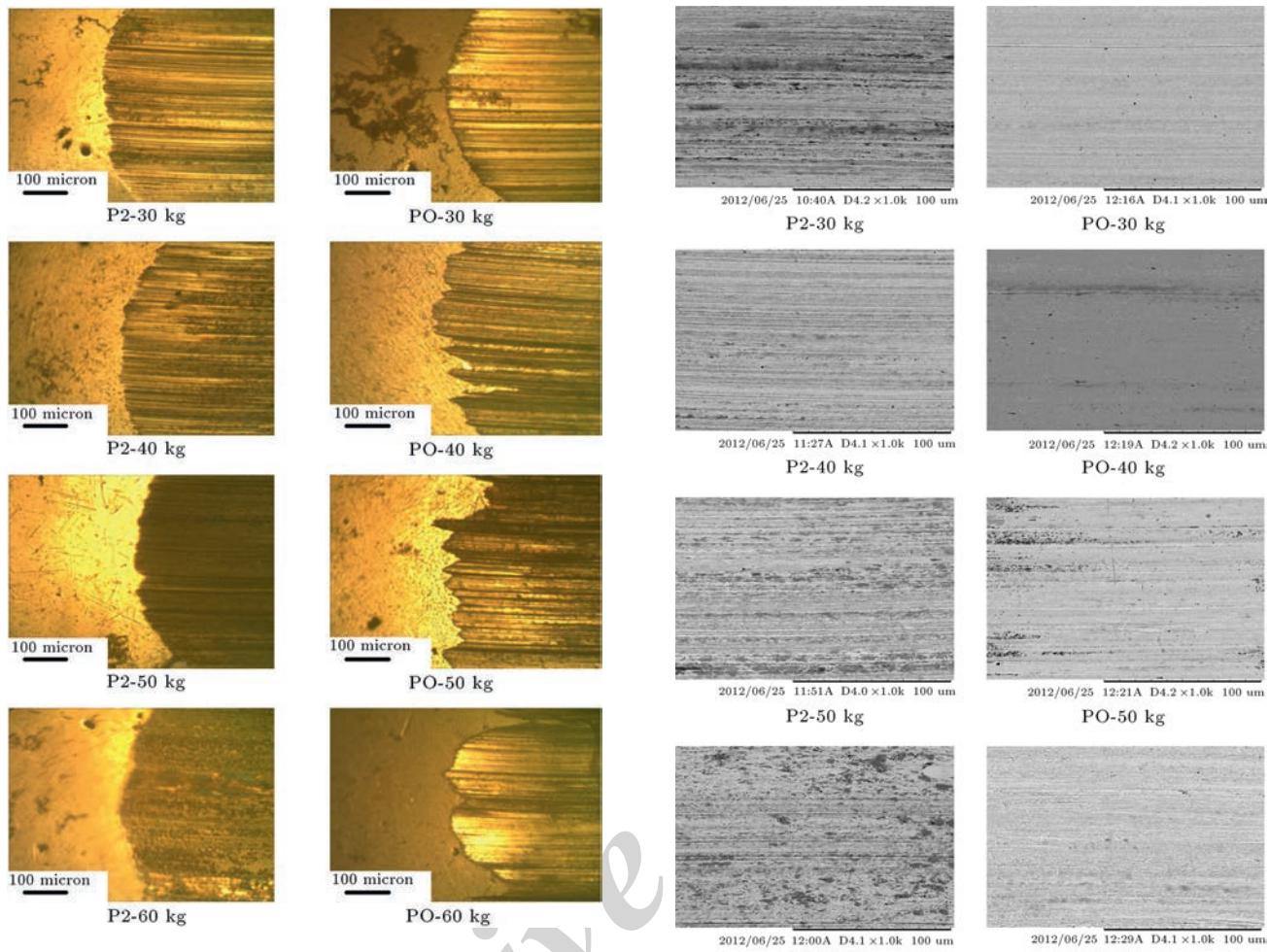


Figure 6: Micrographs of wear worn surface of ball specimens at various normal loads.

Based on the result from Figure 5, it was found out that wear scar for ball bearings lubricated with both lubricants, RBD palm olein and paraffinic mineral, increased when the normal load was increased. From Figure 6, it was found out that for ball bearings lubricated with paraffinic mineral oil, at all the normal load conditions, the wear scars were circular in shape. For normal loads of 50 and 60 kg, the edge were slightly ragged and obscured by metal particle. The worn surface showed abrasive wear and no severe adhesive wear was found. For the ball bearing lubricated with RBD palm olein, only the condition with 30 kg normal load showed the circular wear scar. For the condition with 40–60 kg of normal loads, the edge of the wear scar was totally ragged. Similar to the worn surface of ball bearings lubricated with paraffinic mineral oil, the abrasive wear occurred but no severe adhesive wear was found. For both lubricants, RBD palm olein and paraffinic mineral oil, there were parallel grooves found on the worn surface. Some of the grooves were deep (dark region) and some were shallow (light colour region). Figure 7 shows the SEM photographs for all worn surfaces lubricated with RBD palm olein and paraffinic mineral oil. For those lubricated with RBD palm olein, a thin film reaction seemed to have formed to prevent metallic contact at the smooth surface region whereas for those lubricated with the paraffinic mineral oil, the thin films had broken, and rough region and adhesive wear was possible to occur. The black spot on the worn surface indicated that metal-to-metal contact occurred. Therefore, the RBD palm olein could reduce the

Figure 7: SEM pictures of the worn surface of ball specimens at various normal loads.

metal-to-metal contact and parallel with that, the coefficient of friction for RBD palm was smaller compared to paraffinic mineral oil.

Although the wear scar of the ball bearings lubricated with RBD palm olein was bigger compared to those lubricated with paraffinic mineral oil, the fatty acid in the RBD palm olein helped the lubricant to adsorb onto the metal surface very well and this factor also led to the reduction of the friction coefficient of RBD palm olein. The increment of the wear scar for ball bearings lubricated with RBD palm olein was also caused by the oxygen composition in RBD palm olein that created a tribochemical reaction (the oxygen oxidised the metal surface) and weakened the metal surface. As a result, the metal surface would break easily. A similar study was done by Masabumi et al. [22], and Bowden and Tabor [6], who investigated the tribochemical wear indicated by a smooth and flat surface where the partial tribochemical reaction between the material and the lubricant had occurred [22,6].

#### 4. Conclusion

The tribology behaviour of RBD palm olein at different normal load was evaluated using the four-ball tribotester machine. All the results were compared mutually with additive free paraffinic mineral oil. From the results, it can be concluded

that RBD palm olein showed a lower coefficient of friction compared to the paraffinic mineral oil under all tests at various normal loads. However, RBD palm olein creates larger wear scar compared to paraffinic mineral oil in all experimental condition. From the observation of wear scar condition, both lubricants show abrasive wear. No severe adhesive wear was found.

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