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# Experimental Evaluation on Lubricity of RBD Palm Olein Using Fourball Tribotester

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## 1. Introduction

Tribology is defined as “the science and technology of surface interacting in motion”. Thus it is important for us to understand the surface interaction when they are loaded together as to understand the tribology process occurring in the system. The physical, chemical and mechanical properties not only cause the effects to the surface material in tribology behavior but also the near surface material. Apart from that, on the surface of the bulk material, lies a layer formed as a result from the manufacturing process. This deformed layer is covered by a compound layer resulting of chemical reaction of metal with the environmental substance such as air. In addition, the machining process such as cutting lubricants to be trapped may also cause the deformed regions of the surface. The regions on the surface material can critically affect both friction and wear of metals. In addition, the forces which arise from the contact of solid bodies in relative motion also affect both friction and wear. Thus, it is important for us to understand the mechanics contact of solid bodies in order to evaluate the friction and wear on solid bodies. Solid bodies are subjected to an increasing load deform elastically until the stress reaches a limit or maximum yield stress then deform plastically (Gohar and Rahnejat, 2008).

Friction is known as resistance to motion. Friction can be categorized into five types; which are dry friction, fluid friction, lubricated friction, skin friction and internal friction. The friction forces are divided into two types; static friction force which is required to initiate sliding, and kinetic friction force which is required to maintain sliding. Coefficient of friction is known as the constant of proportionality in which the typical two materials may be similar or dissimilar, sliding against each other under a given set of surfaces and environmental conditions (Arnell and Davies, 1991).

The first laboratory test device for determining lubricant quality was known as fourball tribotester is proposed by Boerlage in the year of 1993 (Ivan, 1980). The concept of friction for this machine is three stationary balls pressed against a rotating ball. The quality and the characteristics of the lubricant were established by the size of the wear scar or the seizure load and the value of friction obtained. The main elements of fourball machine are vertical driving shaft which hold the moving ball at the lower end with conical devices. Besides that,

three stationary balls which are fixed by a conical ring and lock nut are pressed by the moving ball. The stationary ball holder is mounted on an axial bearing so that it can rotate and displace in the vertical direction freely. In addition, a lever device is used to apply load on stationary balls. The friction occurring on the fixed stationary balls by the rotating ball is transmitted by means of a lever to the measuring device. The wear is viewed based on the size of the wear scar on the stationary balls. 12.7mm diameter of balls is usually used. These are specially processed to ensure high dimensional accuracy as well as uniform hardness and surface quality. The tested lubricant was immersed into the stationary balls cup hold with desire volume. Apart from that, the speed for rotating ball depends on the type of machine and the experiment conditions. There are several standards and specifications for fourball machine: such as Socialist Republic of Romania State Standard 8618-70; FTM no. 791 a/ 6503; ASTM D2596-67 and DIN 51350 (Ivan, 1980).

Boundary lubrication is defined as a condition of lubrication in which the friction and wear between two surfaces in relative motion are determined by the properties of lubricant. Lubrication is critical for minimizing the wear in mechanical systems that operate for extended time period. Developing lubricants that can be used in engineering systems without replenishment is very important for increasing the functional lifetime of mechanical components. The additives usually to be added in to the base oil to improve its performance. Joseph Perez stated that the number of additives and the amount present depends on the application (Joseph and Waleska, 2005). They are selected to enhance the base oil performance so that they will meet the system requirement.

The increasing and wide usage of petro and synthetic based oil overwhelm the lubricant industry because the major damage to the environment and the rise of concern about health and environmental damage caused by the mineral oil based lubricant; have created a growing worldwide trend of promoting vegetable oil as based oil in industries. Biodegradable oils are becoming an important alternative to conventional lubricants as a result of awareness of ecological pollution and their detrimental effects on our lives. The use of vegetable oils in industrial sector is not a new idea. They had been used in the construction of monuments in Ancient Egypt (Nosonovsky, 2000). Vegetable oil with high stearic acid content is considered to be potential candidates as the substitute for conventional mineral oil based lubricants because they are biodegradable and non toxic. Besides that, they have better intrinsic boundary lubricant properties because of the presence of long chain fatty acids in their composition (Carcel and Palomares, 2004). Other advantages include very low volatility due to the high molecular weight of triglyceride molecule and excellent temperature viscosity properties. Their polar ester groups are able to adhere to metal surface and therefore possess good lubricating ability. In addition, vegetable oils have high solution power for polar contaminants and additive molecules (Sevim et al, 2006). Vegetable oils show good lubricating abilities as they give rise to low coefficient of friction. However, many researchers report that although the co-efficiency of friction is low with vegetable oil as boundary lubricant, the wear rate is high. This behavior is possible due to the chemical attack on the surface by the fatty acid present in vegetable oil. The metallic soap film is rubbed away during sliding and producing the non-reactive detergents increase in wear (Bowden and Tabor, 2001).

In western country, the common vegetable oils that have been widely used in the tribology test are sunflower oil, rapeseed oil and corn oil. For this research, the authors used RBD palm olein as test oil and evaluated its friction and wear performance using fourball tribotester. Nowadays, palm oil has been widely tested for engineering applications. The

potential of palm oil as fuels for diesel engines (Kinoshita et al, 2003; Bari et al, 2002), hydraulic fluid (Wan Nik et al, 2002), and lubricants (Syahrullail et al., 2011) has been confirmed in previous studies. In addition, Malaysia is one of the world's largest palm oil producers.

Throughout all the previous studies, the characteristics of RBD palm olein were investigated using fourball tribotester. The objective of this experiment is to study the lubricity characteristics of vegetable oils compared to the petroleum based oil. RBD palm olein and additive free paraffinic mineral oil were used as lubricants in this experiment. RBD palm olein is a refined, bleached and deodorized palm olein product and it exists in liquid state at room temperature. Fourball tester was used in this experiment to evaluate the lubricity of those lubricants. The lubricity performance of RBD palm olein and non-additive paraffinic mineral oil were compared mutually. The experiments were carried out at the temperature of 75°C for one hour duration. Besides that, the load applied on the fourball tester was 40 kg (392.4N). Apart from that, the speed of spindle was set to 1200 rpm. At the end of the experiments, the evaluations of lubricants focused on the friction and wear of each lubricant. From the experiments, the authors confirmed that RBD palm olein showed satisfactory lubrication performance as compared to additive free paraffinic mineral oil, especially in terms of friction reduction.

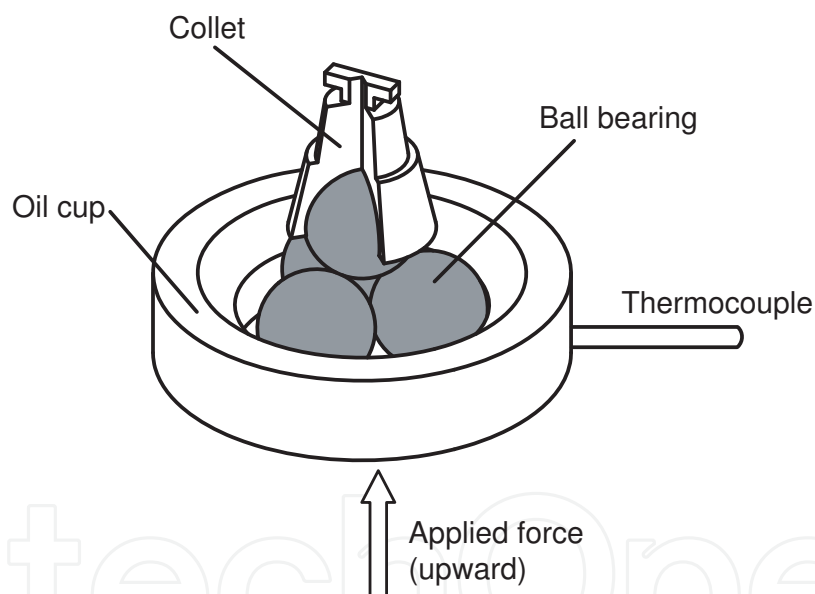


Fig. 1. A schematic sketch of the fourball tribotester

## 2. Experimental procedures

### 2.1 Experimental apparatus

The fourball wear tester machine was first described by Boerlage to have acquired the status of an established institution in the fundamental investigation of lubricants characteristics (Boerlage, 1933). In this research, the fourball wear tester was used. This instrument uses four balls, three at the bottom and one on top. The bottom three balls are held firmly in a ball pot containing the lubricant under test 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. The important components are ballpot (oil cup) assembly, collet, locknut adaptor and standard

steel balls. The components surface needs to be clean with acetone before the tests. The amount of lubricant test is 10 ml.

## 2.2 Test lubricants

The tested lubricants for this experiment were RBD palm olein and additive free paraffinic mineral oil (written as paraffinic mineral oil). The RBD is an abbreviation for refined, bleached and deodorized. As shown in Figure 2, RBD palm olein is the liquid fraction that is obtained by the fractionation of palm oil after crystallization at a controlled temperature (Pantzaris, 2000). In these experiments, a standard grade of RBD palm olein, which was incorporated in the Malaysian Standard MS 816:1991, was used. The amount for all lubricant tests is 10 ml.

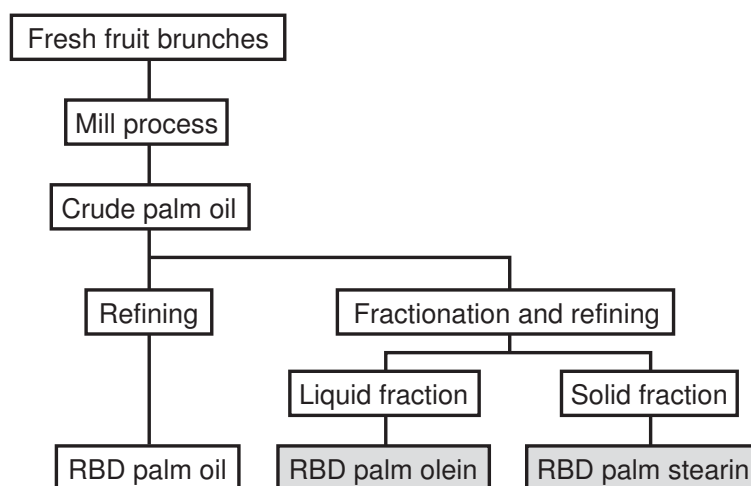


Fig. 2. Refining method of RBD palm olein

## 2.3 Experimental procedures

The wear tests were carried out under the ASTM method D-4172 method B with the applied load of 392.4 N (40 kg) at a spindle speed of 1200 revolution per minute (rpm). The experiment was carried out for duration of one hour and conducted under the temperature of 75 degree Celsius. The three bottoms stationary balls in the wear test were evaluated the average diameter of the circular scar formed. Besides that, the lubricating ability of the RBD palm olein was also being evaluated based on the friction torque produced compared with the additive free paraffinic mineral oil. All parts in fourball (upper ball, lower balls and oil cup) were cleaned thoroughly using acetone and wiped using a fresh lint free industrial wipe. There should not be any trace of solvent remain when the test oil was introduced and the parts were assembled. The steel balls were placed into the ballpot assembly and to be tightened using torque wrench. This purpose was to prevent the bottoms steel balls from moving during the experiment. The top spinning ball was locked inside the collector and tightened into the spindle. 10 ml of test lubricant (RBD palm olein or paraffinic mineral oil) was to be poured into the ballpot assembly. Apart from that, researcher should note or observe that this oil level filled all the voids in the test cup assembly. The ballpot assembly components were installed onto the non-friction disc in the four-ball machine and avoided shock loading by slowly applying the test load up to 392.4 N. After that, the lubricant used was heated up to 75 degree Celsius. When the set temperature was reached, researcher

started the drive motor which had been set to drive the top ball at 1200 rpm. For the duration of one hour, the heater was turned off and the oil cup assembly was removed from the machine. Then, the test oil in the oil cup was drained off and wear scar area was wiped using tissue. The wear scars on the bottom balls were put on a special base of a microscope that has been designed for the purpose. All tests were repeated several times.

### 3. Results and discussions

#### 3.1 Density and viscosity

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. The result was shown in Table 1. Dynamic viscosity is a measure of the resistance of a fluid which is formed by either shear stress or 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. Viscometer rotor was immersed into the lubricants to evaluate its fluidity by turning the rotor for 99 seconds. The viscosity of the RBD palm olein and paraffinic mineral oil was shown in Figure 3. The viscosity of both lubricants dropped as the temperature of the lubricants increased. The lesser the viscosity of the fluids, the easier the particles will move in the fluids.

Test oil	RBD palm olein	Paraffinic mineral oil
Density at 25°C (kg/ m <sup>3</sup> )	915	848
Flash point (°C)	315-330	140-180
Pour point (°C)	18-24	-20

Table 1. Properties of RBD palm olein and paraffinic mineral oil

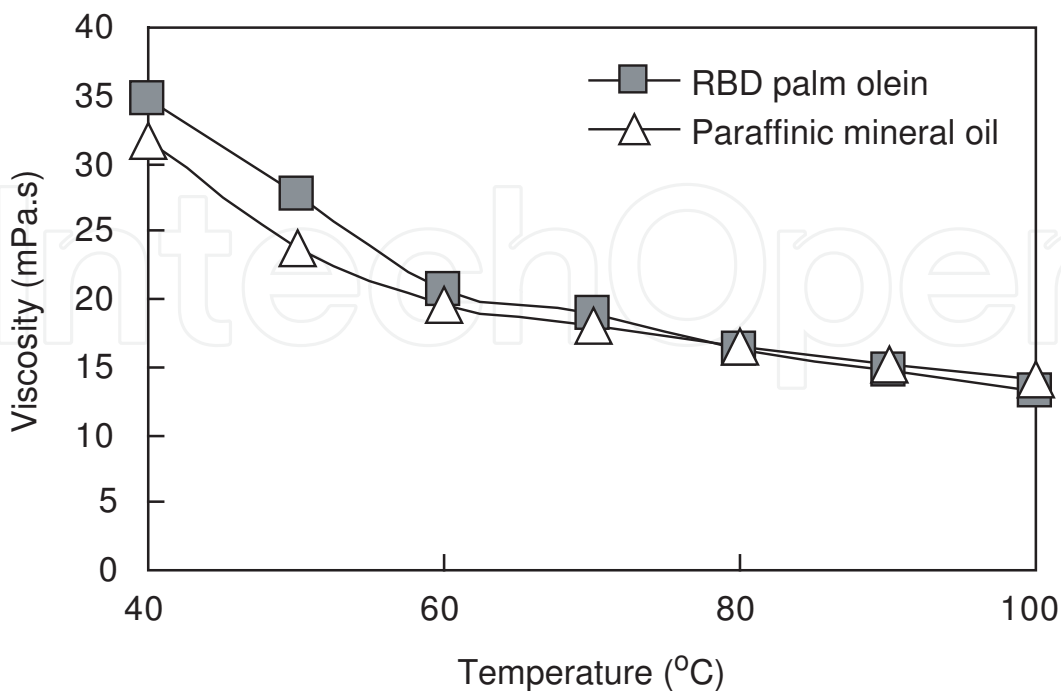


Fig. 3. Viscosity curves of RBD palm olein and paraffinic mineral oil



### 3.2 Friction

$$F = \mu \cdot N$$

The friction coefficient ( $\mu$ ) between two solid surfaces is defined as the ratio of the tangential force ( $F$ ) which required sliding, and is divided by the normal force between the surfaces ( $N$ ) (Jamal, 2008). Coefficient of friction for RBD palm olein and paraffinic mineral oil had been obtained using the relevant software. Figure 4 shows the value of coefficient of friction at steady state for both lubricants in the fourball tribotester. The coefficient of friction for RBD palm olein is lower than paraffinic mineral oil. As shown in Figure 5 the steady state friction torque for RBD palm olein is lower than paraffin mineral oil, thus the steady state coefficient of friction also shows the same trend of result. From the experiment, the value of coefficient of friction for RBD palm olein is 0.065 while the value of coefficient of friction for paraffinic mineral oil is 0.075.

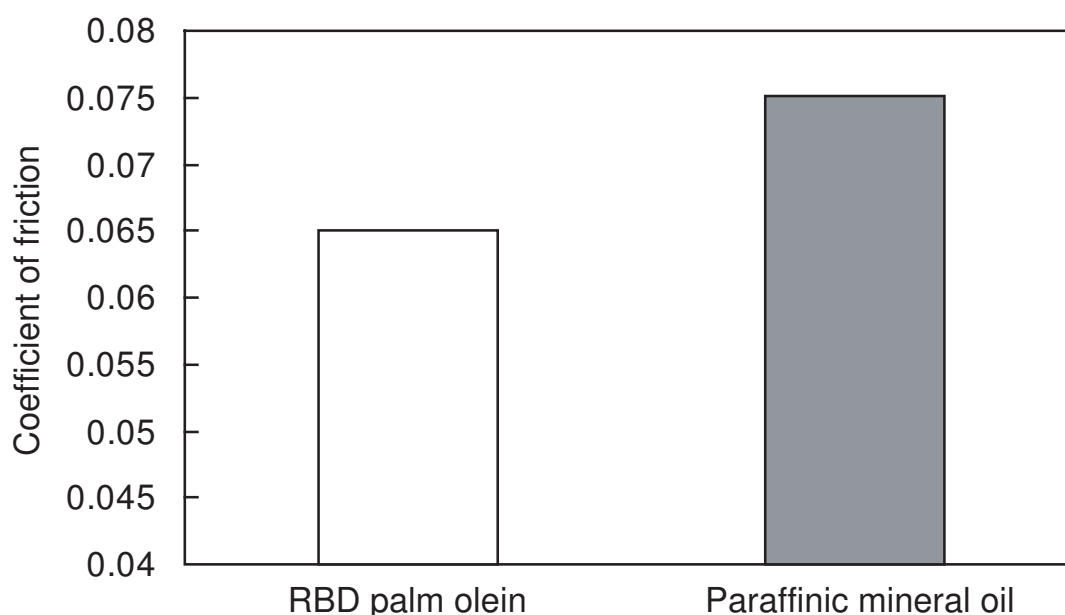


Fig. 4. Coefficient of friction for RBD palm olein and paraffinic mineral oil at steady state condition

Few series of wear tests had been conducted using fourball tribotester. Figure 4 illustrates the friction torque obtained for RBD palm olein and paraffinic mineral oil using fourball tribotester along the period of experiments. The trend of graph for both lubricants was similar to each other. The friction torque for both lubricants was increased along the period of experiments. In Figure 5 the friction torque of RBD palm olein is lower than paraffinic mineral oil. The value of friction torque at steady state for RBD palm olein and paraffinic mineral oil is 0.12 Nm and 0.14 Nm respectively. Based on the previous study, the long chain of fatty acids present in the palm oil has the potential to reduce the friction constraint (Abdulquadir and Adeyemi, 2008).

### 3.3 Wear

The wear scar on the surface of balls bearing was obtained and measured using the CCD microscope and its specific software. The measured wear scar diameter on the balls bearing

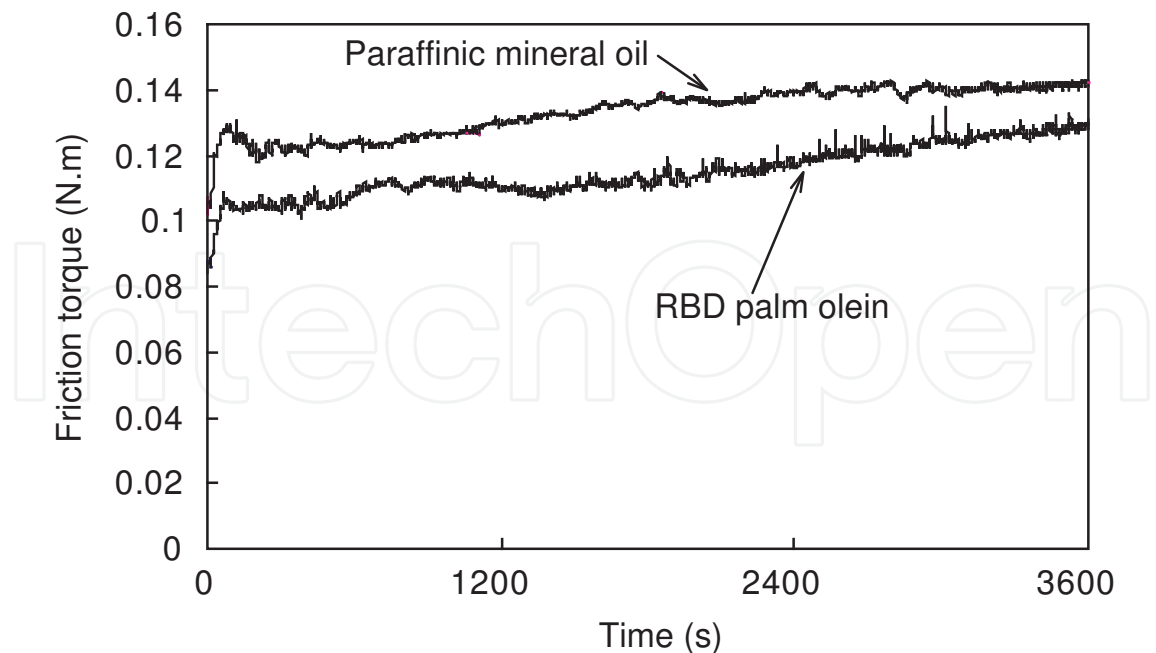


Fig. 5. Friction torque curves for RBD palm olein and paraffinic mineral oil

was recalculated to obtain the mean or average wear scar diameter for each lubricant test. Figure 6 illustrates the average wear scar diameter of fourball tribotester for RBD palm olein and paraffinic mineral oil. The average wear scar diameter measured for RBD palm olein is larger than paraffinic mineral oil in this experiment. RBD palm olein shows 0.828 mm and paraffinic mineral oil shows 0.764 mm in wear scar diameter. In addition, this result is totally opposite with the result of friction. The wear increases as the friction decreases as shown in Figure 4 and Figure 5. This due to the increased shear strength of the adsorbed oil on the surface of the balls and affected chemical attack on the surface by the fatty acid present in vegetable oil (Bowden and Tabor, 2001).

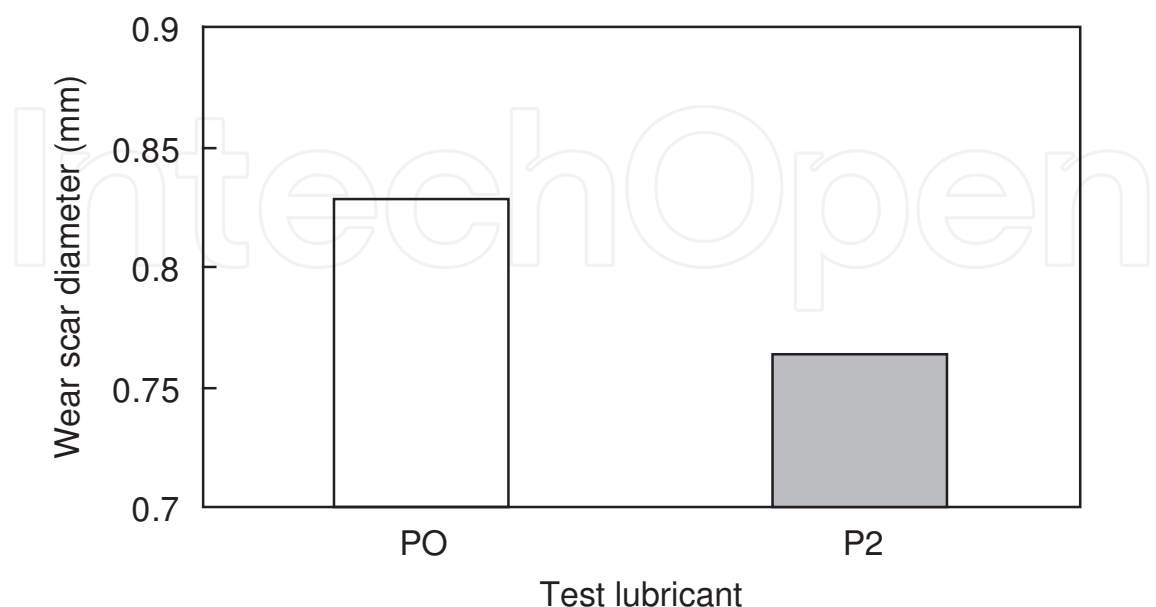


Fig. 6. Wear scar diameter for RBD palm olein and paraffinic mineral oil



Wear scar track that was lubricated with RBD palm olein and paraffinic mineral oil had been viewed and captured using the microscope. The enlargement of wear scar track for both tested oils is shown in Figure 6. The wear scar track on the ball bearing lubricated with RBD palm olein shows smoother surface than wear scar track lubricated with paraffin mineral oil on the surface of ball bearing. The wear scar worn on the ball bearing lubricated with paraffin mineral oil has more ploughed traces or grooves as the result of material transfer. The narrower and deeper of groove on the wear traces would be the sources of roughening the surface of ball bearing after the experiments (Meng and Jan, 2008).

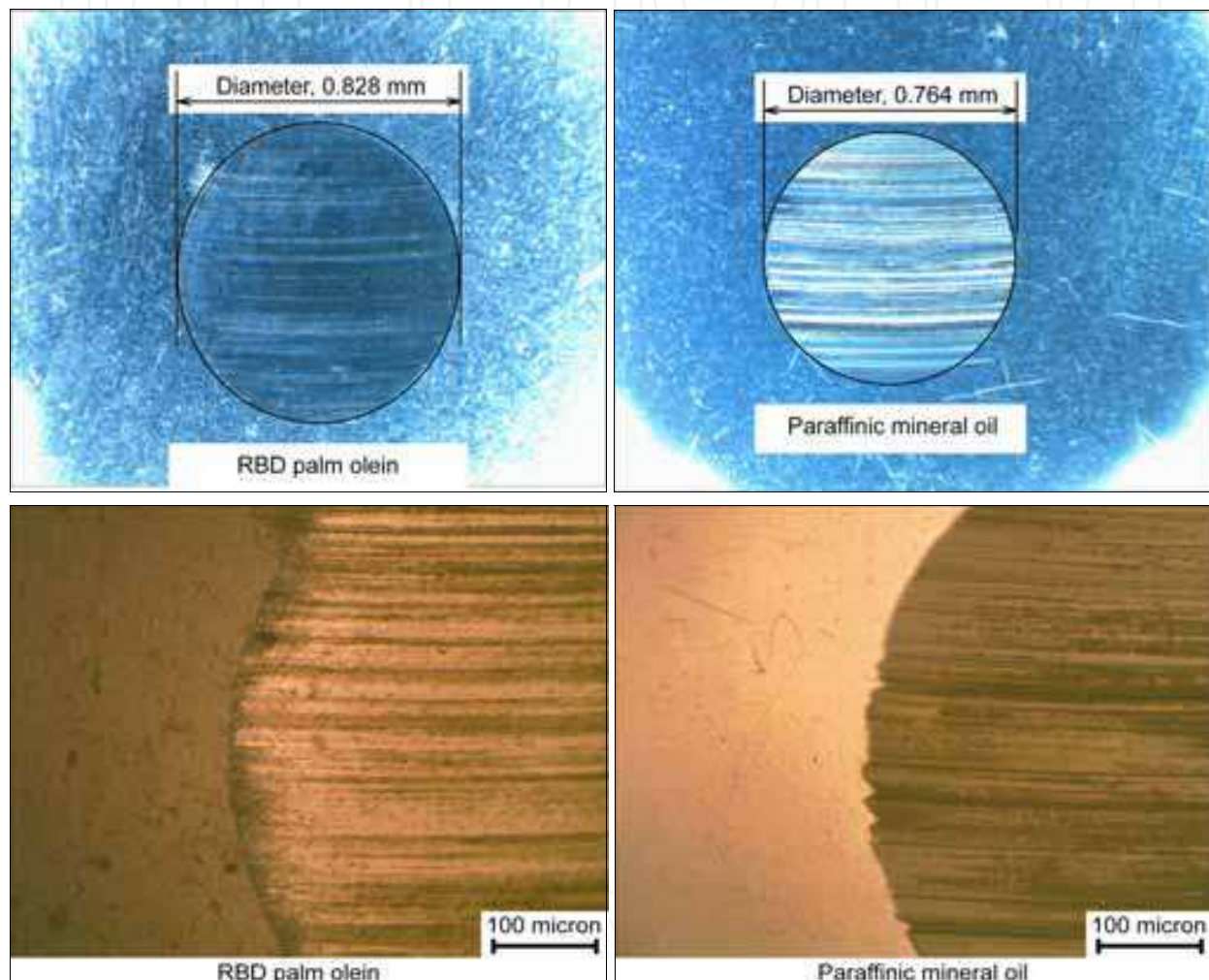


Fig. 7. Observation of the wear scar condition for RBD palm olein and paraffinic mineral oil

#### 4. Conclusion

The lubricating ability of RBD palm olein had been evaluated using the fourball tribotester. All the results were compared mutually with the additive free paraffinic mineral oil. For the reduction in friction, RBD palm olein shows better result compared to the additive free paraffinic mineral oil. RBD palm olein shows lower coefficient of friction and friction torque compared to the paraffinic mineral oil. This behavior is related to the long chain fatty acid in the RBD palm olein. However in wear, due to the increasing shear strength of the RBD palm olein on the surface of the balls, it shows larger wear scar diameter compared to the paraffin

mineral oil. Besides that, from the observation of scar view using CCD microscope, the scar surface of balls lubricated with RBD palm olein looks smoother than paraffinic mineral oil.

## 5. Acknowledgement

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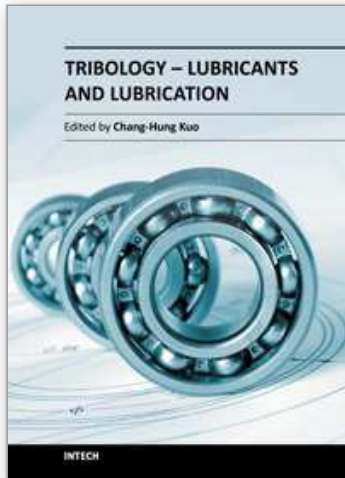
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In the past decades, significant advances in tribology have been made as engineers strive to develop more reliable and high performance products. The advancements are mainly driven by the evolution of computational techniques and experimental characterization that leads to a thorough understanding of tribological process on both macro- and microscales. The purpose of this book is to present recent progress of researchers on the hydrodynamic lubrication analysis and the lubrication tests for biodegradable lubricants.

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