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Development of palm oil blended with semi synthetic oil as a lubricant using four-ball tribotester

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HIGHLIGHTS

- *Coefficient of friction for all sample is reduce compare to engine oil.*
- *Improvement in wear scar diameter performance at 40% of palm olein.*
- *Improvement in surface roughness from all sample compare to engine oil.*

ABSTRACT

Due to environment concern, the current lubricant such mineral oil-based lubricant is not environmentally friendly as it were not readily biodegradable and toxic. Therefore, the vegetable oil-based lubricant has been promoted in order to replace mineral oil-based. In this study, the performance of lubricant for six different ratios between RBD Palm Olein and Semi-Synthetic oil were tested in different loads and been discussed in different parameters including coefficient of friction, wear scar diameter, surface roughness, flash temperature parameter and wear worn surface. Four-ball tribotester machine used to evaluate performance of sample lubricants using ASTM D4172 standard. From the results, it shows that the sample lubricants for engine oil mixing with RBD Palm Olein reduce in 38% of coefficient of friction compared to pure engine oil. From overall of the results, the performance of lubricant was improved as RBD Palm Olein mixing with engine oil.

Keywords:
| Engine oil | Palm olein | Four-ball tester | Coefficient of friction | Wear scar diameter |

1.0 INTRODUCTION

Lubricant is being developed not only based on their properties but it also requires the parameters such as load, temperature and speeds for the scientist to investigate the change that occurs on bulk material when the surface of material contact and moving relatively to each other. Lubrication is simply the use of material to improve the smoothness of movement of one surface over another, and the material, which is used in this way called a lubricant (Lansdown, 1982). Lubricants are also commonly used in reducing and minimising the friction and wear of interacting surface in mechanical system so that the system can operate smoothly and running in long period.

Mineral oil-based lubricants such as petroleum has been used widely in industrial lubrication especially for mechanics and engines industry. However, the used of this lubricants brought a risks to our environment which can cause a greenhouse effect and the issue of global warming since the mineral oil-based lubricants are not readily biodegradable and are toxic (Castro et al., 2006; Zulkifli et al., 2013). Therefore, nowadays the vegetable oil-based have started to replace mineral oil-based as lubricants in lubrication industry as the increase of worldwide concerns on the production of environmental-friendly lubricants. The used of vegetable oil as lubricant in lubrication industry is not a new finding where in India, they used coconut oil as lubricants for two-stroke engine (Ajithkumar et al., 2009). There are many advantages of substituting mineral oil with vegetable oil as lubricants since vegetable oil-based are biodegradable, non-toxic, renewable resources and inexpensive. Additional beneficial properties of vegetable oil, such as a high viscosity index, good lubricity, high flash point and low evaporative loss, have also made it preferable for use instead of mineral oil-based lubricants (Syahrullail et al., 2013; Ghani et al., 2015; Zulkifli et al., 2014).

Palm oil is one of vegetable oil-based that been test widely in lubrication industry because of their advantages over mineral oil which are inexpensive, readily available, biodegradable, environmental-friendly and renewable (Lewate, 2002; Battersby, 2000). Malaysia is now the second largest country as palm oil producer in the world after Indonesia. There are many researches being done on testing the performance of palm oil as lubricants and it reports that they have the abilities to be a good lubricant since its give a low coefficient of friction (Jabal et al., 2014).

Palm oil has been tested by several researches for different engineering application. Syahrullail and his colleagues (Syahrullail et al., 2013; Syahrullail et al., 2011) investigated the characteristic of palm oil as a metal forming lubricant. Besides, palm oil was also investigated to be used as biodiesel engine and hydraulic fluid as proposed by Bari et al. (2002) and Wan Nik et al. (2005).

There are four major groups of palm oil that were investigated by the researchers around the world, namely 100% palm oil as a test lubricant (Masjuki and Maleque, 1997; Tiong et al., 2012), uses palm oil as additives (Maleque et al., 2000), uses palm oil with additive (Chew and Bhatia, 2009) and uses palm oil emulsion (Husnawan et al., 2009). All of the research proved and found out that palm oil shows satisfactory results and has a bright future to be used widely in engineering applications. There is no argument on the performance of palm oil as lubricant. It has also been proven that palm oil has good performance in term of lubrication and has the potential to reduce the dependency on mineral based oil lubricants.

Currently, mineral oil and synthetic oil based has been used widely in lubrication industry. Because of the major damage to the environment due toxicity and not readily biodegradable of these current lubricant, it increases the worldwide concern about health. An alternatives lubricant such as vegetable oils maybe able to solve the problem since its nontoxic, biodegradable and renewable. However, vegetable oil has a poor low temperature behavior, low oxidative stability and poor thermal stability which limit their potential application to be used in industrial lubricants. Therefore, this study will be conducted where vegetable oils which is palm oil will be used as mixture in current lubricant. This paper investigates the tribological properties, such as anti-wear, anti-friction, viscosity index and flash parameter point of RBD palm olein with mineral oil in different blending volume ratio by using a four-ball tribotester.

2.0 MATERIALS AND METHODS

2.1 Apparatus

Four-ball tester is to be used to determine the Wear Preventive (PV) properties, Extreme Pressure (EP) properties and the friction of lubricants. There are three parameters than can be controlled for this machine which are applied load, rotating speed and also the temperature of ball cup. The controlled parameter is adjusted according to ASTM D4172 standard used in this experiment.

The machine is used to evaluate the friction and wear characteristics of the lubricant oil under variety of test condition. The machine is working by pressed the three ball that held together at bottom against rotating ball at the top and immersed in lubricant that being tested. The rotating top ball is held by collet which attached to vertical rotating shaft in the machine while the three bottom balls been held together in the ball cup. The setup of the ball bearing for four-ball tester machine shown in Figure 1.

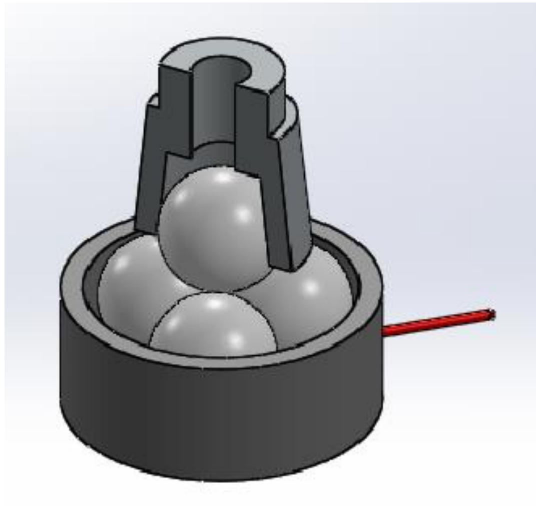

Figure 1: Four-ball schematic diagram

2.2 Material

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

This experiment used palm olein (PO) that mixed with engine oil (EO). The oil composition is (100% - 0%), (80% - 20%), (60% - 40%), (40% - 60%), (20% - 80%) and (0% -100%). This palm olein was mixed with semi synthetic engine oil 15W-50. This oil composition was prepared by measure it using biker. The total of oil that prepare is 400ml for every oil composition. The calculation that use to gets the oil composition as per equation (1).

$$\text{Oil composition} = Y\frac{X}{100} \tag{1}$$

Where Y is total of oil composition (ml) and X is value of composition for one oil. All the oil composition was mix by using mixer. This mixer blade was rotated at 200 rpm within 30 minutes.

2.4 Wear Scar Diameter

After the experiment, wear scar diameter at the surface of balls can be measured using a charge-couple device (CCD) of low and high resolution microscope. To observe the wear scar on the balls. By using CCD microscope, the wear scar at the three balls bearing can be measured right after finish a set of experiment or all the ball can be keep until it cold and measure by group of test. The wear scar diameter of each of the three bottom test balls was measured to determine the lubricity performance of the test lubricant. In general, the larger the wear scar diameter, the more severe the wear.

2.5 Friction Torque and Coefficient of Friction

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.

Golshokouh (Golshokouh et al., 2013) mentioned that the dimensionless scalar value and plays a major role in determining transmission efficiency through the moving parts. From the four-ball tribotester result, all the value of the friction torque is recoded and coefficient of friction will calculate using the equation (2).

$$COF = \frac{T\sqrt{6}}{3Wr} \tag{2}$$

Where *COF* is the coefficient of friction, *T* is frictional torque (kg.mm), *W* is the applied load (kg) and r is the distance from the center of the contact surface on the lower balls to the axis of rotation, which was determined to be 3.67 mm.

2.6 Surface Roughness

The surface roughness test is used in order to understand the wear scar texture at the balls. A stylus test was performance to evaluate the surface texture of the worn halo on the rotating ball and the wear scars on the stationary balls. The profilometry trace was feed into a microprocessor and the resulting signal was displayed on a chart recorder providing surface roughness graphs. The profilometer traces were taken perpendicular to the direction of sliding.

2.7 Flash Temperature Parameter

The flash temperature parameter (*FTP*) is a single number that is used to express the critical flash temperature at which a lubricant will fail under given conditions. The FTP refers less possibility of lubricant film to breakdown (Masjuki and Maleque, 1997). High value of FTP means excellent performance of the lubricant. The *FTP* is usually measured by using the Equation (3) (Ing et al., 2012).

$$FTP = \frac{W}{WSD^{1.4}} \tag{3}$$

Where *W* is the applied load in kg and *WSD* is the wear scar diameter in μm.

2.8 Experimental Conditions

The test is run according to standard ASTM D4172 which is the standard test for Wear Preventive Characteristic of Lubricating Fluid. There are six different ratio of lubricant sample being tested which are the mixture between RBD Palm Olein (PO) and Semi-Synthetic Oil (EO). The condition of the experiment is given as below:

Table 1: Experimental condition

Properties	**Value**
Speed	1200rpm
Temperature	75°C
Time	1 hour
Load	40kg, 60kg, 80kg and 100kg

3.0 RESULTS AND DISCUSSION

The results and data are collected from the experiment. The lubricity performance was analysed with five different parameters which are coefficient of friction (*COF*), wear scar diameter (*WSD*), surface roughness (*Ra*), wear worn surface and flash temperature parameter (*FTP*).

3.1 Density and Kinematic Viscosity

Density also can define as are mass per unit volume of a substance. Density is importance paramount in engine oil. For this research all the oil composition has measure the density by using hydrometer. The result that gets from that test is shown in Figure 2. EO100-PO0 has a low density value around 0.85 kg/m³ and for EO0-PO100 the density value is 0.90 kg/m³. For every added of 20% of palm olein in to semi syntactic engine oil the density value was increase 0.01 kg/m³. As mention by Obasi et al. (2014) the ASTM specification for the density of multigrid engine oil falls within the range of 0.886 to 0.906. But since the value of the 100% of semi syntactic engine oil is without the range this result still valid because the value that get from experiment is same as the value that provide by the manufacture of this semi syntactic engine oil. Base on density condition it shown that all of oil composition can be used as engine oil. But the best density is EO80-PO20 because the value of the density is not different from the EO100-PO0.

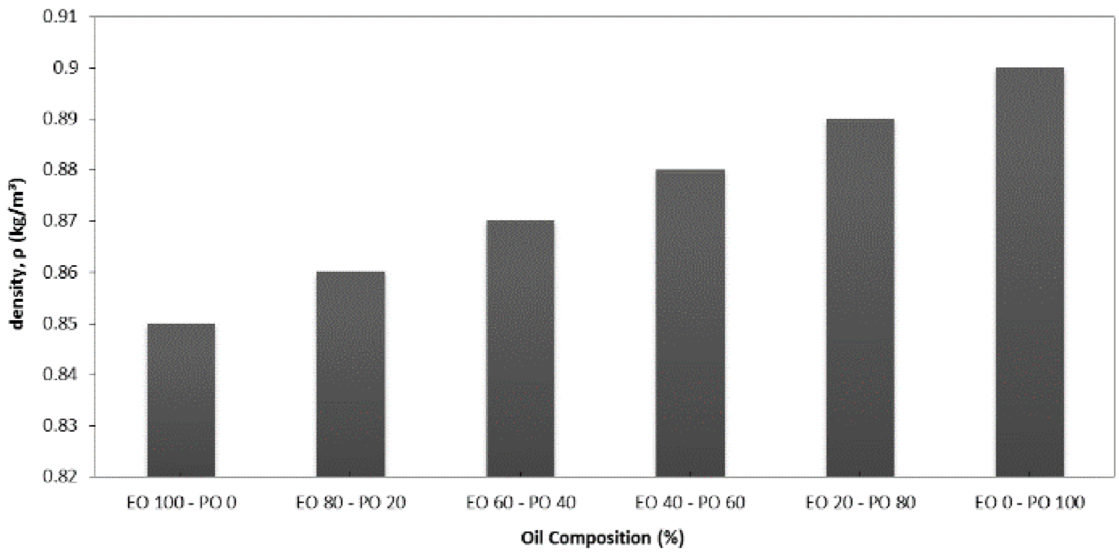

Figure 2: Density for all oil composition

By using rotating viscometer, the reading of viscosity is collected from temperature 30°C until 100°C. The result that get was plotted as per Figure 3. From the graph it shown that all the oil composition value at temperature 100°C is below 36mm²/s. Viscosity value for 100% palm olein (EO0-PO100) at temperature 30°C until 100°C the value is slightly same around 28mm²/s. For 100% semi syntactic engine oil (EO100-PO0) it was start at temperature 30°C with viscosity 253mm²/s and was end at 100°C with value of 36mm²/s. From this the less contain the semi syntactic engine oil will reduce the viscosity of that oil. As mention by Farhanah et al. (2015) that the higher viscosity usually has high anti-friction and anti-wear ability. Base on that statement is true because inside the semi syntactic engine oil has a few of additive that added to improve the properties oil. For every 20% reduce the semi syntactic engine oil by added the palm olein the properties of oil also change because of that the viscosity value also changes.

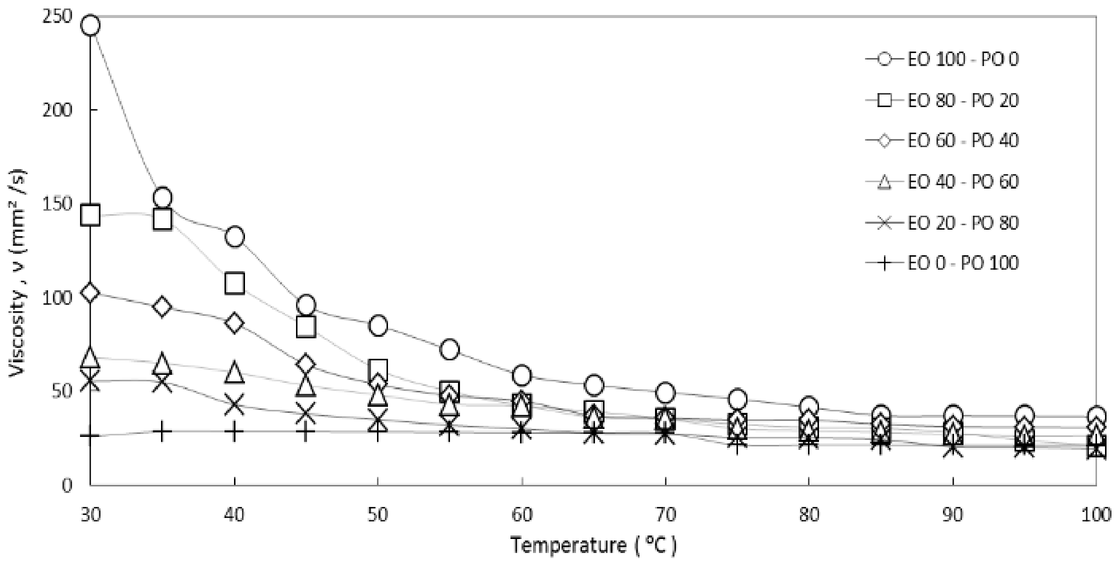

Figure 3: Viscosity for all the oil composition

3.2 Friction Torque

Friction torque is resistance that occurs when two or more solid surfaces are contact and slide between them. Friction torque is a rotational force which may be measured newton meters. Every oil composition has different of the friction torque. From Figure 4 it clearly shown that the trend of the friction torques that occurs for all the oil composition. Friction torque for 100% of semi syntactic engine oil is higher compare to the others composition is 0.154Nm. From this graph it shown that if semi syntactic engine oil mixed with palm olein the value for friction torque is lower. From this graph it shown three composition of oil has low friction torque compare to 100% of palm olein are EO80-PO20, EO40-PO60 and EO20-PO80. It was happening because the fatty acids that have inside the palm olein help the lubricant molecules to stick on the ball bearing surface and also it helps to maintain the lubricant layer this also agree by Jabal et al. (2014). Lubricant film breakdown for EO100-PO0 is much faster compare to the others oil composition because of that the value of friction toque is highest.

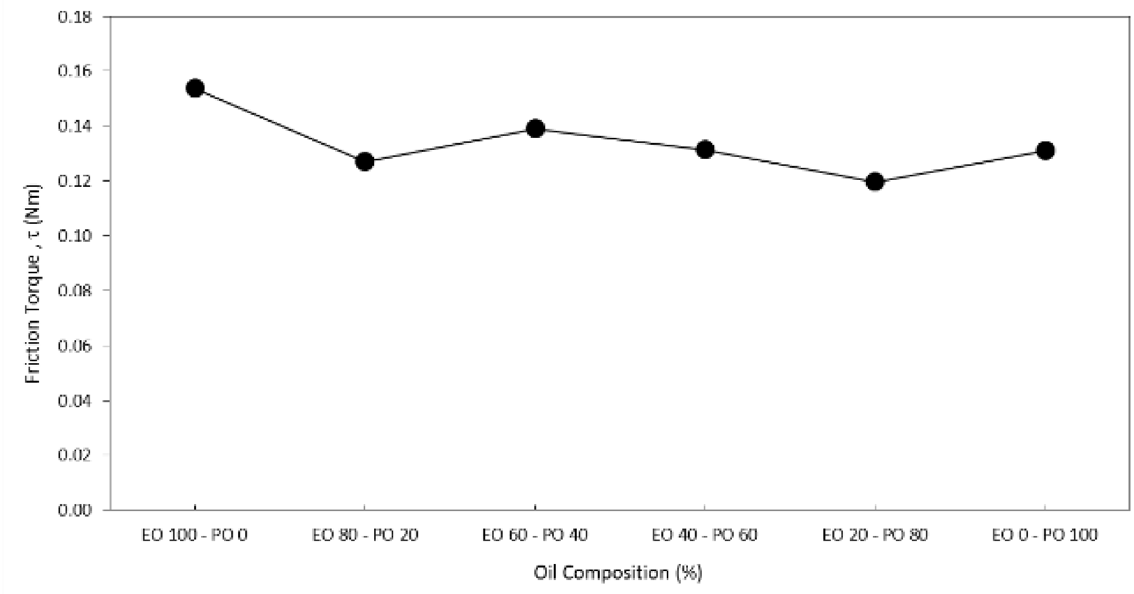

Figure 4: Average friction torque for the oil composition

3.3 Coefficient of Friction

Figure 5 shows the coefficient of friction for all sample at 40kg according to ASTM D4172.

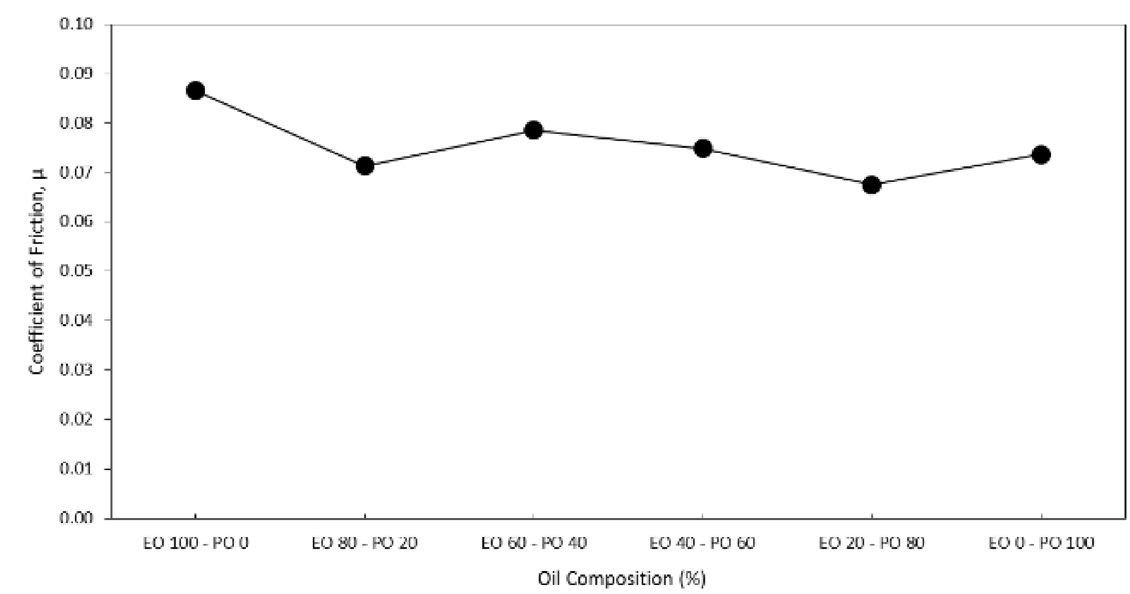

Figure 5: Average coefficient of friction at 40kg for all the oil composition

The highest value that get is for EO100-PO0 is 0.087 and for the lowest value is for EO20-PO80 is 0.068. For EO0-PO100 the value that get is 0.074. Engine oil mixed with palm olein has good lubricity ability in terms of coefficient of friction compare to semi syntactic engine oil. This patent happens because of the fatty acids in the palm olein. This fatty acid helps to maintain the lubricant layer and also giving a lower coefficient of friction compare to the semi syntactic engine oil.

Figure 6 shows the graph of coefficient of friction (*COF*) against load for six different ratio of sample oil between palm oil and engine oil.

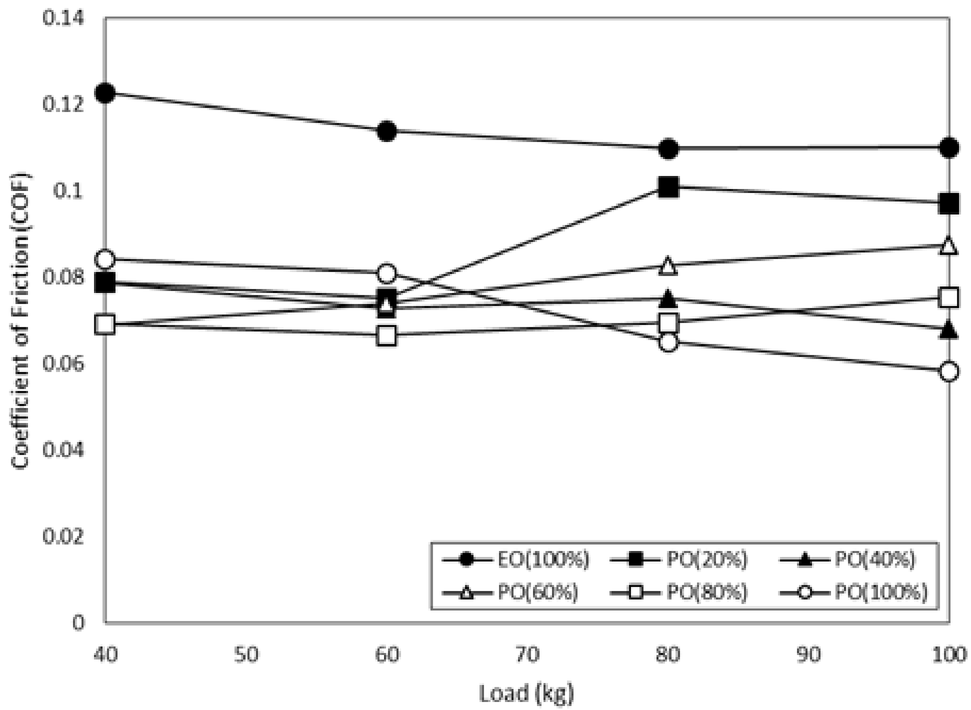

Figure 6: Coefficient of friction of sample lubricant at varies load

From the graph, the sample of lubricant of pure engine oil shows highest *COF* for every load apply. The value of *COF* starts to decrease slightly as the load increase from 40kg to 60kg and continue to decrease from 60kg to 80kg. While from 80kg to 100kg of load, the *COF* for pure engine oil does not show any significant different where 0.109 and 0.11. As the engine oil was mixed with palm oil for certain percentage, the value of *COF* shows lower value than pure engine oil for every load applied. At 40kg and 60kg of load, the value of *COF* for every sample of oil that mixed with palm oil does not shows any significant difference as they are in a range of 0.065 to 0.085. When the load is applied at 80kg and 100kg, the *COF* start to show different value for every sample of oil. The sample lubricant with 20% of RBD palm olein mixture start to increase until the value of *COF* nearly the same as pure engine oil for both load. While for 60% and 80% mixture of RBD palm olein, the value of COF is slightly increase but still below pure engine oil and 20% mixture of RBD palm olein. For 60% mixture of RBD palm olein, the value of *COF* is remaining constant in the same range. Lastly, the value of *COF* for pure

RBD palm olein is start to decrease as the load is applied at 80kg and 100kg and it shows the lowest *COF* compare to other sample of oil.

3.4 Wear Scar Diameter

All the ball bearing that used during experiment were observed using CCD camera. By using CCD camera, the wear scar picture was captured and the diameter of the wear scar was measured.

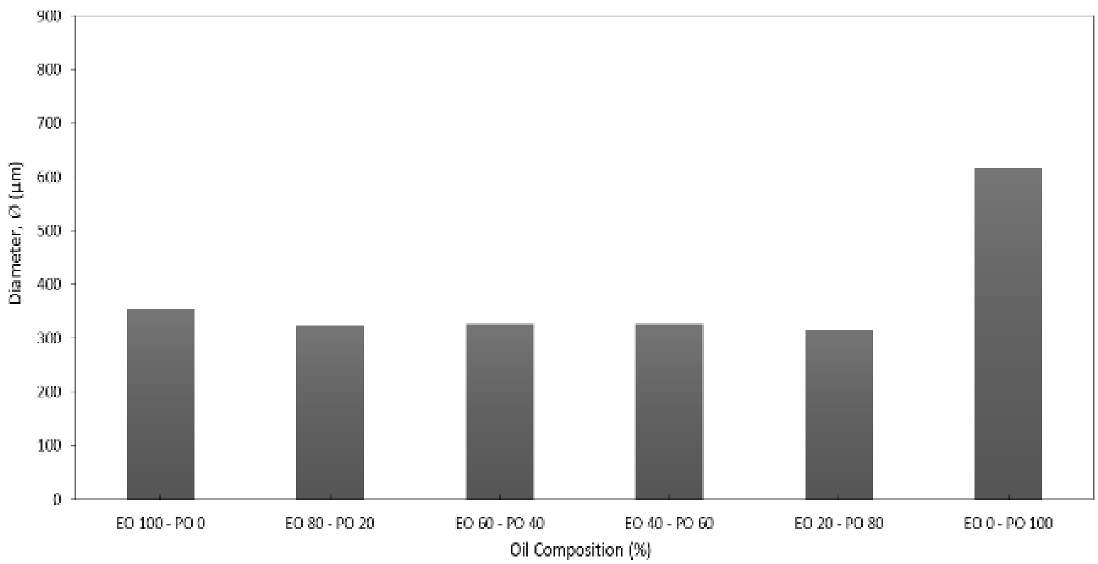

Figure 7: Average wear scar diameter at 40kg for all oil composition.

The average wear scar diameter in Figure 7 shown that the value for PO100-PO0 is 354.80µm and for EO0-PO100 the value for wear scar diameter is 615.22µm. For mixed oil between semi syntactic engine oil and palm olein the value for wear scar diameter is lower than the value of EO100-PO0. The value that get is between 315.08µm to 326.98µm. For EO20-PO80 is shown the best result for wear scar diameter. The value of the palm olein is slightly larger compare to the wear scar that has the semi syntactic engine oil. This behavior is likely due to chemical attack on the surface of the balls by the fatty acids present in vegetable oil. This fatty acid is the product of hydrogenation process that takes place during running this experiment and it will contribute to the corrosive effect to the metal.

Figure 8 shows the wear scar diameter at different load applied. The wear scar diameter for pure RBD palm olein for every load applied give the highest diameter compare to other samples of oil. From 40 kg to 60 kg, the diameter of wear scar for pure RBD palm olein decrease slightly but it starts to increase dramatically as 80 kg load applied and continue until 100 kg of load. For pure engine oil, at 40kg, the wear scar diameter is nearly the same as other sample of lubricant that mixed with palm olein. When 60 kg of load is applied, the diameter is start to increase until it is same as the wear scar diameter of pure RBD palm olein that is 735µm. The wear scar diameter is remaining constant as 80kg of load is applied and increase slightly until 100 kg applied. While for the sample of oil with mixture of 20%, 40%, 60% and 80% RBD palm olein in engine oil show a same diameter of wear scar around 360µm for 40kg and 410µm at 60kg. As 80 kg and 100 kg load is applied, all sample of lubricant with palm olein as mixture starts to show different value of diameter. The diameter of wear scar for sample of lubricant with 20%, 60% and 80% mixture of RBD palm olein is increase drastically but diameter of wear scar for oil with mixture of 40% RBD palm olein retain at range of 350µm - 550µm and it shows the smallest diameter of wear scar among all sample of oil. For the overall of the analysis, it can be concluded that the RBD palm olein that mixing with engine oil, increase the diameter of wear scar.

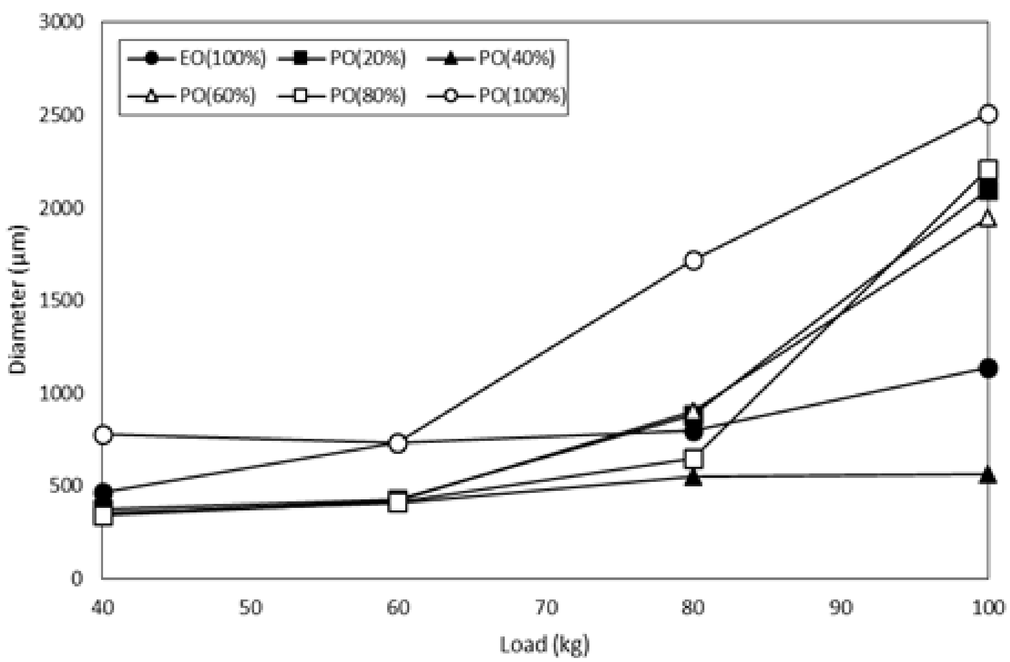

Figure 8: Wear scar diameter of sample lubricants at varies load.

3.5 Surface Roughness

The surface roughness test was conducted in order to understand the wear scar texture on the bottom three balls as mention by Zulkifli et al. (2013).

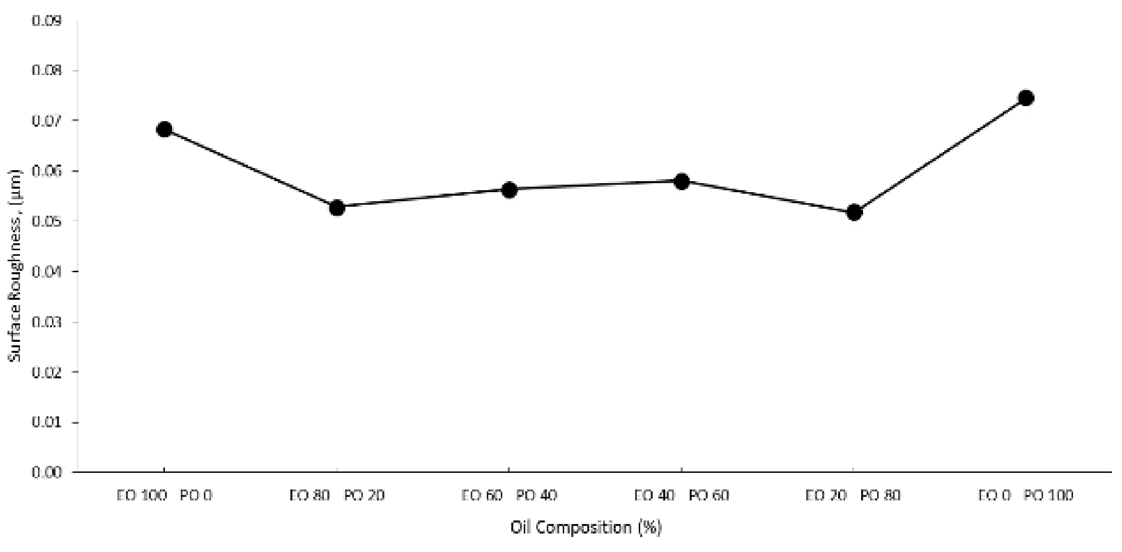

Figure 9: Average surface roughness for all oil composition at 40kg

The average value for all the mixed oil composition between semi syntactic engine oil and palm olein is less than the value of 100% of semi syntactic engine oil and palm olein. The value for mixed oil is 0.053µm (EO80-PO0), 0.056µm (EO60-PO40), 0.058µm (EO40-PO60) and 0.052µm (EO20-PO80). From the values that get it shown that the mixed oil can reduce the surface roughness. The value for palm olein 100% highest compare to others because of the possibility happen oxidized by reacting with free fatty acid, this will cause the physical properties of inner metal surface change brittle and experience abrasive wear. This is one of the factors that cause the surface roughness of wear scar become worst.

Figure 10 shows the relationship of surface roughness against the load applied for every sample of oil. From the graph, it shows that at the load of 40kg and 60kg there are no significant difference value of surface roughness for all sample of oil since all in a range of 0.1 µm to 0.3 µm. At this 40kg and 60kg load, the highest reading of surface roughness can be seen at pure engine oil which are 0.29 µm and 0.35 µm respectively while the lowest reading is shown at 40% mixture of palm olein which are 0.12 µm for both load. When the load is increase to 80 kg and 100kg, the surface roughness for each sample of oil starts to show the difference reading. The highest reading of surface roughness for both load can be seen at 60% mixture of RBD palm olein as it is nearly the same as the surface roughness reading for pure RBD palm olein. The lowest reading for 80 kg load is shown at 80% mixture of RBD palm olein while at 100 kg is 40% mixture of RBD palm olein.

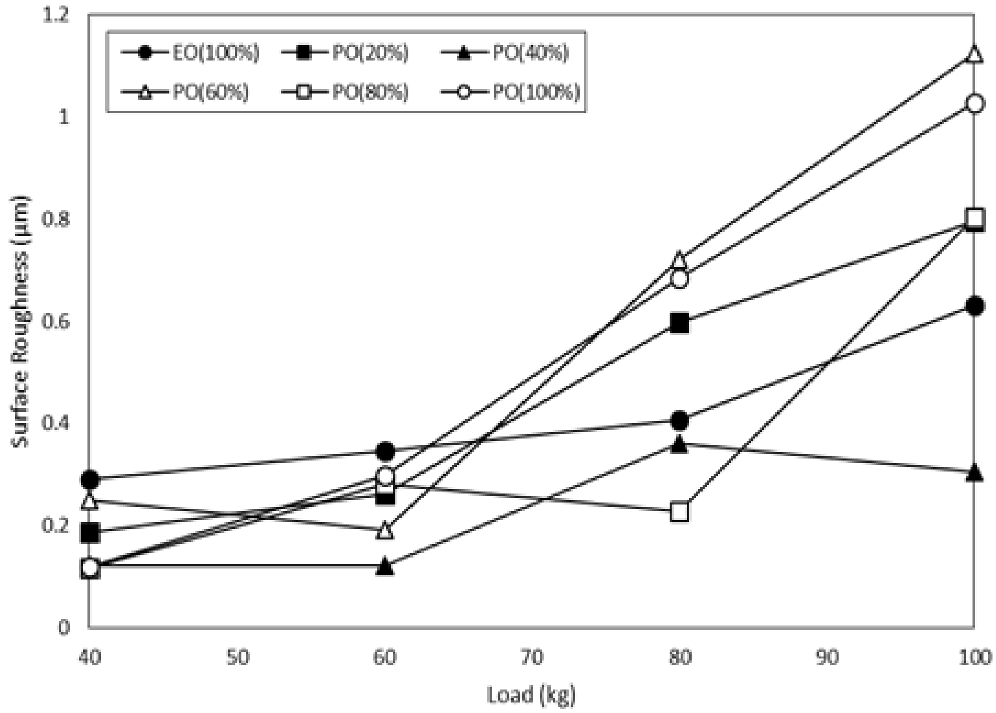

Figure 10: Surface roughness of sample lubricants at varies load

3.6 Flash Temperature Parameter

The flash temperature parameter (*FTP*) is a single number that is used to express the critical flash temperature at which a lubricant will fail under given condition as mention by Jabal et al. (2014).

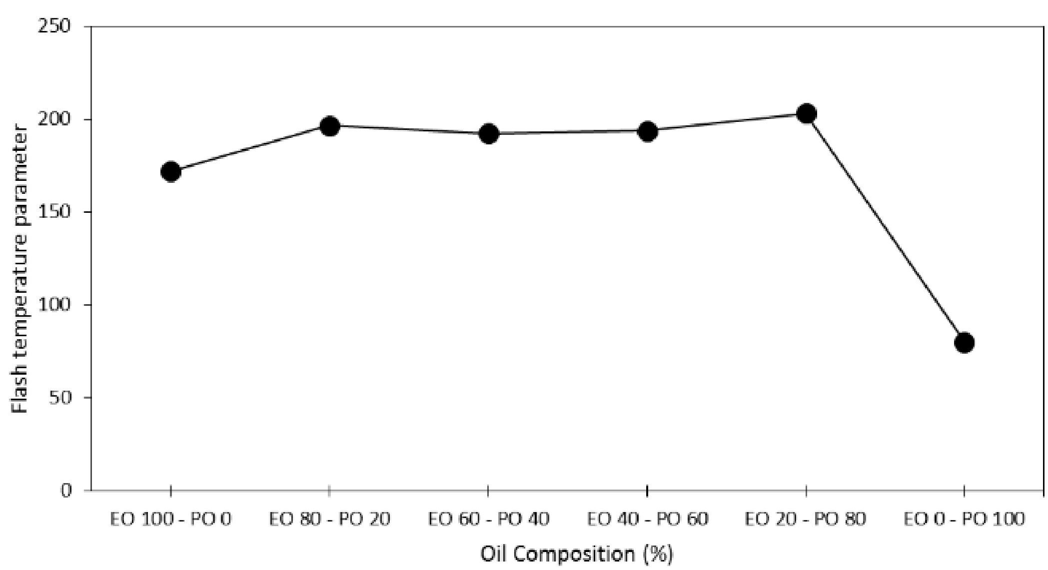

Figure 11: Average flash temperature parameter for all oil composition at 40kg

From Figure 11 it shown that the lowest value is 80.16 for flash temperature parameter is get from EO0 – PO100 and the second lowest is EO100 –PO0 was 171.92. The mixed oil the value that get is slightly same around 192.2 to 203.07. From that result it shown that the mixed oil has good flash temperature parameter.

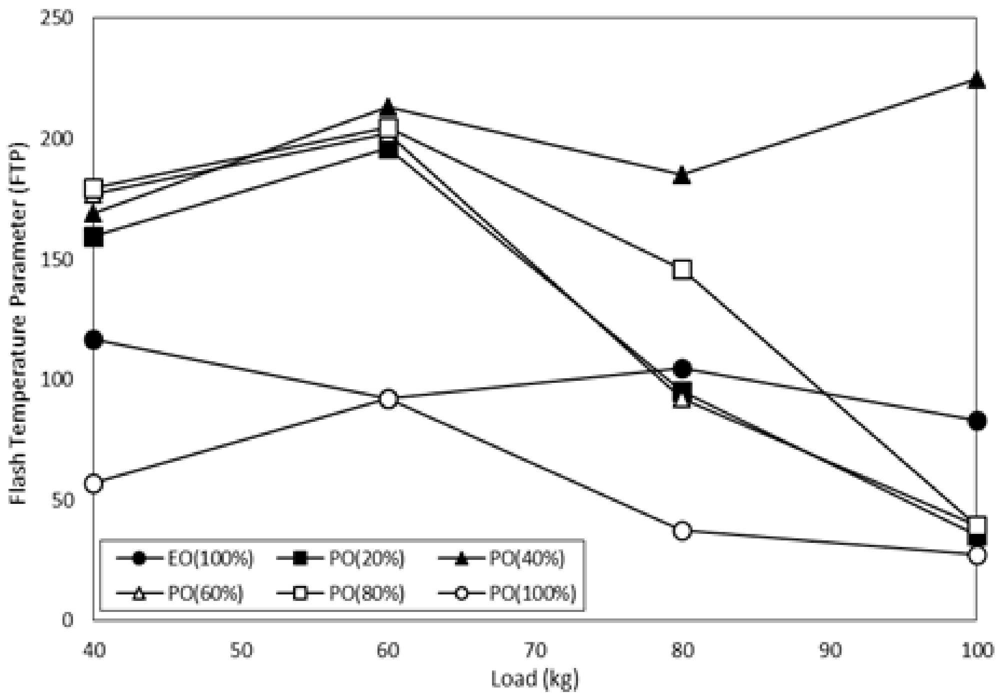

Figure 12: Flash temperature parameter of sample lubricant at varies load

For overall of the values, it can be seen that the sample of lubricant that mixing with 40% RBD palm olein shows the highest value of *FTP*. The maximum values of *FTP* for this sample of lubricant is when 100kg of load is applied with reading of 224.6. While the lowest values of *FTP* are recorded by pure RBD palm olein for every load applied. In general, it shows that most of the sample of oil increase in *FTP* as the load increase from 40kg to 60kg but they start to decrease when the load applied is increase to 80 kg and 100 kg.

3.7 Worn Surface Observation

Due to upper ball bearing rotation, the worn material was swept out to others balls surface and lubricant. The contact surface is destroyed if the thickness of lubricant film was less than particles size as mention by Golshokouh et al. (2013).

Figure 13 shows the image of worn surface on ball specimen that lubricated with pure engine oil as there is no mixture with RBD palm olein. It can be seen that there were parallel groove and narrow grooves found on worn surface and there does not shows any adhesive wear occur. Both deep grooves (dark region) and shallow grooves (light colour region) also found on the worn surface for every load applied. As the 100 kg applied on this lubricant, the worn surface start to show black dot as label with A which mean a material removed occur due to metal to metal contact during sliding at high load.

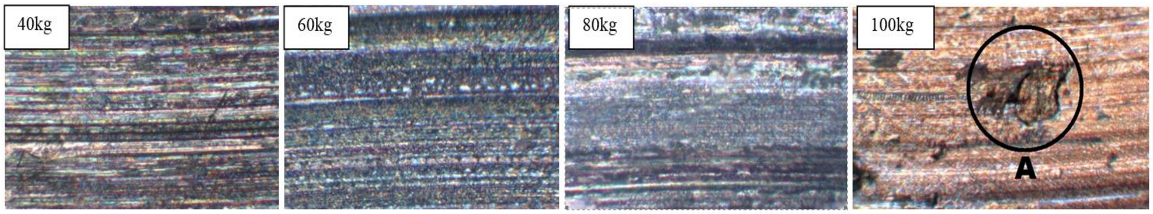

Figure 13: Semi-synthetic engine oil

Figure 14 shows the image of worn surface on ball specimen that lubricated with 20% of RBD palm olein that adding with engine oil. At 40 kg of load applied, the parallel groove can be seen at the worn surface. As the load increase to 60 kg, the worn surface seem rougher than before as there were few parallel grooves shows. This is due to abrasive wear start to occur on this surface of ball specimen. The grooves become deeper and bigger when the load applied increase to 80kg and 100kg. The black region was found on worn surface where it indicates metal to metal contact occurred. Furthermore, it seems to develop a large pit or cavity between the scratches as the surface are plastically deformed and welded together during sliding as label with B.

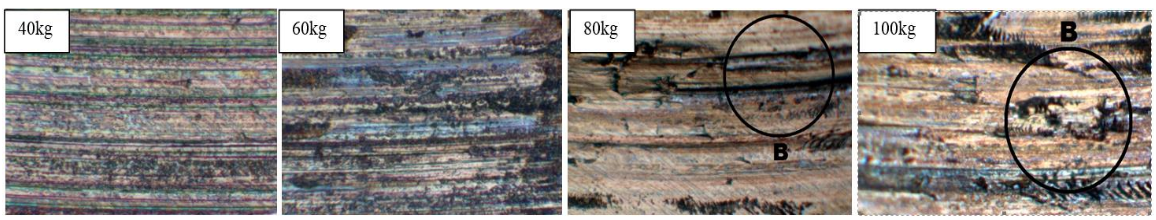

Figure 14: EO 80 – PO 20

Figure 15 represent the image of worn surface of ball specimen as it lubricated using engine oil that mixed with 40% of RBD palm olein. From the images, it shows that the wear produce were relatively fine grooves and shallow grooves for every load applied. The grooves seem parallel where only few of deep grooves found plus there were no any black spot found which means that no severe of abrasive and adhesive of wear occurred.

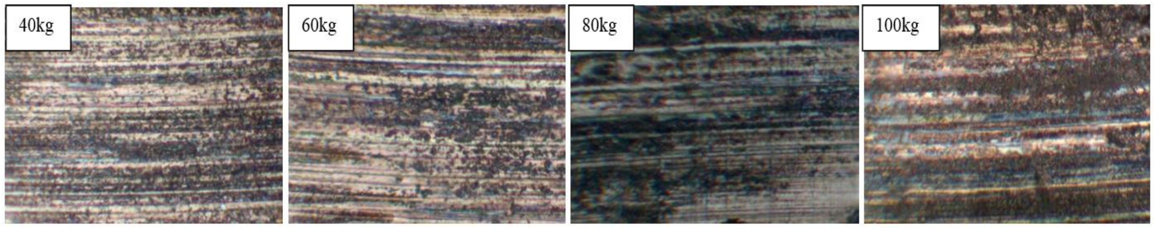

Figure 15: EO 60– PO 40

For Figure 16, the image of worn surface was shows for ball specimen that lubricated using 60% mixture of RBD palm olein with engine oil. The image of worn surface for load applied at 40kg and 60kg shows only fine grooves. As the load applied increase to 80kg and 100kg, both abrasive and adhesive wear occur. From the image, the grooves seem deeper as black region line can be seen clearly and it seems rougher due to cavity look alike develop between the grooves. The big black spot also found on this worn surface with label C which implying the metal to metal contact occurred and the surface were plastically deformed and welded together.

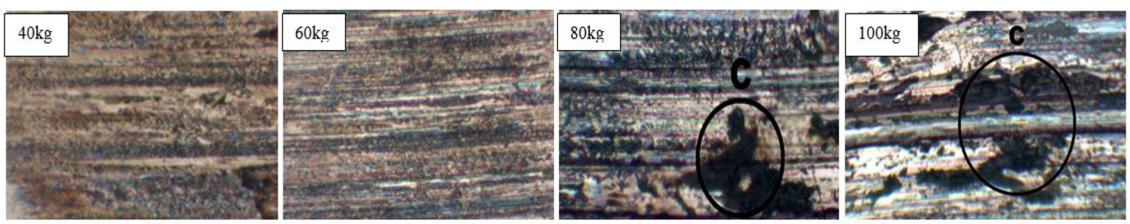

Figure 16: EO 40– PO 60

Then, Figure 17 shows the worn surface image of ball specimen that lubricated with engine oil adding with 80% of RBD palm olein. At load of 40kg, 60kg and 80kg, the worn surface was smooth as there were relatively fine grooves that can be seen. However, at 60kg there were a few of small black spot found. While at 100kg of load applied, the worn surface shows coarse grooves and high scratch which can be seen clearly in the image with label D. It also shown the massive removal of particles. This is due to abrasive and adhesive of wear that occurred.

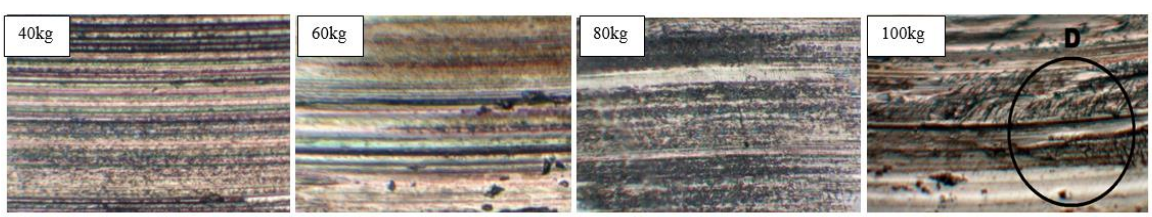

Figure 17: EO 20– PO 80

Lastly, Figure18 represented the image of worn surface for ball specimen that been lubricated using pure RBD palm olein. At 40kg, the worn surface of ball specimen seems very smooth where the grooves look very fine. While at 60kg of load applied, the shallow grooves can be seen with a small particle that been remove due to metal to metal contact that occurred in label E. However, when 80kg and 100kg of load applied, the worn surface look very coarse with a deep scratch and the adhesive wear was occurred as the massive particles that been removed can be seen clearly through the image as it labels with F. While at massive load of 100 kg, the surface shows plastically deformed and finally welded together because of the high pressure that is created.

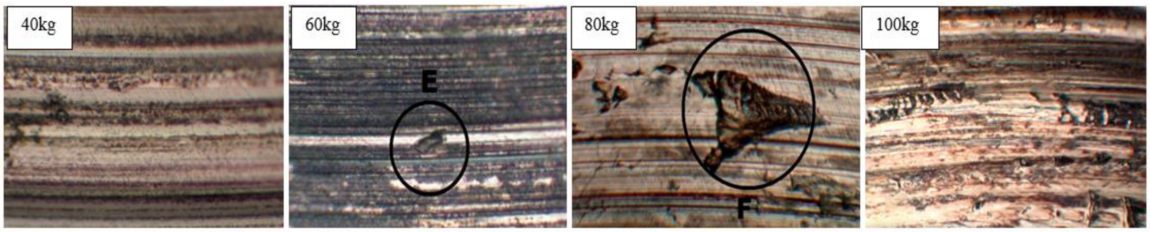

Figure 18: EO 0– PO 100

CONCLUSION

It can be con conclude that by mixed oil between semi syntactic engine oil and palm olein the coefficient of friction was reduce compare if used the 100% of semi syntactic engine oil (EO100-PO0) which is 0.087. The value coefficient of friction for others of oil composition is below 0.079. From this research the best of coefficient of friction was found at EO80-PO20 which is 0.071 and EO20-PO80 which are 0.068.

Wear scar diameter for 100% of palm olein (615.22 µm) and 100% of engine oil (354.80 µm) is highest compare to the all the mix oil. The value for all the mix oil is slightly same is below 327 µm. From this research the best of Wear scar diameter was found at EO80-PO20 which is 324.49 µm and EO20-PO80 which are 315.08 µm. Most of the desired lubricity performance is occur when EO80-PO20.

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