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TRIBOLOGICAL PERFORMANCE OF PALM KERNEL OIL WITH ADDITION OF POUR POINT DEPRESSANTS AS A LUBRICANT USING FOUR-BALL TRIBOTESTER UNDER VARIABLE LOAD TEST

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Graphical abstract

Four-ball tribotester

Abstract

The growing of worldwide trend for promoting the use of the renewable material such as vegetable oil is due to the increasing concern about environmental damage that caused by the use of mineral oil which is not biodegradable. Vegetable oil has a potential to replace mineral oil as a lubricant because of its specific properties that is non-toxic and biodegradable. The main problem in using vegetable oil is having poor low temperature performance. In this research palm kernel oil (PKO) that behave a semi solid phase is used as a bio lubricant mixing with different weightage percentage of poor point depressant (PPD) to investigate the low temperature behaviour performance and also to determine the effect of lubricity performance when blended with different percentage of PPD (5w%, 10wt%, 20wt% and 30wt %). The experiment is according to ASTM D4172 with variation load test. The result of the experiment show that for low temperature performance, PKO with 20wt%PPD (A2-20%) and 30wt%PPD (A2-30%) show great performance which can withstand 15°C. The sample A2-20% shows good lubricity performance in terms of coefficient of friction compare to the other sample. The lubricity performance in terms of wear scar diameter (WSD) it can see that the different percentage PPD do not affect the WSD properties of the pure palm kernel oil. The most consistent and the desired value of the sample in terms of surface roughness is A2-5% and A2-10% where the surface roughness value is stable through the entire load test.

Keywords: Palm kernel oil, PPD, variable load test; ASTM D4172, low temperature performance

1.0 INTRODUCTION

Lubricant is very important in tribological performance in reducing the wear and friction. For better understanding the characteristic effect wear and friction between two moving surfaces, the researchers need to investigate and study the reaction and the fluid present between the moving surfaces. Under boundary lubrication conditions, a sufficient protective lubricant film on the rubbing surfaces plays a main role in the construction of lubricant film layer and controlling the wear behaviour of the test system [1][2]. According to Castro *et al.*, (2005)[24] load can affect the tribological characteristic of the lubricant. Nowadays many researcher is trying to develop new lubricant especially biolubricant to meets the demands of current machinery.

The depleting trend of conventional mineral oil, non-renewable lubricant has triggered research and development on alternative renewable material. Vegetable-based oil products are one of the most promising sources of renewable material in this century [3], [4]. In terms of biodegradability vegetables oils has better properties compare to the mineral oil. Attention has been focused by many party to develop vegetable oils as an industrial lubricant and also biodiesel [5].

Nowadays, the increasing concern of biodegradability product has impact to the increase of interest in using vegetable oils as a lubricant in industry as proposed by Golshokouh *et al*., [6]. Vegetable oils is unique because some of its properties cannot be found in the mineral oil, with a lot of possibilities [7].

Campanella *et al.*, [8] stated that the increase in the use of petroleum-based products has caused the progressive depletion of the world reserves of fossil fuels and there are also concerns on their environmental impact. Many researchers, such as Erhan *et al.*, [9], and Zulkifli *et al.*, [10] agree that most of the lubricant nowadays are hazardous to the environment and cannot be dispose after use.

According to Jabal and friends, The advantages of using vegetable oil as a lubricant compare to other type of lubricant is they are less toxic and more important they are biodegradable [11], [12]. Vegetable oils also a renewable source that easily to reproduce compare to the mineral based oil. Because of the high molecular weight of its triglyceride molecule, vegetable oil has a very low volatility. Vegetable oils also possess a good lubricity due to its polar ester groups that able to adhere to metal surface [8], [9]. Having a high flash and fire point also one of the vegetable oils advantage, because of these properties vegetable oils is very suitable to be used in applications where fire or explosion has a possibility to propagate [13]. Zulkifli and friends state that the vegetable oil has a high viscosity index, which should be high enough to maintain the lubricating film thickness, and low enough to make sure that the oil can flow through all the engine parts. Besides that vegetable oil also has superior anticorrosion properties due to its metal surface affinity [14].

Low temperature performance is one of the weakness using vegetable oils to be a bio lubricant [14], [15]. Vegetable oil become poor flow properties when it exposed to a lower temperature and become cloudiness and solidified upon a long term exposure [16]. Deliberate modification of the chemical structure of vegetable oils is a sound alternative to allow their direct use as lubricant base stocks [8], [17], [32].

Palm oil has been tested by several researchers for different engineering applications. Syahrullail and his colleagues investigated the characteristics of palm oil as a metal forming lubricant [18], [19], [20]. Besides that, palm oil was also investigated to be used as diesel engine and hydraulic fluid as proposed by Bari and Wan Nik respectively [21], [22]. 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 [23], [2], Uses palm oil as additives [24], Uses palm oil with additive [25] and Uses palm oil emulsion [26]. 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.

This research is to investigate the effect of the various percentage (w/w %) of pour point depressant (PPD) to the coefficient of friction and wear performance of the refine palm kernel oil (RBD PKO) using four ball machine. The RBD PKO is a refined palm oil product that is solid at room temperature. The bench mark for the test is using mineral oil and also RBD PKO without PPD. The experiment is conducted following the standard ASTM D4172 with variable load test.

2.0 METHODOLOGY

2.1 Apparatus

Four ball tribotester machine was used to conduct the experiment as shown in Figure 1, the machine is used to investigate the characteristic of the lubricant properties and the wear [27], [30]. The machine test is using four ball, where three balls at the bottom that is held by a ball pot and one at the top that held by the collector. The lubricant is put at the ball pot together with the three ball, and the ball pot will press upward against the top ball that will rotate to a desired level of speed.

The important component of the experiment such as collect, oil cup assembly and ball bearing must be washed with acetone before been used to test it.

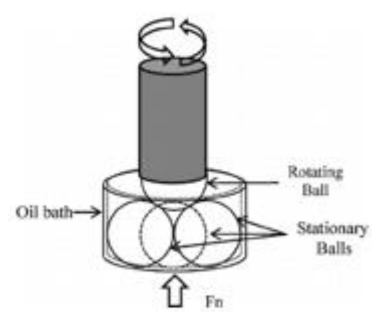


Figure 1 Schematic diagram of four ball tribotester

2.2 Materials

The test material is the balls that is made by chrome alloy steel, made AISI standard steel no. E-52100, with a diameter of 12.7mm grade 25EP. It described in ANSI B#.12. The Rockwell C hardness must at 64 to 66, a closer limit than is found in the ANSI requirement.

2.3 Lubricants

The based lubricant used were palm kernel oil. Malaysia is presently the world's leading exporter of palm oil having a 60 % market share and palm oil is second only to soybean as the major source of vegetable oil worldwide [28]. Malaysia has successful develop the refine of palm oil and one of the product id RBD palm kernel oil. RBD is means refine, bleaching 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 a fractionation process to extract the palm kernel oil. Table 1 shows the percentage of PPD in Palm kernel oil.

Table 1 Percentage of PPD in palm kernel oil

Sample	PPD percentage (%)
PKO	0
A2-5%	5
A2-10%	10
A2-20%	20
A2-30%	30

The lubricant used for this experiment were RBD palm kernel oil and RBD with addition of PPD (5, 10, 20 and 30%w/w). The PPD (A2) used were distribute from HB Laboratories. PPD is based on Alpha-olefin copolymer with heavy aromatic naphtha as it's based. The PPD is used to reduce the pour point of the RBD palm kernel oil. The result obtain will be compared to the mineral oil as a benchmark. For every test of the machine, 10ml of sample will be used. Table 2 shows Composition in Palm Kernel Oil.

Table 2 Composition of Palm Kernel Oil (MPOB)

Fatty acid	C-atoms	Percentage (%)
Caproic acid	6	0.3
Caprylic acid	8	4.2
Capric acid	10	3.7
Lauric acid	12	48.7
Myristic acid	14	15.6
Palmitic acid	16	7.5
Stearic acid	18	1.8
Oleic acid	18	14.8
Linoleic acid	18	2.6
Melting point(˚C)	27.3	

2.4 Test condition

The experimental condition is standard Four-ball Tribotest. The tribological performance of RBD palm kernel oil is evaluate by the standard Fourball Tribotest with different parameter and using different type of PPD concentration in pko.

Table 3 Test condition of the experiment

Properties	Details
Temperature	75˚C
Speed	1200rpm
Duration	60min
Load	40-80kg

2.5 Friction Evaluation

The friction evaluation of the four ball machine was recorded on the data acquisition system. Usually the friction torque reading is increase at the starting experiment. After approximately 10min, the reading is become more stable. The coefficient of friction reading is calculated from the average at the steady state due to the formula (IP-239) as follows:

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

Where,
μ = Coefficient of friction
T = Frictional torque (kg mm)
W = Load (kg)
r = is the distance from the centre of the contact surface on the lower balls to the axis of rotation (3.67mm)

2.6 Wear Scar Diameter

The removal surface material or undesired displacement are called as wear [29][31]. The wear often occur when there are have the relative force or sliding. It should clearly understood that the real area contact between two object is actually very small compare to the apparent area of contact. The wear scar diameter for the three ball at the bottom will be taken using the microscope to measure its diameter to know its lubricity performance. In general, the larger the wear scar diameter, the more severe the wear.

2.7 Surface Roughness

Surface roughness is measured to the texture behaviour of the ball bearing surface. Small deviation indicate that the surface is smooth. Low surface roughness value after test means that the lubricant has success protect the surface from further damage. Surface profiler is used to measure the roughness of the ball bearing [33].

2.8 Wear Surface Characteristics Observation

High power microscope is used to observe the surface profile of the ball bearing after the test. Low adhesive and abrasive wear shows that the lubricant has good performance in protecting the surface of the bearing [34].

3.0 RESULT AND DISCUSSION

The impacts of RBD palm kernel oil blended with PPD was examined and also characterised. The test results will show the performances of RBD palm kernel oil that blended with PPD in term of WSD, COF and also surface profile that will compare to pure RBD Palm Kernel Oil and the mineral oil (SAE-40).

3.1 Low Temperature Ability Observations of a Lubricants

Palm Kernel oil, A2-5%, A2-10%, A2-20% and A2-30% are heated to 30˚C in order to remove the wax crystallize.

From the table 4 it can see that at 25˚C the PKO liquid start to fully solidified, this show that the pour point of the pure RBD PKO cannot withstand at lower temperature without modifying it or adding any additive.

Table 4 Result of pour point test

Sample	Blend ratio (wt/wt)		Liquid Phase Temperature (˚C)
	RBD PKO	PPD	
RBD PKO	100	0	25
A2-5%	95	5	20
A2-10%	90	10	20
A2-20%	80	20	15
A2-30%	70	30	15

At 15 ˚C, all sample PKO, A2-5%, and A2-10% were completely solidified except for A2-20% and A2-30% where the sample behave a liquid and waxy form. PPD has successfully improve the pour point of palm kernel oil by delaying nucleation of the molecule as proposed by Erhan *et al.* (2006) [9].

3.2 Coefficient of Friction μ Evaluation at Varied Load

The value of the coefficient of friction will be compared to the palm kernel oil and mineral oil for each sample of the RBD PKO with PPD. Figure 2, Figure 3, Figure 4 and Figure 5 shows that the comparison of the COF between A2-5%,A2-10%, A2-20% and A2-30% with mineral and RBD PKO. In general the value of the COF for all sample RBD PKO with PPD is higher compare to the mineral oil. The main focus is to get lowest coefficient of friction and can withstand at lower temperature.

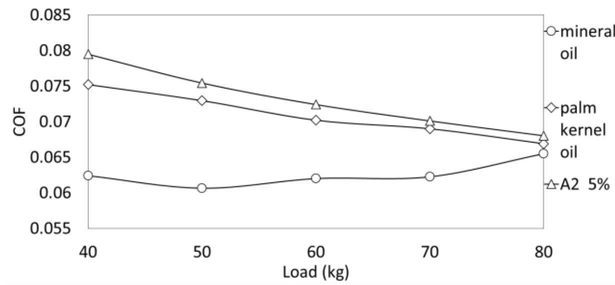


Figure 2 Comparison of the COF between A2-5% with mineral and RBD PKO

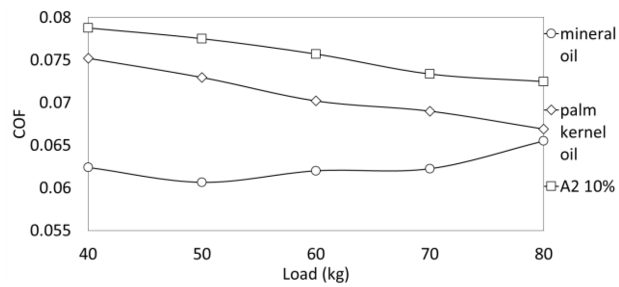


Figure 3 Comparison of the COF between A2-10% with mineral and RBD PKO

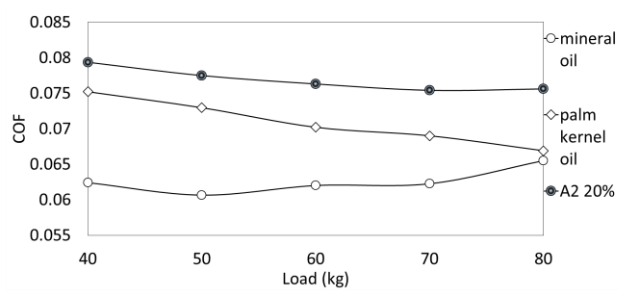


Figure 4 Comparison of the COF between A2-20% with mineral and RBD PKO

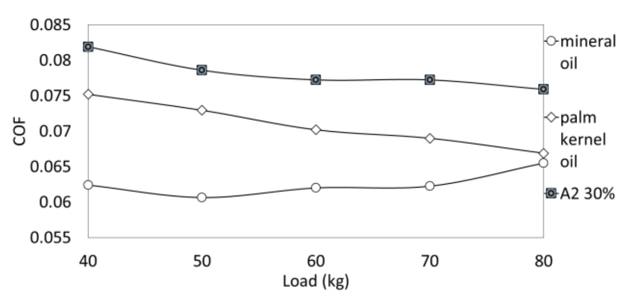


Figure 5 Comparison of the COF between A2-30% with mineral and RBD PKO

The trend of the RBD PKO and all of the sample from the test shows that the value of the COF is decreasing as the value of the load is increase. This shows that for the early stage it undergoes the boundary condition. During this condition the asperities are in contact to each other's the wear additive and extreme pressure is play an important role to form boundary lubricating film to protect the surface.

Figure 6 shows the comparison of the COF between A2-5%, A2-10%, A2-20% and A2-30% where all of the sample is already improve its pour point temperature compare to the pure RBD PKO as discussed earlier, at the early stage between 40kg to 80kg, the value of the COF for A2-5% shows lowest COF value.

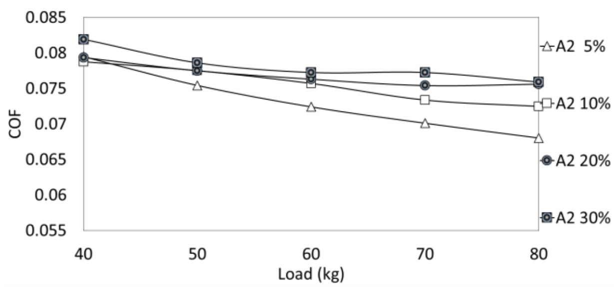


Figure 6 Comparison of the COF between all of the sample

The COF value for A2-30% shows the highest value of the COF almost entire load test, this is may result from the lubrication performance in terms of COF for the sample is reduce because of the PPD but still in considerable level. This is due to the decreasing of the fatty acid of palm kernel oil (pko) as the sample of PPD added is high. According to Lawal *et al*., (2008) [37] the long chain fatty acid can help to reduce the coefficient of friction.

3.3 Wear Scar Diameter

From this research point of view, the lubricity performance of an oils are good when it have lower value of wear scar diameter. Figure below illustrates the average wear scar diameter of three stationary balls bearing after undergo fourball tribotester experiment at different load applied.

Figure 7, Figure 8, Figure 9 and Figure 10 shows the comparison of the A2-5%, A2-10%, A2-20% and A2-30% to the PKO and mineral oil at variable load.

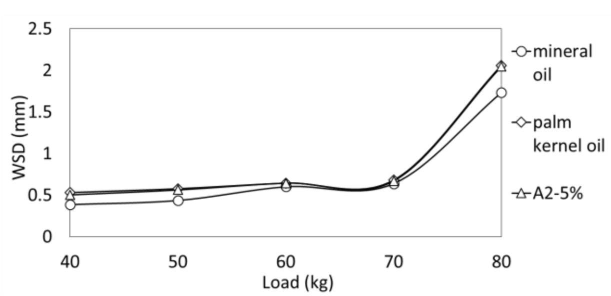


Figure 7 Comparison of sample between A2-5%, PKO and Mineral oil

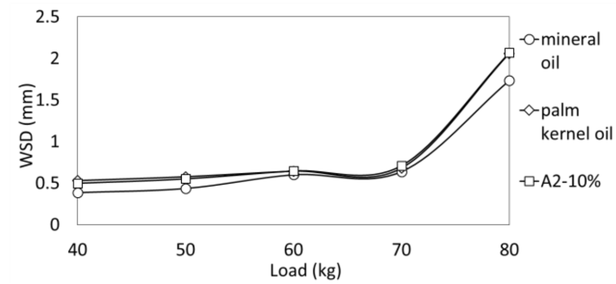


Figure 8 Comparison of sample between A2-10%, PKO and Mineral oil

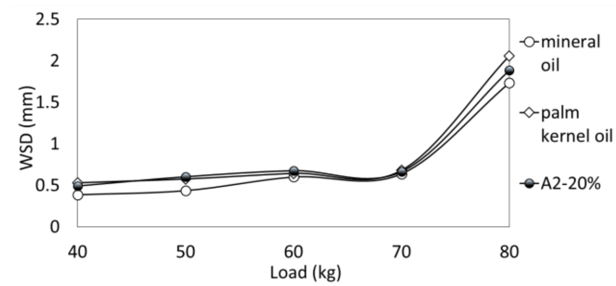


Figure 9 Comparison of sample between A2-20%, PKO and Mineral oil

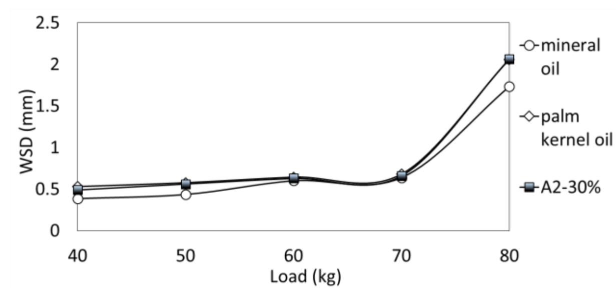


Figure 10 Comparison of sample between A2-30%, PKO and Mineral oil

In general, we can see that the trend of the wear is increasing as the variable load is increase from 40kg to 80kg. The wear is increase because of high load that applied will make the lubricant undergoes boundary lubrication where the surface is in contact and will create bigger wear.

From all the sample result that obtain we can see that the wear scar diameter for mineral oil shows the lowest value of the wear scar diameter through all entire load test. The mineral oil is fully formulated lubricant so its properties already shows a desired lubricant compare to the palm kernel oil. However palm kernel oil wear scar diameter is not far apart from our bench mark mineral oil, this shows that palm kernel oil has a potential to be commercialize. The fatty acids inside the palm kernel oil is responsible in protecting the layer from getting away from the surface [31].

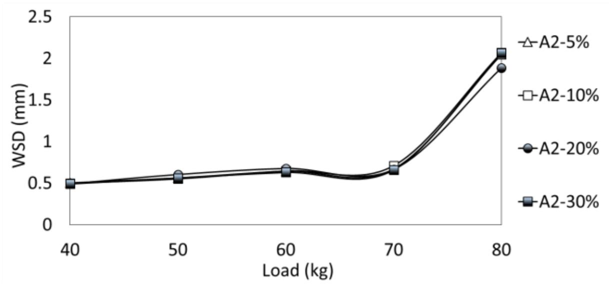
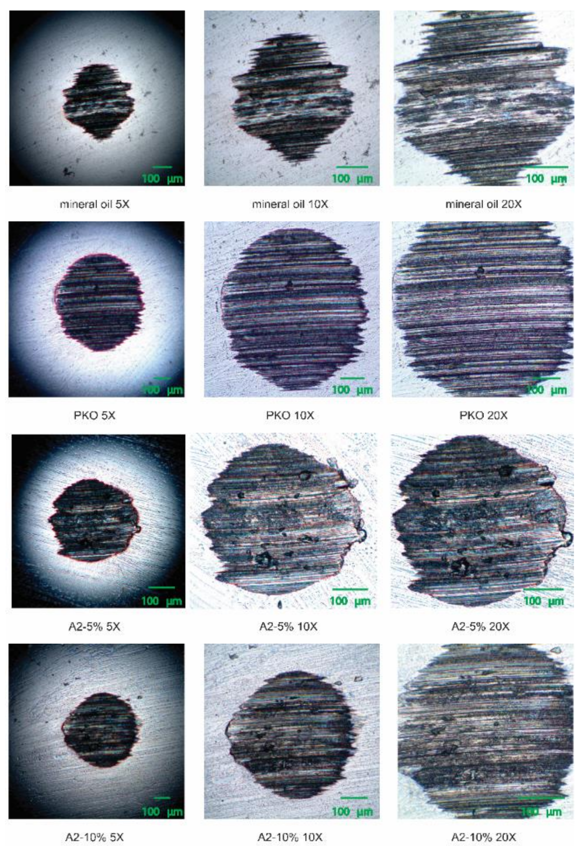


Figure 11 Comparison of sample between all PPD samples

From the graph of all PPD sample (Figure 11) we can see that the lubricity performance in terms of wear scar diameter is having the same trend and the result has a precise value for all the data, this shows that the addition of the PPD will not largely effect the WSD lubricity performance of RBD palm kernel oil.

3.4 Wear Surface Characteristics Observation

Figure 12, 13, 14, 15 and 16 shows the result of the surface observation at three different magnificent level (5X, 10X, and 20X). Most of the result shows, adhesive and abrasive wear is occur through the entire test.



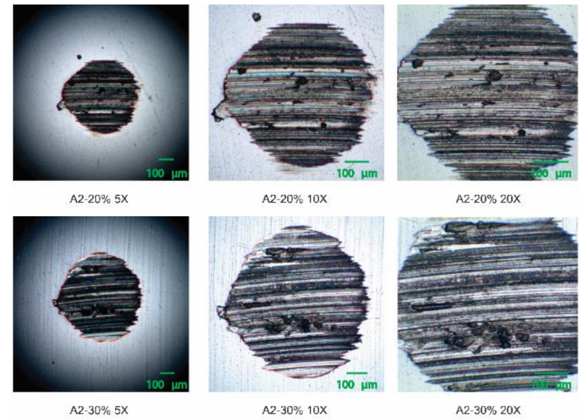
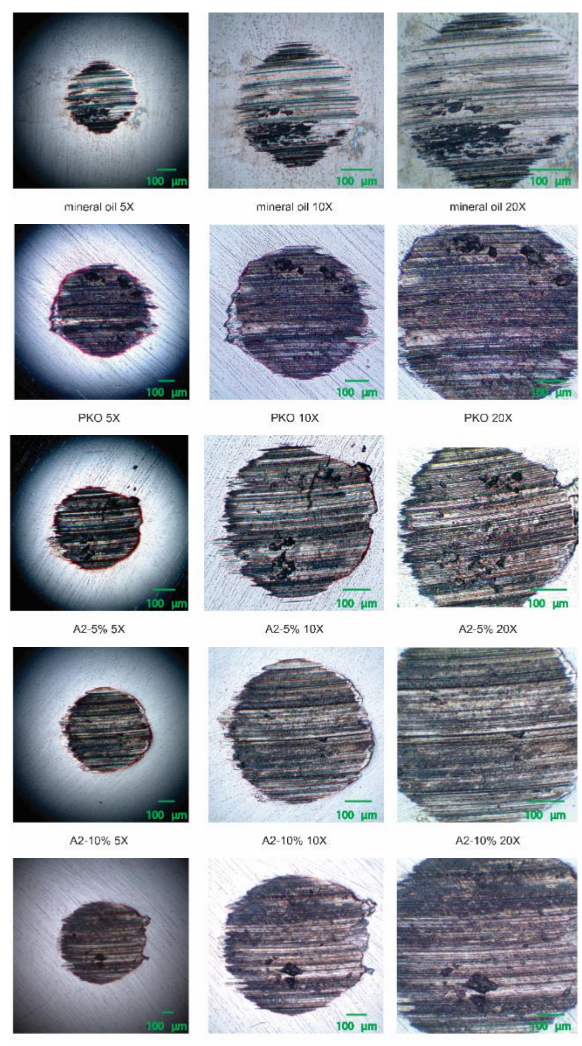


Figure 12 Image at 40kg

From figure 12 mineral oil and palm kernel oil we can see that it has smooth parallel grooves pattern and there is no big adhesive wear occur, but at A2-5% the adhesive wear start merging into the scar. A2-30% has greatest adhesive in the middle of the scar. This is maybe due to the chemical attack on the rubbing surfaces of fatty acid as proposed by Bowden & Tabor, (2001) [38].



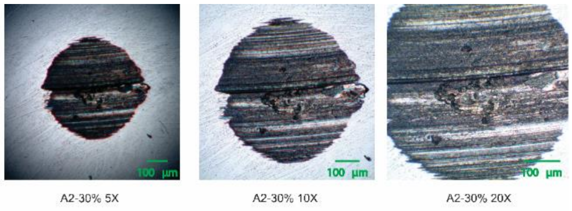


Figure 13 Image at 50kg

From Figure 13 at 50kg, mineral oil scar has started to emerge the adhesive wear at the bottom of the scar, most of the wear in this part of experiment has a small random adhesive occur. A2-30% sample shows the most effected wear in the middle when compare to the other sample.

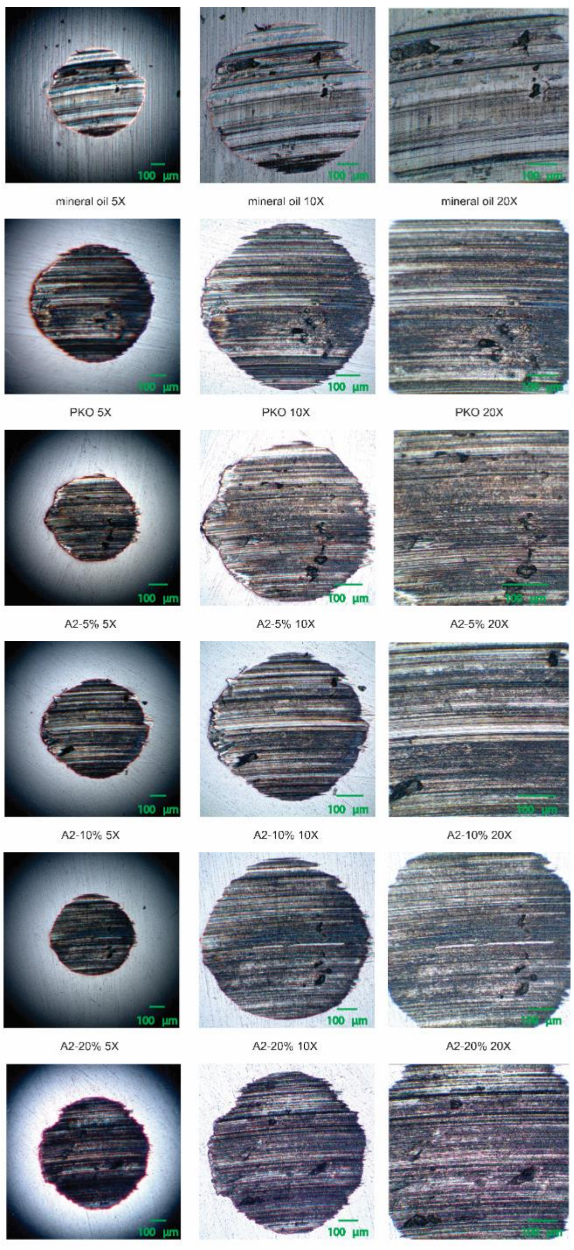


Figure 14 Image at 60kg

From Figure 14 and 15 in general we can see that a thin lubricant film with parallel grooves formed to prevent metallic contact and create smooth surface regions. Some of the grooves were deep and the others were shallow grooves in between. In this region, abrasion was seen as the dominant wear mechanism.

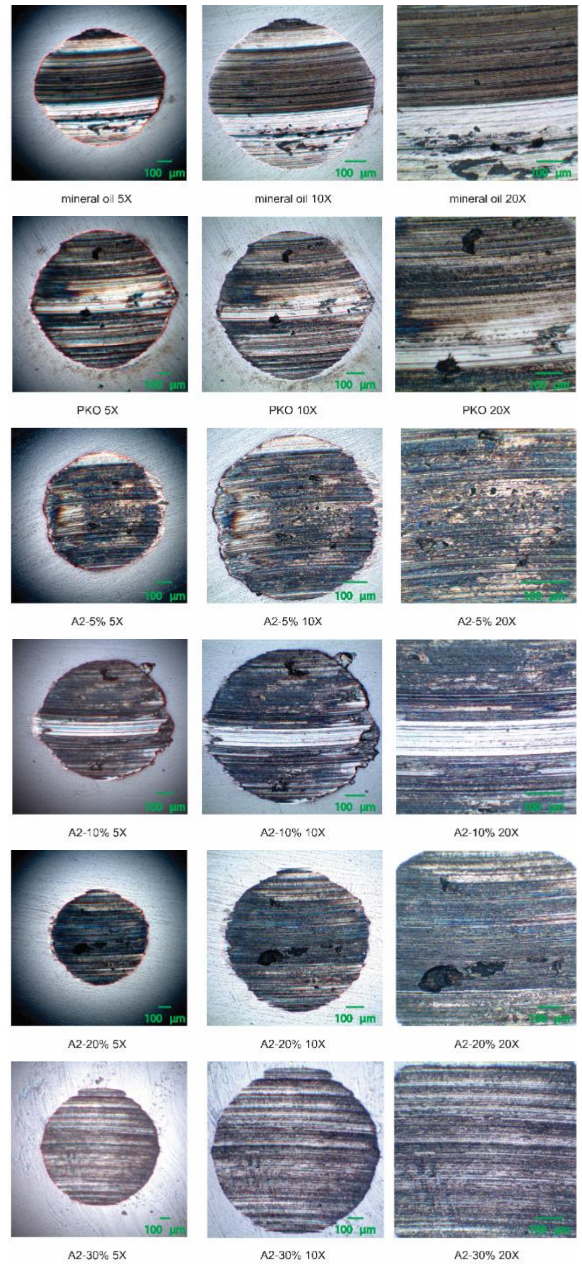
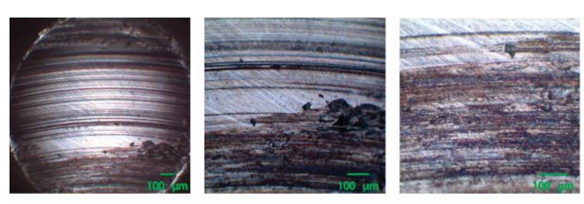


Figure 15 Image at 70kg



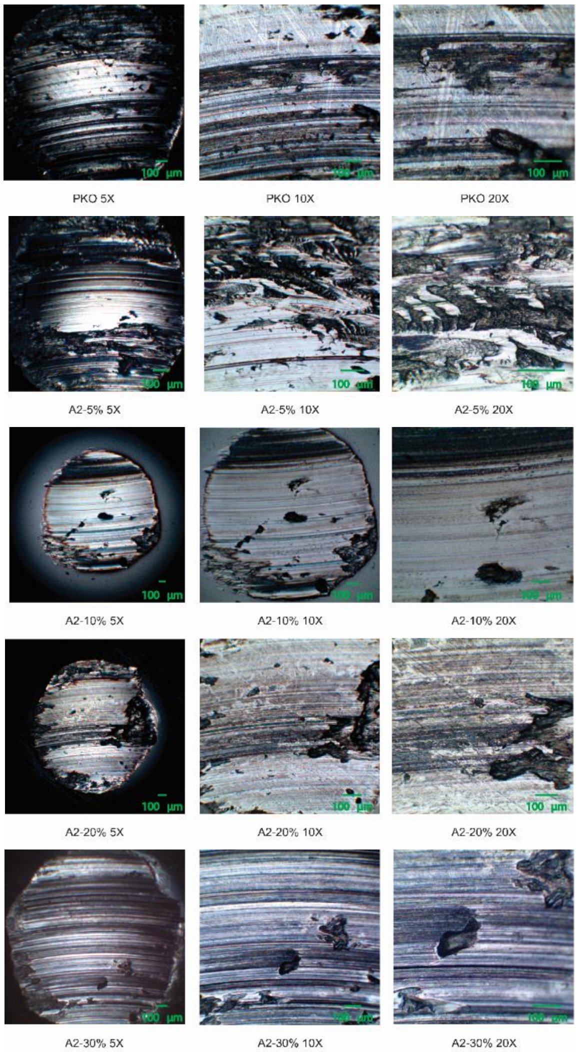


Figure 16 Image at 80kg

Figure 16 shows the wear image at 80kg, we can see that all wear has a major adhesive wear occur in the surface of the ball bearing due to the greater load that applied compare to the other test. The thin lubricant film of sample however start to reduce prevention of the metal to metal contact surface because of high load that going into hydrodynamic regime[32].

The Sample A2-30% has the most effected wear at the surface for almost all the entire test, this is due the lack of fatty acid insides the sample that can help to prevent from the contact interaction between two surfaces [38]

3.5 Surface Roughness (Ra)

Smooth surface scar will produce better surface roughness characteristic. Low surface roughness is needed to shows that the lubricant is good in protecting the surface of the bearing. Surface profiler is used to measure the roughness of the surface.

Figure 17, 18 and 19 shows that the surface roughness of A2-5%, A2-10% and A2-20% compare to the mineral oil and palm kernel oil. The result shows that the surface roughness of A2-5%, A2-10% and A2-20% has slightly lower compare to pure palm kernel oil. The 5%PPD, 10%PPD and 20%PPD show can improve the palm kernel oil lubricity performance in terms of surface roughness.

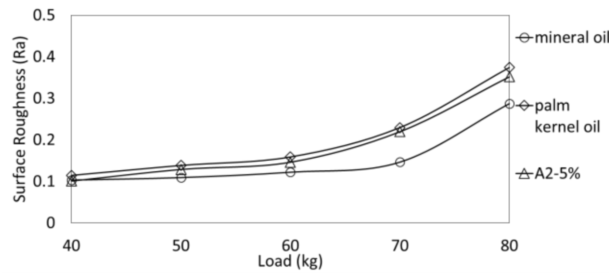


Figure 17 Surface roughness A2-5%

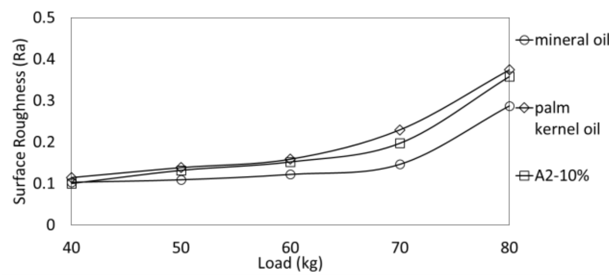


Figure 18 Surface roughness A2-10%

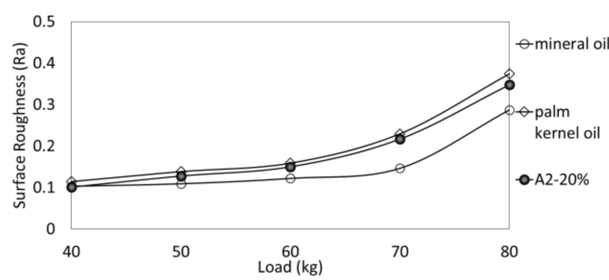


Figure 19 Surface roughness A2-20%

For overall result we can see that mineral oil having lowest surface roughness compare to other sample this is due to its fully formulated lubricant. At 80kg all the sample (A2-5%, A2-10%, A2-20% and A2-30%) has higher surface roughness compare to pure palm kernel oil.

The better performance of the sample shows that the sample can be considered to absorb the wear surface contact from removing ball surface. Palm kernel oil contain polar molecules to form the fluid film on the surface for the separation of adjacent surface and also constraint or limiting the action of metal to metal contact within each ball. The lubricity performance in terms of wear scar diameter after adding more PPD sample is improve due to stable fluid film that prevent from surface contact that reduce thermal energy in sliding contact surface as proposed by Wain *et al*., (2005)[35] and Xu *et al*., (2007)[36].

Figure 20 A2-30% shows that the surface roughness has lower value compare to the pure palm kernel oil. The result from 40-70kg has consistent and low value of surface roughness. However at 80kg the lubricity performance in terms of surface roughness is very poor.

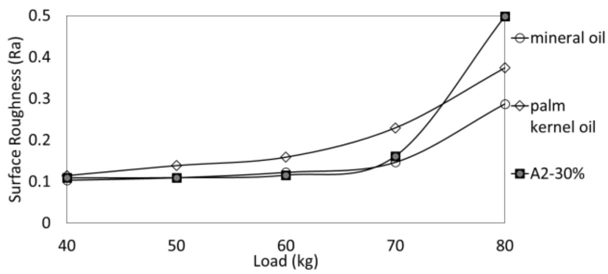


Figure 20 Surface roughness A2-30%

Figure 21 shows the sample comparison, the sample A2-5%, A2-10% and A2-20% has the same trend and more stable value of surface roughness, but A2-30% the value of surface roughness not stable and goes very at 80kg.

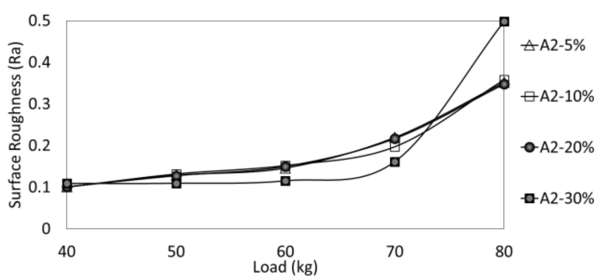


Figure 21 Surface roughness PPD sample

For overall performance, the sample (A2-5%, A2-10%, A2-20% and A2-30%) has good lubricity performance in terms of surface roughness compare to the pure palm kernel oil. The most consistent and the desired value of the sample is A2-5% and A2-10% where the surface roughness value is stable through the entire load test.

4.0 CONCLUSION

From the research that been done, it can conclude that all sample is successful improve its low temperature performance and only the sample of A2-20% and A2-30% can withstand lower temperature (15°C) compare to other sample. The sample A2-20% shows the desired lubricity performance in terms of COF when compare to the other sample of PPD addition. The COF for the A2-20% sample mostly has lower COF compare to other sample of PPD addition through the variation of the load test. But when compare to the mineral oil (SAE 40) all of the sample shows higher COF value. When the lubricity performance is observe in terms of wear scar diameter, it can see that the value of WSD for all sample shows a consistent value when compare to the pure PKO and the mineral oil (SAE 40). Sample A2-20% shows a slightly lower value of WSD compare to all the Sample of PPD. This shows that adding PPD not largely effect wear scar diameter, this mean that the lubricity performance in terms of wear scar has a potential to replace mineral oil. For overall performance, the sample (A2-5%, A2-10%, A2-20% and A2-30%) has good lubricity performance in terms of surface roughness compare to the pure palm kernel oil. The most consistent and the desired value of the sample is A2-5% and A2-10% where the surface roughness value is stable through the entire load test. This shows that by adding PPD it can significantly improve the lubricity performance in terms of surface roughness.

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