

# The Effect of the Different Percentage of Pour Point Depressant (PPD) On the Tribological Properties of Palm Kernel Oil

M.A. Dandan<sup>a</sup>, A. Yahaya<sup>a</sup>, S. Syahrullail<sup>a</sup>

<sup>a</sup> School of Mechanical Engineering, Faculty of Engineering, Universiti Teknologi Malaysia, 81310 UTM Skudai, Johor, Malaysia.

## Keywords:

Wear  
Friction  
Tribology  
Palm Kernel Oil  
Anti-oxidant  
Extreme Pressure

## ABSTRACT

A research has been done to investigate the tribological performance of palm kernel oil (PKO) with addition of different percentage of pour point depressant, PPD (5wt%, 10wt%, 20wt% and 30wt%) according to ASTM D2783. The main analyses that have been done in this research are low temperature performance ability of blended PKO, coefficient of friction (COF), wear scar diameter (WSD) and surface profile. The result of the experiment has shown that for low temperature performance, PKO with 20wt%PPD (A2-20%) and 30wt%PPD (A2-30%) show great performance in withstanding lower temperature (15 °C). Under extreme pressure test, it can be seen that PKO can only withstand lower load (110kg) compared to mineral oil (140 kg). The sample 10wt%PPD (A2-10%) shows good lubricity performance in terms of COF as compared to other sample. 5wt%PPD (A2-5%) and 10wt%PPD show good lubricity performance in terms of anti-wear behaviour (A2-10%) by producing the lowest WSD when compared to other samples. From overall view, PPD is considered as successful in improving low temperature performance of PKO, but in terms of lubricity performance, adding PPD will slightly reduce the lubricity performance under extreme pressure if compared to pure PKO.

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## Corresponding author:

Muhammad Arif Dandan  
Department of Thermofluids,  
School of Mechanical Engineering,  
Faculty of Engineering,  
Universiti Teknologi Malaysia,  
81310 Skudai, Johor, Malaysia.  
Email: [arifdandan92@gmail.com](mailto:arifdandan92@gmail.com),  
[syahruls@mail.fkm.utm.my](mailto:syahruls@mail.fkm.utm.my)

## 1. INTRODUCTION

The research and development of alternative renewable lubricant that was prompted by the depleting trend of conventional and non-renewable petroleum-based products had led to the discovery of the vegetable-based oil products as being one of the most promising alternative and renewable sources [1-3]. Since

the vegetable oils had not only demonstrated a superior biodegradability level, but also unique properties that were different from those of the mineral oil, numerous investigations were thus conducted on these oils (sunflower, castor, soybean, rapeseed and palm) as alternative lubricants for industrial and transportation applications and feedstock in biodiesel production [4-7].

There were also studies that had shown the palm-based oil as having comparable lubricating properties like those of the commercial engine oil [9,10]. Among the studies that were conducted on its development as a bio-lubricant had included those of Syahrullail et al., where they had investigated its characteristics to be used as a metal forming lubricant as well as Bari et al., who had studied its possible niche as an engine diesel and hydraulic fluid [11-13].

Palm oil is one of the famous vegetable oils that has a potential to replace mineral oil lubricant. Many researchers have conducted research to develop a bio-lubricant using palm oil such as Syahrullail and his colleagues who investigated the characteristics of palm oil as a metal forming lubricant [3,14]. Besides, palm oil has also been studied to be used as diesel engine and hydraulic fluid as proposed by Bari and Wan Nik respectively [15,16].

There are four major groups of palm oil research that have been studied by the researchers around the world. Commonly, they used 100 % palm oil as a test lubricant [17,18], palm oil as additives [19], palm oil with additive [20] and palm oil emulsion [21]. All of the research have proved and found out that palm oil shows satisfactory results and has a bright future to be widely used 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 terms of lubrication and can potentially reduce the dependency on mineral oil based lubricants [22,23]

Campanella et al. [24] 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 impacts. Many researchers, such as Erhan et al. [25], and Zulkifli et al. [26,27], agree that most of the current lubricants that contain petroleum base stock are toxic to the environment and also difficult to dispose of after use. Environmental concerns continue to increase on account of pollution from excessive lubricant use and disposal, especially total loss lubricant.

However, low temperature performance is one of the weaknesses of using vegetable oils as new source of bio-lubricant [28,29]. Vegetable oil will exhibit poor flow properties when exposed to a

lower temperature and become cloudy and solidified upon a long term exposure [30]. Deliberate modification of the chemical structure of vegetable oils is considered as an alternative to allow their direct use as lubricant base stocks [24].

Pour point depressant (PPD) is one of the alternatives to improve the low temperature performance of a lubricants. Soldi et al. [31] have studied the effect of the PPD on the paraffinic and from the result it was successful to improve the low temperature performance of the paraffinic. PPD has also been tested on vegetable oil including canola oil, castor oil and soybean oil. The result shows that PPD can reduce the pour point of the vegetable oils tested [32].

Basically, there are two types of oil that can be derived from palm fruit which are palm oil for food applications and palm kernel oil for non-food applications [38]. Therefore, palm kernel oil is selected in order to fully utilize the excess palm kernel oil and due to the consideration that it would not disturb the supply of palm oil for food production.

To the best of the authors' knowledge, there had been no published analysis conducted on the influence of PPD on the palm kernel oil's pour point under an extreme pressure condition. Therefore, the aim of this study is to create a new bio-lubricant source from the improved palm kernel oil with better low temperature performance. As such, the objective of this research is to investigate the effect of the various pour point depressant (PPD) percentages (5, 10, 20 and 30 w/w%) on the low temperature performance, friction coefficient and the wear performance of the refined palm kernel oil (RBD PKO) under extreme pressure through the use of a four-ball tribotester machine. The mineral oil was used as a benchmark lubricant, while the experiment had been conducted according to the ASTM D2783 standard.

## **2. EXPERIMENTAL METHOD**

### **2.1 Lubricants**

Malaysia is not only recognized as a major global producer of several agricultural commodities, but is also well-known for being the world's

leading palm oil exporter with a 60% of the market share [33]. Since palm/palm kernel oils are well-suited to be modified for specific applications in food use, Malaysia is also known for successfully developing a refined version of the palm oil or in other words, the Refined, Bleached & Deodorised (RBD) palm kernel oil (PKO), where the impurities, odour and unnecessary fatty acids had been removed by way of a purifying process. The facts regarding the PKO composition is shown in Table 1.

**Table 1.** Composition of Palm Kernel Oil [34].

<i>Fatty acid</i>	<i>C-atoms</i>	<i>Percentage (%)</i>
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
<i>Melting point(°C)</i>	27.3	

For this study, the lubricants that were used for this experiment had consisted of the RBD PKO, RBD PKO with the added PPD (5, 10, 20 and 30%w/w) and mineral oil (SAE40). The PPD that was used for this test had been based on the Alpha-olefin copolymer with heavy aromatic naphtha as illustrated by their physicochemical properties in Table 2, while each of the sample blends was obtained by mixing the PPD and the PKO with an overhead stirrer for one hour under a temperature level of 30 °C. The results that were obtained from each 10ml tested samples were then compared with the mineral oil for benchmarking purpose.

**Table 2.** Physicochemical properties of PPD.

<b>Types</b>	<b>Alpha-olefin copolymer with heavy aromatic naphtha</b>
Operating Temperature	Min 25 °C to Max 100 °C
Physical State	Liquid
Boiling Point	240 °C
Flash Point	120 °C – 135 °C
Density	900 – 920 kg/m <sup>3</sup> at 20 °C
Appearance	Brownish
Odour	Mild Odour
<b>Ph Level</b>	<b>5 – 6</b>

## 2.2 Lubricant Density and Kinematic Viscosity evaluation

The density test for all of the lubricants that were employed for this research is tabulated in Table 4. From the results of the ASTM D1298 – 12b method that was used for determining the lubricant's density level at a temperature level of 25 °C, it could be observed that the mineral oil had possessed a lower density level than those of the palm kernel oil, while the density of the palm kernel oil with the added PPD was found to have increased when the percentage of the PPD was raised from that of 0.915 (A2-5 % and A2-10 %) to 0.92 (A2-20 % and A2-30 %). The higher density level that was demonstrated by the palm kernel oil was thus explained by Sapawe as being attributed to its more compact molecular structure [37].

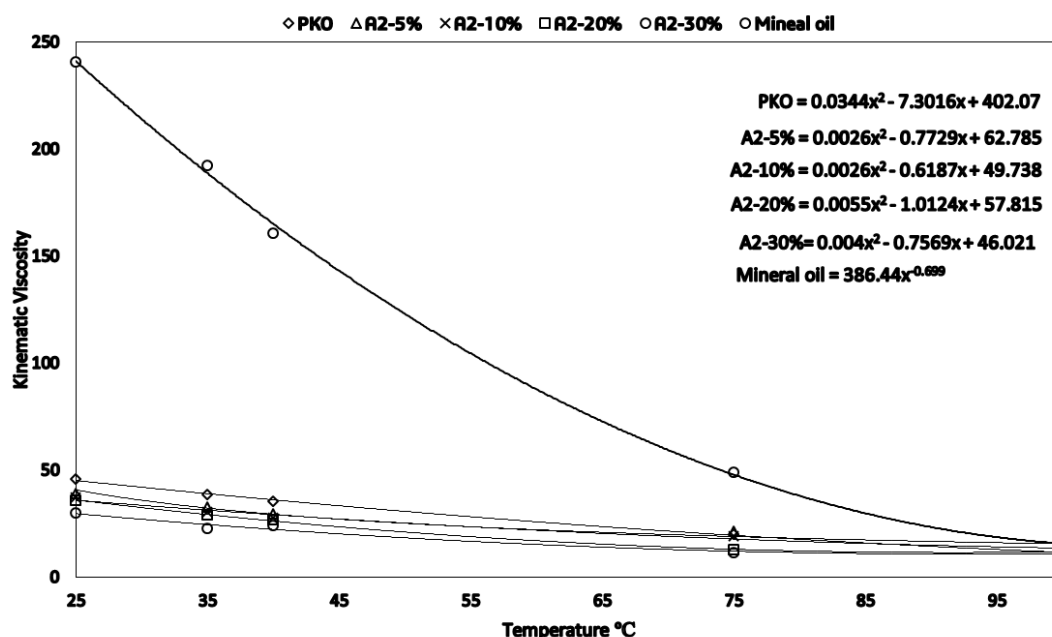
**Table 4.** Density for all lubricant used in research.

<b>Lubricant</b>	<b>Density @ 25 °C, kg/cm<sup>3</sup></b>
Palm Kernel Oil (PKO)	0.91
A2-5 %	0.915
A2-10 %	0.915
A2-20 %	0.92
A2-30 %	0.92
SAE 15W-50 Engine oil	0.8971

**Table 5.** Kinematic viscosity of tested lubricants at selected temperatures.

<b>Temp. (°C)</b>	<b>Kinematic Viscosity (mm<sup>2</sup>/s)</b>					
	<b>Palm Kernel Oil</b>	<b>A2-5%</b>	<b>A2-10%</b>	<b>A2-20%</b>	<b>A2-30%</b>	<b>Mineral Oil</b>
<b>25</b>	45.77	38.8	37.01	35.8	29.8	240.8
<b>35</b>	38.48	32.86	30.58	29.01	22.6	192.3
<b>40</b>	35.36	29.71	27.85	26.6	24.25	160.8
<b>75</b>	20.17	21.17	18.97	12.7	11.54	48.87
<b>100</b>	11.24	13.98	13.00	11.9	10.97	15.2
<b>Viscosity Index</b>	330	485	485	469	479	96

In Table 5, although all of the sample lubricants had demonstrated a decreasing kinematic viscosity trend with increasing PPD percentages and temperature levels, the palm kernel oil's viscosity index was found to be higher than that of the mineral oil, which had been largely due to its triglyceride structure for aiding the occurrence of intermolecular interaction at higher temperature levels. Even though the PPD-added sample lubricant had shown a higher viscosity index as compared to the pure palm kernel oil's with its highest viscosity index being at A2-10 %, there were however, no big gap differences observed between the respective index values [17].



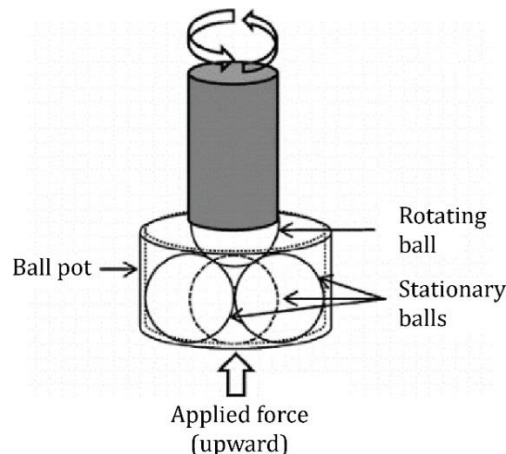
**Fig. 1.** Graph of kinematic viscosity against temperature.

Figure 1 shows that the palm kernel oil has lower kinematic viscosity compare to mineral oil, the result has the same findings by Masjuki et al. [17]. Kinematic viscosity for palm kernel oil at 40 °C has reduce from 35.36 mm<sup>2</sup>/s to 11.24 mm<sup>2</sup>/s at 100 °C. The graph reduction trend shows similar for other sample lubricant, with A2-5% kinematic viscosity at 40 °C has reduce from 29.71 mm<sup>2</sup>/s to 13.98 mm<sup>2</sup>/s at 100 °C, A2-10% kinematic viscosity at 40 °C has reduce from 27.5 mm<sup>2</sup>/s to 13 mm<sup>2</sup>/s at 100 °C, A2-20% kinematic viscosity at 40 °C has reduce from 26.6 mm<sup>2</sup>/s to 11.9 mm<sup>2</sup>/s at 100 °C, and A2-30% kinematic viscosity at 40 °C has reduce from 24.25 mm<sup>2</sup>/s to 10.97 mm<sup>2</sup>/s at 100 °C. From the data below, when comparing to the addition of the PPD, the kinematic viscosity at 30 °C to 90 °C shows that palm kernel oil has higher kinematic viscosity with a decreasing trend, but at 100 °C the palm kernel oil (11.24 mm<sup>2</sup>/s) shows much lower when compare to the sample A2-5% (13.98 mm<sup>2</sup>/s) and A2-10% (13 mm<sup>2</sup>/s). This mean that the sample A2-5% and A2-10% may improve the kinematic viscosity at higher temperature for the palm kernel oil.

## 2.3 Tribological Test

Four-ball tribotester machine is used to investigate the characteristic of the lubricant properties and the wear condition [35]. According to Fig. 2, three balls at the bottom are

held by a ball pot and one at the top is held by the collector. The lubricant is filled inside the ball pot together with the three balls, and the ball pot will be pressed upward against the top ball that will then rotate to a desired level of speed.



**Fig. 2.** Schematic diagram of four ball tribotester.

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

### 2.3.1 Test Condition

The experiment was executed according to the ASTM D2783 as determined in Table 3.

**Table 3.** The test condition (ASTM D2783).

Condition	Details
Temperature	35 °C
Speed	1760 rpm
Duration	10 sec
Load	Starting at 90 kg until failure

Every test was conducted in 10-second duration. The test was repeated with higher applied load until failure weld occurred.

### 2.3.2 Friction Analysis

Friction is an important criterion that needs to be analysed to determine the friction-reducing properties of the lubricant. Friction assessment has been done by referring to the frictional torque data recorded from acquisition system of four-ball tribotester. Then, coefficient of friction was determined using the formula stated in Equation 2.1 [14].

$$\mu = \frac{T\sqrt{6}}{3Wr} \quad (2.1)$$

Where  $\mu$ , T, W and R are coefficient of friction, frictional torque (Nm), applied mass (kg) and distance from the centre of contact surface on the lower balls to axis of rotation (3.67 mm), respectively.

### 2.3.2 Wear Scar Diameter

The value of wear scar diameter (WSD) can reflect the anti-wear performance of lubricant samples. In general, the larger the wear scar diameter, the more severe the wear. It is measured by using a low resolution optical microscope to determine the average WSD value from the three bottom stationary balls.

### 2.3.3 Worn Surfaces Observation

The observations on the worn surfaces of the stationary balls are important to determine the wear behaviour occurring on the contact surfaces whether they are abrasive, adhesive or etc. Based on that analysis, we were able to determine the tribological performance of each lubricant sample. In this study, worn surfaces were observed by using a high resolution optical microscope.

## 3. RESULT AND DISCUSSION

### 3.1 Low Temperature Ability Observation of a Lubricants

PKO, A2-5%, A2-10%, A2-20% and A2-30% were heated to 30°C in order to remove the crystal wax and then the temperature was lowered (25 °C, 20 °C and 15 °C) for one day to observe the capability of the sample to withstand in lower temperature.

**Table 6.** The effect of different percentage PPD added into PKO on its pour point.

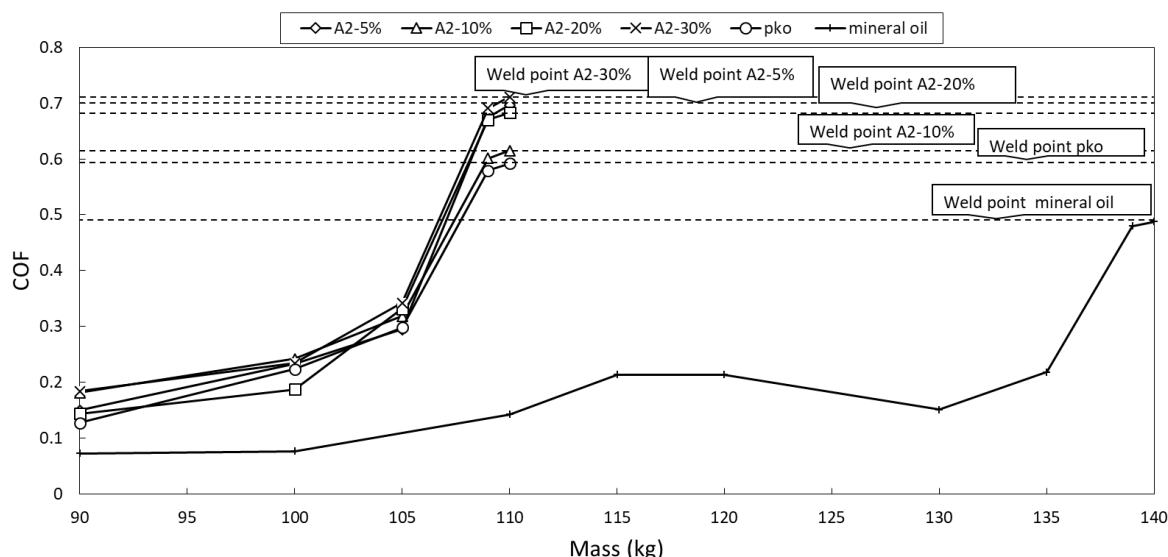
Sample	Blend ratio (wt/wt)		Solid Phase Temperature (°C)
	RBD PKO	PPD	
RBD PKO	100	0	25
A2-5%	95	5	20
A2-10%	90	10	20
A2-20%	80	20	15
A2-30%	70	30	15

From the result obtained, we can see that at 25 °C the PKO liquid has started to fully solidify, which shows that the pour point of the pure PKO cannot withstand at lower temperature without any modification or addition of any additives. At 15 °C, all samples; PKO, A2-5%, and A2-10% had completely solidified except for A2-20% and A2-30 % where the samples behaved as liquid but in waxy form.

### 3.2 Coefficient of Friction

The various coefficient of friction (COF) values that were used for each tests as shown in Fig. 3 is aimed at illustrating the relationship between the COF and the load samples of palm kernel oil (PKO), PKO with 5 % PPD (A2-5%), PKO with 10 % PPD (A2-10%), PKO with 20 % PPD (A2-20%) and PKO with 30 % PPD (A2-30%) as well as the mineral oil, which had acted as a benchmark test. As shown from the results, the mineral oil was found to have exhibited a lower COF value and the ability of withstanding a higher load (140 kg) than those of the other samples.

While the addition of the PPD had increased the COF values with the corresponding lowest and highest COF values at A2-10% and A2-30% prior to reaching its failure points, the lowest COF value however, was observed to have derived from the mineral oil, where its ability for withstanding a higher load had been due to it already being a fully formulated lubricant with well-equipped useful additives.



**Fig. 3.** Comparison of the coefficient of friction.

Since fatty acids have the tendency for forming a thin lubricant layer that breaks easily when being subjected to extreme pressure conditions, all of these lubricant samples were thus found to have exhibited the same value for withstanding the highest load prior to reaching their failure points.

Although the PKO that was formulated with the PPD had not been affected and could maintain its existing properties as shown by its load withstanding failure rate, there had however, been some occurrences of drastic COF value changes on some of its samples as compared to those of the non-additive PKO. The main reason that the samples with PPD had produced a high coefficient of friction value was because the PPD had not only reduced the viscosity of the formulated lubricants, but also had helped in lowering the pour point without the additional anti-friction, anti-wear or extreme pressure elements.

### 3.3 Wear Scar Diameter

This section will discuss on the analysis and the comparison of the wear scar diameter (WSD) of the different loads that were applied to the ball bearings as a way of determining the load failure rates of extreme pressure conditions.

The failure WSDs of each lubricant samples as illustrated in Fig. 4 had shown the mineral oils as producing the lowest WSD at a higher load (140 kg) than those of the PKO (110 kg),

where the long-structured fatty acid composition that had existed in the latter was found to have resulted in a chemical reaction that will severe the chemical compound of the vegetable oil. This statement was also supported by Bowden from his discovery of the increased mean wear scar diameter that was resulted from the chemical attack of the fatty acid on a rubbed surface.

While the comparison of the WSDs had discovered the PPD sample at A2-5% as sharing the same WSD value of the pure PKO, the WSD of the failure points in the other sample on the other hand, was found to have increased with the increasing PPD percentages. This therefore implies that the kinematic viscosity of the lubricant will affect the wear condition of the test sample, while an increased PPD percentage has the inclination for lowering the kinematic viscosity of the lubricant [36].

In extreme pressure condition test, wear scar diameter plays an important role because it can determine which load will cause the ball to reach its failure (weld). Lower viscosity will provide a thin layer protective film, that make the lubricant sample fluid film cannot prevent a good protective layer at higher mass test [22,30]. The breakdown of this fluid film could be attributed to the insufficient lubricant at the. As such, the breakdown of this fluid film could have been attributed to the loss of the lubricant that was experienced by the ball bearing surfaces [37].



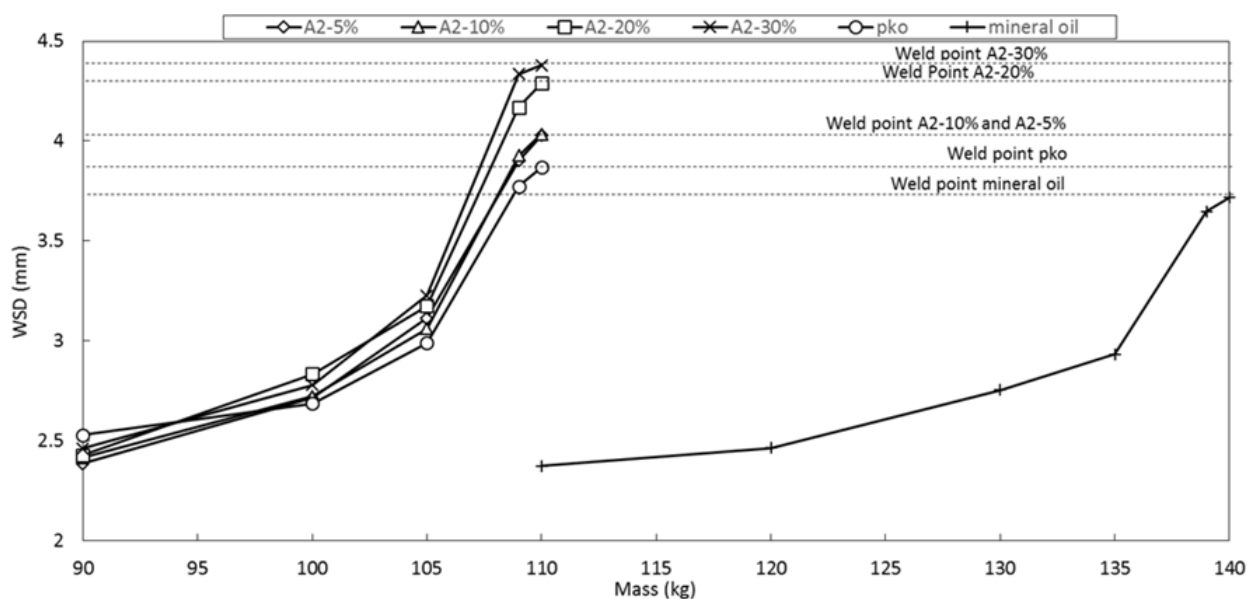


Fig. 4. Wear Scar Diameter.

### 3.4 Worn Surfaces Analysis

The wear surface of the wear scar failures or the weld defects are thus discussed in this section, where the worn scar images of the ball specimen were obtained by using a low resolution microscope of 10x magnification. As mentioned earlier, the failure experienced by both the palm kernel oil and the PPD sample had occurred at 110kg but those from the mineral oil had exhibited a higher failure load at 140 kg.

As shown in Fig. 5, the worn surface of the PKO was found to have been dominated by parallel grooves with the weld occurring at the surface edges, while the sample of A2-5% as depicted in Fig. 6 had revealed 50 % of the worn surface as experiencing a weld failure with parallel grooves located at its failure point.

In Fig. 7, almost all of the parts were revealed to be covered by weld failures with the surface being rougher than those of the PKO. As for the samples at A2-20% (Fig. 8) and A2-30% (Fig. 9), the bearing surface was discovered to have been enclosed by the weld failures, while a deep scratch could be observed on the surface of the sample image for A2-20% as opposed to those of A2-30%, where it had only demonstrated slight scratches on its surface.

The wear shape of the mineral oil had also seemed to be more circular with some of the wear residues observed at the edges as depicted in figure. Although the wear had not seemed to

experience any corrosion as shown by its smooth surface, there were still a minimal number of scratches seen on its surface.

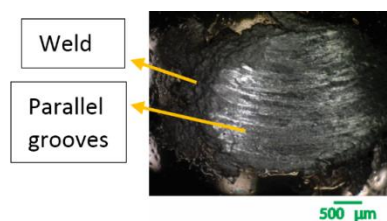


Fig. 5. Wear scar image PKO.

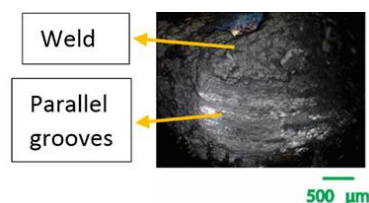


Fig. 6. Wear scar image A2-5%.

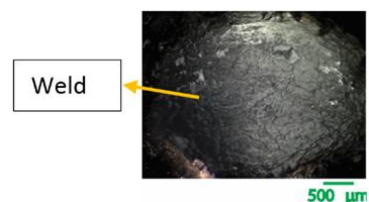


Fig. 7. Wear scar image A2-10%.

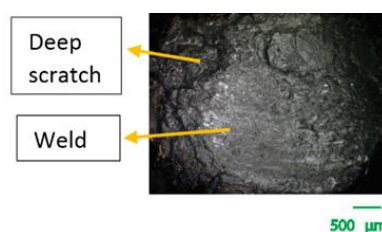


Fig. 8. Wear scar image A2-20%.

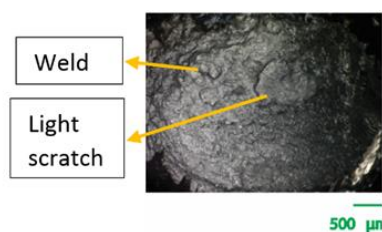


Fig. 9. Wear scar image A2-30%.

In general, the wear observation had confirmed the balls' metal to metal contact of each test. As illustrated in Figs. 5-9, the wear scars of the PKO, A2-5%, A2-10%, A2-20% and A2-30% were found to have shown more asperities and also corrosion at the wear edges. The surface had not only appeared rougher because of the different scratch magnitudes that had occurred within the wear, but the shape of the wear had also seemed to be inconsistent with a certain amount of ball residues observed at the edges.

#### 4. CONCLUSION

As shown from this research, we can thus conclude the samples A2-20% and A2-30% as having the ability for withstanding a lower temperature (15 °C) level than those of the other samples. While the mineral oil was found to have exhibited the lowest COF value, the addition of PPD into the palm kernel oil however, was discovered to have led to a slight increment in the COF value with the lowest value observed at A2-10%. As for the wear scar diameter and surface roughness, the lubricant samples had not only shown slightly higher values than those of the pure PKO, but had also demonstrated the ability of withstanding a 110 kg load prior to reaching their respective failure rates.

While this research had proven the addition of PPD as successfully reducing the pour point of the palm kernel oil, its performance however, had been less favourable than those of the mineral oil. For this reason, the incorporation of an anti-wear element should therefore be considered in subsequent research as a way of improving its lubricity performance.

#### Acknowledgement

The authors would like to express their thanks to the Research Management Centre (RMC) of

Universiti Teknologi Malaysia (UTM) for the Research Grant, GUP (17H96, 15J28, 20H29), TDR Grant (05G23), FRGS Grant (5F074), School of Mechanical Engineering, UTM and Ministry of Education of Malaysia for their support.

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