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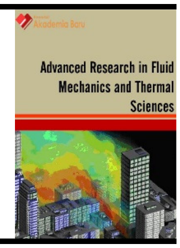

The Effect of Fluidity of Palm Kernel Oil with Pour Point Depressant on Coefficient Of Friction Using Fourball Tribotester

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ABSTRACT

The growing awareness worldwide of the need to promote the use of renewable materials such as vegetable oils is due to increasing concerns about the damage to the environment that is being caused by the use of non-biodegradable mineral oils. Vegetable oils have the potential to replace mineral oils as a lubricant because of their specific properties, namely that they are non-toxic and biodegradable. The main problem with the use of vegetable oils is that they perform poorly at low temperatures. In this research, palm kernel oil (PKO), which behaves as a semi-solid, was used as a bio-lubricant by mixing it with different weight percentages of a pour point depressant (PPD) to investigate the performance of the pour point depressant and also to determine the effect on the lubricity of the bio-lubricant when it is blended with different percentages of PPD (5 wt.%, 10 wt.%, 20 wt.% and 30 wt.%). The experiment was conducted according to ASTM D4172 and ASTM D2783. The results of the experiment showed that at low temperatures the PKO samples with 20 wt.% PPD and 30 wt.% PPD performed well, where they were able to remain in a liquid form at a temperature of 15℃. From all antiwear test result, the coefficient of friction for the PPD sample shows poor tribological performance when adding PPD into the palm kernel oil.

1. Introduction

The increasing concern in using a renewable material has triggered the researcher on the development of more environmentally lubricants [1], and vegetable oil products are one of the most promising sources of renewable lubricant in this century [2-4]. In terms of biodegradability vegetables oils shows superior properties compared to the mineral oil. Attention has been focused by many party to develop vegetable oils as an industrial lubricant and also biodiesel [5].

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Palm oil is one of the famous vegetable oil that has a potential to replace the mineral oil lubricant. Many researcher have done the research to develop a bio-lubricant using palm oil such as, Syahrullail and his colleagues that investigated the characteristics of palm oil as a metal forming lubricant [6,7]. Besides that, palm oil was also investigated to be used as diesel engine and hydraulic fluid as proposed by Bari and Wan Nik respectively [8,9]. 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 [10,11], uses palm oil as additives [12], uses palm oil with additive [13] and uses palm oil emulsion [14]. 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. 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 [15].

Low temperature performance is one of the weakness of vegetable oils to be a bio lubricant [16,17,18]. Vegetable oil become poor flow properties when it exposed to a lower temperature and become cloudiness and solidified upon a long term exposure [19]. Deliberate modification of the chemical structure of vegetable oils is a sound alternative to allow their direct use as lubricant base stocks [20]. Pour point depressant is one of the alternative to improve the low temperature performance of a lubricants such as proposed by Soldi *et al.,* that study the effect of the PPD on the paraffinic and the result shows that it successful improve the low temperature performance of the paraffinic [21]. PPD also has been test on vegetable oil (canola oil, castor oil and soybean oil) that study by Asadauskas and co-workers, the result shows PPD can reduce the pour point of the vegetable oil that been test [22].

The palm kernel oil has poor low temperature performance when the lubricant is exposed at lower temperature, and by adding the PPD the lubricant sample has successful improve its pour point performance with PPD sample A2-20% and A2-30% has the most improvement in low temperature performance where it can maintain in liquid form at 15°C. However in the tribology performance the result shows palm kernel oil has poor coefficient of friction compare to mineral oil (bench mark lubricant), and after adding PPD the result shows that the kinematic viscosity is decreasing as the PPD percentage is increase, besides that the coefficient of friction also increase for almost all tribology test for all sample with PPD lubricant.

2. Methodology

The experiment method will be divided into several step starting with density and the viscosity test, followed by the low temperature ability test and finally the tribology test. For low temperature ability test, it is more focused on the observation of the sample that been test in maintaining its liquid form when expose in lower temperature. And the tribological test will be divided into four main test that is anti-wear fourball test, variable load test, low temperature test and extreme pressure test. All test will be discuss the effect of the fluidity of the different percentage PPD on palm kernel oil on the coefficient of the friction of the material test under different experiment condition.

2.1. Preparation of Materials

In this research palm kernel oil were used as a vegetable oil, the sample lubricant is mixed into 4 different percentage of PPD (5%PPD, 10%PPD, 20%PPD, and 30%PPD) into the palm kernel oil. The mixer were used to blend the palm kernel oil and the PPD sample for 1 hour at 250 rpm, to make sure that the sample will be mixed properly. The mineral oil (SAE 40) is used as a benchmark to compare the tribological performance of the palm kernel oil weather the sample lubricant is applicable to be used in the industry. All the sample (A2-5%, A2-10%, A2-20% and A2-30%) will be test their physicochemical properties that is the density, kinematic viscosity and finally the ability of the sample to withstand at lower temperature. And the last part the sample will be test its tribological properties by using fourball tribotester to study the effect on the coefficient of friction of all sample under different test condition as shown in Figure 1.

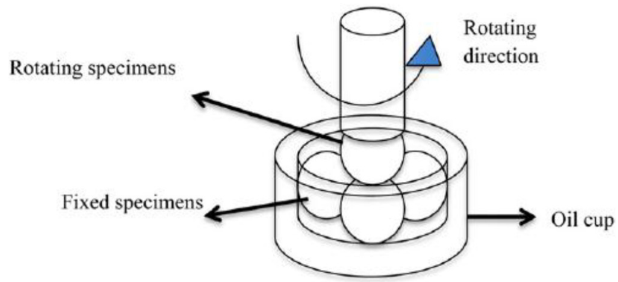

Fig. 1. Four-ball tribotester machine

2.2 Lubricant Sample Preparation

In this experiment, PPD are used to modify the physical state of palm kernel oil from semi-solid to liquid state when at ambient and low temperature. Preparation are begin with adding the PPD into the palm kernel oil. The PPD are added in weightage concentration where the calculation is as in Equation 1.

$$\frac{PPD\ (g)}{Lubricant\ (g)+PPD(g)} \times 100\% = \quad wt\% \tag{1}$$

2.3 Physicochemical Test

The sample is measure their fluidity properties that divided into three main test that is the density, kinematic viscosity and finally the ability of the sample to withstand at lower temperature. Density is a measure according to ASTM D1298 – 12b. 250ml of sample is used and the sample is brought to 25°C temperature. The sample is then brought into the hydrometer cylinder. After that the hydrometer is lowered into the lubricant and let it settle for a few seconds, when the hydrometer is stable we can record the scale read at the hydrometer to determine the lubricant sample density. Kinematic viscosity is a measure of the resistance of a fluid which is deformed by either shear stress or tensile stress of the fluids and also known as the internal friction of the fluids. Viscosity evaluation need to be done in order to find the viscosity of a lubricant since viscosity of oil is most important physical properties. Different oil type and different oil blending may have different viscosity. Viscosity of the lubricant is taken to determine the effect of temperature on viscosity. In this research, kinematic viscosity of five different lubricants (palm kernel oil, A2-5%, A2-10%, A2-20%, A2-30% and mineral oil) will be taken using a viscometer according to ASTM D445. Low temperature ability of lubricants are evaluated by using method of cooling the lubricant at certain temperature in the refrigerator for 1 days. Before lubricant are kept in the refrigerator, all lubricants are heating to 30 °C to ensure all lubricant in liquid state. Then all lubricant are kept in refrigerator with initial temperature set to 25 °C. Temperature are dropped with interval 5 °C for each temperature drop.

2.4 Tribological Test Method

This part of research will be divided into two main part test that is ASTM D4172 and extreme pressure ASTM D2783 The standard Four-ball Tribotest uses four steel bearing balls in evaluating the performance of lubricant tested in term of friction and wear. Below shows the experimental condition under normal test, different load, different low starting temperature and extreme pressure that will conduct in this experiment which are applicable for all the lubricants.

(ASTM D4172)
Experimental conditions.
Antiwear Test
Time : 1hour
Speed : 1200rpm
Temperature : 75˚C
Load : 40kg

Variable load Test
Time : 1hour
Speed : 1200rpm
Temperature : 75˚C
Load : 40kg, 50kg, 60kg, 70kg and 80kg

Low Starting Temperature Test
Time : 1hour
Speed : 1200rpm
Temperature : 75˚C, 20°C, 15°C
Load : 40kg

(ASTM D2783)
Extreme Pressure Test
Time : 10 sec
Speed : 1760 rpm
Temperature : 35˚C
Load : 90kg, 100kg, 105kg, 110kg, 115kg… (Until the weld occur)

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:

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

where,
μ = Coefficient of friction
T = Frictional torque (kg mm)

W = Load (kg)
r = is the distance from the center of the contact surface on the lower balls to the axis of rotation (3.67mm)

3. Results and Discussion

3.1 Lubricant Density and Kinematic Viscosity evaluation

The density test for all lubricants used in this research are tabulated as in Table 4. ASTM D1298 – 12b method is used to determine the density of the lubricant at the temperature of 25°C. From the result obtain it can see that mineral oil has lower density compare to palm kernel oil, and when adding PPD, the palm kernel oil density is increasing as the percentage of the PPD is increase from 0.915 (A2-5% and A2-10%) to 0.92 (A2-20% and A2-30%). According to Faris (2016) palm kernel oil has high density compare to mineral oil because of its molecular structure that has compact structure rather than mineral oil.

Table 4
Density for all lubricant used in research

Lubricant	Density @ 25°C, kg/cm^3
Palm Kernel Oil	0.91
A2-5%	0.915
A2-10%	0.915
A2-20%	0.92
A2-30%	0.92
Mineral oil	0.8971

For viscosity test method, viscometer rotor is used to evaluate its fluidity by turning the rotor at fixed rotated speed and at the same time lubricant is heated until 100 ℃. The kinematic viscosity of tested lubricants are shown in Table 5. The table shows the kinematic viscosity is decreasing as the temperature is higher for all sample. A2-30% has the lowest kinematic viscosity through the entire temperature test. Comparing with mineral and palm kernel oil, it shows that mineral has higher kinematic viscosity but in terms of viscosity index pko has higher value compare to mineral oil as proposed by Zulkifli *et al.,* [23]. The addition of PPD into the palm kernel oil has increase the density from 0.91 kg/cm^3 to 0.915 kg/cm^3 (A2-5% and A2-10%) and 0.92 kg/cm^3(A2-20% and A2-30%).

Table 5
Kinematic Viscosity of Tested Lubricants at Selected Temperatures

Temperature	Kinematic Viscosity (mm^2/s)					
(˚C)	PKO	A2-5%	A2-10%	A2-20%	A2-30%	Mineral Oil
25	45.77	38.8	37.01	35.8	29.8	240.79
35	38.48	32.86	30.58	29.01	22.6	192.34
40	35.36	29.71	27.85	26.6	24.25	128.8
75	20.17	21.17	18.97	12.7	11.54	48.87
100	11.24	13.98	13.00	11.9	10.97	15.2
Viscosity Index	329.9	484.89	484.955	469.004	478.873	96

The viscosity index is calculated based on ASTM D2270. Table 5 shows the effect of kinematic viscosity of all sample lubricant at different temperature, from the table below it kinematic viscosity is decreasing as the PPD percentage and temperature increase. This mean that the fluidity of the sample lubricant getting lower in higher temperature. From the Table 5 also the viscosity index for palm kernel oil is very high compare to mineral oil this is due to the presence of triglyceride structure that help the intermolecular interaction at higher temperature [10]. As we observe on PPD sample it shows the viscosity index is higher compare to pure palm kernel oil. From the PPD sample also the value of viscosity index has slightly difference with A2-10% has the highest value of VI (484.955 mm^2/s).

3.2 Low Temperature Ability Observation 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 and then the temperature is lowered (25˚C, 20˚C and 15˚C) for one day to observe the capability of the sample to withstand in a lower temperature. From the result obtain in Table 6 we 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. 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 form but in waxy form. This shows that the percentage of the PPD is can influence the pour point of the palm kernel oil this result is agreed by Asadauskas *et al*., [22].

Table 6
Summary effect of PPD to the palm kernel oil for different percentage of PPD on its pour point

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

3.3 Coefficient of Friction Antiwear Test

Figure 2 shows the average value of the coefficient of friction for PKO, A2-5%, A2-10%, A2-20%, A2-30% and mineral oil. It is very important to get a lower coefficient of friction (COF) to show the level of efficiency of the lubricant. From Figure 2, the A2-20% sample had the highest coefficient of friction at 0.0854, while mineral oil had the lowest coefficient of friction at 0.0624. This is because mineral oil is fully formulated and is already being used in the industrial sector. In addition, the presence of free fatty acids in mineral oils acts as a friction modifier to produce a good lubrication layer compared to palm kernel oil [24]. The coefficient of friction of all the samples did not differ much from that of the pure palm kernel oil (0.0775). It was shown that the addition of PPD to the palm kernel oil caused the COF to increase due to the effect of the lubrication properties of the lubricant. Besides that this result also might have been due to the decrease in the level of fatty acids in the palm kernel oil (PKO) as the amount of PPD added was high. According to Lawal *et al*., [25], the long fatty acid chains helped to reduce the coefficient of friction.

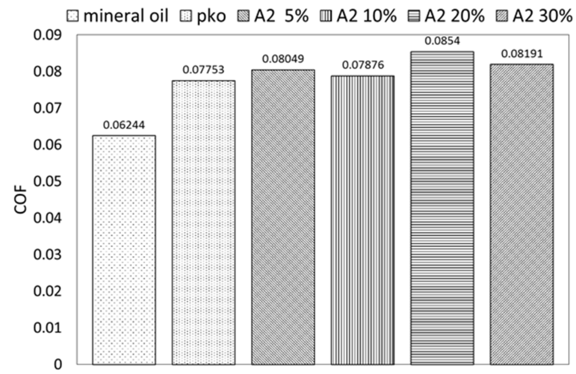

Fig. 2. Coefficient of friction at 40kg

3.5 Coefficient of Friction Low Starting Temperature

The coefficient of friction is presented in Figure 3 for sample pko, A2-5%, A2-10%, A2-20% and A2-30% at its liquid phase. From the data obtain it shows that the coefficient of friction is increasing as the temperature decrease for all sample. Only sample A2-20% and A2-30% will be test at the 15ºC as it's maintain in liquid form in this temperature, the sample shows that for A2-20% the COF is increasing from 0.07935 at normal test to 0.08531 at 20°C and 0.08546 at 15°C, the trend shows the same for sample A2-30% that increase from 0.08191 at normal test to 0.08932 at 20°C and 0.09778 at 15°C. This shows that adding the PPD will slightly increase the COF and A2-30% has the highest value of the COF through the entire starting temperature. The increasing in COF is influenced by the sample kinematic viscosity, higher in kinematic viscosity will produce lower COF for each of the sample lubricant that been test. This is supported by Minami [26]. Besides that, increasing COF as the PPD percentage is increase is due to the decreasing of the fatty acid of palm kernel oil (pko) inside the sample as the sample of PPD added is high. According to Lawal *et al.*, [25] the long chain fatty acid can help to reduce the coefficient of friction. Masjuki *et al.*, [10] stated that the lower boundary effect and/or breakdown of boundary lubrication is due to the lower viscosity. According to Sharma *et al.,* the fatty acid chain are adsorbed to metal surfaces, thus permitting monolayer film formation with the hydrocarbon end of fatty acids oriented away from the metal surface. The fatty acid chain thus offers a sliding surface that prevents the direct metal-to-metal contact.

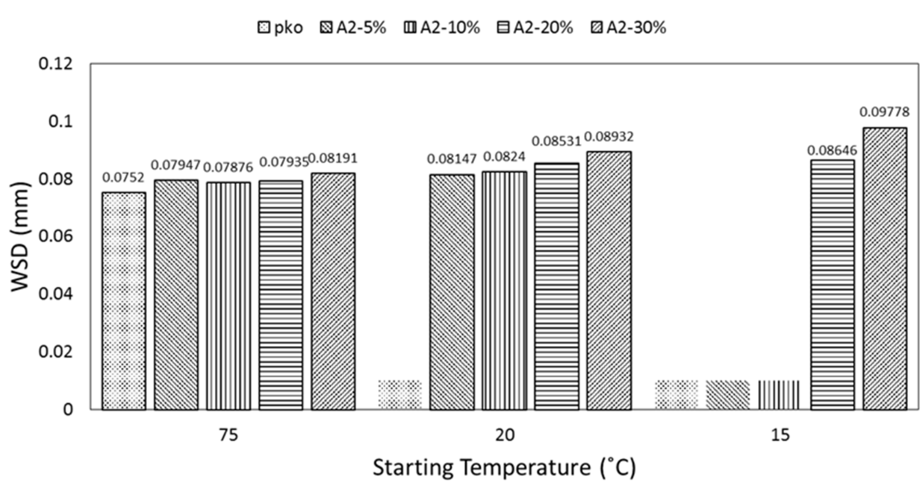

Fig. 3. Coefficient of friction (COF) at its liquid phase

3.5 Coefficient of Friction Variable Load

The trend of the 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. From the result obtain, sample A2-5% shows better lubrication performance in terms of coefficient of friction during entire load test except for 40kg. From the Figure 4, mineral oil has lowest coefficient of friction, this is because the mineral oil has highest kinematic viscosity (48.87 mm^2/s) at 75˚C compare to other sample, besides that mineral oil also is fully formulated lubricant that already been used in industry. The result shows that a similar findings by Masjuki *et al*., (1999), that stated mineral oil exhibits better anti friction performance when compare to the palm oil. The result may due to the high palmitic fatty acid $CH_3(CH_2)_{14}COOHCOOH$ content (43.7%) in palm kernel oil, that make the sample will easily exposed to a corrosive wear, that could attribute to corrosion on the surface, that eventually will increase the friction. Addition of PPD shows increasing in coefficient friction of palm kernel oil this is because of reducing in kinematic viscosity when adding more PPD [26,27]. 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*., [25] the long chain fatty acid can help to reduce the coefficient of friction.

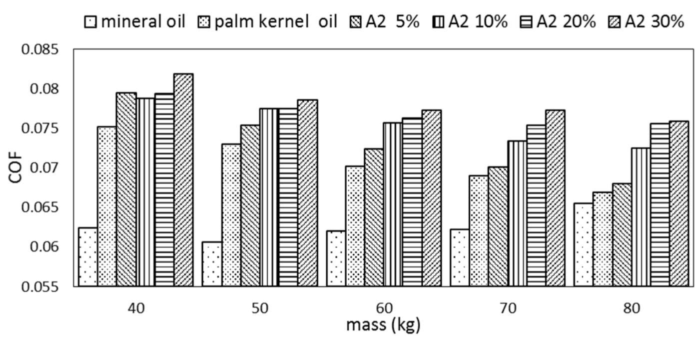

Fig. 4. Coefficient of friction against load

3.6 Coefficient of Friction Extreme Pressure

From the data obtain, it shows that the mineral oil can withstand at higher load (140kg) and at a lower coefficient of friction compare to the palm kernel oil and other sample (110kg). When compare to term of the COF, it shows that adding the PPD will increase the value of the COF, where A2-10% shows the lowest and A2-30% has the highest value of the COF when reaching it failure points. From the Figure 5, the mineral oil has lowest value of the COF and can withstand at higher load because it is already fully formulated lubricant, and it has already been used in industrial. Fatty acid are disadvantages when operating under extreme pressure. This due to that vegetable oil produce thin layer for lubricant which are not suitable for extreme pressure operating and also boundary lubricant film tend to break at extreme pressure condition [28,29]. From the other sample, it can be observe that highest load can withstand reaching to the failure is the same, this shows the palm kernel oil sample adding PPD is not affected in maintain it existing properties in terms of the load withstand failure, but in terms of COF, it shows that some drastic change for a certain sample when compare to the pure palm kernel oil. The main reason that the PPD sample to have high coefficient of friction value are due to the PPD which only can lower the pour point and without any anti-friction, anti-wear or extreme pressure additive added which might lower the coefficient of friction compared to the mineral oil [30]. Besides that adding PPD also will reduce the viscosity of the lubricant.

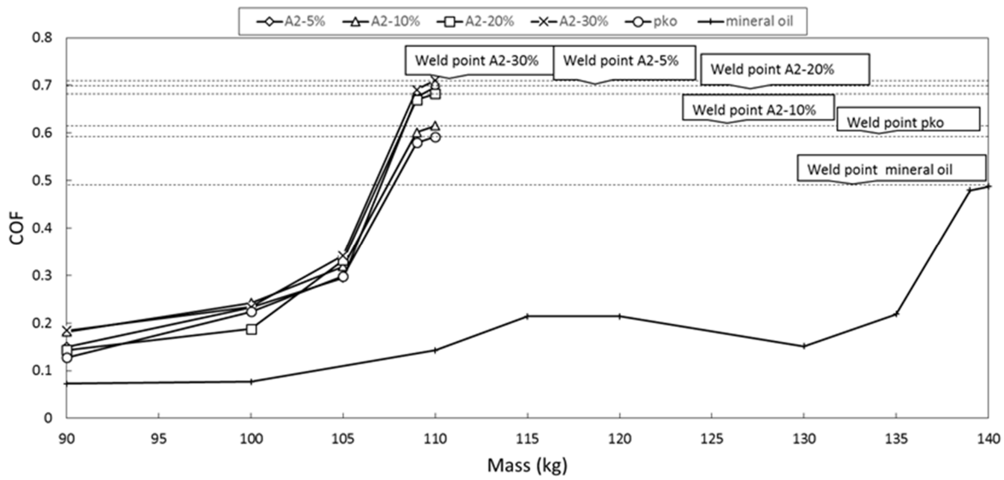

Fig. 5. Comparison of the coefficient of friction under extreme pressure

4. Conclusions

The objective to investigate the effect of the pour point of palm kernel oil (PKO) was achieved when it was blended with a pour point depressant (PPD). The difference in the percentages of the PPD affected the ability of the lubricant itself when exposed to lower temperatures. From the observation, the performance of palm kernel oil at low temperatures was successfully improved from 27.3°C (MPOB) to 20°C for the A2-5% and A2-10% samples, and to 15°C for the A2-20% and A2-30% samples. From the result on normal test, we can see that the coefficient of friction of A2-20% has the highest value of COF. At low starting temperature test, we can see that the increasing in coefficient of friction as the PPD percentage is high, the main reason due to the decreasing in kinematic viscosity with sample A2-30% has the highest value COF in entire low starting temperature test where temperature difference is the main factor on the lubrication performance. The result on variable load test has shown the same trend, although adding PPD has successful improve pour point but the value of the coefficient of friction is increase as the PPD percentage is increase, with sample A2-30% has the highest value on the entire test load. From extreme pressure shows that the mineral oil can withstand at higher load (140kg) and at a lower coefficient of friction compare to the palm kernel oil and other sample (110kg). When compare to term of the COF, it shows that adding the PPD will increase the value of the COF, where A2-10% shows the lowest and A2-30% has the highest value of the COF when reaching it failure points.

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