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Evaluation on the Tribological Properties of Double fractionated palm olein at different loads using Pin-On-Disc Machine

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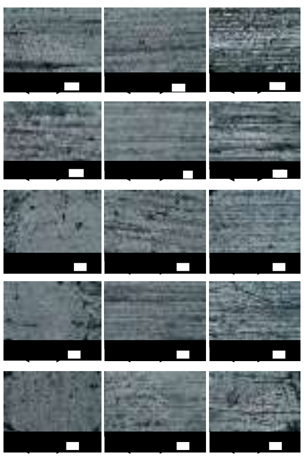
Graphical abstract



Abstract

The use of vegetable oil-based lubricant as a lubricant in various applications has increased and it is eyed by the industry due to its superior tribological properties, besides possessing the potential to replace petroleum-based lubricants. Palm olein is one of alternative lubricants that could be suitable and attractive as a lubricant to be studied due to its advantages and large production in the country. Thus, in this study, the behavior of palm olein characteristics was investigated by using pin-on-disc experiment, in which a hemispherical pin was loaded against the rotating grooved disc. The experiments via sliding were performed with pin-on-disc tester using pure aluminum as the material for hemispherical pin and SKD11 for disc. The test was implemented by dropping continuous flow of palm olein as lubricating oil on sliding surface at different loads applied, which were 10N, 50N, and 100N. The wear rate of the pin and the friction coefficient were also investigated. Moreover, the surface roughness before and after the experiment was analyzed as well. All the results obtained were compared to hydraulic oil and engine oil-SAE 40. From the analysis, the friction coefficient acquired from lubricated with palm olein was the lowest for both conditions. The wear rate obtained for the three lubricants increased from 10N to 100N load for palm oil, but decreased for hydraulic and engine oil-SAE 40. Meanwhile, the wear rate obtained for lubrication with hydraulic oil showed the lowest value compared to Engine oil-SAE 40 and double fractionated palm olein.

Keywords: Palm olein; pin-on-disc; load; friction; wear

Abstrak

Minyak sayuran dikenali sebagai pelincir serbaguna oleh industri disebabkan oleh ciri tribological yang baik, dan mempunyai potensi untuk menggantikan petroleum. Minyak sawit ialah satu daripada pelincir alternatif untuk dikaji kerana kelebihannya dan juga kerana ia merupakan pengeluaran yang besar di negara ini. Kajian tentang minyak sawit telah dijalankan dengan menggunakan eksperimen cakera, di mana pin hemisfera diletakkan menentang disk yang berputar. Eksperimen geseran dijalankan dengan meletakkan cakera , aluminium tulen sebagai bahan untuk pin hemisfera, dan SKD11 untuk cakera. Ujian dilaksanakan oleh aliran berterusan oleh minyak sawit sebagai minyak pelincir di permukaan rata dengan meletakkan beban yang berbeza iaitu 10N, 50N, dan 100N. Kadar kehausan permukaan pin dan kadar geseran juga disiasat. Kekasaran permukaan diambil sebelum dan selepas eksperimen. Semua keputusan yang diperolehi dibandingkan dengan minyak hidraulik dan minyak enjin SAE 40. Daripada analisis yang dibuat, kadar geseran oleh minyak sawit ialah yang terendah. Kadar pengurangan di permukaan pin diperolehi untuk tiga pelincir menambah dari 10N ke beban 100N untuk minyak sawit, untuk hidraulik, dan minyak enjin SAE 40, di mana kadar geseran semakin berkurangan. Selain itu, kadar kehausan yang diperolehi dengan menggunakan minyak hidraulik menunjukkan nilai terendah berbanding dengan minyak Engine SAE 40 dan minyak kelapa sawit.

Kata kunci: Minyak Sawit; pin-atas-cakera; beban; geseran; kehausan

1.0 INTRODUCTION

As machines and engines constantly operate and running condition becomes more severe, more problems are faced with the components due to the damage caused by wear and friction. The most crucial issue is to minimize the amount of wear and friction produced in an operation if any mechanical system systems because wear and friction is the main factor that could lead to mechanical system failure. From the various studies carried out, it has been widely accepted that wear and friction primarily changes with load [1]; speed [2]; temperature [3]; surface roughness[4]; type of material or material component [5]; and environment. The study in understanding the wear mechanism, such as different parameters, plays an important role in identifying new findings and solutions to these particular problems. Moreover, with the presence of lubricants [6, 7] in machines and engines mostly, the economic implication of wear in industry could be overcome.

Lubricant has an important role in this advanced technology era. Almost all equipment or tools that people use in daily life is related to lubricant. Nowadays, there is no doubt that the use of lubricants is important due to its function ability. Friction can be reduced and moving parts can be operated smoothly with the application of lubricants. For example, machines and engine need lubricant to last long, while efficiency of the machines can be maintained with the use of lubricant, even human's hip joints and knee require lubricant so that movement can be done without any difficulty. Lubricant is a substance that is used to reduce friction, as too much of friction will lead to wear, which is harmful to moving parts no matter for engine or human body parts. Basically, various types of lubricants have been fabricated and applied to the required parts, including mineral oils, vegetable oils, and synthetic oils. However, around 38 million metric ton of lubricants per year, which have been applied in the last era, the majority are mineral oil derived from petroleum oil.

Petroleum-based lubricant, which is toxic and non-biodegradable, is harmful to the environment as it leads to ecological pollution. The increase in awareness towards environment and greenhouse effects has turned the sign on finding an alternative lubricant to replace the current petroleum-based lubricant. Hence, vegetable oils are one of the potential alternative lubricants that are suitable to replace the petroleum-based lubricants as they are renewable, environmental friendly, and have less toxic [8]. Besides, other advantages of vegetable oils, such as high viscosity index, high lubricity, and low volatility, which in turn show that vegetable oils also have excellent lubricating properties [9]. Since the properties of vegetable oil have shown its potential to be lubricants for many green industrial activities, there is a possible chance of using vegetable oil-based lubricants as bio-lubricants, which can be used in human's body as biomedical applications.

Therefore, in order to further investigate more information about the use of vegetable oil-based lubricants as bio-lubricants, research on the tribological characteristics of vegetable oil-based lubricants should be carried out. Thus, tribological tests are often carried out by using appropriate wear testing equipment and techniques that can provide relevant information in order to understand the wear behavior of the materials. Pin-on-disc tester is one of the machines that have been used to study the research of tribology by evaluating the properties of wear and friction for the lubricants. The present research used the double fractionated palm olein (DFPO) and looked into the performance of DFPO by using pin-on-disc tester. The objective of the research was to study the wear and friction characteristics with three different lubricants; which were DFPO, Hydraulic oil, and Engine oil-SAE 40.

2.0 EXPERIMENTAL

2.1 Experimental Procedure

Before conducting the pin-on-disc experiment, the viscosity experiment was carried out first. The purpose of the viscosity experiment was to measure the viscosity of the lubricant that was used in this experiment. The viscosity of the lubricant also had an effect on the wear propagation of the pin, as the viscosity of the fluid was a measure of the resistance of a fluid that was deformed by either shear stress or tensile stress. Generally, this experiment used the viscometer as the apparatus to measure the viscosity of the lubricant. Theoretically, a pin clamped firmly was attached to hardened jaws specimen holder, parallel to the plain disc to ensure that the pin and the disc touch the maximum contact surface. Then, some parameters, such as speed (RPM) and time, were inserted.

The pin-on-disc tribo-tester was conducted with continuous lubrication flow during test by adhering to the ASTM G99 standard testing, which describes the standard Test Method for Wear Testing. Following the standard, the pin and the disc were cleaned with acetone before testing to avoid foreign objects on the surface that would scratch the surface and give bad results. The tribological system was tested on a spherical pin via pin-on-disc machine with 6mm diameter, 30 mm in height, while the disc had a diameter of 165mm and a height of 10mm. On top of that, the materials for both samples used in the contact pair were made from Aluminum Alloy (A5083) and the disc was made of SKD 11. The test was run at room temperature 34± 2 °C. In the tests, the disc was rotated based on sliding speed and the test was carried out for an hour (3600s) with normal load, following ASTM G 99-95a for each test. The friction coefficient was recorded via a PLC (Programmable Logic Controller) with data. The values of friction coefficient were determined by the ratio between friction load and applied normal load.

The surface finish after the experiment was measured to analyze the effect of the lubricant during the experiment. After the experiment, the picture of the pin surface that made a direct contact with the disc was captured with a high and low resolution of microscope for observation. After completion of each test, the plain disc was polished with abrasive paper, 1000 micron to grind the surface, because each test was repeated thrice to obtain accurate results. To measure the surface roughness of the pin and disc, the surface roughness profile was used to determine the patterns of both specimen surfaces, which consisted of a stylus protector.

2.2 Lubricants

The lubricants used for this experiment were double fractionated palm olein (DFPO), hydraulic oil (HO), and engine oil SAE 40(EO).

2.3 Friction and Wear Evaluation

The friction coefficient was recorded by using a PLC (Programmable Logic Controller) throughout the experimental process. The experiment was conducted several times to ensure that the results were stable and acceptable. The coefficient of friction was calculated by using Equation (1), where μ represents coefficient of friction, F is frictional force, and N is normal force.

$$\mu = \frac{F}{N} \qquad (1)$$

Meanwhile, the wear rate in this experiment was calculated with Equation (2). The volume loss of the pin was measured with a digital balance before and after conducting the experiment. At the same time, the calculation of the volume loss of the pin was done to verify the measurement data.

$$\text{Wear rate} = \frac{\text{Volume loss}}{\text{Load} \times \text{Sliding distance}} \ (\text{mm}^3/\text{N.mm}) \qquad (2)$$

After the experiment, the wear scar that had developed on the pin was inspected using a high resolution microscope. First, the diameter of the wear scar was measured. Then, the surface roughness of the wear scar was measured using the surface profiler in order to predict the condition of the lubrication.

2.4 Surface Profile

Surface roughness is one of the parameters that should be emphasized so that the experiment can be conducted efficiently due to its factor that could influence wear and friction. Before and after the experiment, the surface roughness of the pin and the disc was measured using surface roughness profiler. It contained a stylus that plays a vital role in evaluating the pattern of the surfaces. Before each experiment, the surfaces of the disc were unidirectionally ground using abrasive paper to a surface finish of arithmetic roughness value, Ra, of about 0.4±0.1μm. The R value was once again measured and recorded after the experiment for further analysis.

3.0 RESULTS AND DISCUSSION

Table 1: Viscosity for both types of lubricant tests at different temperatures

Lubricant	Double Fraction palm Oil (DFPO)	Hydraulic oil (HO)	Engine oil (EO)
Specific density , 25⁰C (kg/m³)	872.5	872	860
Dynamic Viscosity, 40⁰C	37.9	58.4	110
Dynamic Viscosity, 100⁰C	16.4	10.2	17.8
Viscosity Index, VI	443	164	179

The viscosity of the lubricant is critically important in ensuring that the lubricant can provide the correct film thickness in a given lubricating oil to ensure that the metal component does not rub against each other and creates component wear. Viscosity is one key laboratory element conducted on used oil samples in order to determine the condition of the oil samples for correct grade of oil use, oxidating/overheating, fuel dilution, and also oil mixes. In this study, the viscosity between RBD palm oil and mineral oil had been measured. The result portrayed that the viscosity of two lubricants decreased when the temperature increased.

Effects Of Friction Coefficient For Different Lubricants And Loads

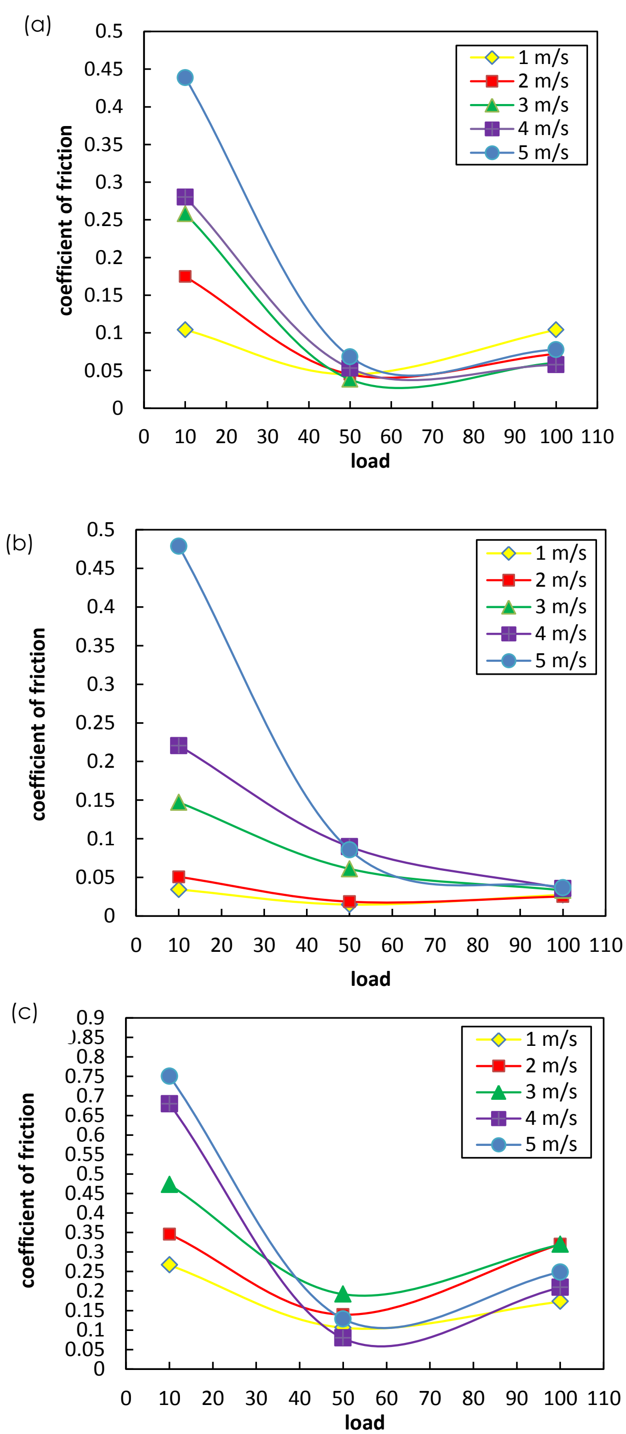


Figure 1: Graph of coefficient of friction versus various loads applied for (a) Double fractionated palm olein (b) Engine oil-SAE 40 (c) Hydraulic Oil.

The discussion of the results begins with the graph of coefficient of friction (COF) with respect to sliding speed of three different lubricants, which were hemispherical pin lubricated with double fractionated palm oil (DFPO), hydraulic oil, and engine oil-SAE 40, as shown in figure 1. During the experiment, three different loads were used, which were 10N, 50N, and 100N. The graph above illustrates that the trend line for each graph of different load increased at the initial stage up to a higher sliding speed in COF values. These results strongly suggest that COF value was inversely proportional to the sliding speed.

As for load 10N, the highest value for coefficient of friction (COF) was recorded for pin lubricated with Hydraulic Oil (HO) with 0.75055 at a sliding speed of 5m/s (1060RPM). In contrast, the lowest COF value was 0.4388 for pin lubricated with Double fractionated Palm Olein (DFPO) at same sliding speed. Meanwhile for load 50N, the highest value of COF is recorded pin lubricated with Hydraulic oil as 0.1918 at 3m/s sliding speed and lowest value of COF is Engine oil-SAE 40, 0.01476 at sliding speed 1m/s. The result is affected with load that applied during this experiment. Then, for load 100N, the trend line presents that highest value of COF is Hydraulic oil with 0.3200 as sliding speed at 2m/s (630RPM) and lowest is lubricated pin with Engine oil-SAE 40 at 0.0367.

Among different types of lubricants which are Hydraulic oil (HO), Double fractionated palm olein (DFPO) and Engine oil-SAE 40, there have their own lubricant performance. DFPO shows lowest and surge during the experiment, and the 50N curves on the graph showed an average result compared to the other two lubricants. The increase in load caused a rise in the friction. It was also because the DFPO is a pure palm oil, with no additives that leads to anti-friction and anti-wear properties compared to hydraulic oil and engine oil-SAE 40, which have already been well-produced. The results also showed that the frictional force decreased as the sliding speed went up for load 50N, might occur as the lubricant still remains as a layer within the two contact parts as the load was applied, whereas the sliding speed still remained slow although it showed increment.

In fact, palm olein has a balanced composition of saturated and unsaturated fatty acids (which are mainly composed of unsaturated fatty acid, triglyceride, and non-glyceride); it will stick very well on a metal surface, and creates a lubricant layer. Besides, it reduces metal-to-metal contact between the pin and the disc, and at the same time, it reduces the COF value. Furthermore, the curves on the graph present low coefficient of friction with increasing load and sliding speed due to the changes in shear rate. These findings are in agreement with the findings obtained by Chowdhury and Khalil [10] for aluminum, in general, for surface comprising moisture, oxidation of metals, and so on. The main influence to this low coefficient of friction was the high proportion of free fatty acids and the presence of polar COOH group contained in palm olein [11,12]. The free fatty acids contain long and covalent hydrocarbon chain [13,14].

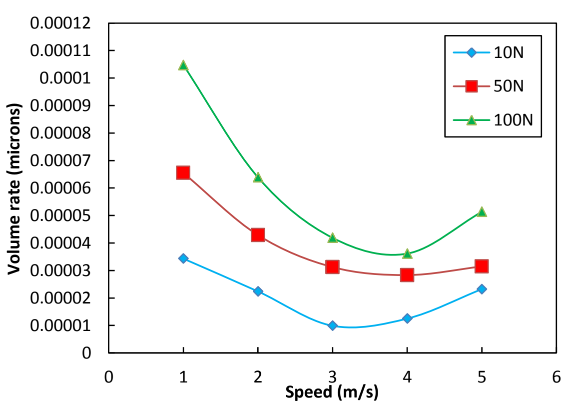
Other than that, hydraulic oil in this experiment functioned as a reference as the purpose of this study was to compare the wear and friction characteristics between palm oil and mineral oil. According to Peter

B. Madakson [15], the effects of surface oxidation and lubricant showed more significance at light load, whereby very little metallic contact was achieved with more lubricants, as it was forced into the sliding interface and caused lifting of the slider, which gave rise to the reduction in metallic contact as the sliding speed was increased. This statement has been further agreed with the finding retrieved by M.A. Chowdhury et al., [10]. As we know, increase in load leads to frictional heat, which is generated between contact surface, and hence, it decreases the strength of the material. When velocity increases, the momentum will transfer in the normal direction increases. With this, an upward force is produced on the upper surface, which results in increased separation between the two surfaces. In fact, real area of contact will decrease as separation between the two surfaces is increased.

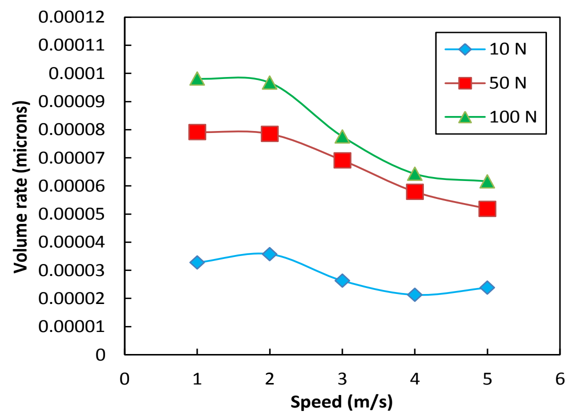
The low coefficient of friction obtained was mainly influenced by lubricating oil, which protected the surface of the mating components. The stability of friction coefficient of palm oil proved that palm oil had the ability to stabilize and to reduce the friction coefficient by forming a lubricating film that can be easily sheared. The excellent lubricating characteristic of friction coefficient for hemispherical pin condition was at high load specifically for palm oil. The presence of monolayer film or molecule layer formation by free fatty acid in palm oil was because the film can be easily adsorbed into metal surface and it could minimize the material transfer [13], besides making the surface mating of the hemispherical pin to slide smoothly against the disc with less resistant force over one another.

Effects Of Volume Rate At Different Lubricants And Loads

(a)



(b)



(c)

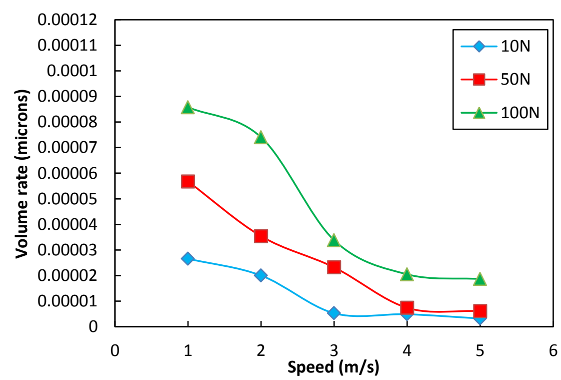


Figure 2: Graph of wear resistance versus various loads applied for (a) Double fractionated palm olein (b) Engine oil-SAE 40 (c) Hydraulic Oil.

The volume rate analysis (wear rate) was used to analyze the wear progression of pin. In this study, figure 2 illustrates the volume rate of pure aluminum pin (a1100) lubricant with different types of lubricants and different loads. Besides, three types of lubricants were used in this study; which were Double Fractionated Palm Olein (DFPO), Hydraulic oil (HO), and Engine Oil-SAE 40. The volume rate result for each particular lubricant with respect to different sliding speeds and loads had been determined in an hour, as depicted in the experiment standard ASTM G99. The experiment was repeated thrice for each type of lubricant in order to justify and to determine the repeatability of the data produced via the pin-on-disc machine. The volume loss of the pin had been directly proportional to the wear scar diameter of the pin and was computed by the following formula, which was obtained from the ASTM G99 standard test procedures

$$\text{Volume loss} = \frac{\pi\,(\text{wear scar diamter,mm})^4}{64\,(\text{sphere radius,mm})} \quad (3)$$

Meanwhile, pin lubricated with engine oil-SAE 40 showed the highest value of volume rate, which was 0.00009813 at a sliding speed of 1m/s (381 RPM) with a load of 100N, whereas the lowest value of volume rate was 0.000003245 at a sliding speed of 5m/s (1060 RPM) with a load of 10N. As the pin was lubricated with hydraulic oil, the trend line indicated a slight decrease in volume rate values as the sliding speed increased. The highest value of volume rate was 0.00008578 at a sliding speed of 1m/s (380 RPM) with a load of 100N, while the lowest value of volume rate had been 0.000003245 at a sliding speed of 5m/s (1060 RPM) with a load of 10N. The trend line for the three different loads slightly reduced at a sliding speed of 3 m/s (818 RPM). Among all the lubricants tested, the volume rate decreased with the duration of rubbing and reducing coefficient of friction.

In other words, a ploughing effect and inclusion of wear debris affected the wear rate. Moreover, there is strong evidence that shows that the decrease in volume rate was due to the lubricants in hydrodynamic regions that make fluid films separate when they rub against the mechanisms. As observed in the graph curves for DFPO, the wear rate increased as the sliding speed increased. The reason was the duration of rubbing had been the same with the sliding speed and the length of rubbing, which increased. Meanwhile, as for Engine oil-SAE and Hydraulic oil, the volume loss plunged and it might be attributed to the increase in the hardness of the material. It was also observed that for all three lubricants applied at the interface, there was a similar pattern of curves plotted after the completion for all loads condition. On top of that, hydraulic oil showed excellent lubricant characteristic due to its ability to reduce the wear dominated by the pin.

The results complemented the wear scar diameter results and further explain the relationship between wear and sliding speed. A good lubricant is expected to reduce and minimize the volume loss of a material. Throughout the experiment, loss of material volume in the pin lubricated by DFPO at load 10N had the lowest value compared to 50N and 100N. Initially, when the pin started rubbing the plain disc, it ruined the surface layers and developed high effectiveness of shear strength. The lubricant thickness of DFPO, which was thicker than other lubricants, increased the shear rates. Besides, the volume rate decreased with the duration of rubbing that was slow and showed reduced coefficient of friction.

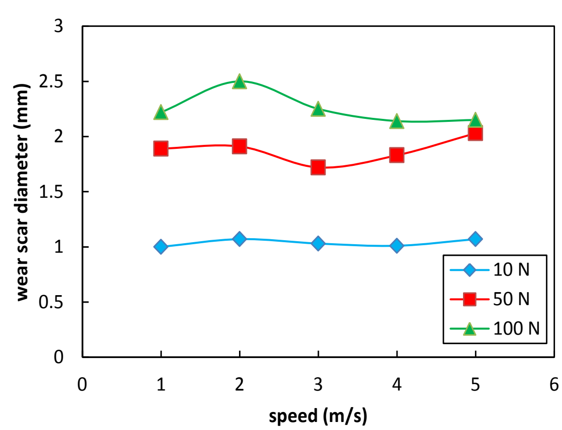
Meanwhile, the graph curves for pin lubricated with DFPO present that the composition of the palm oil itself consists of Palmatic acid, which helps in reducing the wear scar diameter. Masjuki et al. (16) explained that due to this lack of stability, a molecular layer that is created by the unsaturated fatty acid will develop due to the temperature of the lubricating oil. Oxidation caused by fatty acids in vegetable oil (palmatic) might cause a chemical reaction that could oxide the lubricant oil.

Furthermore, Perrin and Rainforth (17) discovered that the damage caused by wear rate pressure acted in relation to subsurface depth. The application of resistant force to the pin as it touched the disc was one factor that caused wear. This finding also supports this experimental study, which concluded that at the highest sliding speed, the wear rate decreased because as the friction coefficient was greatly increased, it would affect the height of the pin touching the rotating discs. Another explanation is that the wear rate increased at a high velocity due to the heat that was generated from the rubbing action and it contributed to the increased temperature of the lubricant. The increase in lubricant temperature had an effect on the stability of thin film layers, making them easy to break down. The high wear rate was obtained after high load was exerted specifically at 50N and 100N. It was believed that the wear particle of pure aluminum pin might get locked between the sliding surfaces or transferred and embedded to the mated discs that give could cause many damages to the pin and lead to the adhesive action, which should enhance volume loss in wear rate. [18, 19]

Furthermore, the volume rate of pin increased due to the heavy load that was applied on it and the sliding speed was increased as well. Moreover, increment in load also increased wear, and it will make the volume loss of metal to increase because of the impact between the pin and the disc. The influence from high loads, as well as pressures and high temperatures during sliding process could facilitate the collision of different variations for hard asperities of the pin and the disc. As the load was increased from 10N to 100N, the increased pressure produced during the sliding accelerated the formation of adhesive wear due to the oxide layer, which did not fully protect the surfaces attributed to the shearing of more junctions at the interface. As the adhesion forces during the sliding were high, the shear of the asperities took place at the weakest point, resulting in detachment of fragments of pin surfaces and attachment to the disc surface. Lower viscosity value for lubricant could attribute to the reduction of protective film in the breakdown of boundary lubrication [20, 21]

Effects Of Wear Scar Diameter Towards Sliding Speed With Different Lubricants And Loads

(a)



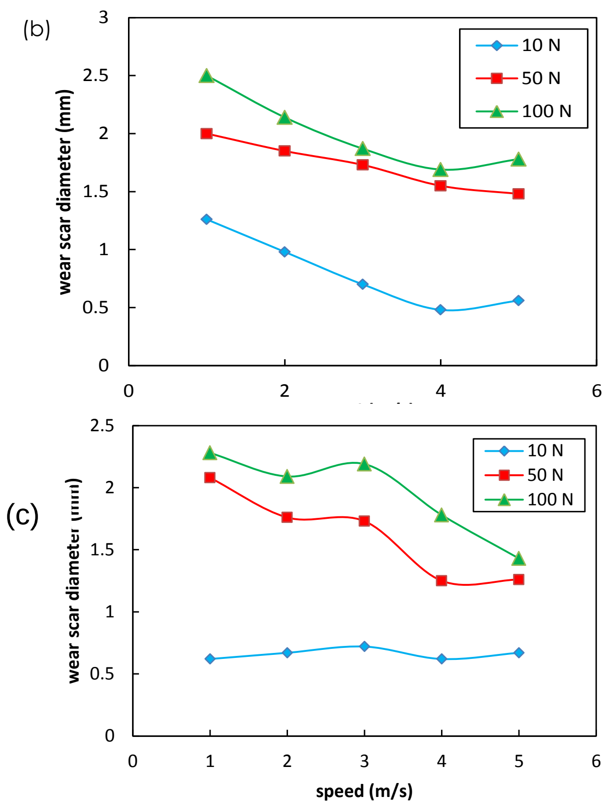


Figure 3: Graph of wear scar diameter versus various loads applied for (a) Double fractionated palm olein (b) Engine oil-SAE 40 (c) Hydraulic Oil.

Wear scar diameter is the diameter of the rubbed surface, which is affected by wear during sliding contact between the pure aluminum pin and the SKD 11 disc. The study focused on wear scar diameter of the pure aluminum as it was used to compute wear volume loss. Generally, wear volume loss, which is calculated from wear scar diameter, had a relationship that was proportional with the wear rate. Wear scar diameter analysis was carried out by using CCD Microscope after the experiment had been conducted for one hour following ASTM Standard G99. The entire stainless steel pins that were lubricated with 3 different types of lubricants, which were measured by using 3X magnification under the CCD Microscope.

Figure 3 above shows the graph of wear scar diameter (WSD) against sliding speed. For all experiments, the wear scar diameter was found to be directly proportional to the sliding speed. The range of results obtained using double fractionated palm olein (DFPO) with load 100N showed the highest value for WSD, followed by load 50N and 10N. As for engine oil-SAE 40, the highest result for WSD was pin with applied load 100N and the lowest value was 10N. Last but not least, the use of hydraulic yielded WSD with the highest value; 100N. In contrast, the lowest value of WSD was obtained when the applied loads were 10N and 50N.

The three oils produced almost similar results as seen from the graphs. Although the use of lubricant resulted in the lowest WSD values, the sliding speeds increased respectively, and with thorough observation, it had been found that the use of engine oil-SAE 40 led to the lowest average WSD values if all sliding speeds were considered and taken into account.

Apart from that, the trend portrayed in the graph had been discovered to be related to the wear scar observation, as shown in figure 4, which was taken from the micrograph from pin at different sliding speeds for all three types of lubricants in this experiment.

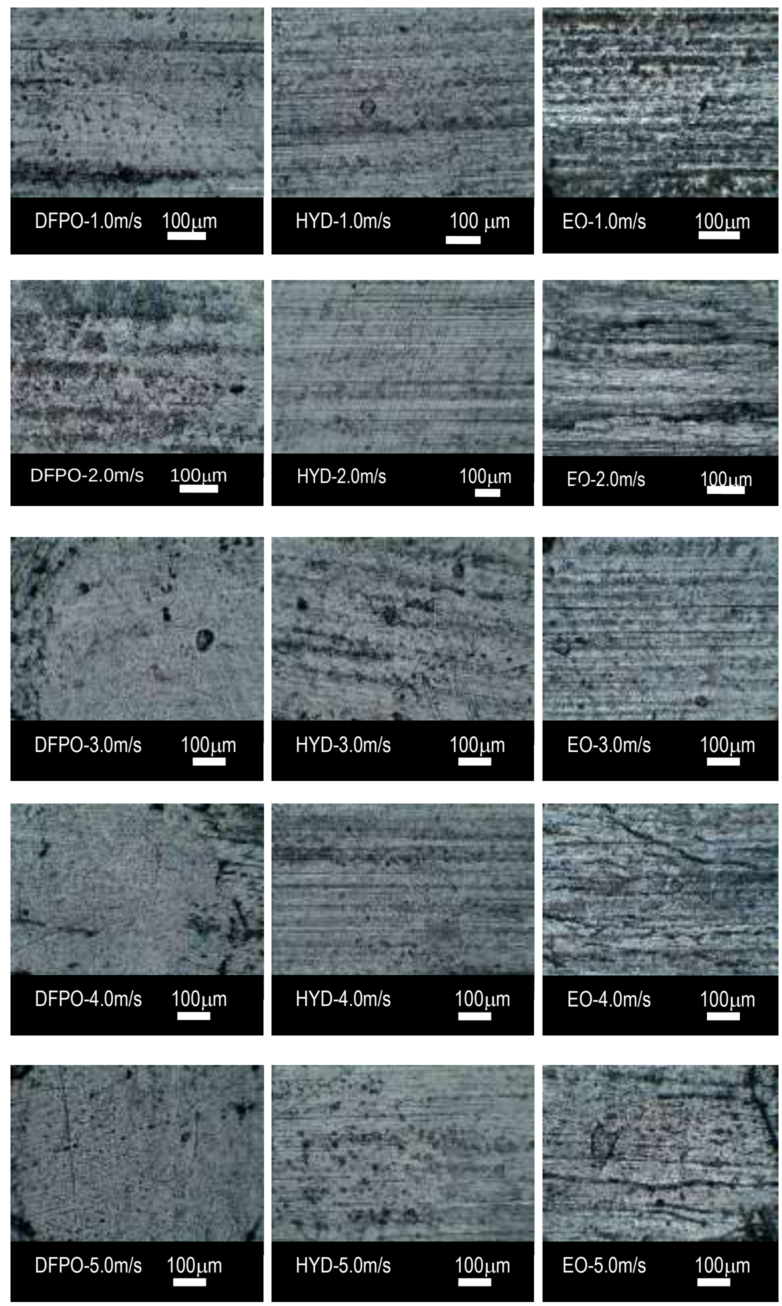


Figure 4: CCD microscope observation for (a) Double fractionated palm olein (b) Engine oil-SAE 40 (c) Hydraulic Oil

For all lubricants, it had been clear that the wear scar diameter increased with the sliding speed. Hence, it could be ascertained that the Engine Oil showed the largest wear scar diameter; however, there was a different range of diameter between the two lubricants. A comparison of the results revealed that the wear scar for DFPO was slightly ragged by the metal surface of the pin as the film lubricant started to break down when the interaction between metal and metal contact occurred. In addition, the temperature of the lubricant was also one of the factors that contributed to the existing wear particle, which is known as adhesive wear. As for hydraulic and mineral oil, there had been larger wear scar and rough surface was produced at the edge of the pin surface. The observation can be seen that when the sliding speed increased, the film lubricant chain easily broke. Moreover, the diameter of wear scar was affected by the thin lubricant film that formed at the surface of the pin to give a smooth region to minimize abrasion and adhesive wear.

As for DFPO, the long chain of fatty acid form of the pin surface reduced the wear and the friction coefficient. The findings are consistent with the findings obtained from past studies by Maleque et al. (22), which reported vegetable oil composition consisted of triacylgcerides, whereby the molecular structures of long chain fatty acids had better fundamental boundary lubricant properties and developed a high strength lubricant film. Besides, there were significant differences between the hydraulic oil and the engine oil in regard to the effect of sliding speed on the wear surface. Some surfaces were deep and grooves on the pin surface were clearly shown when the pin was lubricated with engine oil, which is also known as abrasion wear. In this region, abrasion was detected when the speed increased and the lubricant chain broke, as the adhesive wear appeared slightly dominant.

A comparison of the results revealed that the wear scar for DFPO was slightly ragged by metal surface of the pin as the film lubricant had started to break when the between interaction metal and metal contact occurred. In addition, the temperature of the lubricant was also one of the factors that contributed to the existing wear particle, which is known as adhesive wear. Meanwhile, as for hydraulic and mineral oils, there were larger wear scars and rough surface was produced at the edge of the pin surface. Moreover, increasing the sliding speed broke the film lubricant chain easily. Besides, the diameter of wear scar was affected by a thin lubricant film that was formed at the surface of the pin to create a smooth region to minimize abrasion and adhesive wear. On the other hand, as for DFPO, the long chain fatty acid form of the pin surface reduced the wear and friction coefficient. The findings are consistent with the findings obtained in past studies by Maleque et al. (22), which reported that vegetable oil composition consisted of triacylgcerides, whereby molecular structures of long chain fatty acids had better fundamental boundary lubricant properties and created a high strength lubricant film.

In fact, there were significant differences between the hydraulic oil and the engine oil in regard to the effect of sliding speed on the wear surface. Surprisingly, some surfaces were deep and the grooves on the pin surface were clearly shown when the pin was lubricated with engine oil, which is also known as abrasion wear. In this region, abrasion was noted when the speed increased, the lubricant chain was broken, and the adhesive wear appeared slightly dominant.

Effects Of Wear Surface Roughness With Different Lubricants And Loads

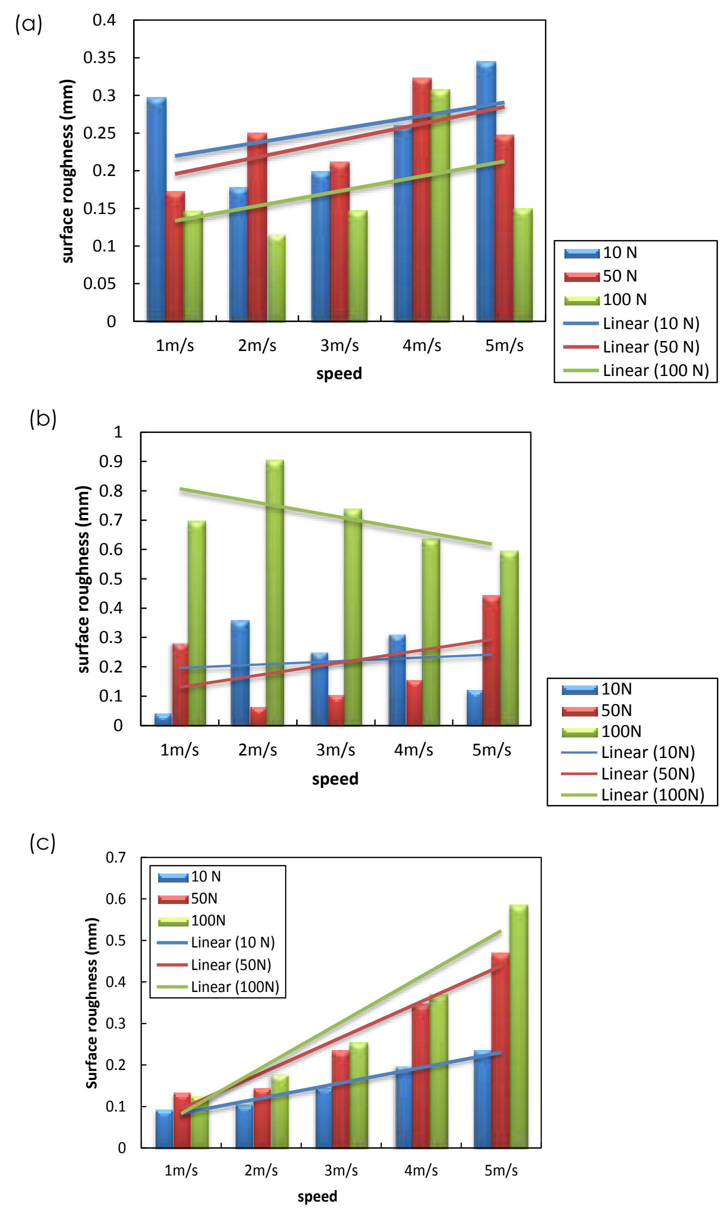


Figure 5: Graph of surface roughness versus sliding speed for different loads (a) Double fractionated palm olein (b) Engine oil-SAE 40 (c) Hydraulic Oil

Surface roughness is another parameter that can give effect to wear resistance and coefficient of friction mating surface. Theoretically, surface with low roughness, Ra has shallow grooves or asperities, while surface with high roughness, Ra has deep asperities or rough. Surface with deep asperities can help lubricant to be trapped inside it and works as oil reservoir on mating surface. The condition of the surface depends on the lubricant that is applied for it and it will affect wear rates and also coefficient of friction. Therefore, it will give effect to worn scar surface rough or slightly rough. In figure 5 for lower speed, surface roughness for palm oil was low compared to engine oil-SAE 40 and hydraulic oil based on applied load, but it increased progressively after sliding speed was increased. Moreover, by comparing the results portrayed in surface roughness graphs, the surface roughness for palm oil with load 10N was higher because the worn scar occurred on the pin surface that was slightly rough compared to the mineral oil. The result indicated that the lubricant that coated the pin broke because of the increased heat or temperature while rubbing. Furthermore, high surface roughness value affected the mechanical properties of component and palm oil with low viscosity, which reduced the wear, while the coefficient of friction increased in a long term period.

Other than that, minerals-based oil (engine oil-SAE 40 and hydraulic oil) showed low surface roughness because there were large wear scars and they were generated by the excessive heat at the initial experiment. The most interesting part had been to prove that vegetable oil has good film thickness and force relationship due to the long fatty acid chain (palmatic), which consists in the oil to increase the bonding strength between film lubricant and the oxide layer on the metal surface, as well as afford good surface protection. Furthermore, higher surface is rougher and the large quantity of wear debris decreased the friction force while the load was heavy.

4.0 CONCLUSION

The investigation on tribological behavior of Double fractionated palm olein (DFPO) was completed by using pin-on-disc tester. The result was compared mutually with hydraulic oil and engine oil SAE 40 oil as tested lubricants. The viscosity of the lubricant was inversely proportional to the lubricant temperature. The friction coefficient obtained for lubrication with palm olein was better than hydraulic oil and engine oil-SAE 40 after various loads were applied. The friction coefficient for all three lubricating oils decreased as the applied load was increased. The wear resulted in the lubrication with palm olein showed better results when the load was 10N and wear dominated by the pin was increased with normal loads of 50 N and 100 N. The increment and the decrement of wear lubricated with hydraulic oil and engine oil showed a similar pattern. The free unsaturated fatty acids play an important role in reducing friction coefficient and wear. The hydraulic oil also showed the ability to reduce wear because it was formulated with additives, and thus, increased the anti-wear performance. The surface roughness value of the pin, Ra, influenced the reduction or the increment of friction coefficient and wear. The higher the load was applied, the higher the increment of the surface roughness value and palm olein gave the lowest value of R. Finally, the palm olein could be used as a great lubricant in pin-on-disc as no formula additive needed to be replenished, especially in reducing friction coefficient at various applied load.

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References

[1] Syahrullail, S., Azmi, S. M., Sapawe, N. and Amir, K. 2014. Wear characterization of aluminum lubricated with palm olein at different normal load. *Applied Mechanics and Materials*. 554: 401–405.

[2] Chowdhury, M. A., Khalil, M. K., Nuruzzaman, D. M. and Rahaman, M. L. 2011. The effect of sliding speed and normal load on friction and wear property of aluminum. *International Journal of Mechanical and Mechatronics Engineering*. 11: 53–57.

[3] Al-Araji, N. and Sarhan, H. 2011. Effect of temperature on sliding wear mechanism under lubrication conditions, *International Journal of Engineering* 5: 176–184.

[4] Hisakado, T., Miyazaji, K., Kameta, A. and Negishi, S. 2000. Effects of surface roughness of roll metal pins on their friction and wear characteristics, *Wear*. 239: 69–76.

[5] Bressan, J. D., Daros, D. P., Sokolowski, A., Mesquita R. A. and Barbosa, C. A. 2008. Influence of hardness on the wear resistance of 17-4 PH stainless steel evaluated by the pin-on disc testing. *Journal of Materials Processing Technology*. 205: 353–359.

[6] Fervel, V., Mischler S. and Landolt, D. 2003. Lubricating properties of cotton transfer films studied with a pin-on-disc apparatus. *Wear*. 254: 492–500.

[7] Hamrock, B. J. 1994. *Fundamentals of Fluid Film Lubrication*. International Edition ed. Singapore, McGraw-Hill Book Co.,

[8] L. A. Quinchia, M. A. Delgado, T. Reddyhoff, C. Gallegos, H.A. Spikes. 2014. Tribological studies of potential vegetable oil-based lubricants containing environmentally friendly viscosity modifiers. *Tribology Internationa.l* 69: 110-117

[9] L. A. Quinchia, M. A. Delgado, J. M Franco, H. A. Spikes, C Gallegos. 2012. Low temperature flow behaviour of vegetable oil-based lubricants. *Industrial Crops and Products.* 37: 383-388

[10] M. A. Chowdhury, M. K.Khalil, D. M. Nuruzzaman, M. L. Rahaman. 2011. The effect of sliding Speed and normal load on friction and wear property of aluminum. *Int. J. Mech. & Mechatronics Eng.* 11: 53-57.

[11] Farooq, M., Ramli, A., Gul, S. and Muhammad, N. 2011. The study of wear behaviour of 12 hydroxystearicacid in vegetable oils. *Journal of Applied Sciences.* 11: 1381–1385.

[12] Yunus, R., Razi, A. F., Ooi, T. L., Iyuke, S. E. and Perez, J. M. 2004. Lubrication properties of trimethylolpropane esters based on palm oil and palm kernel oils. *European Journal of Lipid Science and Technology*. 106: 52–60.

[13] Maleque, M. A., Masjuki, H. H. and Haseeb, A. S. M. A. 2000. Effect of mechanical factors on tribological properties of palm oil methyl ester blended lubricant. *Wear*. 239: 117–125.

[14] Masjuki, H. H., Maleque, M. A., Kubo, A. and Nonaka, T. 1999. Palm oil and mineral oil based lubricants–their tribological and emission performance. *Tribology International.* 32: 305–314.

[15] Peter B. Madakson, 1983. The Frictional Behaviour of Materials. *Wear,* 87: 191-206

[16] H. H. Masjuki and M. A. Maleque. 2000. Palm oil and mineral oil based lubricants their tribological and emission performance. 32(1999): 305–314.

[17] C. Perrin, W. M. Rainforth. 1997. Work hardening behavior at the worn surface of Al–Cu and Al–Si alloys. *Wear.* 203–204

[18] Pradeep, L., Kishore, M. and Kailas, S. V. 2008. Effect of surface roughness parameters and surface texture on friction and transfer layer formation in tin–steel tribo-system, *Journal of Materials Processing Technology*. 208: 372–382.

[19] Hisakado, T., Miyazaji, K., Kameta, A. and Negishi, S. 2000. Effects of surface roughness of roll metal pins on their friction and wear characteristics. *Wear*. 239: 69–76.

[20] Bhattacharya, A., Singh, T. and Verma, V .K. 1990. The role of certain substituted 2-amino- benzothiazolyl benzoylthio carbamides as additives in extreme pressure lubrication of steel bearing balls. *Wear.* 136: 345–357.

[21] Clark, S. J., dos Santos, A. M., de Souza, G. R. and Polito, W. L. 1984. Methyl and ethyl soybean esters as renewable fuels for diesel engines. *Journal of the American Oil Chemists Society*. 61: 1632–1638.

[22] Masjuki, M. M., Maleque, M. A., Kubo, A., Nonaka, T, Based Lubricants-Their tribological and emission Performance." *Tribology International.* 32: 305-314