Tribological properties of aluminum lubricated with palm olein at different load using pin-on-disk machine

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HIGHLIGHTS

- Investigate the influence of wear and friction.
- Consists of a pin on disk machine made from aluminum alloy.
- The different speed affects the coefficient of friction and wear rate of aluminum.
- Coefficient of friction decreased with the increment of load applied.

ABSTRACT

The increased global demand for biofuels has prompted the search for alternatives to edible oils for bio-lubricant production. Today, vegetable oil much desired for its application as lubricant in various application because it is a renewable resources and has high biodegradability compared mineral oil. Thus, this paper presents an experimental analysis on the tribological behavior for aluminum alloy materials under the effect of sliding speed and different loads, where the apparatus pin on disk has been used to study the performance of tribological performance. The experiments had been performed under different parameters, different loads (10N, 50N, 100N), and constant speeds at 3 m/s. This paper evaluates through pin on disc tribotester using hemispherical pin as workpiece material. The test was tested using double fractionated palm olein (DFPO) as lubricating oil. The results show that load 100N show high coefficient of friction compared to 10 N and 50N. Authors found that palm olein has better performance properties in terms of friction reduction (coefficient of friction) and wear resistance (anti-wear properties) at low and high speed. Pin that lubricated with palm olein showed small wear scar diameter compared to the mineral based oil. Therefore, palm olein has possibility to use as a lubricant of mating components.

Keywords: | Friction coefficient | Pin-on-disk | Wear rate | Sliding surface |
1.0 INTRODUCTION

In a mechanical system, wear and friction will produce high level results when it's operating at a long period time. The most crucial issues is to minimize the amount of wear and friction being produced in an operation because wear and friction are the main factor that could lead to mechanical failure. It is hard to stop the wear from forms, but they have many ways to minimize the mechanism and one of them by using lubrication. Consequently, developing lubrication can be used in engineering systems, and it is important for increasing the life of mechanical components. The presence of continuous lubricants thickness (Fervel et al., 2003; Hamrock et al., 2004) in the machines and engines mostly, is effectual on the surface contact and gives benefit to the surface. The interaction between two surfaces will cause friction and lubricant lubricated to prevent from metals part produces wear and friction and then produced excessive heat. Many problems occur between metal-on-metal contact due to wear and friction mechanism.

There have been several studies in the literature reporting that wear and friction primarily changes with load (Syahrullail et al., 2014; Hisakado and Hashizume, 2000), speed (Ameen et al., 2011; Chowdhury et al., 2011), temperature (Al-Araj and Sarhan, 2011), surface roughness (Hisakado et al., 2000; Wang et al., 2006), type of material or mating component (Bressan et al., 2008) and environmental. The study in understanding the wear mechanism in different parameter played important role in identifying new solutions and findings to overcome to these particular problem.

Among of these factors, speed and load are major factors that give high impact to the friction force and wear value. The context of friction is the force resisting the relative motion of solid surface, fluid surface and material elements sliding against each other. The relationship between friction and wear is another consequence which may lead to performance degradation or damage to the components.

Several researchers observed that the variation of friction and wear rate depends on interfacial condition such as normal load, geometry, relative surface motion, sliding speed, surface roughness of the rubbing surfaces, type of the material, system rigidity, temperature, stick-slip, lubrication and vibration (Archard, 1980; Tabor., 1987; Oktay and Suh, 1992; Saka et al., 1984; Aronov et al., 1983; Aronov et al., 1984; Lin and Bryant, 1996; Tabor, 1987; Berger et al., 1997; Bhushan, 1999). There are two major factors that contribute to the formation of wear and friction and give significant changes of load and sliding speed. The impact of load greatly affects the rate of wear which is dependent on the direction of load application either up and down (Wieleba, 2002).

Lubricant oils have a function of decreasing the friction coefficient between two contacting surfaces. The conventional mineral based lubricant has been widely used in mechanical industry and it had caused the ecological pollution due to some degree of toxicity and it generally have high flammability characteristic that can give bad effect to our environment (Husnawan et al., 2007). From previous analysis that conducted, it was
observed that nearly to 12 million ton of lubricant waste dispose to environment. Therefore, due to awareness of environmental and health issues, some solution and steps had been taken by government to reduce and overcome the consumption of mineral based lubricant. The conventional lubricant known as lubricating oil in industry can cause serious pollutant to the environment and giving awareness on the greenhouse effect. Thus, to overcome these problem vegetable oils has been introduced. A vegetable oil is triglycerides extracted from a plant and has widely been used as a lubricant. The usage of vegetable oil as the lubricating oil industry was not a new idea but it was introduced for many thousand years ago. Malaysia is one the largest producers and exporters palm oil in the world, accounting 11% of the world’s oils and fat production and 27% of export trade oils and fats

Palm oil known as *Elaeis guineensis* is an edible vegetable oil that is derived from the reddish pulp of the fruit of oil palms. There are several advantages of using vegetable oil as lubricating oil. These advantages include the biodegradability, the renewal feedstock of local production, lower costs compared to mineral based oil, oxidative stability and low temperatures. Vegetable oils can yield easily biodegradable ester type lubricants from renewal resources. Biodegradable oils can reduce damage and toxic to the environment (Husnawan et al., 2007; Carcel et al., 2005). Vegetable oil has been found to have more oxidation due to the polyunsaturation that exist in the fatty acid. The properties have triggered researcher to enlightening vegetable oils for technical application specifically on machines and engines. Despite, many researches now being focused and discussed on reduction on wear and friction (Petlyuk and Adams, 2004; Kalin and Vižintin, 2006).

Aluminum is material with low density and it is able to resist corrosion occur due to the passive environment. Aluminum is components which made from pure aluminum relatively soft, durable, lightweight, ductile and malleable metal. On present investigation, to study wear and friction characteristic of aluminum, researchers conducting an experiment and study about the influence of varied load applied with different lubricating oil via pin of the disk Tribometer. Double fraction palm olein (DFPO) has been used as sample lubricating oil. DFPO is a liquid fraction that obtained by fractionating RBD Palm Oil by separating liquid parts (olein) from solid parts (stearin). The wear test be examined using spherical pin against plain disk. Reason using spherical pin because spherical tips are frequently used to simplify the geometry.

### 2.0 METHODOLOGY

#### 2.1 Materials and Methods

A pin on the disk type monitor with data acquisition system was used to evaluate the wear behavior of pure aluminum. To study the anti-friction characteristic of palm oil
several experiments were conducted using different speed with a normal load. Pin on disc machine is a laboratory apparatus that is used for measuring friction and wear properties. The pin on disc tester consists of a rotating disc of the material to be tested against a stationary pin. The tribometer conforms to ASTM G99-95a entitled "Standard Test Method for Wear Testing with a Pin-on-Disc Apparatus". In measuring the wear of the pin and disc there are few parameters being determined using which are normal load, rotational speed, and the wear track diameter. Pin on disc machine consist of three types of sensor which is a linear variable transducer (LVDT), load cell and proximity sensor as shown in Figure 1.

![Figure 1: Pin on the disk tribotester machine](image1)

LVDT (Linear variable differential transducer) is a sensor to measure wear between the specimen pin and disc while frictional force sensor measured the friction between the pin and rotating disc by load cell mounted on a bracket at a distance equal to the distance between the specimen and pivot. The plunger of sensor rests on hardened pin projections from the lever. During wear occurs the loading lever lift in an upward direction pushing the plunger. This plunger movement as an indication of wear rate is sensed by LVDT as the plunger lift up. This movement is displayed as wear on the controller.

The friction between the pin and rotating disc was measured by a load cell. The load cell was mounted on a bracket at distances equal to the distance between the specimen and pivot. The load cell with a bracket was fixed with a sliding plate and it moved along with sliding plate while sitting where the track diameter. In order to prevent oil spillage, there was lubrication chamber fixed around the wear disk and in this experiment continuous flow of lubricant was used. The schematic of pin-on-disk tribotester mechanism is shown in Figure 2. The lubricating oil trapped on the surface might control the interaction between the pin and disk to reduce friction and wear.
Rotating plain disk and pin were made from different materials which are pin made from aluminum and plain disk from SKD11. Hardness of the material was explored during an experiment. Spherical pin samples were prepared as 6mm diameter, length 30mm and radius of spherical 4 mm. Double fractionated palm olein (DFPO) was used as a test lubricant and it was compared with hydraulic oil. DFPO is a liquid fraction that obtained by fractionating RBD Palm Oil by separating liquid parts (olein) from solid parts (stearin). In this experiment, continuous flows for both lubricants were tested to ensure that the surface and pin were always lubricated with lubricating oils.

For each completed test, plain disk was polished using abrasive paper, 1000µm to grind the surface as surface finish because each tested was tested three times to obtain accurate results. To measure the surface roughness of a pin and disc, the surface roughness profiler consisted of a stylus detector was used to determine the pattern structure both specimens.

The alloy used to be commercially aluminum alloy with excellent forming characteristics. The various load was according to ASTM G99 was used at constant speeds 3.0m/s. The test was run for 60 minutes. Before testing, the pin and plain disk were cleaned using acetone. During the experiment, wear rate and friction coefficient were recorded. The wear rate in this experiment was obtained measuring the weight loss after each test. The wear rate was calculated together with sliding speed using Eq.(1).

\[
\text{Wear rate} = \frac{\text{Volume loss (mm}^3\text{)}}{\text{Load (kg)} \times \text{Sliding distance (mm)}}
\]

(1)

Friction force was expressed using Eq.(2) where \(F_f\) is a frictional force \((N)\), \(\mu\) is frictional coefficient and \(N\) is normal load.
Volume rate analysis (wear rate) is used to analysis the wear progression of pin. Within this study, volume rate of aluminum alloy pin (A5083) lubricant with different types of lubricants and different load are been analysis. There are total three types of lubricants that been used in this study which are Double Fractionated Palm Olein (DFPO), Hydraulic oil (HO) and also Engine Oil-SAE 40. Volume rate result for each particular lubricant with respect to difference sliding speed and load will determine in one hour which follow the experiment standard ASTM G99. The experiment will repeat triple times for each type of lubricants in order to justify and determine the repeatability of the data produce by the pin on disk machine. The volume loss of the pin is directly proportional to the wear scar diameter of the pin and is computed by the following formula which is obtained from the ASTM G99 standard test procedures.

\[ F_f = \mu \cdot N \]  \hspace{1cm} (2)

3.0 RESULTS AND DISCUSSION

3.1 Effect of Load Applied On Friction Coefficient

The Figure 3 presents a graph of coefficient of friction (COF) with respect to load of three different lubricants exerted to the pin at constant speed, 3m/s for 60 min. During the experiment, there are three different loads was used which are 10N, 50N and 100N. From the graph above, we can see that trend line for each graph of different load increase at the initial stage up to higher sliding speed in COF values. These results strongly suggest that COF value is inversely proportional to the sliding speed.

![Figure 3: Variations of friction coefficient for AA 5083 with (load=10N, 50N, 100N)](image)

For load 10N, the highest value coefficient of friction (COF) was recorded pin lubricated with Engine Oil-SAE 40 (EO) as 0.04092 at sliding speed 3m/s (818 rpm). In
contrast, the lowest COF value is 0.02750 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 Engine oil- SAE 40 as 0.03123 and lowest value of COF is Double fractionated palm olein (DFPO), 0.02095. The result is affected with load that applied during this experiment and coefficient of friction decrease when load increase. Then, for load 100N, the trend line presents that highest value of COF is Engine oil- SAE 40 with 0.02383 as load applied is increase and lowest is lubricated pin with double fractionated palm olein (DFPO) with value 0.0200.

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. For load 10 N and 50 N, DFPO lowest and surged during experiment and 100N curves of graph show all the tested lubricant decrease. The increase in load causes rise in friction. It also because of DFPO is a pure palm oil, no additives which provide anti-friction and anti-wear properties for it as compare to hydraulic oil and engine oil- SAE 40 which already been well produced. Theoretically, contact of two surfaces creates a metal oxide and it reacts with the fatty acid of palm oil to create a thin layer of lubricant. (Syahrullail et al., 2011) proof that this reduced metal-to-metal contact and also decreased the friction coefficient in the experiment. The result shows that frictional force decrease as sliding speed went up for load 10N might due to the lubricant still remain a layer within the two contact part as the load applied and sliding speed still remain slow although it shows increases. 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 create a lubricant layer. It will reduce metal-to-metal contact between a pin and disk and same time, it will reduce the COF value. Furthermore, curves of the graph have present low coefficient of friction as increasing load and sliding speed due to changes in shear rate. These findings are in agreement with the findings of (Chowdhury et al., 2011) for aluminum, in general for surface comprising moisture, oxidation of metals, and so on. This phenomenon can be explained based on Stribeck curve analysis. The Stribeck curve is a function of viscosity, speed and load. At the early of experiment, the friction coefficient increased when load applied is 10N but after increment of load applied, the graph downly decreases and it reaching until stable condition to the completion of the experiment.

Hydraulic oil in this experiment acts as a reference as the purpose of this study is to compare the wear and friction characteristics among palm oil with mineral oil. According to Madakson et al., 2004, which stated that effect of surface oxidation and lubricant shows more significant at light load which very little metallic contact is achieved more lubricants, is forced into the sliding interface and cause lifting of the slider which give rise to the reduction in metallic contact as sliding speed increases. This statement is further been agreed with the finding of Chowdhury et al., 2011. As we know,
increasing in load applied will make frictional heat generated between contact surface 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 produce on the upper surface which results in increased separation between two surfaces. Real area of contact will decrease as separation between two surfaces increase. The low coefficient of friction obtained was mainly influenced by lubricating oil which is protecting the surface of mating components. The stability of friction coefficient of palm oil proved that palm oil has the ability to stabilize and reduce the friction coefficient by forming a lubricating film which can be easily sheared. The excellent lubricating characteristic of friction coefficient for hemispherical pin condition is at high load specifically for palm oil.

3.2 Effect of Load Applied On Wear Rate

Pin lubricated with engine oil-SAE 40, the lowest value of volume rate is 0.000013922 at sliding speed 3m/s (818 rpm) with load 10N and highest value of volume rate is 0.00003156 for pin lubricated with double fractionated palm olein (DFPO) at 10N, as shown in Figure 4. For pin lubricated with hydraulic oil, the trend line indicates a slight increase in volume rate values as the load applied increases. The present finding indicates that pin lubricated with DFPO has higher value of volume loss compare to other two tested lubricant. Trend line for three different load slightly increase when load increased. Among all the lubricant, the volume rate will decrease if the duration of rubbing slowly and reducing coefficient of friction.

![Figure 4: Variations of volume rate with load](image)

In other words, a ploughing effect and inclusion of wear debris will affect the wear rate. There is strong evidence that shows that the decrease in volume rate is due to
lubricants in hydrodynamic regions that make fluid films separate when they rub against mechanisms. As we can see, the graph curves for DFPO, wear rate increase as load applied is increased. The reason is duration of rubbing is same with sliding speed and length of rubbing is increase. Meanwhile, for Engine oil-SAE and Hydraulic oil, volume loss plunged that may attributed to an increase of the hardness of material. The wear increase as coefficient of friction decrease. Bowden and co-worker (Bowden and Tabor, 2001) found that, this behavior might due to the increased shear strength of the absorbed oil on the surface that effected chemical attack on the surface by the fatty acid present in vegetable oil.

The results were 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 is lowest value compared to 50N and 100N. Initially, when the pin starts rubbing the plain disk, it will ruin the surface layers and create a high effectiveness of shear strength. The lubricant thickness of DFPO, which is thicker than other lubricants, will make shear rates increase. The volume rate will decrease if the duration of rubbing slowly and reducing coefficient of friction.

Graph curves that pin lubricated with DFPO presents that the composition of the palm oil itself consists of Palmatic acid which helps in reducing the wear scar diameter. Masjuki et al., 1999, 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.

Tabrett & Sare, 1997, discovered that damage is caused by wear rate pressure acting in relation to subsurface depth. The application of resistant force to the pin as it touched the disk was one factor causing wear. This finding also supports this experimental study which concludes that at the highest sliding speed, the wear rate decreases because, as the friction coefficient greatly increases, it will affect the height of the pin touching the rotating disks. 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.

Furthermore, increasing in volume rate of pin due to the heavy load that applied on it and also sliding speed was increased. Increased in load also was lead to increase of wear and it will make volume loss of metal also increase because of the impact between pin and disk. The influence from high loads; pressures and high temperatures during sliding process which facilitated the collision of the different variation of hard asperities of the pin and disk. As the load increased from 10N to 100N, the increased pressure produced during sliding accelerated the formation of adhesive wear due to the oxide layer
which not fully protects the surfaces attributed to the shearing of more junctions at interface. As the adhesion forces during 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 disk surface.

3.3 Effect of Load Applied On Surface Roughness of Pin

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 trapped into it and work as oil reservoir on mating surface. Condition of the surface depends on lubricant that 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. As shown in Figure 5, at lower speed, surface roughness for palm oil was low compares to engine oil-SAE 40 and hydraulic oil according to applied load but it increases progressively after sliding speed was increasing. Comparing the results of surface roughness graphs, the surface roughness for palm oil with load 10N higher because of the worn scar occurs on the pin surface slightly rough compares to the mineral oil. The result indicates that lubricant that coated pin will breakdown because of the heat or temperature increase during rubbing. Furthermore, high surface roughness value will affect mechanical properties of component and palm oil with low viscosity will reduce the wear and coefficient of friction increase in long term period. Minerals based oil because there create large wear scars and generate excessive heat at initial experiment. The most interesting have proof that vegetable oil has good film thickness and force relationship due to the long fatty acid chain strong bonding with the oxide layer on the metal surface and afford be good in surface protection. Furthermore, higher surface roughening and large quantity of wear debris will decrease the friction force while load are heavy.

3.4 Effect of Load Applied On Wear Scar Diameter

Figure 6 and 7 show the effect of sliding load on the measured wear scar diameter for pin lubricated with double fractionated palm olein(DFPO), Hydraulic oil(HO) and engine oil-SAE 40 with various tested load. Increasing of the roughness of each pin is a factor that affects the surface finished and that attributed different values of friction coefficient and volume rate of pin. The wear scar on pin surface lubricated by palm oil for load 10N shows smoother surface compared to pin with heavy load, 50N and 100 N for speed and load conditions. Theoretically, metal-metal contact area will increase and produce an increase in wear scar diameter while less metal contact occurred show smaller wear scar diameter. These results show that the DFPO has the ability to reduce wear due to its higher proportion of long chain composition. Increased surface roughening and a large
A quantity of wear debris are believed to be responsible for the decrease of friction with the increase of normal load. As load applied is increased, the surface of the pin become more severe as shown in Figure 6. It consistently shows that the abrasion and adhesion will dominate the wear pin surfaces and it will increase as higher load exerted to the pin.

![Variations of surface roughness value, Ra with load=10 N, 50 N, 100 N at different tested lubricant](image)

Figure 5: Variations of surface roughness value, $Ra$ with load=10 N, 50 N, 100 N at different tested lubricant

As the load increased from 10N to 100N, the wear scar track of the pin surfaces observed that pin lubricated with double fractionated palm olein (DFPO) show a smoother surface compare to the wear scar track lubricated with hydraulic oil (HO) and engine oil-SAE 40 (EO). The lubricity of material flow cannot be directly measured, so tests are performed to quantify a lubricant’s performance. The greater the wear scar, the worse the lubricity and roughness of pin is low. For this reason, lubricity is also termed a substantial anti wear property. Palm oil shows good lubricity because low wear scar diameter compared to hydraulic oil show high loss of wear as sliding speed increase. Therefore, palm oil shows better lubricating oil and has the ability to reduce wear due to high proportion of long chain composition. Wear scar for 100 N shows damaged surface due to the adhesion wear of aluminium alloy although material aluminium alloy have high hardness characteristic. Furthermore, wear scar for 10 N found the cracks are vertical on the sliding direction of pin and disk and dislocation of slightly layers from the pin surfaces.

Pin that lubricated with hydraulic oil (HO) and engine oil-SAE 40 were shows mild adhesive wear and the surface generated the groove form on the worn surfaces. The configuration of the surface is parallel to the direction of the pin moved. The narrow groove surfaces observed when pin lubricated with palm oil were smoother because the lubricant that flow continuously protected by the thin film form of oxide layer attributed to less direct contact of mating components.
Figure 6: Images of wear worn surfaces observed using a microscope for load=10N, 50N, 100N.

Figure 7: Variation of wear scar diameter at different load and lubricant.
The findings in Figure 7 shows that the worn surfaces more severe adhesive wear when load applied is 100N. From the graph, we can see that it because of combination between highs loads, pressured and high temperature that influence the collision between hard asperities of pin and disk. As load increased from 10N to 100N, pressure between pin and disk during sliding will form an adhesive wear that due to the oxide layer that not fully covered the pin. It was attributed to the shearing at interface. The worn surface for pin lubricated with palm oil show severe adhesion mostly at 100N because lubricant layer breakdown and not stay on metal surface.

CONCLUSIONS

The present study was designed to determine the effect of load in wear and friction coefficient of palm oil has been evaluated using a pin on disk using aluminium alloy materials. This research has shown that the friction coefficient obtained from lubricated with DFPO for 100N load was lower as sliding speed increased and pin with load 10 N higher. In addition, the volume rate obtained from load pin 10N which is lubricated with DFPO is higher shows that DFPO better lubricating oil for rubbing process and also reduce the volume rate pin losses. Wear rate resulted lubricated with double fractionated palm olein (DFPO) shows better result at 10N, 50N and 100N. The increment or wear lubricated with hydraulic oil (HO) and engine oil-SAE 40 show similar pattern. Composition in the palm oil is use to protect and has ability to reduce wear and friction during rubbing process. The surface roughness value of the pin for pin lubricated with double fractionated palm olein (DFPO) is low and pin lubricated with engine oil-SAE 40 has high surface roughness value. Therefore, we can conclude that pin that lubricated with palm oil has shallow grooves or asperities while surface lubricated with engine oil-SAE 40 that has high roughness, has deep asperities or rough surface. Surface with deep asperities can help lubricant trapped into it and work as oil reservoir on mating surface. It can be pointed out double fractionated palm olein (DFPO) has better performance properties in terms of friction reduction and wear resistance at various load applied and performed better at high speeds because palm oil has a high amount of unsaturated fatty acid that will create a high strength lubricant film and acts as a boundary lubricant. It is recommended that further research need to used various on sliding speed to determine whether it give effect to tribological performance.

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REFERENCES


