Wear Characteristic of Palm Olein as Lubricant in Different Rotating Speed

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Abstract

The main objective of this research was to investigate the performance of refined, bleached and deodorized (RBD) palm olein by using a pin-on-disk tester. The pin was held to the rotating plain disk at a normal load (10 N) according to the American Society for Testing and Materials (ASTM) G99. The RBD palm olein was used as the main lubricant owing to a greater awareness of the greenhouse effect phenomenon which has lessened the usage of conventional lubricants that affect our environment. This trend has strongly encouraged the government to use eco-friendly and biodegradable lubricants in the manufacturing industry. RBD palm olein was selected due to its superior tribological properties and large production in Malaysia. The tests were carried out using a direct lubricant flow of RBD palm olein and hydraulic oil on a plain disk at two different speeds (0.4 m/s and 4 m/s). The material used for both frictional surfaces was stainless steel. The results clearly show that the wear obtained when using the RBD palm olein was lower than that of the hydraulic oil. In addition, the coefficient of friction and wear scar diameter of the sample lubricated with RBD palm olein was remarkably lower at low speeds, and approximately the same as hydraulic oil at high speeds.

Keywords: Palm olein, hydraulic oil, pin on disk tester, friction coefficient, wear scar diameter.

Nomenclature

\( \mu \) friction coefficient
\( F \) frictional force (N)
\( N \) normal load (N)
COF coefficient of friction
PO RBD palm olein
HO hydraulic oil

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1. Introduction

The importance of controlling friction and wear has been emphasized for both economic reasons and long term reliability. It is also important for those involved in the manufacturing industry to understand the effects of unwanted friction, excessive wear and lubrication failure. A lack of consideration and knowledge about tribological designs and manufacturing are more likely to cause economic losses, a shortened life-span of the equipment, excessive equipment use and lower energy output. Commonly, the wear and friction changes with the load, speed [1], temperature [2], surface roughness [3, 4, 5], type of material or mating components [6] and environment. Lubrication is an excellent, alternative way to reduce friction, and is suitable for engines and machinery, and the presence of lubricants [7, 8] in machines and engines can overcome the economic implications of wear for the manufacturing industry.

A conservative lubricant, petroleum, has been commonly used as the lubricant for most industrial mechanics and engines, however, the use of petroleum (oil) presents risks to the environment and for safety due (in some degree) to its degree of toxicity and high flammability [9]. Therefore, researchers are searching for optional lubricants in order to change from the use of conventional oil lubricants. In 2011, Malaysia was one of the countries recognized for being the largest palm oil producers as the main lubricant for reducing the use of mineral oil in industry [9, 10]. Vegetable oils (not necessarily a new discovery) are known as eco-friendly lubricants due to their many advantages, including high biodegradability, non-toxicity, renewable resources, good low temperature properties and low costs [11, 12]. There has been a significant amount of research and improvement done on palm oil use in industry, since the production of palm oil is placed second (after soy bean oil) in vegetable oil production [13]. The botanical classification of palm oil is Elaeis guineensis, and it has been widely applied in applications such as fuels for diesel engines [14], hydraulic fluid and lubricants [15], while reducing the amount of carbon dioxide in the atmosphere that contributes to the greenhouse effect.

In this paper, RBD palm olein was tested using pin on disk tribotester for its lubricity performance according to the ASTM G99. Tests were implemented using a direct lubricant flow of test lubricants on a plain disk at two different speeds (0.4 m/s and 4 m/s). The material used for both frictional surfaces was stainless steel. For this experiment, the coefficient friction and wear rate of the pin were studied, and from this the wear obtained when using the RBD palm olein was lower than that using the hydraulic oil.

2. Experimental method

3.1. Pin on disk tribotester

The pin-on-disk is commonly used because it is a comparative testing method which controls wear and measures friction in study samples. The volume of the wear loss allows the calculation of the wear rate of the material. With this method, the pin was firmly attached to the pin support and then linked to the rotating plain disk with the desired load. Lubricant was then pumped continuously from the machine. A hemispherical pin was used and directly touched the disk surface at the beginning of the experiment. Both the pin and the disk were made from stainless steel (316L). The Vickers hardness for both pin and disk before experiment was 155Hv. A linear voltage differential transformer (LVDT) sensor was used to read and measure the wear rate. Figure 1 showed the schematic sketch of the pin and plate disk.
3.2. Material and lubricants

The pin samples were designed to be 8 mm in diameter, 30 mm in length and have a radius (of the hemisphere) of 4 mm, and a stainless steel plain disk was selected. The density of the stainless steel was 7.48 g/cm³. After the completion of each test, sandpaper with a grain size of the abrasive material (1000 μm) was used to grind the surface so that the surface finish measurement fell between the specifications. The properties of the stainless steel S316L was shown in Table 1 and Table 2. RBD palm olein and hydraulic mineral oil were used as lubricants. RBD palm olein was the refined, bleached and deodorized palm olein. Palm olein is the liquid fraction obtained by fractionation of palm oil after crystallization at controlled temperature. In these experiments, a standard grade of palm olein, which incorporated Malaysian Standard MS 816:2007, was used. The density and kinematic viscosity of the lubricants were measured previously, using a viscometer at different temperature levels (from 40 °C to 100 °C) and shown in Figure 2.

![Diagram of pin and plain disk](image)

**Fig.1. Schematic sketch of the pin and plain disk.**

### Table 1. Properties of stainless steel (S316L)

| Properties                  | Value   |
|-----------------------------|---------|
| 0.2% Proof strength (MPa)   | Min 170 |
| Tensile strength (MPa)      | Min 485 |
| Tensile elongation (%)      | 40      |
| Vickers Hardness (Hv)       | Max 225 |

### Table 2. Chemical properties of stainless steel (S316L)

|     | C   | Si  | Mn  | S   | P   | Cr  | Ni  | Mo  | N   |
|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| Min |     |     |     |     |     | 16.0| 10.0| 2.0  |     |
| Max | 0.030| 1.00| 2.00| 0.030| 0.040| 18.0| 14.0| 3.0  | 0.10 |
3.3. Experimental procedure

The lubricated frictional and sliding wear tests were carried out using a conventional pin-on-disk machine. A flat surface was used for the test arrangement in the present set of experiments, and the surface of the pins and the disc were positioned in parallel to ensure maximum contact. The principle of sliding consisted of a cantilever loaded pin pressed against a horizontal rotating plain disk in a lubricant oil bath. All tests were carried out at room temperature (34 ± 2 °C). In this experiment, the constant load (10 N) and different sliding speeds predicted to affect the friction and wear characteristics were considered. The finished surface of the wear sample and disk were measured both before and after the experiment. Before the experiment began, the disk and pin surfaces were cleaned with acetone to confirm that there were no additional particles on these surfaces. During the wear and frictional coefficient tests, different speeds were applied (0.4 m/s and 4 m/s), and three tests were carried out for each parameter and condition.

3. Results and discussion

3.1. Coefficient of friction (COF)

To study the anti-frictional behaviour of the RBD palm olein, several experiments were carried out using low and high speeds as the main variables (0.4 m/s and 4 m/s) at a constant 10N load, and the duration of the experiment was 1 hour as recommended by the American Society for Testing and Materials (ASTM). All data related to the frictional forces were collected and converted into the frictional coefficient ($\mu$) using Equation (1), where $F$ is the frictional force and $N$ is the normal load.

$$\mu = \frac{F}{N}$$

(1)

The values of the frictional coefficient obtained are presented in Figure 3 for both of the speed conditions. From this figure, one can say that the frictional coefficient acquired from the sample lubricated with the RBD palm olein (PO) showed lower values at low speeds (0.015) when compared to the hydraulic mineral oil (HO), and approximately the same values at high speeds (0.067). The values for the coefficient of friction (COF) measurements are very close together (only 0.001 for both the PO and HO). The frictional coefficient also increased as an increment of the sliding speed. The presence of long chain fatty acids in vegetable oils have the ability to show...
better lubricating properties when attributed to the lower COF obtained. The large quantity of unsaturated fatty acids contained in vegetable oil develops a higher strength in the lubricating film, and acts as a boundary lubricant that protects the contacted surfaces, therefore reducing the coefficient of friction (COF) [16].

![Graph showing COF versus speed at load 10N for RBD palm olein and hydraulic oil.]

**3.2. Wear scar diameter (WSD)**

Wear rate can be calculated using Equation (2). In this case, the load was 1kg and, sliding distance for speed 0.4m/s and 4.0m/s was 1440m and 14,400m respectively. The value for load and sliding distance was constant for each sliding speed. Therefore, the wear rate also could be observed by measuring the value of y-axis (as shown in Figure 1) in micron unit. The load would push the pin on the rotating disk. The higher the wear rate (material loss), the shorter the pin. The y-axis value were plotted as Fig. 4.

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

(2)

It was found that the wear obtained with the samples lubricated with the PO were once again lower than those with the HO. The final wear values obtained by the pin lubricated with the PO were around 22.12μm (for speed 0.4m/s) and 411.92μm (for speed 4.0m/s). The graph indicates that the wear values obtained for the samples lubricated with both the PO and HO were significantly increased from the low speeds to the high speeds.

The mean wear scar diameter (WSD) of the hemispherical pin was measured using a low power microscope as illustrated in Fig. 5. In the figure, it was clearly shown that the WSD observed for the samples lubricated with the PO showed a better result when compared to the HO samples, specifically at low speeds (0.16mm for the PO and 0.45mm for the HO). At high speeds, the results obtained from the samples for both lubricants showed almost the same values (1.97mm and 2.02mm). The values of the WSD were increased as the increment of the sliding speed increased.

Fig. 6 and 7 show the CCD pictures of the worn surface of the pin at sliding speed 0.4m/s and 4.0m/s respectively. The lower values of wear obtained from the samples lubricated with the PO, as discussed earlier, were due to the layer of film formed between the contacted surfaces and the unsaturated fatty acids in the PO. These unsaturated fatty acids created thicker molecular layers that prevented direct metal to metal contact, which protected the surfaces from wear [17,18]. A further analysis was completed using micrographs of the wear-worn surface after 3600 seconds. The results of the tests of both the PO and HO under different temperatures are shown in Fig. 4. As
outlined by Singh [19], all of the parallel grooves were the outcome of certain debris triggering the abrasive wear, which was determined to be dominant on the surface and the grooves created parallel to the sliding direction.

Fig. 4. Wear versus speed at load 10N for RBD palm olein and hydraulic oil.

Fig. 5. Wear scar diameter versus speed at load 10N for RBD palm olein and hydraulic oil.

Fig. 6. Worn surfaces for RBD palm olein (PO) and hydraulic oil (HO) at sliding speed 0.4m/s.
4. Conclusion

Under ASTM experimental conditions, the RBD palm olein showed better anti-frictional and anti-wear performance when compared to hydraulic mineral oil. The frictional coefficient and wear for both lubricating oils were increased as the sliding speed increased, and the free unsaturated fatty acids played an important role in reducing the coefficient of friction and wear.

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