Lubrication performance of double fraction palm olein using pin-on-disk tribotester

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Abstract. Friction, wear and fatigue are the three most commonly encountered industrial problems leading to the replacement of components and assemblies in an engineering system. The present paper experimentally investigated the effect of sliding speed on friction and wear behaviour of an aluminium pin sliding against a SKD11 disc with a constant normal load of 4 kg, lubricated with double fraction palm olein (DFPO) as a test lubricant and commercial hydraulic oil (HO) as a reference lubricant. Experiments were carried out at various sliding speeds from 900rpm to 1800rpm. The experimental works were carried out at room temperature. After the testing was completed, the friction coefficient and wear rates were calculated. The morphology of the worn surface was observed using a charge couple device (CCD) camera. Results showed that the friction coefficient for both lubricants decreased with increments in sliding speed.

1. Introduction

Sliding between mating components in operations of extended duration will produce high levels of friction and wear, as well as ultimately failure of the materials if there is no effective lubrication between the contact surfaces. These high frictional values are usually caused by an inherent roughness of the materials in contact and the large pressures that develop between them. In order to minimise the undesirable effects of wear, lubricants are generally applied along the interface of materials in contact [1, 2].

Lubricants are thus used to control friction and minimise wear [3-5]. When lubricants are applied between the contact interfaces of two sliding surfaces, the material loss due to wear and the energy consumption due to friction are reduced by several orders of magnitude [6-7]. To understand the wear behaviour of materials, wear tests are often carried out with suitable techniques that can provide more analysis of the behaviour of wear. The pin-on-disc test is usually used to conduct wear experiments.

In the pin-on-disk test, the wear volume can be determined either by the changed geometry of the specimen or by reduction in the mass of the specimen. In most studies on wear, the measurements commonly taken are of wear, volume loss, weight loss and wear coefficient. Such results also provide an indication of the anti-friction, anti-wear and anti-scruff properties of oil or an additive in oil. The operating conditions can be made to simulate, as far as possible, those in a real industrial machine. The continuous supply of lubricant conducted in this test causes boundary lubrication, where metal-to-metal contact occurs, and the chemistry of the metals and the oil control the friction and wear. In this study, a pure aluminium pin was tested on a SKD11 disc and lubricated with double fraction palm olein (DFPO) as a test lubricant. Similar tests were conducted using commercial hydraulic oil (HO), as
a benchmark. Normal load was set to 4 kg and rotational speed was set between 900rpm and 1800rpm. After the testing was completed, the friction coefficient and wear rates were calculated. The morphology of the worn surface was observed using a charge couple device (CCD) camera. Results showed that the friction coefficient for both lubricants decreased with increments in the sliding speed.

2. Material and method

Figure 1 is a schematic sketch of a pin-on-disk tribometer. The disc was made of SKD11 and the material for the pin was pure aluminium A1100. The average hardness of the pin before undergoing heat treatment was 52HV and after heat treatment it was 36HV. The hardness of the specimens was measured using a Vickers hardness tester. Rotational speed was set between 800rpm and 1800rpm. Normal load applied on the aluminium pin was set to 4 kg.

![Figure 1. Schematic sketch of pin-on-disk tribotester.](image)

3. Results and discussion

The coefficient of friction can be defined as a measure of the amount of resistance that a surface exerts on substances moving over it, equal to the ratio between the maximal frictional force that the surface exerts and the force pushing the object towards the surface. The coefficient of friction is not always the same for objects that are motionless and objects that are in motion; motionless objects often experience more friction than moving ones, requiring more force to put them in motion than to sustain them in motion.

Figure 2 shows the comparison of the average friction coefficient for an aluminium pin sliding on the rotating SKD11 disc, lubricated with double fraction palm olein (DFPO) and hydraulic oil (HO). Generally, both lubricants showed the same characteristic, namely that the friction coefficient decreased when the rotating speed was increased from 900rpm to 1800rpm. This indicates that the lubrication conditions were favourable at high speeds, probably in or close to the hydrodynamic region, while at low velocities the conditions obviously corresponded to the mixed or boundary regime. Velkavrh et al. [8] obtained the same results: a decrease in friction with the increase of velocity in the low-speed regime and an increase in friction with the increase of speed at high velocity. This is typical behaviour, and the regime transition is found along the Striebeck curve [9].

Moreover, the decrease in friction coefficient with increasing sliding speed may be due to the change in the shear rate, which can influence the mechanical properties of the mating materials. These findings are in agreement with those of Chowdhury et al. [10]. Similar trends were observed for the friction coefficient with variation in the duration of rubbing; the results are presented in Figure 1, which shows that friction decreased with increasing sliding speed within the observed range. Also, increased surface roughening and a large quantity of wear debris are believed to be a major reason for the decrease in the friction coefficient with increasing sliding speed.

The level of the coefficient of friction was also affected by the surface condition. The high temperature generated during the rubbing process between the two oxide surfaces, so that the spherical
aluminium pin had a tendency to reduce the friction. Furthermore, the layer formed on the surface contributed to the friction. Tiong et al. [11] and Syahrullail et al. [12] similarly found that, when the layer substantially covers the sliding surfaces, sliding occurs within the layer and friction is characteristic of that process. When the rate of removal of the surface layer is much faster than that of its formation, the surface is always partially covered and a single-valued friction coefficient results. When the rate of formation is higher than that of removal, there is always a well-formed layer, and a low, single-valued friction coefficient can be anticipated.

![Figure 2. Friction coefficient distribution.](image)

When two surfaces are in loaded sliding contact, stresses are imposed on both solids as a result of normal and tangential forces that arise from sliding. Frictional heat is also generated at the sliding-contact interface. The imposed stresses and frictional heating at the contact interface are the principal factors in causing wear at the sliding-contact interface. Consequently, the wear rates and wear mechanisms are determined in large part by the magnitude of these factors. Figure 3 represents the correlation between wear rates of a spherical aluminium pin with respect to differences in rotational speed using two different types of lubricant. As we can see from the data plotted, the wear rate clearly declines with increasing rotational speed in the case of both lubricants. However, in the range of rotational speed of 900rpm to 1200rpm, the wear rate seems to exhibit a higher difference according to the lubricant, whereas in the range of 1500rpm to 1800rpm, the decrements in the case of both lubricants are comparable with each other.

The decrease of the average wear rate with increasing sliding speed may be due to direct asperity collisions in steel/steel contacts under a constant contact pressure without using any additives. This leads to adhesive wear, as also seen at low velocities, which implies that such asperity contacts occur very seldom on steel surfaces at high velocities, even at the lowest viscosity.

During the rubbing process between two surfaces, a high temperature oxide of aluminium (Al₂O₃) is formed, which subsequently covers both the pin and the disc track surfaces in a layer and reduces friction and wear. This is mainly due to higher temperatures generated at the interface. As this layer offers a certain amount of protection from wear, wear rates of both the pin and the disc are lower at higher speeds. With increasing speed, the amount of layer formation increases, owing to the higher temperatures generated. This may be why the wear rate decreases with increasing speed, as also observed by Ravikiran et al. [13].

The wear rate decrease with increasing sliding can be attributed to several further factors. The first factor influencing the tribological behaviour may be the easier occurrence of plastic flow caused by the decrease of the shear strength in a small volume next to the coatings contact area, or by local...
melting, owing to the high flash temperatures reached. This means that, at high rotational speeds, the
time between passes of the pin over the same point on the disk is reduced, so that the time available
for heat dissipation is shortened and the lubricated surface temperature and flash temperatures,
especially in the contact area between the spherical aluminium pin and the disk, can rise significantly.
The results found by Betancourt-Dougherty [14] were similar to those of this study.

Rotational speed is one of the factors that may allow the reduction of wear. Because of low speeds,
the debris generated is not ejected from the wear track, and will continue to contribute to the track
wear process in the form of abrasive wear. Thus, low speeds may contribute to a high wear rate. In
contrast, at high rotational speeds, most of the debris generated is ejected out of the wear track, such
that debris abrasive wear is minimised.

Figure 3. Wear vs rotation speed.

Figure 4 shows the worn surface characteristics of the aluminium pin for both types of lubricant.
The cluster of debris or particulates produced around the surface for 900rpm using DFPO was
significantly greater compared to HO. This indicates that the cluster of debris formed during the
experiment decreased with increasing sliding speed. The worn characteristic seen at 1800rpm, which
is the wear debris, was greatly reduced around the spherical aluminium surface.

The reduction in debris generated during the experiment may be due to the low speeds, which
means that the debris generated is not ejected from the wear track and will continue to contribute to
the track wear process in the form of abrasive wear. In contrast, most of the debris generated is ejected
out of the wear track at the high rotational speed, thus minimising the debris abrasive wear. This is
why a lot of debris results from slower speeds and the amount of debris is reduced when the speed is
increased. However, the wear debris generated when using HO seems to be less than when using
DFPO. This is because HO has additives that can significantly reduce the friction. In contrast, the
DFPO is pure palm oil, free of additives. Thus, we can conclude that the additives in a lubricant can
influence the worn characteristic of the direct contact between two sliding surfaces.
4. Conclusion
The tribological performance of double fraction palm olein was tested using a pin-on-disk tribotester. Commercial hydraulic oil has a lower friction coefficient and wear rate than double fraction palm olein. However, the difference in value is acceptable and commercial hydraulic oil with additives is judged to give superb performance in terms of anti-friction and anti-wear.
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References
[1] Syahrullail S Nakanishi K and Kamitani S 2005 J. Jap. Soc. Trib. 50 877-85
[2] Syahrullail S Zubil B M Azwadi C S N and Ridzuan M J M 2011 Int. J. Mech. Sci. 53 549-55
[3] Najiha M S Rahman M M Yusoff A and Kadirgama K 2012 Inter. J. Automot. Mech. Eng. 6 766-74
[4] Ghobadian B Najafi G and Nayebi M 2013 J. Mech. Eng. Sci. 4 373-82
[5] Najiha M S Rahman M M Kamal M Yusoff A R and Kadirgama K 2012 J. Mech. Eng. Sci. 3 340-45
[6] Wan N W B Maleque M A Ani F N and Masjuki H H 2007 Ind. Lub. Trib. 59 200-08
[7] Shukla S and Deheri G 2013 J. Mech. Eng. Sci. 4 532-47
[8] Velkavrh I Kalin M and Vizintin J 2009 Trib. Int. 42 1752-57
[9] Wan Nik W B Ani F B Masjuki H H and Eng Giap S G 2005 Ind. Crops and Products 22 249
[10] Tiong C I Azli Y Rafiq A K M and Syahrullail S 2012 J. Zhejiang Univ. Sci. A. 13 633-40
[11] Chowdhury M A Khalil M K Nuruzzaman D M and Rahaman M L 2011 Int. J. Mech. And Mechatronics Eng. 11
[12] Syahrullail S Tiong C I Rafiq A K M and Azli Y 2012 Trib. Trans. 55 539-48
[13] Ravikir A and Surappa M K 1997 Wear 206 33–38
[14] Betancourt-Dougherty L C and Smith R W 1998 Wear 217 147-54