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TRIBOLOGICAL PERFORMANCE OF PALM KERNEL OIL ADDED WITH NANOPARTICLE COPPER OXIDE USING FOURBALL TRIBOTESTER

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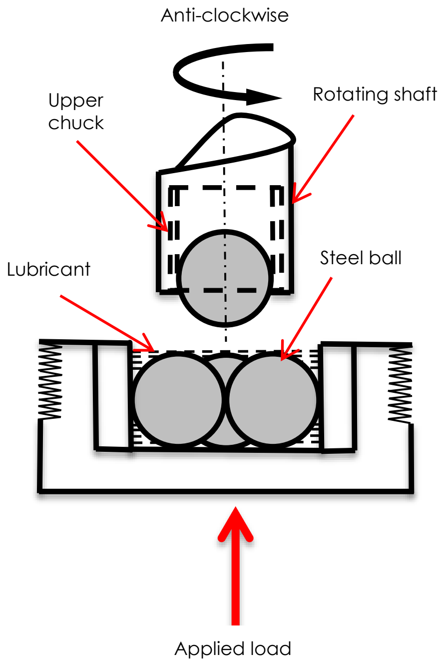
Graphical Abstract



Abstract

The remaining base stock of mineral oil resources is drawing attention to the researchers all over the world as the technology development keep on increasing over the years. Researchers also keep trying to figure out this issue by diverting the attention to other resources such as vegetable oil. This study is focusing on using palm oil based as lubricant with addition of nanoparticles copper oxide to improve the tribological behavior. There are 3 types of lubricant being used in this study which are mineral based engine oil (SAE 40), palm kernel oil (PKO) and palm kernel oil added with nanoparticle copper oxide (PKO+CuO). Fourball tribotester machine was used and the experiment was conducted by following the ASTM D4172 standard. The result analysis was focusing on coefficient of friction, wear scar diameter, surface roughness as well as wear worn observation. It was found that, PKO+CuO exhibited 20.12% and 8.73% lower coefficient of friction compared to SAE 40 and PKO respectively. However, PKO+CuO represented 10.13% and 1.74% higher wear scar diameter compared to SAE 40 and PKO respectively. The physical appearances of wear worn were observed and further discussed in this present study.

Keywords: Palm kernel oil, nanoparticle, copper oxide, tribology, four-ball tribotester

1.0 INTRODUCTION

The major concern of using mineral based lubricant is the capability to react with the environment. It has very high toxic level and nearly impossible to dispose to environment. Vegetable based oil was known to have very good bio-degradable ability that might solve the environment issues. Besides, it has low volatility, good thermal-viscosity properties, high solubilizing power and definitely the resources are renewable [1].

An effort was developed by Golshokouh *et al.* [2] to investigate the performance of Palm Fatty Acid Distillate (PFAD) in petrochemical application. They found that PFAD demonstrated higher anti-friction and anti-wear capability compared to Engine and Hydraulic mineral oil. They also studied the performance of Jatropha oil and confirmed that it has better lubricant properties against engine and hydraulic based lubricant [3]. Another study was carried out by Syahrullail *et al.* [2] in their study of using RBD Palm Stearin in cold work forward extrusion. They revealed that RBD Palm Stearin is effective as Paraffinic mineral oil in reducing frictional constraint in cold work extrusion [1]. Another effort was shown by Syahrullail *et al.* [4] on investigating the performance of Palm Olein in plain extrusion. They found that Palm Olein presented satisfactory performance compared to mineral oil based lubricant [4]. Similar findings were found by Syahrullail *et al.* [5] in which they observed that Palm Olein was showing lower coefficient of friction but exhibited higher oxidation effect compared to mineral oil [5]. There was lot of approaches can be implemented to improve the capability of palm oil based lubricant such as modifying the molecule structures, blending with additives, nanoparticles and many more.

Nanoparticles have good self-repair function to the worn surface and good environment – friendly properties [6]. In contrast, Zulkifli *et al.* [7] and Alves *et al.* [8] reported that nanoparticle might worsen the thin film formation in which it may be molten and welded on the shearing surfaces thus affected wear and friction [7-8]. Wu *et al.* [9] mentioned that nanoparticles technology can be applied in various field.

According to Zulkifli *et al.* [7], there are several characteristics need to be considered when using nanoparticle as an additive in lubricants such as the size, shapes as well as the concentration of nanoparticle [7]. The size of nanoparticle is mostly around 2-120 nm. It was found that the smaller size of nanoparticle is more likely to interact with the surfaces of the friction pairs to form a surface protective layer which increase the anti-wear ability. The similar results also found by Zhou *et al.* [10] which employed the dialkyl-dithio-phosphate (DDP) and modified copper nanoparticles as additives in liquid paraffin.

Rapoport *et al.* [11] studied the inorganic fullerene-like (IF) particles as additives in lubricant. They found that smaller size and more nearly spherical IF particles were likely to exhibit superior rolling, lower affinity to the metal surface, decreased the contact temperatures, provided higher elasticity, and higher chemical resilience [11]. Instead of size and shape of nanoparticle, another factor necessary to be considered is nanoparticle concentration in lubricants. Wu *et al.* [9] mentioned that low concentration of nanoparticles is sufficient to improve tribological properties. Thottacked *et al.* [12] found that the optimum concentration for CuO nanoparticle added in vegetables oils (coconut oils) is 0.34%. At the concentration lower than 0.34%, there are some reductions in friction from 0% to 0.34% due to the presence of nanoparticle that change the contact configuration from sliding to rolling. However if the concentration is higher than 0.34%, it will present more solid to solid contact between nanoparticle thus will increase the friction [12].

Referring to Shahnazar *et al.* [13], there are several type of nanoparticle available which are metal, metal oxide, metal sulfides, metal carbonates, metal borate, carbon material, organic material and rare earth compound [13]. Among those nanoparticle types, copper (Cu) drawn attention from many researchers to be added in lubricant based oil due to its excellent anti-friction and wear resistance properties [14-16].

In this present study, the effect of adding nanoparticle CuO into Palm Kernel Oil will be evaluated in the perspective of coefficient of friction, wear scar diameter, surface roughness and physical wear observation. All these tribological behaviors will be discussed with respect to the changes of rotational speed.

2.0 METHODOLOGY

2.1 Apparatus

The experiment was conducted using four ball tribotester as shown in Figure 1 [17]. Every testing required four steel balls which are made of chrome alloy steel with 12.7mm diameter following AISI E-52100 standard, extra polished (EP Grade 25) and also hardened to 64-66 HRc (Rockwell C Hardness). The steel ball was first being cleaned to remove any foreign material and debris on the surface using dimethyl ketone (Acetone). Three of them will be placed inside the oil test rig and tightened with lock nut for about 68Nm torque. Then 10ml of lubricant will be poured into the test rig to ensure the steel ball surface was immersed by the lubricant. The other steel ball was inserted in the upper chuck that is attached to the rotating shaft. The oil rig then placed on the anti-friction disc which is freely moving up and down. Load was applied using plunger with certain ratios. Thermocouple was fitted on the test rig to control the temperature. The friction torque, temperature and real time applied load were recorded accordingly in the computer.

The coefficient of friction was calculated using Equation (1):

$$Cof = \frac{T\sqrt{6}}{2Wr} \tag{1}$$

Where T is the frictional torque (kg/mm), W is the applied load (kg) and r is the distance from the center of the contact surface on the lower ball to the rotation axis which is 3.67 mm.

In this present study, the experiment condition follows ASTM D4172B standard in which the temperature was controlled at 75°C, load applied at 40kg and duration about 1 hour. The rotational speed was varied from 1200 rpm to 2100 rpm with interval of 300 rpm.

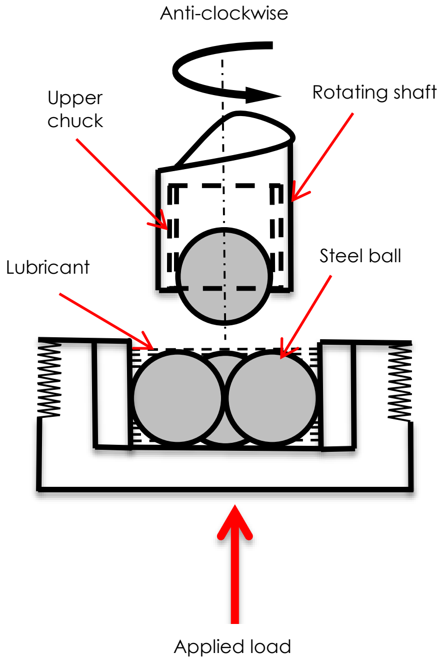


Figure 1 Schematic diagram of oil test rig

2.1 Lubricant

Three types of lubricant will be tested in this present study which are Palm Kernel Oil (PKO), Palm Kernel Oil added with nanoparticle Cooper Oxide (PKO+CuO) and Commercial engine oil (SAE 40) as benchmark. The nanoparticle CuO was homogenized with Palm Kernel Oil with concentration of 0.34%. The nanoparticles CuO used in this experiment were spherical in shape and 99% purity. The size of nanoparticles CuO were 40 nm and the surface area was 80m²/g. The nanoparticles CuO consists of (in ppm) Ba; 0.8, Ca; 400, Co; 2.4, Cd; 6.4, Fe; 87, K; 300, Mg; 72, Mn; 3.2, P; 300, Pb; 100, Sr; 2.4, Zn ; 200 respectively.

3.0 RESULTS AND DISCUSSION

3.1 Coefficient of Friction

The graph of coefficient of friction against changes of speed was plotted as presented in Figure 2. It was found that the trend of coefficient of friction for commercial engine oil (SAE 40) is decreased with the increasing of speed. It is slightly different with the trend shown by palm kernel oil (PKO) and palm kernel oil added with nanoparticle (PKO+CuO). For PKO, the value of coefficient of friction is showing fluctuation trend from speed of 1200 rpm to 2100 rpm. However, the value of coefficient of friction for PKO+CuO is consistent and stable from speed of 1200 rpm to 2100 rpm. From the result, it was noticed that the SAE 40 shows poor characteristics of lubricity compared to PKO and PKO+CuO. PKO+CuO showed better lubricity due to the ability to retain the lower coefficient of friction value at higher speed.

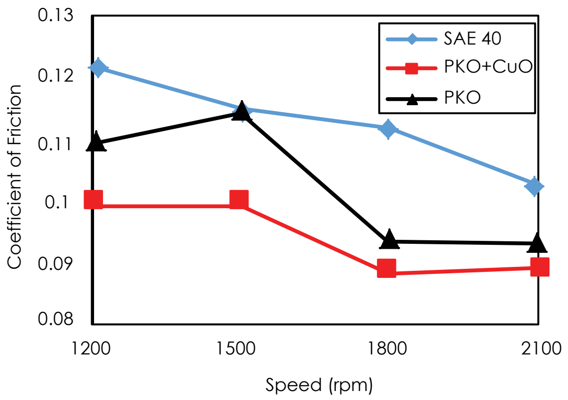


Figure 2 Coefficient of friction against speed

Palm Kernel oil added with nanoparticle (PKO+CuO) was able to maintain low coefficient of friction compared to the others lubricants. It was because of its special characteristic of nanoparticle which is the size and shapes [7]. It was found that smaller size of nanoparticles were more likely to interact with the surfaces of the friction pairs to form a protective layer which could prevent direct metal to metal contact thus can decrease the friction. Rapoport *et al.* [11, 18] also stated that the spherical shape of nanoparticle give the possibility for an effective rolling friction mechanism between the metal to metal contacts which can reduce friction. From the result, PKO also exhibited lower coefficient of friction as compared to SAE 40 because of their molecular structure. Vegetables oils consist of chemical composition of triacylglycerol molecules made up of esters derived from glycerol and long chain of polar fatty acids [19, 20]. Fatty acids structure is necessary during the boundary lubrication for their ability to adhere to metallic surfaces so that the polar carboxyl group will remain closely packed and create monolayer film that is effective in reducing friction by minimizing the metal-to-metal contact [21].

3.2 Wear Scar Diameter

The graph of wear scar diameter against speed was plotted as presented in Figure 3. It was clearly seen that the wear scar diameter is increased with speed increasing for all three types of lubricant. For commercial engine oil (SAE 40), the wear scar diameter is increased steadily from 0.5317 µm, 0.5552 µm, 0.5773 µm, until 0.5828 µm. The trend shown by PKO and PKO+CuO is almost similar. The wear scar diameter for PKO is starting to increase with small increment from 0.5552 µm to 0.5742 µm between 1200 rpm and 1500 rpm, and suddenly increase drastically to 0.6477 µm at 1800 rpm. Then small increment is noticed at speed of 2100 rpm. As for PKO+CuO, the wear scar diameter seems to look consistent with only small increment noticed from 0.569 µm to 0.582 µm at speed of 1200 rpm and 1500 rpm respectively. Then it was increased significantly to 0.6568 µm at 1800 rpm, and again increases with small increment to 0.6663 µm at 2100 rpm. From this result, SAE 40 indicated best lubricity performance as it has the lowest wear scar diameter if compared to the others lubricant.

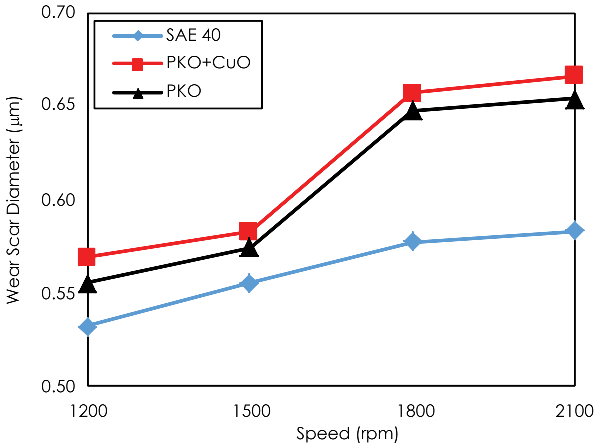


Figure 3 Wear scar diameter against speed

For the wear scar diameter result, the graph analysis has shown that vegetable oil added with nanoparticle (PKO+CuO) has the highest value of wear scar diameter compared to others lubricants. Although the small size of CuO nanoparticle can penetrate the surface and form the protective film in reducing the coefficient of friction, the surface atom (O2-) of the nanoparticle still has active chemical properties that is generated by decomposition of the CuO nanoparticle and easily reacts with the substrate. These activities will enhance their corrosive behavior and result in poor anti-wear property of the lubricants [4]. Besides that, PKO also indicated higher wear scar diameter compared to SAE 40 because the vegetables oils are easily oxidized and cause corrosion to the surface. Azman *et al.* [22] mentioned that the presence of unsaturated fatty acid (C=C) caused the vegetable oils to be easily oxidized due to the existence of bis-allylic protons between two double bonds that is highly susceptible to radical attack. When the sliding motion between the surfaces of the ball bearing occurs, it will generate heat which is acting as catalyst during the oxidation process. SAE 40 represented the lower wear scar value because it was already been formulated with the appropriate additive which can improve the anti-wear performance during the sliding motion between two contact surfaces.

3.3 Surface Roughness Profile

The surface roughness analysis was conducted by using surface profilometer. The surface roughness profile on the wear scars were measured by detectors. The moving distance of the detectors during the measurement was different for each ball bearing and depends on diameter of the wear scar. The result then was plotted against the rotational speed as illustrated in Figure 4. From the graph, it was found that all lubricants are showing similar trend as the value of surface roughness decreases when the rotational speed is increased from 1200 rpm to 2100 rpm. For commercial engine oil (SAE 40), the values of surface roughness start to decrease consistently from 0.086µm at 1200 rpm until 0.061µm at 2100 rpm. As for palm kernel oil (PKO), the value of surface roughness decreases steadily from 0.074 µm at 1200 rpm until 0.034 µm at 2100 rpm. However, the trend shown by palm kernel oil added with nanoparticle (PKO+CuO) is slightly different. The surface roughness value shows fluctuation trend from the speed at 1200 rpm until 2100 rpm.

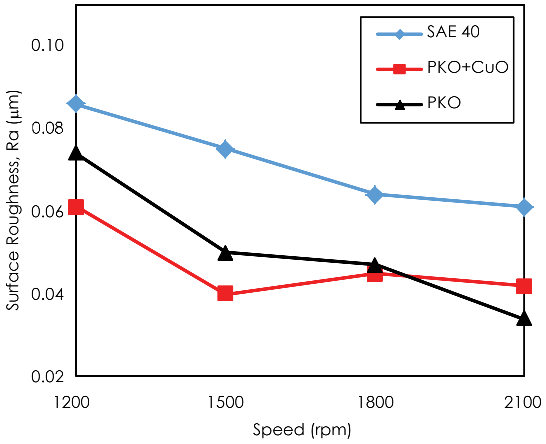


Figure 4 Surface roughness against speed

Generally, SAE 40 presented coarser surface roughness while PKO+CuO demonstrated smoother surface among all tested lubricants. It was because the small size of nanoparticle that is added to the vegetables oil penetrates the surface of the ball bearing and form the protective film which reduces form metal to metal contact thus can lower the surface roughness [7]. The spherical shape of the nanoparticles also attributed to this condition. It was observed that the result is synchronized with coefficient of friction analysis. Besides that, PKO shows the smoother surface roughness when compared to SAE 40 because of their molecular structures which contain long chain of fatty acid that is necessary during the boundary lubrication regime. The presence of fatty acid chain will create strong molecular interaction between the metallic surfaces and the polar carboxyl group. It helps to remain the closely packed structures and create thin layer soap film that is sufficient in reducing friction by minimizing the metal-to-metal contact [21]. The protective layer formed is acting as first line defense to protect the surface from tear and worn.

3.4 Correlation of Surface Roughness and Coefficient of Friction

Figure 5 was showing the correlation between the coefficient of friction behaviors with the surface roughness profiles. It was clearly indicated that the surface roughness trend was directly proportional with the coefficient of friction. The higher the coefficient of friction led to coarser surface roughness. Low coefficient of friction was attributed by less asperities contact between the surfaces. When the asperities contact was at minimum level, thus the metal surface was prevented from being rubbed away from its original position. This resulted in minimum abrasive and adhesive wear thus providing smoother surfaces. On the other hand, when more asperities were contacted, definitely the contact surfaces will be harshly damaged led to the formation of abrasive and adhesive wear. This caused the metal surface becomes rougher and coarser. The PKO+CuO was showing better performance in this analysis as it presented lowest coefficient of friction and smoother surface roughness compared to PKO and SAE 40. The additional CuO nanoparticles was enhanced the performance of PKO itself.

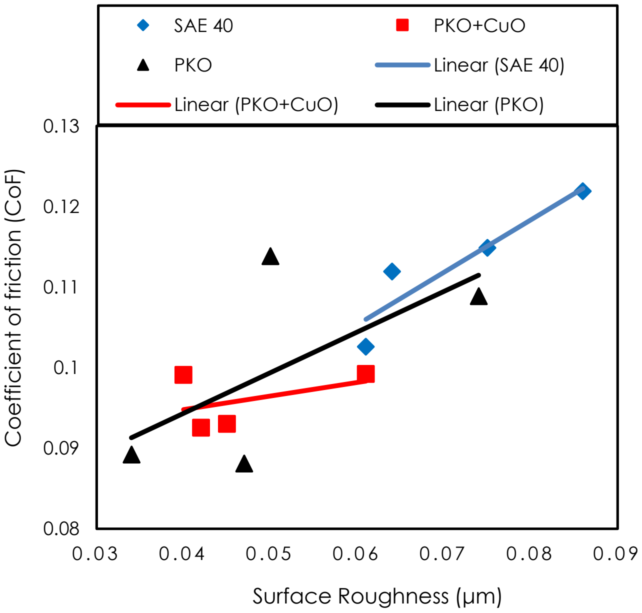
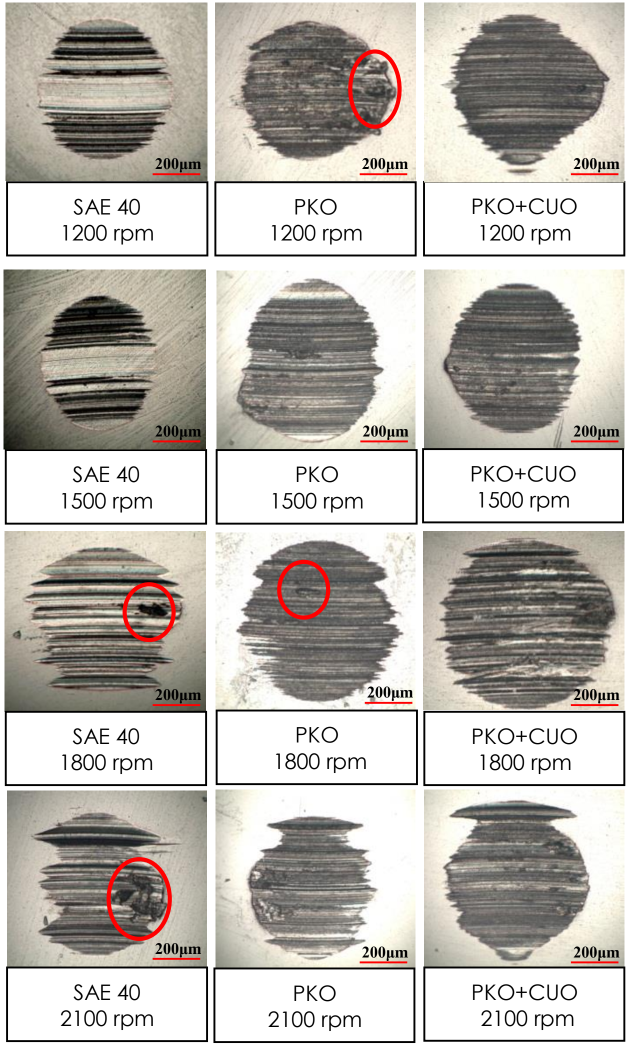


Figure 5 Coefficient of friction against surface roughness

3.5 Wear Worn Observation

The observation of the wear scar images was carried out by using optical microscope equipped with I-solution software. The images were then magnified up to 100x to have clear observation on the wear scars as illustrated in Figure 6. At speed of 1200 rpm, the wear scar of SAE 40 was round in shape and formed in such a uniform geometry. However for PKO and PKO+CuO, there was small bulging towards the right side of the wear scar following the direction of sliding motion. The wear scar formation was also round in shape and well formed. There were dark lines observed at wear scar of SAE 40 located on the upper and bottom part of the scar. However it was more dominant for the steel ball lubricated by PKO and PKO+CuO. It was also observed that at speed of 1500 rpm, there was no significant different compared to wear scar appearances at speed of 1200 rpm. As the speed increases to 1800 rpm, all steel balls were showing rugged at the edges of the wear scar. The wear scar was not round in shape and the diameter was also increased. Similar observation was noticed at speed of 2100 rpm but the round shape disappeared and uneven edges were observed.

Figure 6 Wear scar images at 100X magnification



SAE 40 1200 rpm
PKO 1200 rpm
PKO+CUO 1200 rpm
SAE 40 1500 rpm
PKO 1500 rpm
PKO+CUO 1500 rpm
SAE 40 1800 rpm
PKO 1800 rpm
PKO+CUO 1800 rpm
SAE 40 2100 rpm
PKO 2100 rpm
PKO+CUO 2100 rpm

The dark lines across the wear scar surfaces presented the scratches caused by the asperities contact. It was observed that some areas were having darker line compared to other areas. It was described that darker line presented deep scratches while lighter colors presented light scratches. These scratches significantly impacted the surface roughness of the wear scar. The deep scratches was attributed by the removal of the thin layer soap film which initially formed by the fatty acid chain during boundary lubricant regimes. The scratches on the wear scar surfaces were also caused by the oxidation process. The increased in speed generally produced the heat that eventually promoted the oxidation process. Oxidation process took place as the fatty acid molecules are having double bond which is susceptible to the radical attack. From the figure, it can be said that most of the light and deep scratches were led to abrasive wear. However there was certain areas spotted and marked with red circle is classified as adhesive wear. The existence of nanoparticles CuO significantly helps in reducing the damages on the wear scar surfaces.

4.0 CONCLUSION

From the results, it can be concluded that the additional of nanoparticle (Copper Oxide – CuO) into palm kernel oil based lubricant was able to improve the lubricant property by presenting low coefficient of friction. However, the present of CuO in PKO was unable to prolong the protection on the contact surface resulting larger wear scar diameter. Meanwhile, even with larger wear scar diameter, PKO+CuO still managed to have smoother surface roughness compared to PKO and SAE 40.

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