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INVESTIGATION OF TRIBOLOGICAL PROPERTIES OF PALM OIL BIOLUBRICANT MODIFIED NANOPARTICLES

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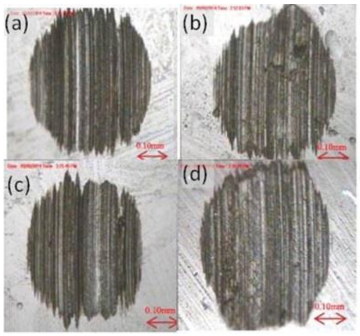
Graphical abstract



Abstract

The performance of a biolubricant especially palm oil is well known to be lower than a mineral oil lubricant. Due to a huge demand towards sustainability, it is extremely important to make an effort for biolubricant to be competitive at the same shelf as the mineral oil in the world's lubricants market. In this study, tribological properties of the palm oil biolubricant modified with Titanium Oxide (TiO_2) nanoparticles as additives were investigated. Palm oil biolubricant with TiO_2 nanoparticles at weight ratios of 0 to 0.2 wt% were mixed using an ultrasonic technique. The viscosity of biolubricant modified additives was conducted using standard of ASTMD445. The tribological behavior was investigated using a four-ball tribotester. Results indicate that the viscosities of samples increased as the weight percentage of the TiO_2 nanoadditives increased for both 40°C and 100°C temperatures Sample of lubricant with 0.1% wt of the TiO_2 nanoadditives produced the lowest coefficient of friction (COF) and wear scar diameter.

Keywords: TiO_2 , nanoadditives, nanoparticles, biolubricant, friction, wear

1.0 INTRODUCTION

History has shown that people had been using vegetables oils and animal fats as a medium to reduce the friction and wear dates back to 1650 B.C. However, the discovery of petroleum oil resulted in replacement of vegetables oils and animal fats. Mineral oils become the primary base stock for lubricants due to lower price and superior overall performance.

With the demand for high performance yet environmentally friendly, a number of works have been carried out to look for alternative of mineral oil lubricant to something more sustainable. Vegetable oils have been identified to be the best candidate to replace mineral oil. The triacylglycerol molecules of vegetable oil can significantly improve its resistance towards wear and extreme pressure. Some of the vegetable oils that are commercially available in the market are castor and corn lubricant oils. Recently identified potential vegetable oils lubricant such as Jatropha oil, rape seed oil and palm oil shows the latest research trend in lubrication [1-3]. Apart from their domestic uses, palm oil has also been used as replacement for biodiesel. Its potential as fuels for hydraulic fluid, diesel engine, and lubricants has been confirmed in many of previous studies.

Additive is commonly added to lubricant oils to enhance its performance. Recent studies show that the size and amount of additives may play a big role in its tribological properties. Several studies reported that adding nanoparticles with the size between 1 to 100 nm into lubricating oil at certain weight percentage can reduce friction and improve anti-wear properties. Nanoparticles used as additives in lubricant is always known as nanoadditives. Modification of lubricant oil with nanoparticle capable to give the sliding effect into rolling effect, thus reduce surface contact and heat production. A study reported by Qiu *et al*. found that the addition of CeF_3 in lubricant oil increased its lubrication performance against friction, wear, and load carrying capacity[4]. Bibliographic research has shown that the optimal concentration range of nanoparticles is between 0.02 – 5wt%. Chou in his study used the concentration of 0.5, 1, and 2wt% for nickel nanoadditives in lubricant [5]. Whereby, Xianmin *et al*. reported that the concentration between 0.9 to 1.1wt% of Ni in base oil gives the minimum value for friction coefficient and wear. Any reduction or increment in nanoparticles content will result in a corresponding increase of the friction coefficient and wear [6].

In this work TiO_2 nanoparticles have been used as the nanoadditives in palm oil biolubricant. Four-ball tribotester was used to investigate its tribological properties under boundary lubrication (metal to metal contact). The lubricant with different weight percentage of nanoadditives was tested to observe their performance towards the friction and wear.

2.0 EXPERIMENTAL

2.1 Characterization of TiO_2 Nanoadditives

The nanoparticles sizes and morphology were studied using Transmission Electron Microscopy (TEM) while the nanoparticles purity is confirmed by using X-ray Diffraction (XRD).

2.2 Preparation of Biolubricant Modified TiO_2 Nanoadditives

The TiO_2 nanoadditives used in this work were purchased from ALDRICH. Commercially available palm oil has been used as the biolubricants. TiO_2 nanoadditives were dispersed in palm oil biolubricant in a concentration of 0.05, 0.01, 0.2% by using an ultrasonic bath for 30 minutes at room temperature. The percentage (%) of nanoparticles in the lubricant is measured by weight.

2.3 Physical Properties of Biolubricant Modified TiO_2 Nanoadditives.

All samples were then tested for its viscosity value at temperature of 40°C and 100°C using U-tube Viscometer and controlled temperature bath. The viscosity of the samples was determined according to ASTMD445 while viscosity index using of ASTMD2270 and ISO 2909.

2.4 Friction and Wear Test

The study of friction and wear were conducted using four-ball tribotester testing machine (Ducom four-ball tribotester). The wear properties were obtained by applying ASTM D4172 which applied load of 40 kg at 1200 RPM speed and 15 minutes test duration and temperature was maintained at 60-70°C throughout the whole test process. The test balls used in this study were made from chrome alloy steel (AISI E-52100) with a diameter of 12.7 mm, Grade 25 EP (extra polish) and Rockwell C hardness 64 to 66. Wear Scar Diameter on the balls (WSD) after friction test were observed and measured using optical microscope.

3.0 RESULTS AND DISCUSSION

3.1 Characterization of TiO_2 Nanoparticles

Figure 1 shows a typical TEM image of the TiO_2 nanoadditives used in this work. The mean nanoparticles size is calculated to be 22.97 nm with a standard deviation of 4.16. This confirmed the specification size given by the supplier. XRD pattern for TiO2 nanoadditives were depicted in Figure 2. The four (4) different peaks of 2-theta(deg) at 25.3°, 37.9°, 48.1° and 62.8° can be indexed to Anatase phase of (101), (004), (200) and (204) respectively. No other impurity can be detected in the sample.

3.1 Physical Properties of Biolubricant Modified TiO_2 Nanoadditives

Four (4) samples of Lub0, Lub1, Lub2, and Lub3 were tested using viscometer at temperature 40°C and 100°C. Figure 3 shows the viscosity of samples at temperature of 40°C and 100°C. It can be seen that the viscosity of the four (4) samples at 100°C greatly drop compared to samples at temperature of 40°C. This might be due to the low boiling point of palm oil. Viscosity of samples at temperature 100°C dropped because the heat gives the energy that breaks the reaction between the palm oil itself, thus resulting in lower concentration compared to samples at temperature 40°C.

At temperature 40°C, no significant changes of viscosity occurred as the weight percentage of nanoadditives increased. Viscosity increased from 46.0 cSt for sample with any nanoadditives to 46.7, 47.5 and 48.1 cSt for samples Lub1, Lub2 and Lub3 respectively. At temperature of 100°C, sample Lub0 recorded viscosity value of 10.0 cSt. Contrarory to the viscosity values at temperature of 40°C, viscosity for samples Lub1 and Lub2 declined to 8.5 and 8.7 cSt respectively, before slightly increased to 9.0 cSt for Lub3. The present of TiO2 nanoparticles may contribute to the viscosity drop while in high temperature. However, it can also cause the viscosity increased in lubricants when the amount increased at certain value. Additional nanoparticles into the lubricants was seen to increase the viscosity of the lubricants at lower temperature but decreased the viscosity at higher temperature for certain weight percentage. The samples were found to be comparable to ISO VG 46 commercial standards for gears, light, industrial applications and other plant based biolubricant.

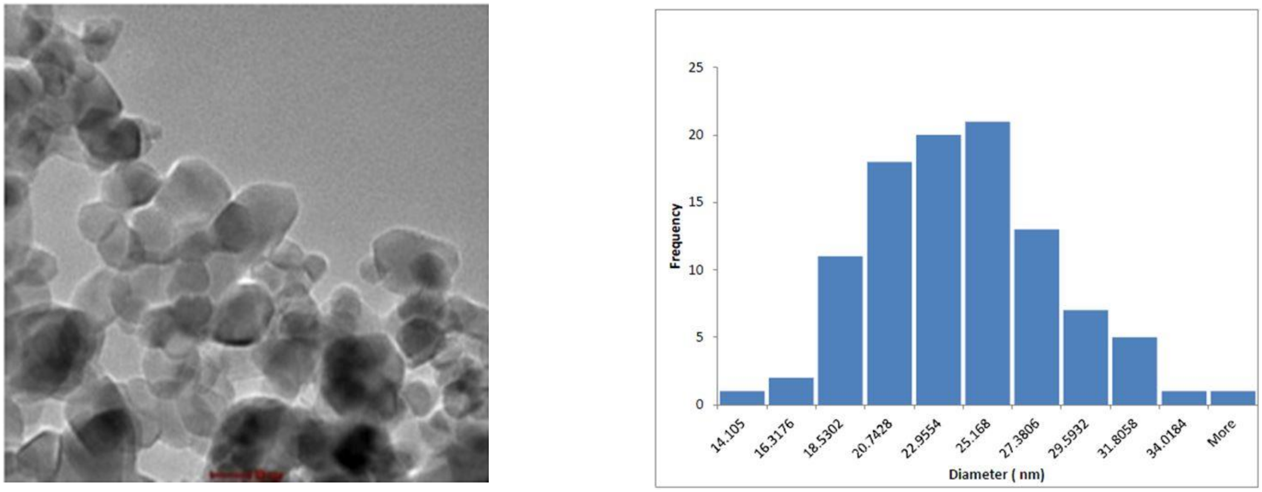
The viscosity index was measured and illustrated in Figure 3. It represents how fast the viscosity change with temperature. Viscosity index of pure palm oil without any nanoadditives is 202.2. The values decreased to 151.7 and 154.2 for samples Lub1 and Lub2. A slight increment to 164.3 was measured when the percentage of nanoadditives was increased to 0.2%. The Lub1 produced the lowest viscosity index, and the highest was obtained from the Lub0. This indicates that the Lub0 has less viscosity change when temperature increased thus better resistance to thinning..

3.3 Coefficient of Friction

Measured coefficient of friction (COF) is plotted in Figure 4. Lub2 showed the lowest value for COF which is 0.11. It is lower than Lub1 which was measured to be 0.13. COF value was then decreased to 0.10 at weight percentage of 0.1 (Lub3) before rising higher than Lub0 to 0.12 (Lub3). The calculated value of COF of base oil (Lub0) is 0.11. The result in Figure 3 can be explained by the possibility of that the Lub1 has less viscosity at temperature of 100°C and lubricated better than other samples. The low viscosity index of the Lub1 explained how rapid the sample can reduce its viscosity when the temperature increased. This condition improved the lubrication properties.

3.4 Wear Scar Diameter

Figure 5 shows the typical wear scars for each samples under magnification of 100k. Summary of measured wear scar diameters is plotted in Figure 6. Based on the measurements, the Lub2 showed the lowest value of wear scar volume at 0.08 mm^2. While the highest value of scar volume was 0.11 mm^2 for Lub1 and Lub3 samples. The results obtained are in agreement with the obtained values of COF in Figure 4.



(a) (b)

Figure 1 (a) Micrograph of nanoadditives and (b) size distributions

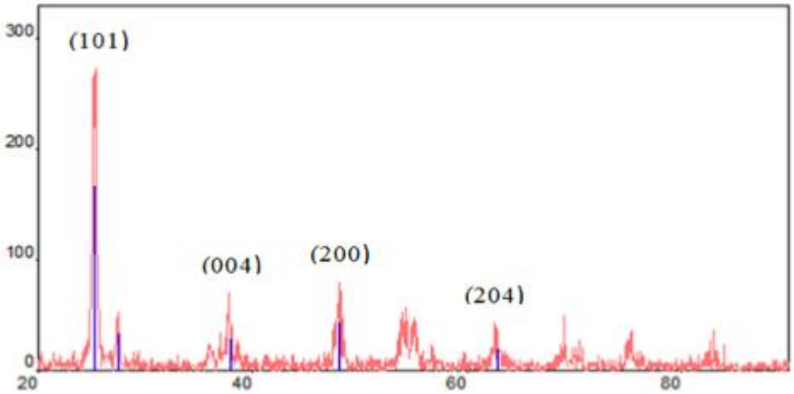


Figure 2 XRD spectrum of nanoadditives

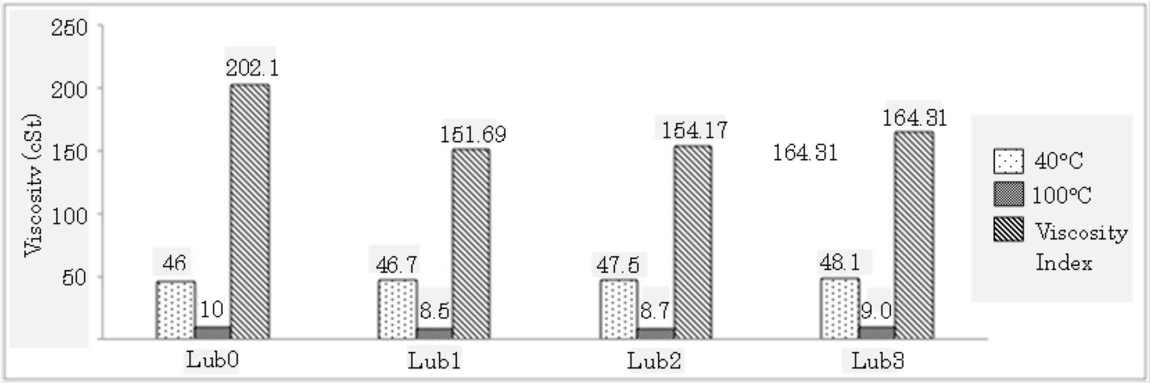


Figure 3 Changes of Viscosity and Viscosity Index for all samples

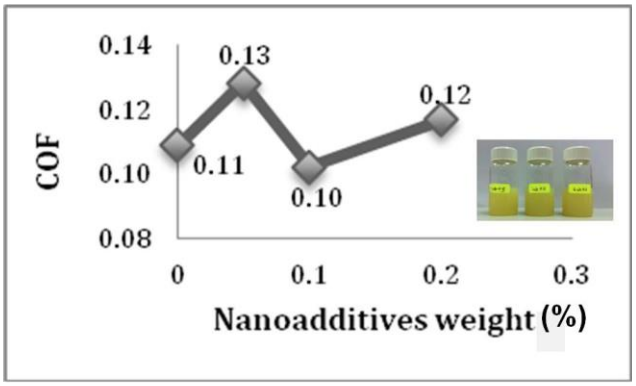


Figure 4 Friction coefficient for samples for different additives weight percentage

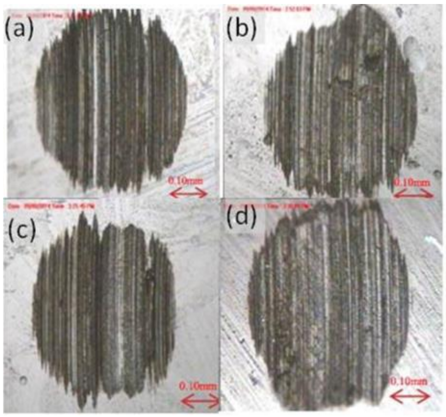


Figure 5 Measured wear scar volumes for all samples

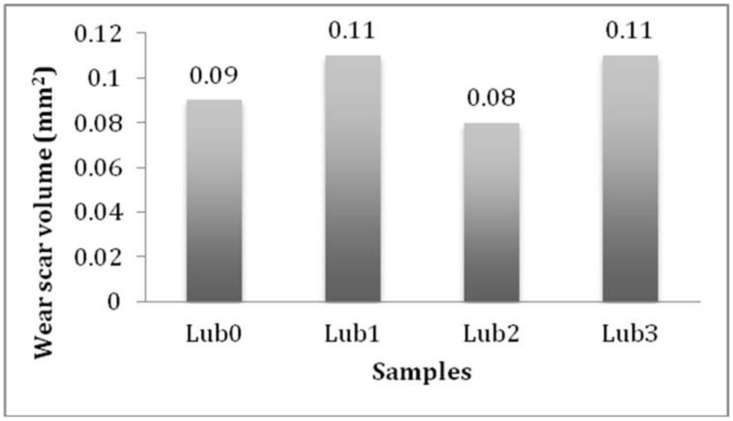


Figure 6 Typical wear scars for each samples under magnification of 100k

4.0 CONCLUSION

Based on the results obtained in this work, the following conclusions can be made:

1. Nanoparticle TiO_2 as additives has slightly improved the lubricating properties of palm oil biolubricant. The Lub1 produced the optimum tribological performance and lowest friction coefficient compared to the other samples.
2. The viscosity of biolubricant reduced significantly with the existence of nanoadditives. Viscosity increased as the nanoadditives percentage increased at a lower temperature of 40°C, but decreased at 100°C.

Acknowledgement

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