Tribological Effects of Additive Hybrid ZrO_2/Al_2O_3 in Bio-Lubrication

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ABSTRACT

Bio-based oil application has increased dramatically in the lubrication industry as an alternative to conventional petroleum-based oil. Due to a huge demand towards sustainability, it is extremely important to make an effort in promoting alternative for synthetic bio-lubricant as an alternative to synthetic oil. In this study of, tribological properties the palm oil, bio-lubricant modified with hybrid of ZrO_2/Al_2O_3 micro-particles as an additive was investigated. The additives was mixed using ultrasonic vibrator to ensure homogenous mixing and consistent characteristic. The tribological performance was investigated using a pin on disk at different loads of 5 kg, 10 kg, 15 kg and 20 kg. It was tested at different weightage percentages of micro-additive varied between 0.1 to 1 wt%. Tribological testing was conducted to obtain the performance of ZrO_2 micro-particle, Al_2O_3 micro-particle and hybrid of ZrO_2/Al_2O_3 micro-particle. It was observed that the coefficient of friction (COF) for zirconia (ZrO_2) and alumina oxide (Al_2O_3) was found to be the lowest at 0.1 wt%.

Keywords: *Bio-Lubricant, Additives, Tribology, Wear, Friction*

Introduction

Concerns on climate change and exhausting petroleum oil source have become a great concern nowadays [1]. Many researches were done to overcome the problem of lubrication fluid that contributes to environmental pollution. Substituting the usage of petroleum based oil in the lubrication system by other lubrication oil has been one of the options to solve the problem. Lubricants are applied on the engine components which when in

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contact can reduce friction and wear. From previous research, it was indicated that the proportion of energy output of fuel in a car engine breaks down into exhaust, cooling agent and mechanical energy system [2].

The use of conventional lubricants, which is petroleum based oil, has risen up the environmental and toxicity issue for over a century. About 50 % of the lubrication oil that we utilize every day will end up in the environment through oil spill from the system, volatility of the oil, and improper disposal of them. In order to replace the usage of petroleum based oil in our lubrication system, another alternative which is eco-friendly and biodegradable lubrication has been developed from bio based oil or vegetable based oil as a new lubrication based medium. The properties of lubricant play a prominent role to fulfill the desired requirements of the engine. Lubricants which have certain properties were designed based on their operating conditions. In order to improve the lubricant performance, additive is added, as it may enhance the properties of the base fluid or develop a new property.

The production volumes of palm oil worldwide from 2012/13 to 2016/17 are shown in Figure 1 [3]. In 2015/16, the global production volume of palm oil amounted to 58.83 million metric tons. Malaysia has grown rapidly throughout the years to become the world’s largest palm oil exporter. In 2003, it was reported that Malaysia’s production of palm oil has contributed about 49 % of world supply and also 8.9 % of the major oils and fats product [4]. With higher performance as a lubricant and lower price compared to crude oil with plenty of source, the palm oil has been the best option to replace mineral oil as lubricant base oil. Apart from its domestic uses, palm oil has also been used as a replacement for biodiesel. Its potential as fuel for hydraulic fluid, diesel engine, and lubricants has been confirmed in many previous studies. A study by Cheenkachorn [5] proved that palm oil exhibits superior tribological performance compared to mineral oil, SAE 40. Masjuki *et al.* (1999) [6] found that palm oil has better performance on wear rate and more effective in reducing the emission levels of carbon monoxide (CO) gas and hydrocarbon (H-C) into the air in internal combustion engine. The wear of the part is resisted by palm oil because its fatty acid contains thicker molecular layer. Thicker layer contributes an advantage to the palm oil to reduce the wear efficiently.

To enhance the properties of bio based oil physically and chemically, an additive was added into the bio based lubrication to improve its properties [7]. Examples of nanoparticle usually used as additives in bio-lubricants are Zirconia (ZrO_2) and Alumina (Al_2O_3). Previous study showed that both elements are able to improve the tribological properties of the bio-lubricant [8-10]. Thus, this paper will study the effect of hybrid zirconia and alumina additives to the tribological properties of palm oil at different loads.

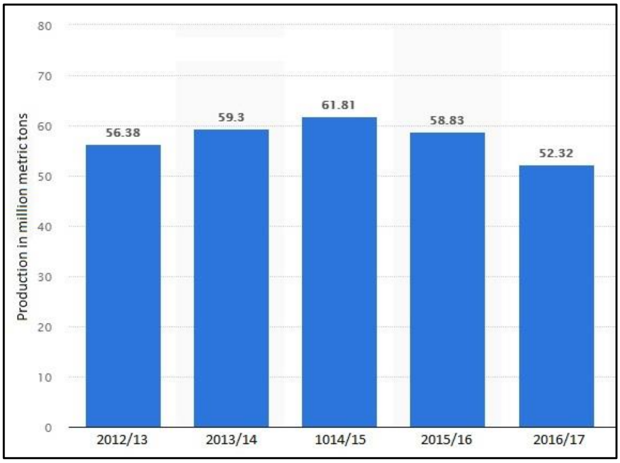

Figure 1. Production volume of palm oil worldwide from 2012/13 to 2017/18 (in million metric tons)

Experimental

Hybrid zirconia and alumina micro particles with an average size of 200 µm were mixed with palm oil and shaken by using an ultrasonic vibrator to ensure homogeneous dispersion of mixture without agglomeration. Tribological characterize performance of bio-based hybrid lubricants was conducted by pin-on-disk at room temperature. Aluminum was used as a pin and cast iron material as a disc.

Table 1. Pin on Disk Testing Parameter

Parameter	
Rotating Speed	1500 rpm
Load	(5, 10,15,20) kg
Duration	1 hour
Based Oil	Palm Oil
Additives	ZrO_2/Al_2O_3

The aluminum pin has a hemispherical shaped tip with a dimension of 8 mm in diameter and 50 mm in length. The disk used to be 70 mm in diameter and 8 mm in thickness. Three types of tests were run, namely: 1) test for bio-lubricant mixed with zirconia micro particle at 0.1 %, 0.5 % and 1 % of weighted percentages; 2) test for bio-lubrication mixed with alumina micro particle at 0.1 %, 0.5 % and 1 % of weighted percentages; and 3) test for bio-lubricant mixed with hybrid micro particles. The test was conducted at 10 kg load and 1200 RPM speed to choose the optimum percentage of particle for the lowest friction coefficient. In the case of bio-lubricant mixed with hybrid of alumina and zirconia, different loadings (10 kg, 15 kg and 20 kg) were used at 1200 rpm speed. The summary of the test is given in Table 1.

Results and Discussion

Coefficient of friction at different ZrO_2 percentages is shown in Figure 2. Adding 0.1 wt% of zirconia to the palm oil tends to decrease the COF to 0.0234. However, the increase in weighted percentage of the zirconia micro particles also increases the COF of the lubricant compared to the pure palm oil. In 0.5 wt% of zirconia, the COF is 0.0721 and at 1 wt% the COF is 0.0736. The COF of pure palm oil has been improved by 30% with the addition of additives into the pure palm oil.

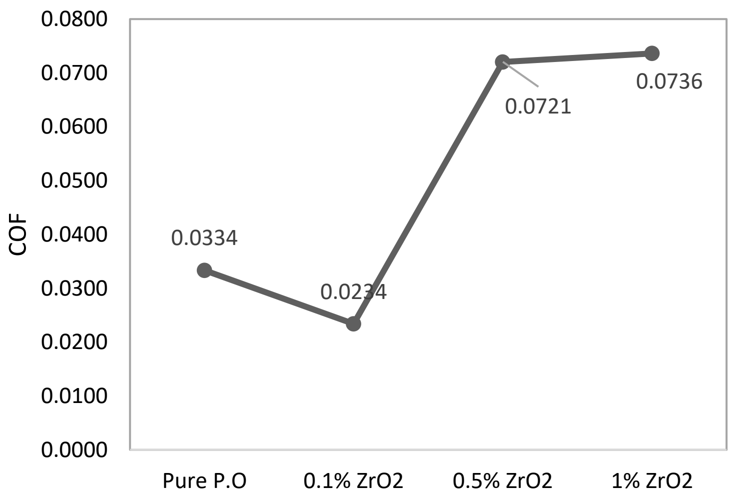

Figure 2. Coefficient of friction for zirconia micro particle

From Figure 2, it shows that the optimum performance occurred when mixing ZrO_2 at 0.1 weight%. Its COF is better compared to pure palm oil. From this result, the amount of microparticle at 0.1% is sufficient to make the contact surface separated with the opposite surface because 0.1 out% microparticle has created sufficient pressure to separate the tribe surface as the surface tends to collide within them. Figure 3 shows the sample of ZrO_2 used.

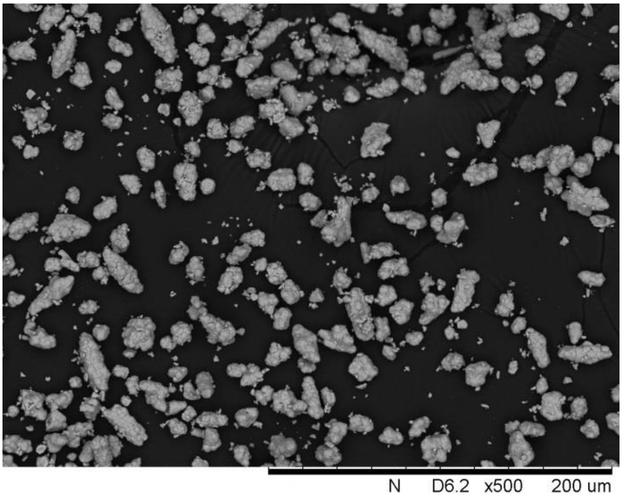

Figure 3. SEM micrograph of zirconia

A study by H. Kato [11] found that tribofilm was produced by sintering the supplied oxide particles, thus, mild wear appeared on the surface of friction. Li *et al*. (2011) [12] stated that at optimum concentration of nanoparticle additives, the particle went into the friction zone and converted the sliding effect to rolling effect. If more additive is added into the bio-lubricant oil, the particle will be sintered into a block of particle and it will scratch the surface and increase the COF values.

Increasing weight percentage of micro particle concentration has increased the COF value. Referring to 0.5 wt% and 1.0 wt% of zirconia, the COF value is way larger compared to the pure palm oil. Luo *et al*. (2014) found that higher additive concentration would make agglomeration of nanoparticle and chemical condensation between particles to appear [13]. Increase in particle additive in lubricating oil has made the particle to collide within each other. When compared with optimum concentration additives, the particle not only fills the asperities valley, but it overflows the surface of friction. Thus, the collision between particles has increased the force that resists the motion.

Another test for pin on disk is by adding alumina micro particles in the palm oil at 0.1 wt%, 0.5 wt% and 1 wt% concentrations. However, adding the micro particles does not improve the COF of the lubricant, but increases the COF performance as shown in Figure 4. The COF for 0.1 wt% Al_2O_3 is 0.0532, for 0.0646 for 0.5 wt% Al_2O_3, and 0.00557 for 1 wt% Al_2O_3.

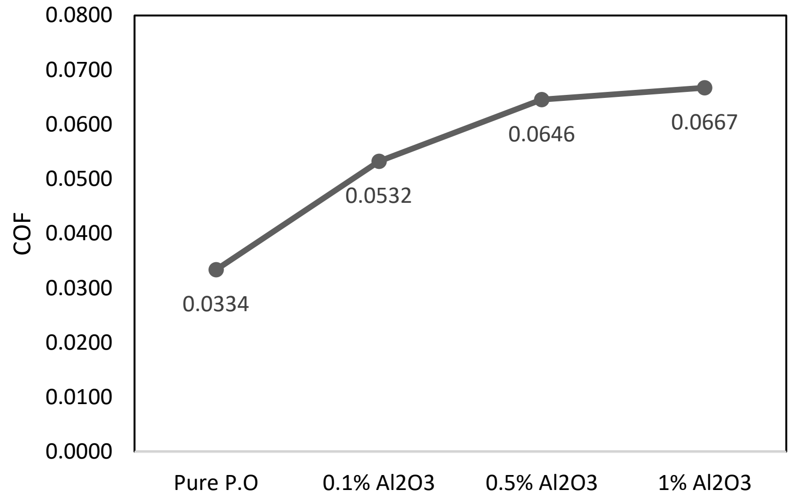

Figure 4. Coefficient of friction for alumina micro particle

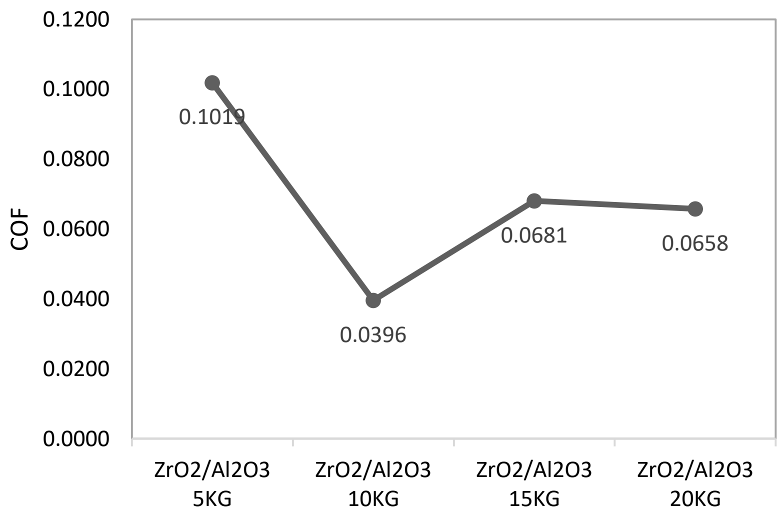

Figure 5. Coefficient of friction for hybrid of ZrO2/Al2O3 micro particle

Based on the discussion in the literature value, the alumina particle is coarse and fine-grained. This is the reason for the increase of COF which is due to the difference in size of particle that contributes to higher frictional force. The particle in the lubricant flows with the lubricating oil in the lubricating system as it is being pumped. As it lubes the machine element, the particle creates a pressure with the lubrication film to prevent friction between two surfaces. However, because of size differences in alumina particle, they collide with each other. The larger particle makes the film thickness more abrasive. Besides that, fine particle that fills the asperities valley may be blocked by larger particle. This situation has created an agglomerate of particle on the surface. So, the surface becomes rougher due to the agglomeration of particle on the surface of contact.

Hybrid zirconia and alumina at a concentration of 0.1 % was mixed with bio-lubricant. Coefficient of friction for hybrid zirconia and alumina is shown in Figure 5.

The result shows fluctuating values of COF as the load increases from 5 kg to 20 kg. Zulkifli *et al*. (2013) [14] found that the COF increases as the load is increased. Thus, 5 kg load should produce lower frictional force compared to 20kg load. However, the outcome of the test is not as expected. There are a few factors that may cause the fluctuation of the result. First, Zirconia and alumina have different shape and also particle size. From the previous research, for hybrid particle, both particles need to be synthesized together so that the particles are bonded together and form a composite particle. Thus, the size and the shape after the synthesis process are more uniform. Non-uniform shape and size of the particle make the hydrodynamic pressure builds up not evenly along the testing process. Uniform hydrodynamic pressure is important to make sure the surface is not in contact with each other at all times.

A study conducted by Li *et al*. (2011) [12] on the particle behavior in base oil found that the particle agglomerated for the unmodified nanoparticle. However, for modified nanoparticle, the particle is well dispersed and has uniform size compared to unmodified particle. The particle also does not show any precipitated sign after being left for the duration of time. A study conducted on Al_2O_3/ TiO_2 by Luo *et al.* (2014) [13] found that for unmodified hybrid particle, the particle shows the obvious agglomeration phenomenon compared to modified particle which is well dispersed in the based oil with more spherical shape. Jiao *et al.* (2011) [15] also agreed that modified nanoparticle has better dispersion compared to unmodified hybrid particle. Based on the result, it shows that the mixed particle is agglomerated and not well dispersed in the based oil. Agglomerate particle has created a block of particle and deposited on the friction surface. Thus, the COF increases due to the friction in between the surface and the particle. Not well dispersed has made the particle not evenly distributed in the oil. As the oil flows into the friction surface, the load carrying capacity given by the particle is not the same at all times. Due to that condition, we can see from the result that the COF fluctuate with the increase of load.

Conclusions

The pin on disk test shows that the best concentration for zirconia and alumina particles is at 0.1wt %. Further increase in particle concentrations may result in an increase of COF and also increase in wear track size. Based on the result of hybrid of ZrO_2 / Al_2O_3 as additive, the coefficient of friction result fluctuates with the increase in load. From the research, we can conclude that non-modified hybrid particle agglomerates and is not well dispersed in the based oil. Not well dispersed in the based oil makes the load carrying capacity given by the particle not the same at all time.

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