Investigating The Tribological Performance of Natural Rubber Additives in Palm Oil-Based Lubricants

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Abstract

Human dependence on mineral-based energy sources poses challenges related to toxicity, depletion, degradation, and environmental hazards. An appropriate replacement for mineral-based lubricants has yet to be realized; one available option for humans is alternative, renewable, environmentally friendly, and biodegradable energy sources. Lubricants play an important role in product processing, transportation, agriculture, and other key sectors in industrial development. This study was conducted to explore the potential use of palm oil as the main ingredient with the addition of rubber as an additive. The method of making the lubricant involved mixing 3%, 5%, and 7% rubber latex with sonicated palm oil using UAE. Next, wear testing was performed using a tribometer based on the ball-on-disc principle, utilizing a modified bench-top drill machine. The testing was carried out at room temperature, maintaining a constant load of 8.83 N and a rotational speed of 180 rpm for 5 minutes per sample. Microscopic analysis of the wear scars on the plate samples showed different wear patterns and characteristics for each lubricant, with measurements taken at various positions for accuracy. The results indicated that the lubricant with a 5% rubber mixture was the best, with a wear width of 535.9126 µm, compared to the commercial lubricant (SAE 15W 40) which had a wear width of 539.906 µm. This research demonstrates the potential use of a palm oil and rubber mixture as a more environmentally friendly lubricant alternative.

Kata kunci: Palm oil, Tribometer, friction wear, Ball-on-disk

Abstrak

Ketergantungan manusia terhadap sumber energi berbasis mineral menjadi sebuah tantangan terhadap toksisitas, penipisan, degradasi, dan bahaya lingkungan. Pengganti yang tepat untuk menggantikan pelumas berbahan dasar mineral belum dapat direalisasikan, salah satu pilihan yang tersedia bagi manusia adalah sumber energi alternatif, terbarukan, ramah lingkungan, dan dapat terurai secara hayati. Pelumas menjadi penting dalam pemrosesan produk, transportasi, pertanian dan bidang penting lainnya dalam pengembangan industri. Penelitin ini dilakukan dengan melihat potensi penggunan minyak sawit sebagai bahan utama dengan penambahan karet sebagai aditif tambahan. Metode pembuatan pelumas yaitu dengan mencampurkan sebanyak 3%, 5%, 7% getah karet ke minyak sawit yang disonikasi dengan menggunakan UAE. Selanjutnya Pengujian keausan menggunakan tribometer yang didasarkan pada prinsip ball-on-disc ini menggunakan mesin bor bench-top yang dimodifikasi. Pengujian dilakukan pada suhu ruangan, dengan mempertahankan beban konstan pada 8,83 N dan kecepatan putaran 180 rpm selama 5 menit per sampel. Analisis mikroskopis terhadap bekas keausan pada sampel pelat menunjukkan pola keausan dan karakteristik yang berbeda untuk setiap pelumas, dengan pengukuran yang dilakukan pada berbagai posisi untuk keakuratannya. Hasil menunjukkan bahwa pelumas dengan campuran karet 5% merupakan yang terbaik dengan lebar keausan 535,9126 µm dengan perbandingan pelumas komersil (SAE 15W 40) sebesar 539.906 µm. Penelitian ini membuktikan potensi penggunaan campuran minyak sawit dan getah karet sebagai alternatif pelumas yang lebih ramah lingkungan.

Kata kunci: Minyak kelapa sawit, Tribometer, uji keausan, Ball-on-disk

1. Introduction

The need for lubricants increases along with the increasing use of vehicles and industrial machines. Most lubricants used today are not environmentally friendly and have a negative impact on the ecosystem. Lubricant formulations based on conventional fossil energy sources face many challenges, such as toxicity, non-biodegradability, and increasing costs due to global environmental damage [1]. The level of fossil oil consumption exceeds the natural growth of its deposits, so alternative energy solutions are needed. Additionally, plant-based materials are more than 95.00% biodegradable and decompose 20-30% faster when compared to mineral-based materials. [2]. To maintain the stability of Indonesia's energy availability, it is necessary to look for alternative energy sources to replace petroleum that are renewable, environmentally friendly and come from nature to encourage further research in the field of biolubricants. From an economic perspective, investment in biobased lubricating oil has high relevance for developing countries, especially where agriculture is considered the largest economic driver [3].

The choice of lubricant is important because of the quality and performance of the engine [4]. The lubricant formulated depends on the type of base lubricant, the processing method used and the type and quality of the mixture used. Vegetable oils were found useful as starting materials in the production of special lubricants [5]. Some of the vegetable oils that are often used as the main ingredients for lubricants are: palm oil, coconut oil, castor oil [6]. The production of vegetable oil itself cannot be separated from the availability of raw materials. Indonesia, especially palm oil, is one of the largest suppliers of vegetable oil production [7].

Vegetable-based lubricants or commonly referred to as biolubricants act as anti-fixing agents that make work easier while reducing the risks associated with engine failure and maintaining optimal engine operation. Lubricants from vegetable oils provide good effects on heat exchange between surfaces, lubrication, corrosion inhibitors in engines and power transmission. Lubricants based on vegetable oils have superior lubrication properties, high viscosity index and excellent flash point [8].

The main use of biolubricants is to provide optimal viscosity, thermal stability and resistance to oxidation, protect contact surfaces from corrosion, minimize wear and improve engine performance [9]. The characteristics of vegetable oil as a lubricant have several advantages compared to mineral oil, such as environmental friendliness, renewable properties, low temperature variations, and good lubrication properties at the lubrication range limit [10]. In making lubricating oil, palm oil can be used as a base oil, then rubber latex can be used as an additive to increase viscosity [10].

In this research, an experimental study was carried out to analyze several tribological characteristics, namely wear on materials lubricated with lubricants made from palm oil with mixed variations of 3%, 5% and 7% rubber latex as an additive and compared with commercial oil SAE 15W 40. Two types Lubricants were used in this study to determine the effect on the shape of scratches and material loss that occurs. Specific wear of the test material consisting of ball bearing steel in the lubricant medium under test, to assess the tribological characteristics of the lubricant [11]. The wear rate of metal materials is calculated by measuring the loss of material wear on specimens that rub together using a tribometer test tool [12] Dimensional measurements of wear tracks were obtained from microscope photos [13]. Lubricant testing uses many types of tribometers, namely: Four ball tribometer [14], tribometer pin-on-disc[15] and tribometer ball on disc [16] by varying speed and load [17], So, from this research, testing was carried out on the potential use of lubricating oil products made from palm oil with commercial oil SAE 15W 40. A strong correlation was observed between the anti-wear properties of the oil with additives, their solubility and the additive content in the base oil. This confirms the high information value of the chosen research method [18].

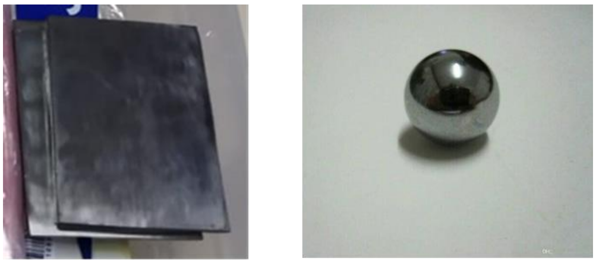
2. Research materials and methods

The lubricant sample uses palm oil mixed with rubber latex as an additive to neutralize the acid in palm oil which acts as a neutralizer, this has the effect of increasing lubrication power, protecting and maximizing vehicle engine performance [19]. In this research, oil samples were made from a mixture of palm oil and rubber latex. Lubricating oil consists of 80-90% based oil and 10-20% additives [20]. The percentage of coconut oil added to SAE 40 mineral oil was varied and the effect on its physical and tribological properties was observed [21]. Samples of vegetable lubricant products were compared with commercial lubricants to see the quality of the wear test. The following is Figure 1. A sample of palm oil lubricant with a mixture of 3%, 5% and 7% rubber.

(a) (b) (c)

Figure 1. Palm oil 3% rubber : (a) Palm oil 5% rubber: (b) Palm oil 7% rubber

Lubricant products are tested using a ball on disc tribometer [16] using samples of 10 mm diameter stainless steel balls and stainless steel plates. The part to be studied is the part that has scratches on the surface of the plate. The plate will be cut to size to suit the lubricant tank. The test specimen used in this test was a square 304 stainless steel plate with a side length of 7 mm and a thickness of 3 mm as shown in Figure 2.



(a) (b)

Figure 2. 304 stainless steel plate specimen: (a) stainless steel ball: (b)

The lubricants used in this test included several variations of palm oil lubricants with mixtures including 3%, 5%, 7% rubber latex and machine oil (SAE 15W 40). A modified ball-on-disk test was developed to identify the tribological characteristics of the plate surface using various types of lubricants. The design of the tribometer test equipment is based on the ball-on-disk test principle [22]. This is illustrated in Figure 3 regarding the initial process which is carried out by placing a 10 mm stainless steel ball in the drill chuck that has been designed. Then at the location of the table on the drilling machine, a tub containing lubricant is positioned along with a 304 stainless steel sample plate mounted on a stand at one end. The testing process was carried out at room temperature using the four types of lubricants. Wear tests of the pins on the disks were carried out at different speeds and loads at constant distances [23]. The constant load used was 8.83 N and moved at a speed of 180 rpm for 5 minutes and use room temperature[24] for each sample. This affects the rubbing surfaces to be closer to each other and increases surface contact between surfaces, to see more clearly the ball-on-disk test equipment can be seen in Figure 3.

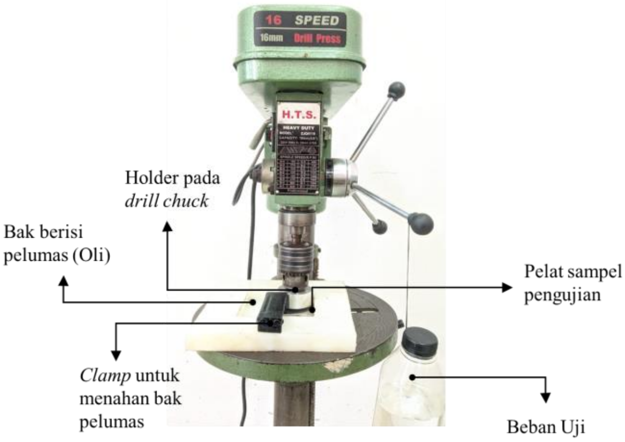


Figure 3. Modified drilling machine

After the testing process, measure the wear marks on the steel plate using an optical microscope [25]. However, it was found that to ensure the accuracy of the wear marks on the plates, wear mark measurements on the samples were taken at 5 positions. Limitations of the equipment used in this research do not allow CoF (Friction Coefficient) measurements [16]. This scar-focused analysis is sufficient to provide general insight into the ability of lubricants to reduce wear. Combined with topographic measurements, scars are best performed using optical methods, due to the short measurement time [26] and widely available in university laboratories or research institutions, the ball-on-disk tribometer method provides substantial results that will assist researchers in developing or analyzing potential lubricant wear behavior.

In ball-on-disc testing, the profile area and maximum wear depth provide a useful quantitative assessment of disc wear [27]. Analysis of scratch marks provides previous qualitative information. The authors believe that by combining wear trace analysis with optical microscopy, they can gain comprehensive insight into wear mechanisms and protective features of lubricants, which can inform the development or selection of lubricants for specific applications. Although CoF measurement is a suitable parameter for lubricant evaluation, especially in the initial evaluation and screening process in lubricant research and development, methods using scar analysis and optical microscopy are reliable and cost-effective.

3. Results and Discussion

Some of the analyzes carried out in connection with this test include modifying the ball-on plate to observe wear on the surface of the plate by using four lubricants or four grades of oil to determine the extent to which its properties can rub against the surface of the plate. This test was carried out to determine the performance of the lubricant as well as the success of the method used on the equipment and the viscosity level of the lubricant (including four types of lubricant such as commercial oil (SAE 15W 40) rubber palm oil as an additional ingredient at 3%, 5% and 7%). During testing, tool speed, load and viscosity are kept stable and constant for maximum results. The measured friction results are observed, examined and analyzed under a microscope to determine the width of the friction and the degree of wear that occurs. Profile areas can be used when the scratch marks profiles are similar to each other [26] this allows data from the friction path geometry to be used as insight into the wear properties of materials subjected to friction.

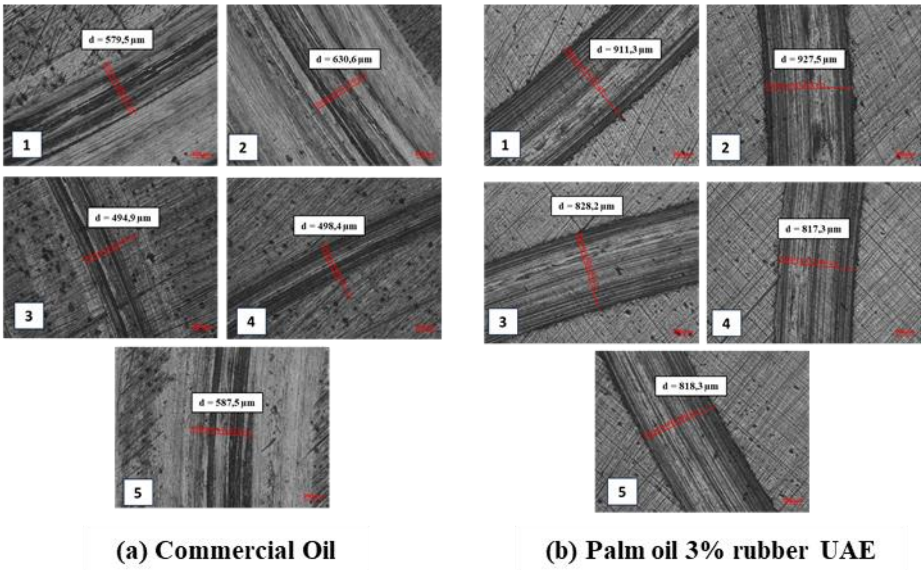


Figure 4. Commercial Oil: (a) Palm oil 3% rubber UAE: (b)

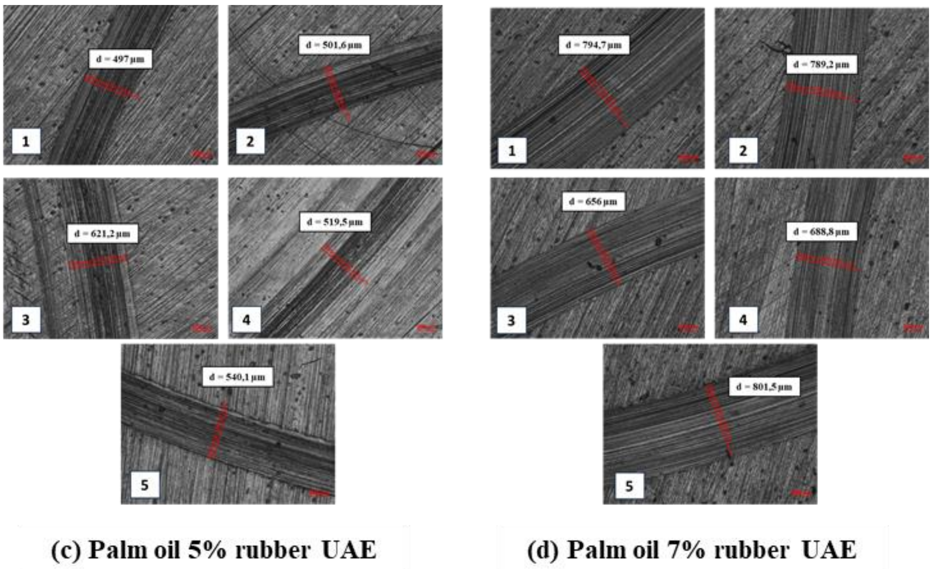


Figure 5. Palm oil 5% rubber UAE: (a) Palm oil 7% rubber UAE: (b)

The results of observations using a microscope during wear tests on SAE 15W 40 engine oil as a lubricant are shown in Figure 4 (a). Palm oil lubricant with a mixture of 3% rubber is shown in Figure 4 (b) and palm oil lubricant with a mixture of 5% rubber. shown in Figure 5 (a) while palm oil lubricant with a 7% rubber mixture is shown in Figure 5 (b). These photos provide important visual information regarding the shape of the wear pattern and surface characteristics on the effect of SAE 15W 40 engine oil and palm oil as a lubricant in 5 different positions. It is clear that the wear track formed from SAE 15W 40 engine oil shows a relatively rough surface with signs of lines forming a track pattern. The visible form of wear is that the wear path on palm oil lubricants is smoother with small signs of abrasion, this is indicated by the thickness of the lines that form a circular pattern. [28]. The wear mode seen on commercial oil and palm oil lubricated contacts is a combination of abrasive and adhesive wear, where signs of adhesive wear are more prominent on palm oil and can be seen from black spots on the wear lines.

After obtaining visual information, quantitative measurements of wear dimensions obtained from microscope photos are collected in the form of data for a detailed assessment of the level of wear and the level of material loss during the testing process. This quantitative analysis provides important information regarding the performance of the lubricant and its ability to reduce excess friction on the plate surface. Another investigation was carried out with palm oil as a lubricant in track wear tests.

The observation results show a different trajectory pattern for palm oil lubricants. Upon closer inspection, it is clear that palm oil lubricant shows slightly different wear characteristics compared to engine oil. This difference can be seen from the scratch marks formed by palm oil mixed with 3% rubber, which have relatively slightly rough surface characteristics and thicker lines at the edges of the track. Palm oil lubricants with a 5% rubber mixture are characterized by smoother wear tracks and smaller track widths compared to other lubricants. Meanwhile, the characteristics of the wear traces found in palm oil lubricants with a mixture of 7% rubber are smoother than other lubricants. Wear traces formed by palm oil lubricants show a lower level of surface hardness compared to commercial lubricants. From this point of view, it can be concluded that palm oil offers a relatively good level of wear protection similar to engine lubricants in these particular conditions.

These results highlight the importance of considering specific applications and operating conditions when selecting lubricants to ensure optimal equipment performance and life. Palm oil abrasion testing, like engine oil testing, is conducted under controlled conditions to ensure consistent parameters for fair comparisons. Experimental evidence shows that these proposed parameters can evaluate the working range and extreme pressure of anti-wear additives in lubricating oils and differentiate their effectiveness. This allows a comprehensive evaluation of the tribological properties of palm oil and facilitates decision making regarding the application of palm oil in various mechanical systems. The results of mechanical test observations regarding track width provide a parameter for comparing lubricants with each other, we can see this in Figure 6 regarding the width of track wear on the plate.

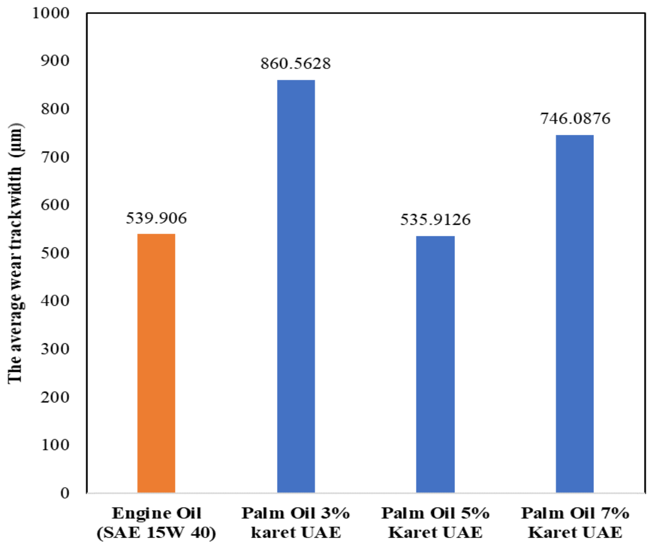


Figure 6. Average wear track width for each lubricant

Figure 6 shows the average width of track wear for each different lubricant, including SAE 15W 40 engine oil and a mixture of palm oil lubricant with rubber latex. The report results from the SAE 15W 40 engine oil showed track wear of 535.906 µm, palm oil lubricant gave scratch marks of 860.5628 µm with a 3% rubber mixture while palm oil lubricant mixed with 5% rubber experienced track wear of 535.9126 µm and coconut oil lubricant the 7% rubber mixture experienced track wear of 746.0876 µm. The results show that the smallest track wear marks are on palm oil lubricant with a mixture of 5% rubber. The width of the wear traces in palm oil lubricant with a 5% rubber mixture is 535.9126 µm, close to the value in SAE 15W 40 engine oil of 539.906 µm [28].

There are several standard test methods for determining the amount of material removed. The wear volume can be calculated from an equation based on the shape of the scar [26]. According to (ASTM G99-17, 2020) the volume loss at the pin and disk is obtained through the following equation:

Loss of pin volume $= (\pi h/6)\left[3d^2/4 + h^2\right]$ (1)

Loss of disk volume $= 2\pi R\left[r^2 \sin^{-1}(d/2r) - (d/4)(4r^2 - d^2)^{1/2}\right]$ (2)

Where $h = r - \left[r^2 - d^2/4\right]^{1/2}$, d = wear scar diameter (µm), r = pin tip radius (mm), R = worn track spokes (mm), d = worn track width (mm). Understandably, the volume loss is proportional to the width of the wear track shown in Figure 6. The calculated values for the pin and disk sides respectively are presented as graphs in Figure 7.

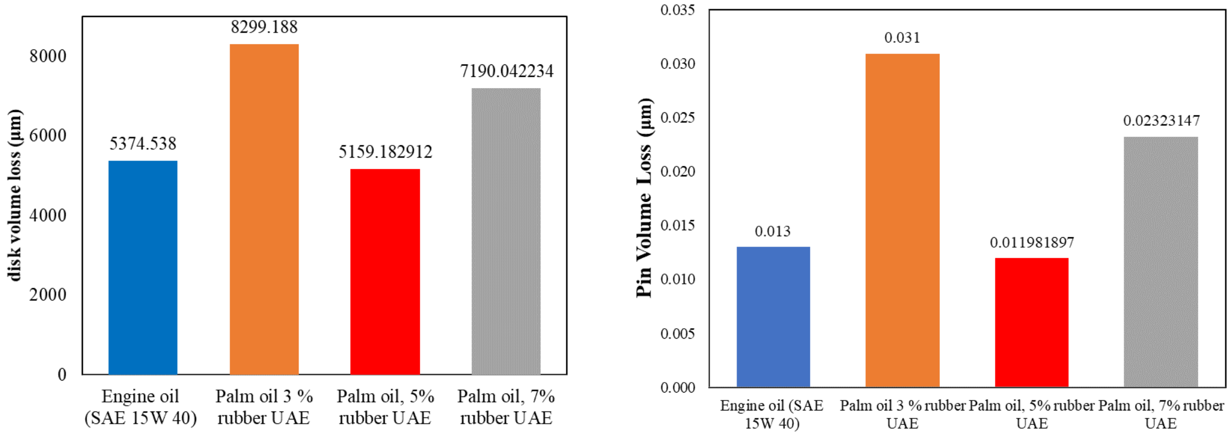


Figure 7. Loss of pin volume: (a) Loss of disk volume: (b)

Report from Figure 7(a) and (b) pin volume loss on the SAE 15W 40 engine oil experienced material loss of 0.013 µm and material loss on the plate of 5374.538 µm. In lubricants made from palm oil with a mixture of 3% rubber, UAE experienced material loss on the pin of 0.031 µm and material loss on the plate surface of 8299.188 µm. Palm oil lubricant with a mixture of 5% UAE rubber latex experienced material loss on the pin of 0.01198 µm, the plate surface experienced material loss of 5159.1829 µm. In the last sample, palm oil lubricant with a mixture of 7% UAE rubber experienced material loss on the pin of 0.02323 µm and experienced material loss on the plate of 7190.0422 µm. The scratches of each disc are carefully observed using a hardness profiler to ensure there is no wear or particles on the disc surface that could affect the results [29].

The results of narrower scratches and consequently less material loss from observations of palm oil lubricants with a 5% rubber mixture indicate good lubrication and protection against friction on the plates compared to machine oil and other palm oil lubricants. This finding is consistent with visual analysis in the form of photos from microscope photos, where palm oil lubricant with a 5% rubber mixture shows wide traces of wear on the track and minimal signs of abrasion as well as an indication of the ability to reduce friction and prevent excessive material loss.

Palm oil, especially when used in cooking, as used in this study, shows some ability to reduce material loss and scratches. The ability of palm oil lubricants is able to equalize engine oil lubricants to reduce wear on materials. It shows better anti-friction characteristics resulting in low scores for all [29]. The wide scratches found in palm oil lubricant with rubber mixture are caused by the composition of the lubricant material and the properties of the lubricant, which may not be optimized for this particular wear test.

The difference in wear track width between engine oil and palm oil lubricant provides important information on lubricant selection in various applications, this is according to load conditions and operational requirements, engine lubricants may be preferred for applications where wear and friction need to be minimized to ensure equipment life and efficiency.

4. Conclusion

The results of testing SAE 15W 40 engine lubricant and palm oil with a mixture of 3%, 5% and 7% rubber using a modified tribometer device using an improvised drilling machine showed success in detecting wear marks on engine oil and palm oil. Microscope photo analysis shows different wear patterns and characteristics for each lubricant, which shows the lubricant's ability to reduce friction and different wear resistance.

The results show that lubricants made from 5% rubber palm oil show better performance compared to SAE 15W 40 engine oil and other palm oil lubricants. This is proven by the smaller average wear trace width, namely 535.9126 µm, which indicates better lubrication and protection against friction. Engine oil shows a wider average wear track of 539,906 µm, which shows its limitations in reducing friction and poor lubrication.

An important conclusion from the above research is that ball-on-disc tribometer testing provides highly reproducible results. Therefore, the use of ball-on-disk tribometers in the compatibility testing of palm oil-based and commercial vegetable lubricants provides reliable information regarding the selected research field by modifying the studies on the tests, thereby obtaining precise data, reducing financial and time costs for controlled use.

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