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Wear evaluation of palm oil and SAE 15W 40 engine lubricants with a ball-on-disk tester based on an improvised drilling machine

D.G.C. Alfian*, D.J. Silitonga, F.M.A. Machzumy, F. Oktaberi, L. Triawan
Study Program of Mechanical Engineering, Department of Technology, Production and Industry, Institut Teknologi Sumatera, Jl. Terusan Ryacudu, Way Huwi, Kec. Jati Agung, Kabupaten Lampung Selatan, Lampung 35365. HP. 082281406065
*E-mail: devia.gahana@ms.itera.ac.id

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ABSTRACT

This paper introduces a modified ball-on-disk test, utilizing a drilling machine, to investigate the tribological behavior of wear on a plate surface under various lubrication conditions. The tribometer, based on the ball-on-disc principle, employs an improvised bench-top drill press machine. Despite its simplicity, it effectively facilitates wear-track experiments using engine oil (SAE 15W 40) and palm oil as lubricants. Tests are conducted at room temperature, maintaining a constant load at 8.83 N and rotational speed of 180 rpm for 2 minutes per sample. Microscopic analysis of wear scars on the plate samples reveals distinct wear patterns and characteristics for each lubricant, with measurements taken at multiple positions for accuracy. The current work focuses exclusively on wear scar analysis, with findings indicating that engine oil outperforms the counterpart, displaying a smaller wear track width, hence superior lubrication and wear protection capabilities. In contrast, palm oil exhibits a larger wear track, implying limitations in friction reduction and material preservation. This work has demonstrated the practical use of the cost-effective tribometer device for conducting preliminary studies of lubricant wear reduction performance. The test outcomes render valuable insights for lubricant formulators, particularly at the early stage of laboratory-scale development.

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1. INTRODUCTION

In the industrial world, the success and durability of a material greatly depend on its ability to operate under friction and wear conditions. Hence, tribology testing plays a crucial role in evaluating material characteristics and performance. One common method employed in tribology testing is using a ball-on-disk tribometer (Choi et al., 2007), where a ball is slid against a disk to observe and analyze the friction and wear properties of the material (Hao et al., 2022).

However, despite the effectiveness of the ball-on-disk method (Kacan et al., 2020), its utilization is often limited due to certain constraints, especially in terms of cost and accessibility of the equipment. Ball-on-disk

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devices can be quite expensive and are only accessible to larger institutions or well-funded companies. Moreover, the use of ball-on-disk tribometers is not widespread in many laboratories or testing facilities.

The utilization of alternative tribometers was conducted by (Aziz et al., 2021; Khalladi et al., 2016) in their respective studies. These studies employed different tribometer designs and methodologies, contributing valuable insights into the behaviour of materials under varying conditions of sliding and lubrication. Therefore, this research aims to design an alternative tribometer using a conventional drilling machine as a substitute for the ball-on-disk apparatus. By modifying the conventional drilling machine, this study seeks to create a more affordable and easily implementable tool in various testing environments. Conventional drilling machines are common equipment available in many facilities, making them a practical choice for conducting tribology testing and easing the burden on institutions with limited resources.

Tribometer serves as a valuable tool for investigating and understanding the tribological behaviour of materials under a wide range of conditions, including varying contact pressure, sliding speed, testing duration, and lubrication conditions (Boidi et al., 2021; Michelberger et al., 2021; Berglund et al., 2021). In this study, the wear testing will involve subjecting the stainless steel 304 plate to sliding friction using the ball bearing as the counterpart, while being lubricated with either engine oil SAE 15W 40 or palm oil. The goal is to examine and analyze the wear patterns and characteristics of the material under the influence of these lubricants (Farfan-Cabrera et al., 2023). By comparing the wear performance between the two lubricants, valuable insights can be gained into their effects on the material's durability and frictional behaviour.

Engine oil SAE 15W 40, being a commonly used lubricant in industrial settings, represents a practical and relevant choice for comparison (Zhang et al., 2021). On the other hand, palm oil, being a more environmentally friendly alternative, presents the opportunity to explore lubricants with potentially lower environmental impacts (Durango-Giraldo et al., 2022). This research aims to contribute to the understanding of how different types of lubricants can influence wear and friction behaviour, ultimately providing valuable information for industries seeking to optimize material performance while considering sustainability aspects.

By utilizing a conventional drilling machine for this tribometer design, the research aims to contribute positively to the field of tribology testing. This cost-effective and accessible tribometer will open opportunities for more institutions or laboratories to conduct wear testing on various lubricants. The research findings are expected to provide valuable information to industries in selecting appropriate lubricants to enhance material performance and reduce friction and wear in their systems. Thus, this research holds significant relevance and can offer real benefits to technology and industry development, particularly in understanding the friction and wear properties of materials under different lubrication conditions.

2. RESEARCH METHOD

A modified ball-on-disk test was developed to identify the tribological characteristics of wear on the plate surface using various types of lubricants. The design of the tribometer testing device is based on the principle of a ball-on-disc test (Ajibola et al., 2021), as illustrated in Figure 1. a. Furthermore, the testing of the tribometer device is conducted using a drilling machine that provides a rotating mechanism for wear testing on several lubricant samples, as shown in Figure 1. b. The initial process involves placing a 10 mm stainless steel ball (similar to a ball bearing) (Lu-Minh et al., 2022) into the designed drill chuck. Then, at the location of the workbench on the drilling machine, a bath is positioned containing lubricant, along with a sample 304 stainless steel plate attached to a holder at one end. The tests were carried out at room temperature using various types of lubricants with variations of two types of lubricants i.e. engine oil (SAE 15W 40) and palm oil, maintaining a constant load at 8.83 N, and running at 180 rpm for 2 minutes for each sample. Furthermore, observations of wear scars were conducted on the plate samples that had been tested using a microscope. To ensure accuracy, measurements of wear scars on the plate samples were taken at 5 positions.

It is important to note that our equipment does not allow for CoF (Coefficient of Friction) measurement. However, focusing solely on wear scar analysis is sufficient for our purpose of providing general insights into the capability of lubricants to mitigate wear. Combined with the use of an optical microscope, which is also standard equipment widely available in universities or research institutions, this method yields substantial results that would assist researchers in developing or investigating the wear behaviour of potential lubricants.

While CoF measurement offers quantitative data, wear scar analysis provides qualitative information that complements the former and can be particularly valuable in the initial screening stages of lubricant assessment. Moreover, the use of an optical microscope, which is a standard and widely available tool in universities and research institutions, enhances the analysis process for authors. This microscope enables them to magnify and examine the wear scars with greater precision, facilitating a thorough understanding of the lubricant's performance at a microscopic level.

By combining wear scar analysis with the optical microscope, authors can gain substantial insights into the wear mechanisms and the lubricant's protective abilities, allowing them to make informed decisions in developing or selecting lubricants for specific applications. While CoF measurement is a valuable parameter in

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lubricant evaluation, the methodology using wear scar analysis and the optical microscope proves to be a reliable and cost-effective alternative, particularly for preliminary assessments and screening processes in lubricant research and development.

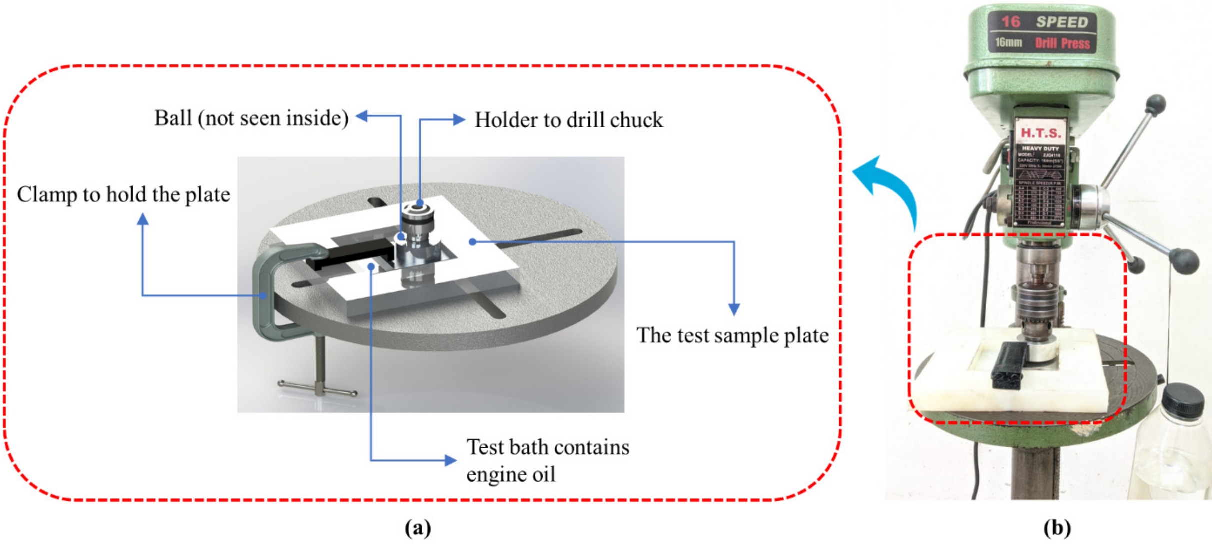

Figure 1. a). Tribometer ball-on-disk test design, b). drilling machine

3. RESULTS AND DISCUSSION

Several investigations have been carried out to evaluate the effectiveness of the designed tribometer testing device. Tests involving wear characteristics were conducted using two types of lubricants under sliding contact to compare their behaviours. The experiment aims not only to study the lubricant's performance but also the efficacy of the testing method utilizing the designed tribometer device at different viscosity of the lubricants (in this case, using engine oil SAE 15W 40 and palm oil). In the present work, the load and speed are maintained constant to isolate the effect of viscosity, and therefore analysis will be limited only to the viscosity factor. During the tests, wear tracks on the plate surfaces were carefully examined using an optical microscope. The wear patterns and characteristics were recorded and analyzed to understand the device's effectiveness in simulating real-world wear scenarios. Additionally, the tribological data obtained from the experiments provided valuable insights into the wear characteristics of the materials being tested.

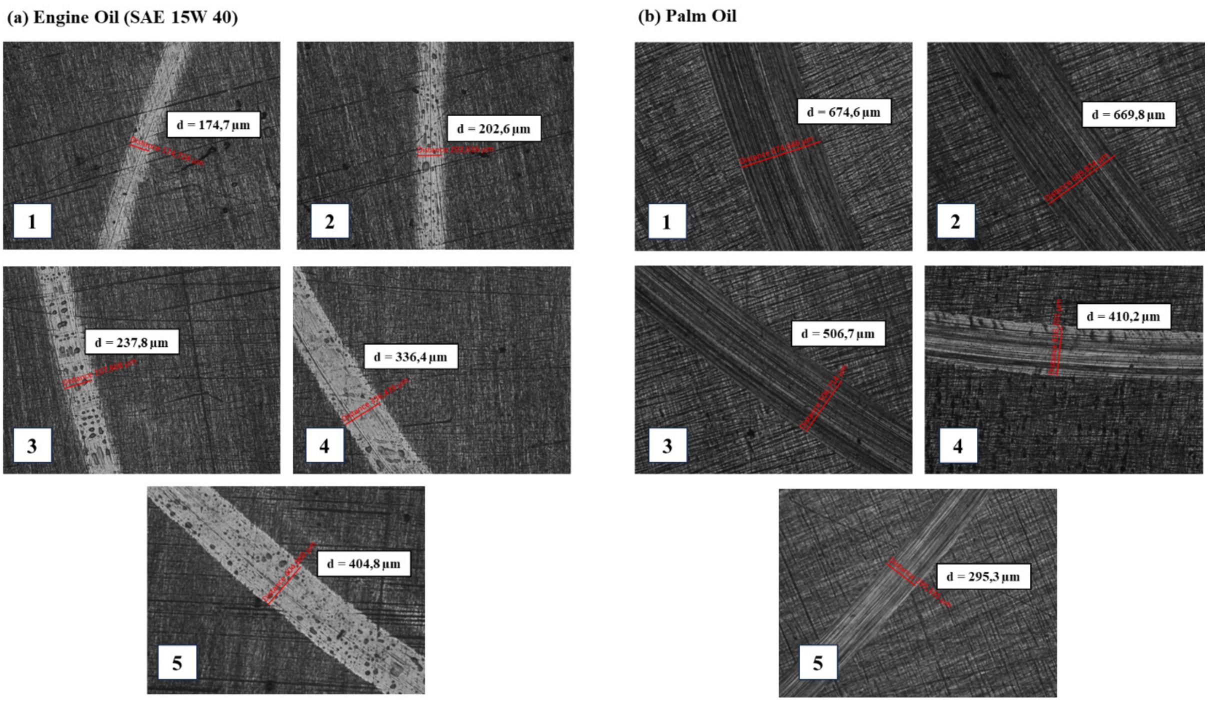

Figure 2. Optical microscope photo of wear track. a). engine oil SAE 15W 40, b). palm oil

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The results of the microscope photo display on the wear track test of the engine oil SAE 15W 40 as a lubricant on the plate surface are shown in Figure 2 (a) the photos provide valuable visual information about the wear patterns and characteristics of the plate surface under the influence of engine oil SAE 15W 40 as a lubricant at five different position. Upon examination, it is evident that the wear track formed by the engine oil SAE 15W 40 lubricant exhibits a relatively smooth surface with minimal signs of abrasion. This indicates that the engine oil SAE 15W 40 effectively reduced friction and wear on the plate, suggesting its suitability as a lubricant in this particular application (Hu et al., 2013). The wear modes apparent in both commercial oil and palm oil-lubricated contacts are a combination of abrasive and adhesive wear, where the signs of adhesive wear are more prominent in palm oil cases as perceived by the dark spots on the wear track. This phenomenon has also been described by (Sapawe et al., 2017) in similar experiments on palm oil.

In addition to the visual analysis, quantitative measurements of the wear track dimensions were obtained from the microscope photos (Kumar et al., 2019). The collected data allowed for a detailed assessment of the wear rate and the extent of material loss throughout the test. This quantitative analysis provides critical insights into the performance of the engine oil lubricant and its ability to protect the plate surface from excessive wear and damage.

Other investigations were conducted using palm oil as a lubricant in the wear track test (Sapawe et al., 2019). The microscope photo results from these experiments are presented in Figure 2 (b) The observations reveal distinct wear patterns and behaviours on the plate surface under the influence of palm oil. Upon careful examination, it became evident that palm oil exhibited slightly different wear characteristics compared to engine oil (Syahrullail et al., 2013). The wear track formed by palm oil displayed a higher level of surface roughness than commercial lubricant. From this point of view, one may infer that this cooking-grade palm oil does not offer the same level of wear protection as engine oil in this specific setup.

Quantitative measurements of the wear track dimensions were also obtained from the microscope photos of the palm oil test. The data analysis provided valuable insights into the wear rate and material loss, allowing for a direct comparison with other lubricants. The results highlighted the importance of considering the specific application and operating conditions when selecting a lubricant to ensure optimal performance and longevity of the equipment. Like the engine oil tests, the wear track tests with palm oil were conducted under controlled conditions to ensure consistent parameters for fair comparison. This approach allowed for a comprehensive evaluation of palm oil's tribological properties and facilitated informed decision-making for its application in various mechanical systems.

The investigations using palm oil as a lubricant in the wear track test offer valuable information about its friction-reducing and wear-resistant capabilities. While palm oil displayed moderate performance, further research is warranted to understand its long-term effects under different loads, speeds, and environmental conditions. Additionally, ongoing efforts to refine the tribometer testing device and experimental setup will continue to expand its versatility and relevance in assessing lubricants' effectiveness for diverse industrial and engineering applications.

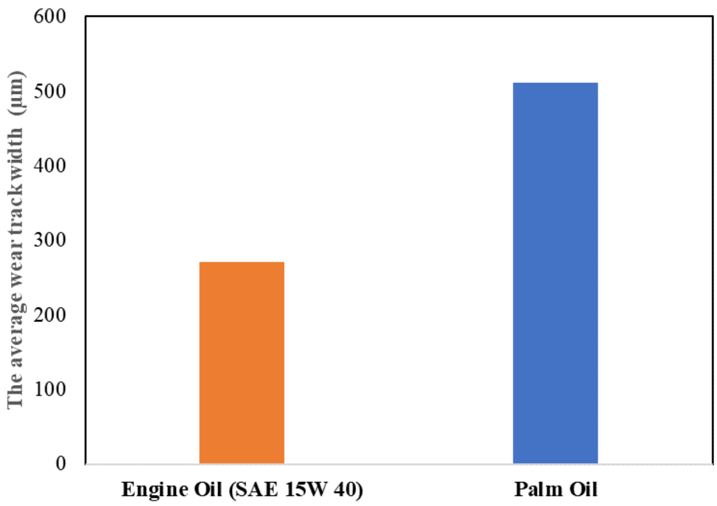

Figure 3. The average wear track width under various oil conditions

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Figure 3 presents the average wear track width under two different lubricants, namely engine oil and palm oil. The results indicate that engine oil exhibited a smaller average wear track width compared to palm oil. The wear track widths were measured to be 271.301 µm for engine oil and 511.344 µm for palm oil.

According to (ASTM G99-17, 2020) volume losses on pin and disk are obtained through the following equations:

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

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

Where $h=r-\left[r^2-d^2/4\right]^{1/2}$ d is wear scar diameter (µm), r is pin end radius (mm), R indicates the wear track radius (mm), and d refers to the wear track width (mm). The calculated values for the pin and disk sides are presented as charts in Figure 4, respectively. Understandably, the volume losses are proportional to the wear track width shown in Figure 3.

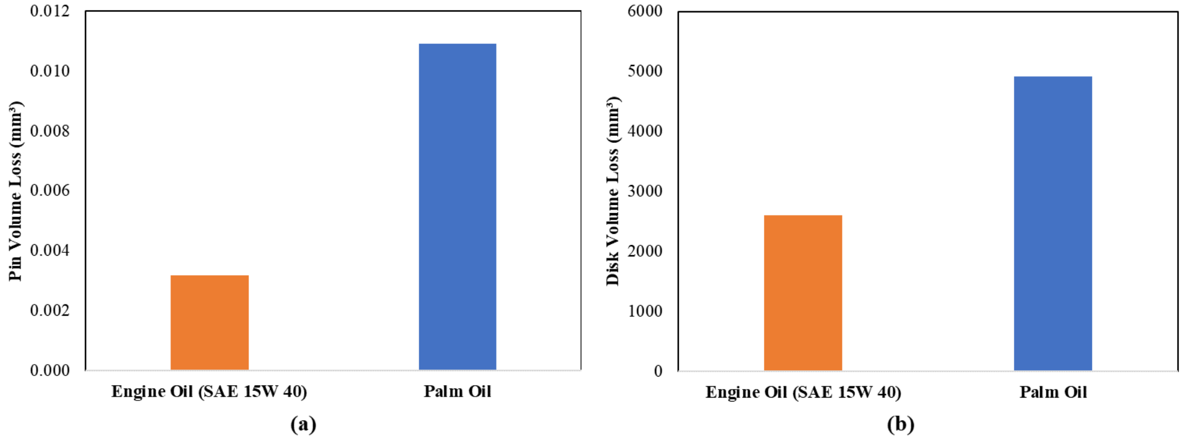

Figure 4. a). Pin volume loss and, b). disk volume loss

The narrower wear track, and consequently the lower material loss (Ahmer et al., 2016), observed with engine oil suggests that it provides better lubrication and wear protection on the plate surface compared to palm oil. This finding is consistent with the microscope photo analysis, where engine oil showed a smoother wear track with minimal signs of abrasion, indicating its ability to reduce friction and prevent excessive material removal. A similar tendency as in Figure 4 was also found by Nuraliza et al. in their investigation of palm oil and SAE 40 oil on aluminium contacts (Nuraliza et al., 2016; Noorawzi et al., 2016), where the volume loss in palm oil experiment is higher than that in the SAE 40 oil, hence confirming the results presented in this paper.

Palm oil, specifically the cooking-grade one as used herewith, despite exhibiting some friction-reducing capabilities, is less effective than engine oil for wear-reduction purposes. The wider wear track observed with palm oil could be attributed to its specific composition and lubricating properties, which may not be as optimized for this particular wear test. The differences in wear track width between engine oil and palm oil underscore the significance of lubricant selection in various applications. Depending on the operational requirements and load conditions, engine oil may be preferred for applications where wear and friction need to be minimized to ensure equipment longevity and efficiency.

4. CONCLUSION

The results of the modified tribometer device design using a drilling machine demonstrate the device's proper functionality. This is evident from the successful execution of the experiments conducted on the wear track test using engine oil and palm oil as lubricants have provided valuable insights into their tribological performance. The microscope photo analysis revealed distinct wear patterns and characteristics for each lubricant, highlighting their different friction-reducing and wear-resistant capabilities.

The results demonstrated that engine oil displayed superior performance compared to palm oil, as evidenced by its smaller average wear track width of 271.301 µm, indicating better lubrication and wear protection. On the other hand, palm oil exhibited a wider average wear track width of 511.344 µm, suggesting its limitations in reducing friction and preventing excessive material loss.

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