Tribological Study of Modified Palm Oil-With Single and Hybrid Nanofluids for Metalworking Fluid

Ainaa Mardhiah Sabri, Norfazillah Talib, Amiril Sahab Abdul Sani, Haslina Abdullah, and Kamaruddin Kamdani

Abstract Metalworking fluids (MWFs) are essential for minimizing wear and friction during machining operations. Vegetable oils have excellent lubricating properties, are highly biodegradable and nontoxic, and are very affordable to manufacture, making them a great replacement for mineral oil as a metalworking fluid. The incorporation of nanoparticles to vegetable oil is a viable strategy to improve the lubricating capabilities of MWFs. The aim of the research is to assess the tribological properties of modified refined, bleached, and deodorized (MRPO) palm oil with 0.025 wt.% of additives. MRPO was produced by transesterification process of refined, bleached and deodorized palm oil (RBD PO). The samples that were tested were MRPO, MRPO with activated carbon (AC) (MRPOa), MRPO with tungsten disulfide (WS_2) (MRPOw), and MRPO with a hybrid of AC and WS_2 (MRPOaw). The oil samples were then compared with synthetic ester (SE). A four-ball wear test was used to evaluate the tribological performance of oil samples based on ASTM D4172. The testing was done at temperature set to 75 ± 2 °C, load of 392 N, rotating speed of 1200 rpm for 60 min. MRPOaw show the lowest COF (0.06281) and smallest MWSD (607.1 μm). The outcomes of the tribological tests offer insightful information on the performance of these nanofluids, opening the door for their prospective use in efficient and environmentally friendly metalworking procedures.

Keywords Hybrid Nanofluids · Modified palm oil · Activated carbon · Tungsten disulfide

A. M. Sabri · N. Talib (✉) · H. Abdullah · K. Kamdani
Faculty of Mechanical Engineering and Manufacturing, Universiti Tun Hussein Onn Malaysia, 86400 Parit Raja, Johor, Malaysia
e-mail: fazillah@uthm.edu.my

A. S. A. Sani
Faculty of Manufacturing and Mechatronic Engineering Technology, Universiti Malaysia, Pekan, 26600 Pahang, Malaysia

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1 Introduction

In machining operations, metalworking fluids (MWFs) are frequently utilized to extend the life of tools, increase surface quality, and disperse heat produced during metalworking processes. However, there are safety and environmental issues with the conventional MWFs [1]. As a result, there is rising interest in creating effective and sustainable substitutes for conventional MWFs. Vegetable-based oil resembles MWF in that it has higher flash points, viscosities, and molecular weights [2]. In recent times, palm oil has emerged as a viable substitute for the manufacturing of coolant or industrial lubricant. On a global scale, Malaysia was responsible for 42.3% of the overall production and 48.3% of the total global exports of palm oil. Given the circumstances, there is a strong rationale for the broadening of palm oil utilization across diverse applications within the lubricant industry [3, 4]. However, to overcome the limits of vegetable oil in terms of oxidation stability, high friction, high viscosity, thermal stability, and corrosion resistance, the oil must be modified before use [5]. Modified palm oil has emerged as a desirable alternative among the numerous base fluids investigated because of its renewable status and superior lubricating qualities [4]. Additionally, adding nanoparticles to MWFs has the potential to significantly enhance their performance. Talib et al. [6] found that the addition of Activated carbon to vegetable oil improve the tribological performance compared to MJO itself. According to the Jumali et al. [7], the incorporation of nano-scale activated carbon particles as an additive in lubricants used for machining processes has been found to result in notable enhancements in both wear resistance and surface morphologies when compared to lubricants without additives. Hence, the utilization of activated carbon as an additive in machining lubricants yields advantages such as enhanced resistance to wear and improved quality of surfaces.

In their study, Paturi et al. [8] employed tungsten disulphide (WS_2) as additives materials during the turning procedure of Inconel 718. It was noted that the utilization of WS_2 resulted in a reduction of approximately 35% in surface roughness. A study conducted by Zhang et al. [9] examined the phenomenon of WS_2 particles adhering to worn surfaces, resulting in the formation of a tribo-layer. This tribo-layer was found to effectively reduce both frictional force and wear. Chen et al. [10] discovered that ultrafine WS_2 particles may fill and level the furrows on abrasive surfaces, providing an outstanding protective coating that can enhance the oil film's severe pressure performance and decrease friction coefficient (COF). The experimental results of WS_2 have demonstrated exceptional tribological characteristics. The distinctive spherical structure and material properties of WS_2 have garnered significant attention in the exploration of various application domains [11]. Nanofluids combining modified palm oil with single, or hybrid kinds of nanoparticles have been presented to improve the tribological performance of MWFs. Different nanoparticles combined with modified palm oil can have synergistic effects that increase lubrication, decrease friction, and wear resistance [12]. Previous studies shown that adding synthetic TiO_2/MoS_2 nanoclusters to lubricants enhanced tribological performance over pure MoS_2 and pure TiO_2 by 30.8% and 40%, respectively

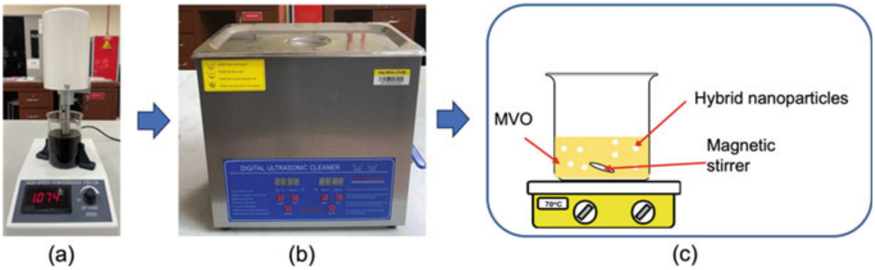

Fig. 1 Mixing process of MRPO with nanoparticles; **a** Homogenizer **b** Ultrasonic vibration **c** Stir process

[13]. The tribological characteristics of hBN/TiO_2 were reported by Huang and Zhao [14]. The findings indicate an improvement in wear resistance. The present research seeks to study the tribological characteristics of modified palm oil-based nanofluids for use as metalworking fluids, both with single nanoparticles and hybrid combinations.

2 Methodology

2.1 Nanofluids Preparation

RBD palm oil undergo chemical modification by using base catalyst transesterification process. RBD palm oil react with methanol with the addition of sodium hydroxide (NaOH) as catalyst to produce palm oil methyl ester (POME). Then, POME react with trimethylolpropane (TMP) with sodium methoxide ($NaOCH_3$) as catalyst and produced modified RBD palm oil (MRPO). MRPO then incorporated with single and hybrid nanoparticles. MRPO mixed with 0.025 wt.% of AC (MRPOa), WS_2 (MRPOw) and hybrid nanoparticle AC + WS_2 (MRPOaw) respectively. MRPO was mixed with nanoparticles through three steps which is 30 min in homogenizer, then another 30 min in ultrasonic homogenizer. The samples than were stirred at 700 rpm for another 30 min and heated at 70 °C on hot plates to ensure the mixture homogeneity as shown in Fig. 1. The samples were compared to a synthetic ester (SE, Unicut Jinen MQL).

2.2 Tribological Testing

The DUCOM TR-30L four-ball tribotester shown in Fig. 2 was used for the tribology testing, which followed ASTM D4712. Each test used four steel balls made of AISI 52,100 with hardness ranging from 64 to 66 HRC and a diameter of 12.7 mm. Ten

Fig. 2 Four ball tribotester machine

milliliters of oil sample were poured into the ball port. The three fixed balls were clamped in the ball pot assembly. The rotating ball was inserted into the collet and placed into the spindle. The ball port was placed in the tribotester machine and a normal load of 392N was slowly introduced. The temperature of the oil heater was set at 75 ± 2 °C. After reaching the required temperature, the revolving ball start operated at a constant speed of 1200 rpm for 60 min. Based on the outcomes of the testing, the coefficient of friction (COF) was computed using the Winducom software. An optical microscope was used to assess the mean wear scar diameter (MWSD) of the stationary steel balls.

3 Result and Discussion

Figure 3 illustrates the graph of coefficient of friction (COF) and mean wear scar diameter for all samples. MRPOs had lower COF compared to SE. This indicates that the presence of a poly branched TMP polyol ester in MRPO enhances the tribological behavior of the biodegradable lubricant [15]. Additionally, the fatty acids in MRPOs can create a thin lubricating film that sticks to contact surfaces. The polar carboxyl group in fatty acids, which is closely packed, produced a good lubricating layer that might reduce friction [16]. Besides that, the long polar ester group found in MRPOs helps to reduce friction and wear in moving components [17]. From the graph, MRPO with the addition of additives show lower COF compared to MRPO itself. MRPOa, MRPOw, and MRPOaw shows decreasing in COF value compared to MRPO itself with 9.36%, 5.51% and 9.58% respectively. Incorporating additives into MRPOs enabled the development of a thicker lubricating layer on the ball surfaces, which minimized direct contact with the metal asperities and, as a consequence, resulted in COF and improved lubrication efficacy [18]. MRPOaw have the lowest COF compared to MRPOa and MRPOw. Activated carbon nanoparticles improve the COF as it offered a rolling effect between the friction surface [16]. Other than that, Khoo and Aziz [19] found that the structure of AC help in reducing COF value. Additionally, WS_2 creates a depositional layer on the surface that fills in and evens out sliding friction and surface roughness [10]. By combining AC and WS_2, it creates synergistic effect of two different nanoparticles, thus improve COF. This finding was similar with the study from Lu et al. [20] that mentioned that the samples with hybrid additives give a better tribological result because the interactive effect between two types of nanoparticles. They also stated that Sulphur (S) from WS_2 react with the friction surface, thus smoothing the friction surface. From Fig. 3, significant reduction in MWSD was shown for all samples. SE had the biggest MWSD of 729.3 μm. MRPOs had smaller MWSD compared to SE. The MWSD of MRPOa was 619.3 μm, MRPOw was 636.5 μm and MRPOaw was 607.1 μm.

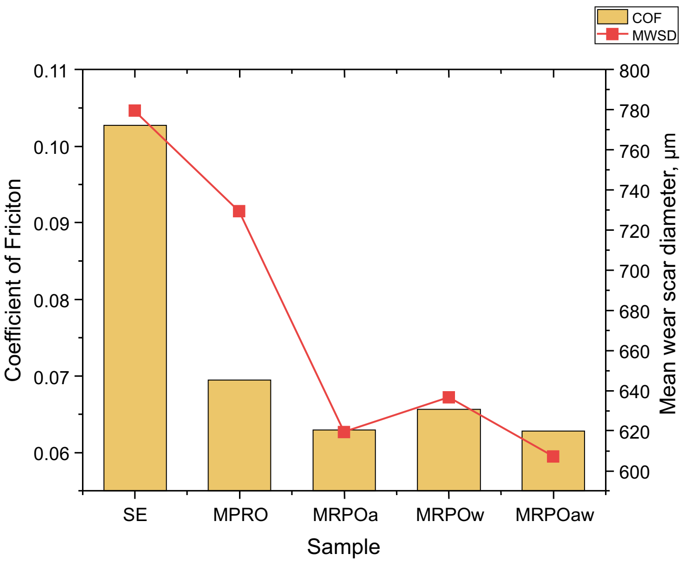

Fig. 3 Coefficient of friction (COF) and mean wear scar diameter (MWSD) for all samples

4 Conclusion

The incorporation of nanoparticles into the MRPO results in improved lubrication and tribological properties. MRPOaw which is MRPO with 0.025 wt.% of AC and WS_2 had the lowest COF of 0.0628 and the smallest MWSD of 607.1 μm. The outcomes showed that MRPOaw has improved tribological performance, making it the best contender for an environmentally friendly MWF for the machining process. MRPOaw with hybrid additives shows outstanding results and is suitable to substitute benchmark oil, Synthetic Ester (SE).

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