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Article

Tribological Behavioural of Bio-Oil Extracted from Peel Waste of Musa Aluminata Balbisiana

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Abstract

The aim of this study is to investigate the effects of applied loads and temperatures on the tribological properties of MBS oil, which is a bio-oil extracted from banana peel waste of Musa Aluminata Balbisiana, MBS. Tribological evaluation of MBS oil was conducted using pin on disc tribometer as per G 99 ASTM standard. In this method, hemisphere pin was loaded against the rotating disc containing the MBS oil . The test was implemented by dropping 2 ml of MBS oil as a lubricating oil on sliding surface at varying loads from 20 to 100 N at 27°C, 40°C and 100°C. The results showed that, at 80 N, the coefficient of friction (COF), volume wear loss (V_{loss}), wear scar diameter (WSD), and wear rate (*Ws*) values were lower at all the tested temperatures. Microscopic analysis revealed that, the above results is due to the formation of tribo-chemical film which existed as protective layer on sliding surface thus preventing metal to metal contacted each other, hence contributed to the favor of frictional reduction.

Keywords

bio-oil, applied loads, temperatures, tribological properties, coefficient of friction, volume wear loss, wear scar diameter, wear rate

1 Introduction

In the last decade, vast of interest was developed to use environment friendly biodegradable lubricant fluids [1-4]. Depletion of world petroleum reserves and uncertainty in petroleum supply also stimulated the investigation for environmental friendly alternative to mineral oils [2, 3]. In this scenario, plant oils have gained great interest as lubricants over the last couple of decades. The conventional mineral based lubricant has been widely used in mechanical industry and it was proven to cause the ecological pollution due to some degree of toxicity. It is generally having high flammability characteristic that can give bad effect to our environment [5, 6]. Previous study shows that, nearly to 12 million ton of lubricant waste dispose to environment. Therefore, due to awareness of environmental and health issues, some solution and steps had been taken by government in order to reduce and overcome the consumption of mineral-oil based lubricant [5]. The conventional lubricant known as lubricating oil in industry which can cause serious pollutions to the environment and creates the greenhouse effect. Thus, to overcome these issues, vegetable oils has been introduced globally. A vegetable oil is extracted from a plant and has widely been used as a lubricant. The usage of vegetable oil as the lubricating oil industry was not a new idea and was introduced for many thousand years ago. Malaysia is one the largest producers and exporters palm oil in the world, accounting 11% of the world's oils and fat production and 27% of export trade oils and fats. Nowadays, around 2% of the base stocks are of plant oil origin [7, 8]. A biolubricants may be plant oil-based or derived from synthetic esters manufactured from modified renewable oils or from mineral oil-based products [9-11]. Biolubricants are generally considered as a lubricant with high biodegradability as well as low human and environmental toxicity [12]. A lubricant is classified as biodegradable if its percentages of degradation in a standard test exceeds a certain marked level.

In mechanical field, friction and wear was attributes by the tribological properties of the conventional oils since it can lead to the mechanical failures. Lubrication is one of the mechanism that being used to eliminates and minimize this failure. The presence of continuous lubricants thickness [13, 14] in the machines and engines mostly, is effective on the surface contact and gives benefit to the surface. The interaction between two surfaces will cause friction and lubricant lubricated to prevent from metals part produces wear and friction and then produced excessive heat. Many problems occur between metal-on-metal contact due to wear and friction mechanism. Previous researcher found that wear and friction primarily changes with load [15-18], temperature [19], surface roughness [20, 21] type of material or mating component [22] and environmental. The study in understanding the wear mechanism in different parameter played important role in identifying new solutions and findings to overcome to these particular problem. Among of these factors, speed and load are major factors that give high impact to the friction force and wear value.

Banana skin had been referred as slipping tools [23]. Coefficient of frictions, COF under an epicarp of banana skin, on the floor material is much lower to the value of common materials and similar to the well-lubricated surface. The lubricating effect of banana skin was contributed by the existence of follicular gel, which is sized about a few micrometers [23]. Another study found that, percentages of extraction yields of bio oil from the peel waste of banana species were influenced by the existence of follicular gel [24]. In their study, the follicular gel was analyses using scanning electron microscopes and they concluded that, the polysaccharide follicular gel is a major key element in formation of oil [24]. Moreover, Rosenthal et al., [25] and Foidl and Eder [26] discussed that for plant materials, the oil constituents are trapped in the meshwork of proteins and cellulose/hemicellulose or also known as polysaccharides which formed a bunch of follicular gel that related to polysaccharide follicular [25-27]. Hamid et al., [28] investigated the effects of banana peel of Cavendish species as a natural additive in paraffin oil. The tribological properties of the specimens were evaluated using four-ball tester. Their findings revealed that, coefficient of friction, μ and wear significantly reduced at high load, temperature and speed. At 100°C, the load of 500 and 1000 N, the COF value reduces from 0.1163 to 0.1012 and 0.1235 to 0.1174 respectively. At the same condition, wear scar diameter was found to decrease from 4.81×10^{-4} mm^3 to 2.33×10^{-4} mm^3 and 4.99×10^{-4} mm^3 to 2.75×10^{-4} mm^3 at 500 and 1000 rpm respectively.

However, the research work on the study of tribological behavior of bio-oil extracted from banana peel wastes of Musa Aluminata Balbisiana (MBS) has not been reported in the literature. Hence, this paper intends to provide information's on tribological behavior of bio-oil extracted from banana peel wastes of Musa Aluminata Balbisiana (MBS) with specific aim to study the effects of applied loads and temperatures on COF, volume wears loss (V_{loss}), wear scar diameter (WSD), and wear rate (Ws).

2 Methodology

2.1 Materials and apparatus

In this study, the MBS oil was obtained using Soxhlet extraction method. The peel waste of MBS was crushed into smaller sizes and dried using and was ground using commercial blender. The ground dried MBS powder was soaked into *n*-hexane (as solvent) for 7 hours. The extraction process was carried out at the boiling points of *n*-hexane solvent in order to achieve a maximum oil yield. The oil was concentrated using rotary evaporator under reduced pressures to remove the excess solvent and pale brownish oil was obtained. The pale brownish oil of MBS oil was subjected to physical, physiochemical and fatty acids analysis before further used in tribological analysis. The physical and physiochemical properties of MBS oil was tabulated in Tables 1 and Table 2 was depicted the fatty acids profile of MBS oil.

In the present investigation, pin on disk had been used to study both wear and coefficient of friction (Fig. 1). A pin was held firmly against a rotating disc connected to a certain dead

Table 1 Physical and physiochemical properties of MBS oil

Properties	Value
Extraction Recovery, (%)	42.38
Colour	Pale brownish
Density at 40 °C, kg/m^3	0.8502
Specific Gravity	0.8536
Kinematic Viscosity (at 40°C), (cSt)	3.29
Total Acid Number (mg KOH/g)	0.52
Free Fatty Acids, FFAs	2.64

Table 2 Fatty acids profile of MBS oil

Fatty Acids	Structures*	% Distribution
Butyric Acid	C4:0	10
Caproic Acid	C6:0	36
Myristic Acid	C14: 1	6
Ginkgolic acid	C15: 1	34
Gondoic Acid	C20: 1	4
Methyl Nerranoic Acid	C24: 1	2
Gamma-Linolenic Acid	C18: 3N6	2
cis-8,11,14-Eicosatrienoic acid	C20: 3N6	2

* Carbon number with 'zero' double bonds are saturated fatty acids, with 'one' double bonds are monounsaturated fatty acids and with 'two' or 'three' double bonds are polyunsaturated fatty acids.

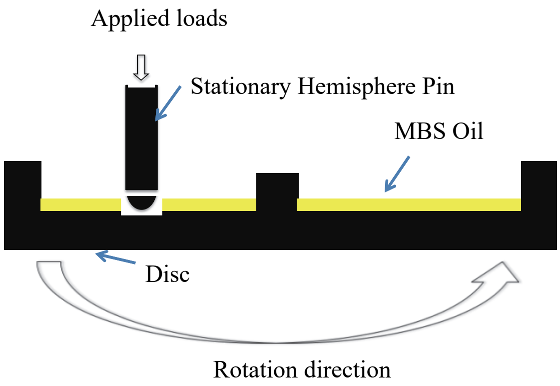

Fig. 1 Pin on disc experimental arrangement

weight with a beam and two pulleys. MBS oil was placed on the disc surface. The wear track was adjusted by loosening the sliding plate at 40 mm and fixed during the experiment conducted. During the experiments, new pins were used for each run and were cleaned with acetone to remove the impurities. The winducom 2008 software was used to record the data from the pin on disc machine.

2.2 Experimental procedures

In this study, the tribological testing was performed according to the ASTM G99-05 standard under wet sliding conditions at different temperatures and applied loads. The detail of pin and disc properties is listed in Table 3 and the operating condition for tribological properties of MBS oil is tabulated in Table 4 below. A constant sliding speed (50 RPM), wear track diameter (314 m) sliding times (50 minutes) were applied along the experiments. The pin was heated using an external heat resource where a thermocouple was placed on the edge of the counterpart pin. An infrared thermometer (Extech 42580) was used to measure the temperature before the test began. During the experiment, a hemispherical pin was clamped against the rotating disc and 2 ml of MBS oil was dropped on the surfaces. Both of the surfaces of the hemispherical pins and disc were made parallel to ensure their maximum contact. The surfaces morphology and wear scar analysis of the pin was then observed using scanning electron microscopes, SEM.

Table 3 Hemisphere pin and disc properties

Properties	Disc	Hemisphere Pin
Materials	En31 Steel	Steel
Surface Roughness, Ra	0.03 μm	0.08 μm
Hardness	64 HRC	62 HRC
Diameter	-	5 mm

Table 4 Operating condition for tribological properties of MBS oil

Test Parameter	Value
Applied Loads (N)	20, 40, 60, 80, 100
Temperatures (°C)	27, 40, 100

2.3 Coefficient of friction (COF) and specific wear rate

The value of coefficient of Friction (COF) and Wear Rate Evaluation were calculated based on Eqs. 1, 2 and 3 below:

$$COF = \frac{F}{W} \tag{1}$$

$$Ws = \frac{Vloss}{W\,x\,L} \tag{2}$$

$$V_{loss} = \pi d^4/64R \tag{3}$$

[Ws is the specific wear rate (mm^3/Nm); W is the applied load (N); L is the sliding distance (m); V_{loss} = wear volume losses of the pins; d = wear scar diameter in unit of meter; R = radius of the pin in unit of meter (0.00149 m)].

2.4 Surface morphology analysis

Morphological characterization of the pin surface was carried out using SEM which produces images of a sample by scanning it with a focused beam of electrons (JEOL, JSM 840). The electrons in the beam interact with the sample producing various signals that can be used to obtain information about the surface topography and composition (EDX). The surfaces of all the samples were coated with a thin film of platinum using Polaron SC 7640 Sputter in order to improve the conductivity and avoid electron-charging effects during analysis.

3 Results and discussion

3.1 Effect of applied loads on friction coefficient, COF at various temperature

Lower coefficient of friction is desirable for proper functioning of equipment's and reduces the energy loss. In wide ranges of automotive applications, most of the researchers agreed that, the acceptable ranges of COF is between 0.05 - 0.14 [12, 29-36]. Based on Fig. 2, the COF value of MBS oil at steady state is range from 0.06 to 0.40. From Fig. 2, it clearly shows that, MBS oil exhibited a similar pattern of COF values at all the tested temperatures. As the load increased from 20 N to 40 N, the COF value is increased (Phase I). However, the COF values start to decrease from 40 N to 80 N (Phase II) and from 80 N to 100 N, the COF value showed an increasing pattern (Phase III).

As depicted in Phase I (Fig. 2), the COF values showed an increasing gradually pattern as the applied load increased.

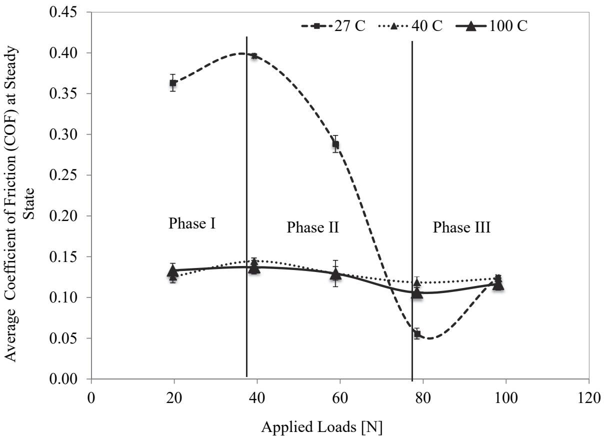

Fig. 2 Average COF at steady state different applied loads [N] at 27°C, 40°C and 100°C

There were clearly observed that, a rapid increment on COF at the beginning of the test due to the running in period. At this period, a high contact pressure between two surfaces caused wear and plastic deformations of the peak surface, the profile contact of the surface is gradually improved and the surface pressure, and COF decreases so it enters a stable wear stage [37]. The increased of the load hence will produce higher stress concentration in localized region. Therefore, this situation can lead to localized plastic deformation and continued by initiation and abrupt propagation of crack which resultant in the spall formation [37, 38]. Moreover, at this phase, the fluid protective film was still in early stage of development process.

At phase II (Fig. 2), the graph showed rapid and gradually decrement in COF as the applied loads was increased. At this region, a layer of protective fluid tribo-chemical film was formed on sliding surface thus preventing metal to metal contacted each other [29]. Furthermore, a tribo-chemical reaction may occur between fatty acids composition in MBS oil with the disc surface, hence may have resulted in the formation of metallic soap layer, and fluid protective layer that contributed to the favor of frictional reduction [29, 39, 40]. As shown in Fig. 3, steel (pin) was believed to exist as contacting surface while steel (disc) acts as opposing contacting surface. The magnitudes of COF indicate that the lubrication regime occurred in the rubbing zone is boundary lubrication. Moreover, at this phase, the fluid protective film was fully developed with functioned to protect the contacted surface. At all the tested temperatures of the load of 80 N, it shows the greatest ability to retain its properties without the breakdown of the lubrication film. In this study, at higher load (80 N), the lubricating film thickness become thinner than some of the asperities present in the boundary lubrication. However, the asperities are covered by the long chain fatty acids and the ester of bio lubricant, which are known as surface-active materials [40].

The presence of adsorption of polar molecules such as long chain fatty acids and ester in bio lubricants act as efficient barrier for protective sliding surface contact and friction surface lead to reduction in COF. In addition, the existences polar group of ester group also provides an affinity to metal surface and contributed to the formation of protective layer between metal surfaces [29, 41]. In other words, the polarity of the ester group creates a strong affinity to the metal by one end of the molecules and it's allowed a nonpolar hydrocarbon to extend out and provides a barrier between surfaces [29].

Moreover, the presence of carbonyl group in MBS oil was believed to be chemically and physically adsorbed onto the steel or metal surface [42-49]. The adsorption therefore provides a prevention of direct contact between frictional pairs due to the formation of orderly and closely packed molecular multi layers. A schematic representation of chemical adsorption of fatty acids molecules of MBS oil on surfaces during friction is shown in Fig. 4 below [39, 43]. Furthermore, fatty acids molecules which known as corrosive component, was believed can cause the corrosion and material removal of fractional pairs. The higher amount of acidic substances will lead to the serious corrosive wear and the highest wear lost [41].

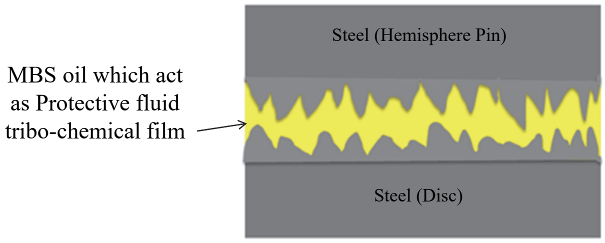

Fig. 3 A schematic representation of the protective fluid tribo-chemical's film and its corresponding contact mechanism in pin on disc under lubrication of MBS oil

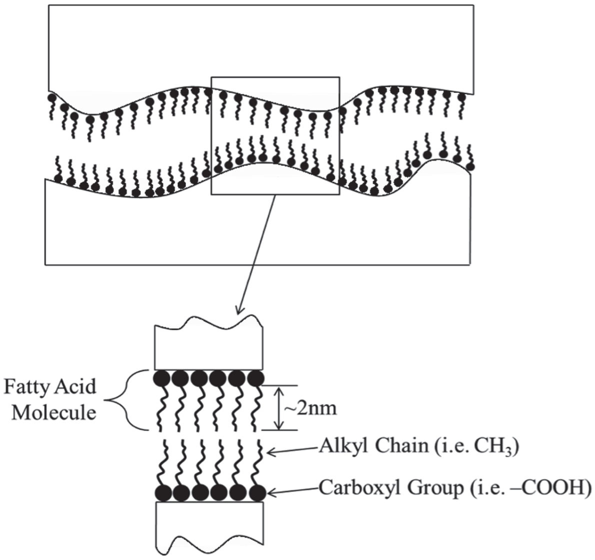

Fig. 4 Schematic representation of the chemical adsorption of fatty-acid molecules in MBS oils on the surface during friction

At Phase III, the COF values showed an abrupt and increasing pattern from 80 N to 100 N. At this phase however, it was believed that, the COF values start to increase as the ability of MBS oil to provide a tribo-chemical protective layers failed to retain. This region was contributed by the heat generated, thus led to the increasing of COF. As the load increased, the more heat produced due to the pressured on the surfaces, hence could cause to the vaporization, degradation, cleavage and chemical oxidation of some of the chemical compounds in MBS oil and this could lead in the failure of the MBS oil in providing a protective layer [37, 41]. This condition hence could be the reason for the increasing COF value along with the increasing in applied load and temperatures of the experiments.

3.2 Effect of applied loads on wear scar diameter (WSD) and wear rate, *Ws* at various temperatures

Wear is the progressive loss material due to interacting surfaces in relative motion. Friction and wear are related both are phenomenon of a solid contact between moving mating components. Figure 5 showed WSD (μm) at different loads and temperatures. It was observed that, for all the operating temperatures, there were shown a similar pattern of curves plotted. The wear dominated by the pin is increasing from 20 N to 40 N. However, the decreasing pattern of WSD was started to observe from 20 N to 80 N and it shows an increasing trend after 80 N to 100 N. The lowest WSD was recorded at the 80 N with the values of 501.143 μm, 250.912 μm and 331.103 μm respectively meanwhile, the highest was observed at the load of 100 N with the values of 1530 μm, 915.926 μm and 1166 μm respectively for all the tested temperatures. The lowest WSD at the 80 N for all the tested temperatures was influenced by the formation of preventive layer of tribo-chemical film.

A COF values and WSD play vital roles in evaluating the

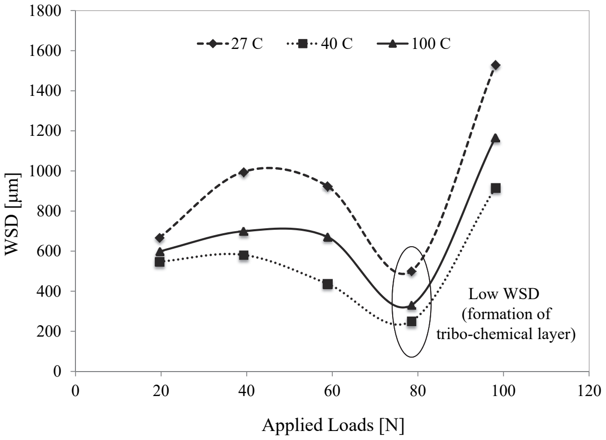

Fig. 5 WSD (µm) at different loads

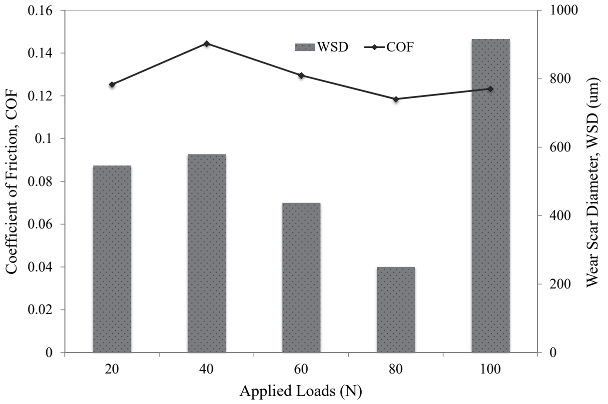

Fig. 7 The relationship of COF values and wear scar diameter at temperature of 40°C

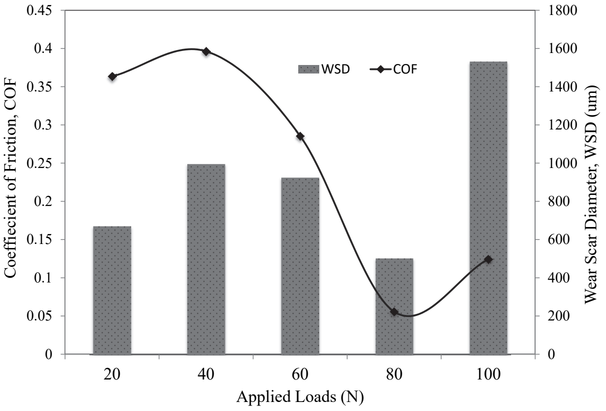

Fig. 6 The relationship of COF values and wear scar diameter at temperature of 27°C

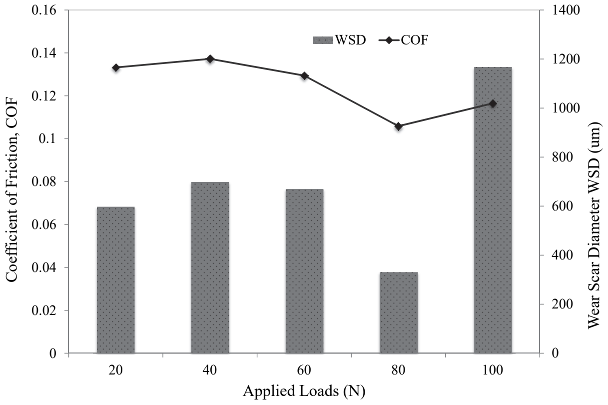

Fig. 8 The relationship of COF values and wear scar diameter at temperature of 100°C

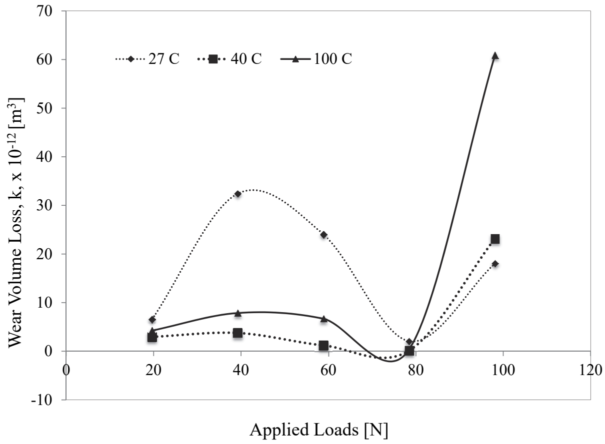

Fig. 9 Specific wear rate and wear volume loss of MBs oil at various applied loads at 27°C, 40°C and 100°C

tribological properties. The relationship of COF and WSD of MBS oil at different loads and temperatures was depicted in Figs. 7, 8 and 9. Bowder and Tabor [50] discussed that, since a friction is caused by somewhat different set of mechanism than wear, the result from experiment might be low wear and high friction and vice versa. This behavior might due to the increased shear strength of the adsorbed oil on the surface of the balls and effected chemical attack on the surface by the fatty acid compositions, which present in vegetable oil.

Figure 9 below shows Specific Wear rate of MBS oil versus various load at operating temperatures of 27°C, 40°C and 100°C. A low wear rate (0.0084×10^{-15} mm^3/Nmm, 0.005×10^{-15} mm^3/Nmm, 0.016×10^{-15} mm^3/Nmm) and volume wear loss (2.08×10^{-12} m^3, 0.13×10^{-12} m^3, 0.40×10^{-12} m^3) was observed at the load of 80 N for all the tested temperatures respectively. These results was attributed by the formation of tribo-chemical layers which role as protective layer to prevent spherical pin metal and disc metal contacting each others. A high wear rates (5.858×10^{-15} mm^3/Nmm, 0.753×10^{-15} mm^3/Nmm and 1.976×10^{-15} mm^3/Nmm) and wear volume losses (18.050×10^{-12} m^3, 23.190 10^{-12} m^3 and 60.890 10^{-12} m^3) were observed at load of 100 N at all the tested temperatures respectively. It is believed that the wear particles of the pin may get locked between sliding surface and/or transferred and embedded to mated discs and subsequently gave many damages to the pin. This condition led to the adhesive action and promoted three bodies, which should enhance volume loss in wear [16, 51]. This wear debris from pin and disc will trapped at interface and thus will act as an extra layer to aid the motion of the pin and disc hence, it will decrease the friction coefficient as the load applied is increased [18]. A good lubricants achieved when its able to reduce and minimize the volume loss of the materials. It is believed that the wear particles of the pin may get locked between sliding surface and/

or transferred and embedded to mated discs and subsequently gave many damages to the pin can caused roughening effect on the pin [52]. This condition might lead to the adhesive action and promoted three bodies, which should enhance volume loss [16, 51, 52]. This wear debris from pin and disc was believed to trap at interface and serves as an extra layer to aid the motion of the pin and disc hence, it contributed to decrease the friction coefficient as the load applied is increased [18]. It also believed that the high temperature generated at interface also influence the wear dominated by the pin.

3.3 Comparison of coefficient of friction with other study

The coefficient of friction of MBS oil in this study were compared with other types of oil including vegetable oils and commercial engine oil. Table 5 summarised the compilation of the coefficients of friction from the literature review.

4 Conclusion

The investigation on tribological behavior of MBS oil was successfully performed using pin on disc tribometer. Qualitative and quantitative analysis were performed and it revealed that, at the load of 80 N, the COF value, wear scar diameter (WSD), specific wear rate (*Ws*) and volume wear loss are much lower due the formation of tribo-chemical film. The finding from this study might contribute to the sustainable development of the biolubricant fields. In addition, this study shows that, MBS oil, which extracted from the waste of banana peels, has a promising future to replace a mineral oil based lubricants.

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Table 5 Compilation of the coefficient of friction obtained from previous and this study

Lubricant	Load (N)	Temp. (°C)	COF	Apparatus	Reference
SAE 20W50	10	-	0.112	Block-on-disc	[53]
SAE 20W40	10	-	0.086	Block-on-disc	
SAE 15W40	10	-	0.093	Block-on-disc	
Paraffin Oil	392	100	0.077	Four-ball	[29]
Calophyllum Inophyllum	392	100	0.065	Four-ball	
Trimethylolpropane	392	27	0.1	Four-ball	[30]
Chemically Modified Rapeseed Oil	80	60	0.082	HFR test rig	[31]
Sunflower Oil	10	50	0.049	HFR test rig	[32]
Soybean Oil	10	50	0.05	HFR test rig	
Coconut Oil	10	-	0.09	Block-on-disc	[53]
Soybean Oil	10	-	0.112	Block-on-disc	
Sunflower Oil	50	22	0.136	Pin-on-disc	[54]
Musa Aluminata Balbisiana Oil	20	100	0.132	Pin-on-disc	Present Study
Musa Aluminata Balbisiana Oil	80	100	0.105	Pin-on-disc	
Musa Aluminata Balbisiana Oil	100	100	0.118	Pin-on-disc	

* HFC: high frequency reciprocating

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