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Determination of Tribological Properties of *Canarium Schweinfurtii* and Paraffin Oil Blend as Metal Forming Lubricants

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Abstract: *The issue of toxicity produced with the use of mineral oil-based lubricants and the depletion stock of petroleum has encouraged research work on alternative lubricants known as bio-lubricants. The tribological performance of canarium schweinfurtii oil as bio-lubricant and the blend* with *paraffin oil was evaluated in order to assess the potential use in metal forming. The tests were performed using a ball-on-disc tribometer in severe contact conditions with alluminium alloy piece. In pure oil state, the canarium schweinfurtii oil (COF- 0.084) performance was found to be competitive in friction coefficient with mineral oil (COF- 0.081). Although, the mineral oil is quite useful in wear protection due to the available additive. For a lubricant formulation at equal ratio, the reduction of friction and wear was not significant. This effect was found prominent when they were blended with paraffin oils where the tribological performance was dominated. However, the addition of 7.5% paraffin oil addictive which was added to 92.5% canarium schweinfurtii oil gave significant improvement on the friction (COF-0.057) and addition of 15% paraffin oil additive which was added to 85% canarium schweinfurtii oil gave significant improvement on the wear (COF-0.080). With this anti-wear additive, the vegetable oils (COF- 0.084) have showed its productivity as a potential candidate to be used as an alternative lubricant in metal forming even though there is still much room for improvement.*

Keywords: *Tribological, Canarium Schweinfurtii, Paraffin Oil Blend, Metal Forming Lubricant; Friction*

INTRODUCTION

Manufacturing, an integral part of civilization is the process of transforming a substance into a more valuable item by altering its shape or qualities. Metal forming processes are used to produce structural parts and components that have widespread applications in many industries. Similarly, Metalworking process is a shaping operation that can be viewed as deformation and material removal processes (Rizvi 2009; Groover, 2010).

In metalworking, lubricants control the interfacial flow of the material, friction and the final surface quality of the product to be formed (Heide and Schipper, 2006). Generally, metalworking operations involve high pressure, temperature, friction and wear which have negative consequences on tool life and high energy consumption. (Rizvi et al., 2009). Friction is required in metal forming applications such as deep drawing, stamping, rolling, and cutting. Wear is the result of two surfaces rubbing against each other, and more precisely the removal and deformation of the surface as a result of the rubbing motion. To reduce friction and wear, a lubricant is usually applied to the contacting surfaces. It reduces the level of high temperature and pressure that may arise due to rubbing contact. The function of the lubricant in metal forming is to control these parameters through lubrication, cooling and protection against corrosion and to increase the efficiency (Rizvi *et al.*, 2009). Mineral oil as commercial oil has been used in various lubrication applications over the years but has its disadvantages such as poor biodegradability, its high rate of pollution in the eco system, high level of inflammability (i.e. when two surfaces in contact at high temperature and pressure, it tends to catch fire). Vegetable oil, a common source of lubricating oil which has being considered for their suitability as industrial lubricant which is less toxic to the ecosystem.

Canarium schweinfurtii oil, which is a case study as the base oil has high content of fatty acid which may greatly reduce the friction coefficient. With this in mind, research on bio lubricants as a commercial lubricant alternative to mineral oil is gaining traction. Bio lubricants are absolutely biodegradable and less toxic which means they are more environmentally friendly (Aluyo, *et al.*, 2009; Luna, *et al.*, 2011). As a result of this, a tribological study of vegetable oil lubrication is required in order to examine their potential usage as bio lubricants in metal forming process. Running the test in its pure oil state is critical to determining the potential of vegetable oils as bio lubricants. This is significant because base stocks have a significant impact on the chemical and tribological properties of fluid lubricants (Srivastava, *et al.*, 2015). The following pure vegetable oils have been tribologically evaluated: coconut oil (Jayada, *et al.*, 2007), safflower oil (Carlton, *et al.*, 2015), corn oil, rapeseed oil (Arnsek *et al.*, 2000), jojoba oil (Biresaw *et al.*, 2003), olive oil, castor oil (Gerbig *et al.*, 2004), palm oil (Masjuki *et al.*, 1999) and soybean oil (Dodos, *et al.*, 2010). Only a few of the tribological investigations conducted on vegetable oils provide a scientific basis to back up their friction and wear findings. Using a reciprocating ball-on-disc tribometer, a comparative analysis of sixteen commercial pure vegetable oils with mineral lubricant and synthetic esters was done (Gerbig *et al.*, 2004). Gerbig simulated two wear mechanisms with a ball-on-disc contact; the adhesive mechanism by using same material for ball and disc (AISI 52100) and abrasive mechanism by using alumina (Al2O3) as the disc. It was found that under the test's representative of adhesive wear, only linseed, olive, walnut and safflower oils showed a stable low friction coefficient (COF ~ 0.11) while the rest of the oils presented unstable friction curves. While olive and safflower oils gave the lowest friction, their wear result also gave the lowest value in wear resistance. However, the vegetable oils were far behind from the mineral oil and synthetic esters in terms of friction and wear performance. However, in terms of wear, significant differences were found in which sesame and castor oils showed the least abrasive wear damage. Gerbig's tests concluded that the tribological performance of the vegetables oils depends strongly on the tribosystem (material used and contact condition).

Another comparative study of vegetable oils performance has been that of (Reeves *et al.*, 2015) on the influence of fatty acids on tribological performance. Their research used pin-on-disc testing in ambient conditions to try to relate the fatty acid content with friction and wear in eight different vegetable oils. By creating the unsaturation number (UN), which refers to the average amount of double bonds, Reeves established a standard for assessing fatty acid contents in vegetable oils. It was found that the avocado oil with the lowest in unsaturation level (UN = 0.985) shown the best tribological performance with the lowest friction (COF= 0.0201) and wear (0.1037 mm3) when compared to other vegetable oils. Contrary to this, soybean oil with UN = 1.451 showed higher friction (COF= 0.4059) and wear (0.3839 mm3). They concluded that the friction and wear could be reduced through formation of a monolayer which serves to minimize the metal-to metal contact by saturated and monounsaturated fatty acids (oleic acid in avocado oil) (Fox *et al.*, 2004). More double bond presence in the fatty acids (linoleic acid in soybean oil) however, decreased the density of the fatty acid monolayer (Reeves *et al.*, 2015).

A blend of oil can be made by combining two or more oils to achieve the desired results. For example, a blend of two vegetable oils (palm oil and olive oil) with similar fatty acid composition and physicochemical properties such as melting point, viscosity, and iodine value (all of which are related to the blend ratio) can be made (Naghshineh *et al*., 2010). A commercial mineral oil was found to perform well in wear (Jayadas *et al*., 2007) (Gerbig *et al*., 2004), friction (Masjuki *et al*, 1999), and oxidation stability (Luna *et al*., 2011) compared to vegetable oil. Mineral oil outperforms vegetable oils, especially in terms of wear resistance (Gerbig *et al*., 2004) has led to an interest in understanding on its tribological response, after an amount of vegetable oil is added into it. A mixture of mineral oil with vegetable oil exhibited different responses at different blend ratio (Jabal *et al*., 2014) and material combination (Shahabuddin *et al*., 2013). Using four-ball-tribotester, (Jabal *et al*., 2014), it was reported that a blend of palm oil and mineral oil (SAE 40) demonstrated the lowest friction coefficient (0.053) at a 60:40 blend ratio while the wear resistance was the best at an 80:20 blend ratio. Contrary to this, when the mineral oil (SAE 40) blended with jatropha oil tested by pin-on-disc (aluminum pin and cast-iron disc), (Shahabuddin *et al*., 2013) found that the friction coefficient and wear were lowest at a 0:100 ratios which means the addition of vegetable oil gave no improvement in friction. However, by using a different test rig (four ball tester – chromium steel ball), a mineral oil-jatropha oil blend showed the best performance in friction and wear at a 10:90 ratios when tested at an extreme pressure condition (Shahabuddin *et al*., 2013). Commercial mineral oils are those mineral oils blended with additives. Additives are synthetic chemicals which serve to improve existing properties or introduce new properties in the base oil. Additives may represent about 1 to 25% of a lubricant (Rizvi, 2009).

MATERIALS AND METHODS

2.1 Materials

The material used in this research includes *canarium schweinfurtii* fruit, paraffin oil, alluminium alloy. Instruments and equipment used are listed out in Table-1;

Table-1 List of equipment and materials

S/N	Name of equipment	Description	Location
1	Charcoal furnace	Casting of alluminium alloy test piece	foundry house, ABU zaria
2	Lathe machine	Turning operation (i.e. 30x10mm) for each test piece	Machine workshop, ABU zaria
3	Sand paper (Grain size 120mm)	hand grinding	metallurgy lab., ABU zaria
4	Weigh balance	To measure weight of sample at different ratio	metallurgy lab., ABU zaria
5	Anton paar ball-on-disc tribometer	Friction coefficient and wear rate test	LNG multi-user, ABU, zaria

2.2 Method

The research was carried out under the following categories; material Collection and preparations of *canarium schweinfurtii* fruit, Extraction of *canarium schweinfurtii* oil, Determination of chemo-physical properties of *canarium schweinfurtii* oil, Lubricant formulation, Preparation of aluminium alloy test piece, characterization of bio-lubricant and optimization of tribological behavior of the bio-lubricant.

2.2.1 Material Collection

The ripe black *Canarium schweinfurthi*i fruits were purchased from Toff village in Plateau state. A total of about 50kg of the fruits was collected from the tree with history of high oil production. The ripe fruits were harvested by hand plucking on the tree tops at morning hours when temperatures are low. The fruits were taken to the laboratory for analysis.

Fig. 1 *Canarium schweinfurtii* fruits

2.2.2 Preparation of Canarium Schweinfurthii Fruit

For the oil extraction, the harvested fruits were first sorted to remove foreign materials, unripe and infected fruits. The fruits were washed with table salt solution for 15 minutes and rinsed extensively with sterile tap water. These were followed by these other processes;

i. Pre-warming
ii. Half drying
iii. Mashing
iv. Fermentation
v. Decantating and
vi. Sieving

2.2.3 Determination of Chemo-Physical Properties of Canarium Schweinfurtii Oil

A. Moisture Content

The moisture content of *canarium schweinfurtii* oil was determined in accordance with ASTM D7546 (2021) to identify the free and emulsified water present in the oil. It was determined by pouring 10kg of the oil into an empty crucible and weighed. The crucible with the content was placed in an oven at 105^{o}C for 1 hour. It was removed after an hour and reweighed after cooling to room temperature. To calculate for moisture content;

$$\text{Moisture content } (\%) = \frac{m_1 - m_2}{m_1} \times 100 \qquad (1)$$

Where,
m_1= mass of the test specimen before drying (kg)
m_2= mass of dried specimen (kg)

B. Free Fatty Acid

The free fatty acid of *canarium schweinfurtii* oil was determined in accordance with AOAC (2000) to identify and quantify the free fatty acid (FFA) in edible and non-edible oil. The oil of 5kg was weighed into 100 ml of hot neutralized ethanol and 3 drops phenolphthalein indicator was added and titrated with 0.1M sodium hydroxide. Free fatty acid was calculated using equation;

$$\text{FFA value} = \frac{28.05VN}{W} \qquad (2)$$

Where,
V = Titrated value of sodium hydroxide (cm^3)
N = Normality of sodium hydroxide
W = Sample weight (kg)

C. Iodine Value

The iodine value of *canarium schweinfurtii* oil was determine in accordance with AOAC (2000) method to measure unsaturation or average number of double bonds in fats and oil. It was analyzed by dissolving 0.1kg of oil in 15ml of carbon tetrachloride and stirring. The solution was mixed with 25ml Wij's solution and stayed in the dark at room temperature for 30 minutes. Distilled water of 100ml and 20ml of 10% (w/v) of potassium iodide were then added to the mixture. It was then titrated with 0.1ml sodium thiosulphate using 10% (w/v) starch indicator. The titration continued until light blue colour was observed. The iodine value was then calculated using this equation;

$$\text{Iodine value} = \frac{12.69(B-S)N}{W} \tag{3}$$

Where,
B = Titrated value of sodium thiosulphate used for blank
S = titrated value of sodium thiosulphate used for sample
N = Normality of sodium thiosulphate
W = Sample weight (kg)

D. Refractive Index

The refractive index of *canarium schweinfurtii* oil was determined in accordance with ASTM D1218-01 (2001) to measure the refractive indices. It is the degree of refraction of a beam of light that occurs when it passes from one transparent medium to another with Digital Abbe's refractometer Model DRA-1. The oil was smeared on the lower position of the refractometer, after some adjustment, the refractive index was read directly at room temperature (25^{o}C).

E. Saponification Value

The amount of potassium hydroxide (KOH) in milligrams required to saponify one kilogram of oil which is determined in accordance with ASTM D5558-95 (2001) method. The oil of 10kg was weighed into 250ml conical flask. Potassium hydroxide solution of 25 ml was added using pipette. The flask content was thoroughly stirred and then connected to reflux condenser to boil for one hour for complete saponification. The cooled content was titrated with hydrochloric acid of 0.5M using phenolphthalein indicator. The value was calculated using:

$$\text{SAP value} = \frac{56.1\ (B-S)N}{W} \tag{4}$$

Where,
B = Titrated value of hydrochloric acid used for blank (cm^3)
S = titrated value of hydrochloric acid used for sample (cm^3)
N = Normality of hydrochloric acid
W = Sample weight (kg)

F. Perioxide Value

The peroxide value of *canarium schweinfurtii* oil was determined in accordance with AOCS (2016) method by dissolving 0.1kg of oil in 15ml of carbon tetrachloride and stirring. The solution was mixed with 25ml Wij's solution and stayed in the dark at room temperature for 30 minutes. Distilled water of 100ml and 20ml of 10% (w/v) of potassium iodide were then added to the mixture titrating iodine liberated from potassium iodide with 0.1ml sodium thiosulphate using 10% (w/v) starch indicator solution. Oils POV below 10meq/kg are considered fresh. The peroxide value were then calculated using this equations

$$\text{POV} = \frac{0.1(S-B)N}{W} \tag{5}$$

Where,
B = Titrated value of sodium thiosulphate used for blank
S = titrated value of sodium thiosulphate used for sample
N = Normality of sodium thiosulphate
W = Sample weight (kg)

G. Acid Value

The acid value of *canarium schweinfurtii* oil was determined in accordance with ASTM D664-18 (2018). The oil of 1kg was weighed into 25ml of isopropyl alcohol in a 250ml conical flask. The solution was titrated using 0.1M potassium hydroxide (KOH) and 3 drops of phenolphthalein was added with constant stirring until a persistent colour appeared. The titer value obtained was used to calculate the acid value using the equation;

$$Acid\ value = \frac{56.1\,VN}{W} \tag{6}$$

Where,
$V = Titre\ value\ of\ potassium\ hydroxide\ used\ (cm^3)$
$N = Normality\ of\ potassium\ hydroxide$
$W = Sample\ weight\ (kg)$

H. Flash Point

The flash point of *canarium schweinfurtii* oil was determine in accordance with ASTM D93-02a (2003) by heating the oil in a container and then introducing a small flame just above the oil surface. The temperature at which an instantaneous flash occur was taken immediately and recorded as a flash point. The fire point is that temperature at which the vapor of the oil burns constantly for 5 seconds when flame is brought near.

I. Pour Point

The pour point of *canarium schweinfurtii* oil was determine in accordance with ASTM D97-05 (2005) by placing the oil sample into a vessel and pre-heated. The lubricant was poured into a test tube and placed in a refrigerator to solidify. The oil was removed after it solidifies and the temperature at which the solidified oil starts to melt and flow was measured using thermometer.

J. Cloud Point

The cloud point of *canarium schweinfurtii* oil was determine in accordance with ASTM D2500 (2017) to indicates the temperature at which the oil begins to cloud resulting from crystallization under controlled cooling. The temperature at which a cloud of crystals first appear when the oil is cooled is the cloud point.

K. Specific Gravity

The specific gravity of *canarium schweinfurtii* oil was determine in accordance with ASTM D1298-17 (2017) by dividing the weight of a unit volume of the oil by the weight of equal volume of water in kilograms. The oil of 5 ml was poured into a weighed beaker and weighed. The specific gravity was determined from the sample weight by using the ratio of weight of the bio-lubricant to the known volume (5 ml).

$$\text{Specific gravity} = \frac{W}{w} \tag{7}$$

Where,
W = weight of a unit volume of the oil (kg)
W = weight of equal volume of water (kg)

L. Viscosity

The viscosity of *canarium schweinfurtii* oil was determined in accordance with ASTM D445-15a (2015) method to measure the oil at high temperatures. This method covers the determination of kinematic viscosity using Smart series rotational viscometer TSML 21105. The viscosity was measured at three different temperatures 28ºC, 40ºC and 100ºC. At a start a proper viscometer spindle was chosen. The samples were transferred to a beaker large enough to hold the viscometer spindle. The beaker was placed on a heating mantle set to a desired temperature, while the temperature of the samples was raised. The viscosity was read at the desired temperature. The spindle was joined to the upper coupling by holding the coupling between the forefinger and thumb while the spindle was cautiously rotating counter clock wisely. The knob was set to the minimum speed. The spindle was immersed into the sample up to the middle of the identification in the shaft. The viscometer was turned on and allowed to run until a constant reading (usually 5 to 10 revolutions) was attained.

$$Viscosity = reading\ obtained\ x\ \frac{factor\ for\ the\ spindle}{speed} \tag{8}$$

M. Lubricant Formulation

The vegetable oil (*canarium schweinfurtii* oil) was mixed individually with 25% by Volume of paraffin oil as addictive to the base oil. This percentage of addictive was added to consecutive blend of different samples to the desired fraction blend. These correspond to a 4:0, 1:1, and 1:3 blend ratios. The mixed oil was blended in a different sample cups and scaled using weigh balance to achieve 4grams for each sample at different fraction blend just before the test was run. The uniformity of each blend was judged by visual appearance of the oil in which no significant layer was seen in the oil blends. The blend of *canarium schweinfurtii* oil and Paraffin oil was then stirred for few minutes and then applied on the aluminium alloy piece surface for testing. This was to ensure that the stirring process was reliable.

N. StatisticaL Analysis

This statistical analysis was done to consolidate and analyze the distinct samples of data at different run order for each level of percentage fraction by volume.

$$\text{Class interval (CI)} = \frac{R}{h} \tag{9}$$

Where,

R= maximum ratio (%) − minimum ratio(%)

h= number of samples

$$\text{CI}= \frac{25-0}{10}= 2.5$$

Two factors, which are; paraffin oil (Pa) and African elemi (AE)

1 levels each = 0, 25, 100
3^2= 9 Runs

Table-2 Statistical analysis

Standard order	Run order	Point type	Blocks	Pa (%) by volume	AE (%) by volume
7	1	1	1	2.5	97.5
3	2	1	1	5	95
1	3	1	1	7.5	92.5
4	4	1	1	12.5	87.5
2	5	1	1	17.5	82.5
9	6	1	1	20	80
6	7	1	1	22.5	77.5
5	8	1	1	10	90
8	9	1	1	50	50

2.3 Friction Test

The anton paar tribometer (Fig. 2) was used for measuring the friction force by means of a calibrated load cell. The coefficient of friction (COF) was then calculated based on the friction force and the normal load applied. The Tribometer software aids in calculating the wear, by multiplying the profile area with the value of the circumference of the wear track to define the total disk-wear volume. The profile of the wear track can provide valuable information about the wear mechanism of the system. The linear reciprocating motion on the tribometer resembles the drawing of a work piece in a die. However, a point contact (ball-on-disc) was chosen in this study in order to eliminate misalignment problems at the sliding surface of the contacting bodies. All of the tests were run at an ambient temperature of 29℃ by means of programmable temperature controller. This was to replicate the oil temperature on friction force and effect of metal flow. A linear speed of 10.00cm/s and a stop condition of 50.0m was selected and the test duration was 8 minute. All test parameters were selected based on preliminary experiments conducted to ensure the production of measurable and comparable wear scars between the test piece lubricated with vegetable oils and mineral oil. Thus, a normal load 8N (yield to a 0GPa Hertzian contact pressure) applied to the ball was selected based on trial and error. The scope of this research was to run the test at only one set of test conditions so that the study could be focused on the response of the lubricants on friction and wear. The tests were run on plain test piece, lubricated with base oil and blended oil at different ratio and the average friction coefficient were then calculated. The standard deviation was calculated and plotted in the graphs.

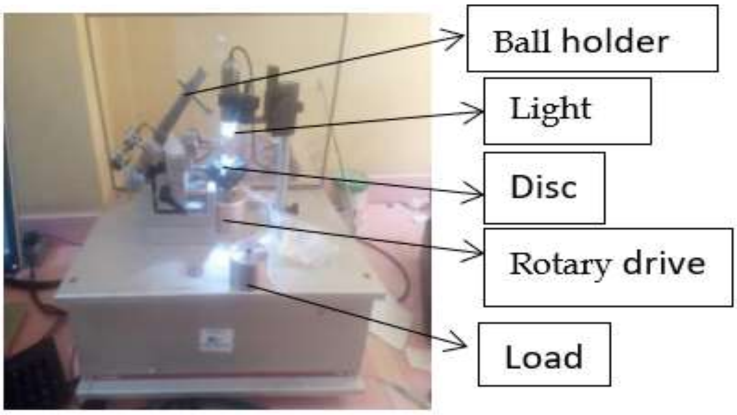
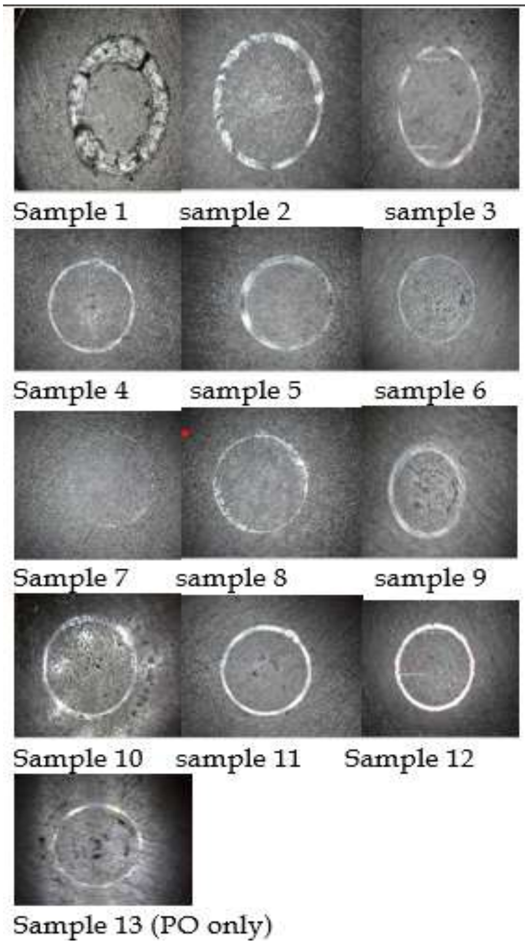


Fig. 2 Anton paar tribometer

The friction tests performed was aimed to simulate the environment in metal forming process. And due to the limitations of time, test conditions and parameters were chosen on the anton paar tribometer that may represent extreme contact conditions between the work piece and the contacting surface. The selection of the experimental parameters are; type of Contact, test piece materials, normal load and contact pressure, linear speed, experiment time, and ambient temperature**.**

2.4 Wear Surface Evaluation

After each test was completed, the AL-alloy test piece was removed from the tribometer and the surface was thoroughly cleaned ensuring that the used lubricant is depleted with the aid of tissue paper. The test piece was then inspected under an optical microscope in order to obtain images of the wear scars in a broader view. Scanning electron microscopy (SEM) was used to inspect the worn piece at a much higher magnification than the optical microscope. The images taken from the microscope were then used for analyzing the underlying wear track session on the surfaces. The formation of round wear scars after the tests (Fig. 3) that mainly occurred on the AL-alloy test piece lubricated with the vegetable oils and their blends has driven the importance in evaluating the surface topography.


Sample 1 sample 2 sample 3

Sample 4 sample 5 sample 6

Sample 7 sample 8 sample 9

Sample 10 sample 11 Sample 12

Sample 13 (PO only)

Fig. 3 Wear scars on each AL-alloy test piece samples.

To calculate for wear track section of the wear surface;
Let A = Overall area of the wear track/scars
20000 = Modification standard
WT = Worn track session
Area (A) = maximum diameter/ minimum diameter
Now,

$$WT = A/20000 \quad (10)$$

RESULTS AND DISCUSSION

The tribological test carried out on the *canarium schweinfurtii* oil, paraffin oil and blended lubricant was to observe the potential use of above mentioned in metal forming. This test was done to determine the chemo-physical properties of *canarium schweinfurtii* oil, friction coefficient, wear track section of the specimens.

Table-3 Chemo-physial properties of *canarium schweinfurtii* oil

S/n	Parameter	*canarium schweinfurtii* oil
1	(%) Moisture content	24
2	(%) Free Fatty acid	1.84
3	Refractive index	1.4619
4	Iodine value (wij's)	89.44
5	Saponification value (KOH/gm)	162.66
6	Peroxide value (mKq/kg)	22.01
7	Acid value (mgKOH/g)	3.83
8	Specific gravity	0.98
9	Viscosity (cSt)	0.61
10	Flash point (°C)	98
11	Cloud point (°C)	9
12	Pour point (°C)	5

Table-4 Average coefficient of friction and standard deviation at 8 min

Sample	Max. COF (μ)	Min COF (μ)	Mean COF (μ)	Standard deviation
1 (plain)	1.045	0.085	0.766	0.056
2 (AE only)	0.160	0.074	0.084	0.007
3	0.163	0.032	0.073	0.009
4	0.167	0.050	0.057	0.011
5	0.158	0.004	0.092	0.019
6	0.162	0.070	0.082	0.010
7	0.175	0.074	0.080	0.008
8	0.125	0.021	0.083	0.004
9	0.179	0.017	0.113	0.005
10	0.121	0.006	0.073	0.006
11	0.142	0.041	0.076	0.006
12 (1:1)	0.147	0.013	0.080	0.007
13 (PO only)	0.126	0.023	0.081	0.007

Table-5 Wear track section

Sample	Worn track section (μm^2)	Wear rate ($mm^3/n/m$)
1 (plain)	1156122.1	0.09079
2 (AE only)	432240.8	0.03394
3	327490.7	0.02572
4	184661.7	0.0178
5	415246.7	0.03261
6	116817.5	0.009174
7	84515.6	0.006637
8	109090.4	0.008567
9	372211.9	0.02923
10	360760.2	0.02742
11	290306.1	0.0228
12 (1:1)	382739.5	0.03006
13 (PO only)	260672.8	0.02047

The result in Table-3 is the test value obtained from standard method mention. For Table-4, the mean coefficient of friction was computed by the summation of maximum and minimum coefficient of friction and dividing it by the number of coefficient of friction. The least value obtained from minimum coefficient of friction indicates just when the static load (ball) begins to come in contact with the aluminium alloy test piece during the running-in operation which explains that there's high viscosity in the blended oil even at high pressure and temperature. Table-5 shows the wear track session value of the test piece after eight minutes of testing for each lubricant and their related wear rate value. The 85% of *canarium schweinfurtii* oil blend with 15% of paraffin oil applied on the test piece had a superior wear resistance and 92.5% of *canarium schweinfurtii* oil blend with 7.5% of paraffin oil is best for low friction coefficient. It was observed that although the mineral oil had a superior performance in preventing wear compared to the pure vegetable oils, the addition of 50% mineral oil in the vegetable oils did not greatly influence the wear resistance result of the blended oils. Fig. 4 shows the Bar graph showing the Average Coefficient of Friction at 8 min under tribological test. The tribological test result on this bar graph indicated that at a normal load of 8N which was added to the ball and covered at 50m (i.e.in 8 minute), the *canarium schweinfurtii* oil only gave a better friction coefficient which only has a slight difference with that of the paraffin oil. The blended oil gave a much better lubricating efficiency (i.e. lower COF). The mean coefficient of friction on plain surface only gave 0.766μ and the lowest mean coefficient is AE: PO (i.e. blended oil at equal ratio) which gave 0.080μ, followed by paraffin oil with 0.081μ and *canarium schweinfurtii* oil with 0.084μ. The fatty acid contents of the investigated oil aided in the reduction of coefficient of friction under the tribological test condition. *canarium schweinfurtii* oil contains mainly saturated fatty acid (71% of palmitic acid and unsaturated fatty acid like 18% oleic acid). The high amount of palmitic acid is responsible for high reduction capacity under *canarium schweinfurtii* oil condition.

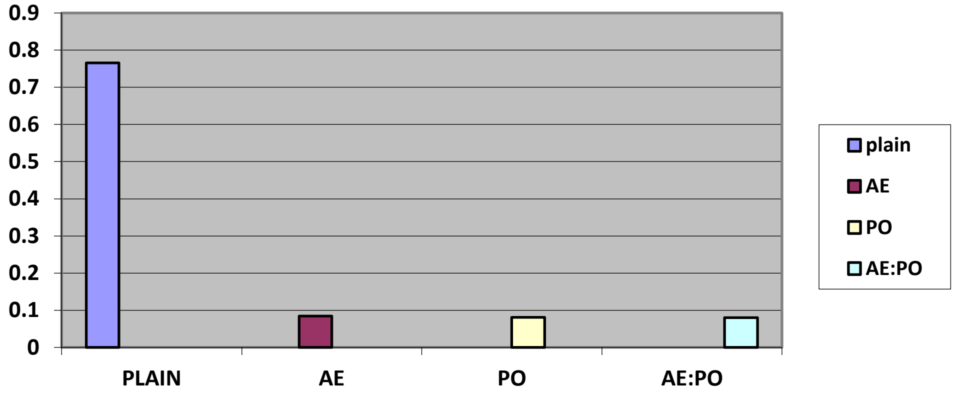


Fig. 4 Bar graph showing the average coefficient of friction at 8 min under tribological test

Fig. 5 A graph of coefficient of friction versus the duration of time (sample 1)

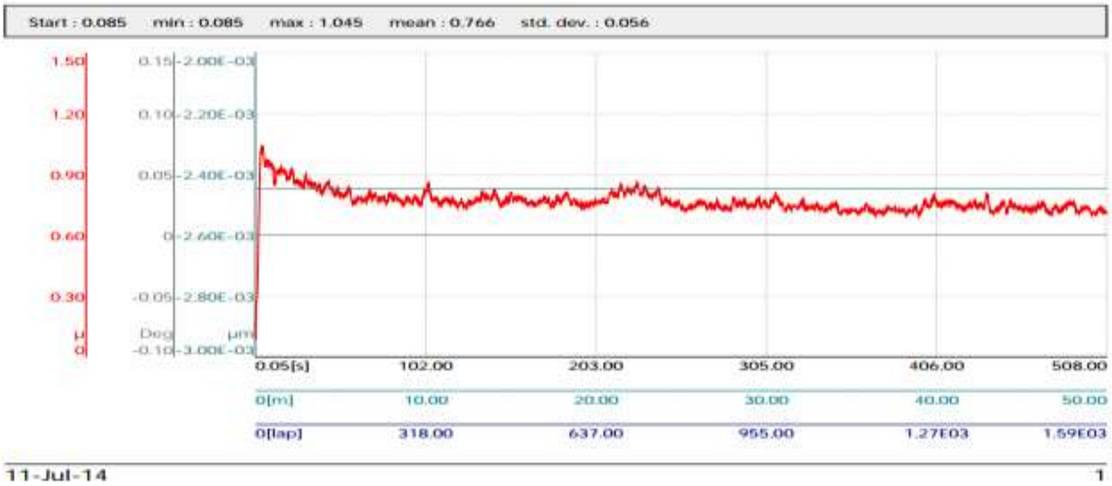


Fig. 6 A graph of coefficient of friction versus the duration of time (sample 2)

The graph of friction coefficient against the duration of time is presented in Fig. 5 and Fig. 6. The coefficient of friction decreases with increase in time for *canarium schweinfurtii* oil, paraffin oil and mixed oil at different sample ratio except for plain which initially increase to 1.045 at high coefficient of friction. The presence of palmitic and oleic acid as shown in table 2 coupled with the increase in temperature which promotes fast reaction of the fatty acids with the mating surfaces should have led to the reduction in coefficient of friction. Any increase in deformation give rise to increase in temperature which leads to a faster reaction rate of fatty acid and as the pressure of the load increases, the thickness of the lubricant film decreases thereby exhibiting greater resistance to wear. From the graph, *canarium schweinfurtii* oil gave the mean coefficient of friction of 0.084 and standard deviation of 0.007. The fatty acid composition of the oil adapted from Lou *et al.,* (2011) are presented in Table-2 and the chemo-physical properties of the oil are presented in Table-3. The high performance of *canarium schweinfurtii* oil can be attributed to the fact that the oil contains high percentage (71%) of palmitic acid. The major limitation of unsaturated fatty acid is their low oxidative stability due to the breakdown at the bonds of unsaturation (Oche, 1992). This stability might have given room for the unsaturated fatty acid components of the oil to improve its performance. The lubrication efficiency of the oil followed the increasing order of their saponification value, since it is a measure of the mean chain length of the fatty acid as it follows that *canarium schweinfurtii* oil with the saponification value of 162.66 KOH/mg gave a low coefficient of friction.

CONTRIBUTION TO KNOWLEDGE

From the output of this study, vegetable oil has indeed brought out its level of potential usefulness which can serve as alternative lubricant in metal forming application. Beside the inherent advantages that they have, like renewable base stock, biodegradability and non-toxic oil. Vegetable oil have shown competitiveness in friction and wear resistance.

CONCLUSION

Results from this study provide a base data for the tribological performance of *canarium schweinfurtii* oil and paraffin oil can be used to support the establishment of bio-lubricants as well as encourage the ongoing research on using renewable natural source as alternative lubricants.

CONFLICT OF INTEREST

There is no conflict of interest for this research work.

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