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Characterisation of Canarium Shweinfurthi (African Elimi) Pulp Enrich with Boron Nitride as Lubricant in Metal Forming

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Abstract: *The negative effects on the ecosystem created by the use of mineral-oil-based lubricants and the depleting stock of petroleum had overtime overridden their functions on metal forming. This has motivated research works on alternative lubricants considered as biolubricants. The tribological behavior of bio-lubricant developed from African Elimi(Canariumschweinfurthii) pulp with additive blend of boron nitride was evaluated through Ring Compression Test. The African Elimi (Canariumschweinfurthii) pulp was separated from the main fruit through the traditional method and developed to lubricant. Lubricants developed from the pulp and oil of the African Elimi were blend with Boron Nitride at 0.02% to 0.4% by weight. The tribological properties of the lubricants was evaluated through Ring compression Test and it was established that 0.068 g of Boron Nitride gave the best result in frictional factor and coefficient at 0.2 and 0.08 respectively. This was against the result of the lubricant without additive and mineral oil with frictional factors of 0.3 and 0.4 and coefficients at 0.10 and 0.12 respectively. The presence of boron nitride greatly influenced the performance of the lubricant in friction.*

Keywords: *Tribological, Evaluation, Canarium Shweifurthi Pulp, Lubricant, Ring Compression Test*

INTRODUCTION

Development efforts have been made over the years for cold extrusions of non-ferrous metals such as aluminum using standard lubricants like petroleum oils and greases (Bottema, 1998). These development efforts were carried out with a view to reducing friction and for improving extrusion parameters such as extrusion ratio, extrusion load and surface finish (Liliang, 2012; Maduelosi & Angaye, 2015).

The use of these petroleum oils as coolant and lubricants in metal cutting and metal forming applications have achieved high quality manufacturing operations (Kasolang, 2012; Mbishida *et al.*, 2018). However, the use of these mineral oils and greases in cold extrusion at higher ratios adversely affects the surface finish and stress-strain distribution of the extruded metal (Huyett, 2014; Maduelosi & Angaye, 2015). The chemical reactions which take place as a result of friction and heat generated between the billet and the die further increase the extrusion pressure (Rajivand Satish, 2006). Furthermore, mineral-based lubricants produce negative effects on the ecosystem. This singular fact has overtime overridden their functions in metal forming process. Research work has continually been carried out to discover new lubricants that are process, human and eco-friendly (Syahrullail *et al.*, 2013). Possible alternative materials are oils or fats of vegetable or animal origin. They are nontoxic; highly biodegradable, and have excellent lubricating properties

Woma, (2019) reported that vegetable oil is much desired for its application as lubricant in metal forming process because it does not affect the chemical composition of the work piece and the environment; it has high biodegradability compared to mineral oils. Furthermore, Syhrullail *et al.* (2011) and Woma, (2019) also affirmed that introduction of additives in vegetable based lubricants improves further the sliding performance of cold extrusion. Several research studies have been carried out on the use of lubricants developed from vegetable oils in the cold extrusion of aluminum alloys**.** Moveh, (2014) developed lubricant from castor seed, neem seed, jatropha seed and cotton seed oils in the extrusion of aluminum with different die shapes. The effect of the lubricants on extrusion in terms of heat reduction, coefficient of friction and surface finish was found to compete favorably with the existing mineral lubricants. Gaminana, (2011) evaluated neem (*azadirachtaindica*), tiger nut (*cyperusesculentus*) and false walnut (*canarium scheinfurthii*) oils as metal working lubricants in friction reduction in cold mild steel drawing and cold aluminum alloy rolling operation. Results of performance of the lubricants in both drawing and rolling showed an average coefficient of friction value of 0.12978 in the drawing test and a percentage reduction of 52.19 in the planestrain compression test. The coefficient of friction for neem oil, tiger nut oil and sodium stearate in drawing were, 0.23042, 0.19622 and 0.16108 respectively. The percentage reductions in plane-strain compression test for neem oil, tiger nut oil and paraffin were 47.0%, 51.5% and 41.1% respectively. Syahrullai *et at. (*2011) focused on palm oil as lubricant in cold forward extrusion of aluminum. The viability of palm oil used as lubricant was compared to additive -free paraffinic mineral oil with satisfactory lubricant performance and advantage in reducing extrusion load as compared to paraffinic mineral oil. Result of their work confirmed that the lubrication performance of palm oil lubricant was as effective as paraffinic mineral oil in its ability to reduce frictional constraint in a cold work extrusion. From the forgoing, it is clear that there is high demand for lubricants from vegetable sources to serve as alternative or replacement for existing mineral lubricants. However, there is also need for balance competing demands between food and industrial usage. In the present study, African elemi *(Canarium schweinfurthii)* fruit pulp has been investigated and evaluated as alternative material for lubricant development using boron nitride as additive in the cold extrusion of aluminum alloy. African elemi *(Canarium schweinfurthii)* fruit pulp that has enjoyed wide availability has not been formulated and used for any research as lubricant for cold extrusion of aluminum. The choice of boron nitride as lubricant additive is because of its excellent properties which can enable it to withstand extreme pressures and temperatures desired in metal forming processes.

Ring Compression Test

The ring compression test according to Mandić & Stefanović, 2003 and Dehghan *et al.*, 2013 is commonly used to evaluate forging lubricants (. The ring test consists of the deformation of a cylinder with a hole drilled through the center of the billet. The billet is compressed to various height reductions and the change in the inner diameter of the billet reflects the friction factor along the tool/work piece interface.

The higher the friction the more the inner diameter of the test piece is reduced. In low friction environments, the inner diameter of the billet increase Fig.1 (a, b, c). The frictional factor and coefficient are determined through the use of calibration curves shown in Fig.2 and 3.

(a) Original ring before compression (b) Ring after compression with high friction (poor lubrication

(c) Ring after compression with low friction (good lubrication)

Fig.1 Compressed rings

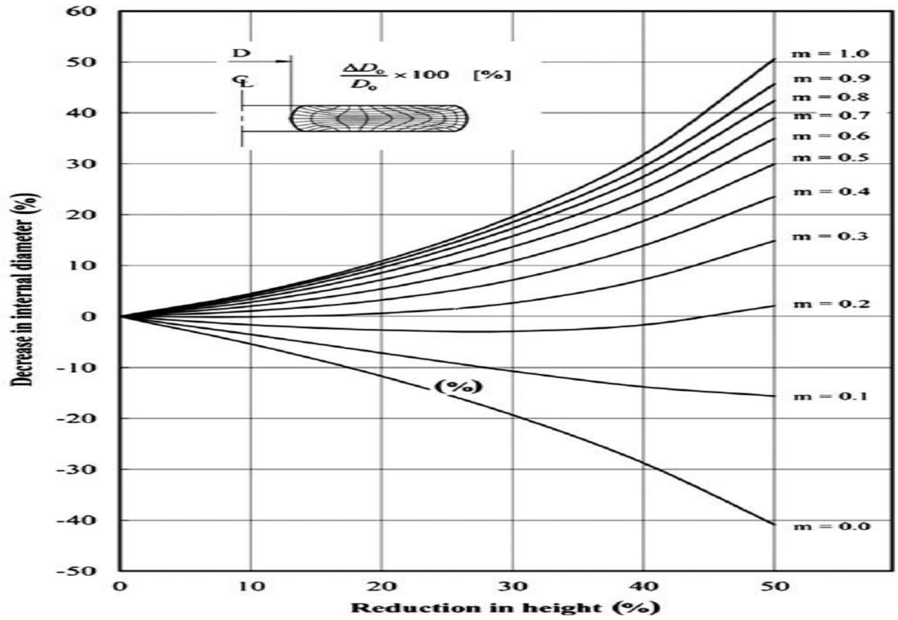

Fig.2 Typical calibration curves for Ring Compression test for shear factor (m)

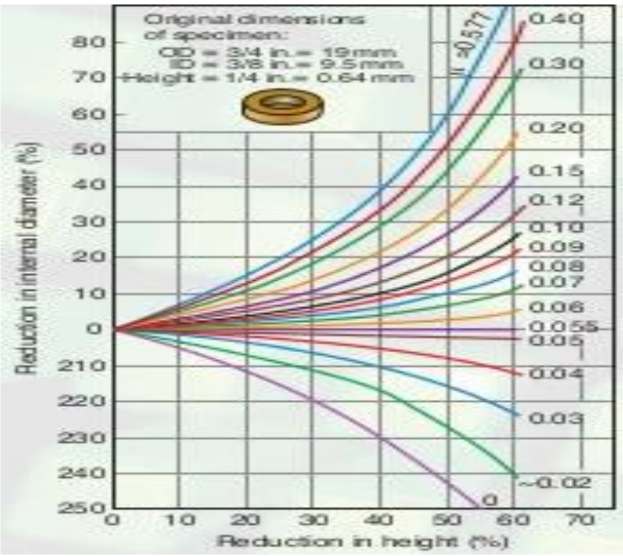

Fig.3 Typical calibration curves for Ring Compression test for frictional coefficient (µ

MATERIALS AND METHODS

2.1 Materials Collection and Preparation

Various components of the fruit (pulp, seed and oil) were separated using the traditional method as described by Nyam *et al.,* (2014). The cleaned fruits were completely steeped in warm water (45°C) for 15 minutes to soften the fruit mesocarp and then sundried for 3 days in cleaned trays. Subsequently, the steeped fruits were mashed into paste using cleaned wooden pestle and mortar. Then the paste formed was packed in a clean plastic bucket mixed with 20 liters boiled water at 100°C and fermented at room temperature (28 °C) for 48 hours. The foam and oil formed on top layer were skimmed and scooped out using sterile wooden spoon. Further, the three other component material (water, pulp and seeds) were sieved with cheese cloths to obtain the pulp. The pulp was dried in a ventilated oven at 40°C for 48hrs to flammable state. Phytochemical screening of the pulp was carried out according to method described by Sani and Hassan, (2007) to determine its constituents as they relate to lubricant formulation (Table-1). The pulp was burned to ash and leached (Babayemi & Adewuyi, 2010; Edah et al., 2017). Through a transparent plastic bottle of four Liter capacity and a baker placed at its base. Plastic bottles were filled with ashes to one-third of their volume and sufficient water was added to the ashes. Each bottle was capped and then shaken thoroughly to dissolve the ashes. The ash was allowed to settle, till a clear liquid was observed at the top. Four pin-holes were made at the bottom of the bottle and then placed on the beaker while the cap was removed. More ashes were added to the solution as it leaked into the beaker. The potash solution (Lye) obtained was clear and yellowish in color. The liquid lye was poured into a beaker and heated with a burner for four hours to evaporate the water content until high concentration of lye in paste form was obtained. Simple mouth and litmus paper tests were carried out to ascertain the concentration of the lye.

Table-1 Phytochemical Screening of *Canarium Shweifurthei* Pulp

Constituent	Wet Pulp	Dried pulp	Ashed pulp
Alkaloid	++	-	-
Saponuis	-	-	-
Tannuis	+	-	-
Flavonoids	++	+++	+
Carbohydrate	+++	++	-
Steriods	++	+++	-
Tapeues	-	-	-
Authraquinones	-	-	-
Cardiac glycosides	+	++	-

***- Present, ++ Moderately Present, +++ Highly Present**

2.2 Development of Lubricant

Development of lubricant from *Canarium shweinfurthi* pulp was done according to Adaku & Melody, (2013). The lubricant was prepared using lye from *Canarium shweinfurthi* pulp and extracted *Canarium shweinfurthi* oil. The lubricant was formulated according to method described by Underwood, (2008) and Edah *et al.,* (2017). The formulation of the lubricant was achieved by mixing concentrated lye of *Canarium shweinfurthi* pulp and *Canarium shweifurthei* oil in the same proportion (98g of concentrated lye to 98g of *Canarium shweifurthei* oil). The concentrated lye was poured into a stainless-steel pot and placed on a burner to be heated until it boiled. The *Canarium shweifurthei* oil was added to the boiled lye and stirred to mix thoroughly. The formulated lubricant was poured into containers to cool at room temperature.

2.3 Design of Experiment

Design of experiment (DOE) for this research was achieved using the software Design Expert (2010). The design of experiment was used in complementing multivariate data analysis, such as development of empirical models, optimization of the process variables and statistical analysis. It was used to obtain the sample size and optimal Lubricant and coefficient of friction. There were three design factors and two levels for the experiment that were used. The design factors for the lubricant were *Canarium shweifurthei* oil, water substance in the oil and Boron Nitride which served as additive. Boron Nitride was added to the lubricants at two levels (low and high) of 0.02% and 0.4%. This gave rise to three combination (three elements for lubricant formulation) at two levels (low and high levels of boron nitride) for the lubricant formulation (3^2). Run Order obtained in Table-2 gave rise to 8 experimental design order. Considering zero boron nitride, no lubricant condition and standard lubricant condition, the total number of experimental designs came to eleven. An additional sample number was added to make it twelve. Table-2 and 3 shows the experimental layout in orthogonal array and addition of boron nitride to the lubricant.

Table-2 Experimental layout in orthogonal array

C1	C2	C3	C4	C5	C6	C7
StdOrder	RunOrder	CenterPt	Blocks	A	b	c
2	1	1	1	0.40	0	0
7	2	1	1	0.02	50	50
4	3	1	1	0.40	50	0
8	4	1	1	0.40	50	50
6	5	1	1	0.40	0	50
3	6	1	1	0.02	50	0
5	7	1	1	0.02	0	50
1	8	1	1	0.02	0	0

2.4 Addition of Boron Nitride to Lubricant

Maximum quantity by weight of boron nitride added to the lubricant ranged from 0.02% to 0.4% as recommended by (Frank K & Handley, 2005; Çelik, 2013). Each of the lubricant sample was shared into twelve sample bottles. The lubricants were weight into the sample bottles at 31.5g. Sample of the lubricant was enriched with boron nitride as described in Table-3. The quantity of boron nitride to be added to every sample was determined according to Stephens and Spiegel, (2007).

$$Number\ of\ class = \frac{Range(R)}{Class\ Interval\ (h)} \tag{1}$$

Where Range R = Highest – Lowest = 0.4% - 0.02 = 0.38%
Class interval h = 10
Number of class = 0.038% = 0.04%

The calculated percentage of the boron nitride (0.04%) was added to the samples as shown in Table-3 and was obtained according to equation 1.

Table-3 Lubricant Formulation with Boron Nitride

Sample	Addition of boron nitride to the lubricant
1	Standaed Lubricant
2	No lubricant condition
3	Lub + 0.00 wt%BN
4	Sample3 + 0.02 wt%BN
5	Sample4 + 0.04 wt%BN (0.06 wt%BN)
6	Sample5 + 0.04 wt%BN (0.10 wt%BN)
7	Sample6 + 0.04 wt%BN (0.14 wt%BN)
8	Sample7 + 0.04 wt%BN (0.18 wt%BN)
9	Sample8 + 0.04 wt%BN (0.22 wt%BN)
10	Sample9 + 0.04 wt%BN (0.26 wt%BN)
11	Sample10 + 0.04 wt%BN (0.30 wt%BN)
12	Sample11 + 0.04 wt%BN (0.34 wt%BN)

2.5 Determination of Chemo-Physical Properties of the Developed Oil

The developed oil, African elimi oil was analyzed. The Quality Assurance laboratory of Grand Cereals Company located at Zawan Roundabout, Bukuru in Jos South Local Government of Plateau State, Nigeria was used for the laboratory test and the result shown in Table-4.

Table-4 shows the determined parameters of the oils

S/N	PARAMETER	DEVELOPED LUBRICANT FROM PULP
1	% Moisture content	65.04
2	% Free Fatty Acid	1.73
3	Iodine Value (wij's)	101.12
4	Refractive Index	1.4633
5	Saponification Value (KOH/gm)	99.29
6	Peroxide Value (mEq/kg)	5.30
7	Soap Value (ppm)	92.96
8	Acid Value(mgKOH/g)	3.44
9	Flash point (°C)	60
10	Cloud point (°C)	2
11	Pour point (°C)	-3
12	Specific gravity	0.85
13	Viscosity (cSt)	0.80

2.6 Tribological Test

A. *Preparation of Test Piece*

Ring Compression Test according Cockcroft, (1965) and Mandic, (2003) was adopted for this work using the (CBR) Californian Bearing Ratio. Aluminum alloy with properties shown in table-5 was prepared and used to produce the test rings. XRF (X-Ray Fluorescence) analyzer machine in National Metallurgical Development Center (NMDC), Jos was used to determine the detectable elements of the aluminum metal as shown in Table-5 and according to AZO Materials (2005) established the aluminum grade as 6063A. This was arrived at by comparing the detected element with the standard grade. The metal was machined to CBR (Californian Bearing Ratio) 6:3:1 outside diameter (D_o) to inner diameter (D_i) to Height (H) (42: 21:7mm) respectively using four jaw chuck lathe machine (Plate 1). Table-5 shows the various elements of aluminum alloy 6063A as detected by XRF (X-Ray Fluorescence) analyzer process.

Table-5 Various elements of aluminum alloy 6063A as detected by XRF (X-Ray Fluorescence) analyzer process

		Parameters (%)							
S/NO	SAMPLE	AL	S	K	Ca	Ti	V	Cr	Mn
1	Aluminum	99.00	0.02	0.02	0.03	0.02	0.003	0.03	0.15
	Alloy	Parameters (%)							
		Fe	Ni	Cu	Zn	Ga	Ba	Pb	
		0.41	0.005	0.05	0.03	0.01	0.009	0.004	

*Key: % = Percentage

Plate 1. Cast Aluminum Billet with Rings

B. *Compression of Test Piece*

The rings were compressed using 300KN capacity universal testing machine in NMDC, Jos Plateau State Nigeria. Three sample rings were compressed using each of the lubricant sample. The lubricant sample was applied on both sides of the ring and was placed between the compression platens of the Testometric machine Plate 2. A force of 270KN was applied on each of the ring at speed of 5 mm/min. Before the next oil was used for test the platens were cleaned with acetone (cleaning agent) using cotton wool. This was done in other to avoid mixture of oil samples at the cause of the experiment. Various compression parameters such as test number, time of test, area of test piece, force at yield, stress at yield strain at yield, force at peak, stress at peak, strain at peak, young modulus and modulus of elasticity were chosen on the machine desktop and subsequently computed and tabulated by the machine.

Plate 2. Test ring placed between upper and lower platen of Testometric Universal testing machine.

RESULTS AND DISCUSSION

Table-4 gives the determined parameters of the developed lubricant and the oil extracted from the fruit. The result gives the value of moisture content as 65.04% for the developed lubricant. This agrees to (Doris and Mary, 2001) who opined that vegetable lubricant used in metal forming as soap/fat paste has a formation of 5% soap, 25% oil and 25% water and 45% solid. It is further recommended that lubricant compound can also be liquid when diluted with water to the required concentration. The Acid Value of 3.44 according to Ioan, (2013) suggested that Low Acid value in oil or lubricant prevents the oxidation of oil which ultimately prevent corrosion hazards, gum and sludge formation. Acid value of 3.44mg KOH per gram further agrees with (Ioan, 2013) who suggested that Acid value for Gearbox and lube oil have acid value ranging from 0.1-10 mg KOH per gram. Iodine in lubricant helps to determine the amount of unsaturated fatty acids (Ebong, 2019). The higher the saturation tendency of oil the better its used for making soap. This research provided an Iodine value for the developed lubricant as 101.2g I_2/100g, this is higher to the finding made by (Ebong, 2019) for some vegetable oils where Groundnut oil > Olive oil > Palm oil > Palm kernel oil > Coconut oil all with iodine value lower than 100g I_2/100g. For an iodine value lower than 100, it is considered to be a non-drying oil which does not harden when it is exposed to air and therefore can be used industrially for the production of hard soaps and are of good nutritional value, hence the oils pose no significant health risks to consumers. Thus, the result of these findings shows that the iodine values obtained were both higher than the ones obtained for some vegetable oils (Groundnut oil, Olive oil, Palm oil, Palm kernel oil and Coconut oil) but lower than 120g I_2/100g recommended value for vegetable oils. The presence of palm kernel in the lubricant mixture justifies the reason for the iodine being greater than that of the other vegetable oils. This makes it more acceptable when compared to the other vegetable oils. The saponification value for the developed lubricant and extracted oil was gotten as 99.29 (KOH/gm). The result for developed lubricant is quite smaller to other vegetable lubricants like palm kernel and olive according to (Cavallaro, 2010). Extracted oil was used in the formulation of Lubricant. The high saponification value of palm kernel did not have much influence on the saponification value of the developed lubricant since the value still remain low. It suggests that the presence of boron nitride as additive to the lubricant could have caused the low value of saponification. This suggest that the developed lubricant does not have much foamability tendency. The extracted oil has high saponification value which is close to olive oil according to (Cavallaro, 2010).The higher the saponification value, the lower the fatty acids average length, the lighter the mean molecular weight of triglycerides and vice-versa. Practically, fats or oils with high saponification value (such as coconut and palm oil) are more suitable for soap making.

Results of refractive index of 1.4633 from this study agrees strongly to work by (Singh, 2002) who got 1.4782. The results were compared to other biolubricants like palm oil and Jatropha. Viscosity of the developed lubricant of 0.80 is also within the permissible range of biolubricants as it nears the finding by (Singh, 2002) who got 1.40. The result of pour point of -3°C agrees with -3°C by (Singh, 2002).

There is strong difference in flash point of 60°C obtained for the developed lubricant as compared with 273°C provided by (Singh, 2002). Results for tribological test for samples compressed during Ring Compression Test are found in Tables-7 to 8 and Fig.4 to 8. The results show the computed reduction in internal diameter and height of the compressed rings. The reduction in internal diameter and height were used to determine the frictional factor and frictional coefficient using the frictional and coefficient calibration curves (Fig. 2 and 3) as opined by (Dehghan *et al.*, 2013). The results show list frictional factor of 0.2 and frictional coefficient of 0.07 respectively. These results agree with that of (Oseni, 2012) where frictional factor range for rubber oil was given as 0.2 to 0.577 compared with values for reference mineral base oil of 0.29 to 0.42. This also falls within the range of some vegetable oils such as groundnut oil (0.072 to 0.5), palm oil (0.3) palm kernel oil (0.084) and shea nut oil (0.092).

Table-6 Quantity of Boron Nitride in grams.

S/No	Sample (g)	% by weight	Bn (g)
1	Ref Oil	Nil	Nil
2	No Oil	Nil	Nil
3	33.55	0.00	0.00
4	33.58	0.02	0.0057
5	33.58	0.06	0.017
6	33.89	0.10	0.035
7	33.63	0.14	0.045
8	33.55	0.18	0.057
9	33.30	0.22	0.068
10	33.58	0.26	0.085
11	33.38	0.30	0.096
12	33.45	0.34	0.1079

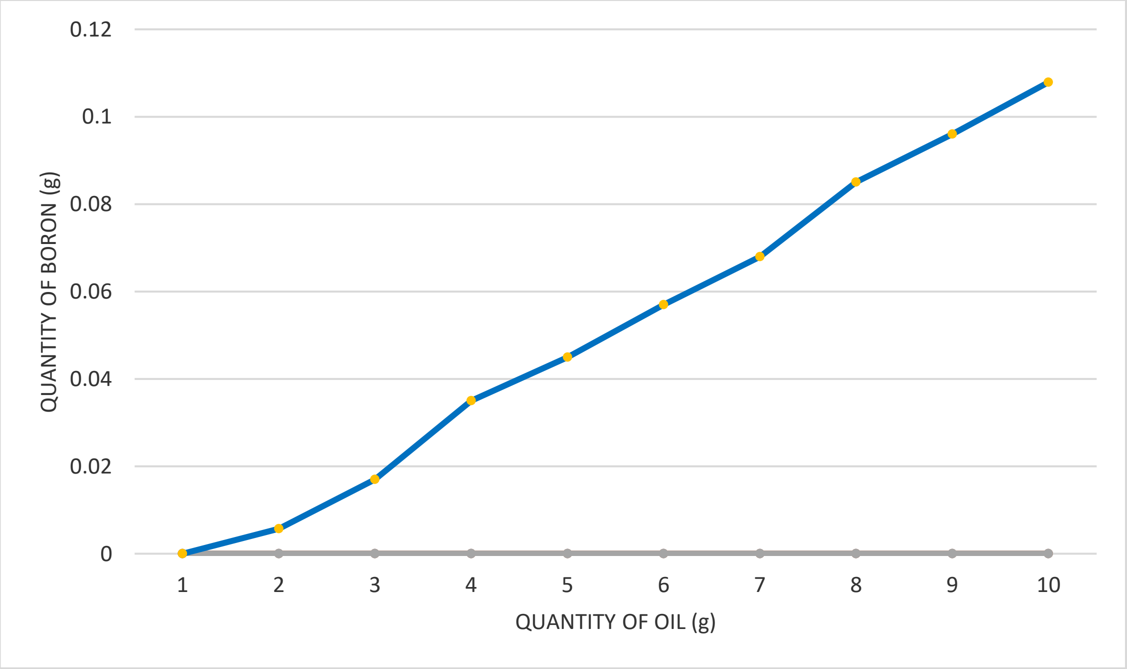

Fig.4 Quantity of Boron Nitride Added to the Lubricant

Table-7 Determination of percentage reduction in internal diameter and height

BN (g)	Do	Aved d_f	do - avgd_f	(do-avgd_f)/do	((do-avgd_f)/do)*100	H_O	Ave dH_f	HO-avgH_f	(HO-avgHf)/HO	((HO-avgH_f)/H_O)*100
Ref.Oil	22	19.63	2.37	0.11	10.76	7	4.6	2.4	0.34	34.29
No Lub	22	20.53	1.47	0.07	6.67	7	5.63	1.37	0.20	19.52
0	21.5	19.43	2.07	0.10	9.61	7	4.5	2.5	0.36	35.71
0.006	22	13.47	8.53	0.39	38.79	7	5.1	1.9	0.27	27.14
0.017	21.5	19.67	1.83	0.09	8.53	7	4.63	2.37	0.34	33.81
0.035	21.5	12.5	9	0.42	41.86	7	4.15	2.85	0.41	40.71
0.045	22	13.4	8.6	0.39	39.09	7	4.5	2.5	0.36	35.71
0.057	21	18.47	2.53	0.12	12.06	7	4	3	0.43	42.86
0.068	21	18.9	2.1	0.1	10	7	3.7	3.3	0.47	47.14
0.085	21.5	19.85	1.65	0.08	7.67	7	4.65	2.35	0.34	33.57
0.096	21	19.75	1.25	0.06	5.95	7	4.55	2.45	0.35	35
0.108	20.7	19.7	1	0.05	4.83	7	4.75	2.25	0.32	32.14

Table-8 Determination of frictional factor and frictional coefficient

BN (g)	REDUCTION IN INTNAL DMTR (%)	REDUCTION IN HEIGHT (%)	FRICTIONAL FACTOR (M)	FRICTIONAL COEFFICIENT (μ)
Ref. oil	10.76	34.29	0.4	0.12
No oil	6.67	19.52	0.6	0.15
0.00	9.61	35.71	0.3	0.10
0.006	8.18	27.14	0.4	0.12
0.017	8.53	33.81	0.4	0.10
0.035	12.79	40.71	0.3	0.12
0.045	8.64	35.71	0.3	0.10
0.057	12.06	42.86	0.3	0.10
0.068	10.00	47.14	0.2	0.08
0.085	7.67	33.57	0.3	0.10
0.096	5.95	35.00	0.3	0.09
0.108	4.83	32.14	0.3	0.08

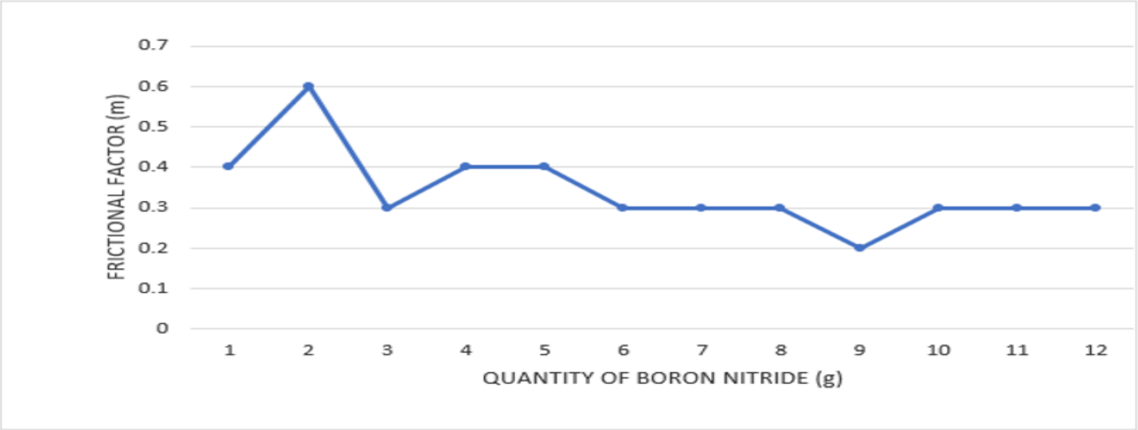

Fig.5 Result of frictional factor (m)

Note:
1=Ref oil, 2=No oil, 3=0.00, 4=0.006, 5=0.019, 6=0.031, 7=0.044, 8=0.055, 9=0.068, 10=0.081, 11=0.092 and 12=0.107.

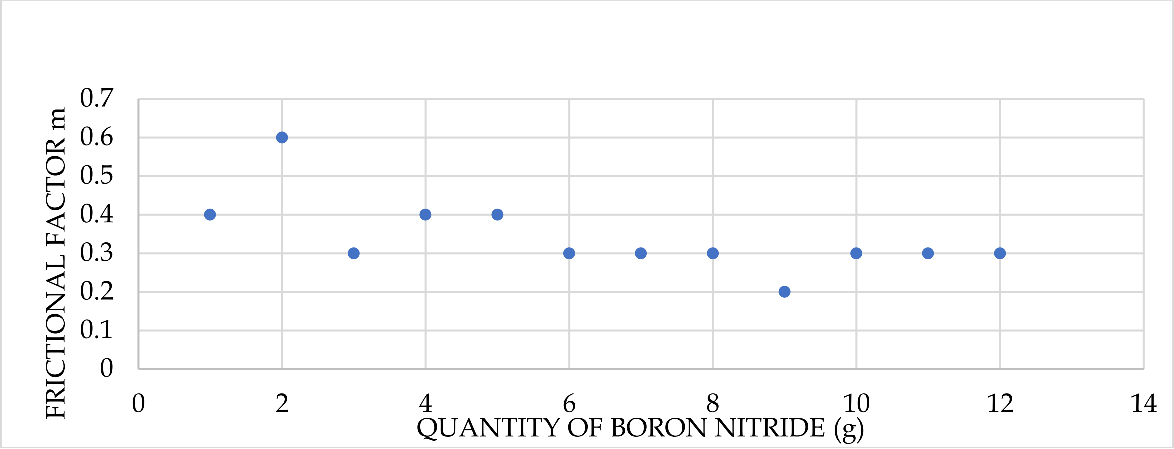

Fig.6 Control chart of frictional factor (m)

Note:
1=Ref oil, 2=No oil, 3=0.00, 4=0.006, 5=0.019, 6=0.031, 7=0.044, 8=0.055, 9=0.068, 10=0.081, 11=0.092 and 12=0.107.

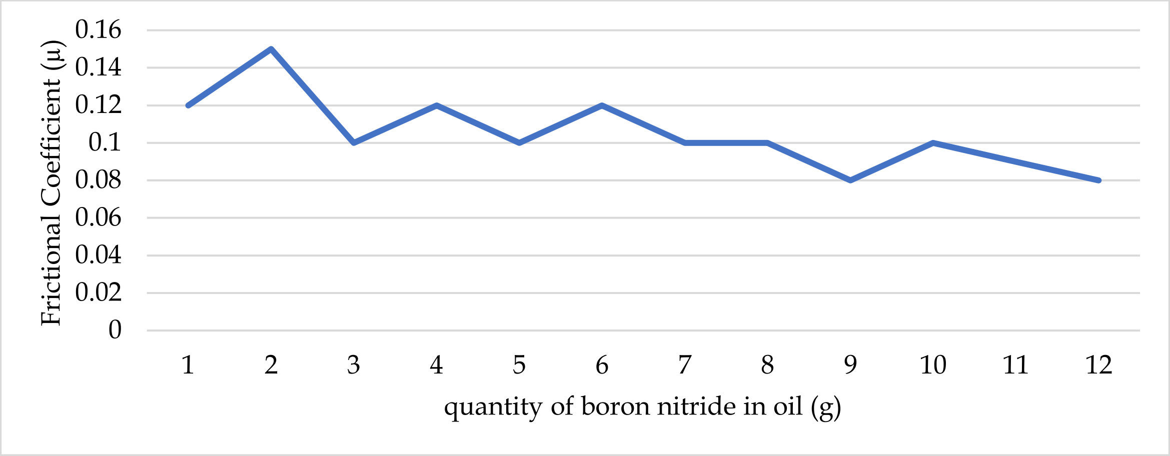

Fig.7 Result of frictional coefficient

Note:
1=Ref oil, 2=No oil, 3=0.00, 4=0.006, 5=0.019, 6=0.031, 7=0.044, 8=0.055, 9=0.068, 10=0.081, 11=0.092 and 12=0.107.

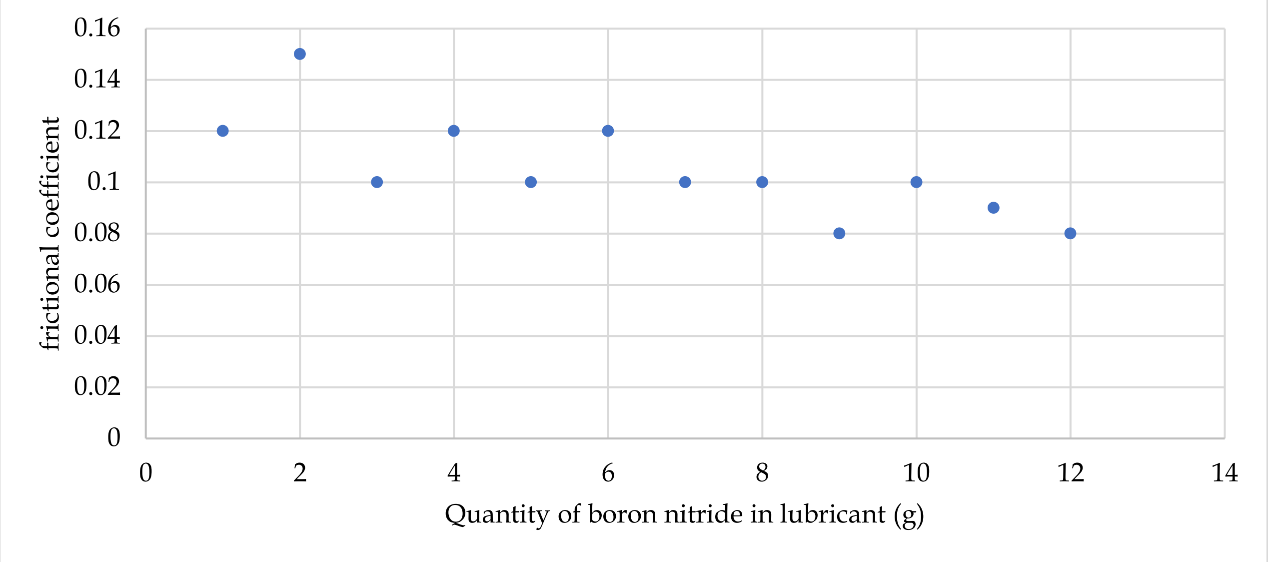

Fig. 8 Control Chart of frictional Coefficient

Note:
1=Ref oil, 2=No oil, 3=0.00, 4=0.006, 5=0.019, 6=0.031, 7=0.044, 8=0.055, 9=0.068, 10=0.081, 11=0.092 and 12=0.107.

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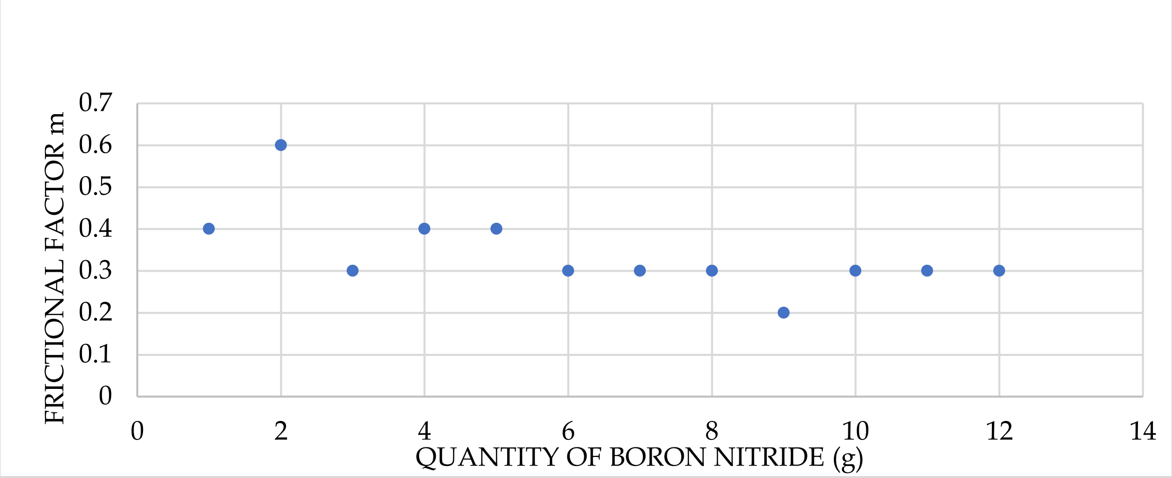

Fig.6 Control chart of frictional factor (m)

Note:
1=Ref oil, 2=No oil, 3=0.00, 4=0.006, 5=0.019, 6=0.031, 7=0.044, 8=0.055, 9=0.068, 10=0.081, 11=0.092 and 12=0.107.

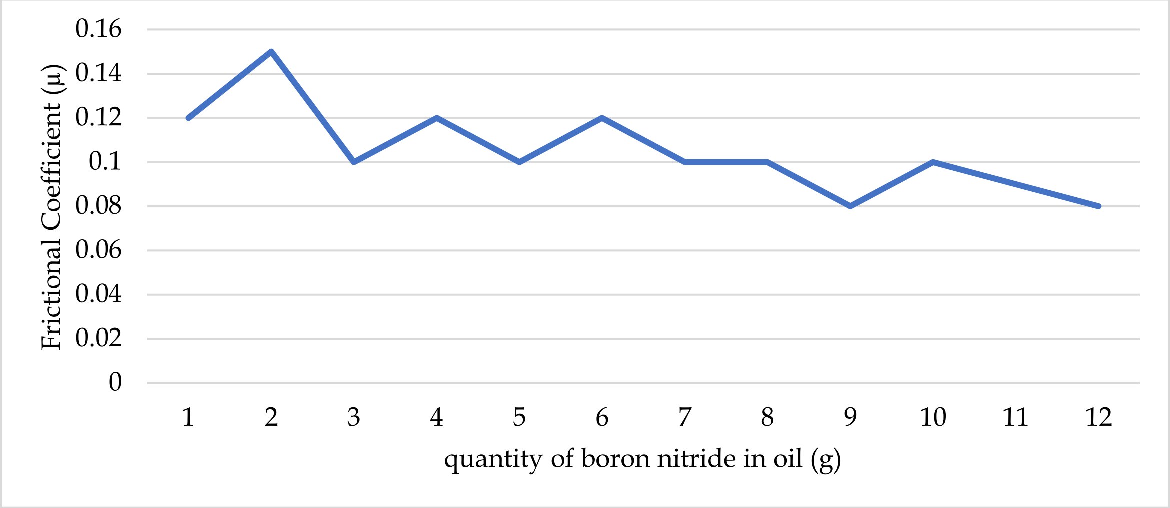

Fig.7 Result of frictional coefficient

Note:
1=Ref oil, 2=No oil, 3=0.00, 4=0.006, 5=0.019, 6=0.031, 7=0.044, 8=0.055, 9=0.068, 10=0.081, 11=0.092 and 12=0.107.

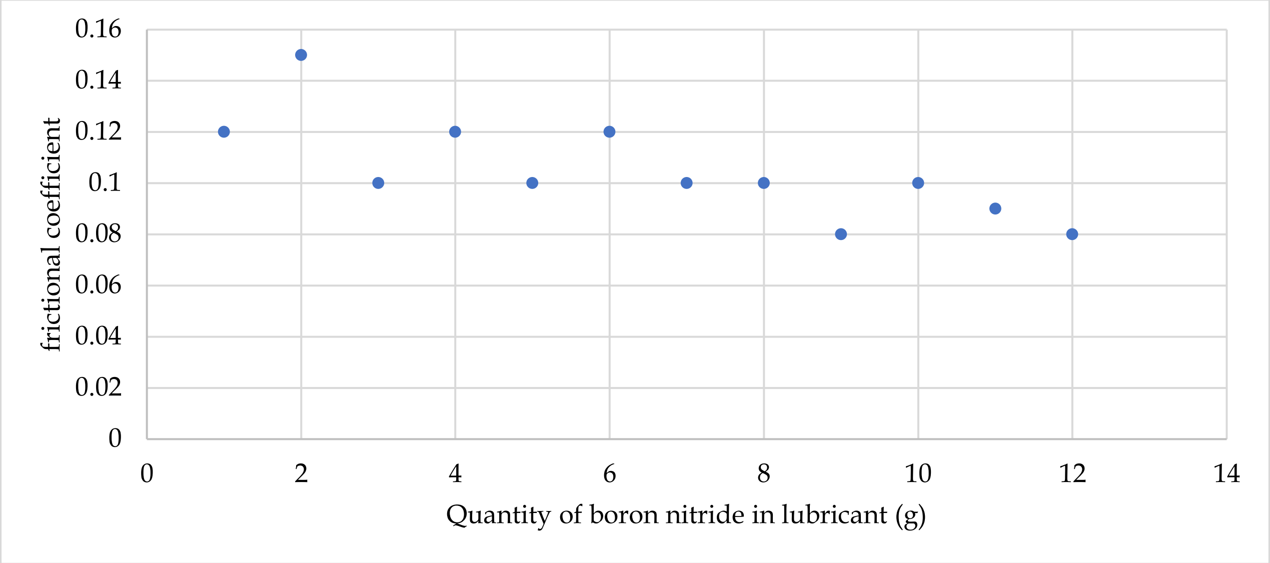

Fig. 8 Control Chart of frictional Coefficient

Note:
1=Ref oil, 2=No oil, 3=0.00, 4=0.006, 5=0.019, 6=0.031, 7=0.044, 8=0.055, 9=0.068, 10=0.081, 11=0.092 and 12=0.107.

CONCLUSION

Besides being alternative, renewable, environmentally friendly and biodegradable, *Canarium schweinfurthii* pulp has been developed to a competent bio-lubricant to favorably substitute the existing mineral oil as lubricant for metal forming. With boron nitride as additive that help to curb extreme pressure, reduce wear and high temperature, the lubricant has shown positive response to both friction, wear resistance and helped to reduce working pressure. Result of the chemo-physical, tribological show great reduction in friction compared to the mineral oil.

In terms of viscosity, all the bio-lubricants met the International Standards Organization (ISO) viscosity grade requirement for metal forming applications. Consequently, this affirm that Canarium Shweinfurthi (African Elimi) pulp can be used as Lubricant in metal forming. On an overall scale it can be concluded that Canarium Shweinfurthi (African Elimi) pulp with boron nitride as additive has the potential in becoming alternative lubricant in metal forming process.

CONFLICT OF INTEREST

There is no conflict of interest with regards to this work.

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