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Evaluation of Canarium Shweinfurthi Pulp 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 over time 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 Canarium Schweinfurthii pulp with Boron Nitride blend was evaluated through ring compression test. Canarium Schweinfurthii pulp was separated from the main fruit through the traditional method and developed to lubricant. Lubricants developed from the pulp was blend with Boron Nitride at 0.02% to 0.4% by weight. The ring compression test established that the developed lubricant at 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 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: *Evaluation, Canarium Shweifurthi, lubricant, Ring Compression Test, Lubricant, Metal Forming*

INTRODUCTION

Several 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 plane-strain 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. Hafis *et al*. (2011) also used palm oil in cold forward extrusion of aluminum in extrusion ratios 1.5, 2, and 3 using Finite Element Method analysis. The FE analysis also accounted for plasticity material flow and equivalent plastic strains in the deformation region

African elemi *(Canarium schweinfurthii)* fruit pulp has enjoyed wide availability but 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. Abdulqadir and Adeyimi (2008) and Syhrullail *et al.* (2011) reported that extensive research has been carried out on many of the vegetable oils with emphasis on forging and the use of ring compression test, double compression test and the ball penetration test with a view to determining their frictional factor. Dehghan *et al*. (2013a) and Sevilla (2015) reported ring compression test as the most effective method of determining the interface friction in metal forming process. Canarium schweifurthii (African olive) fruit is understudied through the use of ring compression test. The study wished to provide in-depth analysis of lubricant formation, frictional factor and frictional coefficient determination. This is aimed at been evaluated and subsequent recommendation for use as metal forming lubricant.

A. Chemophysical Properties

Nyam *et al.* (2014) and Maduelosi, (2015) examined the physiochemical properties of the fruit and the prominate composition of the pulp.

Table-1 Approximate composition of canarium schweinfurthii fruit (Nyam *et al*., 2014)

Parameter	Whole seed	Pulp
Thickness (cm)	4.0	6.0
Fruit length (cm)	4.5	6.0
Shape	Oblong	Oblong
% free fatty acid	3.52	3.28
Melting point (^{0}C)	32	30
% moisture impurity & volatile (miv)	1.72	1.70

B. *Ring Compression Test*

The ring compression test according to Mandić and Stefanović (2003) and Dehghan *et al.* (2013b) is commonly used to evaluate the performance of lubricants in forging. The test is adjudged to be the best method to determine the coefficient of friction (μ) and frictional or shear factor (m) of oils using ring (cylindrical test piece). As the most considered method to determine qualitative interaction between lubricant, cylindrical test piece and tool, the test involved the deformation of the test piece. This is compressed to various height reductions and the change in the inner diameter of the ring reflects the frictional factor/coefficient 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 ring increase. The frictional factor and coefficient are determined through the use of calibration curves shown in Fig. 1a, Fig. 1b and Fig. 1c.

1. Original ring before compression 2. Ring after compression with high friction (poor lubrication)
3. Ring after compression with low friction (good lubrication)

Fig. 1a Deformation of rings

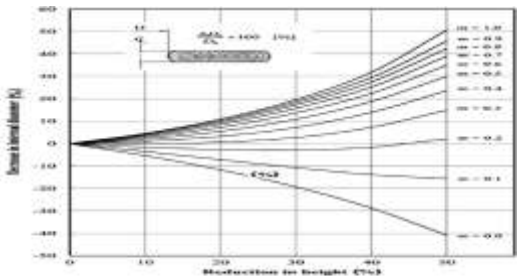

Fig. 1b Typical calibration curves for Ring Compression test for frictional coefficient (μ).

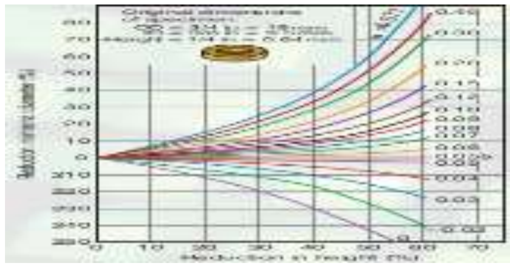

Fig. 1c Typical calibration curves for Ring Compression test for shear factor (m).

MATERIALS AND METHODS

A. *Materials Collection and Preparation*

The materials and additives used in this research include: *Canarium shweinfurthii* fruit was obtained in Jos, palm kernel oil was obtained from the local market in Jos, acetone from obtained from JC Chemical laboratory in Jos, boron nitride was obtained from Mumbai India and aluminum alloy were gotten from *Farin Gada* market in Jos.

B. *Separation of Canarium Shweinfurthii Fruit*

The fruits were then washed with clean water and dried. Various components of the fruit (pulp, seed and oil) were separated using the traditional method as described by Kamtu *et al.*, (2019) and Nyam *et al.*, (2014b). The cleaned fruits were completely steeped in warm water 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 material was sieved with cheese cloths to obtain the pulp (Table-2). The pulp was dried in a ventilated oven at 40 °C for 48 hrs. 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-3 and Table-4). The pulp was burned to ash and leached (Edah *et al.*, 2017; Babayemi and Adewuyi, 2010). Through a transparent plastic bottle of four Liter capacity and a beaker 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 (potassium hydroxide).

Table-2 Elemental parts of fruit after extraction

S/N	item	Weight (g)	Weight (kg)	% of total weight
1	Oil	3,964	3.964	05.15
2	Seed	29,725	29.725	38.60
3	Pulp	19,464	19.464	25.28
4	Moisture	23,849	23.849	30.97
TOTAL		77,002	77.002	100

Table-3 Phytochemical screening of *Canarium Shweifurthei* pulp carried out before ash test

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

+Present ; ++Moderately Present; +++ Highly Prese

Table-4 Chemical analysis of pulp ash for the determination of active element after burning

Parameter	Name	Percentage (%)
Al_2O_3	*Aluminum Oxide*	ND
SiO_2	*Silicon Oxide*	ND
P_2O_5	*Diphosphorus Dioxides*	2.50
SO_3	*Sulfur Trioxide*	1.80
K_2O	*Potassium Oxide*	36.40
CaO	*Calcium Oxide*	40.80
TiO_2	*Titanium Dioxide*	0.25
V_2O_5	*Vanadium(v) Oxide*	ND
Cr_2O_3	*Chromium (III) Oxide*	0.38
MnO	*Magnesium (II) Oxides*	0.38
Fe_2O_2	*Iron (II) Oxide*	2.51
NiO	*Nickel (II) Oxide*	0.05
CuO	*Copper (II) Oxide*	0.25
As_2O_3	*Arsenic Trioxide*	0.005
Rb_2O_3	*Rubidium Oxide*	0.19
SrO	*Strontium Oxide*	0.26
BaO	*Barium Oxide*	0.10
PbO	Lead (II) Oxide	0.53

ND- Not Detectable

C. *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 2.3 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-5 and Table-6 show the experimental layout in orthogonal array and addition of boron nitride to the lubricant.

Table-5 Experimental layout in orthogonal array

C1	C2	C3	C4	C5	C6	C7
Std Order	Run Order	Center Pt	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

D. *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 Çelik, (2013) and Frank K & Handley, (2005). Each of the lubricant sample was shared into twelve sample bottles. The lubricants were weight into the sample bottles at 31.5g. Sample lubricants for Lub1, Lub2 and Lub3 were enriched with boron nitride as described in table 7. The quantity of boron nitride to be added to every sample was determined according to Stephens and Spiegel (2007).

$$Number\ of\ classes = \frac{Range(R)}{Class\ interval\ (h)} \quad (1)$$

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-6.

Table-6 Lubricant Formulation with Boron Nitride

Sample	Addition of boron nitride to the lubricant
1	Standad 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)

E. *Determination of Physical Properties of the Developed Lubricant*

The developed pulp 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-7.

Table-7 shows the determined parameters of the developed lubricant from pulp

S/N	Parameter	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

F. *Tribological Test*

Preparation of Test Piece

Ring compression test as discussed by Mandić and Stefanović (2003) and Dehghan *et al.* (2013b) was adopted for the determination of tribological properties of the lubricant in this work.

Aluminum alloy scraps with chemical composition shown in Table-8 were gathered and subsequently cleaned and melted into circular bar ingots of ϕ45 mm x 300 mm at the temperature of 663 °C using coal fired crucible furnace (Fig. 2). The billets were machined to rings of dimension 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 machines (Fig. 3). The machined rings were compressed using 300 kN capacity Testometric Universal Testing Machine (Fig. 4). Lubricant sample was applied on both sides of the ring and was placed between the compression platens of the Testometric machine. Hydraulic force of 270 kN according to Wang (2012), was applied using the joggling buttons on the machine control unit. The upper platen slides down through the hydraulic ram. This compressed the work piece that was placed on the stationary lower platen (Fig. 5). Before the next round of test, the platens were cleaned with acetone (cleaning agent). This was done to ensure that there was no interference of the previous lubricant on the later. Vernier caliper was used to measure the internal diameter and heights of the compressed rings from which percentage reduction in internal diameter and in height were determined. Using the determined percentages, the frictional factor and frictional coefficient were deduced using charts.

Table-8 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 Alloy	99.00	0.02	0.02	0.03	0.02	0.003	0.03	0.15
		Parameters (%)							
		Fe	Ni	Cu	Zn	Ga	Ba	Pb	
		0.41	0.005	0.05	0.03	0.01	0.009	0.004	

Fig. 2 Cast Aluminum Billet

Fig. 3 Machined Aluminum Rings

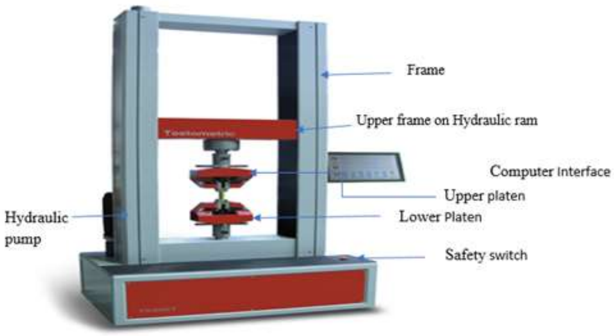

Fig. 4 Photograph of 300KN capacity Testometric universal Testing Machine

Compression of Test Piece

The tribological test was carried out in two stages; the first stage was to establish the similarities of the tribological properties of the lubricant developed from the various processes. This was with the view to selecting the best process for further development. The second stage was the determination of the tribological properties of the developed oil using machined aluminum rings. The tests rings were measured to establish similarities due to machining error. These were selected, grouped labeled in sample bags for ease of use. Three tests rings were used with the oil to carry out the compression test on 300KN capacity Testometric Universal Testing Machine in NMDC, Jos Plateau State Nigeria. Lubricant sample was applied on both sides of the ring and was placed between the compression platens of the Testometric machine as shown in Fig. 5. 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.

Fig. 5 Test ring placed between upper and lower platen of Testometric Universal testing machine

RESULTS AND DISCUSSION

Results of Phyto Chemical Screening and analysis are shown on Table-3 and Table-4. Results show the presence of Alkaloids, flavonoids, carbohydrate, steroids and cardiac glycosides in wet and dry pulp, while only flavonoids are observed in ash pulp. Analysis of the pulp ash showed the presence of Diphosphorus Dioxides as 2.50%, Sulfur Trioxide 1.80%, Iron (II) Oxide 2.51%, potassium oxide as 36.40% and calcium oxide as 40.80% only. The presence of diphosphorus dioxide (2.50%), sulfur trioxide (1.80%) and chlorine in the pulp is a strong indication of the presence of extreme pressure additive in metal forming or anti-seizure and anti-scuffing in lubricants (Ioan, 2013). They provide protection in extreme pressure condition. These would form layers of iron compounds such as sulphides, chlorine and phosphate respectively, through tribochemical reactions. Oxides are binary compounds formed between various elements and oxygen, while phosphates considered as salts based formally on phosphorus (V) oxoacids and in particular salts of phosphoric (V) acid, H_3PO_4. Both oxides and phosphates are among the most important classes of inorganic compounds. The presence of Iron (II) Oxide at 2.51% in the pulp is also an indication of the influence of the element on the lubricity of the lubricant. According to Sumino (2008) it was established that iron oxide layer formed on a surface of work piece plays an important role at lubricating properties in hot rolling. It helps to prevent the effect of scoring on the workpiece.

According to Sani and Hassan (2007) and Hasanuzzaman *et al.*, (2015), alkaloids, potassium and calcium serve as base elements in lubricants. They function as lubricant carriers that help the lubricant to adhere to the surface of the workpiece and also help to neutralize the acids formed in lubricants during metal forming operation. Though not all metals react with acids in the same way, some metals are more vulnerable to corrosion than others (Brennan, 2022) . Hence the need to keep the acid level of lubricants low. Furthermore, study by Hasanuzzaman *et al.* (2015) reveal that potassium oxide (K_2O) and calcium oxide are widely used as glass fluxes to reduce the working temperature, but they also play an important role in setting the thermal expansion. These oxides served as fluxes during the extrusion process. They helped to lower the high operating temperature of metal forming. The computed values of friction factors (m) and frictional coefficient (μ) from the reduction in height and internal diameter obtained by ring compression tests of the plasticine rings for various die – interface and lubrication conditions are obtained Table-10 and Table-11. The frictional and coefficient calibration curves (Fig. 1b and 1c) as opined by Dehghan *et al.* (2013) show the effect of varying boron nitride on friction factor (m) and frictional coefficient (μ) for the developed lubricants. The performance of the developed lubricants was measured against the performance of Reference oil. The friction factors of 0.3 and 0.2 and frictional coefficients of 0.8 and 0.7 for lubricant were obtained from the developed lubricant respectively. The reduction of frictional factor and coefficient of friction was achieved due to the properties of the developed lubricants. Reference oil used as lubricants yielded frictional factor and coefficients of friction of 0.4 and 0.12 respectively. The dry condition yielded frictional factor and coefficients of friction of 0.6 and 0.15 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). It was observed that the developed lubricants in the presence of boron nitride was effective in reducing friction.

Table-12 shows the performance of the lubricant developed from vegetable with frictional factor and frictional coefficient of 0.2 and 0.08 respectively as established by this work. Furthermore, this result was achieved with 0.068g of Boron Nitride added to the lubricant. These results measured better than reference oil with 0.4 and 0.12 and dry condition with 0.6 and 0.15 for frictional factor and frictional coefficient respectively. The result of 0.2 frictional factor and 0.08 frictional coefficient agrees strongly with the range of natural oil recommended as alternative lubricants such as groundnut oil; 0.072 to 0.5, palm oil 0.03, palm kernel oil; 0.084 and sheanut oil; 0.092 that are used in metal forming by as opined (Oseni, 2012).

Table-9 Incremental addition of Boron nitride in grams

S/N	Sample (g)	% By weight	BN (g)
1	Ref oil		
2	No oil		
3	28.93	0.00	0.00
4	30.96	0.02	0.008
5	33.53	0.06	0.017
6	32.59	0.10	0.034
7	32.02	0.14	0.042
8	32.47	0.18	0.051
9	28.60	0.22	0.067
10	28.90	0.26	0.083
11	32.13	0.30	0.100
12	25.95	0.34	0.108

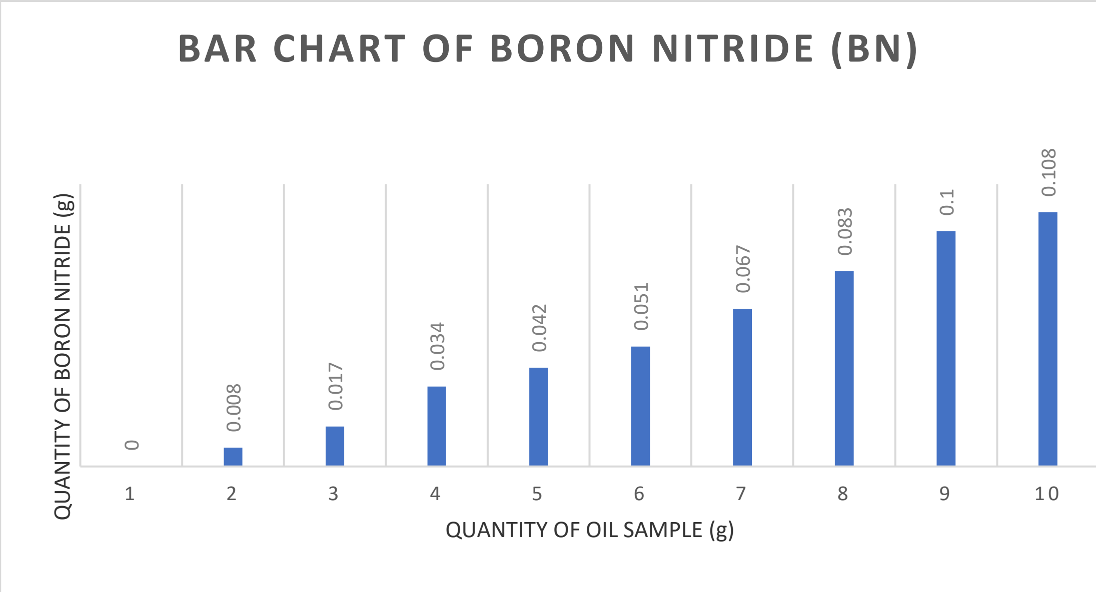

Fig. 6 Bar chart showing the incremental addition of Boron nitride.

Where the x-axis (Quantity of oil sample in g) is defined as: 1=28.93, 2=30.96, 3=33.53, 4=32.59, 5=32.02, 6=32.47, 7=28.60, 8=28.90, 9=32.13 and 10=25.95

Table-10 Determination of percentage reduction in internal diameter and height

BN (g)	Do	Aveg d	do – avg d	(do-avg d)/do	((do-avg d)/do)*100	H_O	Aveg H	H_O-avg H	(HO-avg H)/HO	((H_O-avg H)/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

Where,
Do = Original internal diameter
((do-avgd)/do) *100 = Percentage reduction in internal diameter
Ho = Original height
((HO-avGH)/HO) *100 = Percentage reduction in height

Table-11 Determination of frictional factor and frictional coefficient

BN (g)	Reduction in intnal DMTR (%)	Reduction in height (%)	Frictional factor (M) (From chart)	Frictional coefficient (μ) (From chart)
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

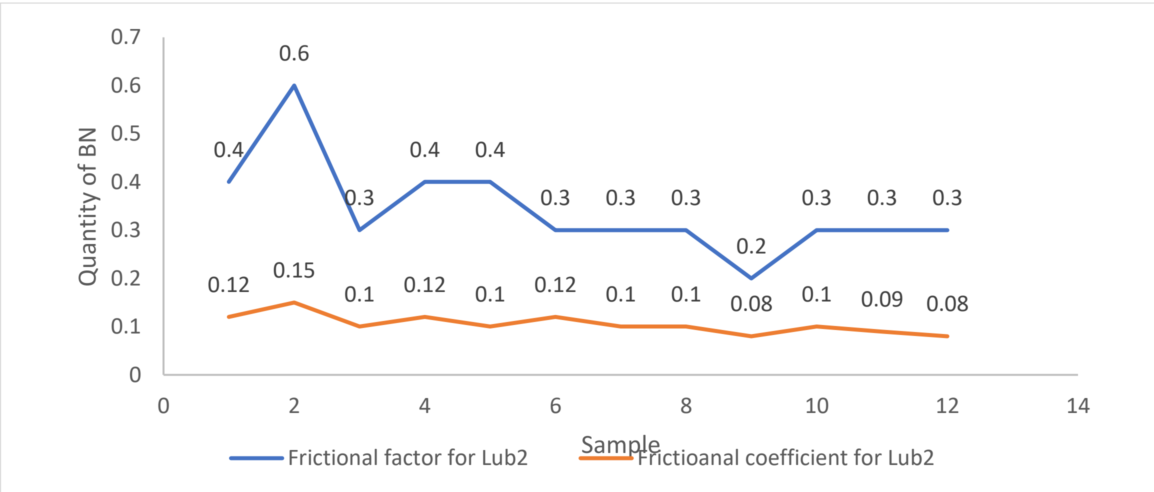

Fig. 7 Chart frictional factor (m) and frictional coefficient (μ)

CONTRIBUTION TO KNOWLEDGE

The work has proven that African Elemi fruit pulp (usually waste) has the requisite chemo physical properties to give comparative tribological performance characteristics when used as lubricants in cold extrusion of aluminum. The tribological performance is improved with Boron Nitride additive.

CONCLUSION

The African Elemi fruit pulp has identical chemo physical properties with the reference oil. The African Elemi fruit pulp gave satisfactory tribological performance as extrusion lubricant in both ring compression and Aluminum extrusion. Tribological performance was enhanced with Boron Nitride

CONFLICT OF INTEREST

No research has been carried out other than this on the tribological performance of the pulp.

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