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Tribological Properties of *Canarium Schweinfurthii* Shells as Frictional Material for Automotive Brake System

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ABSTRACT
Friction material for automobile braking system was developed using canarium schweinfurthii shell (CSS) otherwise known as African elemi. Tribological properties such as thermal conductivity, water/oil absorption test, coefficient of friction, wear rate, hardness test, porosity, compressive and tensile strength, temperature, noise level generated and stopping time-varying speed from 5.56 – 27.78 m/s that directly or indirectly affect brake pad system were investigated. Experimentally developed brake pads (using CSS) were found to compete favourably with conventional brake pads and those from literature studies. The research finding using CSS indicates that CSS particle can effectively and efficiently replace asbestos in brake pad manufacturing.

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INTRODUCTION

The brake pad is a major part of a braking system for the effective and efficient performance of an automobile. It constitutes lining materials which are relatively soft but adequately tough, and are capable of withstanding high temperature without wearing easily when converting kinetic energy of the vehicle to heat energy [1]. These lining materials are distinctly composed of a binder (which hold/prevent constituents from disintegrating of lining material during varying mechanical and thermal stresses; to maintain lining structure), filler (which reduces the production cost of brake pad), reinforcing fibre (which ensures mechanical strength of the brake pads), and a friction modifier (which determines the frictional characteristics of brake pads) [2]. In past decades, asbestos (a hydrated magnesium silicate $Mg_3Si_2O_5(OH)_4$) is majorly used as the base material in the production of brake lining in automobile industries due to its outstanding characteristics of been thermally stable up to 500°C, produces silicates, insulates thermally, though yet flexible, regenerate the friction surface during use, wears and processes well, the fibrous character remains intact up to 1400°C, and readily available [3]. Medical researchers report that asbestos produces dust which if inhaled can result in adverse respiratory and brain condition [4, 5, 6]. With the recent advent in brake lining industries, interest has been shifted from metallic-asbestos to free asbestos with the use of agricultural wastes as a substitute in brake lining production. Adegbola *et al.,* 2017 in their study, cow bone resin composites as a friction material for automobile braking systems compare favourably with conventional brake pads [7]. Effect of periwinkle shell on wear behaviour of asbestos-free brake pad was evaluated by Amaren *et al., 2013.*

Results show that periwinkle shell particles can be effectively used as a replacement for asbestos in brake pad manufacturing [8]. Nuhu (2015) in his study on evaluation of maize husks based brake pad shows its suitability in the replacement for asbestos and many agro-

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biomass friction materials in automotive brake pads [9]. Samples with different percentage of pineapple leaf fibre (PALF) was determined to can give better properties in brake pad production by Felix *et al., 2015* [10]. Study shows that snall shell (as reinforcing agent) and rubber seed husk (as filler) based brake linings exhibit lower wear rate than asbestos, without degrading the surface of the disc brake, and its overall performance is comparable with asbestos-based linings (Abhulimen *et al., 2017)* [11]. Aigbodion *et al., 2013* in the study on banana peels show its suitability in replacement of asbestos brake pad [12]. This study is aimed at optimally utilizing agricultural waste (CSS) to develop an experimental brake pad and in achieving this aim, the study is saddled with the following objectives; determine the physical properties and elemental composition of CSS, develop experimental automotive brake pads using CSS as the base material and to evaluate the performance of the developed brake pads in comparison to the conventional asbestos brake pad.

RESEARCH METHODOLOGY

Materials

The materials used in the course of this study include solid seed from CSS (as filler material), calcium carbonate (used as reinforcing agent), epoxy resin as the binder as well as the catalyst. Graphite (as friction modifier) was used to stabilize frictional coefficient and wear rate while aluminium oxide was used as abrasive.

Methods

Physico-Thermal Characterisation

The pulverised canarium schweinfurthii shells (CSS) was characterised on its physical properties such as thermal conductivity, water/oil absorption and porosity. Thermal conductivity of the sample was computed based on Fourier law of heat transfer as shown mathematically in equation (1);

$$k = \frac{\Delta Q}{\Delta t} \times \frac{L}{A \Delta T} \quad (1)$$

Where; k - thermal conductivity in W/m k, ΔQ - the quantity of heat transmitted in Joules at Δt - time in seconds, L - thickness of the material in metres in a direction normal to A (surface area) in m^2 and ΔT - temperature difference in Kelvin, under steady condition

Mineral Analysis

Atomic Absorption Spectrophotometry (AAS) Procedure was adopted for analysis of CSS minerals composition such as Ca, Mg, Zn, Fe, Cu, Pb, Mn and Cd, while Na and K were analyzed using flame photometry and P was analyzed using vanado molybdate method. The outcome of the analysis are presented in Table 2

Preparation of Materials

Canarium *Schweinfurthii* fruit otherwise known as "Atili" in Hausa and "Ibe" in the Igbo language in Nigeria was harvested from one of the numerous plantations in Panshin Local Government Area, Plateau State, Nigeria. The fruits/seeds are littered in and around the several dumping grounds in the local government area of the state. Water heated up to 300°C was poured in a bowl containing the fruit and left for 30 min. The shell was separated from the seed, washed and left to dry naturally under intense heat from the sun for 4 days and further dried in an electric ovum for three hours at 260°C to remove the remnant of contaminating the oil. 95 kg of seeds were crushed manually with mortar; it was further grounded to powder using a grinding mill (Model-FFC-45A) and finally sieved with 710 μm sieve size. Calcium carbonate, epoxy resin and aluminium oxide were purchase in Niger State, Nigeria.

The weight of CSS and epoxy resin was varied. The weight of aluminium oxide, graphite and calcium carbonate are kept constant as shown in Table 1. Five test samples were produced and stirred

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thoroughly to obtain a homogenous mixture. The obtained mixture was transferred into a designed mould placed on the backing plate obtained by removing the friction material on the used commercial brake pad, coated with mould releasing agent for easy removal of sample and transferred to a hydraulic press. The composite materials are pressed at 100KN for 2 min at atmospheric temperature and subsequently cured at 250 °C for 90 min after. The crushed CSS and polished end-product (developed brake pads) are presented in Figure 1. Twenty different samples each of the product were produced for the study.

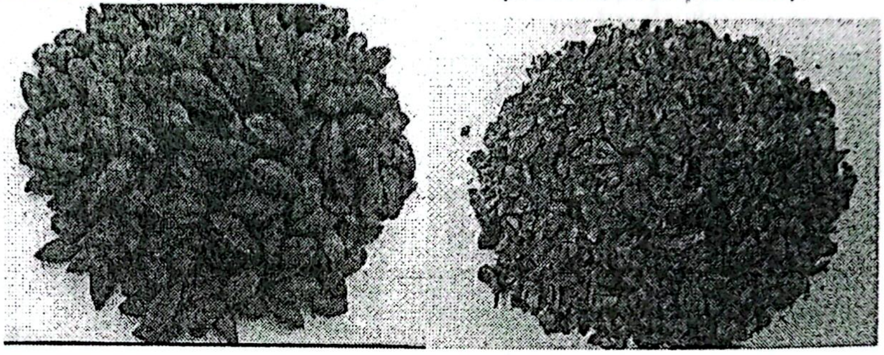

Figure 1: Crushed *Canarium Schweinfurthii* shell

Table 1: Samples Composition of Material for Brake pad Production

Materials	S_1 (%)	S_2 (%)	S_3 (%)	S_4 (%)
CSS	35	25	20	15
Epoxy resin	30	40	45	50
$CaCO_3$	21	21	21	21
Graphite	8	8	8	8
Al_2O_3	6	6	6	6
Total	**100**	**100**	**100**	**100**

Assessment of Developed Brake Liner

Hardness Value

The Brinell hardness values of the developed brake pad samples were determined using a digital hardness tester. A 10 mm diameter steel ball indenter was used with an applied load of 3000 kg for 10 seconds on the samples. The results of the hardness values are shown in Figure 7

Water and Oil Absorption Test

Samples of the developed brake pads were weighed. Samples were then soaked in water and oil (SAE 20/50) for 24 hours, cleaned and weighed. Percentage absorption was measured mathematically as in the equation below;

$$\text{Absorption (\%)} = \frac{W_1 - W_2}{W_0} \times 100 \quad (2)$$

Bonding test

Adherence of the developed composite brake pad was investigated using PERMAFUSE testing machine (Type 05/024, ENERPAC). The binding of the developed pads was evaluated by experts and found satisfactory. The hydraulic arm was allowed to press down the developed brake pad till it sheared. A digital meter reader was mounted on the machine and records were measured up to the point shearing took place.

Evaluation of Developed Brake pad using Inertia Dynamometer

The inertia dynamotor in evaluating developed brake pads by Ikpambese et al., 2016 [15] was adopted in this study. The inertia brake dynamometer system (Model-1250/1252) was used for the study. Each of the developed brake pads was separately placed in a unit containing braking system of the inertia dynamometer, driven by an electric

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motor. An initial motor rotating speed of 5.56 m/s (20 km/hr), *the* brake was applied when the set speed is attained. The experiment was repeated for speeds 9.72 m/s (35 km/hr), 13.89 m/s (50 km/hr), 18.06 m/s (65 km/hr), 22.22 m/s (80 km/hr) and 27.78 m/s (100 km/h), to measure the wear rate and coefficient of friction of the brake pad through software attached to the machine at this given conditions. Other parameters measured were noise level, thermal temperature. This experimentation was repeated for a commercial brake pad purchased from an automobile shop for comparison.

RESULTS AND DISCUSSION

Elemental Composition of CSS

The table below shows the concentration of CSS in the various chemical elements under consideration.

Table 2: Elemental compositions of CSS.

Element	Concentration (mg/100mg)
Potassium	17.4 ± 0.01
Sodium	10.3 ± 0.03
Calcium	36.0 ± 0.02
Iron	3.8 ± 0.01
Magnesium	24.0 ± 0.02
Zinc	5.8 ± 0.01
Manganese	0.4 ± 0.00
Phosphorous	12.6 ± 0.04
Copper	1.8 ± 0.00

Bonding Test

Asbestos and developed CSS based brake pads yield an adhesion of 5386 and 4998 N/s, respectively. Asbestos pad shows better adhesive/bonding force than CSS pad. This can be attributed to high thermal conductivity exhibited with asbestos brake pad resulting in rapid curing of the product when compared to other developed brake pads. CSS developed brake pad falls within the designated range of 4500±2250 N/s (NIS 323, 1997) recommended by the Standard Organization of Nigeria (SON).

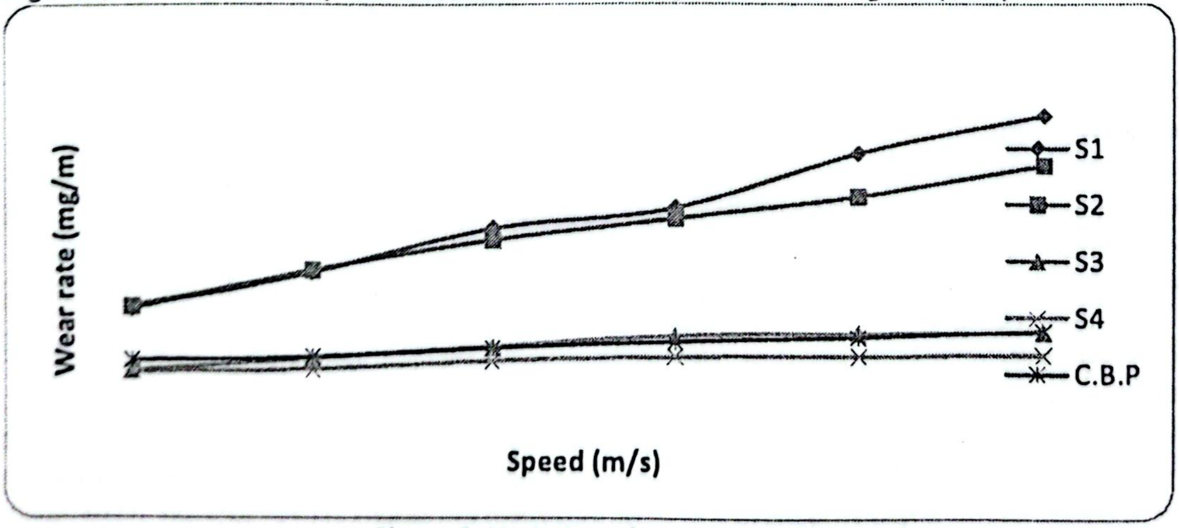

Figure 2: Variation of wear rate with speed

Figure 2, shows the differences in wear rate with speed for the production of brake pad from CSS and compared with a commercial brake pad (C.B.P). Wear rate

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increases with a corresponding increase in speed for all samples but the degree of wears differs for all samples due to differences in its constituents/compositions. Wear rate for developed brake pad varies from 4.68-9.89 mg/m for samples (S_1), 4.72-8.55 mg/m for samples (S_2), 3.01-3.59 mg/m for samples (S_3), 2.98-3.49 mg/m for samples (S_4) and 3.28-4.12 mg/m for commercial base brake pad. Sample S_3 (4.08 mg/m) and S_4 (3.49 mg/m) show less wear rate compared to commercial brake pad (4.12 mg/m). The developed brake pads exhibit better Wear rate compared with 4.12 mg/m of commercial brake pad and 3.62, 3.64 mg/m reported by Ikpambese et al, (2016) and 4.20, 4.40 gm/m by Aigbodion et al, (2010). This can be attributed to reinforcing agent and binder used for pad's formation which provides better bonding characteristics that resist wearing rates. Wear rate of the developed brake pad shows better wear values compared to values reported by Edokpia et al, (2014) using eggshell as filler, Yawas et al, (2013) using periwinkle as a filler and Nuhu et al, (2015) using maize husk as filler. Wear rate decreases with an increase in epoxy resin content from 30 %wt to 50 %wt in composition. This is attributed to an increase in interfacial bonding between the CCS particles and epoxy resin, thereby reducing the chances of particles from been easily pull-out (reduction in wear) (14). Wear rate for all sample composition competes favourably with the conventional brake pad model.

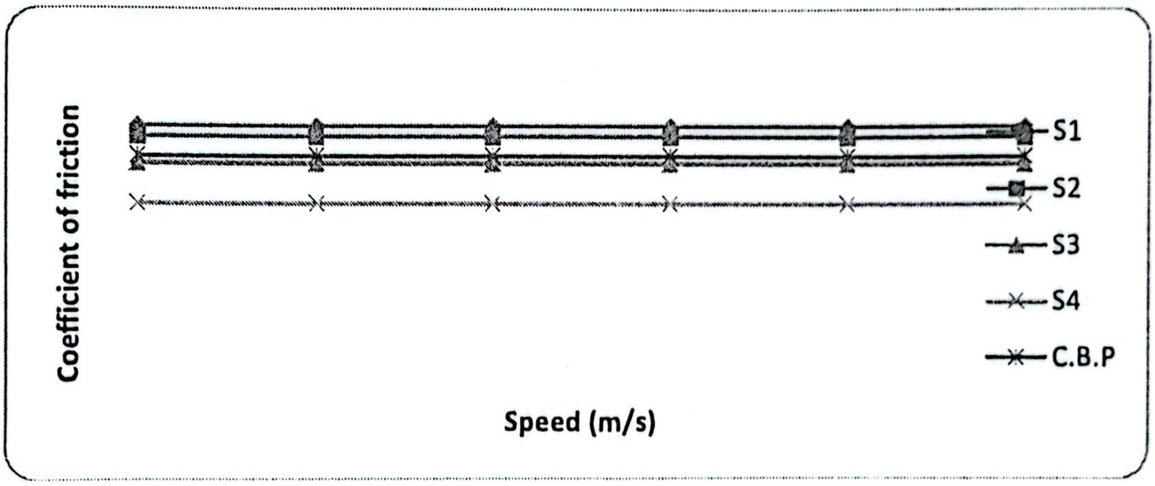

Figure 3: Variation of the coefficient of friction with speed

Adequate brake coefficient of friction at all speed condition plays a vital role in the safety of drivers. Figure 3, shows the variation of coefficient of friction with the speed in developed brake pad and commercial brake pads. It is shown that the coefficient of friction remained constant with variation in speed. By comparison, the value varies from 0.302 to 0.398 at varies speed from 5.56 to 27.78 m/s. Values of the coefficient of friction obtained for sample S_3 (0.352), sample S_4 (0.302) compete favourably with values 0.361 obtained from commercial brake pad, agreed with values 0.16–0.4 reported by Ikpambese et al. (2016) using palm kernel fibre as the base material.

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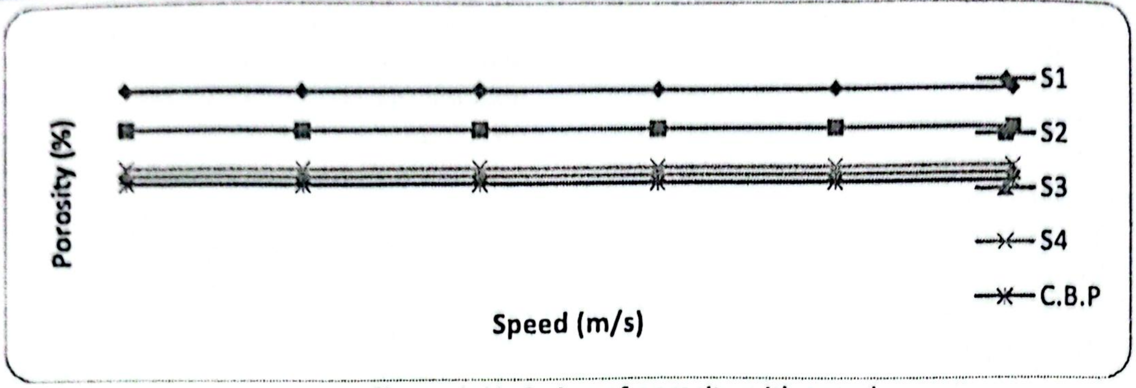

Figure 4: Variation of porosity with speed

Figure 4 presents the variation of porosity with speed for developed brake pads. Porosity remains constant with variation in speed. Sample S_3 (22 %) and S_4 (23 %) exhibits better porosity among the sample composition in the study and agreed with values of 16-32%, 24.45% and 13-23% reported by Ikpambese et al. (2016), Ibhadode and Dagwa (2008) and Chand et al. (2004)

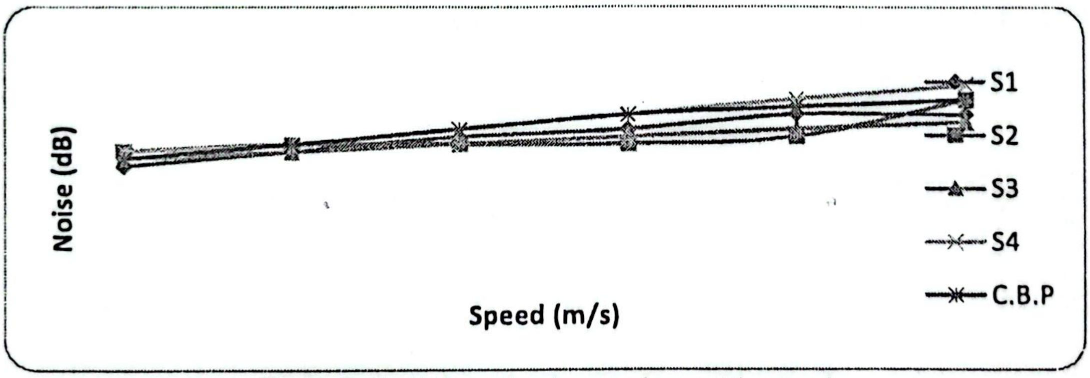

Figure 5: Variation of noise produce with speed

Noise generated by the developed brake pads in comparison with commercial brake pad is presented in Figure 5 above. Noise level for all sample increases slightly with increasing speed with different slopes. Maximum noise level 32dB and 34 dB was observed with asbestos-based commercial pad and CSS based brake pad at speed 27.78 m/s. The noise level generated varied from 23-34dB, agreed with 32dB obtained with the commercial brake pad and the values reported by Lindberg et al. (2013). Low noise generated by the developed brake pads for all sample composition can be attributed to the absence of metallic or harder particle in the formation.

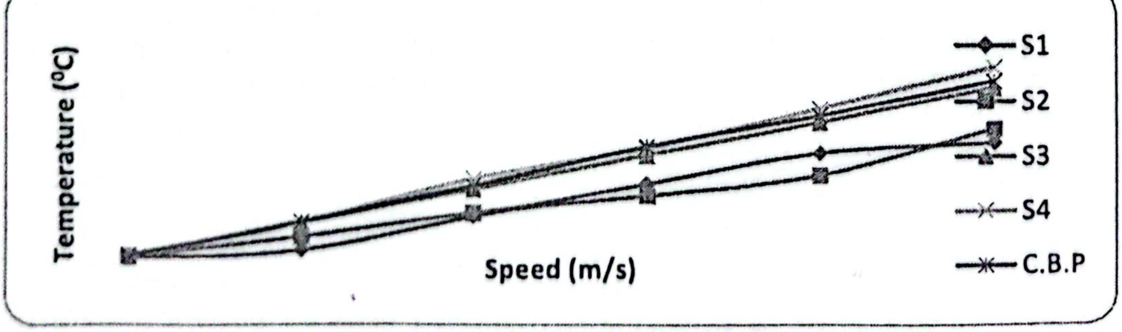

Figure 6: Variation of temperature with the speed

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The differences in temperature with speed are presented in Figure 6. It is shown that the temperature rises with a corresponding rise in speed. The temperature with the developed brake pad varied sequentially from 97-660 ^{0}C compared to 620 LC with the commercial brake pad. The values obtained agree with the trend as it related to increased frictional force that exists between the samples and the surface in contact.

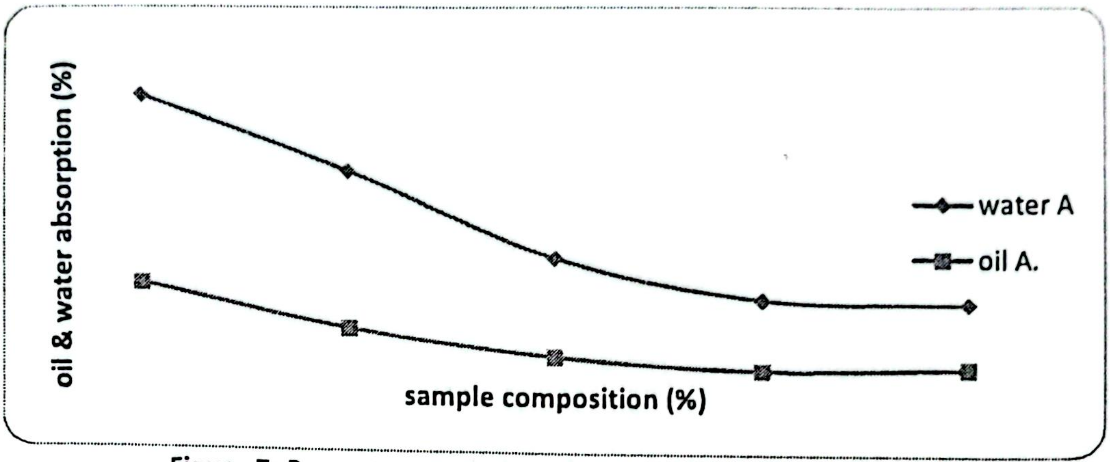

Figure 7: Percentage variation of oil and water absorption rate

The variation of water and oil absorption rate after 24 hours in comparison to a commercial brake pad is presented in Figure 7. Water and oil absorption value with developed brake pad decreases with increasing sample composition. Lower water and oil absorption rate is observed with sample S_4 of 3.18 and 1.32 % respectively. However, the commercial based brake pad (asbestos-based) with lower water and oil absorption rate value of 3.09 and 1.38 % showed better water and oil absorption characteristics than the developed brake pad.

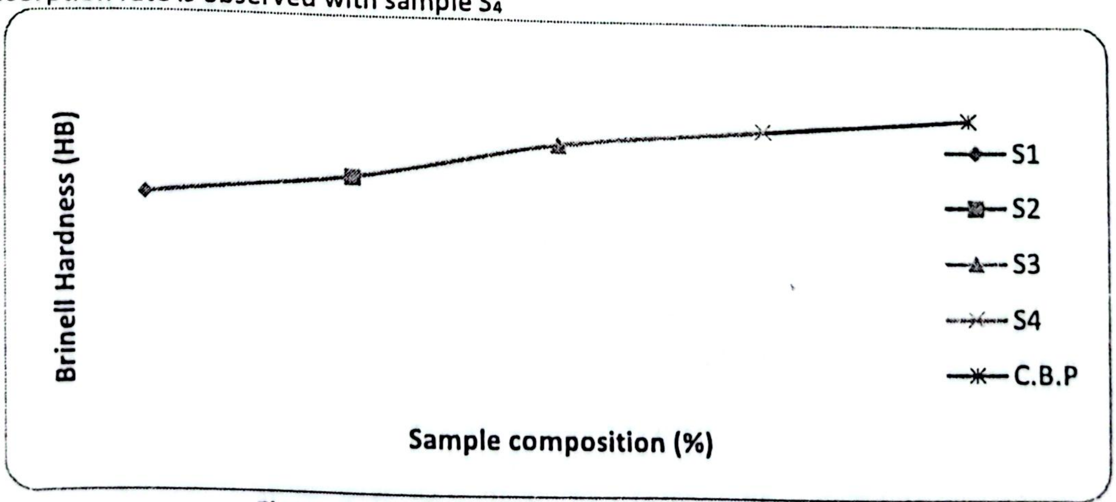

Figure 8: Hardness value of developing brake pad

Brinell hardness of developed brake pad alongside with commercial (asbestos-based) brake pad was presented in Figure 8. The maximum hardness value obtained of the produced brake pad was 98 BHN, commercial (asbestos) based pad showed higher hardness value.

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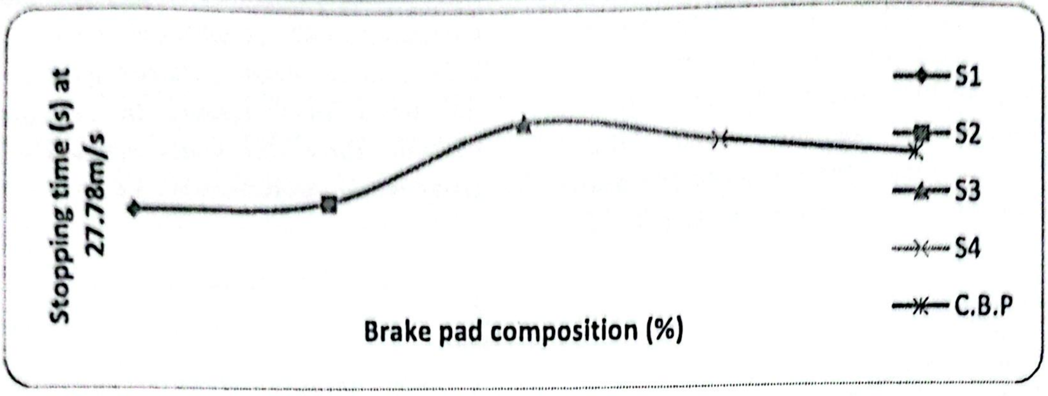

Figure 9: Stopping time at a constant speed of 27.78 m/s

Stopping time is generally known as the time taken for a moving vehicle to come to a stand-still. A constant speed of 27.78 m/s was made to run for the CSS brake pad and subsequently the commercial brake pad. They were brought to a halt; time taken for each CSS's brake pad came to a halt was recorded. The time taken to bring the moving pads to halt is presented in Figure 9. Maximum stopping time for CCS's brake pad was obtained for S_3 and S_4 (5.93 s and 5.43 s) respectively better when compared with 5.01 s for the commercial asbestos pad at a constant speed.

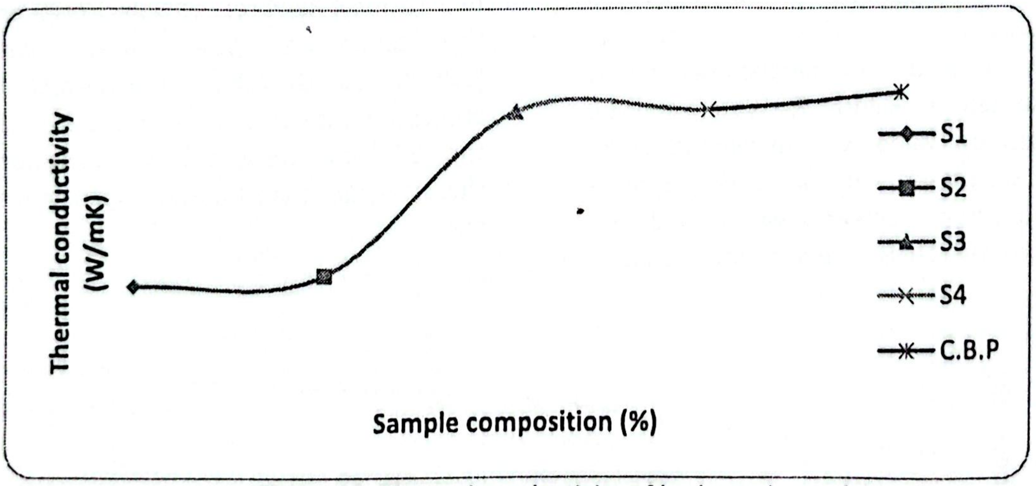

Figure 10: Thermal conductivity of brake pad samples

Figure 10 shows the thermal conductivity from the produced brake pad (free-asbestos) in comparison with the commercial brake pad (asbestos-based). Thermal conductivity varies from each sample composition from 0.4147 – 0.4762 W/mk of sample S_1-S_4. Sample S_3 (0.4758 W/mk) and S_4 (0.4762 W/mk) compete favourably with the asbestos-based commercial pad with 0.4823 W/mk. A summary of physical and mechanical results from the findings in comparison with the existing findings/literature by other authors with asbestos commercial brake pads are as presented in Table 3.

The results obtained from a physical and mechanical evaluation using CSS as a free-based brake pad compared to that of conventional brake pad and existing results possess similar properties to the conventional asbestos-based brake pad. Thus CSS may be considered as a possible substitute for asbestos brake pad system.

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Table 3: Summary of findings compared with existing ones

Properties	Asbestos based (C.B.P)	Laboratory Formulation (PSK Shell)	Laboratory Formulation (Periwinkle Shell)	Laboratory Formulation (Cow Bone)	Laboratory formulation (Snail Shell)	Laboratory formulation (Bagasse)	Quoted from Literature	New Optimu Laboratory Formulatio (CSS)
Compressive strength (Mpa)	110	103	147.0	-	106.55	105.6	70-125	108
Shear strength (Mpa)	5.8	2.45	6.80	-	-	-	5.3	5.12
Modulus of rupture (Mpa)	11.21	11.36	-	-	-	-	34-48	14.52
Hardness, Brinell	102	92	99.1	94	101.7	100.5	-	98
Coefficient of friction	0.361	0.43	0.35-0.41	0.34	0.25-0.43	0.44	0.3-0.6	0.398
Wear rate (mg/m)	4.12	3.98	4.00	4.20	4.62	4.2	3.0	3.49
Surface roughness	3.00	-	-	-	-	-		3.21
Porosity (%)	21	22.45	-	-	-	-	13-23	23
Thermal conductivity (W/mk)	1.526	1.460	-	-	-	-	0.47-0.804	0.509
Water absorption (%)	3.09	5.03	3.21	3.48	3.9	3.48	-	3.18
Oil absorption (SAE 40) (%)	1.38	0.44	1.15	-	2.034	1.11	-	1.32
Temperature (LC)	620	650	-	-	-	-	-	660
Noise level (dB)	32	-	-	-	-	-	-	34
Stopping time (s)	5.01	4.12	-	-	-	-	-	5.93
Elemental composition	Toxic	Non-toxic	Non-toxic	Non-toxic	Non-toxic	Non-toxic	Non-toxic	Non-toxic

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CONCLUSIONS

The evaluation of brake pads developed from *Canarium Schweinfurthii* shell (CSS) was determined and the following conclusions are deduced:

i. That values obtained from CSSs are within (and show better properties) the standard requirement for commercial brake performance pad. The outcome of the research finding indicates that CSS particles can be effectively and efficiently used as a suitable alternative for asbestos in brake pad manufacture.
ii. Asbestos brake pad shows better adhesive properties than developed brake pads but CSS brake pad falls within the recommended range.
iii. The wear rate increases slightly with a corresponding increase in speed, temperature and noise generated.
iv. Sample S_1 exhibits a higher coefficient of friction of 0.385 with corresponding higher wear rate value of 4.720 mg/m than other samples, implying that the friction materials will be efficient but shorter life span.
v. Samples S_4 with a composition of 50% epoxy-resin, 15% CSS, 6% Al_2O_3, 8% graphite, and 21% $CaCO_3$ exhibited better properties than other samples. The sample formulation exhibits better wear resistance as can be shown from the microstructural analysis of the examined surfaces.

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