Development of Asbestos-Free Automotive Brake Pad Using Ternary Agro-Waste Fillers

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Abstract — **This study produced automotive brake pads from composite made of intermixed agro-waste materials (cocoa beans shells - CBS, maize husks – MH and palm kernel shells – PKS). Prior to 1935, asbestos friction material has been in use, but its usage is now discouraged because it was confirmed carcinogenic. Hence there is need to develop alternative friction materials that are ecofriendly. Fillers particulate size considered is 300µm and the binder is epoxy resin. Test specimens were analyzed to evaluate their physical, mechanical and tribological properties. Properties of the intermixed (CBS+MH+PKS) based specimen pads were compared with those made of single filler materials like CBS based specimen pads and MH based specimen pads. The results obtained compared favourably with that of conventional brake pad and others produced from similar researches. Analysis of specimens showed that abrasion resistance, friction coefficient and water soak decrease, while tensile strength and compressive strength increase as matrix wt% increases in the formulation. But, hardness, density, thermal conductivity and oil soak varied non-uniformly with matrix content. The results showed that intermixed (CBS+MH+PKS) particles of the selected agro-wastes could be effectively used as replacement for asbestos in friction materials.**

Keywords—Automotive Brake Pad; Intermixed Agro-waste Filler Materials; Cocoa Beans Shells; Maize Husks; Palm Kernel Shells; Composite

I. INTRODUCTION

Discovery and application of brake lining materials dates back to as far as 117 years ago. Brake lining materials are mostly made with asbestos, metals and ceramics. But, asbestos is now known to be carcinogenic because during application it releases hazardous gases which can cause damages to human health, and this is not desirable, thus leading to searches for more human friendly materials. Asbestos causes serious health risks as it was linked to diseases that include asbestosis, mesothelioma, lung cancer and other cancers [1]. This work aimed at obtaining a friction material that is suitable for automotive applications, taking into consideration; cost, durability and environmental implication. Previous works have considered agro-waste materials suitable as fillers for the manufacture of automotive friction materials. Among those considered include; maize husks – MH [2], cocoa beans shells – CBS [3], and palm kernel shells – PKS [4]. But in this work, MH, CBS and PKS would be intermixed as ternary filler material to produce brake pads. Investigation shall be carried out by comparing properties of the specimen pads (made with intermixed fillers) with those of single filler (each of MH, CBS and PKS) and the conventional brake pad.

Cocoa bean shells, maize husks, and palm kernel shells are agro-wastes which are abundant in various farm centres in Nigeria, and huge amount of money is being expended to get them incinerated before the next planting season. From literature studies, it was discovered that these agro-wastes possess some properties that make them suitable for use in the manufacture of brake pads [5], [6], [7], [8], [9]. Instead of burning off these agro-wastes, making use of them for manufacturing brake pads and other friction materials will enhance their economic value, thereby provides means of "converting waste to wealth." The outcome of the work will introduce a new area for further researches as need arise for continuous improvements.

Brake pads are vital components of braking system for all categories of vehicles that are equipped with brake discs. Brake pads are steel backing plates with friction material bound to the surface facing the brake disc [10]. There are two basic types of automobile brakes: drum brakes and disc brakes. The brake shoes of drum brakes are located inside a drum. On applying the brakes, the brake shoe is forced outward and presses against the drum. One of the major differences between drum brakes and disc brakes is that drum brakes is usually enclosed while disc brakes are usually exposed to the environment [11], [12]. The brake pads generally consist of asbestos fibers embedded in polymeric matrix along with several other ingredients. Use of asbestos fibre is no longer acceptable due to its carcinogenic nature, thus new asbestos-free friction materials are being developed [13].

In 1925, the British Belting and Asbestos (BBA) Limited became known as BBA Group that manufactured such very well-known friction material

brand named as Mintex, Don, and Textar [14]. Owing to its effectiveness, chrysotile asbestos was used as a component in brake linings. However, studies such as a 1989 National Institutes of Health published report showed a rarely high proportion of brake mechanics were afflicted with pleural and peritoneal mesothelioma, both of which were linked to chrysotile and asbestos exposure. Public health authorities made a widespread recommendation against inhaling brake dust. Since then, chrysotile has been prohibited in many advanced countries, like Australia in late 2003. It has been progressively substituted in most brake linings and pads by fibers like synthetic aramids [15].

In the 1930s, Ferodo changed to thermosetting resins and thereafter presented molded linings in place of knitted ones. The molded linings were produced by combining fiber and resin together and also, polymerizing the resin under elevated pressure and temperature. As an extension, efforts have been directed to substitute asbestos fibers in friction linings. This was tried by Nakagawa in his work in 1986, in which metal fibers was used for inclusion in brake pads to prevent environmental contamination. Semi-metallic pad material was developed using chatter–machined short metal fibers because it displayed excellent characteristics of brake pad systems like resistance to wear. The brake pad contained about 60% by weight of steel fibers. Dimension: 60μm diameter and 3mm long [14].

Blau [16] reported the additive effects of different kinds of non-asbestos materials on friction linings. As a result of these efforts, asbestos-free organic, semi-metallic and metallic friction lining materials are now increasingly being utilized. Non-asbestos organic (NAO) based friction materials are basically multi ingredient systems that usually contain over 10 ingredients intermixed to achieve expected combination of performance properties. The list of ingredients used for formulation of brake pad composites contains over 700 items. They are classified into four major categories, namely; binder, fibers, friction modifiers and fillers based on the major function they perform apart from controlling friction and wear resistance. The central part of a system which binds the ingredients firmly so that they can perform the desired function in the friction materials is called binder. Friction modifiers are used to control the desired range of friction while fibers in amalgamation are included usually for strength. The two types of fillers available include; functional fillers for enhancing specific characteristic feature of composites such as resistance to fade, etc; and space/non-reactive fillers employed mainly to cut cost. Both modified and unmodified phenolic resins are always used as binders in friction materials because of low cost with good combination of mechanical properties such as high hardness, compressive strength, moderate thermal resistance, creep resistance, and very good wetting capability with most ingredients. These resins are sensitive to heat and humidity, and have poor shelf life as a result of in-situ polymerization which starts even at ambient temperature.

Brake pads are tested to ascertain properties that make them suitable for the application. Properties to be determined include abrasion resistance, hardness, friction coefficient, compressive strength, specific gravity, water and oil soaks, tensile strength, thermal conductivity, disc temperature and stopping time [4].

Design and development of brake pad wear monitoring system for successful testing and validation was carried out by Sivarao et al. [17]. Suggestion was given to embed sensor at the manufacturing level into brake pad to give wear alerting sound. A method for manufacturing a brake pad included casting back plate in the mould. The plate is shaped with at least one integral projection which overhangs on adjacent surface of the plate. The compositional design of friction materials is a well-known to be difficult with multiple criteria optimization that involves not only the problems of handling different categories of ingredients but also reaching an expected level of performance.

Changes in brake pads formulation were driven by the promulgation of the corporate average fuel efficiency requirements in the late 1970's and mid 1980's. These requirements led the automobile industry to switch from rear wheel drive cars to front wheel drive cars. This switch required more front braking which resulted in higher temperatures and a preference for semi-metallic brakes [18]. Several researches have been carried out in the area of development of asbestos-free brake pads. The use of coconut shell, palm kernel shell (PKS) has been developed for asbestos free brake pads materials [4], [19]. Researches globally today are focusing on ways of using either industrial or agricultural wastes as a source of raw materials in the industry. These wastes utilization will not only be economically advantageous, but may also result to foreign exchange earnings and environmental control. There is evolution of new materials and constituents currently used in automotive brake friction material after the phasing-out of asbestos, which had gained widespread acknowledgments as a carcinogen, although the introduction of the asbestos ban in some countries only came about in 1989. All forms of asbestos are carcinogenic. This ban was overruled in 1991 due to widespread complaints of the difficulty of finding asbestos replacements; existing uses of asbestos are still permitted, while new applications and uses (of asbestos) are banned [16].

Deepika et al. [14] revealed in their work that palm kernel shells (PKS) can be used to make brake pad and friction material as it showed good potentials based on results obtained from evaluation. PKS is cheap to obtain and available in large quantity. It has the characteristics of Influencing adhesion and dispersion of polymer composite fabrication [20].

Bashar et al. [21] produced coconut shells based brake pad. The formulation included ground coconut shells (filler), epoxy resin (binder –matrix),

iron chips (reinforcement), methyl ethyl ketone peroxide (catalyst), cobalt nephthanate (accelerator), iron and silica (abrasives), and brass (friction modifier). Sieve of 710μm aperture was used to sieve the pulverized filler. It was concluded that higher percentage of ground coconut powder gave lower breaking strength, hardness, compressive strength, and impact, and vice versa, thus high percentage of ground coconut powder induces brittleness. This supported the analysis that the tensile - impact strength of treated and untreated palm kernel nut shells polymer composite decreases with increase in its filler content [20].

Yawas, et al. [22] developed brake pads from Periwinkle shells. In the work, periwinkle shell (asbestos-free) brake pad material was characterized and its morphology and properties were determined. The sun dried periwinkle shell was crushed accordingly, milled and sieved using a set of +710, +500, +355, +250, and +125μm sieve aperture. The formulation included periwinkle shell powder, phenolic resin (phenol formaldehyde), engine oil (SEA 20/50), and water.

Geological studies on kaolin clay group within the sedimentary mineral material zone of Ise-Orun-Emure local government areas of Ekiti State, Nigeria was undertaken by Aderiye Jide [23]. The clay major characteristic properties were examined, beneficiated and processed for automotive friction lining material. It was discovered that kaolin clay group can be used because of its good heat resistance for friction lining material in automotive industries.

Idris et al. [24] investigated and produced brake pads using banana peels to replace asbestos with phenolic resin (phenol formaldehyde) as binder. The resin was varied from 5 to 30 %wt in an interval of 5 wt%. Studies were carried out on the physical, mechanical, wear and morphological properties of the brake pad. The results showed that compressive strength, hardness and specific gravity of the samples were increased with increased wt% of resin addition. The oil soak, water soak, wear rate and percentage charred decreased as resin wt% increased. The samples containing 25 wt% in un-carbonized banana peels (UNCBp) and 30 wt% carbonized (CBp) gave better properties in all.

Edokpia et al. [25] developed and evaluated Egg Shells (EG) based eco-friendly (biodegradable) brake pad. Gum Arabic (GA) was used as binder. Both additives were investigated as possible replacement for asbestos and formaldehyde resin which are carcinogenic in nature and non-biodegradable. The brake pad formulation was produced by varying the GA from 3 to 18 wt%. Tests carried out on samples included wear rate, thickness swelling in water and SAE oil, thermal resistance, specific gravity, compressive strength, hardness values and microstructure. Results showed that formulations containing 15 to 18 wt% of GA produced fair bonding. The sample with 18 wt% of GA in ES particles gave the best properties. The temperature of maximal decomposition of ES particle based brake pad was higher than asbestos and many agro-wastes currently used in the production of brake pad materials. Results obtained from formulating 18 wt% of GA with ES particles compared favorably with the commercial brake pad.

Maize husks (MH) based composite brake pad was developed by Ademoh and Adeyemi [2]. Filler particulate size was 300μm and epoxy resin was used as binder. Based on results obtained from the work, it was concluded that reducing the filler content increased the hardness, wear rate, tensile strength, compressive strength and thermal conductivity of the developed brake pad, while density, coefficient of friction water absorption and oil absorption increased with increase in the filler wt%. The results showed that MH particles could be effectively used as replacement for asbestos in automotive brake pad manufacture. Unlike asbestos based brake pad, the developed composite brake pad is eco-friendly without any known health implication.

In another work done by Adeyemi et al. [3], cocoa beans shells (CBS) particles were used as filler in composite brake pad formulation. The newly developed automotive brake pad was investigated by determining its physical, mechanical and tribological properties. Based on properties like density, water absorption, oil absorption, abrasion resistance, coefficient of friction, thermal conductivity, hardness, tensile strength, and compressive strength, the results obtained for the agro-waste based brake pads compared favourably with that of commercial brake pad and other existing ones. Specimen labeled as comp. 3 in particular gave superior performance over others. The density, water absorption, oil absorption, abrasion resistance, coefficient of friction, thermal conductivity, hardness, tensile strength, and compressive strength, of the most effective composite specimen (comp. 3), are 1.010g/cm^3, 1.188%, 0.275%, 3.934×10E-6, 0.32, 0.2387W/mk, 120.33MPa, 16.882MPa, and 23.150MPa, respectively. The results of the work indicated that cocoa beans shells (CBS) which is an agro-waste material can be effectively used as a replacement for asbestos in friction lining/ brake pad materials.

As an effort to complement the ongoing studies of the development of asbestos-free automotive brake pads, this work offers another alternative production of brake pad (composite), using agro-wastes that were intermixed (CBS+MH+PKS) as the filler. In most Nigerian villages, palm kernel shells are burnt for heating purposes. Some are dumped as wastes. Researchers [2], [3], [4], [14], [19] recently showed that it could be used to make brake pad and friction material as it showed good potentials. This work would improve on the existing PKS based brake pad by intermixing it with maize husk (MH) and cocoa bean shell (CBS). PKS is cheap to obtain and available in large quantity. It has the characteristics of Influencing adhesion and dispersion of polymer composite fabrication [20]. Physical and chemical characteristics of palm kernel shell as determined by Edmund [8] are presented in table 1.

Table 1. Bulk physical and chemical characteristics of palm kernel shell.

Property	Parameter	Value	
		Ar	db
Physical	Moisture content (%)	6.11	-
	Ash content (%)	8.68	-
	Bulk density (kg-m^{-3})	740	9.24
	Porosity (%)	28	650
Chemical	C (%)	46.75	49.97
	H (%)	5.92	5.58
	O (%)	37.97	34.66
	N (%)	0.68	0.72
	S (%)	<0.08	<0.08
	Cl (ppm)	84	89
Structural	Hemicelluloses (%)	26.16	
Carbohydrates	Cellulose (%)	6.92	
	Lignin (%)	53.85	

To a large extent, the potential of making use of agricultural by-products has now gained interests. One of these agricultural by-products is maize husk (MH). Utilization of this by-product would benefit both rural and urban development by providing additional value to agricultural activities and environment by saving field leftovers from burning, which is unfortunately a common practice. Particularly, it will serve as a source of raw material for the production of friction lining material in the automobile industry. MH is a lignocellulosic agro-based material that shows a composite structure. This composite structure is constituted by an organic matrix which is reinforced by bundles of cellulose micro-fibres. The organic matrix is mainly composed of lignin, hemicelluloses, pectin, waxes, and proteins [26]. Coefficient of friction of maize husk was determined to be 0.5 and density of 45 and 80Ib/ft^3 [27]. According to Guimarães *et al.* [6], mechanical characterization of maize husks is given in table 2. Chemical composition and fibre characteristics of maize husks are presented in table 3 and 4 respectively [9].

Table 2. Specimen mechanical properties.

	Longitudinal	Transversal
Mechanical Properties	Mean	Mean
Tensile Strength (MPa)	10.8	4.2
Elastic Modulus (MPa)	387.4	169.3
Rupture Strain (%)	5.03	3.7

Table 3. Chemical composition of maize husk

Component	Amount (%)
Lignin	15
Ash	5.09
Alcohol-cyclohexane solubility (1:2 v/v)	4.57
Cellulose	44.08

Table 4. Characteristics of maize husk

Fibre property	Dimension
Fibre length (mm) L	1.71±0.5
Fibre diameter (µm) D	21.89±5.1
Cell wall thickness (µm) CW	7.63±2.3
Lumen width (µm) LW	6.63±3.5

Similarly, cocoa tree (*Theobroma cacao*) is cultivated in Nigeria. In addition to the highly flavoured cocoa, the tree provides by-products like cocoa butter

(CB), cocoa pod husk (CPH) and cocoa bean shell (CBS)

among others. Cocoa bean shell is a potential tropical resource and its utilization in producing composite brake pad or friction lining among other uses will greatly reduce disposal problem facing cocoa processing factories in Nigeria. Cocoa Shell has

Nitrogen: Phosphorous: Potash of 3:1:3 [5]. The proximate composition of cocoa bean shells is summarized in table 5.

Table 5. Proximate composition (% dry matter) of cocoa bean shells.

Proximate	% Composition
Moisture	4.90 – 12.00
Crude Protein	13.20 – 20.10
Crude Fibre	9.30 – 2.05
Ether extractable components	1.90 – 22.00
Nitrogen-free extract	40.20 – 52.50
Ash	6.00 – 10.80

Source: Joseph [7]

II. METHODOLOGY

Materials/equipment

The following materials and equipment were used for this work, namely, palm kernel shells, maize husks, and cocoa beans shells, silica sand (425µm), epoxy resin, calcium carbonate, anhydrous iron oxide, powdered graphite, talc (release agent), sieve of aperture 300µm (BS 410 -1), spatula, stirrer, bowls, LCD series 2-digits and 3-digits electronic weigh balance, aluminum moulds, scrapper, hand gloves, universal testing machine (INSTRON 3369), micro hardness tester (LECO LM700AT), files, taber abrasion tester (TST) instrument (TSE-A016), measuring ruler, inclined plane, water, engine oil (SAE60) and modified Lee's disc apparatus. Engineering Materials Development Institute (EMDI) located in Akure, Nigeria, and Federal University of Technology, Akure, Nigeria, are the places where all laboratory and workshop equipment used were assessed. Table 6 shows the selected materials with reasons.

Table 6 . Materials mix prepared for the brake pad production and reasons for choices

S/N	Materials	Reason for selection
1.	Matrix: Epoxy resin + Hardener (Diethylenetriamine)	To explore its suitability as a binding agent in brake pad manufacturing, because it is not commonly used.
2.	Filler: • Palm kernel shells • Maize husks • Cocoa bean shells	They are readily/cheaply available as wastes at dumping grounds. From literatures, it was discovered that they possess properties which favour their application in friction lining manufacture.
3.	Abrasives: • Silica • Iron Oxide	Easy to come-by and cheaper. It is for increasing friction and controlling the build-up of friction film.
4.	Reinforcement: Calcium Carbonate ($CaCO_3$)	It is a lower cost alternative to barytes [28]. It is for influencing adhesion and dispersion of polymer composite fabrication.
5.	Friction Modifier: Powdered graphite (75microns)	It is not hazardous for improving wet friction.

Specimen Preparation

Powder technology method was adopted in the production of samples because melting is not required to form them [2], [3], [21], [25]. A control test was first performed by pouring 260g of epoxy resin into the moulds in order to determine the exact amount of mixture that would completely fill the mould cavities. For each aggregated composite mix, filler materials (CBS, MH and PKS) and matrix (epoxy resin and hardener) weights were varied while those of the abrasives (silica and Iron Oxide), friction modifier (pulverized graphite), and reinforcement (Calcium Carbonate – $CaCO_3$) were kept constant. For each formulation, certain quantities expressed in wt% (Table 7) of fillers, abrasives, friction modifier and reinforcement were measured into a container and thoroughly mixed for 15 minutes to obtain homogeneity, while a known amount of the epoxy resin (polyepoxide) was also poured into a separate container and a measured quantity of hardener was added to the portion. The epoxy resin and hardener

were thoroughly stirred for 10 minutes to obtain uniform mixture. Thereafter, the matrix mixture was poured onto the powdered material mixture and stirred further to obtain a paste-like homogenous mixture. The formed paste was poured into the mould cavities and allowed to cure. Resistance to flow of paste decreased as percentage by weight of matrix (binder) increased. The curing time was observed to range from 80 minutes to 120 minutes depending on the ratios of epoxy resin to hardener in the mixture. For instance,

1:2 hardener to epoxy resin mixture, the curing time was 80 minutes, while for 1:3 hardener to epoxy resin mixture, the curing time was 120 minutes. During production, it was observed that changing the matrix mixing ratio from 1:2 to 1:3 reduced casting porosity, but increased curing time. The same process was repeated to produce other samples in order to arrive at a composition with best properties. See Appendix B for other necessary plates that pertained to the research work.

Table 7. Composition for intermixed base material (MH+CBS+PKS) (wt%)

S/N	MATERIAL	Comp. 1 (wt%)	Comp. 2 (wt%)	Comp. 3 (wt%)
1.	Epoxy resin + Hardener	50.0	55.0	60.0
2.	$CaCO_3$	4.0	4.0	4.0
3.	• Palm kernel shell powder	6.0	6.0	6.0
	• Maize husk powder	15.0	12.0	9.0
	• Cocoa bean shell powder	10.0	8.0	6.0
4.	• Silica	7.0	7.0	7.0
	• Iron Oxide	3.0	3.0	3.0
5.	Powdered Graphite	5.0	5.0	5.0
	Total	**100.0**	**100.0**	**100.0**

Mechanical, Physical and Tribological Tests

After production of samples, they were left in an aerated environment for 21 days in order to allow them attain full strength before carrying out analytical tests on them. But from literatures, the allowed period to attain full strength before carrying out mechanical tests is 7days [29], [30]. To ascertain the suitability of a material for friction application, tests to be carried out included coefficient of friction test, wear (abrasion) resistance test, water and oil absorption tests, density test, hardness test, tensile strength test, compressive strength test, and thermal conductivity test [14], [19], [25], [31].

Coefficient of Friction Test

The coefficient of friction of each test specimen was determined with the aid of an inclined plane (model number: FUTA/PHY/IP/025) and a 90° wedge. Each specimen was placed on the inclined plane with the wedge in place. The wedge position was varied to increase inclination angle until the test sample was just about to slide down the plane [2], [3]. The resulting coefficient of static friction (µ) calculated using equation 1 [32]

$$\mu = \tan\theta = \frac{opp.}{adj.} \qquad (1)$$

Where: opp. means opposite and adj. means adjacent.

Wear Resistance Test

Each test specimen measured 110mm diameter and 6mm thickness. Abrasion resistance test was carried out with the aid of a taber abrasion tester (TST instrument – model TSE-A016). The specimens were weighed and recorded as W_0 before the test using an FA2204B 4-didit electronic weigh balance. The test specimen was fixed to the rotary disc (100mm dia.) of the machine with the aid of a nut at its centre. Two emery wheels at the upper arm of the machine were allowed to have direct contact with the specimen fastened to the rotary disc. The machine was turned on (powered at 220V) and the disc rotated at a constant speed of 85rev/mins for a pre-set time of 1000seconds. As the disc rotated, the two emery wheels in direct contact with the specimen also rotated at a relative speed to the disc and caused the specimen to wear. After the pre-set time, the machine was turned off automatically. The specimen was thoroughly cleaned and the final weight was measured and recorded as W_1 [2], [3]. The weight loss of the specimen was determined by finding the difference between the final and initial weights. Thus, the wear rate was determined using equation 2 [21], [25].

$$\text{Wear Rate} = \frac{w_o - w_1}{s} = \frac{\Delta W}{S} = \frac{\Delta W}{2\pi ND \times t} \qquad (2)$$

Where: W_0 is the initial weight, W_1 is the final weight, ΔW is the weight loss, S is the sliding distance, D is the disc diameter, N is the radial speed (rpm), and t is the time taken to expose the specimen to wear.

Water and Oil Absorption Test

To determine the oil and water absorption characteristics of the developed brake pad, oil and

water soaking tests were conducted. The initial weight of each specimen was taken and recorded as W_0 before soaking into engine oil and water separately. The oil used was automotive engine oil of rating SAE60. The test took 48 hours. At an interval of 24 hours, specimens were brought out of oil and water, thoroughly cleaned to drain water and oil on their surfaces and reweighed to determine the new weights that were recorded as W_1 and used later to determine the absorption rates [2], [3]. The absorptions were then computed using equation 3 [25].

$$Absorption\ (\%) = \left(\frac{W_1 - W_o}{W_o}\right) \times 100 \qquad (3)$$

Where: W_0 is the weight before immersion and W_1 is the weight after immersion.

Density Test

Density test was conducted on the experimental brake pad by using Archimedes' principle. This principle was useful for determining the volume and therefore the density of an irregularly shaped object by measuring its mass in air and its effective mass when submerged in water [2], [3] (density = 1 g/cm^3). The density is expressed in equation 4

$$Density = \frac{Weight\ in\ air}{Volume\ of\ water\ displaced} \qquad (4)$$

Hardness Test

A digital Micro Hardness Tester of 490.3µN load sensitivity (model: LECO LM700AT) was used. The specimen was indented for 10 seconds (dwell time), after which corresponding Vicker's hardness numbers were automatically read from the digital counter [2], [3].

Tensile Test

The tensile test on the specimen was carried out using an electronic universal testing machine (Model: INSTRON 3369). The specimen average gauge length, width and thickness measured 85mm, 11mm and 6mm respectively. In carrying out the test, one end of the specimen was gripped in the jaws attached to the adjustable crosshead and then after lifting this crosshead to the appropriate height, the other end of the specimen was fixed in jaws in the top crosshead. Then tensile load was hydraulically applied to the specimen by pressing the start bottom provided in the control unit. The input and output display unit in the control unit indicated magnitude of the applied load. The load was gradually increased until specimen broke off and corresponding extension was noted and recorded. The automatically generated test data were shown on the display unit [2], [3].

Compression Test

An electronic universal testing machine (Model: INSTRON 3369) was used to perform compression test on the specimen. Test samples were shaped and averagely dimensioned as 40mm × 12mm × 6mm. The compression was used as the reverse of tensile test as a standard method of testing brittle materials like cast iron, concrete, stones, bricks, ceramics, mortals, and other materials because the compressive strength of materials when carefully done also gives direct information on the tensile strength [33]. The compression test was performed by placing the specimen between the compression plates provided in the adjustable cross head and bottom crosshead. After specimen was properly positioned and gripped firmly between the compression plates, load was applied and the compressive strain was read from the output display unit. The load was gradually applied on the specimen and the corresponding strain was recorded at regular intervals [2], [3].

Thermal Conductivity Test

The thermal conductivity of a material is the heat flow per unit area per unit time when the temperature decreases by one degree in unit distance. It is denoted by λ and its unit is usually written as W/mk or kW/mk. Equation 5 was generated according to Fourier's law [34].

$$Q = -\lambda A \frac{dt}{dx}\ or\ Qdx = -\lambda A dt \qquad (5)$$

Where: Q is rate of heat flow, A is unit area, λ is thermal conductivity of the material, dt is the temperature change, and dx is the length of heat flow. Integration of equation 5 gives rise to equation 6.

$$Qx = -A \int_{t_1}^{t_2} \lambda dt \qquad (6)$$

The above equation can be solved when variation of thermal conductivity, λ with temperature, t known. For most solids, the value of thermal conductivity is approximately constant over a wide range of temperatures. Therefore λ can be taken as constant as shown in equation 7.

$$Q = -\frac{\lambda A}{x}(t_2 - t_1) = \frac{\lambda A}{x}(t_1 - t_2) \qquad (7)$$

The area in the direction at right angles to heat flow remains constant through the thick piece [34]. Therefore, the thermal conductivity test on specimen was carried out with the aid of a Modified Lee's disc apparatus [35]. The setup consists of a power source, a rheostat, an ammeter and voltmeter, four thermometers that measure temperatures of disc A (T_A), disc B (T_B), disc C (T_C) and surrounding (ambient – $T_{Amb.}$) respectively. The experiment was performed in an enclosed environment in order to minimize heat loss to surrounding. The discs were made up of brass and each having diameter of 4.14cm. Each disc had a hole drilled into it via the edge to a certain depth to accommodate the thermometer. Inside each hole was poured glycerine for proper contact. Between disc B and C was the heater that kept disc B and C in thermal equilibrium on heating. The material measured as Ø41mm, 5mm thickness for conductivity test was placed between disc B and A, all in contact with each other. To start heating up (for rising temperature readings), the rheostat was set to adjust the voltage to a maximum value of 6V. After 5 minutes interval, temperature rise readings were taken until equilibrium was attained and this was repeated six times

consecutively. Thereafter, the rheostat was also reset to reduce both the voltage and current in order to make the temperature fall. Falling temperature readings were also taken after 5 minutes interval until equilibrium was attained. Results of the thermal conductivity, λ (W/mk) of each sample of thickness, t (mm) and radius, r (mm) were computed using equations 8-12.

$$\lambda = \frac{ed}{2\pi r^2 (T_B - T_A)} \left[a_S \frac{T_A + T_B}{2} + 2a_A T_A \right] \quad (8)$$

Where e is given by

$$e = \frac{VI}{\left[a_A T_A + a_S \frac{T_A + T_B}{2} + a_A T_B + a_C T \right]} \quad (9)$$

And

$$a_A = a_c = \pi r^2 + 2\pi r l_d \quad (10)$$
$$a_B = 2\pi r l_d \quad (11)$$
$$a_s = 2\pi r l_S \quad (12)$$

Where l_d and l_S were the disc thickness and sample thickness respectively, while a_A, a_B, a_C, and a_S were the exposed surface areas of discs A, B, C and the specimen respectively. T_A, T_B and T_C were the temperatures of the discs A, B and C above ambient (i.e. the thermal equilibrium temperature of disc minus ambient temperature). V and I are the potential difference across the heater and current which flowed through it respectively. To fully analyze the thermal characteristics of samples within the temperature range, a MATLAB programme was developed to compute the thermal conductivity at different time intervals [2], [3], [35].

III.   RESULTS AND DISCUSSIONS

Friction Coefficient of Specimen

Table 8 presents the coefficient of friction of specimens with different composition. Coefficient of friction, μ = tanθ

Table 8. Coefficient of friction (μ) of specimens with different composition.

Test №	Composition/Material	Adj. (cm)	Opp. (cm)	Angle, θ (°)	Average θ (°)	Friction coefficient (μ)	Average μ
1.	Sample Composition 1:	25.90	10.70	22.45		0.41	
2.	PKS+CBS+MH	26.70	10.70	21.84	21.73	0.40	0.40
3.		28.00	10.70	20.91		0.38	
1.	Sample Composition 2:	29.90	10.70	19.69		0.36	
2.	PKS+CBS+MH	29.50	10.70	19.94	20.42	0.36	0.37
3.		27.00	10.70	21.62		0.40	
1.	Sample Composition 3:	38.50	10.70	15.53		0.28	
2.	PKS+CBS+MH	39.40	10.70	15.19	15.86	0.27	0.28
3.		35.30	10.70	16.86		0.30	

From Figure 1 below, it could be inferred that for each of the samples, the coefficient of friction decreased as the %wt of the fillers decreased in the composition. The coefficient of friction of all the samples compares favourably with the standard value. Composition 1 of MH (31%wt) gave the highest value over the conventional model. The coefficient of friction for conventional brake pad ranges from 0.3 to 0.4 [36]. It was also observed from results that the friction coefficient of the intermixed fillers (PKS+CBS+MH) was lowered by the presence of MH particles as it has the lowest values if each of the fillers - PKS [13] or MH [2] or CBS [3] were to be used independently in the composite. The comparison is presented in the appendix A.
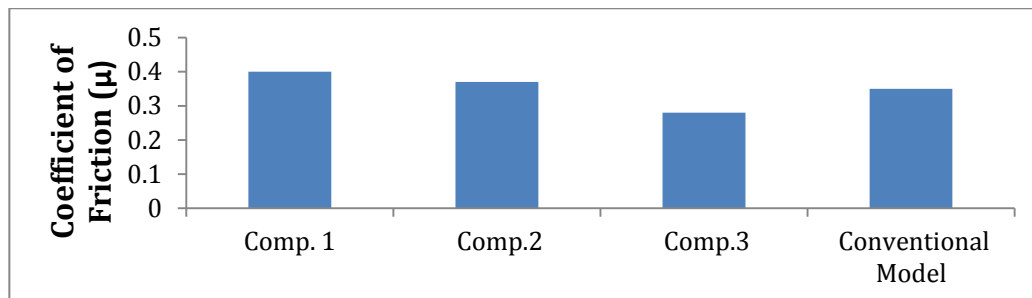

Figure 1. Comparative analysis of coefficient of friction (μ) of different samples

Variances of friction coefficients of each composite specimen from mean value of the conventional brake pad are 0.05 (comp. 1), 0.02 (comp. 2), -0.07 (comp. 3). Mean friction coefficient of conventional brake pad is 0.35. It was discovered that friction coefficient of the specimen labeled as composition 3 (21%wt of filler) is below mean value of that of the conventional brake pad. The negative variance shows that friction coefficient of the composite is below that of the conventional model, thus the positive variance indicates that they are better.

Abrasion (Wear) Resistance of Samples.Wear rates of composite specimens with different composition are as shown in Table9

Table 9. Wear Rate of composite specimens with different composition.

Test №	Composition/Material	W_o (g)	W_1 (g)	Time (sec.)	ΔW(g)	Average ΔW (g)	Wear Rate $\times 10^{-6}$ (g/m)
1.	Sample Composition 1:	102.412	102.379	1000	0.033		
2.	PKS+CBS+MH	126.613	126.607	1000	0.006	0.018	3.218
3.		98.094	98.078	1000	0.016		
1.	Sample Composition 2:	108.183	108.151	1000	0.032		
2.	PKS+CBS+MH	107.071	107.054	1000	0.017	0.017	3.040
3.		92.090	92.087	1000	0.003		
1.	Sample Composition 3:	106.768	106.753	1000	0.015		
2.	PKS+CBS+MH	101.884	101.875	1000	0.009	0.012	2.146
3.		99.706	99.693	1000	0.013		

From Figure 2 below, wear rate of the samples decreased as epoxy resin content increased from 50%wt to 60%wt in the formulation. This could be attributed to increasing interfacial bonding between PKS+CBS+MH particles and epoxy resin, reducing possibility of particle pull out (reduce wear) as binder content increased [25]. For all the samples, the wear rates compared favourably over the conventional model. Wear rate of conventional brake pad is 3.80 × 10^{-6}g/m (Appendix A). It was noticed that the wear rate of the intermixed fillers (PKS+CBS+MH) was reduced by the presence of MH particles in the mixture as it has the lowest values if each of the fillers - PKS [13] or MH [2] or CBS [3] were to be used independently in the composite. The comparison is presented in appendix A.
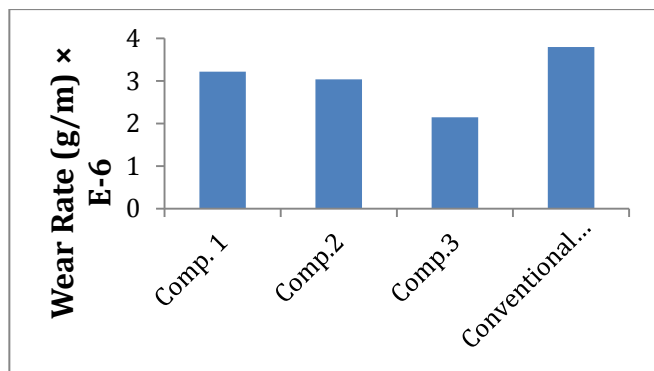

Figure 2. Comparative analysis of wear rate of different samples

Water and Oil Absorption of Specimens

Water and oil absorption of composite specimens were analyzed as shown in Tables 10. The test was carried out on day 2 which was to determine absorption saturation for the various samples of varying composition. It was discovered that all the samples attained water absorption saturation on day 2 as shown in Table 10, but they all reached oil absorption saturation within day 1. Thus, day 1 is considered in estimating the percentage absorptions (water and oil).

Table 10. Water and Oil absorption (%) of composite brake pads.

| Material/Composition | Water | | | Oil | | |
	Average Initial Weight, $W_{0(avg.)}$ (g)	Average Weight gain, $\Delta W_{avg.}$ (g)	Absorption (%)	Average Initial Weight, $W_{0(avg.)}$ (g)	Average Weight gain, $\Delta W_{avg.}$ (g)	Absorption (%)
Sample Composition 1: PKS+CBS+MH	3.575	0.060	1.678	3.315	0.030	0.905
Sample Composition 2: PKS+CBS+MH	4.635	0.045	0.971	3.090	0.010	0.324
Sample Composition 3: PKS+CBS+MH	3.850	0.035	0.909	2.585	0.015	0.580

Note: $Aborption\ (\%) = \frac{\Delta W_{avg.}}{W_{0(avg.)}} \times 100$

The results are analyzed in Figure 3 as shown below. The graph colouration was modified by inserting values on top of bars representing water absorption (%).
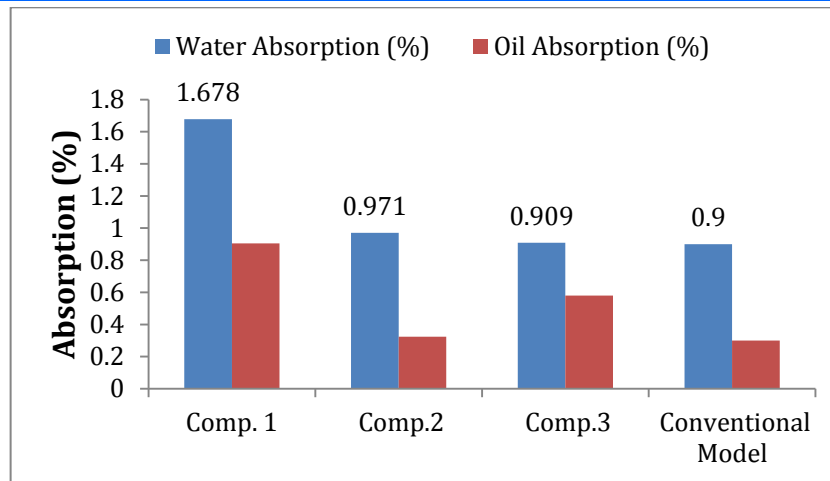
Figure 3. Analysis of water and oil absorption of the various samples

It was obtained from Figure 3 above that water absorbent property of the samples decreased as percentage weight of fillers decreased from 31%wt to 21%wt in the formulation. Whereas, their oil absorbent capability varied irregularly as epoxy resin content in the formulation decreased from 60%wt to 50%wt. Lower water and oil absorption capacity could be attributed to increased interfacial bonding between the binder and filler particles which lead to decrease in porosity level [2], [3], [25]. The results compared favourably with the conventional model. Water and oil absorption of conventional brake pad is 0.9% and 0.3% respectively (Appendix A).

Density of Composite Brake Pads

Table 11 presents density of the specimens, and they are analyzed as shown below in Figure 4.

Table 11. Density of the specimens

| Test №	Materials/Composition	Weight in air, W_{air} (g)	Volume of water displaced, V (cm^3)	Average Weight in air, $W_{air(avg.)}$ (g)	Average Vol. of water displaced, $V_{avg.}$ (cm^3)	Average Density, $\rho_{avg.}$ (g/cm^3)
1.	Sample Composition 1:	3.620	4.580			
2.	PKS+CBS+MH	3.530	4.210	3.575	4.395	0.813
1.	Sample Composition 2:	4.850	5.160			
2.	PKS+CBS+MH	4.420	4.781	4.635	4.971	0.932
1.	Sample Composition 3:	4.280	5.030			
2.	PKS+CBS+MH	3.421	3.995	3.851	4.513	0.853
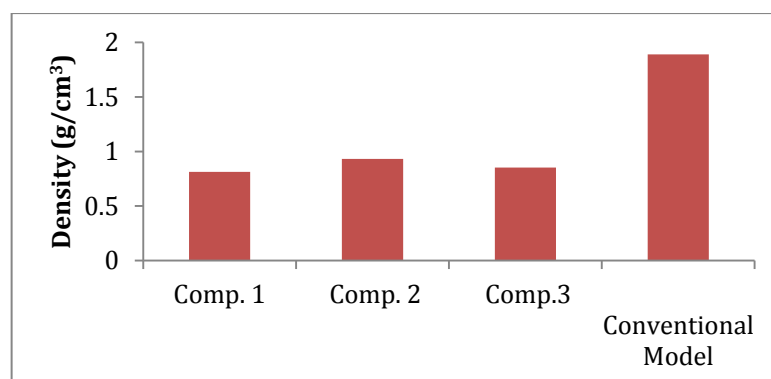
Figure 4. Analysis of density of the various samples.

From the figure above, samples densities varied irregularly as the filler portion in the formulation decreased. I.e. it peaked to a point after which it declined as the matrix wt% increase in the formulation. Increase in specific gravity was attributed to increased packing of filler(s) particles forming more homogeneity in the entire phase of the brake pad composite body [25]. This showed that a particular composition would give the most acceptable density, and this could only be achieved through optimization. However, all weights of the investigated composite specimens compared favourably over the conventional model.

The density of conventional brake pad is 1.890g /cm^3 (Appendix A). Density variance of each composition is -1.077, -0.985, and -1.037 respectively. These densities are lower than the conventional brake pad, and this makes them better in accordance with the standard recommended for brake pad application [25].

Hardness Values of Composite Brake Pads

The result of hardness test is as shown in table 12

Table 12. Hardness (Vicker's) value of composite brake pads

Materials/Composition	S/N	Hardness Number (HV)	Average Hardness Number (HV)	Average Hardness Value (MPa)
Sample Composition 1: PKS+CBS+MH	1.	10.70		
	2.	11.90	11.53	113.07
	3.	12.00		
Sample Composition 2: PKS+CBS+MH	1.	10.10		
	2.	10.90	10.67	104.64
	3.	11.00		
Sample Composition 3: PKS+CBS+MH	1.	14.30		
	2.	12.40	13.03	127.79
	3.	12.40		

Comparative analysis of hardness of the composite brake pads with the conventional model is illustrated in Figure 5.
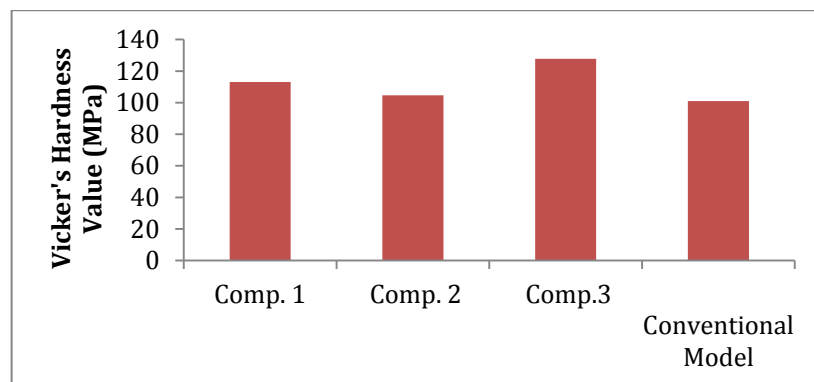

Figure 5. Comparative analysis of Vicker's hardness value of the various samples

From Figure 5 above, it was established that the hardness of the material varied non-uniformly as the epoxy resin percentage weight increased in the formulation (i.e. it declined to a point after which it peaked again as the matrix wt% increase in the formulation). And the hardness values compared favourably over the conventional model, and those produced from independent fillers (MH, CBS and PKS) – see appendix A. The hardness value of conventional brake pad is 101MPa. Also, while preparing the samples for thermal conductivity test through machining (plane turning and facing) on a lathe machine, it was observed that the HSS tool steel used worn out several times and had to be re-ground. This indicated that the materials are very hard.

Tensile Strength of Composite Brake Pads

Tensile strength result of composite brake pads is presented in Table 13

Table 13. Average Tensile strength of composite pads

Materials/Composition	Av. Tensile stress at break (MPa)	Av. Tensile strain at break (mm/mm)	Average Modulus (MPa)	Average Load at break (N)	Average Extension at break (m)
Sample Composition 1: PKS+CBS+MH	12.701	0.047	577.129	810.114	0.004
Sample Composition 2: PKS+CBS+MH	12.830	0.045	562.609	847.304	0.005
Sample Composition 3: PKS+CBS+MH	20.224	0.049	796.209	902.201	0.004

The result trend as presented in Table 13 showed that decrease in filler content from 31 to 21%wt resulted in increased tensile strength of composite brake pads investigated. Tensile strength of each composite was compared with that of the conventional

pad as shown in Figure 6. It was discovered that brittleness developed in the composite brake pad as filler content increased in the formulation. The graphs illustrating load (N) at break to the extension at break relationship are as shown in Figures 4.7.
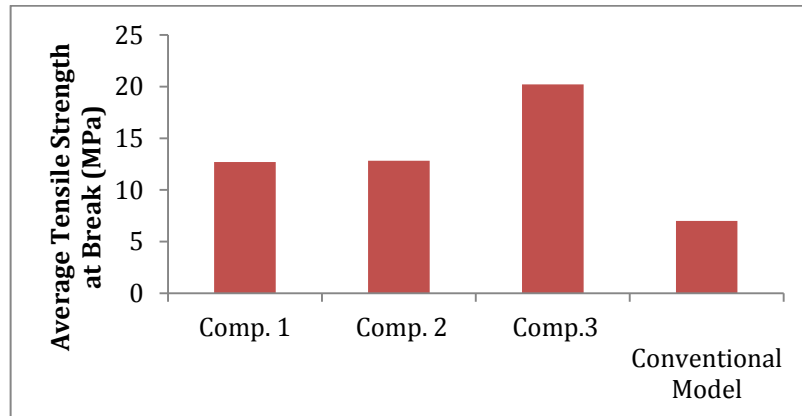

Figure 6. Comparative analysis of tensile strength of composite pads.
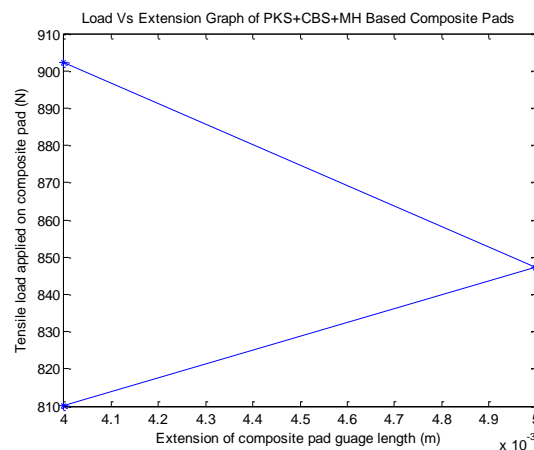
Figure 7. Load VS Extension graph for PKS+CBS+MH based composite pads

On the load/extension graph as shown in Figure 7, each point represents a unique composition of a particular specimen. Their behaviours as seen from the plots show that for each test specimen, there was a significant effect on the tensile load required to produce a specific extension before rupture. This can be used to measure the specimen's plasticity tendency under tensile loading. Tensile strength of the conventional brake pad is 7.00MPa. It was discovered

that for all the investigated composite specimens, tensile strength values are much above that of the conventional brake pad and others developed from similar researches (see appendix A).

Compressive Strength of Specimens

The result of compressive strength of each composite pad is presented in Table 14.

Table 14. Compressive strength of composite pads

Materials/Composition	Compressive Stress (MPa)	Strain at break (mm/mm)	Modulus (MPa)	Load at break (N)
Sample Composition 1: PKS+CBS+MH	(-) 8.251	0.019	438.862	(-) 352.261
Sample Composition 2: PKS+CBS+MH	(-) 9.988	0.020	514.846	(-) 375.096
Sample Composition 3: PKS+CBS+MH	(-) 10.313	0.022	598.498	(-) 401.064

As shown in Table 14 above, the bracketed negative signs preceding both compressive strength and load at break values show that none of the specimen broke under the influence of the applied load. The universal

testing machine used could not compress it further, thus, the values are those recorded at the time the tester could not compress further. This means that the specimens require very high compressive load before

rupture. Recorded compressive strength values of composite specimens were compared with each other based on composition as illustrated in Figure 8.
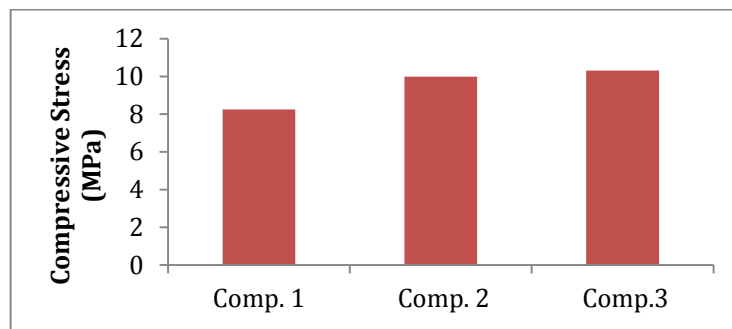

Figure 8. Comparative analysis of compressive strength of composite brake pads.

Figure 8 shows the compressive strengths of the formulated brake pad samples. The results followed the same trend as that of hardness values. The compressive strength increased with an increase in the wt% of epoxy resin content and fair dispersion of the filler (PKS+CBS+MH) particles with the binder resulting in fair filler particle to binder interaction. The fair particle dispersion improved the particle to binder interaction and consequently increased the ability of the brake pad formulation to restrain gross deformation [25]. The stress-strain analysis of each specimen is presented in Figure 9.
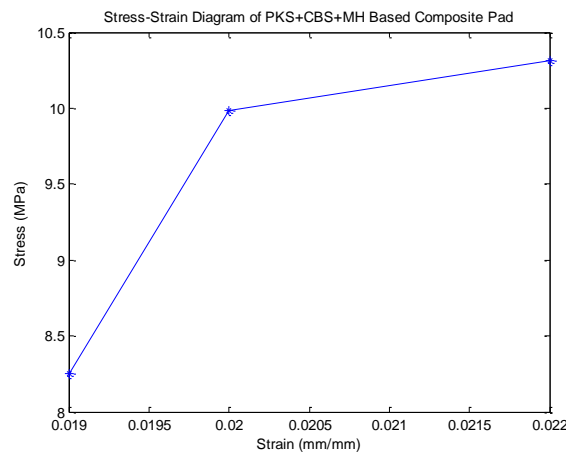

Figure 9. Stress-Strain Diagram of PKS+CBS+MH based samples

From Figure 9 as presented above, it was observed that there is a successive increase in stress-strain values as the filler content decreased in the formulation for each of the specimen types. This can be attributed to an increase in pore packaging capability of the CBS particles with the matrix. The decrease in compressive strength as the wt% of epoxy resin decreased was due to the interference of particles in the mobility or deformability of the matrix.

This interference was created through the physical interaction and immobilization of the binder by the presence of mechanical restraints, thereby reducing the strength [2], [3], [25].

Thermal Conductivity of Specimens

Table 15 presents the thermal conductivity of each composite brake pad.

Table 15. Thermal conductivity of the composite brake pad.

Materials / Composition	Thickness (mm)	Diameter (mm)	Thermal Conductivity, λ (W/mk)
Sample Composition 1: PKS+CBS+MH	5.50	41.00	0.2511
Sample Composition 2: PKS+CBS+MH	4.30	40.00	0.1415
Sample Composition 3: PKS+CBS+MH	5.65	40.25	0.3716

From Table 15 above, it was discovered that thermal conductivity of composite specimens decreased as the wt% of filler increased in the formulation up to a point after which peaked again. This may be attributed to lower interfacial bonding between filler particles and matrix resulting from decreased matrix content.

Thermal conductivity of each composite pad was compared with that of the conventional brake pad as shown in Figure 10.
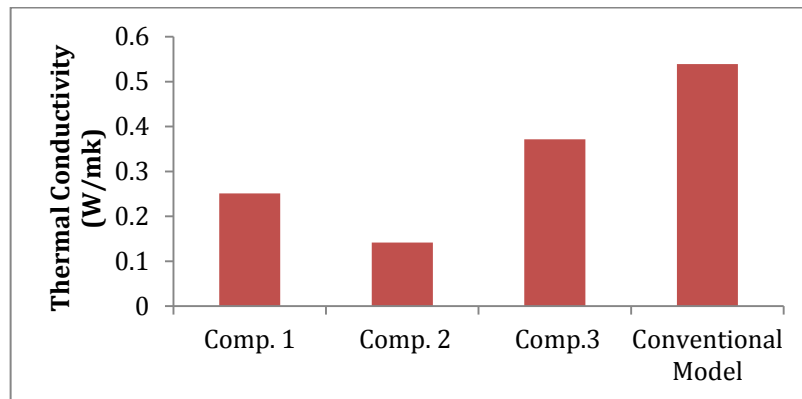

Figure 10. Comparative analysis of the thermal conductivity of composite brake pads

As obtained from Figure 10 above, thermal conductivity of each composite specimen is far below that of the conventional brake pad (0.539W/mK). This infers that the newly developed brake pads have higher heat resistance characteristics than the conventional model. Low thermal conductivity increases tendency of raising pad temperature as increased thermal resistance builds up temperature at the contacting surfaces. For most agro-waste based pads developed as obtained from literature, no information is available on thermal conductivity except palm kernel shell based brake pad (1.460W/mK) developed by Dagwa and Ibhadode [4].

Results of the composite pad that gave optimum performance are summarized as presented in Appendix A. The pad gave optimum performance in terms of the investigated physical, mechanical and tribological properties.

IV. CONCLUSION

The results of this research indicated that the agro-waste material (CBS+MH+PKS) based composite investigated in this work can be effectively used as an alternative to asbestos in friction lining materials, as its performances compare optimally over the conventional model and others developed in similar researches.

Considering the obtained lower specific gravity (54% improvement), lower wear rate (43.5% improvement), higher friction coefficient (10% improvement), lower water soaking tendency (18.89% improvement), lower oil soaking tendency (6.67% improvement), higher hardness (26.53% improvement), higher tensile strength (188.86% improvement), It has been established that the considered agro-waste particles can serve as alternative filler materials for brake pad manufacture.

Unlike asbestos based brake pad, the composite brake pad developed in this work is eco-friendly. Thus, they have no known health implication according to the findings available on the agro-wastes [5], [6], [7], [8], [26].

APPENDICES

Appendix A: Summary of the results compared with the existing laboratory brake pads

Properties	Commercial brake pad (asbestos based)	Laboratory formulation (PKS+CBS+MH at 300µm)	Laboratory formulation (MH at 300µm)	Laboratory formulation (CBS at 300µm)	Laboratory formulation (Palm kernel shell)	Laboratory formulation (Bagasse)	Laboratory formulation (ES particles at 18wt % of GA)	Laboratory formulation (Periwinkle shell at 125µm)
Specific gravity (g/cm^3)	1.89	0.853	0.852	1.01	1.65	1.43	1.65	1.01

Wear rate (mg/m)	3.8	2.146	4.47	3.934	4.4	4.2	4	-
Friction Coefficient	0.30–0.40	0.37–0.40	0.37–0.44	0.32-0.35	0.44	0.42	0.3	0.35–0.41
Thickness swell in water (%)	0.9	0.91	0.73	1.19	5.03	3.48	3.21	0.39
Thickness swell in SAE oil (%)	0.3	0.58	0.66	0.28	0.44	1.11	1.15	0.37
Hardness Values (MPa)	101	127.8	99.3	120.3	92	100.5	99.1	116.7
Compressive strength (MPa)	110	10.3+	6.8+	23.2+	103.5	105.6	103	147
Tensile strength (MPa)	7	20.22	14.41	16.88	6.8	-	-	-
Thermal conductivity (W/mK)	0.539	0.251-0.372	0.233-0.330	0.239–0.338	1.46	-	-	-

APPENDIX B

(a)

(b)

(c)

(d)

(e)

(f)

(g)

(h)

(i)

(j)

(k)

KEY:
- (a) Raw Cocoa Bean Shells (CBS)
- (b) Raw Palm Kernel Shells (PKS)
- (c) Raw Maize Husks (MH)
- (d) Powdered CBS (300µm)
- (e) Powdered MH (300µm)
- (f) Powdered PKS (300µm)
- (g) Thermal Conductivity Test Samples
- (h) Abrasion Test Samples
- (i) Tensile Strength Sample
- (j) Silica sand (425microns)

REFERENCES

[1] Anon (2004). Automotive Brake Repairs Trends and Safety Issues. Retrieved from http://www.sirim.my/amtee/pm/brake.hltm

[2] Ademoh A. Nuhu, Adeyemi I. Olabisi (2015). Development and Evaluation of Maize Husks (Asbestos-Free) Based Brake Pad. *International Institute for Science, Technology and Education (IISTE): Industrial Engineering Letters –IEL.* Vol. 5, No. 2, pp. 67 – 80.

[3] Adeyemi Ibukun Olabisi., Ademoh Nuhu. Adam, Okwu Modestus Okechukwu. (2016). "Development and Assessment of Composite Brake Pad Using Pulverized Cocoa Beans Shells Filler". International Journal of Materials Science and Applications. Vol. 5, No. 2, pp. 66-78. doi: 10.11648/j.ijmsa.20160502.16. ISSN: 2327-2635 (Print); ISSN: 2327-2643 (Online)

[4] Dagwa, I. M., Ibhadode, A. O. A. (2005). Design and Manufacture of Automobile Disk Brake Pad Test Rig. *Nigerian Journal of Engineering Research and Development, Vol. 4, No. 3,* pp.15 - 24.

[5] Olupona, J. A., Abodunwa, J. A., Fayoyin, F. K. (2003). Response of laying hens to graded levels of cocoa bean shells. In: Proceedings of the 28th Ann. Conf., Nig. Soc. Anim. Prod. (NSAP), Volume 28, pp. 247 – 249

[6] Guimarães, G. M., Paes, M. C. D., França, F., Marconcini, J. M. (2008). Corn Husks Mechanical Characterization. Retrieved from marconcini@cnpdia.embrapa.br

[7] Joseph, A. B. (2012). Enhancement of the Nutritive value of Cocoa (*theobroma cacao*) Bean Shells for use as Feed for Animals through a two-stage Solid State Fermentation with *pleurotus ostreatus* and *aspergillus niger.* Kumasi College of Science, Department of Biochemistry and Biotechnology, Kwame Nkrumah University of Science and Technology.

[8] Edmund, C. Okoroigwe, Christopher, Saffron M., and Pascal, Kamdem D. (2014). Characterization of Palm Kernel Shell for Materials Reinforcement and Water Treatment. *Journal of Chemical Engineering and Materials Science. Volume 5 No. 1,* pp. 1-6

[9] Taiwo, K. Fabemigun, Fagbemi, O. D., Otitoju, O., Mgbachiuzor, E., Igwe, C. C. (2014). Pulp and paper-making potential of corn husk. *International Journal of AgriScience. Vol. 4(4),* pp. 209 – 213

[10] Aigbodion, V. S., Akadike, U., Hassan, S. B., Asuke, F., Agunsoye, J. O. (2010). Development of Asbestos – free Brake Pad Using Bagasse. *Tribology in industry, 32 (1),* 45–50.

[11] Bono, S. G., Dekyrger, W. J. (1990). *Auto Technology, Theory and Service* (2nd ed.). DELMAR Publishers, New York, 45–48.

[12] Aigbodion, V. S., Agunsoye, J. O. (2010). Bagasse (Sugarcane waste): Non-Asbestos Free Brake Pad Materials. *LAP Lambert Academic Publishing, Germany,* ISBN 978-3-8433-8194-9.

[13] Dagwa, I. M., Ibhadode, A. O. A. (2006). Determination of Optimum Manufacturing Conditions for Asbestos-free Brake Pad Using Taguchi Method. *Nigerian Journal of Engineering Research and Development. Basade Publishing Press Ondo, Nigeria, 5(4),* pp. 1–8.

[14] Deepika, K., Bhaskar, Reddy C., Ramana, Reddy D. (2013). Fabrication and Performance Evaluation of a Composite Material for Wear Resistance Application. *International Journal of Engineering Science and Innovative Technology (IJESIT) Volume 2, Issue 6,* pp. 1-6.

[15] Publication of the International Ban Asbestos Secretariat (2013). Australia. Retrieved fromhttp://www.commerce.wa.gov.au/worksafe/content/safety_topics/Asbestos/Ban_on_chrysotile_asbestos.html

[16] Blau, J. P. (2001). Compositions, Functions and Testing of Friction Brake Materials and their Additives. Being a report by Oak Ridge National Laboratory for U.S. Dept. of Energy. Retrieved from http://www.Ornl.-gov/-webworks/cppr/y2001/rpt/112956.pdf, 78–80.

[17] Sivarao, M., Amarnath, M. S., Rizal, A. K. (2009). An investigation toward development of economical brake lining wear alert system, *IJENS, Vol: 9, No.9,* pp. 251-256.

[18] Gudmand-Hoyer, L., Bach, A., Nielsen, G. T., Morgen, P. (1999). Tribological Properties of Automotive Disc Brakes with Solid Lubricants. *Wear* 232, 168–175.

[19] Dagwa, I. M. (2005). Development of Automobile Disk Brake Pad from Local Materials, Ph.D. (Manufacturing Engineering) Thesis, University of Benin, Benin City, Nigeria.

[20] Ishidi, E. Y., Kolawole, E. G., Sunmonu, K. O. (2011). Morphology and thermal property of alkaline treated palm kernel nut shell HDPE composite. *Journal of Emerging Trends in Engineering and Applied Sciences (JETEAS), 2(2),* pp.346-350

[21] Bashar, Dan-Asabe, Peter, Madakson B., Joseph, Manji (2012). Material Selection and Production of a Cold-worked Composite Brake Pad. *World Journal of Engineering and Pure and Applied Science (WJEPAS). 2(3),* pp. 96.

[22] Yawas, D. S., Aku, S. Y., Amaren, S. G. (2013). Morphology and properties of periwinkle shell asbestos-free brake pad. Journal of King Saud University – Engineering Sciences.

[23] Aderiye Jide (2014). Kaolin Mineral Material for Automobile Ceramic Brake Pad Manufacturing Industry. *International Journal of Technology Enhancements and Emerging Engineering Research, Vol. 2, Issue 3,* pp. 84 – 88

[24] Idris, U. D., Aigbodion, V. S., Abubakar, I. J., Nwoye, C. I. (2013). Eco-friendly asbestos free brake-pad: Using banana peels. *Journal of King Saud University – Engineering Sciences.*

[25] Edokpia, R. O., Aigbodion, V. S., Obiorah, O. B., Atuanya, C. U. (2014). Evaluation of the Properties of Ecofriendly Brake Pad Using Egg Shell Particles–Gum Arabic. *ScienceDirect, Elsevier.* B.V. DOI: 10.1016/j.rinp.2014.06.003

[26] Nazire, Deniz Yilmaz (2013). Effects of enzymatic treatments on the mechanical properties of corn husk fibres. *The Journal of the Textile Institute, Vol. 104, No. 4,* pp. 1-6.

[27] Chief Agri/Industrial Division (2013). *Apparent Densities of Dry Feed Ingredients.* Kearney, United States. NE 68848

[28] Nicholson, G. (1995). Facts about Friction , P & W Price Entreprises, Inc., Croydon, PA. Retrieved from http://www.google.com.ng/search?q=facts+about+friction

[29] Cease, H., Derwent, P. F., Diehl, H. T., Fast, J., Finley, D. (2006). Measurement of mechanical properties of three epoxy adhesives at cryogenic temperatures for CCD construction: Fermi National Accelerator Laboratory. Batavia IL 60510.

[30] Simpson Strong-Tie (2014): flexiblized Epoxy Adhesive. FX-523. Retrieved from www.strongtie.com/RPS. Accessed in 2015.

[31] Hooton, N. A. (1969). Metal-Ceramic Composites in High-Energy Friction Applications (Concerning aircraft brakes). *Bendix Technical Journal,* 55-61.

[32] Friction Coefficient Experiment (2005). Retrieved from http://www.pstcc.edu/departments/natural_behavioral_sciences/Web%20Physics/Experiment%2005.htm

[33] Khurmi, R. S. and Gupta, J. K. (2004). *A Text Book of Workshop Technology (Manufacturing Processes).* S. Chand & Company Ltd. Reprinted edition. 58 – 67.

[34] Eastop, T. D. and McConkey, A. (2005). *Applied Thermodynamics for Engineering Technologists* (5th ed.). Pearson Education Limited, 582 – 584.

[35] Oluyamo, S. S., Bello, O. R., and Yomade, O. J. (2012). Thermal Conductivity of Three Different Wood Products of Combretaceae Family; *Terminalia superb, Terminalia ivorensis and Quisqualis indica. Journal of Natural Sciences Research. 2 (9),* 18-29.

[36] Ibhadode, A. O. A., Dagwa, I. M. (2008). Development of asbestos-free friction lining material from palm kernel shell. *Journal of the Brazilian Society of Mechanical Sciences and Engineering. J. Braz. Soc. Mech. Sci. & Eng. 30 (2).* Rio de Janeiro. ISSN 1678-5878.