



## ENGINEERING APPLICATIONS OF CHEMICALLY ACTIVATED CARBON COMPOSITES FROM AGROWASTES OF PALM KERNEL AND COCONUT SHELLS

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### ABSTRACT

Epoxy/activated carbon composites of particle sizes (60, 105, 150 $\mu$ m) and reinforcement weight percentages of (2, 4, 6 and 8) have been developed and evaluated for engineering applications. The physicomaterial properties were determined according to ASTM standard methods. Density decreased with an increase in reinforcement weight percentage. 2% weight increment of the particle sizes of the chemically activated carbon fillers yielded tensile and flexural strengths higher than that of the selected commercial brake pads (CB1) and (CB2), with the tensile strength of 4.84 and 6.58MPa, the flexural strength of 12.84 and 21.61MPa respectively while the hardness results compared well with the commercial brake pads samples. In general, from the standpoint of its tensile strength, %elongation at break, flexural strength, and hardness properties, these new formulations can find applications in aerospace and automobile industries where lightweight, high strength materials are sought after, hence a potential organic friction lining precursor for brake pad manufacture.

**Keywords:** *Agro wastes, Activated Carbon, Composites, Physicomaterial Properties, and Engineering Applications.*

### 1. Introduction

With the desire for industrial, economic, and environmental sustainability, the effort is put towards utilising agricultural waste materials for engineering applications, thereby reducing the environmental effects caused by its poor disposal, especially in developing countries. Composites made from agro-waste materials such as palm kernel shell (PKS) and coconut shell (CS) have gained significant applications in the automotive industry in manufacturing components such as brake pads. The environmentally friendly natural fiber composites are widely introduced to industries because they possess many advantages over synthetic fibres, such as renewable sources, biodegradability, low density, low energy consumption, and non-abrasiveness. In their different studies, the authors opined that the composition of engineering material and surface modification has significantly contributed to improving the mechanical properties performance of composites [1, 16]. Most engineering composite materials made up of carbon reinforcement in the thermosetting epoxy polymer required in applications have had a huge upgrade in recent days [4].

Furthermore, as stated by [21], polymeric composites usually use epoxy resin as thermoset

material because of its good chemical and insulation properties and good bonding ability with other materials. The production of activated carbon from palm kernel shell with high porosity as reinforcement in a polymer matrix to function as self-lubricated material has been tested [8]. Palm kernel shell activated carbon-reinforced polymeric composite has found application as an alternative for the current high-cost commercial self-lubricated material due to its low friction coefficient value [20]. Today's advanced technology can simulate test models in the design process for technical insight in order to reduce weight and material cost [10]. The use of agricultural wastes in activated carbon industries is helpful as it is economical and environmentally friendly. In Nigeria, huge amounts of palm kernel and coconut shells are produced as agricultural wastes. Hence its utilization as an activated carbon precursor is very promising. These wastes can also produce fibre-reinforced polymeric composites for commercial use, especially in automotive and packaging materials. Agricultural wastes are renewable resources having marketing appeal as another important economic resource. The growing concern of resource depletion and global pollution has dared many researchers and engineers to seek and develop new materials relying on renewable resources. These include the use of

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byproducts and waste materials in construction. Many of these byproducts are used as fillers to produce a good mix design. With the global economic recession coupled with the inflationary market trends, the constituent materials used for these mixed designs led to a very high construction cost. Hence, researchers in material science and engineering are committed to having local materials to partially or fully replace these costly conventional ones [17].

Several successes have been made in these regards, and this subject is drawing attention due to the functional benefit of waste reusability and sustainable development. Reduction in construction costs and producing a good mix are added advantages [15]. Palm kernel and coconut shells are available in abundance in tropical countries as waste products. This equally contributes to environmental degradation due to poor disposal and waste management systems where these wastes are generated. This kind of waste can find applications as filler-based composites while preserving the environment by reducing waste. In Nigeria today, a pressing issue is the recycling of waste products and other agricultural byproducts suitable for the invention and characterization of new materials [2]. In their separate works, these authors stated that annually, approximately 33 billion coconuts are harvested worldwide, with only 15% of these coconuts being utilized for fibres and chips [14, 22]. This implies that there is considerable opportunity to reduce this kind of environmental degradation and enhance the efficiency of using natural resources. Coconut shells are cheap and readily available in high quantities.

The carbonization process involves converting the coconut shells to char (charcoal). The charring process (making of charcoal) is known as pyrolysis, which is the chemical decomposition of the shell by heating in the absence of oxygen. [12], concluded that surface modification of coconut fiber by plasma treatment to enhance the interfacial adhesion between the coconut fibers and polylactic acid (PLA) matrix improves the mechanical properties, such as tensile strength and young's modulus of coconut fibers/PLA green composites fabricated using commingled yarn method. [9], reported that the tensile strengths of the biocomposites decreased slightly as the filler loading increased; however, the composites retained an acceptable level of strength. [11], were of the view that an increase in coconut shell content increases the tensile strength, young's modulus and water absorption rate but reduces the elongation at break of coconut shell filled polyester composites. [3], observed that coconut shell reinforced composites showed 80% better elongation at break and 20% better Charpy impact strength than softwood composites. According to [5], coconut fibre's

natural waxy surface layer provides a strong interfacial bonding between the fiber and polyethylene matrix. In this study, palm kernel shell and coconut shell were chosen as precursor for production of chemically activated carbon which was used as reinforcement.

## 2.1 Materials and Activated Carbon Production Method

### Materials and Equipment

Materials used in the production of the activated carbon includes palm kernel shells (PKS), coconut shells (CS), calcium chloride, distilled water, volumetric flask, weighing balance, heat source, aluminum pot with lid, ramming mass (castable), small ceramic pot with laboratory mortar, ball milling machine and a timer, which are shown in Figure 1.



Fig. 1 Materials and Equipment

### Activated Carbon Production

The Palm kernel and coconut shells were bought from a local oil palm processing factory in Orlu, Imo State, Nigeria. They were then washed, and non-shell materials were carefully removed. The activated carbon production was done in three runs. The shells were then dried by heating in batches for 30minutes per batch until the required quantities were obtained. First, the weight of the empty aluminium pot with a lid was measured to be 1.2kg. The pot was filled but not to the brim with PKS samples, and the weight of the aluminium pot with lid and the palm kernel shells was measured to be 6.2kg after sealing the lid on the pot with ramming mass (castable). The total weight of the PKS samples was calculated to 5.0 kg i.e. (6.2kg – 1.2kg). An 8mm diameter hole was then drilled on the lid to enable the escape of fumes during pyrolysis. Note

that the gas pressure from inside was higher than the atmospheric pressure, so there was no entrance of oxygen into the heating chamber during pyrolysis.

The heat source was activated, and the sealed pot containing the PKS materials was then placed on the heater. Heating was monitored for about 4 hours until no fumes emerged from the lid's drilled hole. A thermocouple was installed into the aluminium pot via the drilled hole. First, the ambient temperature was measured to be 34°C. The start-up temperature was measured with the thermocouple to be 81°C. Also, at the peak of the fume, the temperature was measured to be 260°C. This was the temperature at which the quantity and pressure of the fumes were high. Finally, the temperature was measured with the same thermocouple when the fumes started diminishing at 265°C. This compared well with the optimum degradation temperature (ODT) of 267.89°C of the palm kernel shell sample when subjected to TGA analysis before the start of the pyrolysis. At this point, the gas supply from the cylinder was shut off.

The content was then allowed to cool to room temperature, and the weight of the aluminium pot and charred PKS samples was measured to be 3.0kg. The ramming mass was removed, and the weight of the lid was measured to be 0.2kg. The weight of the charred PKS samples was calculated by subtracting the weight of the empty pot with a lid from the total weight of the aluminium pot with charred PKS samples, which was measured to be 3.0kg. i.e.  $(3.0 - 1.2 = 1.8\text{kg})$ . Therefore, 1.8kg of charred PKS samples were produced at first pyrolysis. After unsealing the lid and measurements, the content (charred PKS) was removed from the pot. The charred PKS materials were then washed in running water and spread in the open for sun drying for four days. The charred PKS materials were then grinded in a ball mill to get the required granule size. The processes were repeated to produce more quantities of the charred PKS samples.

To produce the activated carbon after pyrolysis, calcium chloride ( $\text{CaCl}_2$ ) was mixed with distilled water in a ratio of 1:3. 100g of  $\text{CaCl}_2$  was mixed with 300ml of distilled water into a volumetric flask and was stirred to form a solution. The PKS granules were mixed with the  $\text{CaCl}_2$  solution on a ratio of 2:1. This implied that 300g of PKS was mixed in a solution of 150ml. The mixture was stirred until a paste-like material was formed. The paste-like material was covered and allowed for 24 hours. Water was drained from the sample as much as possible and the sample was transferred into an aluminum pot with lid and was heated for 3hour to activate. The processes were repeated to produce more quantities of the PKS activated carbon. The same procedure was repeated to

make coconut shell activated carbon at a carbonization temperature of 263.73oC obtained from the coconut shell sample's thermogravimetric analysis (TGA). The produced activated carbon samples are shown in Figure 2.



PKS Activated Carbon (PKSAC) Coconut Shell Activated Carbon (CSAC).

**Fig. 2 Produced Activated Carbon Samples**

### Activated Carbon Composition

The palm kernel shell and coconut shell activated carbon (PKSAC and CSAC) were prepared into three different percentage compositions namely ( $X_{\text{PKSAC}}=0\%$  CSAC:100%PKSAC,  $X_{\text{PKSAC/CSAC}}=50\%$ CSAC:50%PKSAC, and  $X_{\text{CSAC}}=100\%$ CSAC:0%PKSAC in volumes) each having three different particle sizes of (60, 105, 150 $\mu\text{m}$ ).

### 2.2 Fabrication of Epoxy/Activated Carbon Composites

Epoxy/activated carbon composites were prepared using the three activated carbon compositions earlier prepared according to their respective particle sizes into four (4) different reinforcement weight percentages to determine their mechanical properties with application in engineering. The materials used to fabricate the various epoxy composite samples include activated carbon compositions of 0%CSAC:100%PKSAC, 100%CSAC:0%PKSAC, 50%CSAC:50%PKSAC, Epoxy Resin (Epochem 105 epoxy resin, Part A), Hardener (Epochem 205 epoxy hardener, Part B) and mould made from Beeswax. This epoxy resin was used in this study due to its excellent mechanical strength, excellent resistance to heat, excellent resistance to chemicals excellent adhesive strength, low curing contraction. Epochem 205 epoxy resin catalyst (Part B) was used due to its low viscosity, excellent surface appearance, good blush resistance and good mechanical performance.



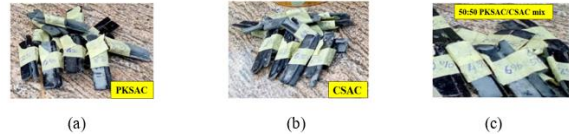
**Fig. 3 Base materials, resin, hardener and mold material**

The Base materials, resin, hardener and mold material used in the present work are shown in Figure 3.

### Fabrication Method

Three (3) base materials were used in the sample fabrication; 0%CSAC:100%PKSAC, 100%CSAC:0%PKSAC and 50%CSAC:50%PKSAC of three particle sizes of 60, 105 and 150  $\mu\text{m}$  in the increasing step of 45 using standard laboratory sieves. For each particle size category, samples were prepared by varying the weight fraction (%wt) in increasing steps of 2% from 2% (lowest) to 8% (highest), i.e. (2, 4, 6 and 8%). The matrix (resin and catalyst), according to manufacturer specification, has a 2:1 mixing ratio. The standard volume of the activated carbon sample was chosen to be 10ml. The sample composition was calculated. For 60 $\mu\text{m}$ , 98% of the resin + catalyst for a 2:1 ratio gave 6.5ml and 3.3ml of resin and catalyst, respectively, yielding a total of 9.8ml in volume, while 2% weight of the reinforcement gave 0.2ml in volume. To determine the weight of each % reinforcement, the mass was calculated by multiplying the volume by the density.

The process was repeated for the other particle sizes of the activated carbon compositions. Beeswax casting method was used to produce the specimens, which were then sized in accordance with ASTM standards for physico mechanical testing. To prepare the moulds for casting of the samples, raw beeswax was bought from a local market in Orlu, Imo state, Nigeria. Moulds were then prepared in beeswax (Inverse of lost wax casting process). Calculation and measurement of required weight percentage was done. The sample was mixed and stirred mechanically. To determine the curing period, a representative sample was prepared and used to measure the hardness daily until the hardness value stabilized. A total of five (5) days were expended to have the hardness stabilize. This was used as the basis for the curing time for the rest of the samples. The mixed samples were then poured into the mould and allowed to cure for five (5) days at room temperature. Then the cast sample was removed after curing, cleaned, cut and dressed to the respective sample shape and dimension for mechanical tests (tensile, hardness, flexural tests) as per the ASTM standards. This process was repeated for other particle sizes. Epoxy composite samples produced for the Physico-mechanical test are shown in Figure 4.



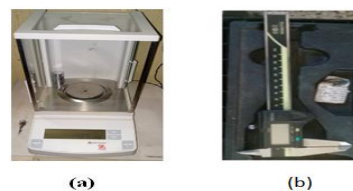
**Fig. 4 Epoxy composite samples produced for Physico-mechanical test (a) 0%CSAC:100%PKSAC (b) 100%CSAC:0%PKSAC (c) 50%CSAC:50%PKSAC**

### 2.3 Density of epoxy/activated carbon composite samples

Each sample's length, width, and depth were measured using a vernier caliper (Figure 5b) and used to calculate the volume. The volume was calculated by taking the length, width, and depth product. The sample was then weighed using Ohaus digital balance (AR2140) with a precision of 0.0001g or 0.1mg manufactured by Ohaus Corp. Pine Brook, NJ, USA (Figure 5a) to determine the mass. The density was then calculated by using Equation 1. This was repeated for all samples.

$$\rho = \frac{m}{v} \quad (1)$$

Where  $\rho$  is the density ( $\text{g}/\text{cm}^3$ ),  $m$  is the mass of sample (g), and  $v$  is the volume of sample ( $\text{cm}^3$ )



**Fig. 5 (a) Ohaus digital balance (b) Digital vernier caliper**

### 2.4 Mechanical Testing

Mechanical properties tested include tensile strength, flexural strength, and hardness. All tests were carried out at PGE Applied Resources Material Testing Laboratory, Orlu, Imo State, Nigeria.

#### Tensile Test

To obtain the ultimate tensile strength of the samples, a tensile test was conducted on all the samples according to their weight percentage, particle size and activated carbon compositions by using the EZ 250 AMETEK Tensile-Compression Digital testing

machine, as shown in Figure 6. The sample preparation and procedure followed the ASTM D638–14 standard for tensile testing. The tensile strength was calculated using Equation 2.

$$\sigma_{max} = \frac{P}{A} \quad (2)$$

Where;  $\sigma_{max}$  is the ultimate tensile strength (MPa),  $P$  is the Maximum load at failure (N).  $A$  is the original cross-sectional area ( $\text{mm}^2$ ).



Fig. 6 EZ 250 AMETEK Digital Tensile Machine

### Flexural Test

To obtain the flexural strength of the samples, a 3-point bending test was conducted on all the samples according to their weight percentage, particle size and activated carbon compositions by using the EZ 250 AMETEK Digital 3-point Flexural testing machine as shown in Figure 7. The samples were prepared based on ASTM standard (D790-03). Sample dimensions were measured using a digital vernier caliper. To evaluate the flexural strength of the respective representatives from the three-point bending test, Equation 3 was applied accordingly using the values of specimen dimension, the peak force at breaking and the length of the support span.

$$\sigma_f = \frac{3FL}{2bd^2} \quad (3)$$

Where,  $F$  = Maximum load applied on test specimen (N),  $L$  = Length of support span (mm),  $b$  = Width of specimen tested (mm),  $d$  = Thickness of specimen tested (mm).



Fig. 7 EZ 250 AMETEK Digital 3-point flexural test machine set up

### Hardness Test (Shore D)

The new formulations' hardness (Shore D) was determined using CV Instrument SHD0002 Analogue Shore “D” scale as shown in Figure 8a. This hardness tester is standardized in ASTM according to A956-06. The advanced Shore Scale Durometers provide fast, easy-to-read instruments ideal for testing rubber, plastic, leather, and composite materials. ASTM standard stipulates that the applied force should be 44.4N. In order to authenticate the test values, the force gauge on the tensile testing machine was used to determine this force by installing the Shore D hardness tester on the tensile testing machine, as shown in Figure 8b.



Fig. 8 (a) Shore D Hardness Tester, CV Instrument, England. (b) Shore D Hardness Tester installed on Tensile Machine

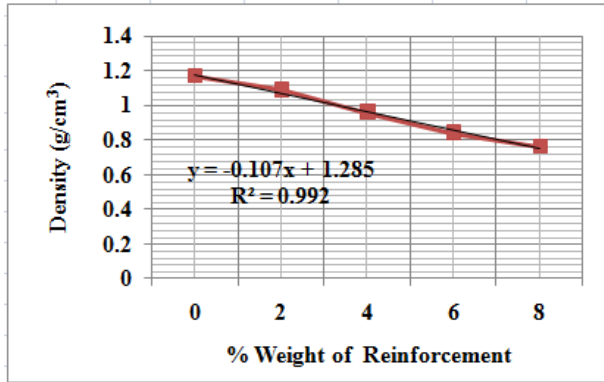
## 3. Results and Discussions

Two (2) different commercial brake pads were bought from a local automobile market in Port Harcourt, Nigeria. The brake pads were designated as CB1 (TOYOTA with OEM No/Model: 04465-33450) and CB2 (SUPERFIT with Model No D2223) manufactured in Japan and China, respectively and were used as control samples for comparison with the developed epoxy/activated carbon composites having three different particle sizes. The results of the comparison are discussed here below.

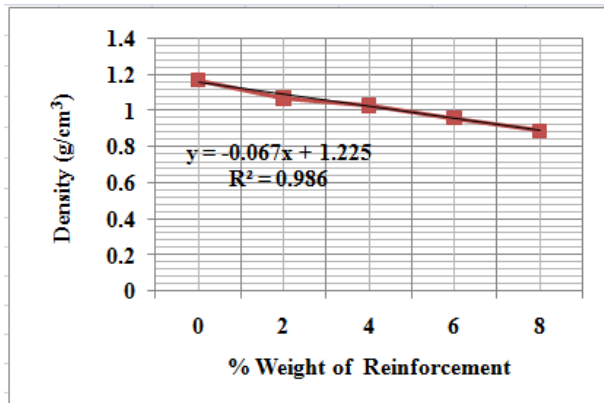
### 3.1 Density analysis of epoxy/activated carbon composite samples

Figure 9 to 11 revealed a decreasing density of the epoxy/0%CSAC:100%PKSAC, epoxy/ 100%CSAC: 0%PKSAC and epoxy/50%CSAC:50%PKSAC samples as the percentage weight of the respective filler content increased. Carbon is lighter than the epoxy which will consequently lower the density of the composites. When compared with the control samples i.e., the commercial brake pads (CB1) and (CB2) with densities of  $1.687\text{g/cm}^3$  and  $2.065\text{g/cm}^3$  respectively, the various activated carbon compositions showed lower densities. It is suspected that the commercial brake pads samples contain other constituent which might have improved its density. From Table 1, it can be seen from the below

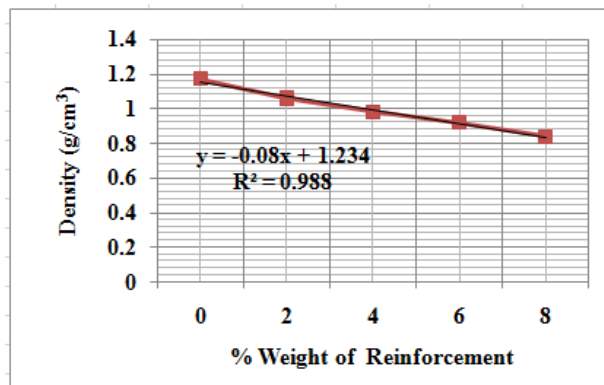
plots that the regression models are reliable from the standpoint of the error in the regression.



(a)

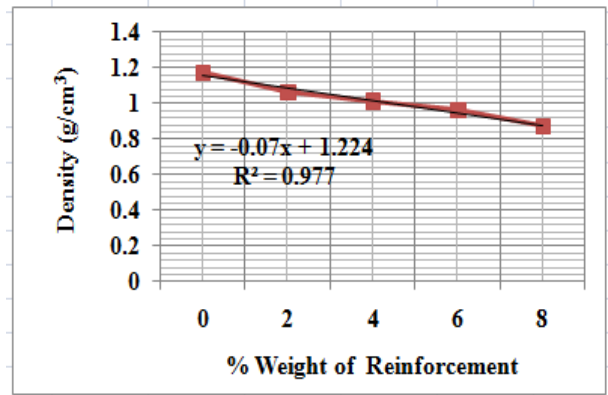


(b)

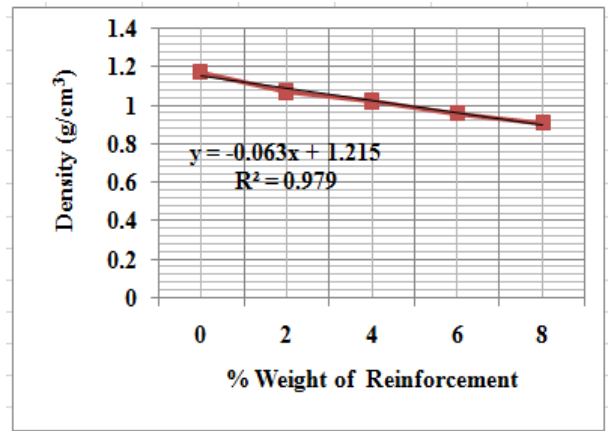


(c)

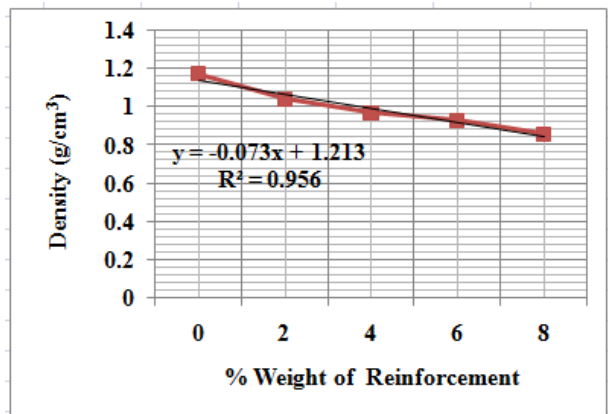
Fig. 9 Density of epoxy/0%CSAC:100%PKSAC samples; (a) 60, (b) 105, (c) 150µm



(a)

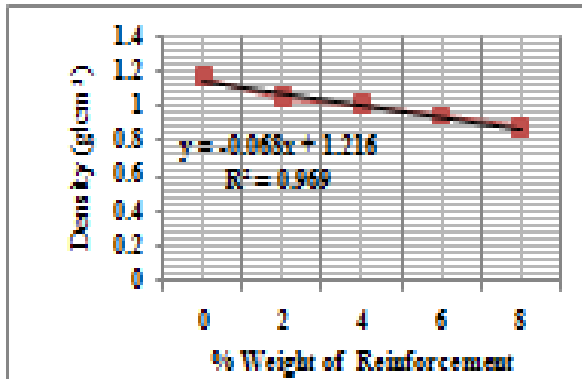


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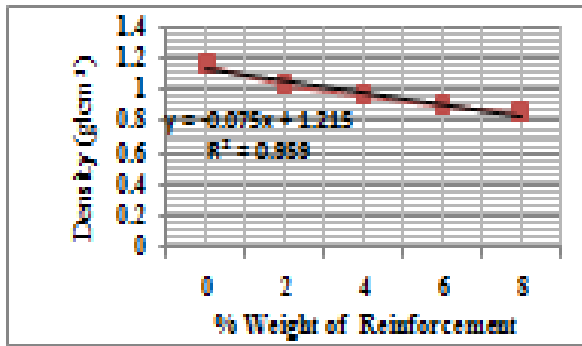


(c)

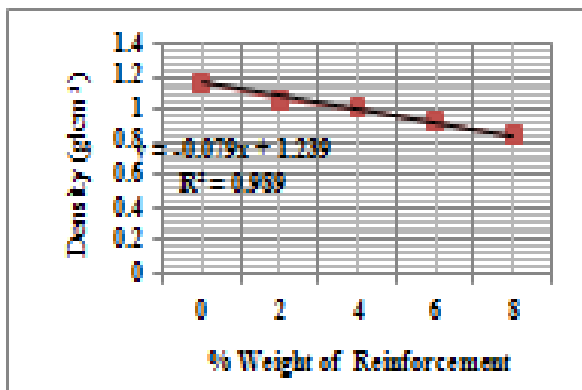
Fig. 10 Density of epoxy/100%CSAC:0%PKSAC samples; (a) 60, (b) 105, (c) 150 µm



(a)



(b)



(c)

Fig. 11 Density of epoxy/50%CSAC:50% PKSAC samples; (a) 60, (b) 105, (c) 150 μm

Table 1 Regression equations and R<sup>2</sup> values of plots of density of epoxy/ activated carbon composites versus % weight of reinforcement

Particle Size (μm)	Plot title	Regression equation	Regression type	R <sup>2</sup> value	Error (1 - R <sup>2</sup> )
60	Density <sub>0%CSAC:100%PKSAC</sub> vs %Wt	Y = -0.107x + 1.285	Linear	0.992	0.008
105	Density <sub>0%CSAC:100%PKSAC</sub> vs %Wt	Y = -0.067x + 1.225	Linear	0.986	0.014
150	Density <sub>0%CSAC:100%PKSAC</sub> vs %Wt	Y = -0.08x + 1.234	Linear	0.988	0.012
60	Density <sub>100%CSAC:0%PKSAC</sub> vs %Wt	Y = -0.07x + 1.224	Linear	0.977	0.023
105	Density <sub>100%CSAC:0%PKSAC</sub> vs %Wt	Y = -0.063x + 1.215	Linear	0.979	0.021
150	Density <sub>100%CSAC:0%PKSAC</sub> vs %Wt	Y = -0.073x + 1.213	Linear	0.956	0.044
60	Density <sub>50%CSAC:50%PKSAC</sub> vs %Wt	Y = -0.068x + 1.216	Linear	0.969	0.031
105	Density <sub>50%CSAC:50%PKSAC</sub> vs %Wt	Y = -0.075x + 1.215	Linear	0.959	0.041
150	Density <sub>50%CSAC:50%PKSAC</sub> vs %Wt	Y = -0.079x + 1.239	Linear	0.989	0.011

### 3.2 Mechanical properties of fabricated samples

#### Tensile strength of epoxy/ 0%CSAC: 100%PKSAC composite samples

Figure 12 compared the tensile strength of the developed epoxy/ activated carbon composition of 0%CSAC:100%PKSAC with that of the commercial brake pads. The developed epoxy/0%CSAC: 100%PKSAC samples of various particle sizes and % weight of filler content showed higher tensile strength than that of the two commercial brake pads, which makes it suitable for brake pad production.

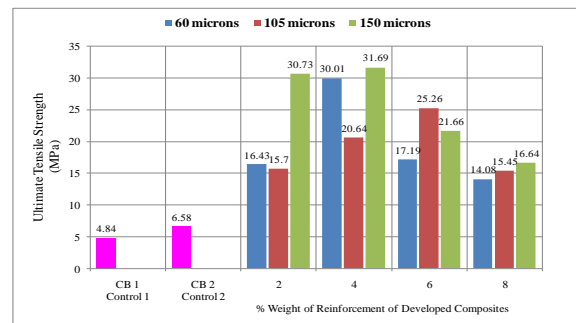
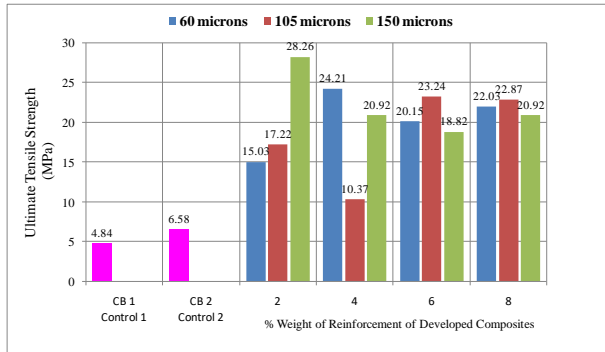


Fig. 12 Tensile strength of developed epoxy/ 0%CSAC: 100%PKSAC composite samples compared with commercial brake pads

#### Tensile strength of epoxy/ 100%CSAC: 0%PKSAC composite samples

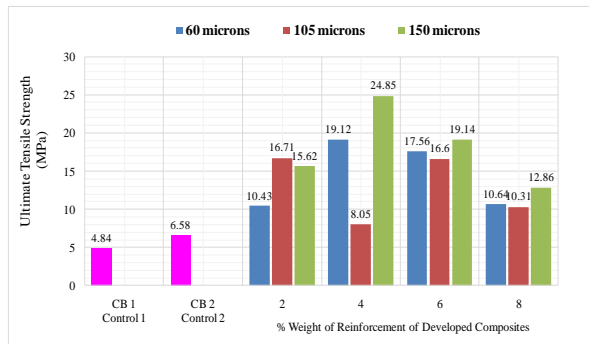
Figure 13 compares the tensile strength of the developed epoxy/ activated carbon composition of 0%CSAC: 100%PKSAC with that of the commercial brake pads. The developed epoxy/100% CSAC: 0%PKSAC samples of various particle sizes and % weight of filler content showed higher tensile strength than the two commercial brake pads.



**Fig. 13 Tensile strength of developed epoxy/ 100%CSAC: 0%PKSAC composite samples compared with commercial brake pads**

**Tensile strength of epoxy/ 50%CSAC: 50%PKSAC composite samples**

Figure 14 compares the tensile strength of the developed epoxy/ activated carbon composites of 0%CSAC:100%PKSAC with that of the commercial brake pads. The developed epoxy/50% CSAC:50%PKSAC samples of various particle sizes and % weight of filler content showed higher tensile strength than the two commercial brake pads.

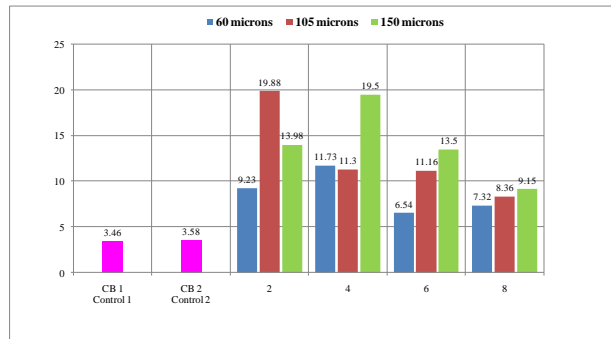


**Fig. 14 Tensile strength of developed epoxy/ 50%CSAC: 50%PKSAC composite samples compared with commercial brake pads**

**% Elongation at break of epoxy/ 0%CSAC: 100%PKSAC composite samples**

Figure 15 compares the % elongation at break of the developed epoxy/ activated carbon composites of 0%CSAC:100%PKSAC with that of the commercial brake pads. The developed epoxy/0%CSAC:100%PKSAC samples showed higher ductility than the two commercial brake pads. 60µm of epoxy/0%CSAC:100%PKSAC samples showed lesser ductility than 105 and 150 µm, which reveal that an increase in particle size increases ductility. This conforms to the conclusions of [7, 19, 23]

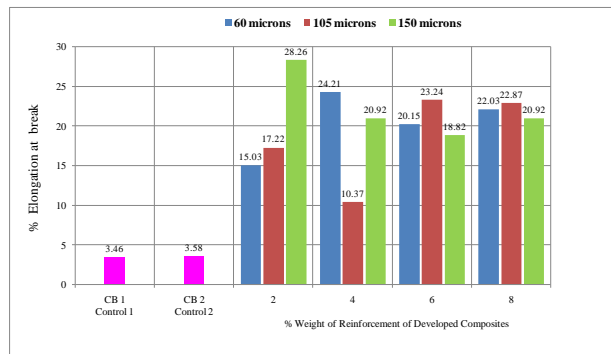
that when the particle size increases, the elongation of the composite can either increase or decrease [6, 7, 24] in different strength matrices. It is essential to achieve a relatively high ductility when pursuing a higher-strength composite [24].



**Fig. 15 % Elongation at break comparison of epoxy / 0%CSAC: 100%PKSAC composite samples with commercial brake pads**

**% Elongation at break of epoxy/100%CSAC: 0%PKSAC composite samples**

Figure 16 shows a comparison of the % elongation at break of the developed epoxy/ activated carbon composition of 100%CSAC:0%PKSAC with that of the commercial brake pads. The developed epoxy/100%CSAC: 0%PKSAC samples showed higher ductility than that of the two commercial brake pads. 60µm of epoxy/0%CSAC: 100%PKSAC samples showed maximum ductility of 24.21% at 4% whereas, 105µm and 150µm showed a maximum of 23.24% and 28.26 % at 6% and 2% weight respectively.

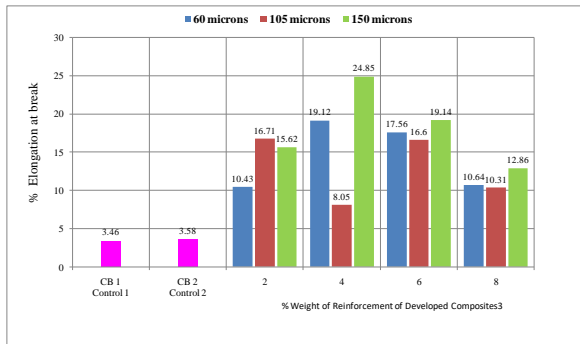


**Fig. 16 % Elongation at break comparison of epoxy / 100%CSAC: 0%PKSAC composite samples with commercial brake pads**



**%Elongation at break of epoxy/ 50%CSAC: 50%PKSAC composite Samples**

Figure 17 compares the % elongation at break of the developed epoxy/ 50%CSAC: 50%PKSAC samples with that of the commercial brake pads. The developed samples showed higher ductility than that of the two commercial brake pads. 60µm of epoxy /50%CSAC: 50%PKSAC samples showed maximum ductility of 19.12% at 4% weight whereas, 105µm and 150 µm showed a maximum of 16.71% and 24.84% at 2% and 4% weight respectively.



**Fig. 17 % Elongation at break comparison of epoxy / 50%CSAC: 50%PKSAC composite samples with commercial brake pads**

**Young Modulus at break of epoxy/ activated carbon composite samples**

As seen from Table 2, for epoxy/ 60µm of 0%CSAC: 100%PKSAC samples, the young modulus at break increased as % weight increased but declined when the % weight increased to 8%. For epoxy/ 105µm of 0%CSAC: 100%PKSAC samples, the young modulus increased with an increase in % weight but dropped slightly at 8% weight. For epoxy/150µm of 0%CSAC:100%PKSAC samples, young modulus decreased with an increase in % weight but increased slightly at 8% weight reinforcement. Also from Table 2, for epoxy/ 60µm of 100%CSAC:0%PKSAC samples, the young modulus at break increased as % weight increased with a stability at 4% and 6% weight and then increased at 8%. For epoxy/ 105µm of 100%CSAC:0%PKSAC samples, the young modulus showed fluctuating trends with the highest young modulus at break recorded at 6% weight reinforcement. For epoxy/150µm of 100%CSAC: 0%PKSAC samples, young modulus at break showed also fluctuating trends with the highest young modulus was recorded at 2% weight. For epoxy/60µm of 50%CSAC:50%PKSAC samples, the young modulus at break increased as % weight increased but dropped at 6% weight. For epoxy/105µm of 50%CSAC:50%PKSAC samples, the young modulus showed fluctuating trends with the

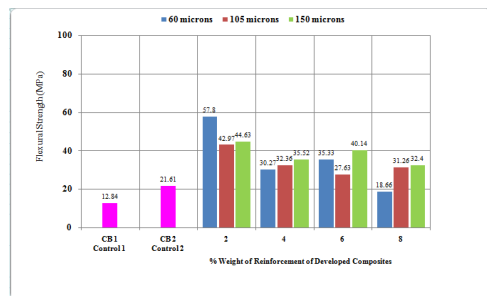
highest young modulus at break recorded at 6% weight reinforcement. For epoxy/150µm of 50%CSAC: 50%PKSAC samples, young modulus at break showed also fluctuating trends with 4% weight recording the highest young modulus at break.

**Table 2 Young Modulus at break (MPa) of epoxy/ activated carbon composite samples**

Particle Sizes (µm)	% Weight	0%CSAC:100%PKSAC	100%CSAC:0%PKSAC	50%CSAC:50%PKSAC
60	2	178.06	49.37	30.51
	4	255.77	156.46	221.72
	6	262.77	154.76	190.2
	8	192.34	208.46	57.03
105	2	79.01	113.33	90.54
	4	182.72	47.52	41.85
	6	226.26	227.7	113.85
	8	184.83	151.7	63.34
150	2	219.81	264.85	205.55
	4	162.57	79.73	257.11
	6	160.4	173.08	183.04
	8	181.88	212.65	223.52

**Flexural strength of epoxy / 0%CSAC: 100%PKSAC composite samples**

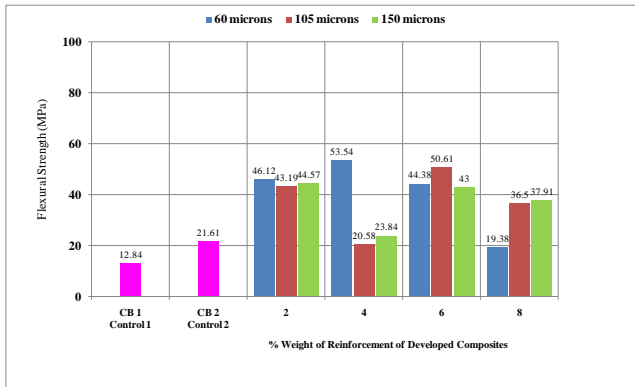
Figure 18 shows a comparison of the flexural strength of the developed epoxy/activated carbon composites of 0%CSAC: 100%PKSAC with that of the commercial brake pads. The flexural strength of the developed compared well with that of the two commercial brake pads. Though the 8% weight reinforcement of the 60µm epoxy/0%CSAC: 100%PKSAC sample was found to be better than commercial brake pad (CB1) but not better than commercial brake pad (CB2) in terms of flexural strength. Furthermore, it was observed all three particle sizes (60, 105, and 150µm) of this composition showed maximum flexural strength of 57.8, 42.77 and 44.63MPa respectively at 2% weight. This may be attributable to carbonization which enhanced the structural strength of the coconut shell particle to withstand excessive particle crumble during use as stated by [13, 18].



**Fig. 18 Flexural strength of epoxy / 0%CSAC: 100%PKSAC samples compared with commercial brake pads**

**Flexural strength of epoxy / 100%CSAC: 0%PKSAC composite samples**

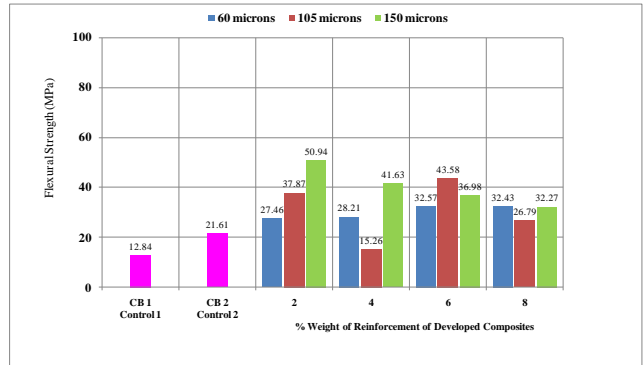
Figure 19 shows a comparison of the flexural strength of the developed epoxy/ activated carbon composite of 100%CSAC:0%PKSAC with that of the commercial brake pads. The flexural strength of the developed samples showed better performance than that of the two commercial brake pads. It was observed that the particle sizes (60, 105, and 150µm) of the epoxy /100%CSAC:0%PKSAC showed maximum flexural strength of 53.54, 50.61 44.57 MPa at 4, 6 and 2% weight, respectively.



**Fig. 19 Flexural strength of epoxy /100%CSAC: 0% PKSAC samples compared with commercial brake pads**

**Flexural strength of epoxy / 50%CSAC: 50%PKSAC composite samples**

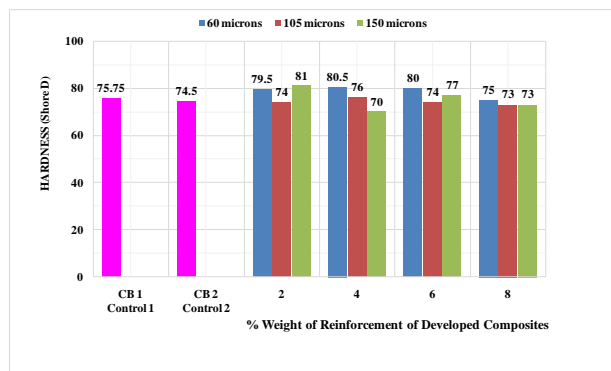
Figure 20 shows a comparison of the flexural strength of the developed epoxy/activated carbon composites of 50%CSAC:50%PKSAC with that of the commercial brake pads. The flexural strength of the developed samples compared well with that of the two commercial brake pads. Though the 4% weight of the 105µm epoxy/50%CSAC:50%PKSAC sample was found to be better than commercial brake pad (CB1) but not better than commercial brake pad (CB2) in terms of the flexural strength. However, the three particle sizes (60, 105, and 150µm) of the epoxy/50%CSAC:50%PKSAC showed maximum flexural strength of 32.57, 43.58 and 50.94MPa at 6, 6 and 2% weight.



**Fig. 20 Flexural strength of epoxy /50%CSAC: 50% PKSAC samples compared with commercial brake pads**

**Hardness of epoxy / 0%CSAC: 100% PKSAC composite samples**

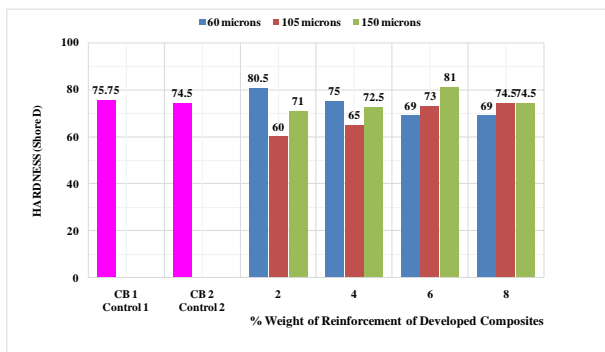
Figure 21 revealed that epoxy/0%CSAC: 100%PKSAC samples fabricated with 60µm particle size recorded the minimum hardness (Shore D) of 75 at 8% weight and a maximum of 80.5 at 4% weight which was more significant than the commercial brake pad samples (CB1) and (CB2) with a hardness of 75.75 and 74.5 respectively. Epoxy/0%CSAC: 100%PKSAC samples compared well with the commercial brake pads.



**Fig. 21 Hardness properties of epoxy / 0%CSAC: 100%PKSAC samples compared with commercial brake pads**

### Hardness of epoxy / 100%CSAC: 0%PKSAC composite samples

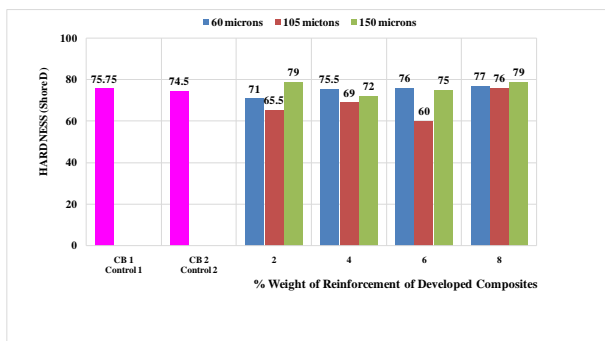
From Figure 22, it was observed that epoxy/100%CSAC: 0%PKSAC samples fabricated with 60 $\mu$ m particle size recorded the minimum hardness (Shore D) of 69 at 6% and 8% weight and a maximum of 80.5 at 2% weight which was greater than the two commercial brake pads samples (CB1) and (CB2) with a hardness of 75.75 and 74.5 respectively. All epoxy/100%CSAC:0%PKSAC samples compared well with the commercial brake pads.



**Fig. 22 Hardness properties of epoxy /100%CSAC: 0%PKSAC samples compared with commercial brake pads**

### Hardness of epoxy / 50%CSAC: 50%PKSAC composite samples

Figure 23 shows the hardness comparison of the epoxy/50%CSAC: 50%PKSAC samples fabricated with 105 $\mu$ m particle size recording the minimum hardness of 60 at 6% weight and a maximum of 76 at 8% weight. This result compared well with commercial brake pads samples (CB1) and (CB2) with a hardness of 75.75 and 74.5, respectively.



**Fig. 23 Hardness properties of epoxy / 50%CSAC: 50%PKSAC samples compared with commercial brake pads**

## 4. Conclusions

New light weight, high strength chemically activated carbon epoxy composite materials have been developed and evaluated using agrowastes. Based on experimental evidence, these new formulations revealed decreasing densities with increasing weight percentage of the reinforcement. The study found that increasing the weight percentage of microns of activated carbon compositions greatly affected the mechanical properties of the various composite materials. 2% weight increment of the particle sizes of the activated carbon fillers yielded tensile strength, %elongation at break, Young modulus and flexural strengths higher than that of the selected commercial brake pads (CB1) and (CB2) while the hardness results compared well with the commercial brake pads samples. In general, from the standpoint of its tensile strength, ductility, flexural strength, and hardness properties, these new formulations can find applications in aerospace and automobile industries where light weight, high strength materials are sought after and especially as organic friction lining materials for brake pad manufacture.

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