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Characterization and development of asbestos-free brake pad, using snail shell and rubber seed husk

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ABSTRACT

Development of asbestos-free brake pad was investigated with a view to replacing the use of asbestos, whose dust is carcinogenic. This is an interim report on the development and characterization of asbestos-free automotive brake pad, using snail shell as a reinforcement and rubber seed husk as the frictional filler material, with a view to exploiting the characteristics of snail shell and rubber seed husk, which are largely deposited as waste in our environment. The effective and eco-friendly utilization of these materials, for a scientific application has always been a challenge. The pulverized snail shells were sieved into sieve grades of 125, 250, 355, 500 and 710 µm. The composite brake pad was produced in the ratio of 65% snail shell-10% rubber seed husk-25% resin, using compression moulding. The characterization of the snail shell was investigated through X-ray Fluorescence Spectrometry (XRF), X-ray diffractometer (XRD), thermogravimetric analysis (TGA) and differential thermal analysis (DTA). The brake pad was investigated for properties such as hardness, compressive strength, abrasion resistance, density, coefficient of friction and porosity. The microstructure reveals uniform distribution of resin in the snail shell The results obtained showed that the final the sieve size, the better the properties. The results reported has compared favourably with that of common brake pads (asbestos based and palm kernel shell based). This work confirmed that snail shells and rubber seed husk can actually be used in the production of brake pad.

Keywords: Snail shell, rubber seed husk, density, abrasion resistance, porosity, microstructure.

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INTRODUCTION

Brakes are one of the most important safety and performance components in automobiles, while brake pads are important parts of braking systems for all types of automobiles that are equipped with disc brake. Development of frictional composite brake pad of lighter weight, improved mechanical properties and corrosion resistance capability is essential in minimizing cost, material and wear while improving the safety on our high ways. The significance of brake pad is to transform the kinetic energy of a vehicle to heat energy via friction and ejecting the heat to the surrounding environment. Drum (shoe) brake and disk (pad) brakes are the major types of friction brakes (Aigbodion and Agunsoye, 2010).

There are more than 2,000 different materials and their variants are used in commercial brake components (Blau, 2001). Composite brake pad constituent materials are composed of varied composition of reinforcements, fillers, binders and friction modifiers (Hooton, 1969).

Asbestos had a few engineering properties that made it very suitable for inclusion in brake liners, and was the most preferred filler material up till 1989 (Bashar et al., 2012). However, its use is being avoided because of health implications (Nicholson, 1995). Therefore, the materials engineer is faced with the need to develop a replacement and brake pads having asbestos free friction materials.

A lot of researches have been carried out in the area of development of asbestos free brake pads. The use of palm kernel shell (PKS) etc has been investigated (Dagwa and Ibhadode, 2006; Aigbodion et al., 2010; Kim et al., 2003; Sasaki et al., 2000; Smales, 1995; Mathur et al., 2004; Ishidi et al., 2011; Dreifuss, 2002; Seringueira,

2009; Dagwa and Ibhadode, 2005). The focus now worldwide is on the utilization of either industrial or agricultural waste as a source of raw material for the industry. These waste utilizations will not only be economical, but may also earn foreign exchange for the country and environmental control.

The main essence of this work is therefore to develop and characterize a new asbestos-free brake pad, using snail shell and rubber seed husk, since these materials are eco-friendly, readily available and affordable.

Asbestos as brake pad material

Asbestos fibers are long, thin and extremely small brake pad material with good braking characteristics (Figure 1). It offers good strength, temperature and chemical resistance. In addition to its resistance to the effects of heat and fire, asbestos is long-lasting and bonds well with many materials, to which it adds strength and durability. But the physical properties that makes asbestos such a good fiber, also makes it a hazardous one. Exposed fibers easily shred into thin needle like strands that can drift in the air and be inhaled. The size of the fibers is such that they are not easily filtered out by the mucus linings in the nose and lungs. Hence, the fibers lodge deep in the lungs where their sharp needle like presence becomes a source of constant irritation. Human body cannot rid itself of these fibers because they are impervious to biochemical assault. So, over time, exposure to asbestos fibers may result in lung disease or cancer (www.aa1car.com/library.htm).

Back in the early 1980s, the health conscious Scandinavians were the first to ban asbestos containing products, including brake linings, clutch linings and engine gaskets. This led to the introduction of non asbestos substitutes.

Figure 1. Asbestos fibers.

Snail shell

The snail belongs to the phylum Mollusk and class Gastropods. The gastropods are the largest class of the phylum Mollusk (Brunt et al., 1999). The family members include (i) *Achatina achatina*, (ii) *Achatina maginata* (iii) *Achatina fulica* and (iv) *linicolarial* species (Jatto et al., 2010).

The achatine snails are the largest terrestrial snails on earth. The largest, *Achatina achatina* may grow to a body size of more than 12 inches and length of the shell to 10 inches. The main constituent of the shell is calcium carbonates which are either of two crystalline forms; calcite and aragonite. The remainder is organic matrixes which constitute a protein known as conchiolin that usually make up to 5% of the shell. A snail's shell (Figure 2) is secreted by glands in its mantle rim. It serves to protect its internal organs, prevent water loss, provide shelter from cold, and protect the snail from predators. The shell consists of three layers, the hypostracum, the ostracum and the periostracum. The hypostracum is the innermost layer of the shell and lies closest to the snail's body. The ostracum is the middle, shell-building layer and consists of prism-shaped calcium carbonate crystals and organic (proteid) molecules. Finally, the periostracum is the outermost layer of a snail's shell and it consists of conchin (a mixture of organic compounds) and is the layer that gives the shell its color.

Rubber seed husk

Rubber seed husk is obtained from the rubber tree (*Havea brasiliensis*). The rubber tree is a tree belonging to the family, Euphorbiaceae (Figure 3).

Rubber seed husk is an agricultural by-product of the rubber tree. The economic importance of the rubber tree has largely focused on the rubber latex with little or no attention paid to the potential usefulness of its by-products. While significant progress has been made in the development and utilization of modified agricultural by-product in water and wastewater treatment, there is little information on the potential for the application of this by-product as an extender and/or filler in the processing of polymers (Ekebafe et al., 2010).

Figure 2. Snail shells.

Figure 3. Rubber trees, seed husks and seeds.

MATERIALS AND METHODS

Materials

The materials used in the course of this work include snail shell (which was used as the reinforcement), rubber seed husk (as the filler) and epoxy (which is a phenolic resin) used as the binder, as well as catalyst and accelerator. The snail shells was obtained from snail marketers and snail restaurant operators while the rubber seed husk was gathered from one of the numerous rubber plantations, all in Ohordua, Edo State.

Equipments

The equipments used in the course of this work are; wooden block, muffle furnace, digital weighing balance, sieve, hardness tester, X-ray fluorescent spectrometer (XRF), X-ray diffractometer (XRD), thermogravimetric analyzer (TGA) and differential thermal analyzer (DTA).

Methods

The snail shell was pulverized by breaking it down with the help of wooden block into smaller sizes and packed into an empty crucible placed in a muffle furnace which has been preset at 350°C and timed for five minutes. Thereafter, the furnace was switched off and the snail shells recovered and pounded to fine texture. The product was transferred into ball milling machine and was left in the mill for 2 h; after which the product was transferred into set of sieve of +710 µm, +500 µm, +355 µm, +250 µm, +125 µm, and was sieved for 30 min using sieve shaker machine. While the oversize at +710 µm was returned or recycled for regrinding until it passes through the sieves.

The samples were produced using a compression moulding machine. Different composition and sieve grades (710, 500, 355, 250 and 125 µm) of snail shell and resin was added together in the ratio 65% snail shell - 10% rubber seed husk - 25% resin respectively. The combination was properly dry mixed in a mixer to give almost a homogeneous mixture. The mixture was transferred to a mould kept in a hot platen press at 140°C and 100 kN/cm^2 pressure for two minutes. After removal from the hot press, the samples were cured in an oven at 120°C for eight hours (Kim et al., 2003; Sasaki, 2000).

Characterization

X-ray fluorescence spectrometry

The elemental composition of the snail shell was determined with minimal sample preparation using an Energy Dispersive X-ray Fluorescence Spectrometer and the results are displayed in Table 1.

The result of this XRF analysis suggests a strong possibility of using snail shell particles as brake pad materials since the chemical composition is in consonance with that of asbestos and other materials like palm kernel shells currently being used as brake pad materials.

X-ray diffraction analysis

XRD analysis of the snail shell particles was carried out by recording the angles and intensities of diffractions electronically, using a detector, electronics and specialized software resulting in a plot of 2θ (horizontal axis) vs. intensity (vertical axis) for the specimen, with a view to identifying the crystalline phases present. Results obtained are shown in Figure 4.

Figure 4 illustrates the analysis of the crystalline phases present in snail shell. Complete mineralogical analysis carried out by X-ray diffraction also revealed that the snail shell particles contains each of these elements; C, O, Si, Ca, Fe, Cr, Cu, Al and none of these elements; "H, He, Li, Be, B, N, F, Ne, Na, Mg, P, S, Cl, Ar, K, Sc, Ti, V, Mn, Co, Ni,, Zn, Ga, Ge, As, Se, Br, Kr, Rb, Sr, Y, Zr, Nb, Mo, Tc, Ru, Rh, Pd, Ag, Cd, In, Sn, Sb, Te, I, Xe, Cs, Ba, La, Ce, Pr, Nd, Pm, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, Lu, Hf, Ta, W, Re, Os, Ir, Pt, Au, Hg, Tl, Pb, Bi, Po, At, Rn, Fr, Ra, Ac, Th, Pa, U, Np, Pu, Am, Cm, Bk, Cf, Es, Fm, Md, No, Lr, D, T".

With the absence of all these other elements, it implies that snail shell particles contain no radioactive and harmful materials and can therefore replace asbestos conveniently.

Thermogravimetric analysis and differential thermal analysis

The TG/DGA data of the snail shell powder was recorded on “Derivatogragh OD 102”, at a heating rate of 20°C/min

Table 1. XRF analysis of snail shell.

Compound	Al_2O_3	CaO	SiO_2	Na_2O	Fe_2O_4	Cr_2O_3	TiO_2	CuO
% Conc./unit	0.30	97.06	1.54	0.34	0.64	0.04	0.06	0.002

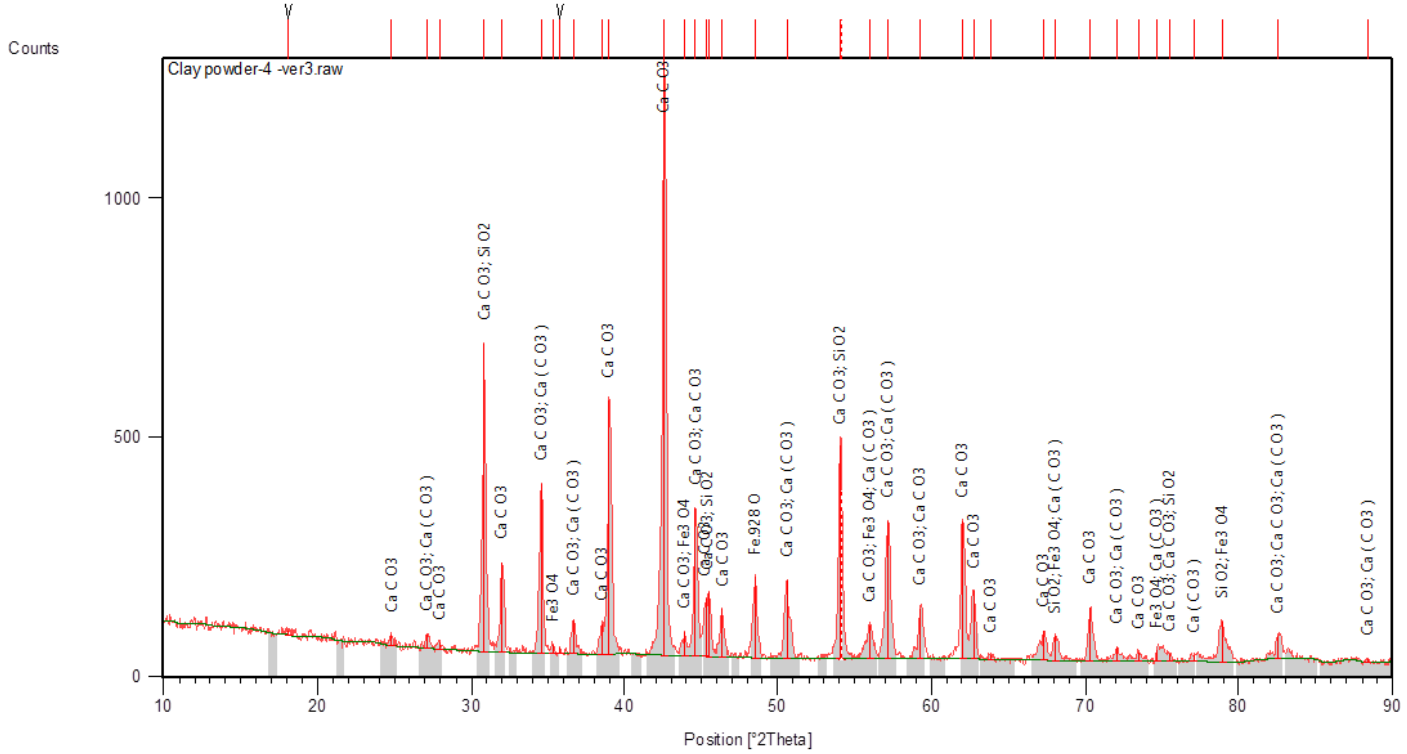

Figure 4. XRD analysis of snail shell.

to 900°C in argon. The result is as shown in Figure 5.

TG/DTA curve shows that the temperature of maximal decomposition/destruction was about 880^{0}c (Figure 5). The presence of endothermic effects in snail shell particles is as a result of two processes- dehydrogenation and evaporation of non-cellulosic materials. This was confirmed by the decreased mass of the sample. On the analogy of these results, it was assumed that the total burning/degradation of the residual snail shell particles occurred at a temperature range of 800 and 900°C. The higher temperature of maximal decomposition of snail shell than that of asbestos and most other agro-wastes currently used as break pad materials simply means that brake pad produced from snail shell particles can withstand higher temperatures.

RESULTS AND DISCUSSION

The developed brake pads of different sieve grades were tested for various properties such as hardness value, compressive strength, density, wear rate, water absorption and oil absorption. The microstructure distribution of the various sieve grades was equally analyzed.

Hardness value

The Brinell hardness values of the produced samples were obtained using a digital hardness tester. The sample of diameter 22.7 mm was used to carry out the test as different sieve grades. The test was conducted using 10 mm diameter steel ball indenter with a load of 3000 kg. The results of the hardness values are shown in Figure 6. From the figure it can be seen that as the sieve grade is decreased the hardness values of the samples increases.

Compressive strength

Figure 7 shows the compressive strengths of the produced samples. The compressive strength test was

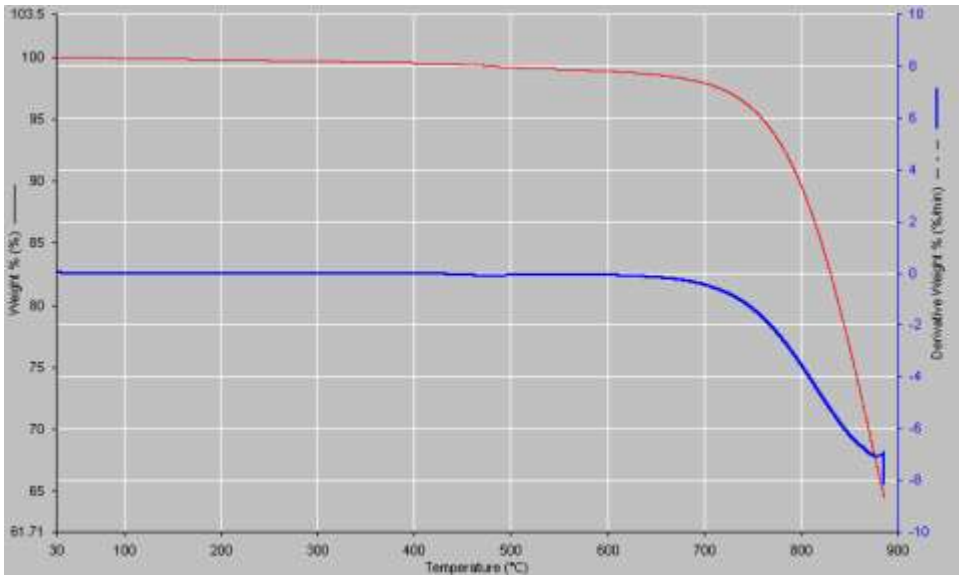

Figure 5. TG/DTA of snail shell (---TGA, ---DTA).

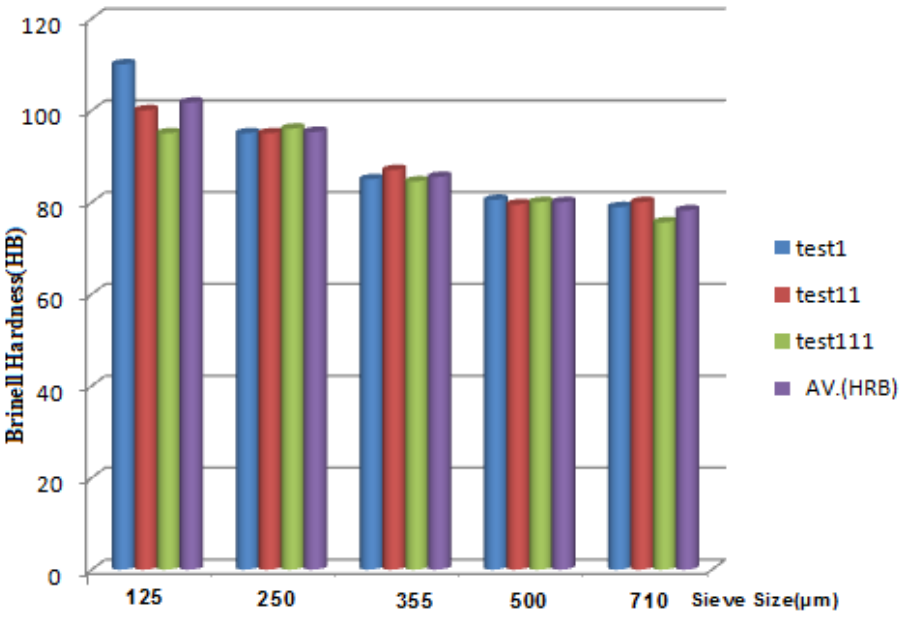

Figure 6. Results of hardness values of the developed brake pad.

done using the Honsfield Tensometer. The samples of diameter 22.7 mm was subjected to compressive force, loaded continuously until failure occurred. The load at which failure occurred was then recorded. From the results, similar trend with that of hardness values was observed. The compressive strength increases with decrease in sieve size of the samples. The 125 µm sieve grade has the highest compressive strength of 106.55 N/mm^2. The gradual decrease in compressive strength as the sieve size increases can be attributed to the decreasing surface area and pore packaging capability of the snail shell particles in the resin.

Density

The basic method of determining the density of brake pad samples by measuring the mass and volume of the sample was used. A clean sample is weighed accurately in air using a laboratory balance and then suspended in water. The weight of the sample when suspended in water was determined, the volume of the sample was

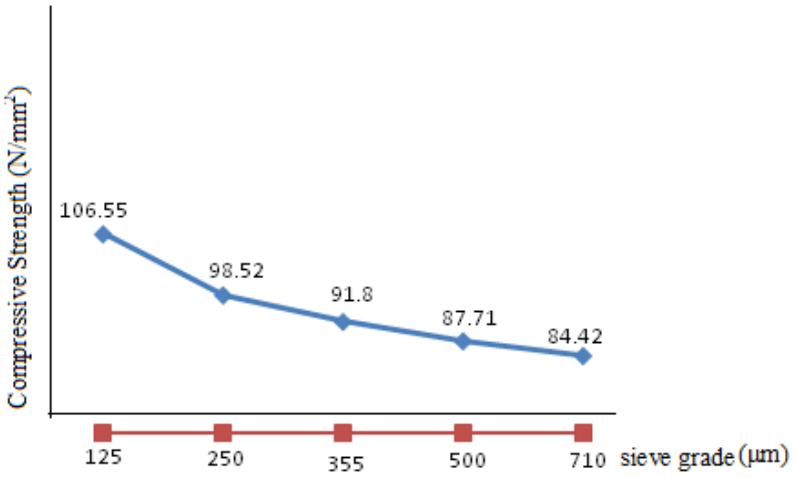

Figure 7. Result of max. compressive strength (N/mm^2).

determined from the effect of displacement by water (Archimedean principle). The density of the sample was estimated from the following equation:

$$Density = \frac{Mass}{Volume}$$

Figure 8 shows the result of the density with sieve size. The density decreases as the sieve size of the snail shell particles increases in the resin. The decrease in density can be attributed to the increase in particle size, that is, increased packing of snail shell. The 125 µm has the highest density which is as a result of closer packing of snail shell particles creating more homogeneity in the entire phase of the composite body.

Wear resistance

The wear rate of the sample was measured using pin on disc machine by sliding it over a cast iron surface at a load of 20 N, sliding speed of 5.02 m/s and sliding distance of 500 m. All tests were conducted at room temperature. The test was carried out in University of the Witwatersrand**,** Johannesburg, South Africa. The initial weight of the samples was measured using a single pan electronic weighing machine with an accuracy of 0.0001 g. During the test, the pin was pressed against the counterpart rotating against a cast iron disc (hardness 65 HRC) of counter surface roughness of 0.3 µm by applying the load. A friction detecting arm connected to a strain gauge held and loaded the pin samples vertically into the rotating hardened cast iron disc. After running through a fixed sliding distance, the samples were removed, cleaned with acetone, dried, and weighed to determine the weight loss due to wear. The differences in weight measured before and after tests give the wear of the samples. The wear rate of the produced samples increases as the sieve grade of the snail shell increase as shown in Figure 9. This resulted from the higher/ closer packing of smaller sieve grades which has affected strongly, the binding of the snail shell with resin.

It may also be due to high hardness values and compressive strength of the samples as sieve size is decreased.

Coefficient of friction

From the experimental set up and procedure in Figure 9, the coefficient of friction was then calculated by:

$$\mu = \frac{F_f}{N}$$

Where µ is the coefficient of friction, F_f is the frictional friction read direct from the friction detecting arm strain gauge and N is the normal reaction (20 N).

The coefficient of friction, of the produced samples decreases as the sieve grade of the snail shell increases as shown in Figure 10. This is owing to the fact that the finer the sieve size, the higher the surface area and more grip the brake pad has.

Porosity

Figure 11 shows the percentage water and oil absorption of the produced samples. It indicates the amount of water and oil absorbed under specified conditions. The specimens were dried in an oven for a specified time and temperature and then placed in a desiccator to cool. Immediately upon cooling, the specimens were weighed. They were then immersed in water and oil respectively; at

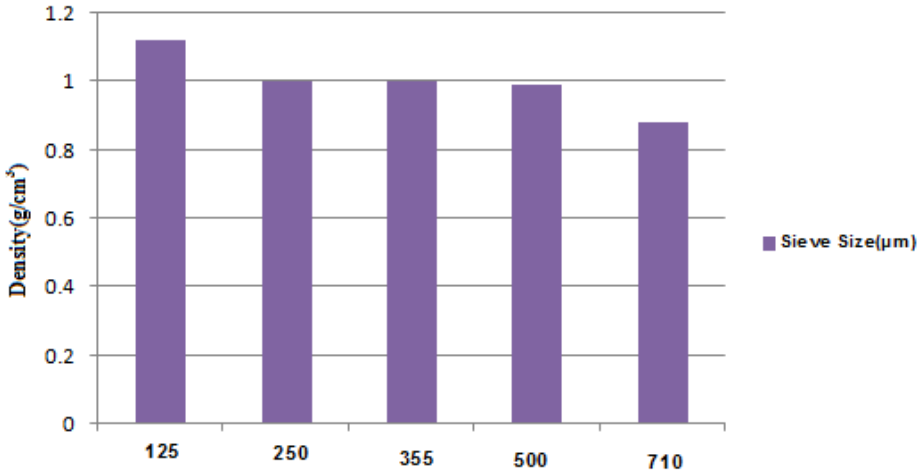

Figure 8. Variation of density with sieve grade.

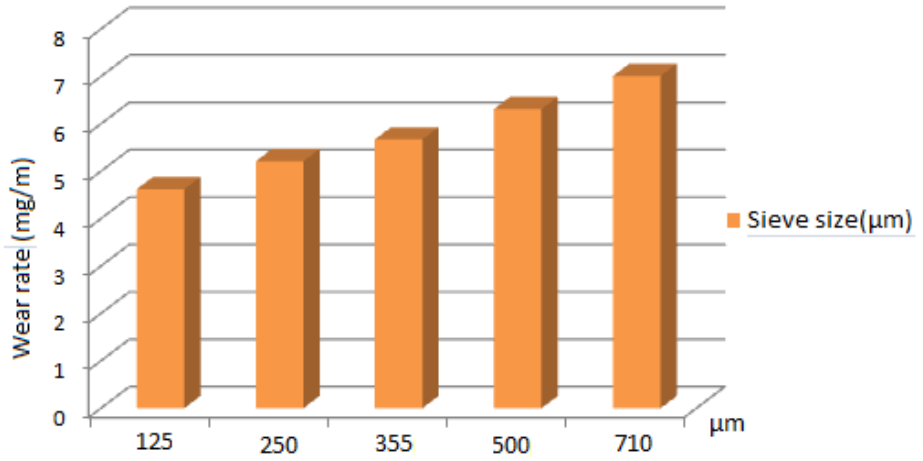

Figure 9. Variation of wear rate with sieve grade.

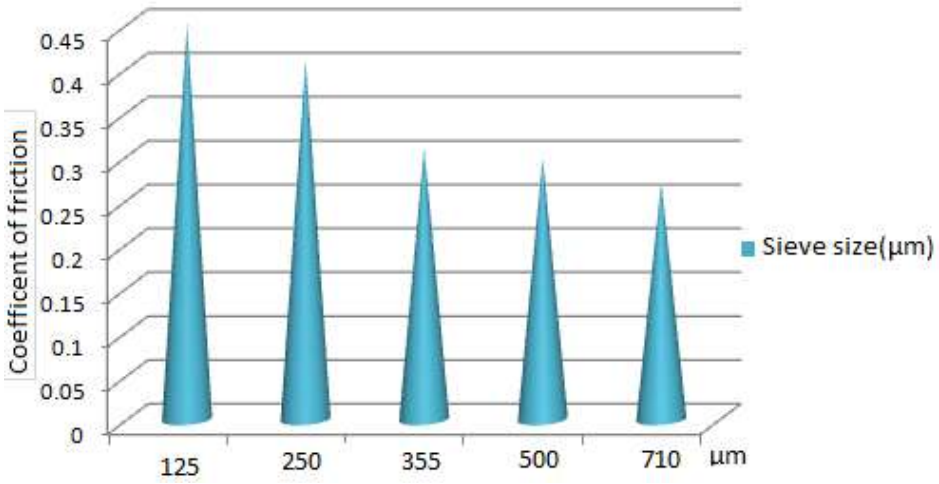

Figure 10. Variation of coefficient of friction with sieve grades.

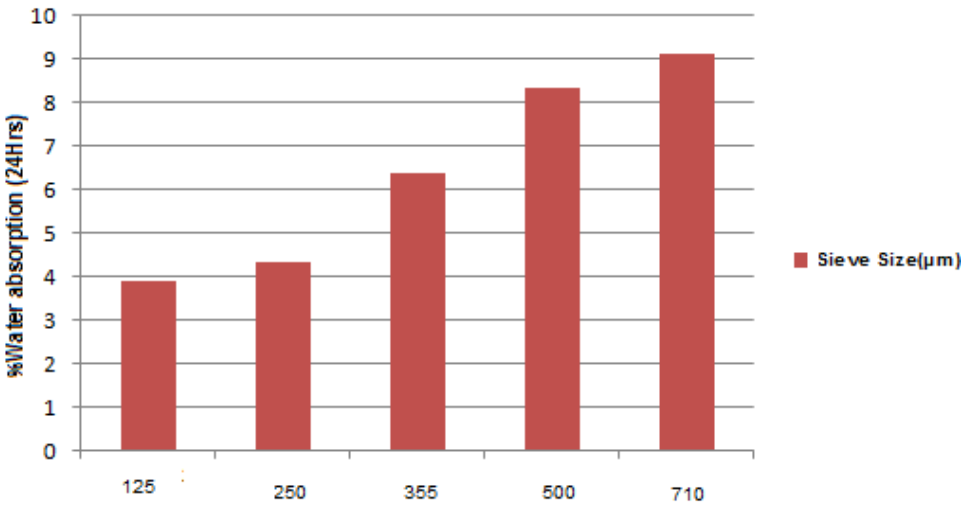

Figure 11a. Variation of % water absorption with sieve grade.

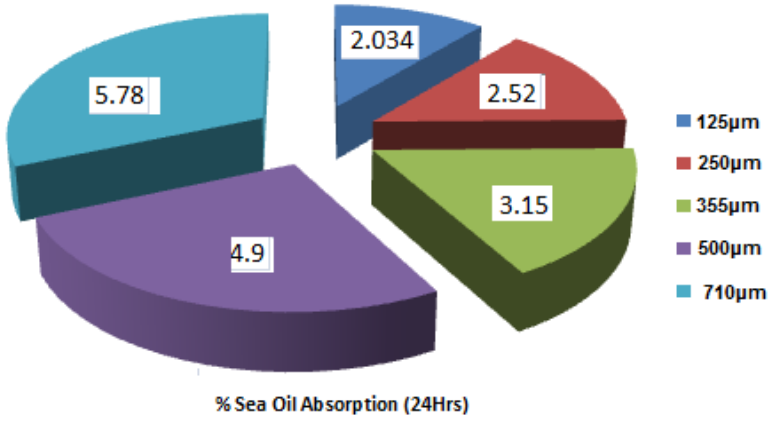

Figure 11b. Variation of % oil absorption with sieve grade.

23°C for 24 h. Specimens were removed, patted dry with a lint free cloth, and weighed.

Water and oil absorption is expressed as increase in weight percent. Percent Absorption = [(Wet weight - Dry weight)/ Dry weight] × 100.

These properties increased as the sieve grade increases which can eventually be attributed to the increased pores as sieve size increase.

Microstructure

The microstructure of the test samples were studied using a JOEL JSM 5900LV Scanning Electron Microscope equipped with an Oxford INCA™ Energy Dispersive Spectroscopy system. The polished samples were firmly held on the sample holder using a double-sided carbon tape before putting them inside the sample chamber. The SEM was operated at an accelerating voltage of 5 to 20 kV. The test was carried out in University of the Witwatersrand, Johannesburg, South Africa. The results are shown in Figure 12.

From the results and findings above, sample with 125 µm gave the best properties as a result of a very good dispersion of the particles which led to a better interfacial bonding of the resin and the snail shell particles. The result of this work indicates that sample containing 125 µm (65% snail shell - 10% rubber seed husk - 25% resin) gave better properties than other samples tested. Hence, the lower the sieve grades of snail shell, the better the properties.

The 125 µm sieve size results were compared with that of commercial brake pad (asbestos based) and other formulated laboratory brake pad (Palm Kernel Shell PKS, and bagasse based) which was tested under similar conditions. The results are in close agreement as shown in Table 2.

Hence asbestos free brake pad can be produced with

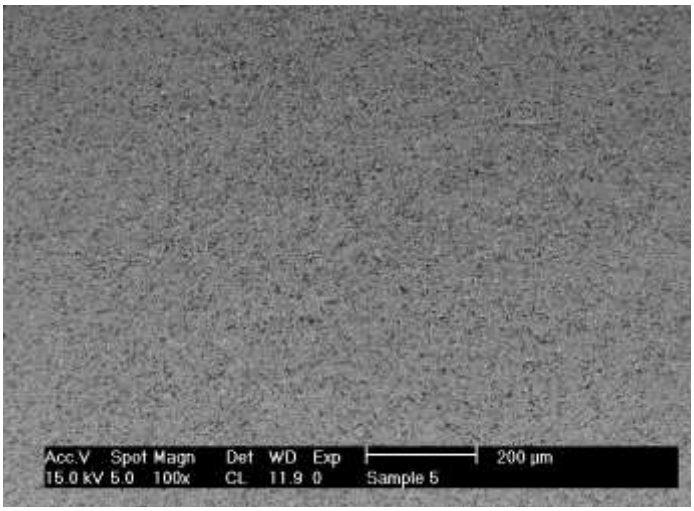

Figure 12a. Microstructure of 125 µm sieve grade sample (X100) showing uniform distribution of resin and snail shell.

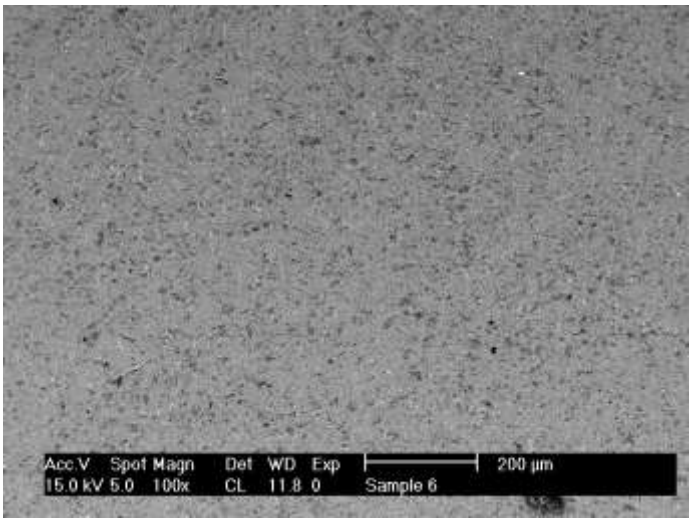

Figure 12b. Microstructure of 250 µm sieve grade sample(X100). Showing uniform dark region of resin and white region of snail shell.

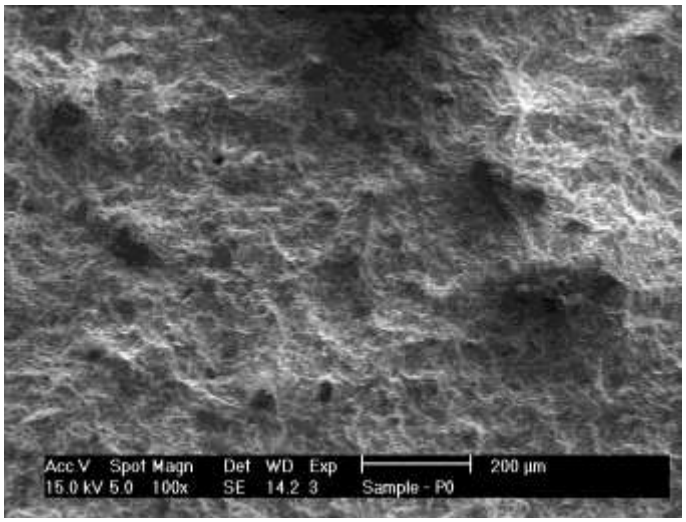

Figure 12c. Microstructure of 355 µm sieve grade sample(X100). Showing a decrease in uniformity of resin and snail shell.

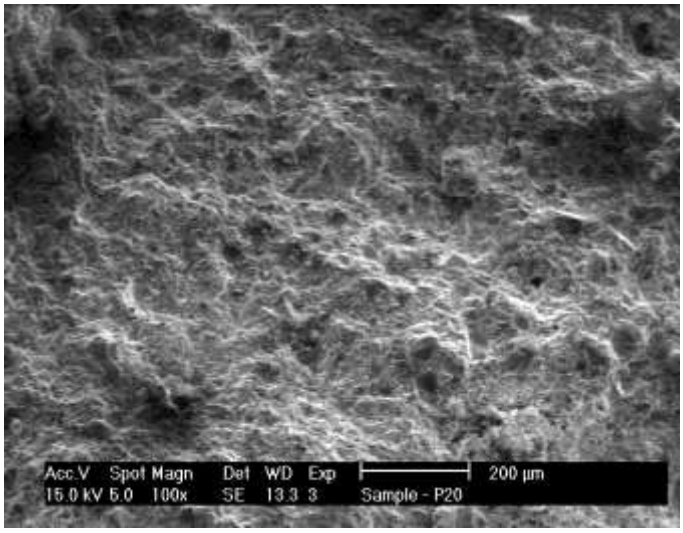

Figure 12d. Microstructure of 500 µm sieve grade sample (X100) showing degradation of uniformity.

125 µm sieve size formulation.

CONCLUSION

From the results and discussion in this work, the following conclusions can be made:

1. The samples, 125 µm sieve grade of snail shell gave the better properties in all.
2. Compressive strength, hardness and densities of the produced samples were seen to be decreasing with increase in sieve grade while the oil soak, water soak, and wear rate properties increased as sieve grade increased.
3. The result of this research indicates that snail shell can be effectively used as a replacement for asbestos in brake pad manufacture by using the 125 µm sieve grade of snail shell with a composition of 65% snail shell - 10% rubber seed husk - 25% resin.
4. Snail shell based brake linings will therefore be thermally resilient enough not to decompose at typical braking temperatures and durations.
5. Snail shell based brake linings will exhibit lower wear rate than asbestos, without degrading the surface of the disc brake.
6. Overall performance of the snail shell is comparable with asbestos-based linings, and is within the limits recommended by the Standard Organization of Nigeria.

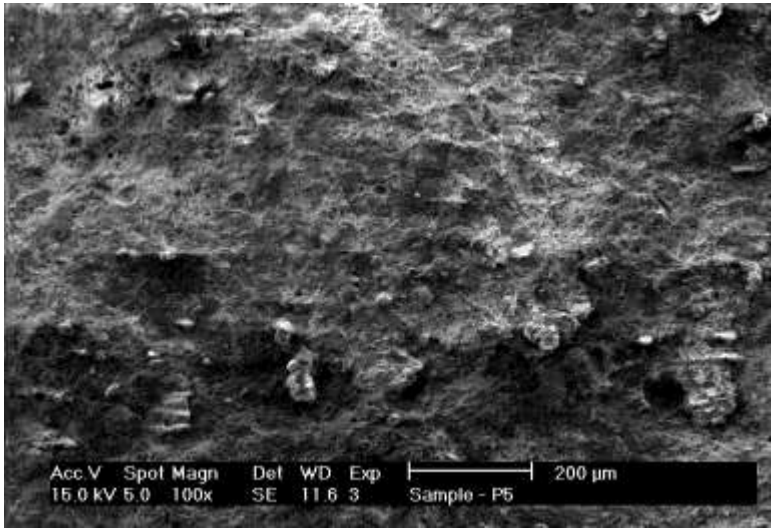

Figure 12e. Microstructure of 710 µm sieve grade sample (X100). Showing very high degradation of uniformity as particle size increases.

Table 2. Summary of results and findings, compared with existing ones.

Property	Commercial brake-pad (asbestos based)	Formulated laboratory brake pad (PKS based)	Formulated laboratory brake-pad (bagasse based)	Formulated laboratory brake-pad (snail shell based) recommended
Hardness, Brinell (at 3000 kgf)	101	92	100.5	101.7
Compressive strength (MPa)	110	103.5	105.6	106.55
Thickness swell in water after 24 h (%)	0.9	5.03	3.48	3.9
Thickness swell in oil (SEA 40) after 24 h (%)	0.3	0.44	1.11	2.034
Specific gravity	1.89	1.65	1.43	1.12
Average wear (mg/m)	3.8	4.4	4.2	4.62

Source: Aigbodion and Agunsoye (2010).

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