

N. A. Lamidi, J. I. Braimah, M. A. Adebayo

50 - 58

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Whale Optimization Algorithm for Optimal Location and Sizing of Renewable Distributed Generation

Olatunde Oladepo, Isaiah Adebayo, O. Obiseye Obiyemi, Tolulope Tola Awofolaju

59 - 67

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Assessing the Ceramic Suitability of Obe Clay Reinforced with Rice Husk Ash

S. G. Borisade, O. A. Oyelaran, O. M. Sanusi, C. I. Madueke

68-76

[Click to Download PDF](#)

Operation and Optimization Techniques for Integrated Distributed Energy Resources: A Review

Olatunde Oladepo, Tolulope T. Awofolaju

77 - 91

[Click to Download PDF](#)

Production of Automobile Brake Pads from Palm Kernel Shell, Coconut Shell, Seashell and Cow Bone

O. T. Popoola, A. B. Rabi, H. K. Ibrahim, P. O. Omoniyi, M. A. Babatunde, N. Muhammed, F. O. Isiaq

92 - 101

[Click to Download PDF](#)

Effect of Residence Time on Performance of a Developed Drum Washer for Cleaning Sweet Potatoes

A. Fadeyibi

102 - 112

[Click to Download PDF](#)

Production of Automobile Brake Pads from Palm Kernel Shell, Coconut Shell, Seashell and Cow Bone

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ABSTRACT

The commercial brake pads made from asbestos are found to be carcinogenic hence, researchers and brake pad manufacturers have diverted attention to the use of agricultural wastes to replace asbestos made brake pads. This study investigated the use of palm kernel shell, coconut shell, seashell and cow bone as base material for the development of automobile brake pads. This work focused on combining the aforementioned agricultural wastes with 45% base material, 30% binder, 10% filler, 10% lubricant, and 5% abrasive. The samples were produced using sieve grades of 150 μm particle size and were compressed in a mould at a pressure of 15MN/m² and a temperature of 195°C. Results were compared with both commercial asbestos-based brake pad and laboratory formulated palm kernel shell-based brake pad. The results showed that sample S3 which is a combination of palm kernel shell, coconut shell and seashell; and sample S5 which is a combination of cow bone, seashell and palm kernel shell are the best substitute to replace the commercially manufactured asbestos brake pad.

1 INTRODUCTION

The development of automobile vehicles is one of the greatest inventions of the nineteenth/twentieth century (Nyamwange & Nyamwange, 2014). Apart from being able to assist in moving haulage from one place to another, it reduces time to move humans from place to place. This invention would not have been complete without inventing the brake system which is a system that serves as a means of stopping the vehicle once it is on motion. The most important component of a braking system is the brake pad because it is responsible for retarding and bringing the automobile to a stop (Nagesh, Siddaraju, Prakash, & Ramesh, 2014). The increase in demand for more automobiles all over the world causes a tremendous increase in demand for brake pads. In the past, brake pads were made from organic materials such as asbestos, resin and other frictional additives. However, the resolution 60.26, asbestos materials were declared carcinogenic by World Health Organisation (Neira, 2014). Due to the harmful nature of asbestos materials, researchers are looking at the possibility of replacing it with materials such as Kevlar, glass, metal, graphite, ceramics, agricultural wastes, and natural ashes (Choosri, Sombatsompop, Wimolmala, & Thongsang, 2019).

Elakhame, Alhassan, & Samuel, (2014) developed an asbestos-free brake pad using palm kernel shell (PKS) that is sieved into 100, 350, 710 μm and 1mm particle sizes. Different samples ranging from 35-55% PKS, 20% phenolic resin, 10% graphite, 15% steel dust and 0-20% silicon carbide (SiC) were mixed to produce brake pad using compressive moulding at pressures of 80 and 100 kN/cm² for 2 minutes for cold and hot treatment respectively. Results showed that the sample with 100 μm particle size gave the best properties when compared with the commercial brake pad. Ikpambese, Gundu, & Tuleun, (2016) in their study, produced brake pad from Palm Kernel Fibres (PKFs) with epoxy-resin as its

binder. Different samples were considered by varying the formulation of resin, PKF particle size, fillers and lubricant. Various tests such as friction coefficient, wear rate, hardness and mechanical tests were carried out on the samples. The samples were subjected to a compressive force of 100kN for 2 minutes in a mould and curing of the brake pads was done at a temperature of 250°C for 90 minutes. They concluded that the sample with 40% epoxy-resin, 10% PKFs, 29% graphite, 6% aluminum oxide (Al_2O_3) and 15% calcium carbonate (CaCO_3) gave a better property than other samples produced. Egeonu, Oluah, & Okolo, (2015) conducted a study by developing brake pads from Palm Kernel Shell (PKS) and Coconut Shell (CS) powder with 0.63 μm particle sizes as base material, polyester resin as the binder material, graphite as lubricant, metal chips and carbides as the abrasives. For comparison with commercial brake pads, the samples of the brake pad was produced by varying the base material composition while other ingredients were kept constant. Sample A contained equal mass of PKS and CS, while Sample B and C contained 83.03% PKS, 12.68% CS and 14.79% PKS, 35.92% CNS respectively. The samples were subjected to compressive pressure of 16.75kN/m² for 6 hours in a mould. The result revealed that sample C displayed superior mechanical properties such as moderate water absorption, wear rate and hardness but with least coefficient of friction when compared with other samples and commercial brake pad. Aigbodion, Akadike, Hassan, Asuke, & Agunsoye, (2010) developed brake pad from bagasse sieved into 100, 150, 250, 350, 710 μm particle sizes. The ratio of the bagasse to phenolic resin was 70-30% and samples of brake pad were produced using compressive moulding. These samples were subjected to pressure of 100kN/cm² at 140°C for 2 minutes and were cured in an oven at a temperature of 120°C for 8 hours. Various mechanical tests were carried out revealing a uniform distribution of resin in the microstructure of bagasse. The results showed that the finer the particle size of the base material the better the properties in comparison with commercial (asbestos based) and PKS based brake pads. Idris, Aigbodion, Abubakar, & Nwoye, (2015) investigated the behavior of brake pads produced from uncarbonized and carbonized banana peels by varying the percentage of phenolic resin in an interval weight percentage of 5 from 5-30 (wt%). In their study, 100 μm particle size of the samples were mixed and transferred into a mould kept in a hot plate press at 150°C and 9.81x10⁷N/m² pressure for 2 minutes. The brake pads were then cured in an oven at 130°C for 8 hours. Their result revealed that samples with 25 (wt%) and 30 (wt%) phenolic resin for un-carbonized and carbonized banana peels respectively provided better mechanical properties than other samples tested. Ilori-Olutosin, Adedokun, Umama, Olagunju, & Olasunkanmi, (2021) investigated the behavior of sets of brake pads produced from bagasse, banana peels and periwinkle shell in order to replace brake pads made from asbestos. Two particle sizes of 180 and 250 μm were used for the study. Different samples were made by varying the percent weight (%wt) of bagasse, banana peels and periwinkle shell while the weight of crystalline silica, lead sulphide and epoxy resin were made constant. Samples A, B, C and D have bagasse of 30 (%wt), 15 (%wt), 15 (%wt), 20 (%wt), banana peels of 15 (%wt), 15 (%wt), 30 (%wt), 20 (%wt) and periwinkle of 15 (%wt), 30 (%wt), 15 (%wt), 20 (%wt) respectively. The crystalline silica and lead sulphide are kept at constant 10 wt% while resin is kept at constant 20 wt%. Results from the microstructural analysis and hardness test showed that sample B and C can be used as substitute for asbestos in automobile brake pads. Palm kernel shell, seashell, cow bone, coconut shell are materials that have been extensively studied either individually or in combination of two in replacing asbestos as base material. However, little attention has been paid to studying the materials in combination of three or more. The current study is directed towards this.

2 METHODOLOGY

2.1 Materials

The base materials for the current work are PKS, CS, seashell and cow bone. The materials are selected based on the fact that they are non-toxic, readily available and cheap. They have high coefficient of friction, low wear rate, good heat dissipation and high mechanical strength with high dry rate when exposed to water (Onyeneke, Anaele, & Ugwuogbu, 2014). Other materials used were phenolic resin, graphite, calcium carbonate, aluminum oxide, caustic soda and ethanol. Figures 1a to 1d show the pictorial diagram of palm kernel shell, coconut shell, seashell and cow bone used.

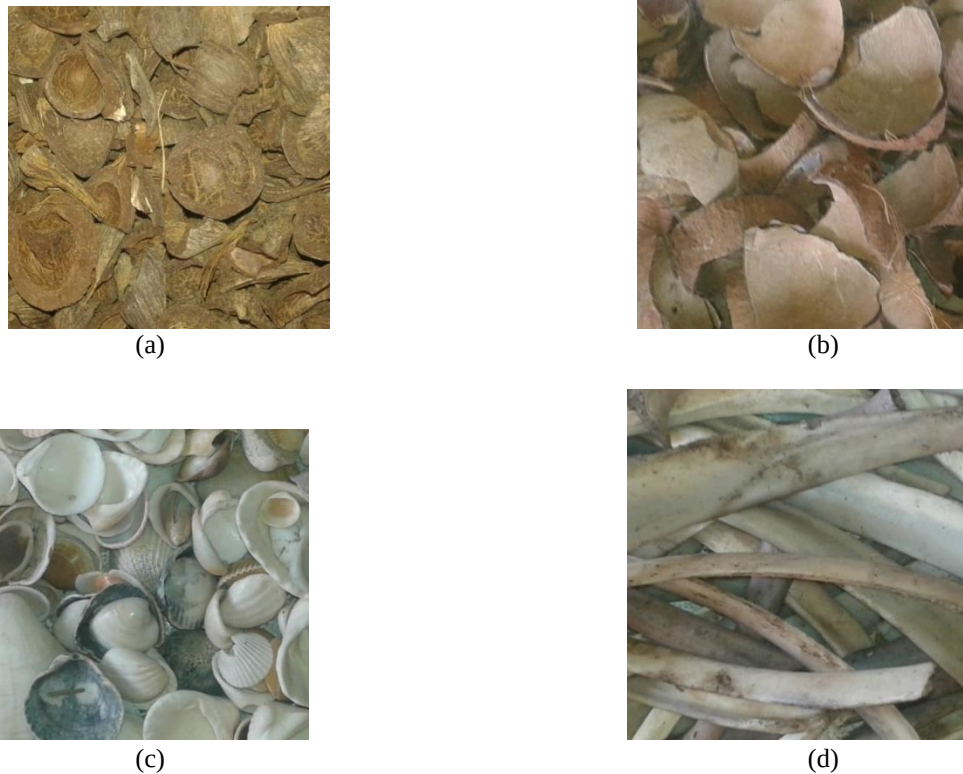


Figure 1: (a) – Palm Kernel Shell, (b) – Coconut Shell, (c) – Sea Shell, and (d) – Cow bone

2.2 Types of equipment used

The types of equipment used are; hydraulic press, brake pad mould, band heater, crusher machine, grinding machine, sieve of 150 μ m aperture, scanning electron microscope (SEM) using petrological microscope(serial number:. TZ-200TA, made in China) in association with photomicrographic software AmScope 3.7, and digital weighing machine (by Kern and Sohn GmbH, model D-72336, serial number: W 15 00761, made in Germany).

2.3. Preparation of the raw materials

The palm kernel shells were suspended in a solution of caustic soda (sodium hydroxide) for 24 hours to remove the traces of red oil after extraction and cracking of the shell. Caustic soda was removed by washing the shell in water and sun-dried for three weeks. The Coconut shells were collected and cleaned thoroughly using ethanol to remove impurities and dried in the sun for three weeks. The Seashells were thoroughly cleaned and sun-dried for three weeks to remove the moisture content completely. The Cow bones were collected and scraped using a knife to remove leftover tissues then broken to pieces by hammer to remove marrows inside the bones. The bones were suspended in caustic soda to remove traces of blood and oil (fat) then rinsed in water to remove NaOH and sun-dried for three weeks to evacuate moisture content to the barest minimum.

2.4 Material Processing

After treatment, each of these materials were crushed manually into smaller pieces and ground into fine particles using a grinding machine. The powdery materials were sieved using 150 μ m standard sieve (ASTM specification no_100) placed on a shaker (OCT-5875-08) which was electronically operated. Bigger particle sizes that could not pass through 150 μ m sieve aperture were re-grinded several times until the required quantities were obtained.

2.5 Preparation of Brake Pad Samples

After the necessary treatments and processing of the frictional materials, 1000g formulation of five brake pad samples was formed by varying the base materials and other constituents were kept constant. The base materials were split into the following proportions:

Sample S1 - 112.5: 112.5: 112.5: 112.5g - PKS: CS: Seashell: Cow bone
 Sample S2 – 150 : 150 : 150g – PKS: CS: Cow bone
 Sample S3 - 150 : 150 : 150g – PKS: CS: Sea Shell
 Sample S4 - 150 : 150 : 150g –CS: Sea Shell: Cow Bone
 Sample S5 - 150 : 150 : 150g – Cow Bone: Sea Shell: PKS

The mix ratio of constituents forming each sample is shown in Table 1:

Table 1: Mix ratio of Samples

Composition	Samples in percentage weight				
	S1	S2	S3	S4	S5
Phenolic resin	30	30	30	30	30
Base material	45	45	45	45	45
Aluminum oxide	5	5	5	5	5
Calcium carbonate	10	10	10	10	10
Graphite	10	10	10	10	10

Each formulation was thoroughly mixed using a stirrer until a homogenous mixture was achieved and transferred to a mould for hot pressing at 195°C with the hydraulic press for 2 mins under an applied pressure of 15MPa. The samples were cured in an oven at a temperature of 120°C for 8 hours. The manufactured samples were polished using a polish-grinder with grinding paper of various sizes to obtain the final product.

2.6. Evaluation of the developed brake pads

2.6.1 Hardness Test

The resistance of the produced samples to indentation was carried out at Landmark University, Omu-Aran, Kwara State using Brinell Hardness Testing machine (model: EEDB, serial number: EEDB 0006/13, EDIBON with pressing hardened steel ball diameter D into a test specimen). Based on ASTM E10-15 specification, a 10 mm diameter steel ball was used, and the load applied P was kept stable at 500kg/f. The diameter of the indentation d was measured along two perpendicular directions, using an optical micrometer screw gauge. The mean value was taken and used to obtain the Brinell Hardness Number (BHN).

2.6.2 Compressive Strength Test

The compressive strength test was done on the samples using the Tensometric Machine (model: DBBMTCL-5000kg, serial number: 38140, manufactured by Rochdale England). Each sample with a diameter of 25mm was subjected to a compressive force, loaded continuously until failure occurred. The load at which failure occurred was then recorded in accordance with ASTM 3410 standard.

2.6.3 Water and Oil Absorption Test

The water and oil (SAE 20W50) absorption properties of the produced samples were determined by soaking the samples in water and oil for 24 hours. The weight of the samples were determined before and after the tests. The percentage of absorption is given as:

$$\text{Absorption (\%)} = \frac{W_1 - W_0}{W_0} \times 100\% \quad (1)$$

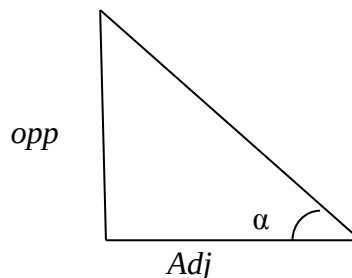
Where; W_1 = weight after immersion and
 W_0 = weight before immersion.

2.6.4 Friction Test

For the coefficient of friction test, each of the samples was placed on an inclined plane of known angles and a 90° wedge. Wedges of known heights were positioned on one another and varied to increase the angle of inclination while the horizontal distance is kept constant until the specimen was just about to slide down the plane. The coefficient of static friction is obtained using Equation. 2 and Figure 2:

$$\tan \alpha = \frac{\text{opp}}{\text{Adj}} = \mu \quad (2)$$

Where; μ = coefficient of friction


Figure 2: Inclined plane of known Angle α

2.6.5 Microstructural Analysis

The microstructural analysis of the samples was carried out by grinding the surface of the samples using carborundum abrasive. The smooth surface was then attached to clear glass of 25.4 × 76.2mm edges and thickness 1mm using Araldite adhesive and left for 24 hours. The samples were cut into a thin section using thin sectioning machine and then further ground into a thinner section using carborundum abrasive until a clear microstructure of the samples was realised. The thin sections were transferred to the micro-graphic laboratory where the microstructure of the samples was viewed and captured on the screen with petrological microscope which is a scanning electron microscope (SEM) (serial number: TZ-200TA, made in China) in association with photomicrographic software AmScope 3.7.

2.6.6 Density Test

The true density of the samples was determined by weighing the sample's mass on a digital weighing machine and dividing it by measuring their volume through liquid displacement method. Equation 3 was then used to obtain the density:

$$\text{Density } (\rho) = \frac{m}{v} \quad (3)$$

Where: m = mass of test piece (kg) and
 v = measuring the volume of the test piece (m^3) by liquid displacement method.

3 RESULTS AND DISCUSSION

The produced samples from different materials is shown in Figure 3



Figure 3: Produced Brake Pad Samples S1, S2, S3, S4 and S5

3.1. Performance Test Results

Various performance evaluation tests were carried out on the brake pad samples produced and the results of these tests were analyzed to determine the potential of the eco-friendly brake pad for application as a brake pad material. The test results were compared with existing asbestos based commercial brake and laboratory formulation (PKS)

3.2 Hardness Test

Figure 4 shows the hardness values of the newly produced samples as compared with the commercial brake pad which is Asbestos-Based (Asb) (Aigbodion et al., 2010) and laboratory formulation (PKS) (Ibhadode & Dagwa, 2008). The result indicated that the produced samples have hardness values less than the values obtained for commercial brake pad and laboratory formulation (PKS). The difference in the hardness value can be ascribed to the difference in base materials used for the study. S3 has the highest hardness value out of the produced samples, followed in descending order by S5, then S4, S2 and S1. However, all have lesser hardness values in comparison to Asb and laboratory formulation (PKS).

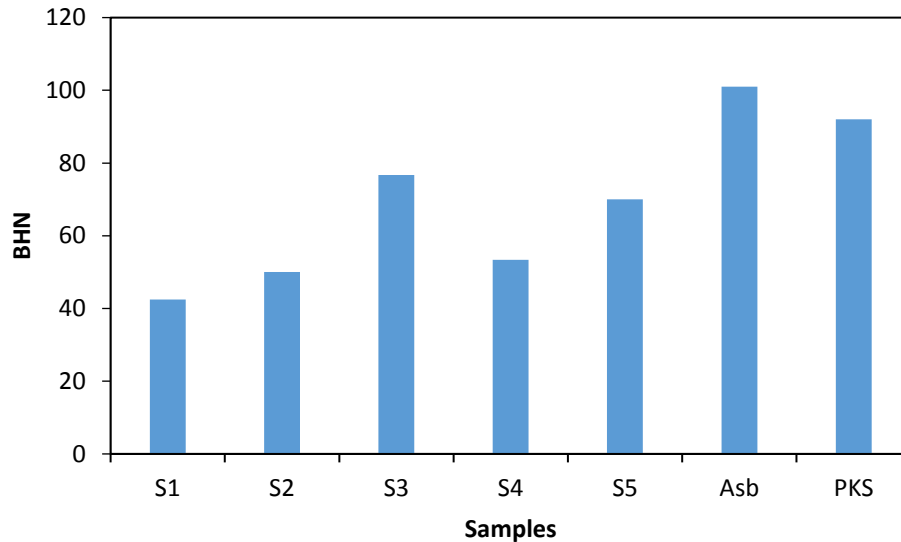


Figure 4: Hardness Test of Brake Pad Samples

3.3 Compressive Strength Test

Figure 5 shows the result obtained from the compressive strength test carried out on the developed brake pad samples with that of Asb and laboratory formulation (PKS). Sample S3 has a higher strength when compared to all the developed brake pad samples in the current work followed by S5. This is expected because of the direct relationship between the hardness value of material and its strength. However, all the samples are of lower compressive strength when compared with Asb and laboratory formulation (PKS).

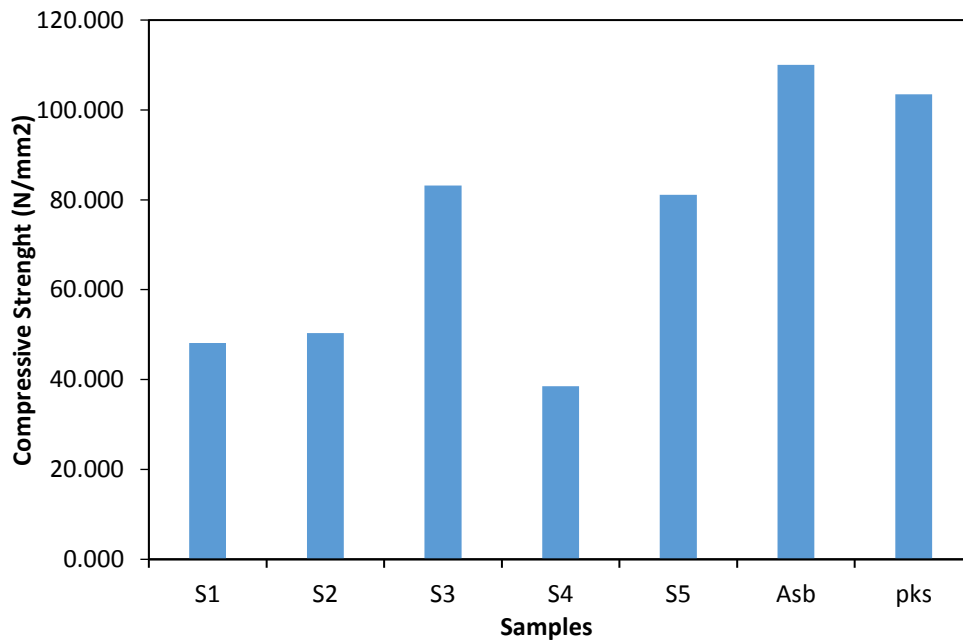


Figure 5: Compressive Strength of Brake Pad Samples

3.4 Oil and Water Absorption Test

Figure 6 shows the absorption rate of the developed brake pad samples as compared to Asb and laboratory formulation (PKS). Sample S5 has the lowest absorption rate in oil and water of 0.441% and 1.6% respectively among the produced samples of the study which is very close to the absorption rate in oil and water of Asb which is 0.3% and 0.9% respectively.

However, the water absorption rate of S5 is significantly lower than the absorption water rate of laboratory formulation (PKS) which is about 5.03%. For oil and water absorption test, the lower the value, the more suitable the material is for brake pad. Higher water and oil absorption values imply the material is not oil and water resistant and might not be suitable for use for example during the rainy season.

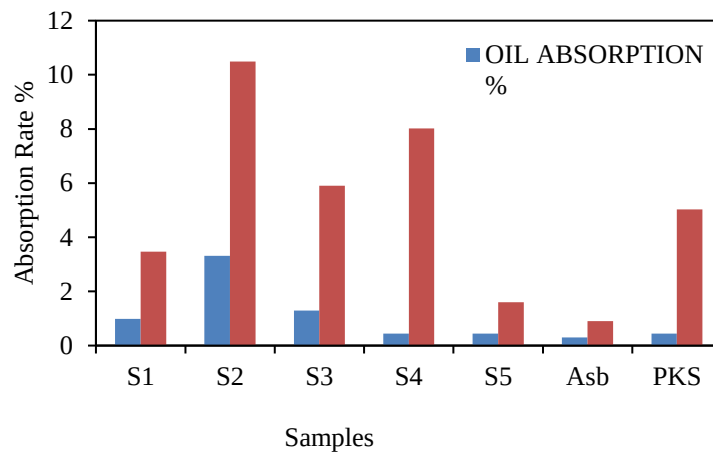


Figure 6: Absorption Rate of Brake Pad Samples

3.5 Coefficient of Friction Test

Figure 7 shows the friction coefficient properties of the newly produced brake pad samples as compared with Asb and laboratory formulation (PKS). A high coefficient of friction is desired in a brake pad so that the automobile can decelerate and stop when the brake is applied. The results of all the samples (S1, S2, S3, S4 and S5) produced are in close range with those of both Asb and laboratory formulation (PKS) which are 0.3-0.4 and 0.44 respectively.

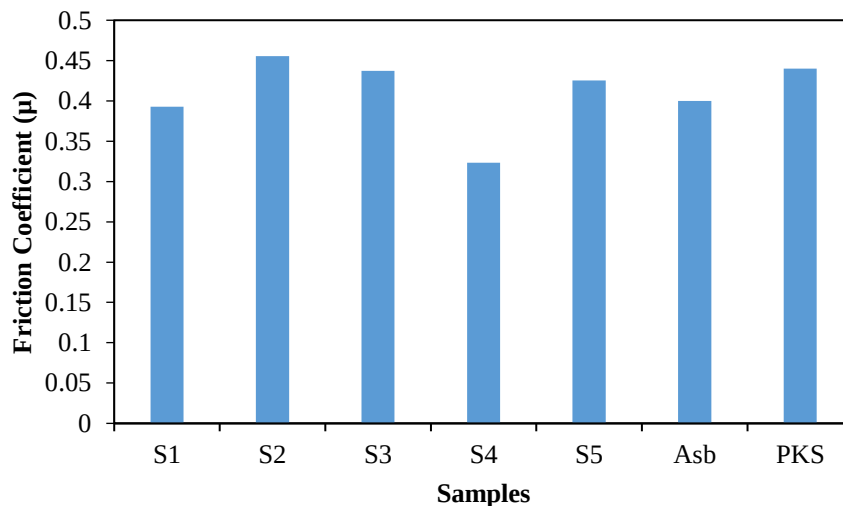


Figure 7: Coefficient of Friction of Brake Pad Samples

3.6 Micro-structural Analysis

Observation of the microstructure of the produced samples shows that there is a uniform distribution of resin with other constituents since all the samples are of the same sieve size of 150μm. The distribution of the particles is influenced by good bonding of the resin and base materials (palm kernel shell, coco-nut shell, sea shell and cow bone) which resulted in good interfacial bonding as shown in Figure 8(a) to (j):

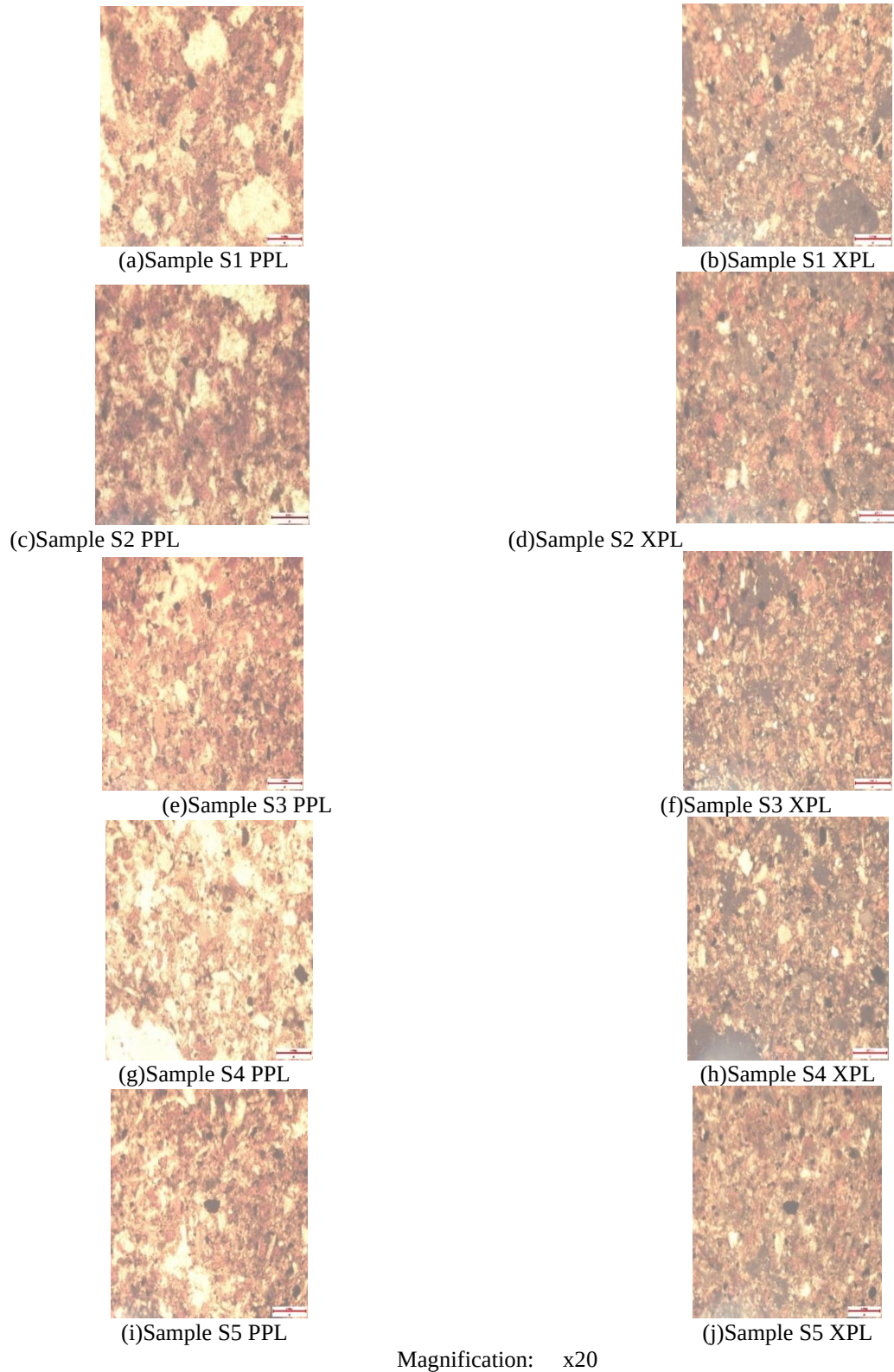


Figure 8: Microstructure of Produced Samples

Where: PPL and XPL denote Plain Polarised Light and Cross Polarised Light respectively.

3.7 Result of Density Test

Figure 9 shows the results of the density test of the recently produced brake pad sample as compared with Asb and laboratory formulation (PKS). The densities of samples S1, S2, S3 and S5 are in close range to that of Asb and laboratory formulation (PKS). This is due to the dense nature of the constituents that make up each sample.

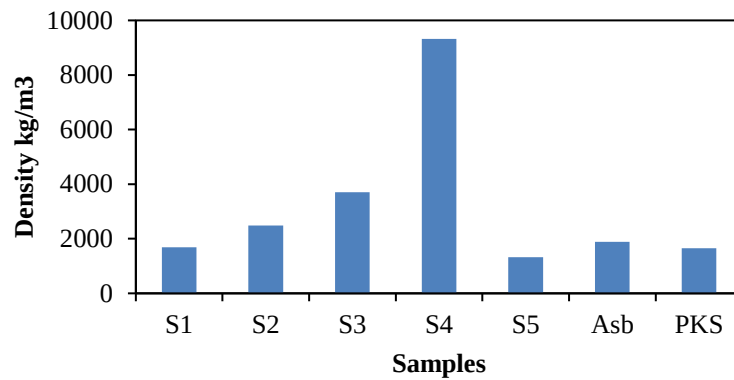


Figure 9: Plot of Densities of Brake Pad Samples

3.8 Comparison of Properties of Existing Brake Pad and Newly Produced

Table 2 compares the properties of the produced samples of brake pads S3 and S5 with the properties of Asb and laboratory formulation (PKS) brake pads. Samples S3 and S5 properties, compares favourably well with that of Abs and PKS brake pads.

Table 2: Comparison of Properties of Existing Brake Pad and Newly Produced

Properties	Commercial Brake Pad (asbestos-based)	Laboratory Formulation (palm kernel shell)	Newly Produced Sample (S3 and S5)
Compressive Strength (N/mm ²)	110	103.5	83.192 and 81.126
Water Absorption (%)	0.9	5.03	5.905 and 1.6
Oil Absorption (%)	0.3	0.44	1.295 and 0.441
Coefficient of Friction	0.3-0.4	0.44	0.44 and 0.43
Density (kg/m ³)	1890	1650	3705 and 1329.03
Hardness Values (BHN)	101	92	76.74 and 70.05

4 CONCLUSION

The results of this research work have shown that a combination of agricultural waste materials; coconut shell, seashell, palm kernel shell and cow bone could be very useful in producing brake pad samples using compressive moulding techniques. Sample S3 and S5 are seen to possess better compressive strength and hardness values of (83.192N/mm², 76.74BHN) and (81.126 N/mm², 70.05BHN) respectively. Sample S5, with a density of 1329.03kg/m³, is a combination of palm kernel shell, seashell and cow bone. It has the least oil and water absorption rate of 0.44% and 1.6% respectively, which is very close to commercial (asbestos-based) brake pad of oil and water absorption rate of 0.3% and 0.9%. Though, sample S3 has values of oil and water absorption rate of 1.30% and 5.91% respectively, which render it unfavorable in these two properties when compared with the commercial (asbestos-based) brake pad. The coefficient of friction obtained for samples S3 and S5 are 0.44 and 0.43 respectively and is within the recommended standard of 0.3-0.4 for commercial brake pad (asbestos-based) and 0.44 for laboratory formulation (PKS) brake pads. Samples S3 and S5 which are non-carcinogenic, can be used as substitutes in replacing asbestos-based during the production of automobile brake pads.

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