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Research article

Tribological Evaluation of the Developed Eco-Friendly Agro-Residues Composite Brake Pads

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A B S T R A C T

Braking in an automobile is very important, as the lives of the drivers, passengers, and road users are in danger when failure occurs. The brake pad is the essential component of the disc braking system that controls or regulates the movement of the vehicle in motion. Brake pad friction material consists of composite materials with different functions with specific percentages; hence, this work employs seashell as structural material, sawdust as fillers, palm kernel shell as abrasive, charcoal as friction modifiers or lubricant, and epoxy resin as binders using three sieve ranges (400-300 µm, 300-250 µm, and 400 µm and below). Tribology is a major determinant of a good friction material as it evaluates the wear characteristics, absorption, and coefficient of friction. The wear resistance is determined in the laboratory using the pin-on-disc method with the wear apparatus, while the absorption and coefficient of friction are usually conducted via Archimedes' principle and inclined plane apparatus, respectively.

The coefficient of friction of the three main brake pads produced are 0.416, 0.347, and 0.372, the water/oil absorption of 0.992/0.804, 0.756/0.614, and 0.851/0.898, and wear rate/resistance of 0.1164/0.8593, 0.1668/0.5993, and 0.3252/0.3075 for sample A, B, and C respectively.

1. INTRODUCTION

A brake in automobile is the mechanical part that control the motion or regulate the movement of the automobile in operation by overcoming its momentum [1]. Brake pad is an essential component of disc braking system which convert the kinetic energy of a moving vehicle to thermal energy through friction occurrence between the surfaces in contact [1-3].

A good brake pad material should have the following tribological properties such as moderately high Coefficient of friction, minimum wear rate alongside a good wear resistance when subjected to heavy loads and high speeds [4,5]. Friction occurs in braking when the brake pads installed in the calliper are either hydraulically, mechanically or pneumatically applied which pushes the pads against the rotor/disc connected to the wheel of vehicle thus; generating friction and this normally accompanies wear on both the friction material and disc, and the wear effect is always significant on the brake pad due to the low wear resistance as compared to that of the disc because of its replacement cost implication.

There are different classes of friction materials that has been employed but asbestos-lined type of brake pad was mostly used due to its outstanding performances and characteristics including low density, moderate mechanical properties, good thermal resistance, appropriate frictional coefficient, and excellence wear resistance to disc. Researches have pronounced asbestos carcinogenic to human respiratory organs [1] and this has led to the ban of asbestos usage for brake pad production in over sixty countries of the world. As such, researchers continue to investigate for potential and permanent replacement with similarity in properties or better performance to the asbestos-lined brake pads [6]. Several materials have been used of which agro-residues composite material have displayed a huge potential for brake pad application and some of these eco-friendly agro-residues materials includes seashell, snail shell, periwinkle, coconut shell, rice husk, cow bone, cow hooves, palm kernel shell, sawdust, maize husk, banana peels, bagasse, cocoa beans shell etc. [1,7-11].

For this reason, this work looks at the tribological performance of brake pads made from composite of eco-friendly agro-residues material (seashells) and compares its tribological properties with the selected available brake pad in the market.

2. METHODOLOGY

2.1 Material Sourcing and Collection

The materials used for the research are seashell, sawdust, palm kernel shell, charcoal, epoxy resin (polyepoxide) and hardener (Diethylenediamine) as binders. The seashell (Mercenaria Mercenaria) was collected at the beach, Ajah, Lagos state; sawdust of Ayunre tree (Albizia zygia) and charcoal of white kola (Garciana Cola) tree of approximate 8 and 10 years of age respectively were collected at Igbo-alahun village, Oluyole local government, Ibadan, Oyo State; the palm kernel shell (Elaeis guinensis) was sourced and collected at Iyeku of Odo-otin south local government area of Osun State; Epoxy resin (Polyepoxide) and hardener (Diethylenediamine) were purchased at Ojota chemical market (Lagos).

2.2 Material preparation

The raw materials (seashell, sawdust, palm kernel shell and charcoal) were washed and dried under the sun for seven days with average time of five (5) hours per day to remove surface moisture. They were grinded using attrition milling and passed to three sieve ranges of 400-300 μm, 300-250 μm and 400 μm down with the epoxy resin and hardener (Diethylenediamine) mixed in ratio 2 to 1, as shown in Fig. 1

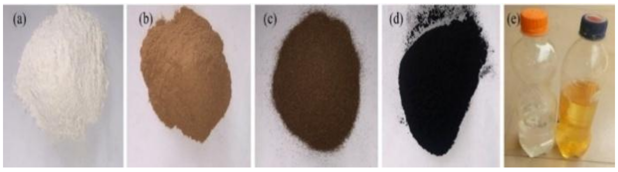


Fig. 1. Pulverized materials (a) Seashell (b) Sawdust (c) Palm kernel shell (d) Charcoal (e) Epoxy resin and hardener.

2.3 Sample formulation and production

The material selected for the production are clam seashell (Mercenaria Mercenaria), Ayunre sawdust (Albizia zygia), palm kernel shell (Elaeis guinensis), charcoal (Garciana Cola), and epoxy resin (polyepoxide) with hardener (Diethylenediamine). The composite formulations were prepared using three different sieve ranges of seashell, sawdust, palm kernel shell, charcoal and binder contents as shown in the Table 1 based on the modified suggestion by Adekunle et. al., (2023) [1].

Table 1. Sample formulation for Production.

Comp	Sieve (μm)	Ss	Sd	Pks	Chl	Binder	Total
A	400-300	30	20	17	6	27	100
B	300-250	30	20	17	6	27	100
C	400	30	20	17	6	27	100

The selected materials; seashell (Ss), sawdust (Sd), palm kernel shell (Ps) and charcoal (Chl) were thoroughly mixed with an electric-powered mechanical mixer for ten minutes (10 min) to give a homogeneous material mixture. The epoxy resin and hardener with ratio 2:1, was mixed in a separate container. The production flowchart is presented in Fig. 2.

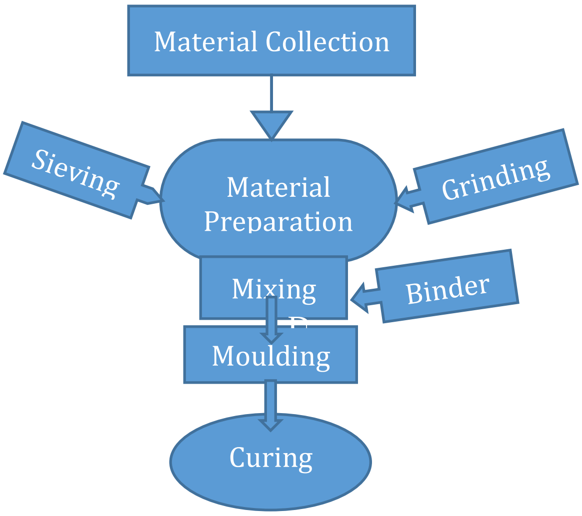


Fig. 2. Brake pad production flowchart.

The two mixtures were then blended with a mechanical mixer until a low-moisture homogenous mixture was formed, the blended mixture was compressed in a fabricated metallic mould placed on a backing plate of 4mm thickness (High carbon steel plate). The backing plate cut into dimension to be accommodated by the brake calliper and was subjected to a compressive force of 40kN to bind the material with the backing plate with a holding time of 5 minutes using compression testing machine (STYE-2000) shown in Fig. 3.

Fig. 3. Compression Testing Machine

After five minutes holding time, the moulded brake pad was ejected from the mould and kept at room temperature for 24 hours before curing in an electric oven at 150 °C for 60 minutes. Fig. 4 shows the brake pad produced.

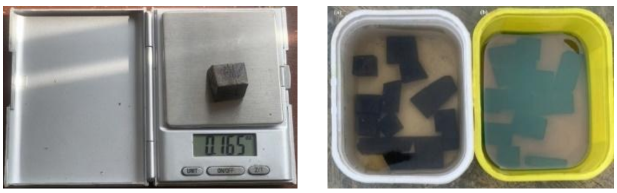
Fig. 4. Produced brake pad samples

3. TRIBOLOGICAL PROPERTIES OF THE BRAKE PADS

The following experiment were carried out on the produced friction material and the control sample for determination of their tribological behaviour and better comparisons among the samples' performances.

3.1 Water and oil absorption tests

The rate at which the produced and control samples absorbed water and oil absorption were conducted according to ASTM D570 standard to know the vulnerability of the samples when stocked in water and oil over a specific time. Equation 1 was used for determination of the absorption. The equipment used is highly sensitive Camry pocket size weighing balance shown in Fig. 5a. The initial weight of each specimen was taken and recorded as W_i before soaking into water and engine oil separately. The oil used was automotive engine oil of rating SAE40. The samples were soaked in distilled water and oil for 12 hours at interval of 2 hours for 5 consecutive measure before it was left for 14 days (460 hrs) as shown in Fig. 5b.



(a) (b)

Fig. 5 (a) Camry pocket size weighing meter, (b) Absorption test.

Samples were removed from water and oil, thoroughly cleaned to remove surface moisture and reweighted to know the weight gained and recorded as W_f. The percentage absorption was then computed using Equation 1 [5,12-14]

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

where W_i is the weight before immersion and W_f is the weight after immersion.

3.2 Coefficient of friction

The coefficient of friction of the produced and the control samples were conducted using inclined plane apparatus according to ASTG219 standard. The test procedure was inline as recommended by Standard Organization of Nigeria (S.O.N) [13]. The inclined plane apparatus tilted at an angle α (40°) and the frictional coefficient of each sample was determined as shown in Fig. 6. Small hole of 3mm diameter was made on the brake friction material using drilling machine and a thread of negligible weight was attached to the weighed sample (F) and was made to pass across the frictionless grooved pulley and connected to weight hanger. The load on the weight hanger was gradually increased until the composite just slides at constant velocity. the procedure was repeated three (3) times and the load was recorded as (X) which was used to calculate the coefficient of friction, and the average was found and recorded as average coefficient of friction. The coefficient of friction was calculated using Equations (2) and (3).

$$W = m \times g \quad (2)$$

where m is mass; g is acceleration due to gravity m x g

$$\text{Coefficient of friction}\ (\mu) = \frac{X - F\sin\alpha}{F\cos\alpha} \quad (3)$$

Where X is the load on the hanger; F is the weight of the samples

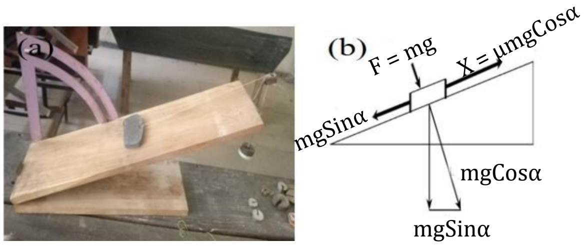


Fig. 6. Analysis of coefficient of friction, (a) Test equipment setup (b) Analysis of forces.

3.3 Wear rate test

Wear rate/resistance test was carried out with the aid of weight loss/wear test machine at Obafemi Awolowo University, Ile-Ife, Osun State, Nigeria. The test was conducted following ASTM G99 standard procedure using pin-on-disc apparatus. The equipment used is as shown in Fig. 7.

Fig. 7. Weight loss/wear testing machine.

The samples were cut to size (30 by 30 mm) which can be accommodate by the specimen holder, the specimens were weighed in air as W_i and the volume of each specimen was determined by submerging in a calibrated cylinder filled with water and the volume displaced was recorded, After drying for 48 hours at room temperature, the sample was tightly fixed to the specimen holder and a load of 20 N was applied on the stylus pin which rest on the fixed sample, the electric motor was switched on and was made to rotate the specimen holder with the sample for only 200 rpm. The sample was then removed from the specimen holder and the sample was reweighed and the value was recorded. The specific wear rate is expressed as shown in Equation (4).

$$W_s = \frac{\Delta V}{F \times S} \quad (4)$$

where W_s is specific wear rate (mm^3/Nm); ΔV is the Volume loss (mm^3); F is the applied load (N); S is the sliding distance (m).

4. RESULTS AND DISCUSSION

4.1 Tribological behaviour of the produced and control samples

These are the measurable properties whose values describes a state of the brake pad tribological performance and the comparison of the behavior of the produced with respect to the selected control material.

4.2 Absorption rate

Fig. 8 present the comparative analysis of water/Oil absorption of the produced samples with respect to the control sample. The absorption rate decreases from sample A to sample B as the particle size decreases, the rise in water and oil absorption rate of sample C resulted from the interwoven activities of different particle sizes of the composite of the formulated samples. The highest water absorption obtained in sample A with total absorption of 1.275g followed by sample C and B with 1.040 g and 0.992g respectively which is 77.73%, 72.6% and 71.37% higher than the control samples with total water absorption of 0.284g. The trend displayed is different for the oil absorption test carried out as a result of the resistance of the binder in the formulation where the saturation degree of the binder decreases as the particle size decreases (that is, the finer the particle sizes, of the composite, the more the quantity of binder required to effectively saturate the composite formulation. Sample C has the highest oil absorption of 1.040g followed by sample A and B which is 72.79%, 70.05% and 62.56% respectively higher than the control sample with total oil absorption of 0.283g. This property could be enhanced by increasing the compressive load.

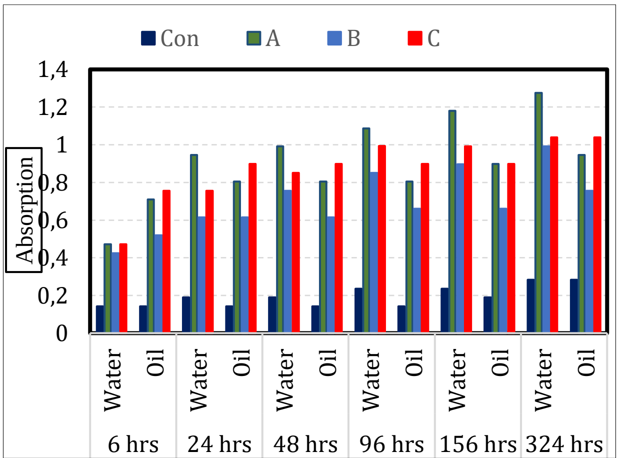


Fig. 8. Graphical representation of absorptionrate of produced and control samples.

4.3 Coefficient of Friction Assessment

According to the results obtained as shown in Fig. 9, the coefficient of friction decreases with decrease in particle size of the composite content. The projection in value of coefficient of friction of sample C was attributed to the mixture of different particle sizes which gave rise to increase in density as a result of interrelationship between different particle sizes of the composite formulation which is in agreement with a periwinkle shell [14,15], who studied the effect of periwinkle particle size on the wear of brake pad using full factorial experimental design. Also, the same trend with respect to particle size was reported by Aigbodion *et al.* [12] which employs bagasse for the study of the development of asbestos-free brake pad. The coefficient of friction of the control sample is 0.325 which deviate from that of the newly formulated composite sample by 21.87%, 6.34% and 12.63% for sample A, B and C respectively. The deduction from the result showed that sample B (0.347) has the closest coefficient of friction to the control friction material sample (0.325) which is in agreement with the Adekunle *et al.*, [1]. The coefficient of friction for conventional friction material ranges from 0.3 to 0.4 [16-18]. Coefficient of friction of composite sample B of 300µm particle size is 6.34% higher to the coefficient of friction of the control sample. However, the coefficient of friction of the developed friction material ranges from 0.347 – 0.416, which is still within the standard range as reported by Idris *et al.,* [18].

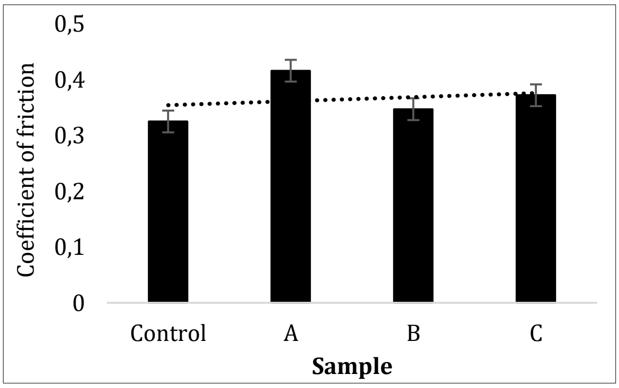


Fig. 9. Graph of coefficient of friction of produced and control samples.

4.4 Wear Rate

The wear rate of the developed composite brake friction material and the control sample is as shown in Fig. 10. It was observed that the specific wear rate of composite increases with decrease in particle size of the content in the formulation which also result in decrease in hardness of the samples. This could be attributed to increasing interfacial bonding between the composite formulation particle sizes and the saturation of the binder, thereby reducing possibility of pulling out of higher particles as the degree of saturation decreases with decrease in particles sizes as this trend was also observed by Edokpia et al. and Adeyemi et al. [11,19]. The specific wear rate increase uniformly from sample A to C and sample B has the closest value of wear resistance lower than that of the commercial sample by 2.65%. the control sample with hardness of 153.95BHN has the specific wear rate of 0.1624986mm^3/Nm which is lesser in resistance to wear of sample A by 28.38%. This depict that the higher the specific wear rate of the sample, the lower the wear resistance and vice versa.

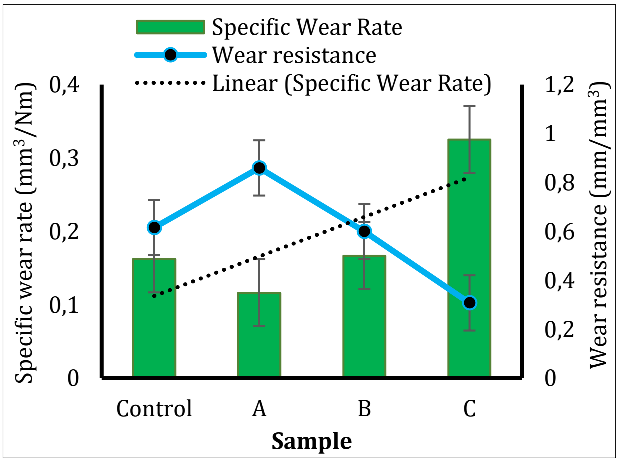


Fig. 10. Graphical representation of the specific wear rate of produced and control friction material samples.

5. CONCLUSION

The tribological features of the produce brake pad showed suitability of its potential replacement for asbestos and its composition additives in brake pad formulation. The water/oil absorption, coefficient of friction and the wear resistance of the produced samples displayed an efficient performance with a closer result when compared with the control sample. The tribology behavior of the produce samples increases from sample A to C with the value of 0.416, 0.347, and 0.372; 0.992/0.804, 0.756/0.614, and 0.851/0.898; and 0.1164/0.8593, 0.1668/0.5993, and 0.3252/0.3075 for coefficient of friction, water/oil absorption and wear rate/resistance respectively while control sample has the tribological value of 0.325, 0.198/0.142 and 0.1625/0.6154 respectively for coefficient of friction, water/oil absorption and wear rate/resistance respectively.

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