



EXPERIMENTAL INVESTIGATION OF PALM KERNEL SHELL AND COW BONE REINFORCED POLYMER COMPOSITES FOR BRAKE PAD PRODUCTION

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ABSTRACT

Formulation of brake pad from palm kernel shell (PKS) and cow bone reinforced polymer composite was investigated. Palm kernel shell and cow bone were added in different sieve grading into an epoxy resin and hardener at 100, 100 and 120 sieve grading respectively. The formulated brake pads were characterized based on the requirements for brake pad uses. All properties investigated were observed to be within the acceptable requirement for brake pad function. The impact test for PKS and cow bone show 1.0 J and 1.5 J respectively. The hardness test show 55.7 HRB and 46.0 HRB values for PKS and cow bone respectively. While the water absorption test for PKS was 5.05% and cow bone was 5.53%. Oil absorption test for PKS was 2.23% and 4.16% for cow bone. The values of thermo-gravimetric analysis (TGA) were measured in terms of highest percentage weight loss and for PKS it was 57.14% and 63.24% for cow bone. While the values of coefficient of friction for PKS and cow bone were 0.735 and 0.677 respectively. Wear rate for PKS was $9.57E-7$ and $1.44E-6$ for cow bone. Crushing strength for PKS was $23N/mm^2$ and $21N/mm^2$ for cow bone.

Keywords: Friction, Water absorption, Brake pad, Wear rate, Impact test.

Contribution/ Originality

The paper's primary contribution is finding that reinforced polymer composite of PKS and cow bone particles can be an alternative to asbestos based reinforced material in brake pad formulation.

1. INTRODUCTION

Brake pads are very important in the braking system for all types of vehicles that have disc brake. Cars producers such as; Toyota, Nissan, Honda, and a host of others all use brake pad in

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braking system. They have steel back plate, with the frictional material fixed to the surface facing the brake disc [1, 2]. Brake pads for an automotive brake system are friction complex composite because they contain numerous ingredients that are diverse in physical, mechanical and chemical properties [3]. The major component in brake pad is the lining material which are categorised into metallic, semi-metallic, organic and carbon based, depending on the composition of the constituent elements [4]. These brake pad or friction composites comprise of many disparate ingredient such as binders, fibres, fillers and frictional modifiers / additives. Asbestos fibres which occurred naturally as mineral have been used as reinforcing fibres ingredient to reinforce the constituents in frictional materials or to provide mechanical strength [5] due to its good engineering properties. However, the use of asbestos has been suppressed because of health implications [6] and the search for safer and cheaper alternatives. In this work, the use of natural materials reinforced polymer composite was contemplated on the basis of its engineering properties reported in the literature [6].

Palm kernel shell and cow bone reinforced polymer composite as brake pad ingredients with a polymer composite of epoxy resin and hardener. Large quantities of these by-products are generated annually from the agricultural sector everywhere in Nigeria, and only some fractions are used for other purposes. These products are environmental friendly and easy to access, with no side effects and are renewable. Although, these agricultural by-products must all be dried and grounded to fine particles, to be suitable for use in the production of brake pads. In this work, the use of natural materials reinforced polymer composite were used on the basis of its engineering properties reported in the literature, to investigate its effect on the production of brake pad. The investigated values for all the properties of brake pad produced from this experiment show that both palm kernel shell and cow bone could be a substitute for reinforced material.

2. MATERIALS AND METHOD

2.1. Materials

2.1.1. Palm Kernel Shell

The palm oil plant (*elaeis guineensis*) can be classified into three different varieties *durà*, *pesipherà* and *tenerà*, which produces an edible fruit similar to an apricot which has a nut. During the crude palm oil process, the fruit's flesh is melted through a steaming treatment. The residual nuts are further mechanically crushed to extract the seeds or kernels. The crushed shells are called palm kernel shells (PKS), a virgin biomass with a high calorific value of 3,800 Kcal/kg (ASTM D5865 – 02). PKS has a very low ash and sulphur contents of 3% weight (ASTM D3174-02) and 0.09% weight (ASTM D4239 – 02) respectively. PKS can be considered like a natural pellet and a high grade solid renewable fuel for burning in coal firing with steam coal or burned at biomass power plants and usually blended with other grades of biomass, like wood chips. Palm kernel is a perennial crop, which make it available all-round the year, which means the PKS is available always. Palm kernel shell as shown in Figure 1 were obtained from Kure market Minna, Niger state and the shell was separated manually.



Fig-1. Palm Kernel Shell (PKS) obtained from Kure Market, Minna, Nigeria.

2.1.2. Cow Bone

Cow bone consists of living cells widely scattered within a non-living material called the matrix. The matrix is formed by osteoblasts cells that are constantly renewed in the bone. Osteoblasts make and secrete the protein collagen, which makes bones elastic so that they can withstand the stresses generated by walking, lifting, and other activities. Since bone is so strong and can withstand a lot of stresses, it can be used as composite in engineering material. It should be noted that cow bone is always available all the year round everywhere in the country. Figure 2 shows cow bone as obtained from Central Abattoir Minna, Niger State.



Fig-2. Cow bone obtained from Central Abattoir, Minna

2.1.3. Epoxy Resin and Hardener

Epoxyes are thermosetting polymer resins where the resin molecule contains one or more epoxide groups. The epoxy compounds were obtained in two separate containers A and B. Container A is the epoxy resin and container B is the polyamine hardener. Epoxy resins are normally clear to slightly amber, high viscosity liquids which may be filled with mineral fillers to improve performance and low cost. It can sometime settle to the bottom of the container and must be stirred to a homogeneous consistency before adding the hardener. Epoxy resins can cause

mild skin irritation and a form of dermatitis upon repeated contact. It is important to limit skin contact with any epoxy resin or hardener.

Hardener is typically a polyamine or mixture of polyamines and can have strong ammonia-like smell. Most are considered corrosive materials and should be respected as such. They are typically light colored to dark amber liquids. The hardener like the resin can be filled with metal or mineral fillers to improve performance or lower costs. And just like the resin, these fillers may settle over time and must be stirred to a homogeneous consistency before mixing with the resin. Epoxy resin and hardener used for this study were obtained from Suleja market in Niger State, Nigeria.

3. METHODOLOGY

3.1. Experimental Method

The PKS collected were sun dried for 3-4 weeks and grounded into powder using a grinding mill and subsequently subjected to sieve analysis to classify the powdered shell into sizes. Similarly, the dried cow bone was grounded into a fine powder using a conventional mill and equally subjected to sieve analysis. The fractions retained below the 100 μm , on 100 μm and 120 μm , were used [7] in the production of brake pad. Figures 3 and 4 shows the grounded PKS and cow bone respectively.



Fig-3. Grounded PKS



Fig-4. Grounded cow bone

3.2. Formulation of Brake Pad

Formulation of brake pad consists of a series of unit operations including mixing, cold and hot pressing, cooling, post-curing and finishing. The particle sizes of each of the samples were collected and graded, then 30% of different grade sizes of amount retained on 120, 100 and grading below 100 (-100%) was used in the production of the brake pad, with 60% epoxy resin and 10% hardener. The composition was properly mixed together for 20-30 minutes to achieve almost homogeneous mixture inside the injection moulding machine mixer, then it was sent into the mould and about 50g of the blend was discharged into each preform. The composite was then subjected to cold pressing. The preform pressure was varied between 0.40 MPa and 0.60 MPa for 2-4 seconds. The assembly was then subjected to hot pressing, which induced curing, at a pressure of 0.27 MPa and temperature at 200°C, with breathing at 30 and 45 second after one minute of pressing. The curing continued for another 10 minutes at 0.90 MPa. The product was then allowed to cool at room temperature. The product was subsequently baked in an electric oven at 200°C for 2 hours. The procedure was adopted for both PKS and cow bone samples.

3.3. Characterization of Formulated Brake Pad

(i) Density

The ASTM standard D792-00 specification was used to calculate the density of the composite specimens. A clean sample is weighed accurately in air using an electronic pocket scale model: EHA901, and then suspended in water. The weight of the sample when suspended in water was determined, and the volume of the sample was determined from the effect of displacement by water [8]

$$\text{Density} = \frac{\text{Mass}}{\text{Volume}} \quad 1$$

(ii) Impact Energy Determination

The impact energy tests of the reinforced polymer composites were carried out using Avery Denison impact testing machine. The machine has two-scales for reading the energy which are the Charpy and Izod scales. In these work, the charpy scale of the impact energy testing machine was used in taking the readings. Standard square impact test sample measuring 75 mm × 20 mm × 10 mm was used. Before the test sample was mounted on the machine, the pendulum was released to calibrate the machine. The charpy scale reading calibres were set at the highest readable value of 300 J. The test sample was then placed horizontally in a vice and the force require to break the bar was released by allowing the pendulum to swing. The energy absorbed was displayed on the dial gauge and recorded.

(iii) Hardness Value Determination (Rockwell Hardness Test).

The hardness test was carried out by using Avery Denison Rockwell hardness (model: 6407) machine using the M-scale in line with ASTM 785 specification. A 6.35 mm steel ball indenter was used with minor and major of load of 98N and 980N respectively. The sample has a

dimension of 30 mm x 20 mm x 10 mm. Before the test was carried out, the mating surface of the indenter, plunger rod and test samples were thoroughly cleaned to remove the dirt. The sample was placed on anvils, which act as support for the test sample. A minor load of 96.10N was applied to the sample in a controlled manner without including impact or vibration and zero datum position was established. Then the major load of 980.7N was applied. The reading was taken when the large pointer came to rest or had slowed appreciably and dwelled for up to 2 seconds. The load was then removed by returning the crank handle to the latched position and the hardness value read directly from the digital scale.

(iv) Water Absorption Test

The composite samples were dried in an oven to constant mass and immersed in distilled water at room temperature. The water absorption was determined by weighing the samples (W_a). The samples were immersed in water at room temperature for 24 hours. The sample was then removed, wiped with a tissue paper and weighed (W_b). At least three specimens for the sample were used. A digital electronic scale, model: EHA901 was used with a precision of 0.01g to weigh the samples. Then percentage of water (PWA) absorption was the determined

$$PWA = \frac{W_b - W_a}{W_a} \times 100\% \quad 2$$

Where W_a and W_b are original dry weight and wet weight after exposure respectively.

(v) Oil Absorption Test

The composite sample was dried in an oven and immersed in brake fluid (WEBBER Brake and Clutch fluid with SAEJ1703 and DOT 3 specification) at room temperature. The oil absorption was determined by weighing the sample (O_a). The sample was immersed in oil at room temperature for 24 hours and then removed, wiped with a tissue paper and weighed (O_b). At least three specimens for the sample were used. A digital electronic scale, model: EHA901 was used with a precision of 0.01g to weigh the samples. Then percentage of oil absorption, (POA) was determined.

$$POA = \frac{O_b - O_a}{O_a} \times 100\% \quad 3$$

Where O_a and O_b are original dry weight and wet weight after exposure respectively.

(vi) Thermal Examination (TGA)

Thermo-gravimetric analysis (TGA) which is the changes in weight of the friction composites with increasing temperature was used to evaluate the thermal integrity of the brake pads. The size of test specimen was 20 mm × 20 mm. Each sample was kept in a mild steel crucible and heated in a furnace from 100 - 500°C. The change in the sample's weight was monitored. At each observation when the set temperature was attained; a choke time of 10

minutes was allowed for even heat distribution into the sample. The weight losses at each observation were plotted against the temperature.

(vii) Coefficient of Friction

The friction coefficient of the composite on steel plate was determined on a horizontal plane apparatus (model 12558, Norwood Instrument Ltd). The composite was loaded with a load M_1 . A cord was attached and a weight hanger to the composite. The load of the weight hanger was gradually increased until the composite just slides at constant velocity. The load was recorded as M_2 and used to calculate the coefficient of friction. The load placed on the sample was varied to determine its possible effect on the friction coefficient, and the average was found and recorded as

$$\text{Coefficient of friction } (\theta_K) = \frac{M_2}{M_1} \quad 4$$

$$\text{Average coefficient of friction } (\theta_{KH}) = \frac{\theta_K}{n} \quad 5$$

Where θ_{KH} = Average coefficient of friction, M_1 = Weight that is been loaded of the polymer composite. M_2 = Weight that make the polymer composite to just want to slide, n = Number of coefficient of friction used.

(viii) Wear Test

The wear test was carried out by taking the different composition and model and placing each sample along the disc of an electronic grinding machine for 5 seconds. A grinding machine of model MD3215E was used. The sample weight was taken before and after grinding using a digital electronic scale model: EHA901. The weight different from each sample indicate the lost in weight. The speed of the grinding machine and its disc diameter are 2950 rpm and 150 mm respectively.

$$\text{Wear rate} = \frac{\Delta W}{S} = \frac{\Delta W}{2\pi ND \times t} \quad 6$$

where Δw = weight loss, S = sliding distance, D = diameter of disc, N = rpm, and t = time (the time it takes each sample exposed on the grinding machine).

(ix) Compressive Strength Test

The compressive test was performed by using a Brembate Sopra 24030 crushing machine. The test was conducted in accordance with ASTM D 3039-76 (2000) specification. The prepared sample of 75 x 20 x 10 mm was placed between the jaws of the machine. The machine reading was set at 0.00kg/cm², the machine was pumped and it continued to exert pressure on the sample till it just crushed or deformed the shape of the sample that was placed in it. Then, the readings at

which it crushed was taken on the scale. This procedure was repeated three times for each sample and recorded. The average of the readings was calculated and taken as our crushing strength.

4. RESULTS AND DISCUSSION

The products obtained using injection moulding machine mixer and subsequent procedure to reinforce polymer matrix with palm kernel shell and cow bone are shown in Figure 5 and 6.



Fig-5. Formulated brake pad from palm kernel shell reinforced polymer matrix composite



Fig-6. Formulated brake pad from cow bone reinforced polymer matrix composite

(i) Density

The density of the composites was calculated and the graph plot of the results is shown in Figure 7. From the graph, it is observed that as the particle size increases, the density decreases. This is probably because the smaller particle size occupies higher surface area. Also, cow bone composite is higher in density than that of PKS, and this might be due to higher mass of cow bone relative to PKS.

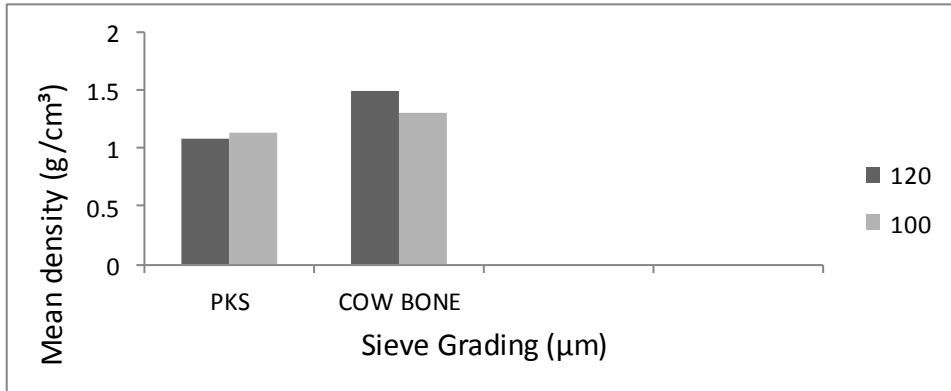


Fig-7. Effect of sieve size on mean density of brake pad formulated from PKS and cow bone composites

(ii) Impact Test

Figure 8 shows the charpy impact strength of the composites with the variation in the sieve size of PKS and cow bone. It is observed that the composite with higher sieve size presented a significant increase in impact strength when compared to composites with finer particle sizes. This graph further shows that cow bone has better impact strength compared to PKS. This fact can be related with a higher content of fibre and the poor dispersion and distribution of the particles in the matrix.

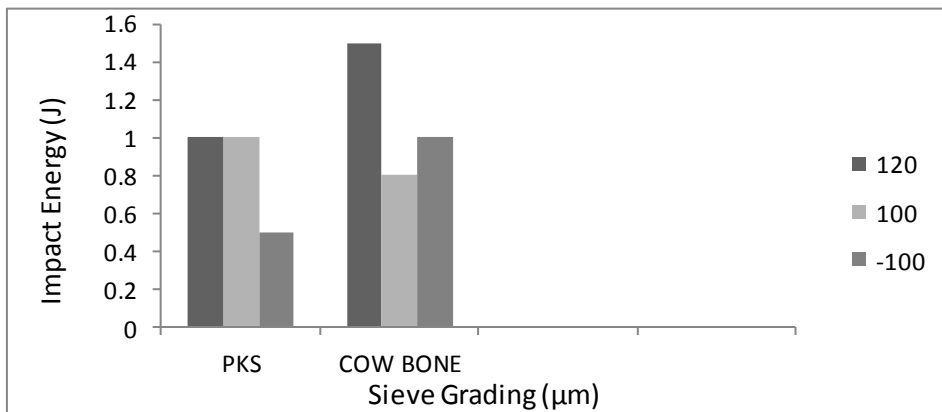


Fig-8. Effect of sieve size on impact energy of brake pad formulated from PKS and cow bone composites

(iii) Hardness Test (Rockwell)

Figure 9 shows that the hardness behaviour of the composites. It was noted that hardness was significantly affected by the sieve size. PKS gives a better hardness result than cow bone, probably due to the elemental composition of the PKS, and a closer packing together of PKS with resin and hardener than cow bone.

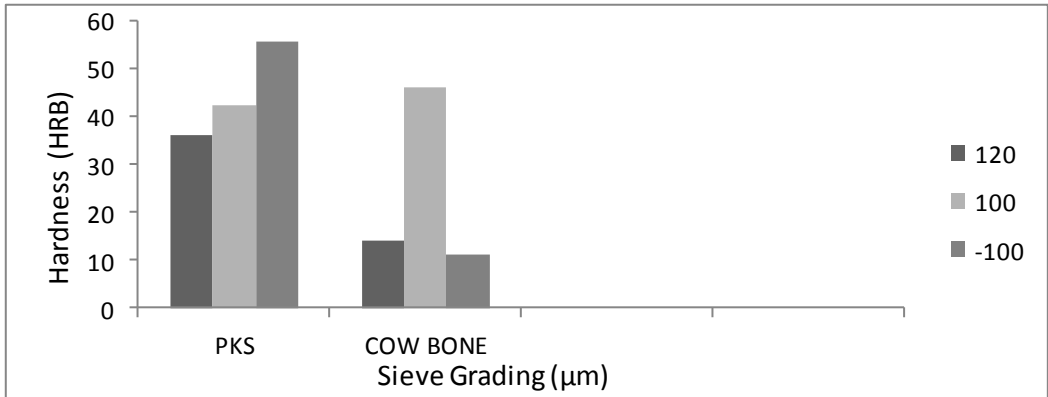


Fig-9. Effect of sieve size on hardness of brake pad formulated from PKS and cow bone composites

(iv) Water Absorption Test

Figure 10 shows that the amount of moisture in the composite decreases as the sieve grading decreases. The probable reason for the decrease in water absorption is due to the decrease in volume of pores created by the PKS and cow bone. Also, it was observed that PKS composition tends to absorb less water than cow bone composition under the same condition. This may be due to many particles and closer packing in PKS than in cow bone, which gives it a stronger binding and hence hardly allows water to pass through.

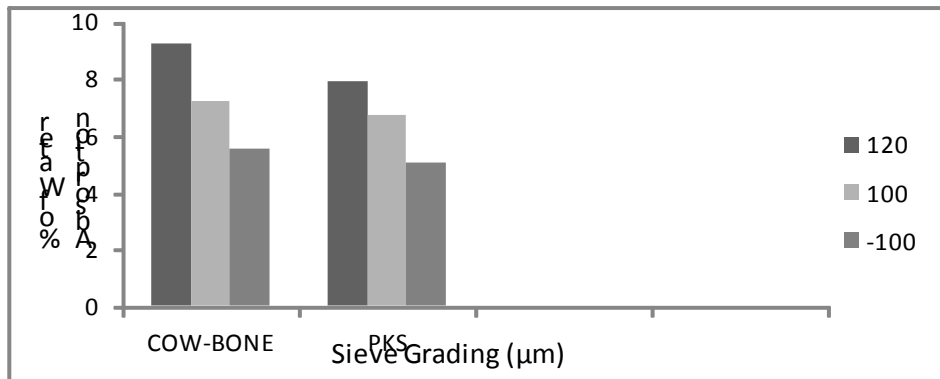


Fig-10. Effect of sieve size on water absorption of brake pad formulated from PKS and cow bone composites

(v) Oil Absorption Test

Figure 11 shows that the amount of oil absorbed by the composite decreases as the sieve grading decreases. The probable reason for the decrease in oil absorption is due to the decrease in volume of pores created by the PKS and cow bone. Also, it was noted that PKS composition tends to absorb less oil than cow bone composition under the same condition, probably because of much lesser pore hole than cow bone, which gives it a stronger binding and hence hardly allows fluid to pass through.

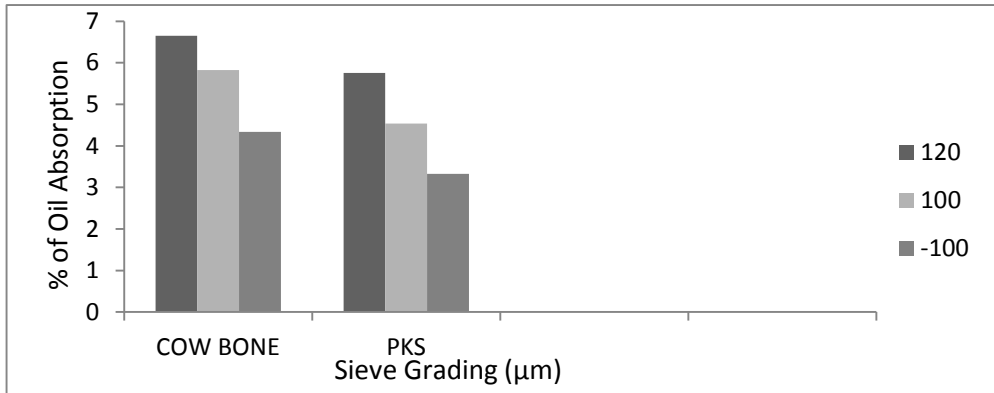


Fig-11. Effect of sieve size on oil absorption of brake pad formulated from PKS and cow bone composites

(vi) Thermal Gravimetric Analysis (TGA)

Figure 12 shows the thermal analysis of the composites. The weight loss was measured against the temperature. It is interesting to note that the percentage weight loss started to increase as the temperature increases in the range of 200-500°C. Also, the amounts of weight loss increases as the sieve size increases. Furthermore, the total percentage of weight loss by the cow bone is more than that of PKS. This is probably caused by the PKS smaller particle size. On the analysis of the results of the composites, it was observed that the total degradation of the composite took place in the temperature interval of 400 - 500°C. Brake pad temperatures are rarely subjected to temperatures larger than 389°C [9]. Therefore, it is believed that PKS and cow bone will not degenerate under practical application temperature and time duration.

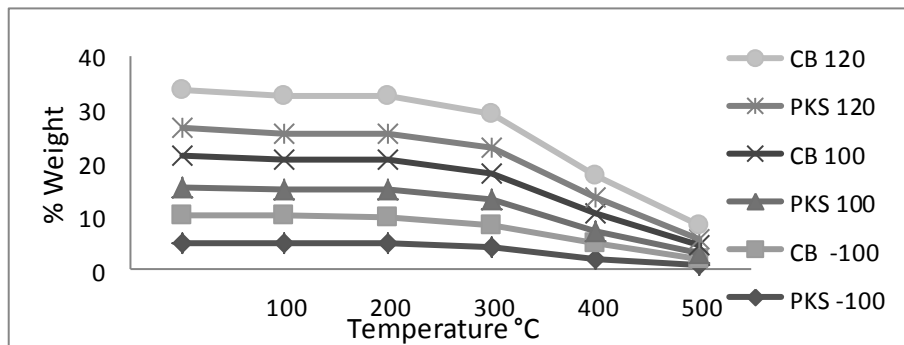


Fig-12. TGA curve for brake pad formulated from PKS and cow bone composites.

(vii) Coefficient of Friction Test

Figure 13 shows that the coefficient of friction of the composite. It was observed that as the sieve size decreases, the coefficient of friction value increases. Also, the PKS gives better coefficient of friction result than cow bone, probably due to the better bonding of the PKS particles and its smaller particle size which gives it a better grip than cow bone.

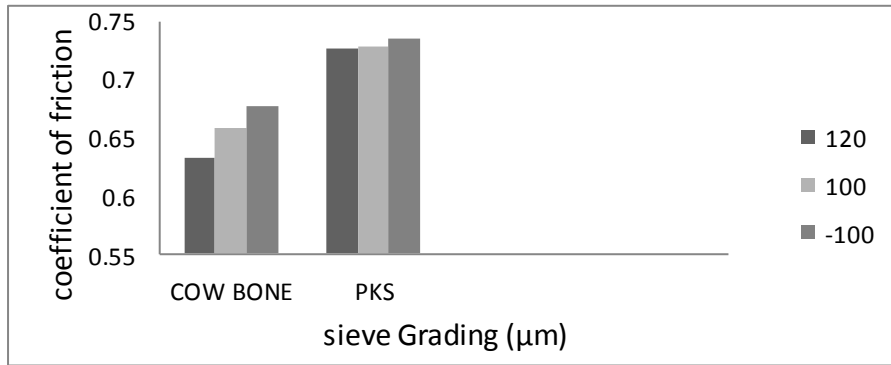


Fig-13. Effect of sieve size on coefficient of friction of brake pad formulated from PKS and cow bone composites

(iix) Wear Rate Test

Figure 14 shows the wear rate of the composites against sieve size and it was noted that as the sieve size decreases, the wear rate increases, which mean that the rate of wear is strongly affected by the sieve size. Also, it can be noted that PKS composite gives a lower wear rate than cow bone, probably due to the smaller particle size and better bonding. Moreover, the fact that PKS composite is much harder that cow bone is also a possible reason.

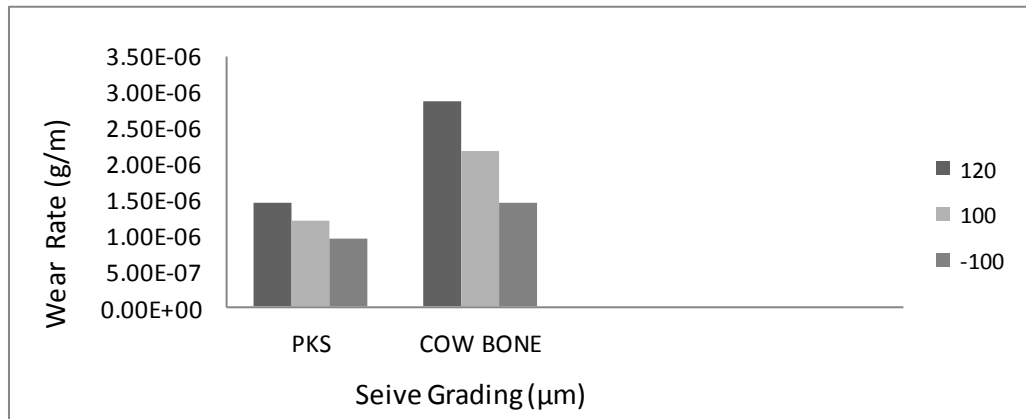


Fig-14 Effect of sieve size on wear rate of brake pad formulated from PKS and cow bone composites

(ix) Compressive Strength

Figure 15 shows that the compressive strength increases as the sieve size decreases. This probably is caused by better packing that occurs as the sieve size decreases, therefore causing a stronger bonding with epoxy resin and hardener. Also, it is noted that PKS tends to have a higher tensile strength than cow bone. This may be as a result of it smaller particles, better packing, stronger bonding and greater hardness of PKS than cow bone.

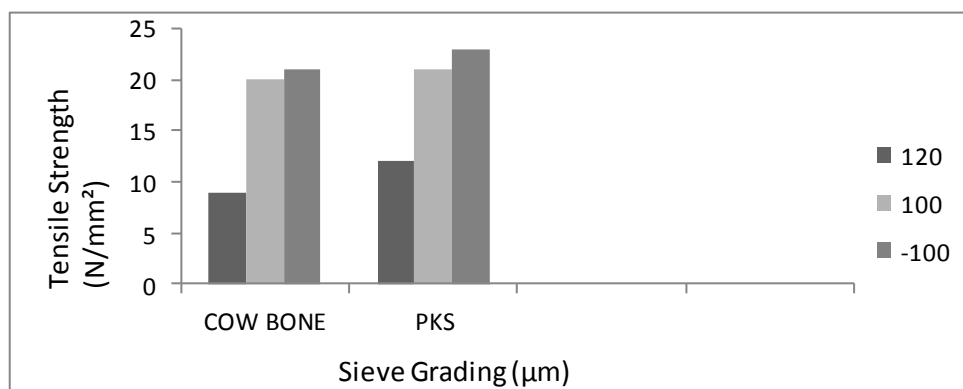


Fig-15. Effect of sieve size on compressive strength of brake pad formulated from PKS and cow bone composites

4.1. Comparison between Formulated and Existing Brake Pad

It is observed from the tests carried out on the formulated brake pad in this study that PKS and cow bone could be a possible replacement to asbestos as reinforced material. For instance, the recommended value of tensile strength ranges between 20 and 27 N/mm², but in this study the value of 23 and 21 N/mm² were obtained for brake pad produced from PKS and cow bone respectively [10]. The values of coefficient of friction for brake pad from PKS and cow bone are 0.73 and 0.677 respectively and this favourably compared with literature value of 0.3 to 0.6 [11]. The literature value of impact strength ranges from 0.0115 to 0.0154 J while in this study the values of 1.0 and 1.5 J were obtained for PKS and cow bone respectively. The wear rate obtained for brake pad produced using PKS and cow bone were 9.57 E - 7 g/m and 1.44 E-6 g/m respectively which is quiet in agreement with literature value of 1.85E -6 g/m [12, 13]. However, the hardness values obtained for PKS and cow bone in this study which are 55.7 and 46 HRB are quite in agreement with literature value of 54.8 HRB especially the PKS value [14]. The recommended values for oil and water absorptions are 0.3 and 0.9 % respectively while the values obtained for oil absorption were 2.23 and 4.16% for PKS and cow bone respectively. The values obtained for water absorption were 5.05 and 5.53% for PKS and cow bone respectively [15, 16].

5. CONCLUSIONS

Reinforced polymer composite of PKS and cow bone particles can be an alternative to asbestos based reinforced material in brake pad formulation. When combined properly with other additives the brake pad formulated from PKS and cow bone reinforced material were found to be thermally resilient enough not to decompose at braking temperatures and durations. The hardness values obtained for the PKS and cow bone compared favourably with the existing value. Further research should be conducted to improve the oil and water absorption properties of KPS and cow bone formulated brake pads.

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