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Characterisation of Asbestos-Free Brake Pad Using Elephant Grass (Pennisetum Purpureum)

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Abstract—Brake pads are essential components in braking system of automobile. Manufacture of brake pad first started with use of asbestos which has the best mechanical properties for frictional lining. However, asbestos has been confirmed to be carcinogenic, hence the need for suitable replacements. A new brake pad composition has been developed with the Elephant Grass (EG), Silicon Carbide (SC), Steel Slag (SS), Carbon Black (CB), Epoxy Resin and Hardener (ERH). Five different samples of varying constituents were made with three different sieve sizes for each sample investigated. The result showed that sample A of the 100 µm with composition 32 g of EG, 26 g of SC, 14 g of SS, 5 g of CB and 23 g of Epoxy resin and hardener had the best properties for which the Brinell Hardness Number (BHN), compressive strength, porosity, ash content, density and wear rate were 115 BHN, 3.99%, 46%, 228 MPa, 1.61 kg/m^3 and 3.20, respectively and which are acceptable. Therefore, this proves that elephant grass can be used as filler in the production of eco-friendly brake pads.

Keywords—Brake pad, Organic material, Elephant grass, Non-asbestos, Frictional lining.

1 Introduction

Brakes are indispensable components in all means of transportation. Their function is to slow down or stop a vehicle by friction, converting kinetic energy to heat energy which is dissipated thereafter. There are two main types of modern brakes which make use of the hydraulic braking system: the drum brake and disc brake. The disc brake is generally more efficient than the drum brake as reported by [1], and is widely used in different types of automobile. Some recent cars employ the use of disc brakes on all wheels while the use of drum brakes on the four wheels of a vehicle can only be found in very old models. The disc brake uses brake pads made of asbestos which has excellent mechanical properties including high strength, thermal stability, low wear rate and high hardness [2].

The disc brake assembly, unlike the drum brake, is exposed to the environment and produces tiny particles of the asbestos dust in surrounding air as the brake pads wear. Meanwhile, study has confirmed asbestos to be a carcinogenic material that causes cancer and lung diseases [3]. Therefore, some countries have banned use of asbestos while there are health concerns of both manufacturers and end users in countries where they are still in use [4].

Many researchers have developed asbestos-free brake pads from different agro-waste materials like rice straw and rice husk dust [5]; Bagasse [4]; periwinkle shell [6]; coconut shell [7]; palm kernel shell [8], [9]; banana peel powder [3]; pineapple leaf fibre [10]; maize husk [11]; fly ash [12]; egg shell [13]; pulverized cow hooves [14]; bamboo leaves [15] and sawdust [16]. These agro-waste materials required much processing before they can be used for the brake pad production. However, this present study will make use of a plant, an elephant grass (Pennisetum purpureum), that requires lesser processing for producing brake pad. The elephant grass has its origin from Africa and maturity period less than a month with ability to survive in adverse conditions and fixing atmospheric CO_2 [17]. The objective of this study is to investigate the properties of elephant grass composite brake pads.

2 Materials and Methods

2.1 Materials and Equipment

The material and equipment used were ball milling machine; sieves (75 µm, 100 µm and 150 µm); digital weighing scale; jaw crusher; electric heater (220/240 V); hydraulic press (maximum of 100 kN/mm^2 capacity); mixing pan and spatula; Avery Denison strength - 500 kN capacity for compressive strength test; Frank Welltest Brinell Hardness tester; Radicon MD10.00UM with automated powder diffractometer; and Pin on disk machine. Other materials include silicon carbide (Fig. 1) as abrasive, carbon black (Fig. 2) as lubricant, epoxy resin and hardener (Fig. 3) as binder and Steel slag (Fig. 4) as the reinforcing material.

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Fig. 1. Silicon Carbide

Fig. 2. Carbon Black

Fig. 3. Epoxy resin and hardener

Fig. 4. Steel slag

2.2 Method

The base raw material (elephant grass) was collected, cleaned to remove impurities and properly sun-dried on screened surface (Fig. 5). It was then crushed to make milling faster and ground into powder using the ball milling machine. The resulting powder was sieved into grades of 75 µm, 100 µm and 150 µm which are to be investigated (Fig. 6). Other constituents chosen were also appropriately labelled.

Fig. 5. Dried elephant grass

Fig. 6. Milled elephant grass being Sieved

The formulation quantities expressed in percentage weight were measured into mixing vessel and thoroughly mixed for about 15 minutes to ensure homogeneity. The desired amount of epoxy resin was thereafter poured into a separate container with the required quantity of hardener added in the ratio 2:1 to form the matrix and thoroughly stirred for about 5 minutes to obtain uniform mixture. Next, the matrix mixture was poured onto the powdered friction material mixture and stirred further to obtain a paste-like homogenous mixture. This mixture was transferred into a designed mould previously oiled for easy removal of the sample. The mould containing the friction materials was cold pressed with the hydraulic press after which it was left for 24 hours to dry and harden. After removing from the mould, the sample was cured in an oven for 8 hours at 120^{o}C. Five composites were developed as illustrated in Table 1. Fifteen samples were investigated for each test.

Table 1. Composition of each Samples of brake pads produced in weight percentage (wt%)

	Materials	Sample A	Sample B	Sample C	Sample D	Sample E
Filler	Elephant grass powder	32	37	42	47	52
Abrasive	Silicon Carbide	26	21	16	11	6
Reinforcement	Steel slag	14	14	14	14	14
Lubricant	Carbon Black	5	5	5	5	5
Binder	Epoxy resin and hardener	23	23	23	23	23

2.3 Experimental Procedures

2.3.1 Brinell Hardness Test

The Brinell hardness values of the samples A to E in triplicate were obtained using a hardness tester. The Brinell Hardness Number (BHN) of each of the samples was calculated using Equation (1).

$$BHN = \frac{2P}{\pi D(D\sqrt{D^2 - d^2})} \quad (1)$$

where

P =Applied force, N
D=Diameter of indenter, mm
d =Diameter of indentation, mm

2.3.2 Compressive Strength Test

The compressive strength test was carried out using Hounsfield tensometer. The loads at which each failure occurred was recorded while both the tensile stress and strain at this point was calculated using Equation (2).

$$\sigma_e = \frac{F}{A_o} \quad (2)$$

where

σ_e =Tensile Strength, N/mm^2
F =Applied force, N
A_o=Cross-sectional area of sample, mm^2

2.3.3 Porosity test

The samples for each composition were weighed to the nearest milligram (mg) and soaked in a water between 90-100^{o}C for 8 hours. The samples were left for 24 hours. Finally, the test samples were weighed again to the nearest mg. Equation (3) was be used to determine its porosity.

$$P_o = \frac{M_2 - M_1}{\rho_o} \times \frac{100}{V} \quad (3)$$

where

P_o= Porosity

ρ_o =Density of test oil and water, g/cm^3

M_2 =Mass of test piece after absorbing water, g

M_1 =Massof test piece, g

V =Volume of test piece, cm^3

2.3.4 Ash content test

About 1.20 g ± 0.1 g of the samples were weighed in a cooled crucible previously oven dried by heating in a furnace at 55°C for 1 hour. After the time, the samples were charred by heating in a hot plate and taken into the furnace and heat at 55°C for 1 hour. They were then cooled in a desiccator and weighed. The processing of heating, cooling and reweighing were repeated until a constant weight was obtained. Percentage of ash (%ash) was calculated using Equation (4).

$$\%ash = \frac{W_2 - W_0}{W_1 - W_0} \times 100 \quad (4)$$

where

W_0 = Weight of empty crucible, g

W_1 = Weight of crucible plus sample, g

W_2 = Weight of crucible and residue after cooling, g

2.3.5 Density test

The true density of the samples was determined by obtaining sample masses and volume on a digital weighing machine and by liquid displacement method, respectively and using Equation (5).

$$\rho = \frac{m}{V} \times 100 \quad (5)$$

where

ρ = True density of the samples, g/cm^3

m=Mass of test piece, g

V=Measuring volume of test piece, cm^3

3.6 Wear rate test

The wear rate for the samples was measured using pin on disc machine by sliding it over a cast iron surface at a load of 10 N and 20 N, sliding speed of 125 rev/min and sliding distance of 2000 m. All tests were conducted at room temperature. The initial weight of the samples was measured using a single pan electronic weighing machine with an accuracy of 0.01 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 was 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 gave the wear of the samples. The wear rate is calculated using Equation (6).

$$WR = \frac{s}{\Delta w} \quad (6)$$

where

WR=Wear rate of samples, m/mg

Δw=Weight difference of the sample before and after the test, mg

s = Total sliding distance, m

3 Results and Discussion

3.1 Brinell Hardness Test

The hardness values increased as the sieve grade decreases from 150 µm to 75 µm for each sample, respectively (Fig. 7). Hence, the samples with the 75 µm had the highest hardness value ranging from 108.5-115.0 BHN for samples A to E. It was also observed for each sieve size, hardness value decreased from samples A to E indicating a reduction in hardness as more elephant grass was added. The high hardness values for the 75 µm sieve grade can be attributed to the reduced particle size of the elephant grass which allowed the surface area to increase, giving room for more compactness and also allowed for the increased binding ability with the resin. The average hardness obtained from the hardness test for this material, 110.5 BHN was then compared with that of standard brake pad (101.0 BHN) and was found acceptable.

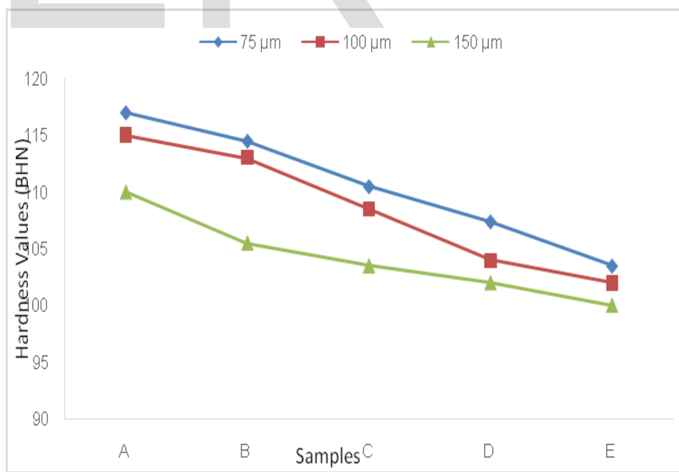

Fig. 7. Variation of hardness with sieve grades

3.2 Compressive Strength Test

As shown in Fig. 8, the 75 µm sieve grade samples had higher compressive strengths of 225.0-241.0 MPa for samples A to E while the samples of 100 µm and 150 µm gave values between 220.0-228.0 MPa and 222.2-227.0 MPa, respectively. It can be observed that as the sieve size increases, the compressive strength decreases which is a similar pattern as the hardness values. This can be attributed to the fact that the surface area and pore packaging capability of the filler in the resin are decreasing with increasing particle size. It can also be seen

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that with increase in the amount of EG from samples A to E, the compressive strength varied for sieve sizes 75 µm and 100 µm but non-uniformly. For both sieve sizes, there was a gradual decrease in compressive strength from samples A-C while a spike was noticed in sample D with a sharp decrease in sample E. The values for sieve grade 150 µm, however, was found to decrease uniformly from sample A-E.

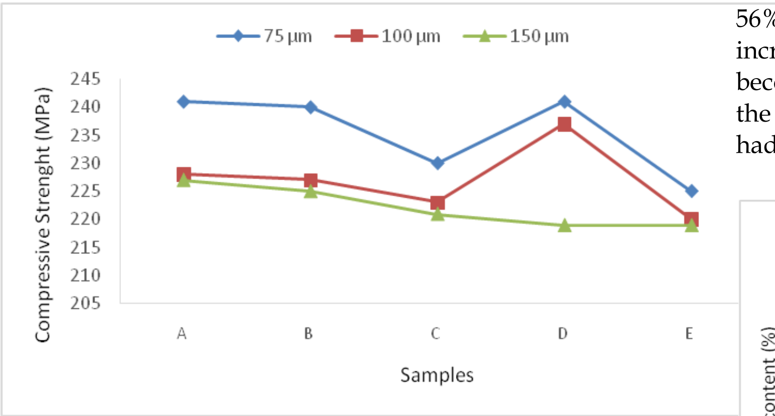

Fig. 8. Variation of compressive strength with sieve grades

3.3 Porosity Test

The variation of the porosity of the produced samples was found to increase as the sieve grade increased (Fig. 9). This can be attributed to an increase in the number and size of pores in the samples as the sieve grade increases hence the ability of more water molecules to seep. It can also be observed that the samples of the 75 µm sieve grade gave the best results of 3.02-3.44% in water for samples A to E while the samples with 100 µm and 150 µm gave values between 3.99-5.01% and 4.22-6.25% in water, respectively. It can also be noted that for all sieve grades, porosity of the samples increased from A to E as more EG were added indicating that the harder the sample, the lesser the porosity. A sharp increase occurred, however, for sample E which has the highest percentage of EG. This can be attributed to the organic and hydrophilic nature of the filler material.

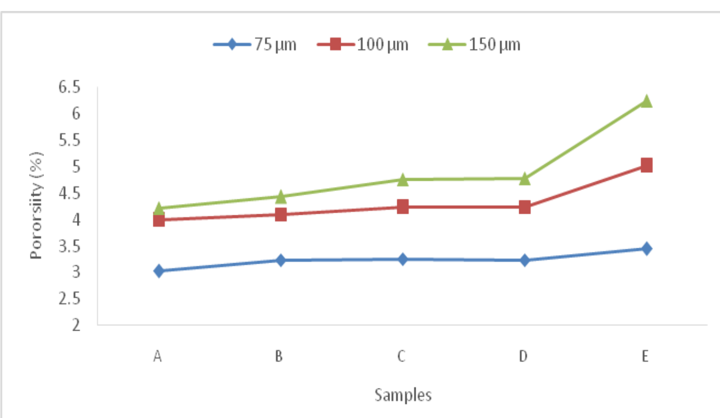

Fig. 9. Variation of porosity with sieve grades

3.4 Ash content

The ash content of the produced samples decreases as the sieve grade increases for each sample (Fig. 10). This can be as a result of an increase in the density of the samples as the sieve grade becomes smaller and increase in pore spaces as the particle size increases. For each sieve grade on the other hand, the ash content varied non-uniformly. The 75 µm sieve grade samples gave the results between 50-62% for samples A to E while the samples with 100 µm and 150 µm gave values of 46-56% and 45-55, respectively. This can be attributed to an increase in the density of the samples as the sieve grade becomes smaller. This ash content was comparable to that of the commercially available brake pad which when charred, had 54% ash content.

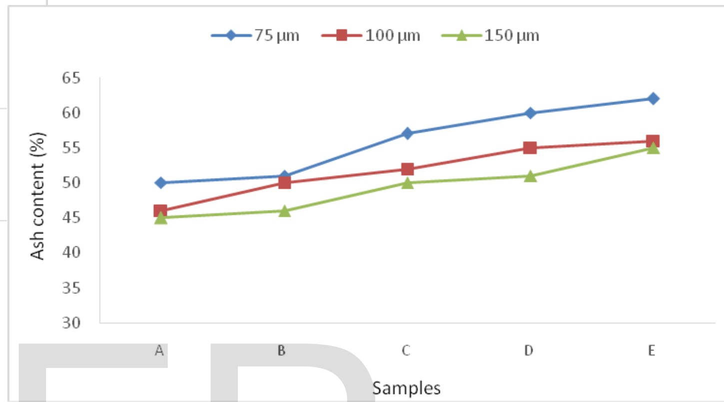

Fig. 10. Variation of ash content with samples

3.5 Density Test

As presented in Fig. 11, it can be seen that the density increases as the sieve grade decreases from 150 µm to 75 µm for each sample respectively. The increase was due to increased packing of filler particle that formed better homogeneity in composite brake pads. The high density for the 75 µm sieve grade can be attributed to the closer packing of EG particles creating more homogeneity in the entire phase of the composite body in agreement with the findings of [4], [18]. It is also observable that for each sieve size, density decreased from samples A to E indicating a reduction in density as more EG is added since the EG has relatively lower density when compared to other constituents of the sample.

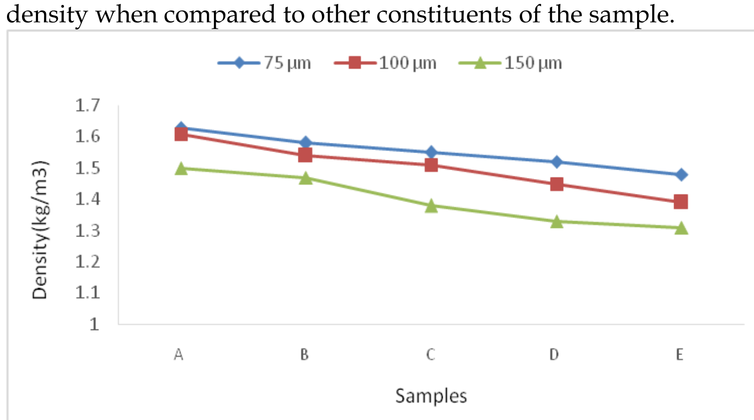

Fig. 11. Variation of density with samples

3.6 Wear rate

The variation of the wear rates of the samples tested is shown in Fig. 12. It can be seen that the wear rate varied non-uniformly as the 75 µm had an average wear rate of 4.00 but decreased to 3.48 but later increased to 4.40 as we move to 150 µm. This is due to the fact that a fine sieve grade such as the 100 µm grade results in better binding of the composite as there are less pores. However, when the grade becomes too fine such as the 75 µm, the abrasiveness of the material reduces and this leads to a high wear rate. It is also observable that as the percentage composition of elephant grass increases for each sieve grade, the wear rate increased. This is in agreement with [10], [19]. This observation suggested the trend of wear rate occurred due to increase in the organic filler as we move from samples A to E, resulting in a lower interfacial bonding. It can also be seen from Table 2 that the average wear rates of the 75 µm, 100 µm and 150 µm sieve grade samples are 4.00×10^{-2}, 3.48×10^{-2} and 4.40×10^{-2} g/km respectively, the values are relatively higher but compare favourably with that of the commercially available brake pads. The comparison of present study with results in literature shows that is elephant grass is best alternative material to asbestos.

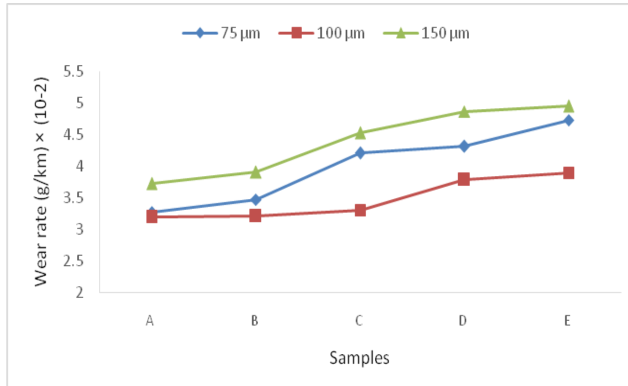

Fig. 12. Variation of wear rate with samples

Table 2. Summary of result findings compared with existing ones

	Asbestos	Palm Kernel shell (PKS)	Bagasse	Egg shell	Periwinkle	PKS+Coconut shell+Maize husk	Elephant grass (present study)
Swell in H_2O (%)	0.9	5.03	3.48	3.21	0.39	0.91	3.02
Compressive Stress (MPa)	110	103.5	105.6	103	147	103.7	228
Hardness (BHN)	101	92	100.5	99.1	116.7	127.8	115
Wear rate (g/km) ($\times10^{-2}$)	3.8	4.4	4.2	4.0	-	2.146	3.99
Density (kg/m^3)	1.32	1.46	-	-	-	0.251-0.372	1.61
Flame resistance test after 10 minutes	Charred with 54% ash	Charred with 46%	Charred with 34% ash	-	-	-	Charred with 46% ash

4 CONCLUSIONS

A new asbestos-free brake pad composite has been developed and sample A of the 100 µm sieve grade of elephant grass was chosen as the best composite because all its properties compared favourably with that of the commercially available brake pad and it gave better results in terms of wear rate when compared to other sieve grades. Based on the test results of these brake pads composite, elephant grass can be used as a filler or organic replacement for asbestos because the derived properties are within the range of the standard commercial brake pads and literature values.

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