DEVELOPMENT AND EVALUATION OF ASBESTOS-FREE BRAKE PADS PRODUCED FROM COSTUS AFER WASTE AND LOCAL GUM ARABIC

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ABSTRACT: *This study dealt with the development and evaluation of a new asbestos-free non-carcinogenic brake pads with Costus afer waste particle as the base material. Three sets of brake pads with different sieve sizes (90, 100 and 200 μm) were developed, through compression molding from a 55% Costus afer waste particles, 22% local gum Arabic as binder, 5% of rubber seed husk and 5% of walnut shell as fillers, 10% iron filling as frictional addictive, 1% of carbon black as friction modifier, 1% of cobalt nepthanate as catalyst and 1% of Methyl ethyl ketone as accelerator. Physico-mechanical test was carried out on the Costus afer waste-based brake pad with a Brinell hardness test value of 103HB, Compressive strength of 115Mpa and density of 1.3 g/cm^3 which is far better than the commercially available brake pad upon comparison. These properties were found to increase with a decrease in particle sizes while the water absorption (1.2%), oil absorption (0.55%), wear rate(1.8mg/m), and flame resistance (Charred with 20% ash) increased with increasing particle sizes due to enhanced porosity. The Coefficient of friction is approximately 0.3 μm which is within the acceptable standard and the element analysis based on Energy-Dispersive X-Ray Fluorescence for the developed Brake pad was carried out. The developed Costus afer waste-based brake pad especially with the grain size of 90μm, shows a better wear performance and other properties as compared to the control commercial brake pad. The study can conclude therefore that the Costus afer waste-based brake pad stands as a better replacement for the existing commercial asbestos-based brake pads.*

KEYWORDS : *Non-Carcinogenic Brake Pads; Costus Afer Waste; Compression Molding; Grain Size; Bush Cane*

1.0 INTRODUCTION

In recent times, several research efforts in the automobile industry are being channeled to the production of organic brake pads to replace the currently used Asbestos-based brake pads that has been found to contain several negative components that affects human health and the environment. Asbestos, which has some good engineering properties (e.g., quality strength, wear, and heat resistance) that has made them very suitable for inclusion in brake liners and as filler material up till 1989 [1], are being withdrawn gradually from almost all its applications where there is possibility of man consuming or inhaling its dust, due to its carcinogenic nature.

To mitigate the health risk associated with the use of asbestos material for brake pad design, it is necessary therefore, to use ecofriendly materials or organic materials for their development. Among the ecofriendly materials that has found application in literature include cashew nut shells and palm kernel shells (PKS) [2], Coal ash and palm kernel fiber [3], banana peels [4], coconut shells [5], snail shell [6], periwinkle shell [7], Canarium sweinfurthii shell [8], cocoa beans shell and maize husk [9], hazelnut powder

[10], sawdust [11], sugar cane bagasse [12], palm kernel shell and cow bone [13], palm ash [14], Bamboo fiber [15], Walnut shell powder [16], Coconut shell powder and palm kernel shell [17], Miscanthus [18] , Recycled clay tiles [19], Groundnut shell [20], and Kenaf fiber [21].

In other application of ecofriendly and organic materials for brake pad design and development, Ossia and Big-Alabo, [24] investigated the development and characterization of green brake pads using waste shells of giant African snails (Achatina Achatina L) and resin. Their result showed that an increase in the sample particle size leads to a decrease in density, Brinell hardness, and compressive strength of the snail shell (SS) brake pads. This followed a negative index power-law model after the order of the Hall-Petch equation, whereas the absorption features increased with an increase in particle size, and the model followed a positive index power law because of the pores in the matrix. Their result also shows that the snail shell-based brake pad has a better frictional grip at the rubbing interfaces than the commercial brake pad sample. Also, the density, Brinell hardness, and compressive strength of the snail shell brake pad were better or superior to the commercial sample used while the wear rates of the commercial brake pad were superior to that of the developed brake pad, and they suggested that, the result can be improved by adding more iron fillings to improve the thermal conductivity and the wear features. Resins which is very toxic was used by the author for the brake pad design and has been utilized by several researchers as binders in the development of brake pads with either organic waste [2,6,10-11,22-24] or inorganic waste [25]. Hence, in this paper the authors seek to replace the toxic resins binder with a new ecofriendly and easily available material and to address the wear performance issues. A locally sourced material, Gum Arabic has been proposed as a replacement for the resins, while costus afer waste as a replacement for the asbestos material. The remaining part of the paper is organized as follows, in section 2, the methodology used in the design and development of the brake pad is presented. This is followed closely by the results and discussion in Section 3, while some concluding remarks are presented in Section 4.

2.0 METHODOLOGY

2.1 Materials

The reinforcing fibers or base material for the brake pads development is Costus afer waste (Bush cane) sourced from Obingwa in Osisioma Ngwa Local Government Area of Abia State, Nigeria. Figure1, shows a typical picture of Costus afer leaf and Costus afer waste. The following components were used in formulating the CAW-brake pads matrix; Costus afer waste (Fiber) as the base material (55%), Rubber seed husk and walnut shell (Fillers, 5% each), Local Gum Arabic as Binder (22%), Iron Filling as Frictional addictive (10%), Carbon Black as Friction Modifier (1%), Cobalt Nepthanate as Catalyst (1%) and Methyl ethyl ketone as Accelerator (1%). Other components and equipment used include the following: SAE 40 Oil (Engine oil), distilled water, brake pad mold fabricated from carbon steel plate (grade: A36), Vernier caliper, weighing balance, hardness tester, crushing machine, sieves of different sizes, milling machine, electric oven, universal wear machine and compression machine.

Figure 1: Diagram of (a) Costus afer leaf, (a) Costus afer Waste and (c) Grounded Costus afer waste

2.2 Methods

The method adopted in the development of this CAW brake pad and its performance evaluation is similar to the one presented by Ossia and Alabo, [6], where they develop an asbestos-free and non-carcinogenic brake pads from waste shells of giant African snails. In this paper however, a different set of material types has been used. The materials and their composition are discussed in Table 1, while the steps required for development and production of the brake pad are presented in Figure 2.

Table 1: Material Compositions

ITEM	MATERIAL	COMPOSITION (wt%)
1	Costus afer waste (Fiber)	55.0
2	Rubber seed husk (Filler)	5.0
3	Walnut shell (Filler)	5.0
4	Local Gum Arabic (Binder)	22.0
5	Iron Filling (Frictional addictive)	10.0
6	Carbon Black (Friction Modifier)	1.0
7	Cobalt Nepthanate (Catalyst)	1.0
8	Methyl ethyl ketone (Accelerator)	1.0

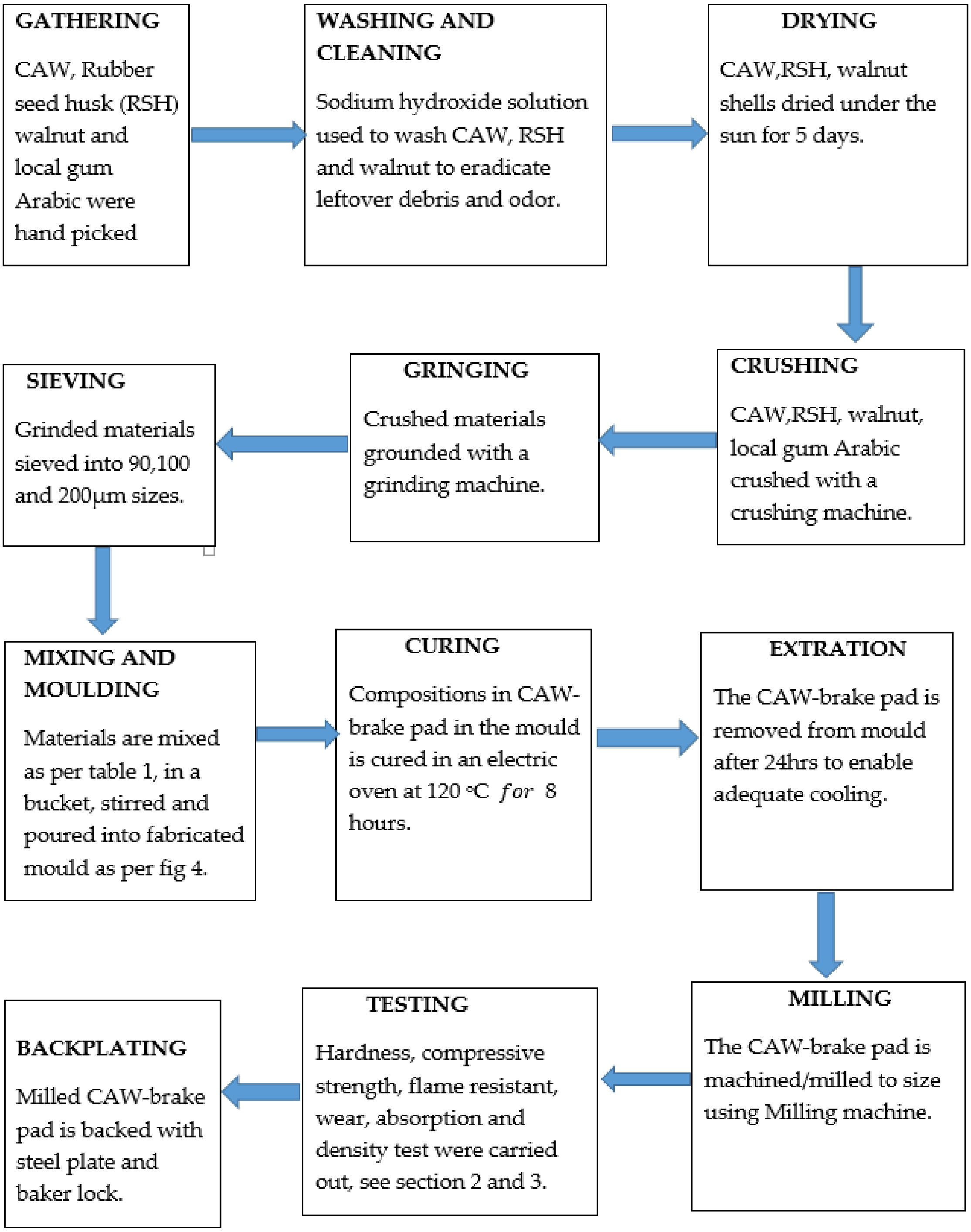

Figure 2: The process of development of the CAW –brake pad.

2.3 Performance Evaluation

In the testing and evaluation of the feasibility and usability of the newly developed CAW-brake pad, the following physico-mechanical test has been carried out for its performance evaluation.

2.3.1 Absorption Test

The water and oil absorption test helps to determine the effect of the absorbed water and oil in its dimensions. The specimen is oven-dried at 25 °C for 3 hours and its initial weight is measured by weighing balance. Subsequently, the dimensions (thickness) of the specimen were measured using a Vernier caliper, after twenty-four hours of submersion in water and engine oil (SEA 40) at 30°C the specimen was weighed after the excess water and oil had drained off. The percentage absorption of CAW-brake pad samples in oil and water was determined using equation (1) [22].

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

where W_f is the weight of the sample after immersion into a given absorbent media, and W_b is the weight of the sample before immersion into a given absorbent media.

2.3.2 Density test

The density measurement on the CAW-brake pad sample was carried out using Archimedes principles as per equation (2). The buoyant force on a submerged object is equal to the weight of the fluid displaced. This principle is useful for determining the volume and therefore the density of an irregularly shaped object by measuring its mass in air and its effective mass when submerged in water. This effective mass underwater was its actual mass minus the mass of the fluid displaced. The difference between the real and the effective mass, therefore, gives the mass of water displaced and allows the calculation of the volume of the irregular-shaped object. The mass divided by the volume thus gives a measure of the average density of the sample. Hence, determining the density of the CAW-brake pad samples [26].

$$\text{Density } (\varrho) = \frac{\text{Mass(m)}}{\text{Volume (v)}} = \frac{M_0}{M_0 - M_1}\ \text{g/cm}^3 \tag{2}$$

where M_0 is the mass of sample in air, and M_1 is the mass of the sample in water. Other test types carried out on the newly developed brake pad include, hardness test, (as per ASTM E10) compressive strength test (as per BS EN 12390 Part 9), wear test (as per ASTM G99 and SAE 1661.), flame resistance test and energy-dispersive X-ray fluorescence (EDXRF) test.

3.0 RESULTS AND DISCUSSION

As stated above, the physico-mechanical test carried out for the performance evaluation of the newly developed CAW-based brake pad include, oil and water absorption test, density test, and mechanical property test that include Brinell hardness test, compressive strength, flame resistant test, and wear test. These performance evaluation tests have been discussed and compared with existing brake pad in this section.

Results from the water and oil absorption test for the CAW-based brake pad shows that the brake pad samples increased with an increasing grain size and vice versa, this results which are compare with sample from a commercial brake pad (CBP) in the market are shown in Figure 3. This can be attributed to the increase in pores as the sieve size increases. Furthermore, the improved bonding between the smaller grain (90µm) sizes and the binder could be responsible for this. For the oil absorption test for the CAW-based brake pad, the samples results can be attributed to improved bonding between the smaller grain size and the binder. The sample size- 90µm showed a better property and will do better where there is oil leakage from the hydraulic system. These results are in agreement with the findings of earlier researchers as shown in Ibahadode and Dagwa, Yawas et al., Akincioglu et al. and Aigbodion et al work [2, 7, 10 and 12]. For instance, Yawas et al. [7] studied the microstructures of brake pads made of periwinkle shell show that the surface morphology of the brake pad became increasingly homogenous with the decrease in the sieve sizes of periwinkle. This further explains the increase in the pores as the Costus afer particle sizes increases. This means that as the sieve size increases, this will lead to increase in the grain size of the Costus afar particles and this increases the pores. The increase in porosity with grain size causes the absorption to increase. Also the interfacial bonding between Costus afer particles and the binder also affects the porosity of the samples, proper bonding will be achieved when decreasing the sieve size from 200 to 90 µm.

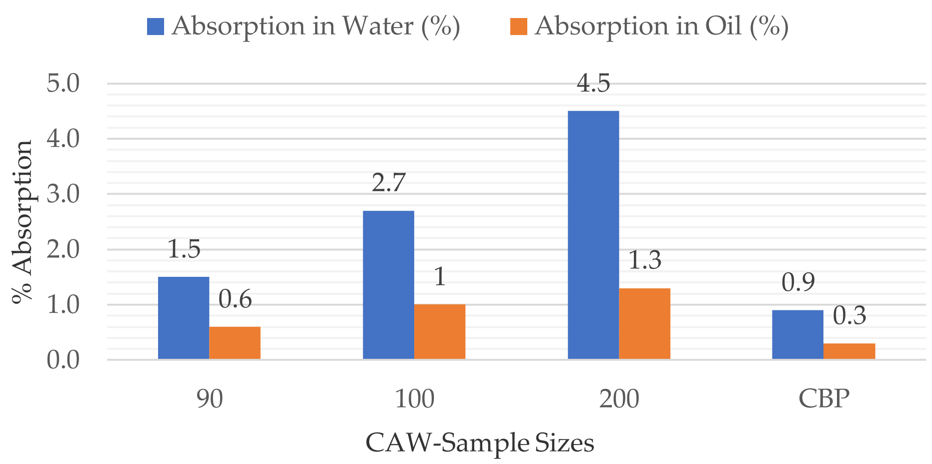

Figure 3: Comparison of water and oil absorption of the brake pads produced with varying sample sizes of the Costus afer waste with CBP.

Results from the density test for the CAW-based brake pad samples shows that the samples progressively increased with decreasing particle size of the CAW from 200 µm to 90 µm and this have been shown in Figure 4. The decrease in density can be attributed to the increase in pore size due to increased particle size. The least sample size- 90 µm has the highest density (1.3 g/cm^3) which is due to close packing of CAW particle with binder and other filler materials creating more homogeneity in the entire phase of the composite body. Other researchers had earlier reported similar results [6-7, 12]. Conversely, the study by Olabisi et al. [29] reported an irregular change in brake pad density of based-brake pad with increase in the percentages of base materials (cocoa bean shell, maize husk and palm kernel shell).

According to Edokpia et al. [26] the increase in the density of brake pad is as a result of the increased packing of the filler particles forming more homogeneity in the entire phase of the brake pad composite body. In this regard, a certain composition of the composite will give the blend with the most acceptable density, but this can only be achieved by optimization of the constitutes. However, the densities of all CAW-based brake pad samples were lower than the commercial brake pad (CBP) density (1.89 g/cm^3), this makes the CAW-based brake pad lighter and contributes to mass reduction of the automotive braking assembly.

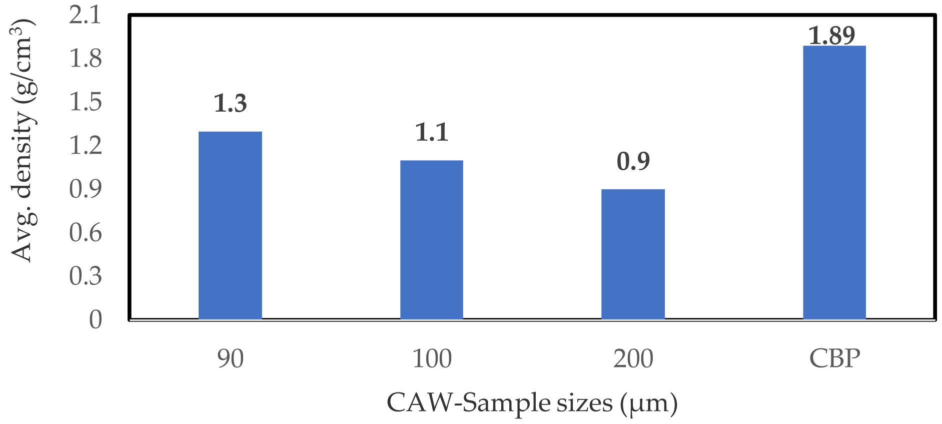

Figure 4: Comparison of density of brake pads produced with varying sample sizes of the Costus afer waste with CBP.

The hardness test value of the CAW-based sample brake pad varies with increase in grain size as shown in Figure 5. The 90 μm sample which has the highest hardness value with 103 HB, is higher than the hardness test value of the CBP sample which is 101 HB, as well as that of palm kernel shell which is 92 HB and bagasse which is 100.5 HB [12]. However, it is less than the value obtained by Yawas et al., [7] for periwinkles shell-based brake pad which is 116.7 HB, the hardness value however is decreases sharply with an increase in the grain size.

The hardness value increase of the CAW-based sample brake pad with the 90 μm sample was as a result of increase in surface area of the CAW-particles which is due to increase in its bonding ability with the binder. The hardness value compares reasonably with results from previous studies presented in Yawas et al., Aigbodion et al. and Ossia et al. work [7, 12, 24].

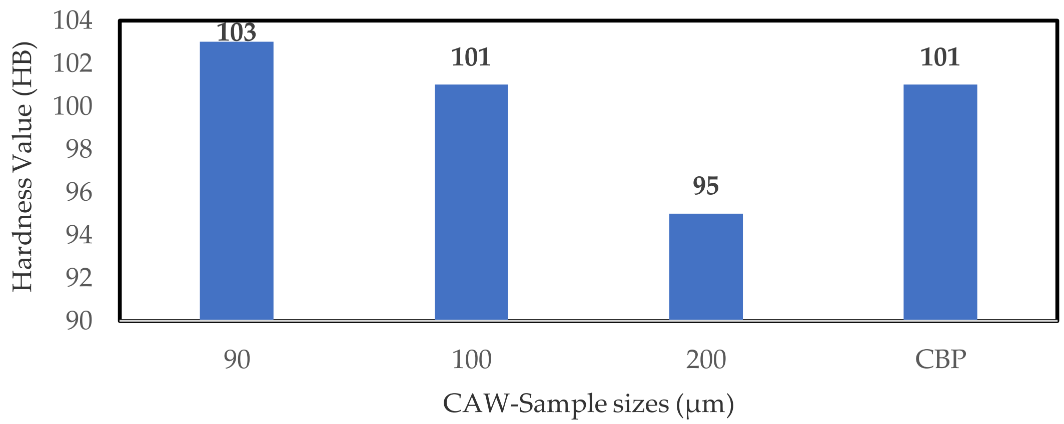

Figure 5: Comparison of hardness value of various sample sizes of the Costus afer waste particles- based brake pads with CBP.

Results for the compressive strength test increases with decrease in the CAW-sample grain size as shown in Figure 6. The CAW-sample size of 90 µm had the highest compressive strength of 115 MPa which was greater than that of the control commercial brake pad (110 MPa). The decrease in compressive strength of the CAW-samples as the grain sizes increases can be attributed to decrease in surface area of the CAW particles in the binder. Therefore, the compressive strength of the CAW-brake pad samples increases as the CAW- particles decreases. Similar result was obtained by Olabisi et al. [29], here, they noted that increase in the percentage by weight of the epoxy resin decreased the compressive strength of the brake pad. Their study opined that the decrease in the compressive strength of the brake pad was as result of interference of particle mobility or deformability of the matrix. This interference according to Ademoh and Olabisi. [9] and Adeyemi et al. [27] was created through the physical interaction and immobilization of the binder by the presence of mechanical restraints, thereby reducing the strength of the brake pad. Brakes are exposed to continuous compressive force during braking and this result shows that sample size 90 µm will do well under such condition. This result agrees with other researchers [7,12,24] finding using different materials.

Results of the wear test shows that, there are decrease in wear rate as the CAW-based brake pad sample grain size decreases and this is shown in Figure 7. The sample size with 200 µm has been found to have the highest wear rate with 6.47 mg/m, while the sample size with 90 µm has least rate with 1.8 mg/m. These wear rate however are far better as compared to the control CBP that is 3.8 mg/m. This could be attributed however, to the closer packing which has the chances of influencing a stronger bonding of the CAW-particles with the binder and other components. This may also be due to the high values of both the hardness number and compressive strength [1]. The Frictional coefficient were determined from the wear test carried out. Figure 8 shows the frictional coefficient of the CAW-samples which increases with an increasing CAW-particle sizes. These results corroborate with findings from other researchers as shown in Lawal et al. and Aigbodion et al. work [11-12].

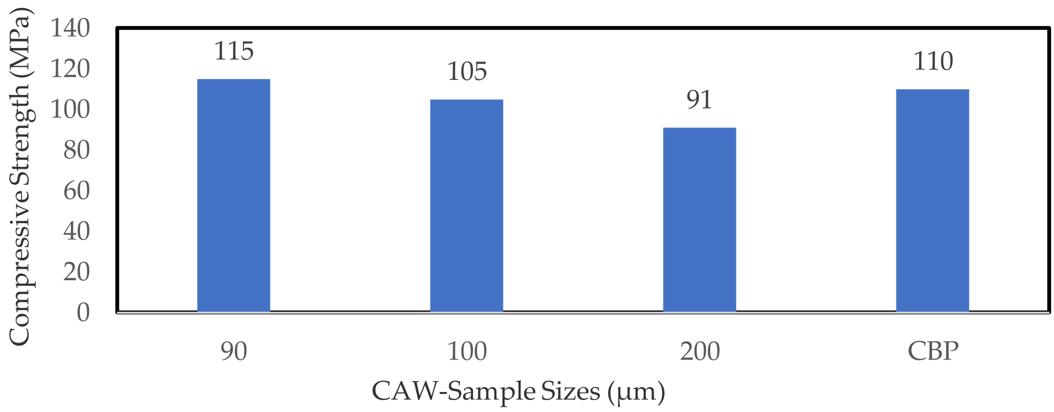

Figure 6: Comparison of the compressive strength of brake pad produced varying sizes of Costus afer waste with CBP.

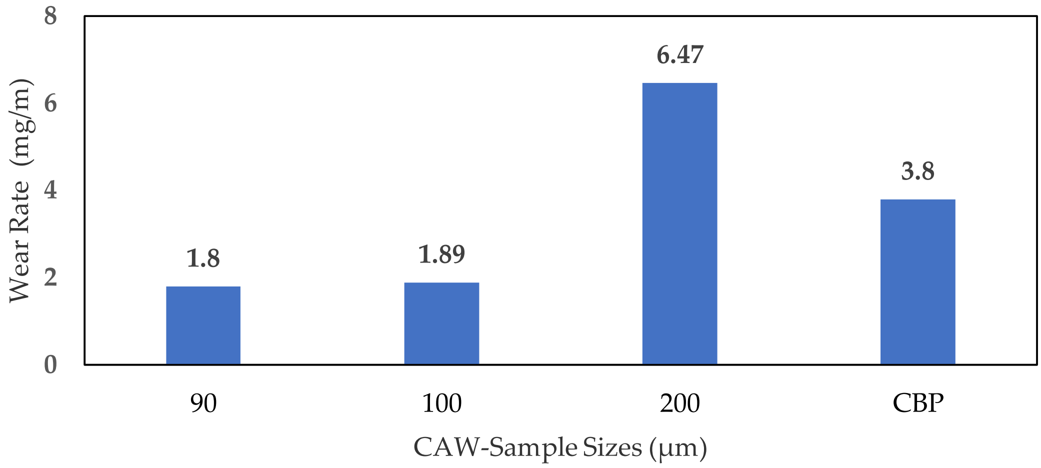

Figure 7: Comparison of wear rate of brake pads produced with various sample sizes of the Costus afer waste particles with commercial brake pads CBP.

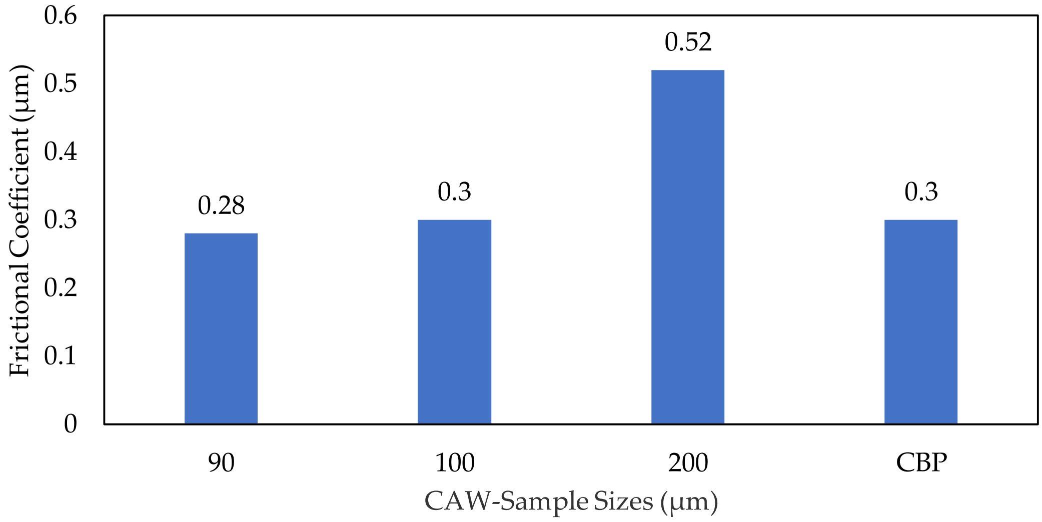

Figure 8: Comparison of frictional coefficient of brake pads produced with various sample sizes of the Costus afer waste particles with commercial brake pads CBP.

The flame resistance of the CAW-brake pad samples was tested by placing the sample on wire gauze positioned directly on the blue flame of a Bunsen burner. The CAW-brake pad sample weight before and after were measured after 10 minutes, and this was used to determine the percentage of flame resistance. Results from the flame resistance test for the CAW-based brake pad samples shows an increase as the CAW-sample grain size increases. This result has been depicted in Figure 9 which also compare the results from CBP sample. This can be attributed to the increase in pores as the CAW-sample grain sizes increases. Sample size 90 µm charred at 20% after 10 minutes. This result also corroborates with previous research by Aigbodion et al., [12] and Lawal et al. [11].

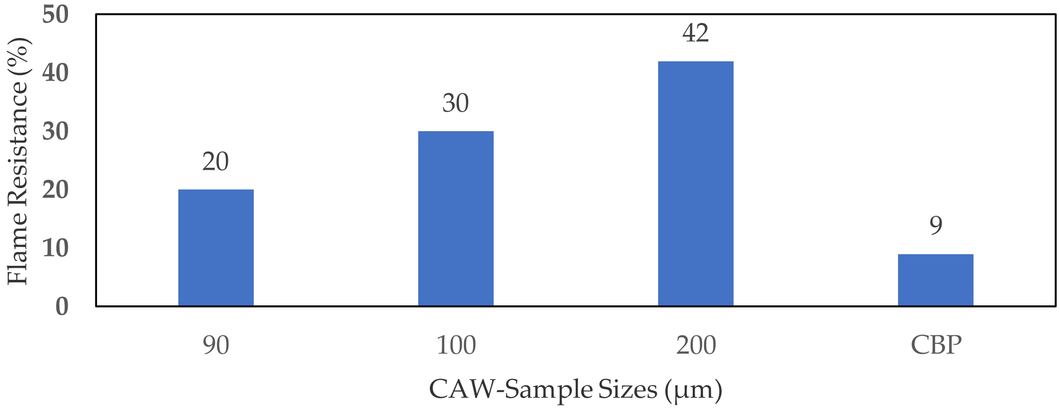

Figure 9: Comparison of flame resistance of brake pads produced with various sample sizes of the Costus afer waste particles with commercial brake pads CBP.

EDXRF analysis was carried out using an Oxford X-Supreme 8000 to determine the chemical composition of the Costus afer waste and brake pad. The test was carried out under controlled temperature and Humidity conditions of 22.9oC and 52%RH respectively. The result revealed that CAW mainly contains semi-metals and non-metals, that is: Silicon, Manganese, Iron, Cobalt, Nickel, Copper, Zinc, Lead, Phosphorus, Molybdenum, Magnesium and Titanium. These elements are equally found in asbestos which suggested that CAW can be used as a replacement of asbestos for brake pads. The chemical composition of CAW was comprised of mainly iron (Fe) (52.78 %), magnesium (Mg) (23.22 %) and Zinc (Zn) (9.95 %). The chemical composition of CAW compares reasonably with other agricultural materials previously used for non-asbestos brake pad production [30].

From Table 2, it can be observed that, the values for the properties such as compressive strength, hardness, wear rate, coefficient of friction, flame resistance, density and absorption obtained from CAW particle size of 90 μm compares favorably with values reported by Aigbodio et al. [12] and to replace commercial brake pad with compressive strength -110 Mpa, Hardness Values- 101, Wear rate-3,8 mg/m, Coefficient of friction- 0.3 μm, Density-1.89 g/cm3, Flame resistance- 9% of charred ash, absorption in water 0.9 % and absorption in oil -0.3%. The best values obtained using CAW particle size of 90 μm are: compressive strength -115 Mpa, Hardness Values- 103, Wear rate-1.8 mg/m, Coefficient of friction- 0.28 μm, Density-1.3 g/cm3. It is obvious that these value compare favorably, hence suggesting the promising prospect of replacing asbestos based brake pad with CAW based brake pad. The Finished CAW-based Brake Pad with 90 μm particle size is shown in Figure 10.

Table 2: Summary of Result Findings Compared with Existing Ones

Features	Palm based (Aigbodio et al., 2010).	Bagasse based (Aigbodio et al., 2010).	Asbestos – based (Commercial)	Costus afer waste based (Proposed material)
Compressive strength (MPa)	103.50	105.60	110.00	115.00
Brinell hardness value	92.00	100.50	101.00	103.00
Specific gravity (g/cm^3)	1.65	1.43	1.89	1.30
Average wear (mg/m)	4.40	4.20	3.80	1.80
Coefficient of friction (μm)	-	0.42	0.30	0.28
Flame resistance after 10 minutes (%)	Charred with 46% ash	Charred with 34% ash	Charred with 9% ash	Charred with 20% ash

Thickness swell in water after 24hrs (%)	5.03	3.48	0.90	1.20
Thickness swell in oil (SAE 40) after 24hrs (%)	0.44	1.11	0.30	0.55

Figure 10: Finished CAW-based Brake Pad with 90 μm particle size

4.0 CONCLUSION

Eco-friendly asbestos-free brake pad from CAW base material and local gum Arabic binder has been developed by compression molding and curing at 120 ^{0}C for 8 hours. The CAW-based brake pads with different particle grain sizes (90, 100 and 200 μm) were subjected to several physico-mechanical and tribological performance tests and the results compared with the commercial brake pad used as control.

The compressive strength (115Mpa), hardness (103) and density (1.3g/cm^3) of the developed CAW-based brake pad samples were increasing with a decrease in the particle sizes. But the water (1.2%) and oil absorption (0.55%), wear rate (1.8 mg/m) and flame resistance (Charred with 20% ash) increased with increasing CAW- particle sizes. The CWA brake pad showed a better wear performance than commercial brake pad. The Coefficient of friction is approximately 0.3(μm). The CAW-brake pad sample with grain size of 90 μm showed the best properties in the entire test performed and the results obtained compared favorably with that of the commercial brake pad, hence the research objective is achieved. Also, the element analysis based on Energy-Dispersive X-Ray Fluorescence for the CAW and Brake pad was carried out. The developed brake pad performed well when used in a Toyota Camry (2006 Model). Hence, the result of this work showed that CAW and local gum Arabic can be used as replacements for asbestos and resin binders respectively in the manufacture of brake pads.

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