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Investigation of The Potentials of Sisal-Palm Slag Composites as Materials for Asbestos-Free Brake Pad

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Abstract. *Asbestos conventionally used as frictional materials in brake pads causes environmental pollution and is unsafe for human health. This study's goal was to assess alternative brake pads made from sisal-palm slag. Ten composite brake pads were produced by combining sisal-palm slag with epoxy resin, silica and steel slag using formulations obtained from the rule of mixture experimental design method. The produced brake pad composites physical properties (density (ρ), porosity (φ) and tribo-mechanical properties (wear rate ($\hat{W}$), hardness (HB), compressive strength (σ) were evaluated. From the results, the control sample (Auto-boss brake pad) recorded values of 1.7800 g/cm^3, 18%, 1.127 mg/min, 110BHN and 43.204N/mm^2 for ρ, φ, $\hat{W}$, HB and σ respectively. The best performing sample was sample 5 with recorded values of 1.3329 g/cm^3, 23.40%, 1.143mg/min, 102.28BHN and 39.642 N/mm^2 respectively, while sample 9 was the least performing samples with recorded values of 1.3123 g/cm^3, 30.43%, 1.571mg/min, 76.77BHN and 26.74 N/mm^2 for the above parameters respectively. The study showed that the produced samples offered comparable performance to that of asbestos-based and hence could serve as possible replacement for them.*

Keywords: Brake Pad, Asbestos, Pin on Disc Wear Tester, Hardness, Sisal, Palm Slag, Porosity.

Introduction

The use of automobiles as a mode of transport on roads is an essential part of everyday activities [1]. The high-tech developments emerging in the automobile industry seeks to make vehicles that are secure, effective and precise [2]. [3] noted that the principal safety component peculiar to every automobile on the road is the braking system. The braking system is an indispensable component of an automobile and is composed of many parts, including brake pads, a master cylinder, wheel cylinders and a hydraulic control system [4]. The two types of braking systems used in automobiles are the drum/shoe brake and the disc/pad brake systems or a combination of the two [1]. The disc/pad brake system has gained more popularity than the drum/shoe brake system because it causes heat to vanish and reduces wear better than drum brakes [5].

Asbestos and its composites have been used for several decades with varying compositions as brake pad material [6]. During braking operations, both the brake pad and counter face disc wear out, releasing huge amounts of wear debris or particulate matter in the surrounding atmosphere [7]. Medical research has shown that asbestos usage can induce adverse respiratory conditions [8]. Concerted efforts have been channeled towards replacing asbestos and other carcinogenic materials in the production of brake pads [9]. In order to reduce or completely get rid of the health

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risks posed by asbestos in brake pads, this work aimed at investigating the potentials of sisal-palm slag in brake pad applications.

Theoretical Background and Methods

Sisal was harvested and dried as shown in **Figure 1**.

Figure 1. Harvesting of sisal

Dried sisal was pulverized into ultra-fine particles using a planetary ball mill (model; 87002 Limoges France, type machine A50….43) with milling duration of 96 hours at 195 revolutions per minute of vial rotation **Figure 2**.

Figure 2. Ball milling machine

Pulverized materials of sisal, palm slag is presented in **Figures 3** and **4**.

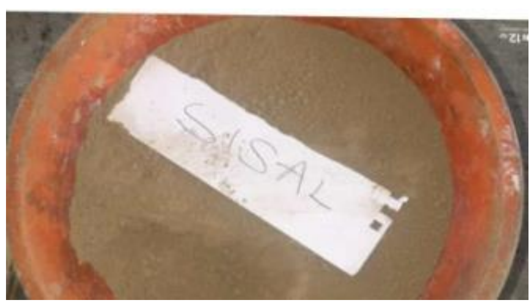

Figure 3. Pulverized sisal

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Figure 4. Pulverized palm slag

Table 1. Aggregate mix of materials for brake lining samples

Constituent	Samples in percentage weight (% wt)									
	S_1	S_2	S_3	S_4	S_5	S_6	S_7	S_8	S_9	S_{10}
Sisal	20	30	20	25	25	20	25	20	20	25
Palm slag	20	20	20	20	20	25	20	25	25	20
Epoxy resin	20	15	15	15	15	15	15	15	20	15
Steel dust	20	10	20	15	15	20	15	15	10	20
Silica	10	15	10	15	10	10	10	15	10	10
Graphite	10	10	15	10	15	10	15	10	15	10
Total	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**

The pulp-like homogenous mixture was transferred into a cylindrical mould plate of 29 mm diameter and 70 mm height **Figure 5**.

Figure 5. Cylindrical mould and die

Where it was compacted at a compression pressure of 50MPa using a hydraulic press machine (model P16H-type, 16t Serial No-29580 machine) **Figure 6**.

Figure 6. Hydraulic press

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The mould was greased internally with engine oil before compaction for easy removal of the samples after compaction [10]. The compacted samples shown in **Figure 7** were carefully removed from the mould and transferred into an electric oven (model: Memmert, Western Germany) where it was cured at a temperature of 150°C for 6 hours. Original equipment (Autoboss brake lining sample) was used as a standard reference sample to compare to the produced brake lining samples and is referred to as control sample (SC).

Figure 7. Produced brake pad

Physical properties

Density

The volume of the samples was measured using the water displacement method. The mass in (grammes) of brake pad material was measured using a digital weighing balance (SF-400 Zhongsan, China). A graduated cylindrical container measuring 100ml was used to measure the volume of water displaced by each of the samples. The density of each of the samples was then calculated by dividing the mass by the volume [11].

$$Density(\rho) = \frac{Mass(m)}{Volume(V)} \qquad (1)$$

Porosity

The porosity test was conducted using samples of diameter 28.440mm. The samples were weighed to the nearest milligram (mg), before being soaked in a water bath at 90˚C for 8 hours. The samples were left in the water bath for 24 hours before they were taken out one after the other. They were then weighed to the nearest mg. The porosity of the test samples was calculated using Equation 2.

$$Porosity\ (\varphi) = \frac{M_2 - M_1}{D} \times \frac{100}{V} \qquad (2)$$

Where M_2 is the Mass of the sample after soaked in water
M_1 is the Mass of the sample before being soaked in water
D is the density of the samples
V is the volume of the samples

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Tribo-mechanical properties

Wear rate

The test was conducted using a pin-on-disc wear tester (PoD). The (PoD) was used to experimentally investigate the sliding wear behaviour of each of the samples under dry sliding contact conditions according to ASTM G99 standard test procedure [10]. The arrangement was made such that each sample pin was tested by sliding it against a cast iron surface at a load of 10N, sliding speed of 125rev/min and sliding distance of 500m. All tests were conducted at room temperature [10]. The initial weight of the samples was measured using a digital weighing balance (SF-400 Zhongsan) and recorded as W1. Each sample was then subjected to run on the counter disc at a sliding speed of 125rev/min through a sliding distance of 500m and a normal load of 10N. The worn samples were removed and cleaned using tissue paper and weighed to determine the weight loss due to wear. The difference in weight measured before and after the tests gave the wear loss of the samples and the wear rate is calculated by Equation 3.

$$Wear\ rate = \frac{\Delta W}{S} \qquad (3)$$

Where ΔW = Weight difference of the sample before and after the test (g)
S = Total sliding distance (m)

Hardness

The hardness test was carried out in using ASTM D2240 [5]. It was conducted to determine the resistance of the brake lining samples to indentation [2]. The test was carried out using Brinell hardness testing equipment, Tensometer (M500-25KN, hardened steel ball of diameter 10mm to indent the test samples of diameter 28.40mm by pressing the hardened steel ball into the test samples. In the test, the diameter of the ball D was kept constant at 10mm, and the load applied W was maintained at 300kg. The samples were each mounted in the holding device and the ball location was fixed. A hand wheel was rotated so that the ball moved toward the sample held in the holding device, with a gear driven screw pressing the ball into the sample. The depth of the indenter point penetration made by the pressed ball was measured using an optical micrometer screw gauge. The diameter of the indentation d was measured along two perpendicular directions with the mean value used to obtain the Brinnel Hardness Number (BHN) using equation 4 [4].

$$BHN = \frac{2P}{\pi D\left(D - \sqrt{D^2 - d^2}\right)} \qquad (4)$$

Where
P = applied load
D = Diameter of hardened steel ball
d = diameter of Indentation

Compressive strength

The tests were carried out as per ASTM D695 testing standard at a test speed of 70mm/min. Composite samples of diameter 28.440mm were subjected to compressive force by placing each sample in between two hardened blocks and were compressed until failure occurred. The load at

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which failure occurred was then recorded and divided by the area of each of the samples to give the compressive strength.

Results and Discussion

Physical properties

The physical properties of the produced brake pad samples examined were density and porosity.

Density

The variations in the density of the samples are presented in **Figure 8**. From the figure, it can be seen that produced brake pad sample 2 with 30% sisal content and 15% steel dust content has the highest density of 1.4375g/cm^3, while sample 9 with 20% sisal and 10% steel dust has the lowest density value of 1.3123g/cm^3. The results showed that the density of the brake pad samples increases with increasing sisal particle content. This could be attributed to the increased packing of the sisal particles forming more uniformity in the entire phase of the brake pad. This agrees with [2], who stated that an increase in density was attributed to the increased packing of filler particles forming more homogeneity in the entire phase of the brake pad composite body. The density value of 1.7800 g/cm^3 of the control sample is higher than the values from the produced samples. A higher density is not desirable in modern vehicles. Concerning density, the produced samples will perform better than the control

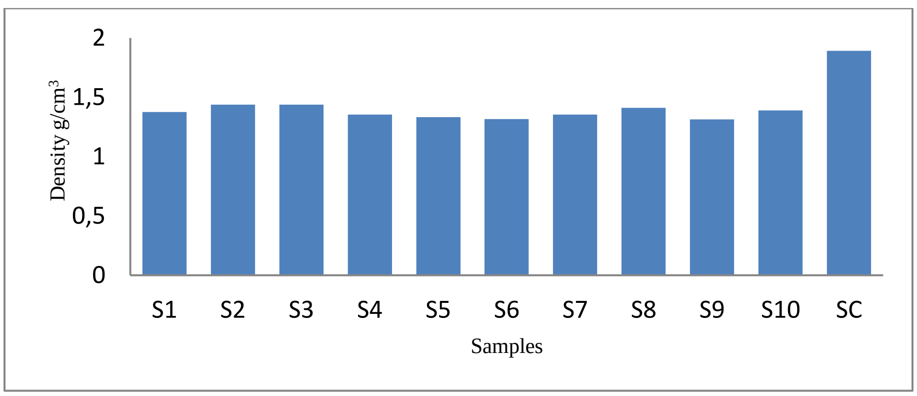

Figure 8. Comparative analysis of the density of samples produced

Porosity

The porosity values of the samples are presented in **Figure 9**. It can be seen from the figure that sample 5 with 25wt% of sisal has the lowest porosity value of 23.40% while sample 9 with 20wt% sisal has the highest porosity value of 30.43%. The result shows that the porosity of the brake pad samples decreases with increasing sisal particles in the composite. This may be attributed to closer bonding between the sisal particles and the binder. This agrees with [12] who stated that a closer interfacial bonding between the particles of lemon peel powder and binder will reduce the level of porosity. The control sample with a porosity value of 22.23% is lower than the values from the produced samples, which means that in terms of moisture absorption, the control sample will perform slightly better than the produced samples.

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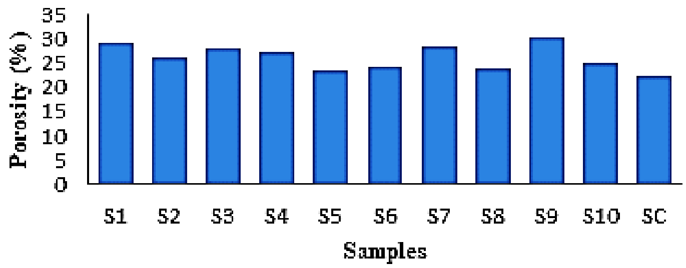

Figure 9. Comparative analysis of the porosity of samples produced

Tribo-mechanical properties

Wear rate

The wear rates of the samples are presented in the **Figure 10**. The wear rate values of the produced brake lining samples vary from 1.143 mg/min to 1.571mg/min, with sample 5 having the lowest and sample 9 having the highest. From the results, the wear rate was observed to be increasing as the percentage weight of palm slag and silica in the composite decreased. This may be attributed to silica providing a better rubbing surface by removing undesirable surface films formed during braking as stated by [11]. The control sample with a value of 1.127 mg/min when compared with the produced brake pad samples showed a close correlation.

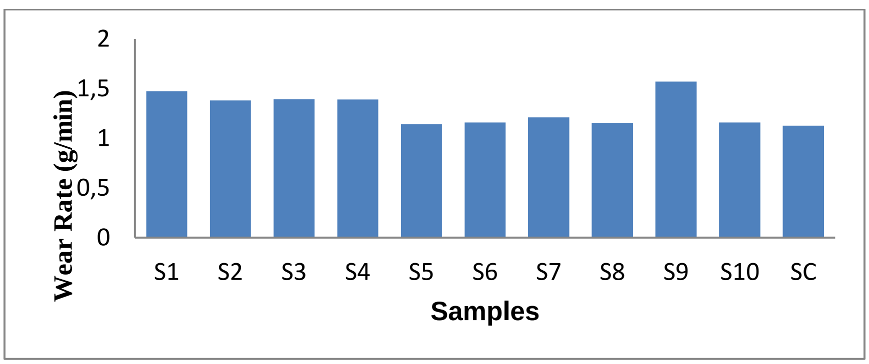

Figure 10. Comparative analysis of the porosity of samples produced

Hardness

The variation of the hardness of the produced brake pad samples is shown in **Figure 11**. The values vary from 76.77 BHN to 102.28 BHN. From the figure, it can be seen that sample 5 has the highest hardness value of 102.28BHN, while sample 9 has the lowest hardness value of 76.77BHN. The result shows that the hardness increases as the sisal and steel dust content in the composite increases. This could be attributed to the presence of compounds such as silicon dioxide also known as silica (SiO_2) and Iron (III) oxide (Fe_2O_3) in the composite. According to [5], SiO_2 and Fe_2O_3 are among the hardest substance, and their presence will increase the hardness of the composite. The control sample had a hardness value of 110.00 BHN. The hardness value

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of the control sample though higher than the values obtained from the produced samples closely match up.

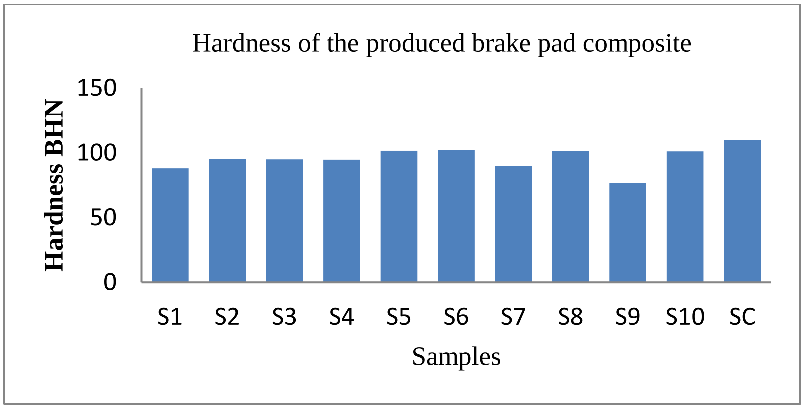

Figure 11. Comparative analysis of the hardness of samples produced

Compressive strength

The variation in compressive strength of the produced brake pad samples is presented in **Figure 12**. As can be seen in the figure, each produced brake pad sample had different compressive strengths. Brake pad sample 5 with compressive strength of 39.642N/mm^2 had the highest value, while sample 9 with a compressive strength value of 26.740.N/mm^2 was the lowest. From the results, the compressive strength was observed to be increasing as the percentage weight of palm slag in the composite increased. This may be attributed to the hardening of the resin by the palm slag particles. This agrees with [4] who stated that, the compressive strength of produced brake pad increased as periwinkle particle size increased due to the hardening of the resin by periwinkle shell particles. The control sample with a compressive strength value of 43.20N/mm^2 is higher than the values from the produced samples. This means that the control sample had a slightly superior force resistance to the produced samples.

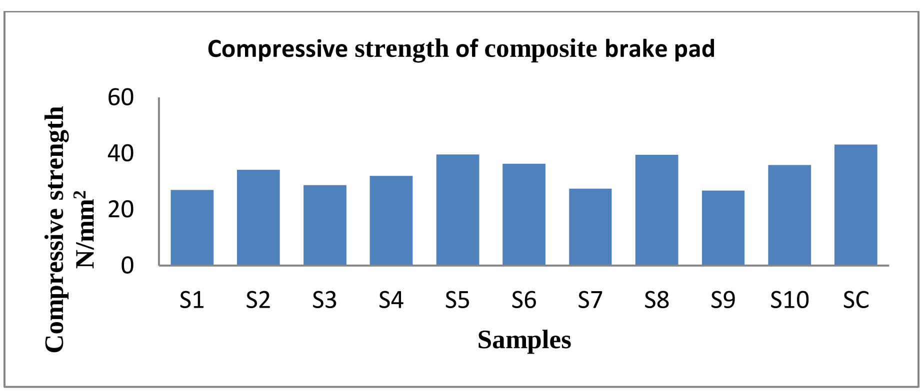

Figure 12. Comparative analysis of the compressive strength of samples produced

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Conclusions

The research as set out was to probe into the potentials of sisal-palm slag composites as substitutes for asbestos in brake pads. Based on the experimentation analysis, the following conclusions are drawn.

- Samples of brake pad prototypes were successfully produced from sisal-palm slag particles by moulding in a 16-ton capacity hydraulic press using moulding die of diameter 29mm and height 70mm.
- The physical properties examined revealed that the density of the sisal-palm slag brake pad composite sample produced increases as the sisal particles in the constituent increase, while the porosity decreases as the palm slag particles in the constituent decreases
- The tribo–mechanical test conducted on the samples revealed that the wear rate was found to be decreasing as the percentage weight of palm slag in the composite decreased, while the hardness and compressive strength increases as the sisal and steel dust content increased.

The study showed that the produced brake pad samples examined offered competitive performance to that of asbestos based, hence, can serve as a possible replacement for them.

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