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Water and Oil Absorption Behaviour of Sustainable Brake Pad Composites with Cow Hoof and Bamboo Fillers

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***ABSTRACT**: This research explores the water and oil absorption behaviour of eco-friendly automobile brake pad composites produced with cow hoof and bamboo fibres as sustainable fillers. The composites were fabricated with varying ratios of the fillers, bonded with phenolic resin, and tested for water and oil absorption in accordance with ASTM standards. Findings revealed that the absorption behaviour was strongly dependent on the filler composition and immersion duration. Composites with higher bamboo content showed greater water absorption, attributed to the hydrophilic nature of bamboo fibres. Conversely, samples with higher proportions of cow hoof recorded lower oil absorption, indicating stronger resistance to petroleum-based fluids. These results highlight how the selection of filler ratios significantly influences fluid interaction properties of the composites. Overall, the study demonstrates that brake pads formulated with cow hoof and bamboo fibres present a viable, environmentally sustainable alternative to conventional asbestos-based brake pads.*

Keywords: Brake pad composites, cow hoof, bamboo fibres, water absorption, oil absorption, sustainable materials

1. Introduction

Brake pads are composite materials designed from multiple constituents that collectively generate friction, thereby enabling braking (Singh et al., 2023). Their primary role is to convert kinetic energy into heat, slowing or halting moving vehicles (Kumar & Suman, 2017). Typical formulations consist of binders, abrasives, lubricants, reinforcing fibres, and fillers.

Brake pads are generally classified as asbestos-based, metallic, or ceramic. Asbestos pads once dominated due to their excellent frictional and thermal performance, but their carcinogenic nature limited usage (Blau, 2001). Ceramic pads reduce vibration and dust while exhibiting moderate disc wear, whereas metallic pads offer long service life but increase rotor wear (Verma, 2016; Xingming et al., 2016).

Asbestos, historically incorporated at 30–70%, possessed exceptional durability, tensile strength, and thermal stability up to 500 °C (Nicholson, 1995; Blau, 2001). During braking, silicates formed enhanced hardness and wear resistance (Hase & Belkar, 2015). However, inhalation of asbestos fibres leads to severe respiratory illnesses including cancer (Swiatkowska et al., 2016). Consequently, many countries have restricted or banned its use (Moda et al., 2018).

This has driven research into renewable, eco-friendly fillers such as coconut shells, rice husk, bamboo, cow hooves, seashells, and others (Abutu et al., 2018; Onyenanu et al., 2024). Combining fillers can optimize tribological, physical, and chemical properties (Egeonu et al., 2015). Selection often depends on availability, accessibility, and performance efficiency, aligning with global sustainability goals.

Water and oil absorption are critical properties that significantly influence the durability and performance of brake pads. During vehicle operation, brake pads are constantly exposed to varying environmental conditions, including rain, mud, and oil spills on road surfaces. If the brake pad material absorbs excessive water, its structural integrity weakens, leading to reduced frictional efficiency, swelling, or softening of the pad. This condition results in poor braking response, longer stopping distances, and accelerated wear. Similarly, high oil absorption can create a lubricating film on the friction surface, drastically lowering the coefficient of friction and making braking less effective and unsafe.

The extent of water and oil absorption also impacts the thermal stability and mechanical strength of the pads. Excess absorption may cause delamination, cracking, or loss of bonding between constituents, thereby shortening the service life of the component. For this reason, an ideal brake pad should exhibit minimal water and oil uptake to maintain consistent performance under both wet and dry conditions. Testing for these properties is therefore essential in the development of new eco-friendly materials, such as composites reinforced with natural fibers or waste-derived fillers. Low absorption ensures reliability, safety, and long-term durability in automotive braking systems.

2. Materials

2.1 Materials for the fabrication of brake pad lining

The materials used for the production of brake pad lining and their functions are listed in Table 3.1. The choice of filler materials and other additives is justified by its availability, accessibility, affordability, as well as the health and environmental safety of the materials.

Table 2.1: The selected brake pad lining materials and justification for their choice.

Material	Function	Justification for selection
Cow hooves Bamboo	Filler	Cow hooves have been revealed to contain silicon (50.20 %), with analyses showing it as a predominant inorganic constituent within the cow hoof's composition (Bala, Okoli, Abolarin, 2016). Fastest growing plant in the world and readily available in Nigeria. Studies have shown that it has desired physical, mechanical and tribological properties for the brake pad lining development and structural design (Purboputro, Hendrawan, and Hariyanto, 2018).
Phenolic resin	Binder	Phenolic resin is a crucial component in brake pad production, acting as the primary binder that holds together various friction materials ensuring structural integrity, thermal stability, and effective braking performance. Its excellent high-temperature resistance is vital for maintaining consistent friction and preventing brake fade, while its mechanical strength and durability are essential for absorbing impact and stress during braking.
Aluminum oxide	Abrasive	Readily available and helps prevent glazing of the rotor surface, which can reduce braking efficiency.
Graphite	Friction modifier	Widely used and cheap. Burns above 700^0C. Has a high friction coefficient (0.47-0.52). Used due to its excellent lubricating properties, heat dissipation capabilities, and ability to reduce noise and vibration during braking.
Barium sulphate ($BaSO_4$)	Reinforcement	Inert, increases density, stable at high temperature and aid in wear resistance. It is used due to its high thermal stability, minimal water solubility, and low cost.

The materials in their raw state are provided as given in Plate 2.1 to Plate 2.5

Plate 2.1: Unpulverised Cow Hooves

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Plate 2.2: Split lengths of Bamboo sticks

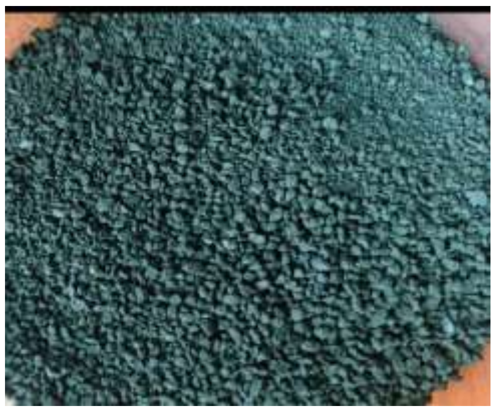

Plate 2.3: Phenolic Resin

Plate 2.4: Aluminum Oxide (Al_2O_3)

Plate 2.5: Graphite

2.1.1 Equipment for the production of brake pad lining

The following equipment are used for the production of the brake pad samples:

(i) Conventional milling maching, for reducing the particle size of cow hooves and Bamboo fibres.
(ii) Thermostatic oven, for initial drying of the shredded cow hooves and Bamboo fibres.
(iii) Dessicator, for storage of samples.
(iv) Electronic weighing balance, for measurement and proportioning of samples.
(v) 100 µm Mesh sieve.
(vi) Kitchen blender, for blending and homogenization of sample materials.
(vii) Compression moulding machine, for production of brake pad samples.

2.2 Method

2.2.1 Sample Preparation

The preparation of brake pad specimens involved several key steps. Cow hoof and bamboo fibres were first cleaned, thoroughly dried, and ground to fine particles. The ground materials were sieved to obtain a uniform particle size, typically within 100 µm, to ensure consistency. These fillers were then blended with resin and other additives according to the table below, to achieve a homogeneous formulation.

Table 2.2: The formulations for brake pad samples production (% Weight)

Sample ID / Materials	01	02	1	2	3	4	5	6	7
Cow hooves filler (%wt.)	10	-	8	7	6	5	4	3	2
Bambo fibre (%wt.)	-	10	2	3	4	5	6	7	8
Phenolic Resin (%wt.)	70	70	70	70	70	70	70	70	70
Aluminum Oxide (%wt.)	5	5	5	5	5	5	5	5	5
Graphite (%wt.)	5	5	5	5	5	5	5	5	5
Barium Sulphate (%wt.)	10	10	10	10	10	10	10	10	10

where
01 = Formulation without bamboo fibre;
02 = Formulation without cow hooves filler;
1 – 7 = Formulations with varying amounts of cow hooves filler and bamboo fibre

Each sample formulation was prepared and compression-moulded at a mold temperature of 130 ^oC and clamping pressure of 100 psi using a compression moulding machine (see Plate 2.10). After compression-mulding, each sample was post-cured for 5 minutes. Thereafter, the fabricated brake pad samples were removed and air-dried for 2 hours before they were kept in the dessicator prior to characterization.

2.3 Water and Oil Absorption Test

The water and oil absorption tests for brake linings are essential quality control procedures to evaluate how a brake lining material responds when exposed to water and oil. These tests help determine the brake lining's ability to resist deterioration and maintain its frictional properties in the presence of these substances, which could be encountered during real-world vehicle operation.

The water and oil absorption test measures the amount of water and oil a brake pad lining can absorb. Excessive absorption can lead to swelling, softening, or degradation of the material, adversely affecting its frictional properties and overall performance.
The water and oil absorption of the sample was determined by soaking the sample in water and engine oil for 24 hours (1day), respectively. Prior to the test, each sample was oven-dried and weight measured. The samples were cleaned after 24 hours in water and oil (engine oil), and weight taken thereafter. The percentage absorption of water and oil was estimated using the equation (2.5) according to Idris, Aigbodion, Abubakar and Nwoye (2015).:

$$\text{Absorption} = \frac{W_1 - W_0}{W_0} X\ 100\ \% \tag{2.5}$$

Where W_0 = Weight (g) of sample before immersion, W_1= Weight (g) of sample after immersion.

A high percentage of water absorption indicates that the brake pad lining material is prone to absorbing moisture, which could negatively impact its performance. Therefore, materials with low water absorption are preferred for brake linings to ensure consistent performance in wet conditions.

3. Results

3.1 The produced brake pads

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Plate 3.1 shows the nine (9) different samples of brake pad lining produced using each of cow hoof and bamboo filler and combination of both cow hoof and bamboo fibre as fillers. The shape of the brake pad samples produced was circular as shown. The average thickness of the brake pad samples were determined to be 5.80 mm. All the nine (9) samples with different amounts of cow hoof and bamboo fibre were analyzed. Thus, the effect of varying proportions of cow hooves and bamboo fibres on the thermal, physical, mechanical and tribological properties of the fabricated brake pads were investigated.

Plate 3.1: Produced samples of brake pad lining

3.2 Water and oil absorption

The values of water and oil absorbed by the fabricated brake pad samples are clearly presented in Table 3.1.

Table 3.1: Percent water and oil absorptions by the fabricated brake pad samples

Sample ID	**01**	**02**	**1**	**2**	**3**	**4**	**5**	**6**	**7**
Water Absorption, % wt.	0.781	7.810	0.935	1.314	0.954	1.077	0.799	1.617	1.709
Oil absorption, %	0.324	8.720	0.386	0.898	1.418	1.005	0.794	0.891	2.022

These values are graphically depicted in Figure 3.14 and Figure 3.15 for water absoprtion and oil absorption, respectively.

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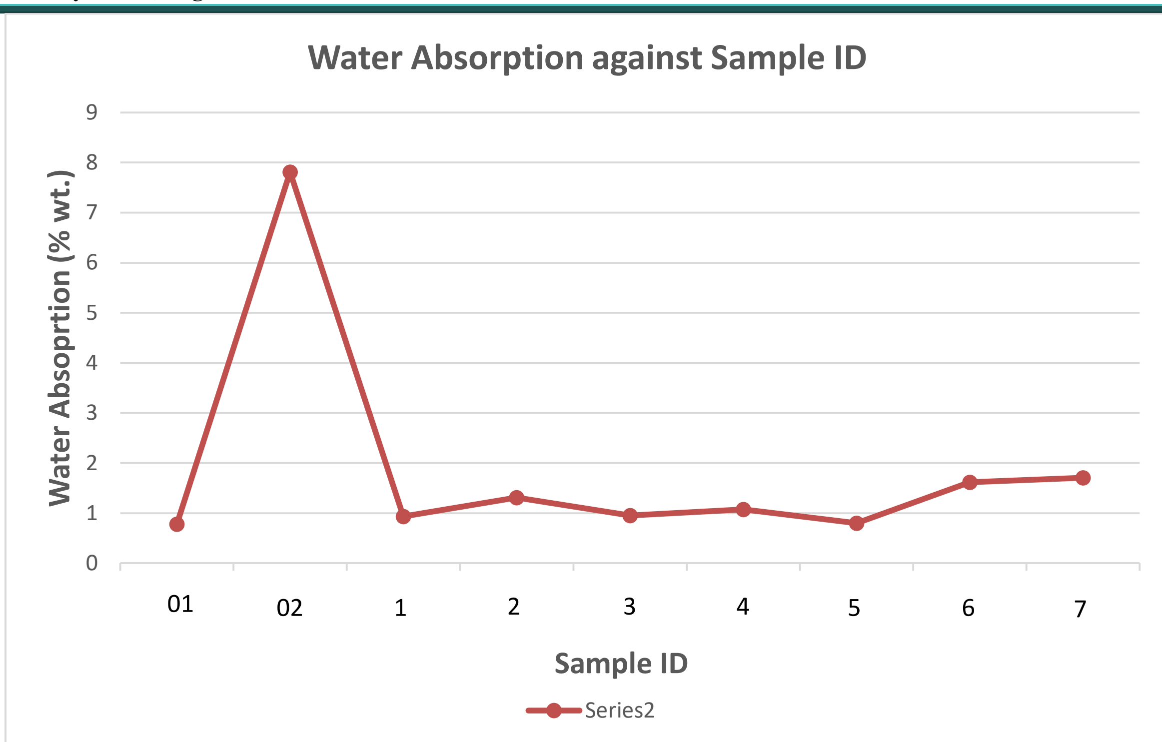

Figure 3.1: Plot of water absorption by the fabricated brake pads

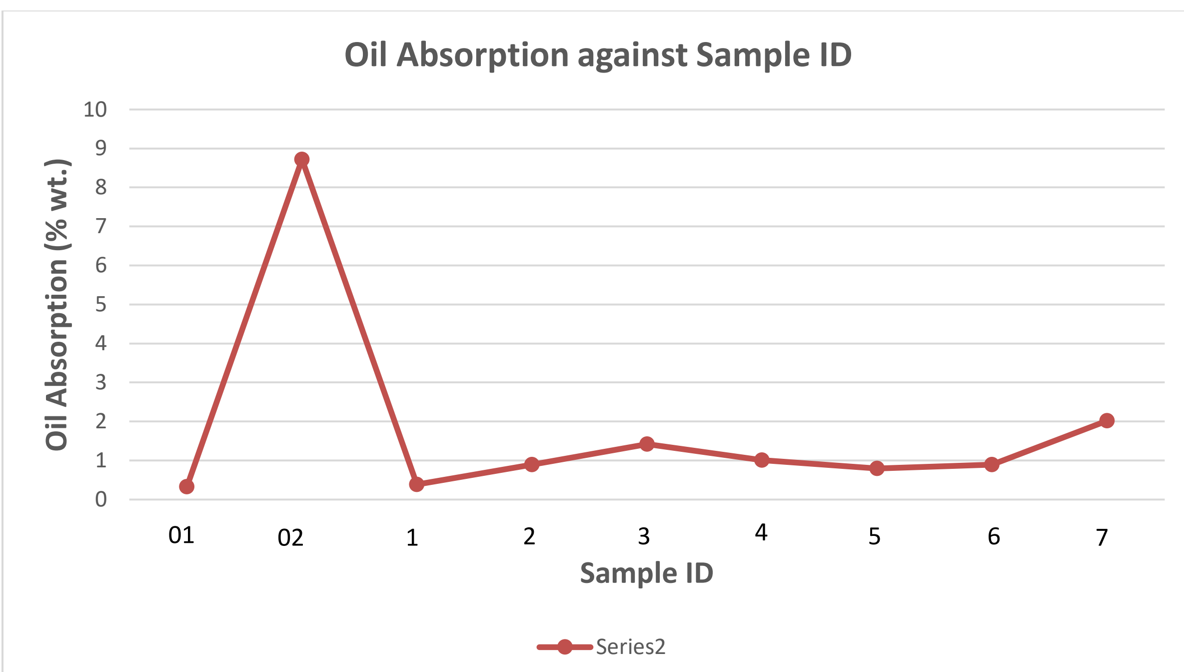

Figure 3.2: Plot of oil absorption by the fabricated brake pads

From the results above, the brake pad sample 02 with only bamboo fibre as filler material exhibited higher water (7.810 %wt.) and oil (8.720 %wt.) absorptions compared to sample 01 with only cow hoof as filler material which displayed very low water (0.781 %wt.) an oil (0.324 %wt.) absorptions. Considering the effect of varying proportion of cow hoof and bamboo fibre, sample 7 with higher proportion of bamboo fibre than cow hoof gave the highest water and oil absorptions. The reason is the bamboo fibres have many hydroxyl (–OH) groups, and thus are hydrophilic in nature. Thus, the sample 7 that has very high proportion of –OH groups tend to show low moisture resistance. This is in agreement with Dhakal (2007) who posited that the maximum water uptake increased as the natural filler content increased.

4. Discussion

With respect to the water and oil absorptions, the brake pad sample 02 with only bamboo fibre as filler material exhibited higher water (7.810 %wt.) and oil (8.720 %wt.) absorptions compared to sample 01 with only cow hoof as filler material which displayed very low water (0.781 %wt.) an oil (0.324 %wt.) absorptions. Considering the effect of varying proportion of cow hoof and bamboo fibre, sample 7 with higher proportion of bamboo fibre than cow hoof gave the highest water and oil absorptions. Sample 2 and 5 gave the lowest water and oil absorption.

5. Conclusion

Cow hoof and bamboo composites exhibit varying water and oil absorption based on filler ratio. Higher bamboo content gave more water absorption while higher cow hoof content gave less oil absorption.

Optimal blend ensures balance between water resistance, oil resistance, and sustainability.

Research findings highlight the viability of agro- and animal-waste fillers for eco-friendly brake pad production.

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