EDSU Journal of Engineering and Technology (EDSUJET) Vol. 2 (1), pp. 84 – 96. 2026
ISSN (Print):3121 – 8725 eISSN (Online): 3121 – 8597

Development of Composite from Waste Materials for the Manufacturing of Automotive Brake Pads

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Received: 30th October, 2025, Accepted: 14th January, 2026, Published: 31 March 2026

KEYWORDS

Composite,
Coconut shells,
Sawdust,
Ceramic Clay,
Formulations,
Waste materials

ABSTRACT

Asbestos-based brake pads pose health and environmental risks, while conventional alternatives are costly. This study aimed to develop an eco-friendly, cost-effective brake pad using locally available waste materials: sawdust, coconut shells, and ceramic clay. The materials were cleaned, ground into fine powders, and mixed with polyester resin, benzoyl peroxide, and MEKP in varying ratios to form three composite batches (A, B, C). Samples were molded under 6 MPa at 120 °C and cured for 24 hours. They were tested for density, hardness, wear resistance, and water absorption, and compared with a commercial brake pad. Results showed densities of 2,414–2,480 kg/m³, slightly lower than the commercial pad (2,920 kg/m³), hardness values of 94.16–97.66 HD, and wear resistance comparable to commercial pads, with Batch C performing best. Water absorption (0.001474–0.000986kg) was higher due to the organic content but did not compromise mechanical performance. The study demonstrates that combining organic and inorganic waste can produce strong, durable, and environmentally safe brake pads. This approach offers a sustainable, affordable alternative for automotive applications, turning local waste into valuable engineering materials.

1. INTRODUCTION

The automotive industry is increasingly seeking lightweight and eco-friendly materials to replace traditional metals and asbestos-based components. This shift is driven by environmental concerns, rising fuel efficiency standards, and the demand for improved vehicle performance (Adam, 1997; Taub and Luo, 2015; Gory and Yang, 2013). Globally, research shows that using recycled and sustainable materials in composites can reduce production costs while supporting circular economy practices (Ouda et al., 2025). However, most conventional solutions still rely on virgin resources, such as carbon or glass fibers, which are expensive and create environmental challenges during extraction and disposal (Taurino et al., 2022). Brake pad materials are particularly critical because conventional types can release particulate matter, contributing to air pollution (Kulkarni and Kendrick, 2021).

In Nigeria, rapid population growth and industrial activity generate large quantities of solid waste, estimated at roughly 32 million tons per year (Nwosu and Chukwueloka, 2020). A significant portion of this waste including sawdust, coconut shells, nut shells, and ceramic residues ends up in landfills, causing environmental degradation, soil pollution, and health hazards (El-Fadel et al., 1997; Alam and Ahmade, 2013). These challenges underscore the urgent need for innovative approaches to convert low-value waste into valuable engineering materials, while also supporting local production and sustainable development (Seid et al., 2025).

Recent research has highlighted the potential of agro-waste and other natural fillers in brake pad composites. Studies have shown that palm kernel shell, coconut shell powder, sugarcane bagasse ash, banana peel ash, and groundnut shell can achieve high hardness, wear resistance, and thermal stability, making them suitable replacements for asbestos (Nwankwo et al., 2025). For instance, palm kernel shell composites demonstrated compressive strength up to 96.2 MPa, while coconut shell-based materials achieved high hardness (up to 186.2 BHN) and excellent wear resistance. Banana peel ash and sugarcane bagasse ash improved thermal stability due to their silica content, confirming that locally sourced, renewable materials can meet rigorous performance standards and reduce environmental and health risks.

Wear rate evaluation is a key property for determining brake pad lifespan. (Ajibade et al., 2025) demonstrated that agro-waste composites can achieve wear rates comparable to commercial pads, with the 15.5 mm specimens showing wear as low as 1.56 mm^3/Nm. They also proposed a pseudo wear rate model that considers inflationary and opportunity costs, linking technical performance with cost-effectiveness an important consideration for local composite manufacturers.

This study focuses on developing brake pads using locally available Nigerian waste materials sawdust, coconut shells, and nut shells, reinforced with ceramic clay. The aim is to produce eco-friendly, cost-effective, and high-performance brake pads as alternatives to asbestos-based products. Earlier local studies have reported promising results, such as high hardness, low water absorption (<0.1%), and wear rates comparable to commercial pads (Ogbe and Erekosima., 2025). By converting waste into valuable engineering materials, this research supports circular economy principles, enhances local material production, and addresses environmental and public health concerns in Nigeria.

Through testing different ratios of these materials, this work aims to optimize critical properties such as hardness, wear resistance, coefficient of friction, and moisture stability (Vijayasankar and Paramasivam, 2025). In doing so, it provides both technical and economic insights into the production of sustainable, high-performance brake pads from locally available waste materials

2. MATERIALS AND METHODS

2.1 Materials and Equipment

The materials used in this research were sawdust, coconut shells, ceramic clay, polyester resin, benzoyl peroxide, and methyl ethyl ketone peroxide (MEKP). All materials were locally sourced from Auchi, Edo State, Nigeria. The sawdust was collected from sawmills around Otaru Palace Road, the coconut shells from local food vendors, and the ceramic clay from the Department of Art and Design, Auchi Polytechnic. The polyester resin served as the binding matrix, benzoyl peroxide acted as the hardener, and MEKP was used as the catalyst. A hydraulic press (6 MPa, 120 °C) was used for compression molding. Laboratory testing equipment included a digital durometer (for hardness), abrasion testing machine, density measurement setup, analytical balance, and water absorption test apparatus.

2.2 Experimental Procedure

All collected materials were cleaned and sun-dried. The coconut shells were crushed and ground into powder. Sawdust and ceramic clay were sieved through a 300 µm mesh to ensure fine and uniform particle sizes.

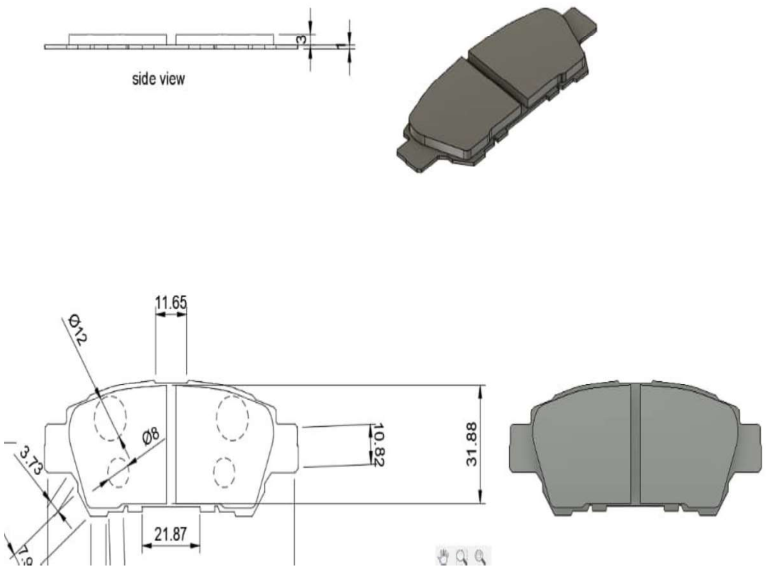

Fig 1: Drawing of the brake pad

Fig 2: Recycled back plates

2.3 Composite Formulation and Production

The mass of a conventional brake pad was determined, and based on it a formulation was drawn. Mass of the Back plate of conventional brake pad= 0.1628 kg, Mass of the Conventional brake pad= 0.2919kg, Mass of the friction material of the brake pad= 0.2919 – 0.1628 = 0.1291 kg

Three composite formulations were prepared Batch A, Batch B, and Batch C each having five samples (A1–A5, B1–B5, C1–C5). The proportions of sawdust, coconut shell, and ceramic clay were varied while keeping the amount of binder, hardener, and catalyst constant.Each mixture was thoroughly blended, placed into a mold, and compressed using the hydraulic press at 6 MPa and 120 °C for 10 minutes. The molded samples were then cooled and cured at room temperature for 24 hours before testing.

Fig 3: samples of brake pads made.

2.4 Performance Evaluation

For all performance evaluations, including density, water absorption, abrasion, and hardness, the composite samples from Batches A, B, and C were tested alongside a commercially available brake pad under identical laboratory conditions to establish a direct comparative baseline

A. Density Test: The **mass** of each specimen was first measured using an **analytical balance.** The **volume was determined through a water displacement method.** The density of each specimen was calculated using the relation:

$$\text{Density} = \frac{Mass}{volume} \quad \text{in kg}/m^3 \qquad (1)$$

B. Water Absorption Test: The percentage of water absorbed by each sample was calculated using the formula:

$$\text{Mass of water absorbed} = M_w - M_d \quad \text{in kg} \qquad (2)$$

$$\%\text{Water Absorption} = \frac{M_w - M_d}{M_d} \times 100 \ \% \qquad (3)$$

Where: M_w = Wet Mass and M_d= dried Mass

C. Abrasion Resistance Test: The brake pad samples were first **cut into smaller test pieces** using a *test piece cutter* to ensure uniform size. Each specimen was then **weighed on an electronic analytical balance** to determine its initial Mass. After weighing, the specimens were **mounted on the abraser machine** and subjected to **42 revolutions under standard load** to simulate abrasive wear. Once the test was completed, the specimens were **removed, cleaned, and re-weighed** to obtain the final mass. The following equations are used:

$$\text{Weight loss } (\Delta W) = M_I - M_f, \qquad (4)$$

$$\text{Volume loss } (\Delta V) = \frac{\Delta W}{\rho} \times 1000 \text{ in } [mm^3] \qquad (5)$$

$$\text{Specific wear rate } (W) = \frac{\Delta V}{F \times S} \ [m^3/Nm] \qquad (6)$$

$$\text{Wear resistance} = \frac{S}{\Delta V \times 1000} \ [m/m^3]. \qquad (7)$$

Where F = applied load (10 N), S = sliding distance (18.5 cm = 185 mm = 0.185 m) (Bakare.,2023).

The design formulations are as follows:

Table 1: Formulation of Brake Pad Batches (Batch A).

Formulation	Coconut Shell (kg)	Clay (kg)	Sawdust (kg)	Polyester Resin (kg)	Benzoyl Peroxide (kg)	Methyl ethyl ketone peroxide (MEKP)(kg)
1	0.05	0.01	0.04	0.075	0.005	0.005
2	0.05	0.02	0.03	0.075	0.005	0.005
3	0.05	0.03	0.02	0.075	0.005	0.005
4	0.05	0.04	0.01	0.075	0.005	0.005
5	0.05	0.025	0.025	0.075	0.005	0.005

Table 2: Formulation of Brake Pad Batches (Batch B).

Formulation	Coconut Shell (kg)	Clay (kg)	Sawdust (kg)	Polyester Resin (kg)	Benzoyl Peroxide (kg)	Methyl ethyl ketone peroxide (MEKP)(kg)
1	0.01	0.04	0.05	0.075	0.005	0.005
2	0.03	0.02	0.05	0.075	0.005	0.005
3	0.025	0.025	0.05	0.075	0.005	0.005
4	0.02	0.03	0.05	0.075	0.005	0.005
5	0.04	0.01	0.05	0.075	0.005	0.005

Table 3: Formulation of Brake Pad Batches (Batch C).

Formulation	Coconut Shell (kg)	Clay (kg)	Sawdust (kg)	Polyester Resin (kg)	Benzoyl Peroxide (kg)	methyl ethyl ketone peroxide (MEKP)(kg)
1	0.01	0.05	0.04	0.075	0.005	0.005
2	0.02	0.05	0.03	0.075	0.005	0.005
3	0.03	0.05	0.025	0.075	0.005	0.005
4	0.03	0.05	0.025	0.075	0.005	0.005
5	0.04	0.05	0.01	0.075	0.005	0.005

D. Hardness Test: The Hardness test was done using a digital durometer. Each test sample was placed flat on a smooth, hard surface to ensure proper contact. The **digital**

durometer was then pressed gently but firmly against the surface of the sample, and the hardness reading was displayed on the digital screen. Two trials were taken for each sample to ensure accuracy and consistency. The **average of the two readings** was then recorded as the hardness value for that sample. The same procedure was repeated for all samples in batches A, B, and C.

$$\text{Average hardness } = \frac{First\ trial + second\ trial}{2} \quad (8)$$

$$\text{Average performance of each batch } = \frac{Number\ of\ samples\ of\ samples}{5} \quad (9)$$

3. RESULTS AND DISCUSSION

The results are first presented in tables and figures for clarity. After that, they are analyzed and interpreted to understand what they mean in relation to the objectives of the project. The findings are then compared with existing standards and other research work to see if the samples are within acceptable ranges.

3.1 Results of Average Mass, Volume, and Density

Table 4: Mass (kg), Volume (m^3) and Density (kg/m^3) of Brake Pads

Mass (kg)						
Batch	Sample 1	Sample 2	Sample3	Sample 4	Sample 5	Average
A	0.3631	0.2823	0.3049	0.2978	0.3056	0.3107
B	0.3037	0.2792	0.3628	0.2984	0.2702	0.3029
C	0.2885	0.2975	0.2988	0.2930	0.2946	0.2945
Com.brake pad	-	-	-	-	-	0.2919
Volume (m^3)						
Batch	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Average
A	0.000128	0.000125	0.000130	0.000125	0.000130	0.0001276
B	0.000125	0.000125	0.000125	0.000125	0.000120	0.0001240
C	0.000120	0.000125	0.000125	0.000120	0.000120	0.0001220
Com.brake pad	-	-	-	-	-	0.000100m^3
Density (kg/m^3						
Batch	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Average
A	2836.7	2429.6	2345.4	2382.4	2350.7	2468.82
B	2429.6	2429.6	2902.4	2387.2	2251.6	2480.08
C	2404.1	2380.0	2390.4	2441.6	2455.0	2414.22
Com.brake pad	-	-				2920.0

From Table 4, commercial brake pad had a density of 2920.0kg/m^3all fabricated brake pads have lower densities than the commercial brake pad which means that they are lighter in weight. The closest in density to the commercial brake pad is batch B which means batch B's composition and compaction during fabrication was more balanced. It is important to note that Batch B due to its closeness in density to the commercial brake pad shows better potentials in performance in terms of frictional stability, wear resistance, thermal behaviour. However, a slightly lower density can also be beneficial if it helps to reduce the overall vehicle weight as long as performance isn't compromised.

3.2 Water absorption test

The water absorbed and water absorbed in percentage by each sample was calculated using:
Water Absorbed (g) =Wet Mass – Dry Mass,

$$\text{Water Absorption (\%)} = \frac{Water\ absorbed}{Dry\ mass} \times 100 \quad (11)$$

Table 5: Water Absorption Test

Batch	Sample	Dry mass (kg)	Wet mass(kg)	Water absorbed (kg)	Water absorption (%)
A	1	0.02241	0.02369	0.00128	5.7117
A	2	0.02822	0.03093	0.00271	9.6031
A	3	0.03055	0.03182	0.00127	4.1571
A	4	0.03917	0.03984	0.00067	1.7616
A	5	0.02892	0.03036	0.00144	4.9790
Average		-	-	0.001474	5.2425
Batch	**Sample**	**Dry mass (kg)**	**Wet mass(kg)**	**Water absorbed (kg)**	**Water absorption (%)**
B	1	0.02634	0.02753	0.00119	4.5178
B	2	0.02780	0.02909	0.00129	4.6403
B	3	0.02944	0.03067	0.00123	4.1770
B	4	0.03051	0.03197	0.00146	4.7850
B	5	0.02973	0.03197	0.00224	7.5344
Average	-			0.001482	5.1309
Batch	**Sample**	**Dry mass (kg)**	**Wet mass (kg)**	**Water absorbed(kg)**	**Water absorption (%)**
C	1	0.02440	0.02526	0.00086	3.5200
C	2	0.02576	0.02697	0.00121	4.6970
C	3	0.02499	0.02628	0.00129	5.1621
C	4	0.02755	0.02835	0.00080	2.9038
C	5	0.02538	0.02615	0.00077	2.9040
Average	-			0.000986	3.837
Commercial brake pad.				0.000613	1.045

Batch A absorbed 0.001474 kg
Batch B absorbed 0.001482 kg
Batch C absorbed **0.000986**kg
While the commercial pad absorbed only **0.000613 kg**
This shows that the commercial brake pad has the lowest water absorption value, which means it is more compact and has fewer pores inside its structure. Among the fabricated samples, Batch C performed better because it absorbed less water than Batches A and B. This indicates that Batch C has better bonding between its particles and fewer voids or gaps in its structure.
Generally, when a brake pad absorbs more water, it means it has more open pores. This can weaken the pad during operation, as moisture can enter those pores and affect its friction and

wear resistance.
So, from this test, Batch C shows performance that is closer to the commercial brake pad. It is therefore the most promising sample among the fabricated ones in terms of moisture resistance and structural integrity.

3.3 Wear Test

The objective of this test was to determine the wear resistance of the fabricated brake pad samples when subjected to abrasion, simulating conditions of continuous rubbing during braking.

Fig 4: Abrasive wear tester used for the wear test

3.4 Hardness Test

Fig 10: Hardness Durometer

Interpretation of this test

Base on the average performance all the fabricated pads shows higher wear loss than the commercial pad. Batch A wear fastest, Batch B was next to A while Batch C shows the lowest increase and was closer to the commercial brake pad. All fabricated pads have lower wear resistance compared to the commercial pad. Batch C is closest to commercial performance. Batch C demonstrates the best wear performance among the fabricated pads. Further optimization of Batches A and B may involve adjusting the polyester resin content, filler distribution, or compaction process to improve durability.

Table 6: Results of wear test

Sample A	Initial mass (kg)	Final mass (kg)	Wear loss (kg)	Density (kg/m³)	Volume loss (m³)	Wear resistance (m/m³)
1	0.00172	0.00097	0.00075	2836	2.6446×10^{-7}	699.5
2	0.00220	0.00087	0.00133	2429.6	5.4742×10^{-7}	338.0
3	0.00350	0.00235	0.00115	2345.4	4.9032×10^{-7}	377.3
4	0.00290	0.00169	0.00121	2382.4	5.0789×10^{-7}	364.3
5	0.00261	0.00204	0.00057	2350.7	2.4248×10^{-7}	762.9
Average	-	-	0.001002	2468.82	4.1051×10^{-7}	508.4
1	0.00298	0.00204	0.00094	2429.6	3.8689×10^{-7}	478.17
2	0.00307	0.00234	0.00073	2429.6	3.0046×10^{-7}	615.72
3	0.00263	0.00223	0.00040	2902.4	1.3782×10^{-7}	1342.36
4	0.00279	0.00207	0.00072	2387.2	3.0161×10^{-7}	613.38
5	0.00287	0.00175	0.00112	2251.6	4.9742×10^{-7}	371.92
Average	-	-	0.000782	2480.08	3.2484×10^{-7}	684.31
Sample C						
1	0.00248	0.00174	0.00074	2404.1	2.5342×10^{-7}	730.0
2	0.00304	0.00222	0.00082	2380.0	2.8034×10^{-7}	660.0
3	0.00186	0.00138	0.00048	2390.4	1.6410×10^{-7}	1127.0
4	0.00281	0.00164	0.00117	2441.6	4.0068×10^{-7}	462.0
5	0.00236	0.00184	0.00052	2455.0	1.7808×10^{-7}	1039.0
Average	-	-	0.000746	2414.22	2.5532×10^{-7}	804.0
Commercial brake pad	0.003759	0.003230	0.000529	2920.0	1.8116×10^{-7}	1021.5

This test is to determine the hardness of the fabricated brake pad samples from batches A, B and C using a digital durometer.

3.5 Hardness Test Remark

From the results obtained, the hardness values of the fabricated brake pad samples for batches A, B, and C showed noticeable variation.Batch A recorded an average hardness of 94.16 HD, while batch B gave 97.66 HD, and batch C had 96.23 HD. Comparing these with the commercial brake pad, which recorded an average hardness of 97.75 HD, it can be observed that batch B showed the highest hardness value among the fabricated samples and is very close to the commercial brake pad.

This indicates that the material composition of batch B has better surface strength and compactness compared to batches A and C. The high hardness value of batch B suggests that it will offer better resistance to wear and deformation when in contact with the rotating disc during braking operations.

Batch A, having the lowest average hardness, may contain slightly higher proportions of softer components (such as sawdust or polymer matrix), which could make it less resistant to surface indentation. Batch C also performed well but was slightly below batch B, possibly due to a minor variation in material ratio or compaction during molding.

In general, all fabricated samples exhibited hardness values within a close range to that of the commercial pad, showing that the developed composite materials possess good potential for practical application in automotive braking systems. However, batch B stands out as the most suitable based on hardness characteristics.

Table 7: Results of hardness test

Batch	**Sample**	**1st Trial (HD)**	**2nd Trial (HD**	**Average (HD)**
Commercial brake pad	Sample	98.8	96.7	97.75
A	1	87.1	89.1	88.1
A	2	96.5	97.9	97.2
A	3	97.4	95.4	96.4
A	4	92.1	95.4	93.8
A	5	97.4	93.2	95.3
Average of batch A	**-**	**-**	**-**	**94.16**
B	1	97.2	97.7	97.45
B	2	96.6	95.3	95.95
B	3	98.9	98.7	98.8
B	4	97.7	98.9	98.3
B	5	97.4	98.1	97.8
Average of batch B	**-**	**-**	**-**	**97.66**
C	1	98.5	96.2	97.35
C	2	96.7	96.2	96.45
C	3	97.3	96.9	97.10
C	4	98.2	97.6	97.9
C	5	91.9	92.8	92.35
Average of batch C	**-**	**-**	**-**	**96.23**

4. CONCLUSION

This study focused on making a brake pad that is safe for the environment and also affordable, using waste materials that can be found easily around us like coconut shells, sawdust, and ceramic clay. The aim was to replace asbestos, which is harmful and costly, with something better and locally made.

From the results, it was seen that the brake pads made from these waste materials performed very well when compared with a standard commercial brake pad. The density values ranged from about 2,410 kg/m³ to 2,480kg/m³which is slightly lower than the commercial pad 2,920 kg/m³ This means the ones made in this study are lighter, which is actually good for vehicles because lighter pads reduce weight and improve fuel use.
The water absorption test showed that the samples absorbed a bit more water (around 0.001474kg – 0.000986 kg) than the commercial one (0.000613 kg). This is expected since materials like sawdust and coconut shell are natural and can hold water. But even with that, the amount absorbed was not too high, and it did not affect how strong the pads were.
The wear test showed that Batch C performed the best, with wear resistance values close to the commercial brake pad. That means it can last longer and resist surface wear during braking. Also, the hardness test confirmed that all the samples were strong and firm enough, with hardness values between 94.16 HD- 97.66 HD almost the same as the commercial pad (97.75 HD).

From all the tests, Batch C came out as the best because it had a good mix of density, hardness, and wear resistance. This shows that combining organic waste (like sawdust and coconut shell) with inorganic waste (like ceramic clay) can actually produce a brake pad that is strong, durable, and safe.

This project proves that waste materials can be useful if we handle them the right way. By turning what people throw away into something valuable, we can help solve waste problems, reduce cost, and support local industries. With more improvement, this type of brake pad can be used in real vehicles and even produced on a larger scale in Nigeria.

NOMENCLATURE

A	Cross-sectional area (m^2)
F	Applied force (N)
H	Height (m)
M_d	Dry mass (kg)
M_w	Wet mass (kg)
ΔW	Weight loss (kg)
ΔV	Volume loss (m^3)
ρ	Density (kg/m^3)
S	Sliding distance (m)
W	Specific wear rate (m^3/Nm)
HD	Hardness (Durometer reading)
%WA	Percentage of water absorbed (%)

Greek Symbols

ρ Rho, density (kg/m^3)

Δ Delta, change or difference

µ Mu, coefficient of friction (dimensionless)

Subscripts

d Dry condition

w Wet condition

i Initial

f Final

avg Average

Superscripts

n Power or exponent

Abbreviations

MEKP Methyl Ethyl,Peroxide

ACKNOWLEDGEMENTS

The authors acknowledge the use of laboratory facilities at the Polymer Laboratory, Auchi Polytechnic Auchi, the Mechanical Workshop, Edo State University, Iyahmo; and the Mechanical Engineering Laboratory, ABU Zaria, for the experimental work conducted in this study.

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