



ORIGINAL RESEARCH ARTICLE

PRODUCTION OF GOAT HORN PARTICLES REINFORCED EPOXY RESIN COMPOSITE FOR AUTOMOBILE BRAKE PAD

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ARTICLE INFORMATION

Received: 20<sup>th</sup> November 2025

Revised: 20<sup>th</sup> January 2026

Accepted: 4<sup>th</sup> February 2026

Keywords:

Goat horn

Asbestos-free friction material

Abrasion resistance

Coefficient of friction

Brake pad

ABSTRACT

The development and evaluation of goat horn as asbestos-free friction material for the production of automotive brake pad was carried out in this work. Asbestos friction material that been used has been found to be carcinogenic and has prompted several research efforts for its replacement in brake pads application. In this research, six samples of composites were produced using goat horn particulate size of 300  $\mu\text{m}$  and 600  $\mu\text{m}$  as reinforced material with epoxy resin as the matrix with the following percentage compositions for specimen A, B, C, D, E, and F (21 wt% goat horn and 60 wt% epoxy resin, 21 wt% goat horn, 60 wt% epoxy resin, 26 wt% goat horn and 55 wt% epoxy resin, 26 wt% goat horn and 55 wt% epoxy resin, 31 wt% goat horn and 50 wt% epoxy resin and 31 wt% goat horn and 50 wt% epoxy resin with 3 wt% iron chips, 7 wt% silica, 4 wt% graphite, and 4 wt%  $\text{CaCO}_3$ ; in each sample) respectively. These specimens were made by compression molding method and subjected to mechanical and physical tests to ascertain their performance in service using standard test procedures, materials and equipment. The result showed that specimens composite samples A and B gave optimum performance for water and oil absorption of 0.725%, and 0.494%, hardness and compressive strength of 121.21 MPa and 10.313 respectively. furthermore, samples E and F gave the optimum performance for coefficient of friction (0.47) and abrasion resistance ( $4.297 \times 10^{-6} \text{g/m}$ ) respectively. It was observed that increase in the reinforcement content increased hardness, water and oil absorption and coefficient of friction of the composite brake pad, while wear rate and compressive strength decreased. The results showed that goat horn particles are an effective replacement for asbestos in automotive brake pad application.

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1.0 Introduction

Brake pads are critical components of the vehicle's braking system used for slowing it down (Lawal et al., 2019). The friction force between the brake pads and the rotating disc/drum is what allows the vehicle to be controlled. The friction material must have a high coefficient of friction, good thermal conductivity, and wear resistance to achieve this braking (Lawal et al., 2019). Because of their carcinogenicity, asbestos-based friction materials have been banned since in the 1990s. Organic friction materials with the same ideal tribological properties as asbestos are being developed (Abhulimen and Orumwense, 2017). The friction material must have a high coefficient of friction, good thermal conductivity, and wear resistance to achieve this braking. Asbestos-based friction materials have been used for a long time but are now prohibited due to their carcinogenicity (Yao et al., 2022). Organic friction materials with the same ideal tribological properties as asbestos are currently under development.

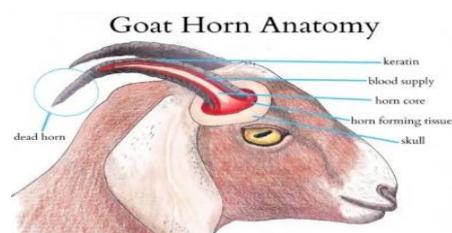
Aside from binders, fillers, and reinforcement agents, friction material is an essential constituent in brake pads. Friction material has a significant role in brake pad properties such as improving fade resistance, controlling the friction coefficient, reducing porosity/noise, and increasing strength (Gonçalves *et al.*, 2022). Asbestos as a friction material dominated the industry for over 8 years before it was banned due to its carcinogenic and hazardous properties (Olabisi *et al.*, 2016). Considering environment, aqua species, and human life, innovation in friction material formulation has been developed using ecofriendly and renewable materials. In the past few years, researchers have been focusing on developing an environmentally friendly brake pad using biomass as a non-asbestos organic material (NAOM) (Velmurugan *et al.*, 2022). The utilization of biomass such as sawdust (Mohammed *et al.*, 2018), palm kernel shell (Nwankwo *et al.*, 2024), periwinkle shell (Iwalola *et al.*, 2024), cocoa beans (Olabisi *et al.*, 2016), rice husk (Anggraeni *et al.*, 2022), and seashell (Adekunle *et al.*, 2023) in brake pad has been studied. Embedded biomass has been proven to improve mechanical properties, friction coefficient, and brake pad's water absorption. In addition, agro-waste materials such as Keratin have advantage over synthetic reinforcement due to its high fiber content. Keratin is one of the most common biopolymers in nature due to its high fracture, hardness, and Young's Modulus, as well as its excellent mechanical properties which play important role in determining brake pad performance. (Bello *et al.*, 2020).

According to Amjad *et al.*, (2022), goats were the first animals that humans domesticated. There are now 921 million goats in the globe, with over 90% of them being dispersed mostly in poor nations. Around 60% of the world's goats are found in Asia, with the largest amount of goat breeds (26%). Asia accounts for around 59% of global goat milk output. Asian demand for animal products is quickly expanding, owing to rising population and disposable income. In Nigerian agriculture, goats have a significant socioeconomic role, particularly for impoverished people living in difficult settings. There are 470 million goats in underdeveloped nations, accounting for large percentage of the total population.

Animal horns are predominantly found in the Bovidae (cows, sheep, goats, buffalo, and antelope) and antelope (such as pronghorn) families of animals (Yang *et al.*, 2022), and are employed as weapons of attack and defense in certain fights. These weapons come in a variety of shapes and forms. The primary component of horn cells is crystalline keratin filaments embedded in an amorphous keratin matrix. Keratin is found in the wool, hair, hooves, and horns of mammals, as well as the feathers, claws, and beaks of birds and reptiles. Keratin materials are categorized as soft or hard based on the amount of disulfide bonds generated during the biosynthesis process and the presence of cystine. Soft keratins, like the stratum corneum, have less sulfur, but hard keratins, like wool and hair, have more sulfur crosslinks, resulting in higher hardness and durability (Bello *et al.* 2020). These keratinous materials serve a variety of purposes, including protection (waterproof feathers), defense (horns), and predation (e.g., claws). All horns must be able to resist bending, given the lifespan of mammals and the inability of most horns to regenerate (the pronghorn is an exception). Horns must fulfill some mechanical criteria (impact resistance, energy absorption, high compression, and tensile strength) as a major weapon in battle to fit their species-specific combat behavior (Dhaka *et al.*, 2023).



**Plate I:** Goat horn



**Figure I:** Goat horn anatomy (source: Bello *et al.*, 2020)

Adekunle *et al.* (2023) developed vehicle brake linings that employ powdered cashew nutshell instead of asbestos, a lining material with good physical and chemical characteristics that has long been used in automobile brakes. Compression molding technique was used for fabrication of the brake lining samples, which were then examined for their physical and mechanical characteristics. The weight percent of the powdered particles and epoxy resin varies between 10% and 40% in a range of 5% for the formulation of seven samples, while the weight of alumina and graphite is 10% and barium sulfate is 30%. The results demonstrated adequate adhesion at high weight percentage of epoxy resin (Panda *et al.*, 2021). The brake pads' hardness, compressive strength, friction coefficient, water and oil absorption, relative density, and wear rate were all tested and compared to existing brake pad performance (Gholinezhad *et al.*, 2022). The findings suggest that crushed cow hoof might be utilized as a brake lining material in cars.

Lawal et al. (2019) produced agricultural-based vehicular brake pads with cashew shell and gum Arabic adhesives. The work aimed at producing green brakes pads that will be safe for human health. Taguchi design of experimental technique was created using the Minitab software tool, twenty-seven (27) distinct runs were obtained. The composite material developed showed good characteristics such as hardness (76.66BHN), compressive strength (12.187N/m<sup>2</sup>), friction coefficient (0.4848), wear index (1.16g/m), and extremely high ash retention (97.71 %), suggesting that the brake pad has strong heat capacity.

Maleque et al, (2012) developed natural fiber reinforced aluminum composite materials for automobile brake pads. Four different laboratory formulations were prepared using powder metallurgy technology to develop the natural fiber reinforced aluminum composites, with coconut fiber content ranging from 0, 5, 10, and 15 volume fractions. Other additives such as binders, friction modifiers, abrasives, and solid lubricants were appropriately incorporated. Density, porosity, microstructure analysis, hardness, and mechanical characteristics are among the attributes examined with a densitometer, scanning electron microscope, hardness tester, and universal testing machine. The coconut fiber composites with 5% and 10% coconut fiber exhibited better properties in terms of density, porosity and compressive strength. The compressive strength reveals that the BP3 formulation containing 10% coconut fiber has a stronger capacity to endure load applications and sustain compressive force. The coconut fiber is well dispersed in the matrix and works as a filler in the friction material. According to the morphological analysis of the material, the microstructure indicates a homogeneous dispersion of resin and coconut fibers. In comparison to other formulations, the physical and mechanical characteristics of the 5% and 10% formulations are superior. From the result obtained, natural coconut coir might be utilized as a potential filler in car brake pads. Table 4 showed the strength properties of best samples (BP2 and BP3).

**Table I:** Strength Properties of Sample BP2 and BP3

Properties	BP2	BP3
	5%	10%
Compressive strength (MPa)	414.75	393.11
Compressive strain (%)	9.11	11.61
Compressive load (N)	76742.7	75961.4

Source: Maleque et al., (2012)

## 2. Materials and Method

The materials selected for this work materials based on their functions are presented in Table 2 below, while laboratory equipment used included; sieve of aperture 300µm and 600µm (BS 410 -1), spatula, stirrer, bowls, 4-digits electronic weigh balance, scrapper, hand gloves, universal testing machine (INSTRON 3269), micro hardness tester (LECO LM700AT), Taber abrasion tester (TST) instrument (TSE-A017), extensometer, measurement tape, and inclined plane. All laboratory and workshop equipment used were assessed at Defense Industrial Cooperation of Nigeria (DICON) research and development center (R&D) situated in Kaduna, Nigeria, and Ebonyi state University of Technology, Ebonyi, Nigeria.



**Plate 2:** Unpulverized goat horn

### 2.1 Production and Formulation of the Composite

Six samples, each of varying percentages of reinforcement and matrix were prepared as presented in Table 3. Samples of the composite material made from goat horn as reinforcement and epoxy resin as binder for the brake pad was developed using compression molding technique; after which their mechanical and physical properties were studied.

**Table 2:** Functions of selected experimental Materials Used

S/No	MATERIALS	FUNCTIONS	REASON FOR SELECTION
1	Goat horn	Reinforcement	Goat horns are sometimes disposed as waste has low-cost with good mechanical and physical properties which can be custom fitted to meet the prerequisites of a specific application composite fabrication.
2	Epoxy resin and hardener	binder	Epoxy resin + Hardener (Diethylenetriamine) Since it is not commonly used in brake pad manufacture, its suitability as a binding agent was to be explored
3	Iron chips	filler	Iron chips are wastes cheaply/readily available at several workshop during machining in Nigeria, and studies from literatures revealed that they have properties which makes it suitable for application in friction lining manufacture.
4	Calcium carbonate (CaCO <sub>3</sub> )	adhesion	It is the cheaper alternative to barites. It influences adhesion and disperses polymer in composites.
5	Graphite	Friction Modifier	Powdered graphite has no potential danger as it is used for improving wet friction.
6	Silica	Abrasives	Silica is used because of its potential abrasive properties which enhances friction coefficient
7	Engine oil (SAE60)	Mould/Sample interface lubricant	Aid in detaching the sample after moulding.

**Table 3:** Weight (%) Composition of specimen formulation

Samples	A	B	C	D	E	F
Grain size (µm)	300	600	300	600	300	600
Epoxy resin (%)	60	60	55	55	50	50
Goat horn (%)	21	21	26	26	31	31
Iron chips (%)	3	3	3	3	3	3
Silica (%)	7	7	7	7	7	7
Graphite (%)	4	4	4	4	4	4
CaCO <sub>3</sub>	4	4	4	4	4	4
<b>Total (%)</b>	<b>100</b>	<b>100</b>	<b>100</b>	<b>100</b>	<b>100</b>	<b>100</b>

## 2.2 Method

The epoxy resin with hardener, graphite powder and iron chips powder presented in Plate 3,4, and 5 respectively were all obtained from a store house in Muda Lawal market Bauchi, Bauchi state Nigeria. The goat horn was obtained from a slaughterhouse in Sabon Tasha market Kaduna Nigeria, it was properly sun-dried by placing it under direct sunlight in an open environment and cleaned to remove impurities and subsequently pestle and mortar was used to smashed it into a smaller particle, attrition grinding machine was used to grind and sieve using a sieve of 300 µm and 600 µm aperture



**Plate 3:** Epoxy resin and hardener



**Plate 4:** Graphite Powder



**Plate 5:** Iron chips



**Plate 6:** Pulverized goat horn of 300µm and 600 µm



**Plate 7:** Mould



**Plate 8:** Mould cavity

A control test was first performed by pouring 300g of goat horn into the moulds (Plates 7 and 8) to determine the exact amount of mixture that would completely fill the mould cavity. Reinforcement material (goat horn), matrix (epoxy resin and hardener) weights were all varied while the friction modifier (pulverized graphite), filler (iron chips) and silica (abrasives) weight were constants. For each formulation, known amount (expressed in wt.%) of filler, friction modifier, abrasive and reinforcement were measured into a container and thoroughly mixed for some minutes to obtain homogeneity. A known amount of epoxy resin was poured into a separate container with a measured quantity of hardener added to the portion. The mixture of epoxy resin and hardener were also thoroughly stirred to obtain homogeneity. Then, this matrix mixture was poured onto the powdered material mixture and stirred to obtain a paste-like homogenous mixture and was pressed with the aid of the hydraulic press machine at 100 KN force for 5 minutes at room temperature and allowed to cure for 80 minutes. Before pouring the paste into the mould, engine oil (SAE 60) initially was applied to the mould for easy removal of specimens after curing. Resistance to flow of paste decreased as percentage by weight of matrix (binder) increased. The curing process timed for some minutes depends on the ratios of epoxy resin to hardener in the mixture.



**Plate 9:** Brake pad made from goat horn

## 2.3 Mechanical and Physical Properties Test

To ascertain the suitability of a material for friction application, tests carried out included water and oil absorption tests, wear (abrasion) resistance test, frictional test, hardness test and compressive strength test.

### 2.3.1 Water and oil absorption tests

Six samples of dimension 20 mm x 10 mm x 5 mm were cut out of the molded samples and used for the water and oil absorption test. Initial weight (dry weight) of each specimen was taken and recorded as  $W_0$  before soaking in SAE60 auto engine oil and distilled water separately for 21 days. After that, specimens were brought out of oil and water, thoroughly cleaned to remove water and oil on surfaces, a new weight was recorded as

$W_1$ . Differences in initial and final weights for each specimen were then used to determine absorption Rate. (Ogundana, 2015). The percentage of absorption of the samples was obtained using the following Equation (i)

$$\text{Absorbion \%} = \frac{w_1 - w_0}{w_0} \times 100 \quad \text{I}$$

Where:  $W_0$  = specimen weight before immersion and  $W_1$  = specimen weight after immersion.



**Plate 10:** Water(distilled) absorption test



**Plate 11:** Automotive oil absorption test

### 2.3.2 Wear (abrasion) resistance test

This test was carried out with the aid of a Taber abrasion tester (TAT instrument). Each test specimen measured 100 mm diameter and 10 mm thickness. The specimens were weighed and recorded as  $W_0$  before the test using a 4-digit electronic weigh balance (Mobi et al., 2021). The test specimen was fixed to the rotary disc (100 mm dia.) of the machine with the aid of a nut at its center. Two emery wheels at the upper arm of the machine had direct contact with the specimen fastened to the rotary disc. When the machine was turned on (powered at 220V) and the disc rotates at a constant speed of 100 rev/mins for a pre-set time of 100 seconds. As the disc rotates, the two emery wheels in direct contact with the specimen also rotated at a relative speed to the disc which caused the specimen to wear. After the pre-set time, the machine was turned off. The specimen was then cleaned thoroughly before the final weight was measured and recorded as  $W_1$ . The weight loss of the specimen was determined by finding the difference between the final and initial weights. Where,  $W_0$  is the initial weight,  $W_1$  is the final weight,  $\Delta W$  is the weight loss,  $S$  is the sliding distance,  $D$  (100 mm) is the disc diameter,  $N$  (100 rev/mins) is the radial speed (rpm), and  $t$  (100 secs) is the time taken to expose each specimen to wear as reported by Olabisi et al., (2016).

$$W_r = \frac{\Delta W}{2\pi N R t} \quad \text{2}$$

where:  $W_0$  = initial weight;  $W_1$  = final weight;  $\Delta W$  = weight loss;  $S$  = sliding distance;  $D$  = disc diameter;  $N$  = radial speed (rpm) and  $t$  = time taken to expose specimen to wear

### 2.3.3 Friction coefficient test

The coefficient of friction between the linings and steel was determined using a steel inclined plane. The plane was kept at  $180^\circ$  (horizontal position). Each sample was attached to a string and placed on the plane. The string was passed through a pulley, which was connected to a mass hanger. Standard masses were added to the mass hanger until the lining began to slide along the surface of the steel plane. The coefficient of friction is the ratio of frictional force (equivalent to mass at hanger to initiate sliding) to the normal reaction (weight of break lining). The equation below was used to calculate the coefficient of friction ( $\mu$ ) between the linings and steel as used by Bala et al., (2016).

$$\text{Coefficient of fiction}(\mu) = \tan(\theta) \quad \text{3}$$

### 2.3.4 Hardness test

This test was performed with the aid of a digital Micro Hardness Tester of 490.3 $\mu$ N load sensitivity. This was used to assess the resistance of the manufactured brake pad against indentation. It was carried out in accordance with the American Society of Testing and Materials' guidelines (ASTM). The sample was cut into a rectangular form as required. Each sample was flattened out on a firm surface. After that, the instrument's

indenter was pushed into the specimen. The durometer was used to determine the hardness values done by Olabisi et al., (2016).

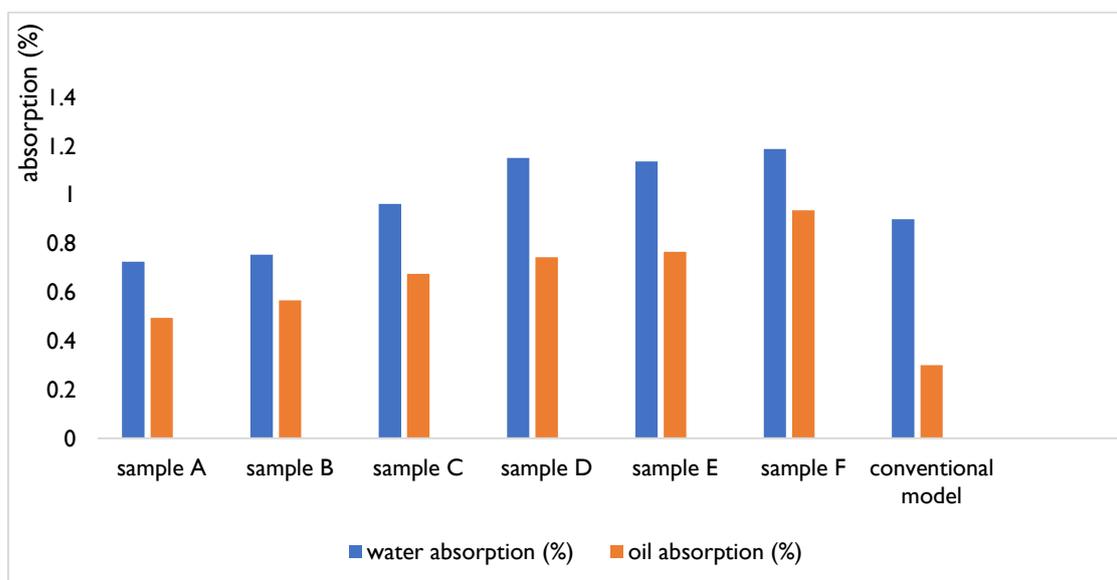
### 2.3.5 Compressive strength test

Compression test on the specimen was done with the aid of an electronic universal testing machine (model: INSTRON 3369). Test samples were shaped and dimensioned as 30 mm x 15 mm x 5 mm. The compression was used as the reverse of tensile test as a standard method of testing brittle and other materials because the compressive strength of materials when carefully done also gives direct information on the tensile strength (Xiao et al., 2024). The compression was performed by placing the specimen between the compression plates provided in the adjustable cross head and bottom crosshead. After the specimen was properly positioned and gripped firmly between the compression plates, load was applied and the compressive strain reading was shown from the output display unit. The load was gradually applied on the specimen, and the corresponding strain was recorded at regular intervals.

## 3. Results and Discussion

### 3.1 Water and oil absorption

The average water and oil absorption test results for the six (6) formulated composite specimen of brake pads are shown in Figure 2. The bar chart showed the percentage of oil/water per composite pad composition as computed using equation (1).



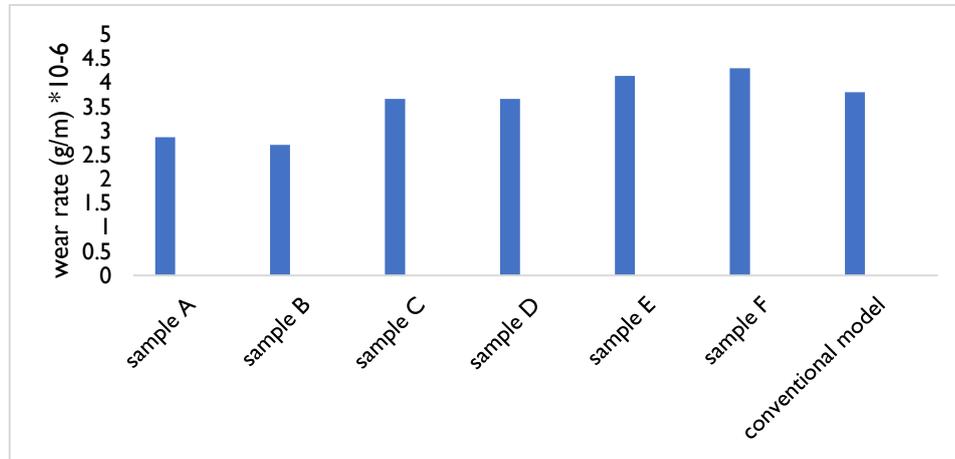
**Figure 2:** Water and oil absorption of various samples

It can be seen from Figure 2 that the water absorbent property of samples increased as weight percentage of reinforced material increased from 21% to 31% in the formulation. Oil absorption of samples increased as reinforced content increased from 21% to 31% in formulation respectively. This increased water and oil absorption rate may be due to the increased interfacial bonding between binder and filler particle that caused increased porosity (Akıncioğlu et al., 2021). The result compared favorably with the conventional model rate of water and oil absorption rates of 0.9% and 0.3% respectively. Water absorption rate of each composite A, B, C, D, E and F deviated from that of conventional brake pad by 0.175, 0.146, -0.063, -0.62, -0.238 and -0.288 respectively. While the Oil absorption rate of composites A, B, C, D, E and F deviated from that of conventional brake pads by -0.194, -0.267, -0.375, -0.466, -0.466 and -0.637 respectively. Negative variance indicated that water and oil absorption of composite was lower than that of conventional model showing its superiority over the latter (Ogundana, 2025). This shows that the goat horn reinforced composite brake pad produced in this work had better water/oil absorption than conventional model and will offer better resistance on exposure to environmental water vapor and oil on application.

### 3.2 Abrasion (wear) Resistance

Three (3) sets of wear rate tests were conducted for each specimen composition and the average value was determined using equation 2. Figure 3 shows the wear rates comparison between experimental composite

brake pad and commercial brake pad, the result shows that wear rate of experimental brake pads increased as epoxy resin content decreased from 60 to 50%. This is because the reinforcement acted both as friction and abrasion resistant material in the composite. This could be attributed to decreasing interfacial bonding between goat horn particles and epoxy resin, increasing possibility of particles pull out (increase wear) as binder content decreased. Wear rate of conventional brake pad is  $3.80 \times 10^{-6}$  g/m as reported by Olabisi et al., (2016) indicating that the samples A, B, C and D meet up to the required values of the wear rate while samples E and F having higher wear rates.

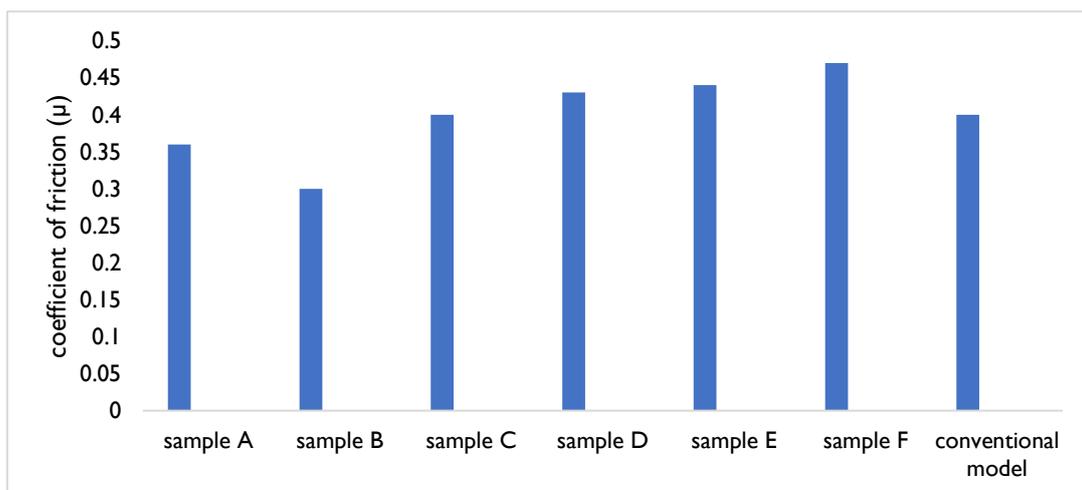


**Figure 3:** Wear rate of different samples

The wear rates of the composite brake pad samples compositions A, B, C, D, E and F differed from that of conventional brake pad by 0.935, 1.094, 0.139, 0.139, 0.338 and -0.497 respectively. Sample A with 60% binder and 40% composite has superior wear rate as compared with the conventional brake pad.

### 3.3 Coefficient of Friction

Figure 4 showed the results for coefficient of friction of different samples produced (A, B, C, D, E and F) as 0.36, 0.30, 0.40, 0.43, 0.44 and 0.47 respectively. The results reveal coefficient of friction increased as filler content of mix increased in each sample. The samples coefficient of friction was compared to conventional model and was found favorable. Sample F with 50% epoxy resin and 31% of goat horn composition was the highest with friction coefficient of 0.47. The coefficient of the friction of any conventional brake pad is usually in the range 0.3 - 0.4 (Ogundana, 2015). This shows that the six composites' formulations satisfy the range required for coefficient of friction of brake pad material.

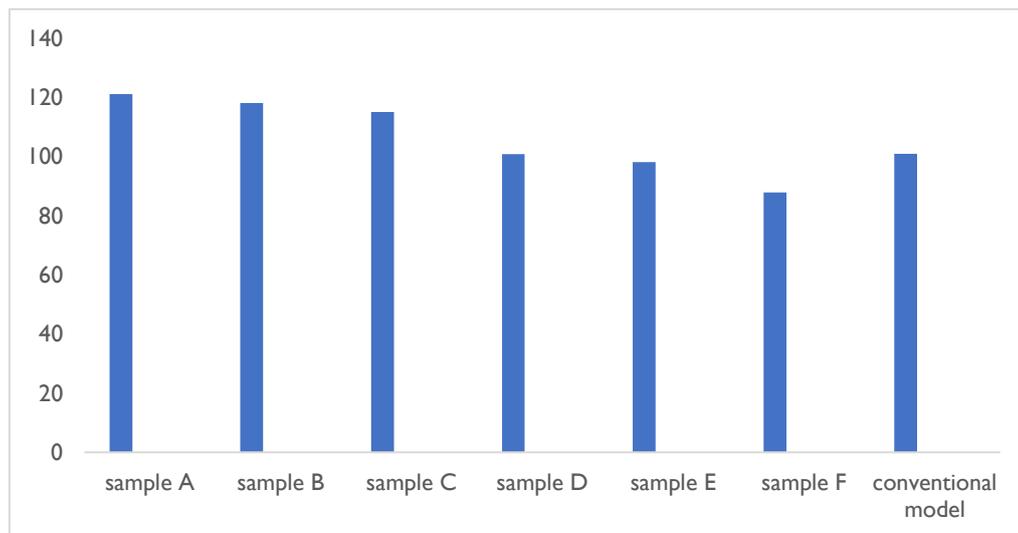


**Figure 4:** Coefficient of friction of different samples

### 3.4 Hardness

Figure 5 showed the hardness (Vickers) value of brake pads samples. The results established that the materials' hardness varied non-uniformly as the epoxy resin (binder) percentage by weight decreased in the formulation.

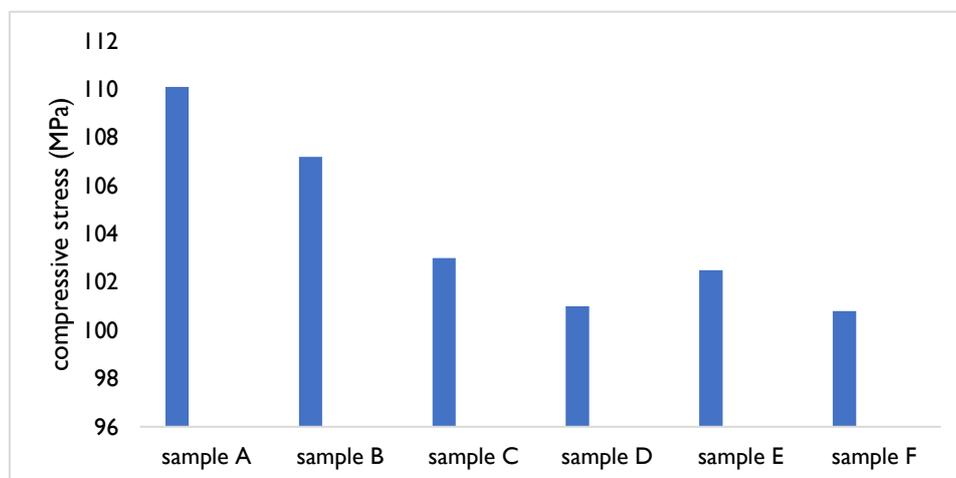
The hardness value of conventional brake pad is 101 MPa while that of experimental composite specimen sample A, B, C, D, E, F had 121.21, 118.13, 115.11, 100.83, 98.18 and 87.94 respectively. From the results obtained, it can be concluded that the samples produced can compete favorably with the conventional one falling within the range of 78 – 110MPa (Essam *et.al.*, 2025).



**Figure 5:** Vicker's hardness value of the various samples

### 3.5 Compressive Strength

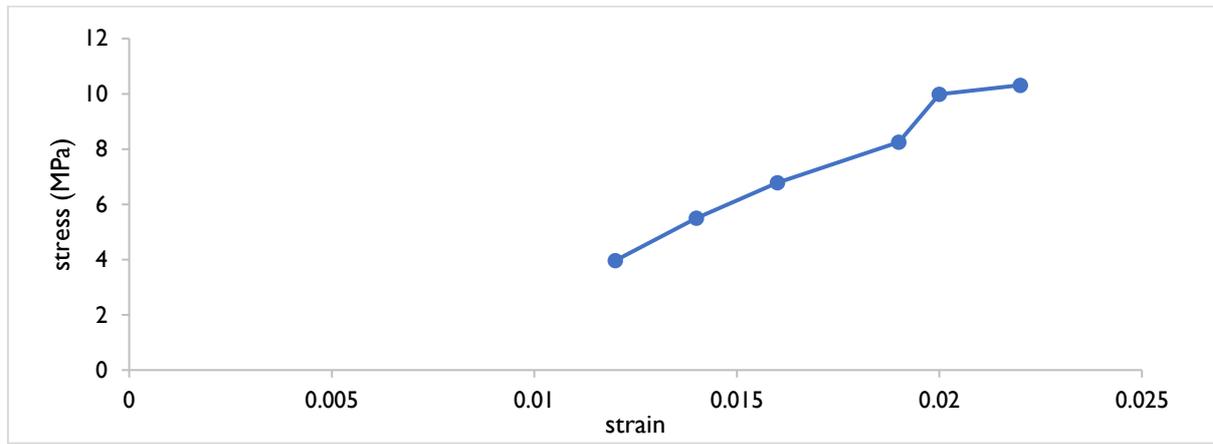
Figure 6 showed the result of compressive strength of the composite pad produced. The compressive strength values recorded for each composite specimen were compared with each other based on composition.



**Figure 6:** Compressive strength of different brake pad composites

The compressive strength decreased with a decrease in the wt.% of epoxy resin content and fair dispersion of the filler (goat horn) particles with the binder resulting in fair filler particle to binder interaction. The fair particle dispersion improved the particle to binder interaction and consequently increased the ability of the brake pad formulation to restrain gross deformation (Olabisi *et al.*, 2016). The stress-strain analysis of each specimen is presented in Figure 6.

Figure 7 shows a successive increase in stress-strain values with relative increase in filler content in the formulation for each of the specimen types. The decrease in compressive strength with relative decrease in epoxy resin was due to the interference of particles in the mobility or deformability of the matrix. This interference was created through the physical interaction and immobilization of the binder by the presence of mechanical restraints, thereby reducing the strength (Olabisi *et al.*, 2016). Table 4 compares the properties of the produced samples of brake pads A and B with the properties of conventional brake pad (Asbestos-based), Palm kernel shell brake pads and Egg shell-based brake pads, an indication that goat horn based brake pads can also be a suitable substitute for automobile brake pads.



**Figure 7:** Stress-Strain graph of composite brake pad samples

**Table 4:** Summary of the results compared with the existing laboratory brake pads

Properties	Asbestos-based Brake pad	Palm kernel Shell Brake pad	Egg Shell particles Brake pads	Goat Horn Particles Brake pads (Samples A and B)
Water Absorption (%)	0.90	5.03	0.90	0.73 and 0.75
Oil Absorption (%)	0.30	0.44	0.31	0.49 and 0.57
Coefficient of Friction	0.3-0.4	0.44	0.3	0.36 and 0.30
Compressive Strength (MPa)	110.0	103.5	103.0	110.1 and 107.2
Hardness (MPa)	101	92	99.1	121.21 and 118.13
Wear Rate (g/m) $\times 10^{-6}$	3.8	4.4	4.0	2.85 and 2.7

Source: Adekunle et al. (2023) and Nwankwo et al., (2024)

#### 4. Conclusion

This study investigated production of goat horn particles as a reinforcement in epoxy resin composite for automobile brake pad applications. The composite material was fabricated by mixing the goat horn particles and epoxy resin in different proportions and then curing them at room temperature. The composite material is tested for its mechanical and physical properties. The results showed that specimen composite samples produced gave the optimum performance results for water absorption and oil absorption, abrasion resistance, coefficient of friction, hardness, and compressive strength with the following values; 0.725%, 0.494%,  $4.297 \times 10^{-6}$  g/m, 0.36, 121.21 MPa and 103.13 MPa respectively. The results were compared with the conventional brake pads and those of other research works produced in past related to asbestos free brake pads making. Based on the results, goat horns are very suitable eco-friendly replacement for asbestos friction materials in automotive brake pads.

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