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PRODUCTION AND TRIBOLOGICAL EVALUATION OF BRAKE PAD MADE FROM LOCALLY AVAILABLE MATERIALS

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Abstract: *This study explores the design and production of environmentally sustainable automobile brake pads using locally sourced and renewable materials. Cow horn and palm kernel shells, known for their non-toxic properties, were selected as primary base materials, while epoxy resin with hardener functioned as a binder. Additionally, iron filings were incorporated as a reinforcement agent, and graphite powder was included to enhance lubrication. The developed composite brake pads were subjected to comprehensive physical, mechanical, and tribological property evaluations to determine their suitability for automotive applications. Key parameters such as density, compressive strength, and wear resistance were analyzed, with results demonstrating that brake pads produced from locally available materials exhibited promising properties.Among the tested formulations, the sample comprising 40% cow horn, 25% palm kernel shell, 5% graphite, 10% iron filings, and 20% epoxy resin with hardener yielded the most favorable performance metrics, including optimal density and compressive strength, as well as minimal wear rate. These findings highlight the potential of integrating agricultural and animal by-products into advanced material design, providing an eco-friendly and cost-effective alternative to conventional brake pads while addressing environmental and health concerns associated with asbestos. This study underscores the viability of sustainable materials for high-performance automotive applications and contributes to the growing body of research on green composite materials.*

Keywords: *Automobile, Sustainability, Brake Pad, Environmental, Renewable Materials,*

1 Introduction

The growing global demand for eco-friendly and sustainable materials has sparked significant interest in the development of renewable alternatives to conventional engineering materials. This shift is driven by the need to mitigate environmental degradation and address health hazards associated with synthetic materials. In the automotive sector, brake pads are among the most critical components for ensuring vehicle safety. These components must exhibit excellent mechanical strength, thermal stability, wear resistance, and durability to withstand the rigorous conditions of operation (Abutu et al., 2018). Traditionally, asbestos and other synthetic materials have been the preferred choice for brake pad manufacturing due to their superior

performance. However, extensive research has shown that asbestos poses serious health risks, including carcinogenic effects on individuals exposed to wear-out particles. Such risks, particularly for vehicle mechanics who handle and replace worn brake pads, have led to a global movement discouraging the use of asbestos (Baskara Sethupathi & Chandradass, 2021; Gudz et al., 2023; Lemen, 2004; Ragadhita et al., 2023; Yawas et al., 2016). As a result, the exploration of sustainable and biodegradable alternatives has gained considerable momentum in recent years (Juan et al., 2020). These days, the demand for eco-friendly products has grown significantly as a result of strict regulations meant to stop future environmental harm and increased global eco-awareness. One potential way to lessen the health risks associated with particle release during braking is to incorporate eco-safe ingredients into materials for production of items, such brake pad systems (Di Confiengo & Faga, 2022).

Braking is a fundamental process that ensures the safety of vehicles by decelerating or halting their motion. This process is enabled by a braking system, which consists of multiple devices working in conjunction to achieve effective braking (Ilie & Cristescu, 2022). Within this system, the brake pad serves as the stationary friction material that comes into contact with a rotating brake disc or drum. The quality and performance of the brake pad are pivotal to the overall efficiency of the braking system. Consequently, brake pads are required to possess specific properties, including lightweight design, corrosion resistance, low wear rate, reduced noise during operation, extended service life, and cost-effectiveness (Akagündüz et al., 2014). However, the reliance on asbestos-based brake pads has raised significant environmental and health concerns, emphasizing the urgent need for safer and more sustainable alternatives.

In the quest for eco-friendly materials, agricultural and animal waste by-products have emerged as promising candidates for brake pad production (Anaidhuno et al., 2017). These materials are not only renewable but also readily available, making them cost-effective and environmentally sustainable. Among these, cow horn and palm kernel shell have shown considerable potential due to their unique mechanical and thermal properties. Cow horn, primarily composed of keratin and calcium phosphate, is known for its strength and thermal resistance, making it suitable for high-stress applications (Yu et al., 2014; Li et al., 2010). On the other hand, palm kernel shell, which is rich in carbon content, offers excellent abrasion resistance and wear properties. The combination of these materials in a composite formulation provides an innovative approach to developing brake pads with enhanced performance characteristics while addressing sustainability goals.

This study is aimed at the production and performance evaluation of brake pads made from cow horn and palm kernel shell composites. The research focuses on optimizing the composite formulation to achieve superior mechanical properties and operational efficiency. Specific objectives include assessing critical properties such as compressive strength, wear rate, and thermal resistance. By leveraging locally available and renewable materials, this study seeks to contribute to the global effort of reducing environmental impact and dependency on non-renewable resources. Furthermore, it addresses the need for a safer alternative to asbestos-based materials, aligning with the growing demand for sustainable and health-conscious innovations in the automotive industry. Through this work, it is anticipated that the findings will pave the way for the development of cost-effective, high-performance, and environmentally friendly brake pads suitable for widespread application.

2.0 Methodology

2.1 Material collection

The cow horns used in this study were procured from Owode Market, located in Offa Local Government Area of Kwara State, Nigeria. The horns were sun-dried for three days to reduce moisture content and subsequently polished using abrasive materials to eliminate residual carbon deposits from their surfaces. The polished horns were then transported to the Nigerian Institute of Leather and Science Technology (NILEST) in Zaria, where they were milled into a fine powder.

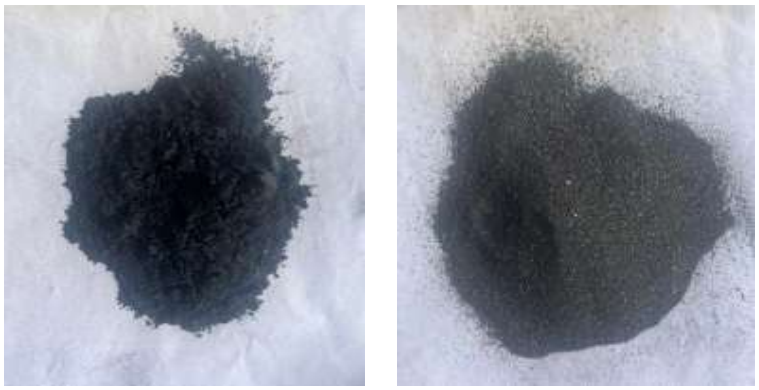
Similarly, palm kernel shells were sourced from Ikirun, situated in the Ifelodun Local Government Area of Osun State, Nigeria. To remove residual oil, the shells were soaked in a solution of soapy water for 24 hours, thoroughly washed with clean water, and sun-dried for three days to ensure complete moisture removal. The dried shells were then milled into powder for further analysis.

2.2 Preparation of raw samples

The mass of each sample was determined using a digital analytical balance. The pulverized samples were classified based on particle size using a series of sieves with apertures of 25 µm, 50 µm, 65 µm, and 80 µm. Following sieving, the constituents of each sample were accurately weighed using the digital balance. Subsequently, the weighed samples were transferred into individual plastic containers, and the appropriate quantity of epoxy resin was measured and added.



(a) **(b)** **(c)**



(d) **(e)**

Figure 1: Constituents of the Brake Pad (a) Powdered form of Cow horn (b) the mold, (c) Palm kernel shell powder (d) Graphite Powder (e) Iron filings

2.3 Formulation and Production of the Brake Pad

The production process of brake pads involves a series of unit operations, including mixing, cold and hot pressing, cooling, post-curing, and finishing. The primary constituent materials used in this study include cow horn powder, palm kernel shell (PKS) powder, graphite powder (CAS No. 7782-42-5), iron filings, and epoxy resin as shown in figure 1. These materials were combined in varying compositions and particle sizes. Initially, the measured quantities of cow horn powder, PKS powder, graphite powder, and iron filings were manually blended to ensure uniformity. Subsequently, a mixture of epoxy resin and hardener was added to the blend and thoroughly mixed using a manual stirrer to achieve a homogeneous composition. The resulting mixture was then transferred into a prepared mold and subjected to compression at a pressure of 100 kN/m² using a manual compression machine. This was achieved by placing the mold between the compressive plates of the machine and releasing the piston to apply the required force, forming the brake lining. The mold being equipped with a heating element was heated to 90 ℃ simultaneously during compression and for a curing time of 8 minutes for each sample.

The varying compositions resulted in the production of distinct samples, each weighing 100 g, designated as Samples A to D. The specific mass composition of each sample is detailed in Table 1.



Figure 2: Cow horn reinforced brake-pad samples

Table 1: Sample Compositions of Brake Pad

Samples	Cow Horn (g)	Palm kernel shell (g)	Graphite Powder (g)	Iron fillings (g)	Epoxy Resin (g)	Total (g)
A	80	-	-	-	20	100
B	55	25	-	-	20	100
C	40	25	5	10	20	100
D	40	30	5	5	20	100

2.4 Physico-mechanical Characterization of the Produced Brake Pad

2.4.1 Density Test

The density of the samples was determined by weighing the samples on mass on a digital weighing machine and measuring their volumes by liquid displacement method.

$$\rho = \frac{m}{V}$$

where ρ, m and v are the density, mass and volume respectively

2.4.2 Compressive Strength Test

The compression test was conducted to evaluate the maximum compressive load the brake lining could withstand prior to fracture. The experiment was performed using a Universal Testing Machine (Testometric FS5080) with a load capacity of 50 kN. During the test, the specimen was subjected to a gradually increasing load applied between the plates of the compression testing apparatus. The compressive strength (F) is determined using the following equation:$F = \frac{P}{A}$

Where *P* is the maximum force or load applied at the point of failure and *A* is the cross-sectional area of the specimen.

2.4.3 Wear Abrasion Test

The wear testing process was conducted using a pin-on-disc apparatus, as illustrated in figure 3, under controlled dry wear conditions. The procedure began with the measurement of the initial weight of the specimen to establish a baseline for the subsequent wear analysis. Following this, the specimen was carefully inserted into the specimen holder, ensuring proper alignment and secure fixation to prevent any undesired movement during the test. A load of 10 N was then applied to the supporting rod, ensuring that the stylus pin made firm and consistent contact with the surface of the specimen, as depicted in the diagram.

Once the setup was confirmed to be secure, the electric motor of the apparatus was activated, rotating the specimen for a total of 20 cycles. This controlled rotation facilitated the wear process under uniform conditions. Upon completion of the cycles, the specimen was removed, and its final weight was meticulously measured to quantify the wear that occurred during the test. Additionally, the sliding distance covered by the

specimen during the test was carefully calculated to provide a comprehensive understanding of the wear characteristics under the given conditions. This systematic approach ensured the reliability and reproducibility of the wear testing process.



Figure 3: Wear Abrasion Test machine

$$W_s = \frac{\Delta V}{Fn \times S_s} \quad \ldots\ldots (1)$$

Where S_s = Sliding distance (mm), F_N = Normal load (N)

$$\text{Wear resistance} = \frac{\text{Sliding Distance (S)}}{\Delta V} X\ 1000 \quad \ldots\ldots (2)$$

3.0 Results and Discussions

3.1 Results

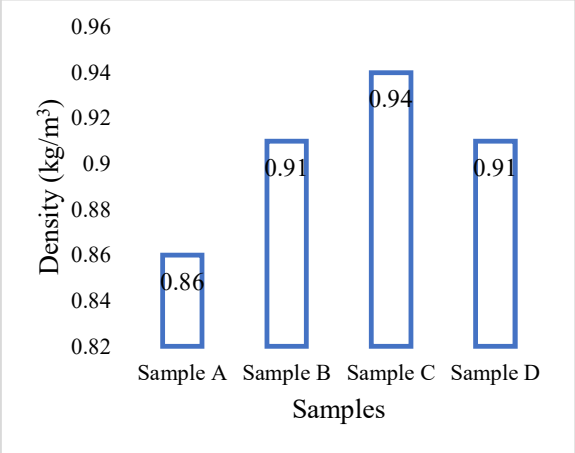


Figure 4: Bar charts showing the densities of the samples

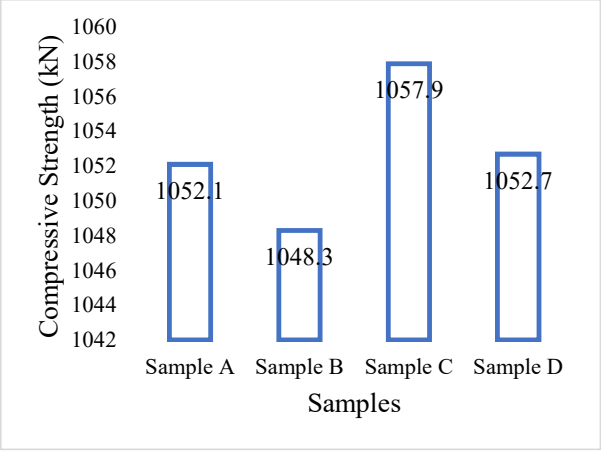


Figure 5: Bar charts showing the Compressive Strengths of the samples

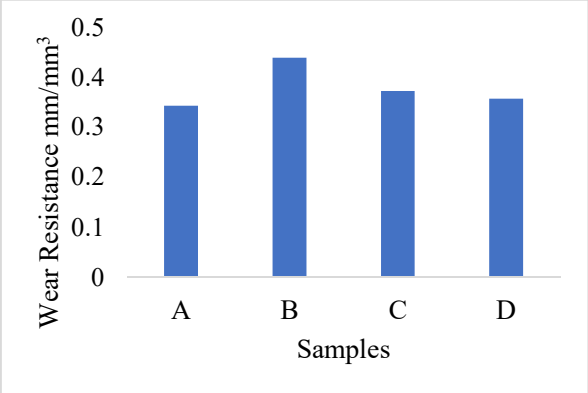


Figure 6: Bar charts showing the Wear Resistance of the samples

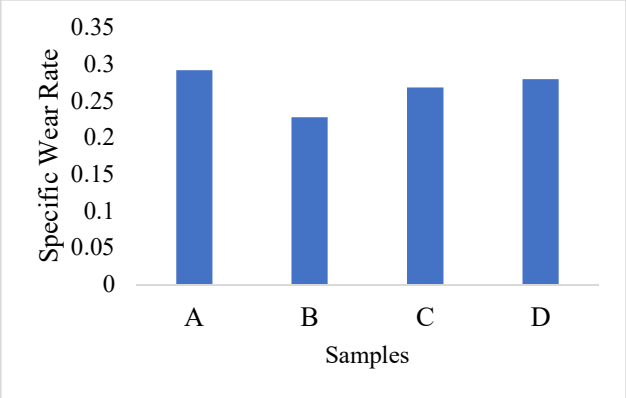


Figure 7: Bar charts showing the Specific Wear Rate of the samples

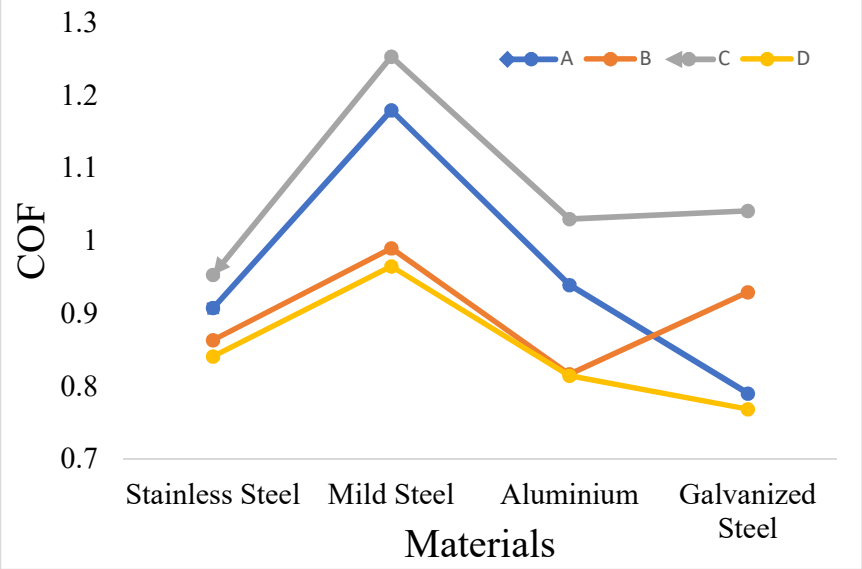


Figure 8: Graph showing the Coefficients of Friction of the samples on different materials

3.2 Discussions

Due to the presence of significant amount of iron filings, reduction to the least volume was easier in sample C, thereby increasing its density. As shown in figure3, sample C exhibits the largest density (0.94 kg/m^3) while samples B and D both have equal density of 0.91 kg/m^3.

Figure 5 presents the results of the compressive strength test conducted on the produced samples. Among all the samples, Sample C exhibited the highest compressive strength, measuring 1057.9 kN. This superior performance can be attributed to the higher content of iron filings present in Sample C. The observation is further supported by the compressive strength results of Sample D, which, although slightly lower than that of Sample C, provides insight into the role of material

composition. Despite Sample D containing a higher quantity of palm kernel shell (30 g) compared to Sample C (20 g), the increased proportion of iron filings in Sample C (10 g) compared to Sample D (5 g) appears to significantly enhance its ability to withstand compressive loads. This suggests that the iron filings, being mechanically stronger than the palm kernel shell, contribute more effectively to the overall compressive strength of the sample.

The tribological performance of the evaluated samples is comprehensively presented in Figures 6, 7, and 8, offering a detailed comparison of their wear resistance and coefficient of friction (COF) under different testing conditions. Among the analyzed samples, Sample B exhibits the highest wear resistance, indicating its superior ability to withstand material degradation under sliding contact. This performance is closely followed by Sample C, which also demonstrates commendable wear resistance, albeit slightly lower than that of Sample B. On the other hand, Sample A shows a markedly higher wear rate compared to both Sample B and Sample C, suggesting its lower tribological efficiency and reduced durability under similar conditions.

When examining the coefficient of friction (COF), Sample C consistently records the highest values across tests conducted against various counterface materials. This finding highlights Sample C's comparatively greater frictional resistance, which is notably higher than that observed for both Sample A and Sample B. The elevated COF of Sample C may be indicative of its surface characteristics or the nature of interactions with the tested materials, warranting further investigation into the underlying mechanisms. These findings provide valuable insights into the comparative tribological properties of the samples, showcasing distinct performance trends across different parameters.

Conclusion

In conclusion, the study highlights the pivotal role of material composition in determining the mechanical and tribological properties of the analyzed samples. Sample C, with its higher iron filing content, consistently outperformed the other samples in terms of density, compressive strength, and coefficient of friction, emphasizing the superior contribution of iron filings to structural integrity and frictional performance. Despite the increased palm kernel shell content in Sample D, its compressive strength was slightly inferior to that of Sample C, reaffirming the mechanical dominance of iron filings over less robust components. On the other hand, Sample B demonstrated exceptional wear resistance, showcasing its potential for applications requiring enhanced durability under sliding contact. These findings underscore the complex interplay between constituent materials and their collective influence on performance metrics.

The observed trends not only advance our understanding of material optimization but also pave the way for tailored applications in industries where mechanical strength and tribological efficiency are critical. Future research should delve deeper into the microstructural and interfacial dynamics to elucidate the mechanisms underlying these performance characteristics, thereby offering avenues for further refinement and innovation.

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