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GREEN REINFORCEMENTS IN FRICTION MATERIALS: THE CASE OF EGGSHELL PARTICULATES IN NON-ASBESTOS BRAKE PADS

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ABSTRACT

As the automotive industry transitions toward environmentally sustainable technologies, there is a growing need to replace hazardous materials in critical components such as brake pads. This study examines the reliability and environmental sustainability of non-asbestos brake pads reinforced with eggshell particulates (ESPs), a biodegradable, calcium carbonate-rich waste material. Considering the health and environmental hazards associated with asbestos, there is a growing demand for safer, eco-friendly alternatives in friction materials. Composite formulations incorporating ESPs of 20 µm, 25 µm, and 30 µm particle sizes were developed to evaluate their effects on key performance metrics, including wears resistance, hardness, and long-term reliability. The results reveal that brake pads reinforced with 20 µm ESPs demonstrated superior hardness and wear resistance, achieving a 94% reliability rating over one year of simulated use. These findings highlight the potential of ESP-based composites as sustainable, high-performance alternatives for automotive braking systems, offering both environmental and functional benefits.

KEYWORDS: Reliability, Brake pads, Wears resistance, Composite.

1.0 INTRODUCTION

The braking system is a critical component in any vehicle, responsible for safe conversion of kinetic energy into heat to bring the vehicle to a stop. Traditionally, brake pads were made using asbestos due to their durability, high-temperature tolerance, and cost-effectiveness. However, research over the past decades has revealed significant health risks associated with asbestos, including respiratory diseases and cancer, leading to its restriction and the search for safer alternatives (Gonzalez & Silva, 2021; Kumar, Singh & Ahuja, 2022). Regulatory agencies and industry stakeholders have intensified efforts to transition to safer materials, with non - asbestos organic (NAO) brake pads gaining popularity because of improved safety and environmental considerations (Oke, Adegbenjo & Udo, 2023).

The automotive industry is under increasing pressure to adopt safer, more sustainable materials, especially considering environmental and health concerns surrounding conventional brake pad materials. Asbestos, a historically popular material in friction applications, has been widely used in brake pads due to its outstanding thermal stability, frictional characteristics, and durability (Edokpia et al., 2016; Kumar, Singh & Ahuja, 2022). However, numerous studies have documented the severe health risks posed by asbestos exposure, including lung diseases and mesothelioma, prompting a global shift towards non-asbestos brake pad formulations (Gonzalez & Silva, 2021). This regulatory and societal pressure has catalyzed research into non-asbestos organic (NAO) brake pads that aim to deliver comparable performance while being safer for both manufacturers and end-users (Oke, Adegbenjo & Udo, 2023).

In response to these demands, researchers have explored various organic and mineral-based additives, with a particular focus on renewable and waste-derived materials. Bio-waste sources such as rice husks, palm kernel fibers, and coconut shells have shown potential in terms of thermal and wear properties, but each presents unique challenges in manufacturing and performance consistency (Bello et al., 2018; Liu, Chen & Wang, 2023). Among bio-waste materials, eggshells offer distinct advantages: they are abundant, largely underutilized, and composed mainly of calcium carbonate, which gives them notable hardness, thermal stability, and compatibility with composite materials (Ibrahim, Mustapha & Hassan, 2023). Moreover, using eggshells as an additive aligns with circular economy principles, promoting waste-to-wealth initiatives that reduce environmental pollution by repurposing biowaste (Choudhury, Ahmed & Roy, 2022).

Eggshells consist primarily of calcium carbonate (94%), along with minor organic compounds that contribute to their toughness and wear resistance (Rahman, Basha & Ali, 2021). As a brake pad additive, eggshell particulates provide the potential to enhance key performance indicators such as wear resistance, heat dissipation, and friction stability across a range of operating conditions. The introduction of eggshell particulates could also help offset the need for synthetic fillers, which are often more costly and less environmentally friendly (Sa'ad et al., 2021). Recent studies indicate that the mechanical strength and thermal conductivity of bio-derived additives like eggshells can improve the operational efficiency and longevity of non-asbestos brake pads, making them a viable alternative for automotive applications (Zhang, Lee & Park, 2023).

This study examines the dependability of non-asbestos brake pads that contain eggshell particles and examines how this bio-derived additive influences wear resistance, thermal performance, and frictional stability. It aims at demonstrating the feasibility of eggshells as an environmentally friendly alternative that meets industrial standards through extensive laboratory testing and performance evaluation. The findings of this study contribute to the global effort to remove asbestos from brake systems, which will help the automobile industry transition to safer and more ecologically friendly materials. By elucidating the performance attributes and practical applications of eggshell-derived brake pads, this investigation seeks to establish a scientific basis for their integration into conventional automotive usage, promoting a harmonious coexistence of performance, sustainability, and economic feasibility.

1.1 Objectives of the Study

The objectives of this study are:

i. To evaluate the reliability, hardness, and wear resistance of non-asbestos brake pads reinforced with eggshell particulates (ESPs) of varying particle sizes (20 µm, 25 µm, and 30 µm).

ii. To assess the long-term reliability of the developed brake pads using a failure rate model.

2.0 MATERIALS AND METHODS

This study adopted an experimental research design to evaluate the mechanical and reliability performance of composite brake pads formulated with eggshell particulates (ESPs) of varying particle sizes. The research simulates real-world use conditions and assesses how the particle size of ESP affects critical performance metrics. Polyethylene, MAX 1618 hardener, and alumina powder were sourced from chemical vendors in Ojota, Lagos State, Nigeria. Barite and basalt minerals were obtained from Keffi, Nasarawa State, Nigeria and processed through crushing, grinding, and milling using a planetary ball mill at the ceramic department, Federal Institute of Industrial Research Oshodi (FIIRO), Lagos State, Nigeria. Eggshells were collected as waste from food vendors around the Yaba College of Technology (Yabatech) campus, Lagos, Nigeria. The eggshells were cleaned, sun-dried, milled, and sieved to three particle sizes: 20 µm, 25 µm, and 30 µm, respectively.

Table 1 presents the formulation breakdown, composite specimens were produced in rectangular molds (7 cm × 12 cm × 0.5 cm depth), with petroleum jelly used as a release agent. Polyethylene was melted at 140°C, mixed with hardener, and stirred magnetically at 150°C before combining the dry ingredients. Compression molding was then carried out at 20 MPa and 150°C for 20–25 minutes. Post-curing was done at 80 – 100 °C for 2 – 3 hours to reduce residual stress and improve bonding.

Three composite sample types were produced: Sample A (20 µm), Sample B (25 µm), and Sample C (30 µm). These were not compared to a commercial control pad but rather benchmarked internally against each other to evaluate the impact of particle size variation.

The hardness and wear resistance tests were carried out at the Metallurgical Laboratory, University of Lagos, Akoka, Lagos, Nigeria. The Brinell hardness test used a 2.5 mm steel ball tip with a 62.5 kgf load. Wear tests were performed under controlled conditions (lining pressure of 1.05 MPa and speed of 6 m/s), and reliability analysis was derived from wear rates using an exponential model to simulate 1-year operational life.

Table 1: Material, Task and Weight %.

Constituents	**Material Group and Tasks**	**A = Weight % 20µm**	**B = Weight % 25µm**	**C = Weight % 30µm**
Polyethylene (HDPE)	Binder	35	35	35
Basalt powder	Lubricant	15	15	15
Eggshell powder	Abrasive/reinforcement	10	10	10
Alumina powder	Abrasive	10	10	10
Barite	Space filler	20	20	20
Steel fiber	Reinforcement	15	15	15

Figure 1: (a) basalt (b) eggshells powder (c) eggshells powder (d) carbonized eggshells powder (e) heat treatment furnace (f) digital weighing samples (g) produced sample (h) break lining (i) wear.

3.0 RESULTS AND DISCUSSION

3.1 Hardness Test

A steel ball tip with a diameter of 2.5 mm was used as the puncture tip in the hardness measurement processes. The applied load is taken as 62.5 kgf (612.9 N). Hardness measurements were made on the rubbing surface of the samples. Since the dimensions of the samples are Ø21.4 × 7 mm, the values were calculated from the middle and close points of the surface. The arithmetic means of three sample results with the same content for each sample was taken. The hard test results for the brake pad samples are presented in figure 2.

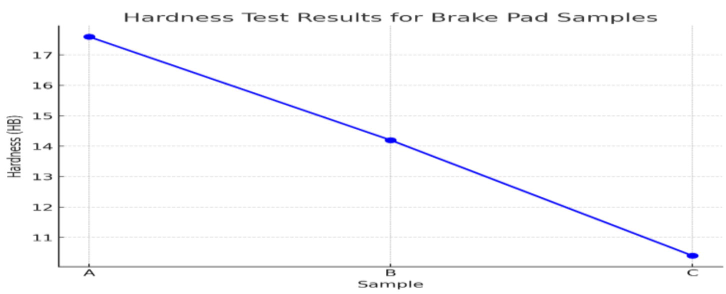

Figure 2: Shows Hardness (HB) Values versus Sample.

The hard test results for the brake pad samples (A, B, and C) show a clear trend: as the particle size of eggshell powder increases, the hardness of the composite decreases. Specifically:

- Sample A (20 µm eggshell powder): 17.6 HB
- Sample B (25 µm eggshell powder): 14.2 HB
- Sample C (30 µm eggshell powder): 10.4 HB

This trend suggests that smaller eggshell particles (20 µm) provide a more compact and harder composite material than larger particles. The increased hardness in Sample A could be attributed to the finer distribution of particles within the matrix, which enhances bonding and compactness. As the particle size increases (as in Samples B and C), there is likely a reduction in the uniform distribution and packing density, leading to a softer composite.

For brake pad applications, hardness is a critical property as it influences wear resistance, durability, and overall braking performance. Higher hardness generally indicates better resistance to abrasion and less wear, which is essential for brake pads subjected to frequent frictional contact. Thus, the findings imply that using finer eggshell particles (20 µm) may improve the longevity and performance of non-asbestos brake pads. Conversely, larger particle sizes (25 µm and 30 µm) may compromise these properties, making them less suitable for high-performance applications.

3.2 Wear Test and Reliability of Non-Asbestos Brake Pad

The linings produced were placed in the wear test device with the help of lugs and operated at a speed of 3 m / s under 0.7 MPa pressure until 95% of the sample surface touched the disc surface to ensure that the friction surfaces coincide. The tests were carried out at 1.05 MPa lining surface pressure and 6 m / s speed. The friction coefficient and time values taken during the tests are the arithmetic means of the values taken from three samples produced with the same mixture and properties. Wear rate was calculated using the equations 1 and 2 below.

Wear volume = $\frac{mass}{density}$……………………………………………...……….equation (1)

Wear rate = $\frac{wear\ volume}{Applied\ loadx\ slidding\ distance}$……………………………………..........equation (2)

$$R(t) = \exp\left[-\int_0^t \lambda dt'\right] = e^{-\lambda t}, \qquad t \geq 0$$ ………………...equation (3)

Table 2: Hardness, wear rate and reliability of the composites.

Sample	A	B	C
Brinell Hardness (HB)	17.6	14.2	10.4
Wear rate (cm3/Nm)	$1.5x10^{-4}$	$2.94x10^{-4}$	$3.04x10^{-4}$
Reliability (%)	0.9467	0.8982	0.8724

3.3 Reliability of Non-Asbestos Brake Pad

Reliability refers to the ability of a system, component, or product to perform its intended function consistently over time under specified conditions. Reliability often involves assessing how well a system avoids failure, maintains functionality, and meets performance standards over its operational lifespan. The reliability of the composite samples was treated as wear rate using failure rate and investigated using eqn. 3 as follows.

R(t) = reliability

λ = hazard rate = failure rate = wear rate

t = 1 yr = 365 days

Sample A: 20µ particles size

Thus, $R(1) = e^{-(1.5X10\text{-}4)\,(365)} = 0.94672$ (Application of eqn. 3)

Sample B: 25µ particles size

Thus, $R(1) = e^{-(2.94X10\text{-}4)(365)} = 0.89825$ (Application of eqn. 3)

Sample C: 30µ particles size

Thus, $R(1) = e^{-(3.74\ X10\text{-}4)\,(365)} = 0.8724$ (Application of eqn. 3)

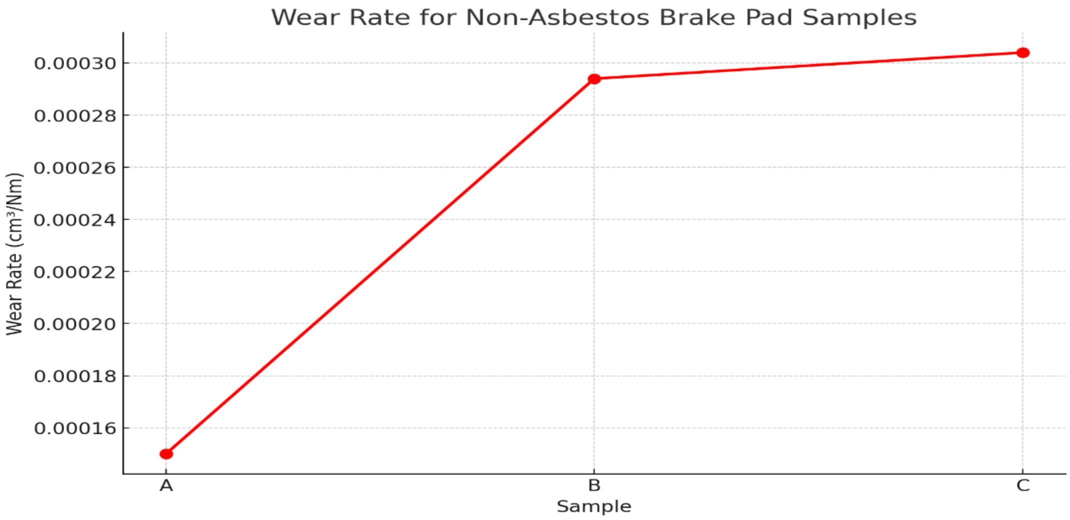

Figure 3: Wear rate versus Sample.

Figure 3 shows that the wear rate increases as the particle size of the composite sample increases. Sample A (20 µm) has the lowest wear rate, while Sample C (30 µm) has the highest wear rate.

This indicates that smaller particle sizes contribute to greater wear resistance, which is beneficial for non-asbestos brake pads as it enhances their durability and lifespan.

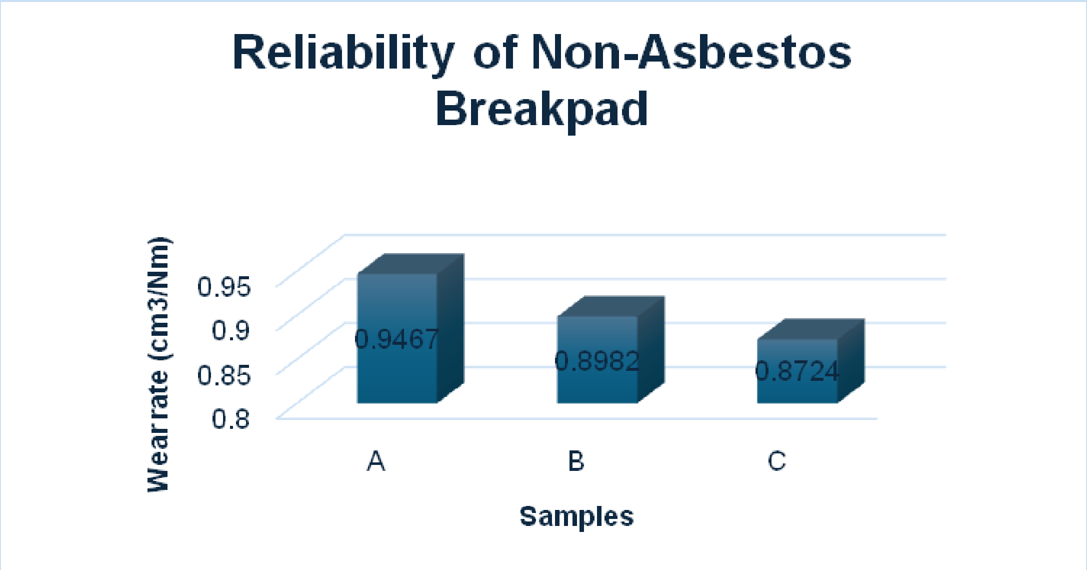

Figure 4: Wear rate Versus Composite sample.

Figure 4 shows that reliability decreases as particle size increases. Sample A, with the smallest particle size (20 µm), shows the highest reliability at approximately 94.67%, while Sample C (30 µm) has the lowest reliability at around 87.24%. This trend suggests that smaller particle sizes result in higher reliability, likely due to improved wear resistance, which in turn leads to more consistent performance and reduced failure over time. The hardness of the non-asbestos brake pad composites decreases with increasing particle size of eggshell additives. Sample A, with 20 µm particles, exhibits the highest hardness (17.6 HB), followed by Sample B (25 µm, 14.2 HB), and Sample C (30 µm, 10.4 HB).Higher hardness values suggest that smaller particle sizes in the composite structure contribute to improved resistance against deformation, which is advantageous in brake pad applications where durability and resistance to wear are critical.

4.0 CONCLUSION

This study has demonstrated the effectiveness of incorporating eggshell particulates (ESPs) as sustainable reinforcements in non-asbestos brake pad composites. The results indicate that smaller particle sizes (20 µm) significantly improve mechanical performance, offering the highest Brinell hardness of 17.6 HB, lowest wear rate of 1.5×10^{-4} cm³/Nm, and highest reliability of 94.67% after one year of simulated use. In contrast, larger particle sizes (30 µm) resulted in decreased hardness (10.4 HB), increased wear (3.04×10^{-4} cm³/Nm), and lower reliability (87.24%).

These findings highlight the crucial role of particle size in determining the tribological and structural behavior of friction composites. The 20 µm ESP formulation showed optimal compactness, improved bonding, and superior resistance to surface degradation, making it a strong candidate for commercial, eco-friendly brake pad applications.

From an environmental standpoint, utilizing eggshell waste aligns with circular economic principles and reduces dependency on synthetic and hazardous friction materials. The study supports the broader shift toward green materials in the automotive industry by offering a reliable and high-performing alternative to asbestos-based components.

Future research should explore extended field testing under real driving conditions, fatigue life analysis, and the integration of other bio-fillers to further enhance performance and scalability. Additionally, life-cycle assessments (LCA) can be conducted to quantify the environmental impact and cost-effectiveness of eggshell-reinforced brake pads on a commercial scale.

REFERENCES

1. Choudhury, P., Ahmed, K., & Roy, S. Sustainable alternatives in brake friction materials: A review on bio-based reinforcements. Journal of Cleaner Production, 2022; 340: 130737.
2. Edokpia, R. O., Aigbodion, V. S., Atuanya, C. U., Agunsoye, J. O., & Mu'azu, K. Experimental study of the properties of brake pad using eggshell particles–Gum Arabic composites, J Chinese Adv Mater Soc. ens, 2016; 4(2): 172-184.
3. Gonzalez, R. & Silva, M. Health risks associated with asbestos-based friction materials in automotive applications: A review of regulatory perspectives. Environmental Health and Safety, 2021; 28(4): 233-248.
4. Ibrahim, A., Mustafa, M., & Hassan, S. Eggshell-derived materials for sustainable applications: Advances in waste-derived composites for automotive brake pads. Materials Science and Engineering: A, 2023; 876: 145109.
5. Kumar, R., Singh, H., & Ahuja, A. Replacing asbestos in automotive friction materials: A review on non-asbestos organic brake pads. Tribology International, 2022; 168: 107421.
6. Liu, Y., Chen, J., & Wang, Z. Bio-waste derived friction materials: Potential and challenges in non-asbestos brake pad formulations. Composites Science and Technology, 2023; 231: 109582.
7. Oke, S., Adegbenjo, A., & Udo, S. Advancements in non-asbestos organic brake materials and their performance characteristics. Composite Materials, 2023; 45(3): 145-160.

8. Rahman, N., Basha, M., & Ali, H. Mechanical and thermal properties of calcium carbonate-based materials in friction applications: The role of eggshell powder in automotive components. Materials Today: Proceedings, 2021; 45: 2215-2222.
9. Bello, S. A., Agunsoye, J. O., Adebisi, J. A., Kolawole, F. O., Raji, N. K., & Hassan, S. B. Quasi Crystal Al (1xxx)/Carbonized Coconut Shell Nanoparticles: Synthesis and Characterisation, Int. Journal of Materials Research Society, DOI: 10.1557/adv., 2018; 369: 2559-2571.
10. Sa'ad, H., Omoleyomi, B. D., Alhassan, E. A., Ariyo, E. O. & Abadunmi, T. Mechanical performance of abrasive sandpaper made with palm kernel shells and coconut shells, J. Mech. Behav. Mater., 2021; 30(1): 28-37.
11. Zhang, X., Lee, C., & Park, H. Frictional behavior and thermal stability of natural fillers in brake pad composites: A focus on eggshell and bio-waste derivatives. Tribology and Materials Science, 2023; 56(7): 89-102.