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DEVELOPMENT AND CORROSION RESISTANCE PERFORMANCE OF GREEN AUTOMOTIVE BRAKE PADS DEVELOPED FROM THE WASTE SHELLS OF GIANT AFRICAN SNAILS

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Abstract.*In this study, morphological and corrosion analyses (Fourier transform infrared spectroscopy, scanning electron microscopy, and electrochemical tests) were used to investigate the properties of newly developed, non-toxic organic brake pads. The green automotive brake pads were developed from waste giant African snail shell as reinforcement materials. Also, Fourier transform infrared spectroscopy (FTIR) was used to determine the functional group of the developed brake pad samples. The developed brake pad corrosion resistance was studied using open circuit potential (OCP), Potentiodynamic polarization (PDP), and electrochemical impedance spectroscopy (EIS). Additionally, scanning electron microscopy (SEM) was used to examine the surface morphology of the developed green brake pad. The findings revealed that the developed brake pad with a 75-grain size exhibited optimal corrosion resistance when compared to the control, 40µm and 90µm, samples. SEM analysis revealed enhanced interfacial bonding between the binder and snail shell particles as the grain size decreased, attributed to improved bonding and reduced inter-packing distance with decreasing sieve grade. The existence of corrosion debris was more evident on the deformed surface of the control sample compared to the developed brake pad samples. The study showed that the brake pad developed from snail shells has better morphological and corrosion resistance performance than the control sample brake pads and can be applied in heavy-duty vehicles.*

Key words:*Brake pad,Giant African snail shell, Corrosion resistance, Electrochemical measurement, Degradation, Functional group*

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1.INTRODUCTION

In recent years, there has been an increasing global emphasis on sustainable practices and the utilization of renewable resources in various industries. The automotive sector, in particular, faces mounting pressure to reduce its environmental footprint while maintaining high performance and safety standards. One area of interest within this context is the development of green automotive brake pads, which are essential components for vehicle safety and performance.

Brakes constitute a crucial aspect of both safety and performance in automobiles, with brake pads serving as integral components within disc brake systems seen in many types of vehicles. The imperative to reduce costs, materials, and wear, while simultaneously enhancing safety on our roadways, necessitates the development of frictional composite brake pads that possess reduced weight, greater mechanical qualities, and enhanced corrosion resistance capabilities. The brake pad plays a crucial role in converting the vehicle's kinetic energy into heat energy through the process of friction, subsequently dissipating this heat to the surrounding environment. According to Aigbodion and Agunsoye [1], the two primary categories of friction brakes are drum brakes and disk brakes.

Extensive study has been conducted in the field of asbestos-free brake pad development. Previous studies have examined the utilization of palm kernel shell (PKS) and other related materials [1,2-5]. Currently, there is a global emphasis on the exploitation of animal and plant waste as a viable supply of raw material for various industries. The exploitation of waste materials not only has economic benefits, but also has the potential to generate foreign exchange for the country and contribute to environmental management.

Automotive brake pads play a crucial role in ensuring safe and efficient vehicle operation by providing the necessary friction to decelerate or stop a vehicle. Traditionally, brake pads have been manufactured using non-renewable resources such as asbestos and heavy metals like lead and copper. However, the environmental and health hazards associated with these materials have led to the exploration of alternative, more sustainable options.

Green automotive brake pads offer a promising solution to this challenge by incorporating renewable materials into their composition. By reducing reliance on non-renewable resources and minimizing environmental pollution throughout the product lifecycle, green brake pads contribute to the overall sustainability of the automotive industry. Moreover, as consumer awareness and demand for eco-friendly products continue to grow, the development of green automotive brake pads presents a significant market opportunity for manufacturers.

The Giant African snail (Achatina fulica) is a large terrestrial mollusk native to East Africa but widely distributed in tropical and subtropical regions worldwide. Due to its invasive nature and detrimental impact on agriculture and ecosystems, efforts have been made to control its population and manage its waste. The shells of Giant African snails, which are composed primarily of calcium carbonate, have been identified as a potential source of renewable and corrosion-resistant material for various applications, including automotive brake pads [6,7].

Several studies have investigated the feasibility of utilizing waste shells from Giant African snails in brake pad formulations. These shells possess inherent properties such as high hardness, thermal stability, and corrosion resistance, which are desirable for brake pad applications. Moreover, their abundance as a byproduct of pest control measures makes them an attractive and cost-effective alternative to traditional fillers and reinforcements. By incorporating waste shells into brake pad matrices, researchers aim to enhance both the sustainability and performance of these critical automotive components[8,14].

Corrosion is the irreversible breakdown or degradation of a material (metal, ceramic, or polymer) as a result of an interaction between the material and its environment or the deterioration of the material in an aggressive medium [15]. Friction material (FM) is a composite material used in brake pads. It consists of abrasives, solid lubricants, metallic particles, filaments, and organic compounds. Consequently, it is evident that when exposed to belligerent conditions and antagonistic environments, all the components of a braking system are susceptible to galvanic couplings and severe corrosive phenomena. This emphasizes the importance of having comprehensive protection measures in place to keep the brake system secure and operational under extreme conditions. When travelling in heavy traffic, brakes may be exposed to nitrogen oxides and sulfur oxides. When cleansing a car, brakes may come into contact with surfactants [16].

Corrosion resistance is a critical requirement for automotive brake pads, particularly in regions with harsh environmental conditions or exposure to corrosive agents such as road salts and moisture. Corrosion can compromise the structural integrity of brake components, leading to reduced braking efficiency, increased maintenance costs, and safety hazards for vehicle occupants. Hence, there is a growing demand for corrosion-resistant materials that can withstand aggressive environments without compromising braking performance.Various strategies have been employed to enhance the corrosion resistance of brake pad materials, including surface coatings, alloying elements, and inhibitor additives. Zinc-based coatings, for example, have been widely used to provide sacrificial protection against corrosion by forming a protective barrier on the substrate surface. Similarly, the incorporation of corrosion inhibitors such as cerium oxide and graphene oxide has shown promise in mitigating corrosion in brake pad formulations. Moreover, the selection of corrosion-resistant reinforcements and binders can further improve the long-term durability of brake pads under corrosive conditions [17-25].

The Society of Automotive Engineers (SAE) has predicted that the rate of corrosion of automobile brake pad system is approximately 8.5 micrometers per year. There are therefore a need for measures in place to curb these effects. Evaluation and assessment are required for these materials in corrosive environments in order to prevent them from corroding [26]. The primary objective of this study is to investigate the development and corrosion resistance performance of green automotive brake pads fabricated from waste shells of Giant African snails.

2. MATERIALS AND METHODS

2.1 Materials

The main materials used for the development of the brake pads are as follows: This snail shell (56.1%) was sourced locally and used as reinforcement; phenol formaldehyde (29%) was used as a resin. Calcium carbonate (4.5%) was used as filler. Methyl ethylketone peroxide (MEKP) (5%) and cobalt naphthenate (2.1%) were used as accelerators and catalysts, respectively, iron filings (0.8) were used as abrasive, and carbon black (2.5%) was used as a friction modifier. The formulation of the percentage composition of the used materials is detailed in table 1.

Table 1. The formulation of the percentage composition of the weight materials applied

S/n	Materials	Composition (%wt)
1	Snail shell (reinforcement)	(56.1)
2	phenol formaldehyde (Binder)	(29)
3	Calcium carbonate (Filler)	(4.5)
4	Methyl ethyl ketone peroxide (Catalyst)	(5)
5	carbon black (Frictional modifier)	(2.5)
6	cobalt naphthenate (Accelerates)	(2.1)
7	Fe filings (Abrasive)	(0.8)

2.2 Method

2.2.1 Development process of the fabricated green brake pad

The manufacturing process for the brake pads closely follows the methodology utilized by Ekpruke et al. [8] in their production of brake pad samples from waste coconut shells, illustrated in Figure 1. This approach aligns with similar methodologies found in other literature [27-32]. The acquisition of giant African snail shells involved a purchase from the local market. These shells underwent a thorough cleaning process to eliminate any dirt and were subsequently sun-dried for seven days to remove moisture. Following this, the dried shells were subjected to crushing using a grinding machine, ultimately being pulverized with the Denver laboratory ball milling machine. The resulting ground shells were then sieved into various particle sizes, specifically 45µm, 75µm, and 90µm, employing the sieve shaking machine and sieve stack. In a meticulous process, a weighted percentage blend of the shells, CaCO3, Fe filings and carbon black were prepared and mixed thoroughly in a designated bowl, referred to as Mix 1. Simultaneously, another mixture, consisting of phenol formaldehyde, methyl ethyl ketone peroxide, and cobalt naphthenate in a ratio of 2:2:1, was created in a separate bowl, known as Mix 2. The contents of Mix 2 were then carefully poured into Mix 1, and the combined mixture underwent thorough stirring to achieve a homogeneous composition. This resulting homogeneous slurry was carefully poured into a rectangular mold for setting. The set samples were left within the mold, subjected to a load of 15 MPa, and allowed to cure for 24 hours. Subsequently, the developed samples were extracted and underwent heat treatment in an electric oven (model: SX4-2-12) for a curing time of 2 hours at a temperature of 1200C.

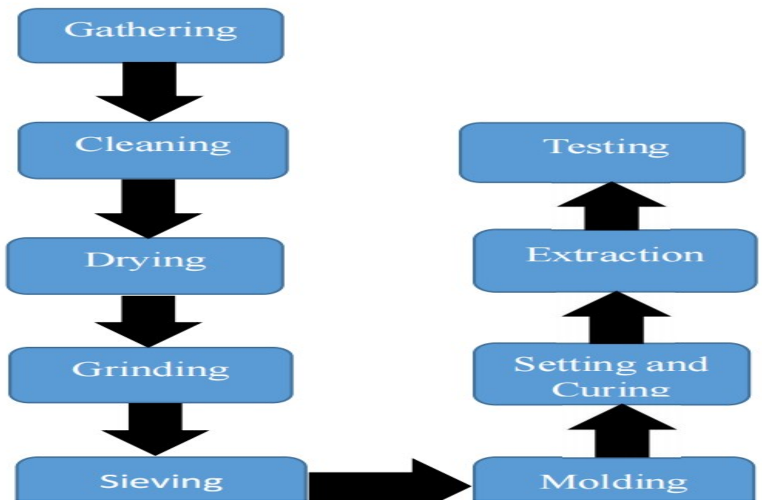

Fig.1. Snail shell based sample development process [33]

2.2.2 Characterization of developed brake pad using FTIR Analysis

The developed sample was studied using Fourier transform infrared spectroscopy (FTIR) to identify the various functional groups present in the developed brake pad [34,35].

2.2.3 Electrochemical corrosion studies

Electrochemical impedance analysis has been identified as a very successful approach for conducting corrosion testing on various materials, as highlighted by Wang et al. [36]. The experiment included using electrode samples with different compositions of the brake pad, each with varying percentages. These samples were then immersed in stagnant water. Electrochemical measurements at corrosion potential (Ecorr) from 100 kHz to 0.1 Hz with a signal amplitude perturbation of 5 mV were performed [37]. The corrosion rate of various brake pads of grain size of 45um,75um and 90um samples were determined using equation 1.

$$Corrosionrate\left(\frac{mm}{yr}\right) = \frac{0.00327 \times jcorr \times Ew}{\mathrm{D}} \quad (1)$$

Where: jcorr = Corrosion current density (A/cm2); Ew = Weight percent of carbon steel; D = metal density (g/cm3).

2.2.4 Scanning Electron Microscopy (SEM)

The samples were studied using an SEM machine to evaluate the morphological analysis. This was done by subjecting the material to a cutting process, followed by gluing it to the sample holder and coating it with carbon using a carbon coater [38].

3. RESULTS AND DISCUSSION

3.1 FTIR Analysis

The corrosion resistance of the developed brake pads is closely linked to the adsorption ability of their functional groups onto brake pad surfaces [39]. Organic compounds with heteroatoms, aromatic rings, and conjugated groups exhibit a greater likelihood of adsorption on the developed brake pad surfaces, thereby playing a protective role against the degradation of the brake pad [40]. Thus, an FTIR analysis of the brake pad was conducted to explore its functional group information. The FTIR spectrum is depicted in Fig. 2. The peak at 2933 cm−1 is ascribed to the stretching vibration of C–H of the intermolecular hydrogen bond; the peak at 2101 cm−1 signifies the presence of conjugated C=C bonding [40]. The peaks at 1722 cm−1 and 1449 cm−1 correspond to the stretching vibrations of C=O and inorganic carbonate C–O, while the absorption band at 1271 cm−1 represents the stretching vibrations of C–N amide bonding [39]. Finally, the peaks at 1118 cm−1 and 857 cm−1 indicate the bending vibration of the C–O bonding and =C–H2 wagging [41]. These characteristic peaks in the FTIR spectrum establish the specific functional groups inherent in the developed brake pad. Each of these functional groups contributes to the brake pad's potential corrosion resistance, emphasizing the crucial role played by organic compounds with unique structural features in enhancing the protective properties against brake pad degradation.

3.2 Electrochemical Analysis

3.2.1 Open Circuit Potential (OCP)

In Fig. 3, the graph depicts the Open Circuit Potential (OCP) changes over time when samples are submerged in stagnant water for a maximum of 300 seconds. Across the potential range, the OCP patterns displayed a consistent behavior: the samples' potential gradually shifted towards a more noble direction and remained relatively constant as the immersion continued, suggesting the development of a protective surface film [42,43]. Notably, the OCP of the control, 45µm, and 90µm brake pad samples exhibited a more positive trend compared to the 75µm sample. Specifically, the 75µm sample stabilized at a potential of -0.032 V, which was nobler than the other samples with potential values of 0.07, 0.10, and 0.13 V for 45, 90, and control, respectively.

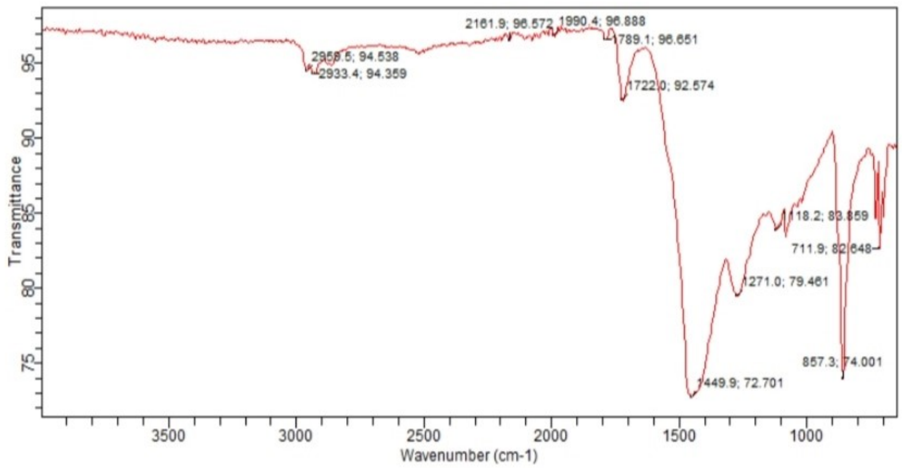

Fig. 2. FTIR spectrum of the developed brake pad.

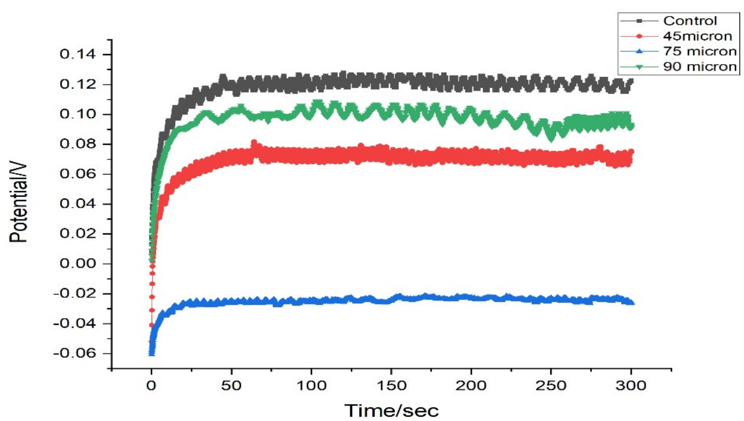

Fig.3. Open circuit potential plots of brake pad samples in stagnant water

3.2.2 Potentiodynamic polarization (PDP) measurement Analysis

Fig. 4 displays the polarization curves for brake pad samples immersed in stagnant water solutions. Key potential kinetic parameters, including the corrosion potential (Ecorr), corrosion current densities (icorr), cathode Tafel slope (βc), anode Tafel slope (βa), and corrosion rate, were obtained from these polarization curves and are detailed in Table 2. Notably, the icorr value exhibited a significant decrease. Moreover, an analysis of the polarization curve revealed that the change in the cathode was more pronounced than that in the anode. Additionally, the corrosion potential (Ecorr) shifted towards the cathode when compared to the curve obtained for various grain sizes (45µm, 75µm, and 90µm), with the maximum shift being 13 mV observed at 75µ.

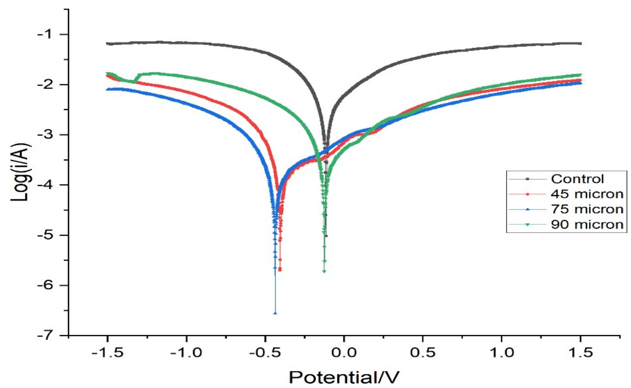

Fig.4. Tafel plots of developed brake pad at different grain size in stagnant water

Table 2. Tafel data from Potentiodynamic polarization measurement

Samples	βa(Vdec^{-1})	βc(Vdec^{-1})	icorr(u/Acm^{-2})	-Ecorr(V)	Corrosion Rate (mm/yr)
Control	4.083	5.878	3.107	0.125	1.54
45µm	2.933	6.209	2.93	0.441	2.18
75µm	3.903	6.27	1.48	0.462	1.23
90µm	3.839	5.963	2.21	0.125	1.59

3.2.3 Electrochemical impedance spectroscopy (EIS) Analysis

To validate the polarization measurement results and gain additional insights into the corrosion mechanism of an engineered brake pad, we conducted Electrochemical Impedance Spectroscopy (EIS) on the sample brake pad immersed in stagnant water with varying grain sizes. The significant findings are presented in Table 3, and Fig. 5 depictsthe Nyquist data. Notably, Fig. 5 illustrates that the largest semicircular graph corresponds to the 75um grain size brake pad, surpassing those of 45um and 90um. The Nyquist data is composed of the following parameters: solution resistance (Rs), charge transfer resistance (Rct), and the lower double-layer capacitance (Cdl). The findings from the EIS are in agreement with the obtained PDP result.

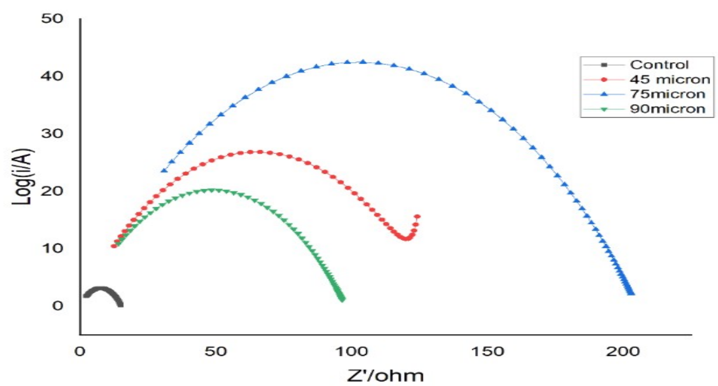

Fig. 5. Nyquist plots for developed brake pad in stagnant water

Table 3. Nyquist parameters from the EIS data Analysis

Samples	Rs(Ωcm²)	Rct(Ωcm²)	Cdl(μF/ cm²)
Control	23.61	15.27	185.62
45μm	43.72	26.27	129.6
75μm	22.68	28.14	39.49
90μm	28.52	36.12	54.12

3.3 Scanning electron microscopy (SEM)

The SEM analysis, as shown in Fig. 6, indicates a strong presence of heterogeneous distribution. The variance in particle sizes contributed to this heterogeneity. Upon closer inspection, it was evident that the mixture of brake pad materials was well-dispersed, although some pores were detected, likely due to variations in particle sizes within the admixture materials. It was confirmed that the presence of pores correlated with particle size content, decreasing as particle size decreased, especially in comparison to the 45μm particles, which were finer than the 75μm and 90μm particles. Notably, robust interfacial bonding between the resin and snail shell particles was observed, with this bonding becoming stronger as particle size decreased. This strengthening was attributed to the improved bonding between snail shell particles and the resin as the sieve grade decreased and the inter-packing distance was reduced.

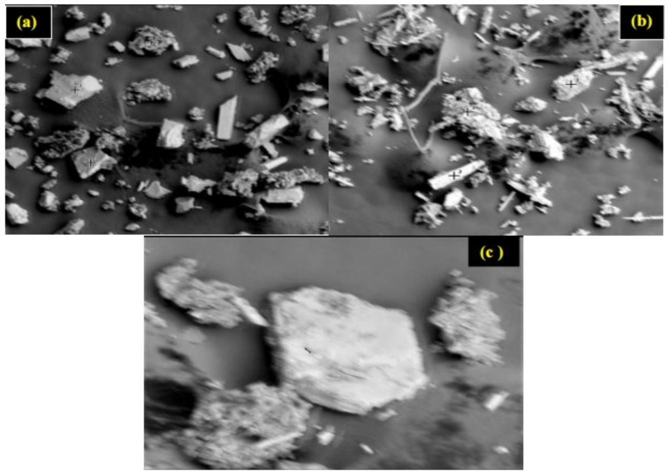

Fig.6. SEM microstructure of developed brake pad with (a)45 µm, (b) 75 µm and (c) 90µm snail shell particles.

4. CONCLUSIONS

The study examined the microstructure, morphological and corrosion resistance of organic automotive brake pads developed from giant snail shells. The following main conclusions were drawn from this study:

1. The electrochemical measurements revealed that the brake pad developed with 75 µm grain size exhibited the optimal corrosion resistance compared to the control sample, as well as those with 45 µm and 90 µm grain sizes.
2. The SEM analysis also revealed that as the grain size decreased, the interfacial bonding between the binder and the snail shell particles improved. This enhanced bonding led to a more uniform distribution of the particles, which helped to improve the overall corrosion resistance of the developed brake pad.
3. The results suggest that the development of brake pads with lower grain sizes of snail shells is beneficial in terms of improving corrosion resistance.
4. Fourier transform infrared spectroscopy (FTIR) was able to identify the various functional groups present in the developed brake pad from the organic material. The study showed that the brake pad developed from snail shells has better morphological and corrosion resistance performance than the control sample brake pads, and that it can be applied in heavy-duty vehicles.

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Competing interest: *The authors declare that there is no potential conflict of interest with respect to the research, authorship, and/or publication of this article.*

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