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Tribological Properties of Snail Shell Powder Developed Wear Materials

Isaac O. Igwe[1], Favourite C. Solomon[1], John C. Mbachukwu[1], Favour C. Ebisike[1], Emmanuel C. Ogbonda[1], Daberechi M. Ebonine[1], Timothy J. Ukeme[2], Fabian C. Onunwa[1], Moses O. Onyeagba[1], Ndifreke M. Udoh[1]
[1]Department of Polymer Engineering, Federal University of Technology, Owerri, Nigeria
[2]Department of Polymer and Textile Engineering, Nnamdi Azikiwe University, Awka, Nigeria

ABSTRACT: In this study, automotive brake pads wear materials based on waste snail shell (*Achatina achatina* L.) powder as filler were developed as possible replacement for carcinogenic asbestos - based commercial brake pads by open tool technique. The snail shell powder characterized for filler properties contained appreciable proportions of calcium oxide (89.63%) followed by aluminum oxide (4.10%) with the other oxides in smaller proportions. Epoxy resin was used as the polymer matrix, and the filler of particle sizes 63, 125, 300, 425, and 600 µm were incorporated into the formulations at filler content, 52.5% by weight of materials. The hardness, and compressive strength of the brake pads increased with decrease in snail shell powder particle size. Brake pads of snail shell powder (63 µm) exhibited the highest brake pad hardness (99.11 BHN), and compressive strength (81.70 MPa), properties which were similar to those of control brake pad hardness (101.30 BHN), and compressive strength (83.0 MPa). The brake pad developed with snail shell powder (600 µm) had the least density (1.50) compared to the control (1.71), and thus, capable of giving a weight reduction in the automotive braking system. The water, and oil absorptions of the brake pads were generally lower than that of the control pad; an indication that the developed brake pads will perform better than the control pad in a wet environment, and in the event of oil leakage that comes in contact with brake pad. Brake pads containing snail shell powder of particle sizes 300, 425 and 600 µm exhibited the same thermal conductivity (0.08 Wm/k), and which was the same as that of control brake pad. The snail shell powder (63 µm) brake pad exhibited wear rate of 3.60 mg/m compared to the control brake pad (2.81mg/m), and the wear rates decreased with filler particle size. The study has highlighted the potentials of developing green low - cost automotive brake pads based on snail shell powder as an alternative wear material to carcinogenic asbestors -_based brake pads.

KEYWORDS: Snail shell powder, brake pad, particle size, thermal conductivity, wear rate, compressive strength.

1.INTRODUCTION

Automotive brake pads are vital components of a vehicle braking system which on application, converts kinetic energy into thermal energy through friction thereby, slowing down or stopping the vehicle [1]. Thus, brake pads contribute to the overall efficiency and reliability of the automotive braking system. Insufficient brake pads generally lead to wearing of wheels, and reduced braking power capable of jeopardising the safety of vehicle occupants. The average lifespan of a set of brake pads is around 50,000 miles (80467.20 km) mark. The wearing out of brake pads in a vehicle is indicated by bad vibration, loud screeching, noticable wear and tear, and even, the vehicle's tendency to pull to one side on braking in addition to warning light from the vehicle dashboard. Brake pads are formulated using different materials, each performing specific function in the formulation. The materials include binders, modifiers, abrasives, accelerators, hardeners, catalysts, etc. The binders, for example, help to hold the friction materials together thereby, preserving the brake pads structural integrity while reinforcement improves the mechanical strength of the brake pads. The careful mixing of ingredients, and subsequent production of brake pads takes place in multi – steps that ensure desired standards are met for optimum performance. There are different types of automobile brake pads in use today that suit different car models, and these are semi - metallic, non - asbestors organic (NAO), low metallic NAO, and ceramic brake pads. Semi - metallic brake pads, for example, find applications in heavy - duty vehicles while organic and ceramic pads find applications in passenger cars because of low dust emissions, and smooth operations. The transition to semi - metallic and ceramic brake pads results from advancements in material science. The brake pads are formulated to meet specific performance characteristics, and suitability for specific driving conditions [2]. Nowadays, materials selected for brake pad production are required to be efficient under extreme mechanical and thermal conditions in addition to being environmentally friendly. The shift reflects broader industrial response to customer needs.

The introduction of asbestos in the automotive braking system was one of the earliest breakthroughs in automobile technology. Asbestos is cost – effective, and possesses excellent frictional properties and heat resistance. However, asbestos is known to be carcinogenic. The fibres released on braking a vehicle can be airborne which on inhalation, poses health risks that include asbestosis, mesothelioma, and lung cancer in humans. This user drawback has led to global regulatory restrictions on the use of asbestos in brake pad production, and thus, necessitating the urgent need to seek alternative substitutes for asbestos [2 - 4]. There is presently, the emphasis on sustainability on brake pad production as well as the use of natural and waste materials that are eco - friendly as alternatives to asbestos. Thus, the following bio - materials have been investigated for possible use in automotive brake pad production with varying successes: palm kernel fibre [5], rice straw dust and husk [6,7], baggage [8], periwinkle shell [9], egg shell [10 -12], corn stalk [13], hazelnut shell[14], wall nut [15], kenaf, pineapple, hemp, *Arera javanica*, banana fibres [16 - 18], corn fibre [19], and abaca fibre [20]. The use of lignocellulosic materials such as natural fibres, and agro wastes is attracting the attention of researches in the automotive industries, and this has been attributed to their low density, renewability, biodegradability, low cost, availability, non-toxic, and non - abrasive in different applications. Natural fibre - reinforced composites have been reported to exhibit satisfactory friction and wear performances which in some cases, approach those of commercial friction materials, an indication of their comparable braking power. Unlike natural fibres, conventional renforcing fibres such as glass, Kevlar, and carbon usually utilized as friction materials have disadvantages such as high density, non-biodegradability, health hazards on inhalation, high production costs, and high energy consumption during manufacturing [21].

Snail shells which are bio - shells of domestic agricultural waste represent a new class of engineering material in science and technology that are under explored. The shells result from eating the edible portion (meat) of snail, a popular delicacy in Nigeria because of its health benefits, and unique taste. The shells are littered in our homes, and market places arising from increased demand for snail meat. Snail shells which are non - biodegradable have no economic benefit. Worse still, the presence of snail shells in our surroundings is a source of environmental pollution due to the activities of microbes and bacteria that feed on the food remnants in the shells. There are presently concerted efforts to efficiently use snail shells for innovative, and cost - effective products thereby, removing them from the environment. These efforts are in line with global actions on sustainability, and the environment. Thus, snail shells have been studied for utilization in waste water [22], biomaterials and pharmaceuticals [23], composite materials [24 - 26], and activated carbon [27].

The present paper reports the development of sustainable wear materials automotive brake pads using snail shell powder as filler. The snail shell powder prepared from snail shells collected from Ihiagwa market, Owerri West Local Government Area, Imo State, Nigeria was sieved to 63, 125, 300, 425, and 600 μm particle sizes, and used at 52.5 wt.% based on the weight of materials in the brake pad formulation. The developed brake pads were characterized for filler properties. Snail shell powder has been receiving attention in our laboratory in the formulation of innovative, and sustainable products such as oil paint [28], polyester tile [29], polymer composite [30], and vulcanized rubber [31]. This study is a continuing effort in investigating the use of snail shell abundant in many locations in Nigeria in developing cost - effective automotive brake pads as few of such works have been reported in the literature [32, 33].

2. MATERIALS and METHOD

2.1 Materials

Epoxy resin used as the polymer matrix was purchased from a chemical shop at Lagos, Nigeria. The snail shell powder was processed from snail shells collected from Ihiagwa market, Owerri West Local Government Area, Imo State, Nigeria. It was sieved to 63, 125, 300, 425, and 600 μm sizes. A Toyota saloon car brake pad was used as the reference brake pad. Other materials such as diethylenetriamine(hardener), cobalt naphthenate(catalyst), calcium carbonate (reinforcement), carbon black(friction modifier), silica(abrasive), iron fillings (thermal conductivity), and methyl ethyl ketone peroxide(MEKP)(accelerator) were purchased from chemical shops at Lagos, Nigeria.

2.2. Methods

2.2.1. Characterization of Snail Shell Powder

The snail shell powder used in this study was characterized for filler properties as follows: specific gravity (ASTM D 153 - 84), bulk density (ASTM D 7481-18) , pH (ASTM D 1208-960), moisture content (ASTM D 1510, 1983), refractive index (ASTM D 1208 - 98), oil absorption (ASTM D 281-12), and chemical composition (ASTM D 5381- 94).

2.2.2 Preparation of Automotive Brake Pads

Samples of the automotive brake pads were prepared using the ingredients shown in Table 1 and the particles investigated were 63, 125, 300, 425, and 600 μm. Plastic bowls were used in mixing the ingredients which were stirred until homogenous mixtures were obtained. The mixtures were poured into a 2 - in - 1 aluminum mould with each compartment measuring 11.80 x 7.80 x 1.0 cm, and prepared by rubbing silicon oil on their inner surfaces. The mixtures were compressed, and allowed to dry for 7 days. Later, the cured samples were demoulded, and kept in a clean ventilated room for subsequent use. Figures 1 shows the constructed mould containing the produced brake pad samples.

Table 1. Formulation of Automotive Brake Pads.

S/No	Ingredients	Parts by Weight (wt.%)
1.	Epoxy resin	25.0
2.	Snail shell powder	52.5
3.	$CaCO_3$	9.0
4.	Carbon black	0.3
5.	Silica	2.0
6.	MEKP	2.5
7.	Diethylenetriamine	3.0
8.	Cobalt Naphthenate	2.0
9.	Iron-fillings	3.7

(a) (b)

Figure 1. Constructed mould (a), and mould containing developed brake pads (b).

2.2.3 **Tests on Prepared Brake Pads**

2.2.3.1 **Thermal Conductivity**

The thermal conductivity of the prepared automotive brake pads was determined using a 1300 W hot plate (Super Sony, SSJ-06-STV, Japan) as shown in Figure 2, digital vernier caliper (DIGITAL CALIPER 150 mm (6") CHINA), and thermometer according to the method

Figure 2. Hot plate(1300 W).

of Ossia *et. al* [34]. The thermal conductivity(k) was estimated using the equation,

$$k = Q \times d / a(\Delta t) \quad (1)$$

where Q = Power of hot plate(W)

d = Thickness of brake pad(m)

a = Surface area of brake pads(m^2)

Δt = Temperature difference between the hot and cold surfaces of brake pad(K)

2.2.3.2 **Liquid Absorption**

The liquid (water or motor engine oil, 20W - 50) absorbed by the developed brake pad was determined as follows. A known weight(W_1) of the sample brake pad was immersed in a given volume of water or oil contained in 250 cm^3 beaker, and left for 24 h. The sample was carefully removed from the liquid using a tweezer at the expiration of 24 h. The liquid adhering on the surfaces of the brake pad was carefully removed using a folded filter paper. Care was taken not to remove the liquid absorbed by the brake pad. The brake pad sample was weighed again(W_2). The liquid absorbed by the pad was calculated as follows:

$$\text{Liquid absorbed (\%)} = W_2 - W_1/W_1 \times 100 \quad (2)$$

where W_1= Initial weight of sample (g)

W_2= Weight of sample after immersion in liquid(g)

2.2.3.3 **Hardness**

The hardness of the automotive brake pad samples was measured using non - destructive digital Brinell hardness tester (B3000H) and calculated as,

Brinell hardness number (BHN) = F/D x d (3)

where F = Applied load (kg)

D = Diameter of identer (mm)

d = diameter of identation (mm)

2.2.3.4 **Compressive strength**

A Universal Testing Machine (UTM) was used to determine the compressive strength of the developed automotive brake pads after the prepared samples were secured firmly between the upper and lower grips of the instrument, and the tests performed according to instructions.

2.2.3.5 **Density**

The density of the developed brake pads was determined using the displacement method. A known weight (W_1) of the developed brake pad was immersed in a given volume of water (V_1) contained in a measuring cylinder. The new volume of water (V_2) in the measuring cylinder was noted. The change in volume of water was determined and was taken to be equal to the volume of the immersed brake pad. The density of the sample brake pad is calculated as,

Density = $W_1/V_2 - V_1$ (5)

2.2.3.6 **Wear Rate**

A pin - on - disc (PoD) machine (CSM Instruments Tribometer, Italy) was used to determine the wear rate of the prepared automotive brake pads according to ASTM G99 – 17 method at a room temperature of 33.5°C, and humidity 86%. The loss in mass of the brake pad, and the sliding distance were used to calculate the wear rate (Ws) as follows,

Wear rate (Ws) = $\Delta m/L$ (6)

where Δm = loss in mass (mg)

L = sliding distance (m)

3. RESULTS AND DISCUSSION

3.1 Characterization of Snail Shell Powder

Snail shell powder used in this study as filler has the following properties: pH (5.71), specific gravity (1.80), oil absorption (7.90 g/100 g)), bulk density (1.56), moisture content (9.03%), and refractive index (1.69). X - ray fluorescence spectrometer determinations showed the abundance of CaO (89.63%) in snail shell powder followed by Al_2O_3 (4.10%). The other oxides such as MgO (0.97%), TiO_2 (0.03%), SiO_2 (0.83%), and ZnO (0.04) are present in smaller proportions. CaO is a stable compound that withstands high temperature having a melting point of 2600°C.

3.2 Properties of Developed Brake Pads

3.2.1 Density

Figure 3 illustrates the variation of densities of the developed brake pads with snail shell powder particle size. The density of the control brake pads is 1.71. The brake pad developed

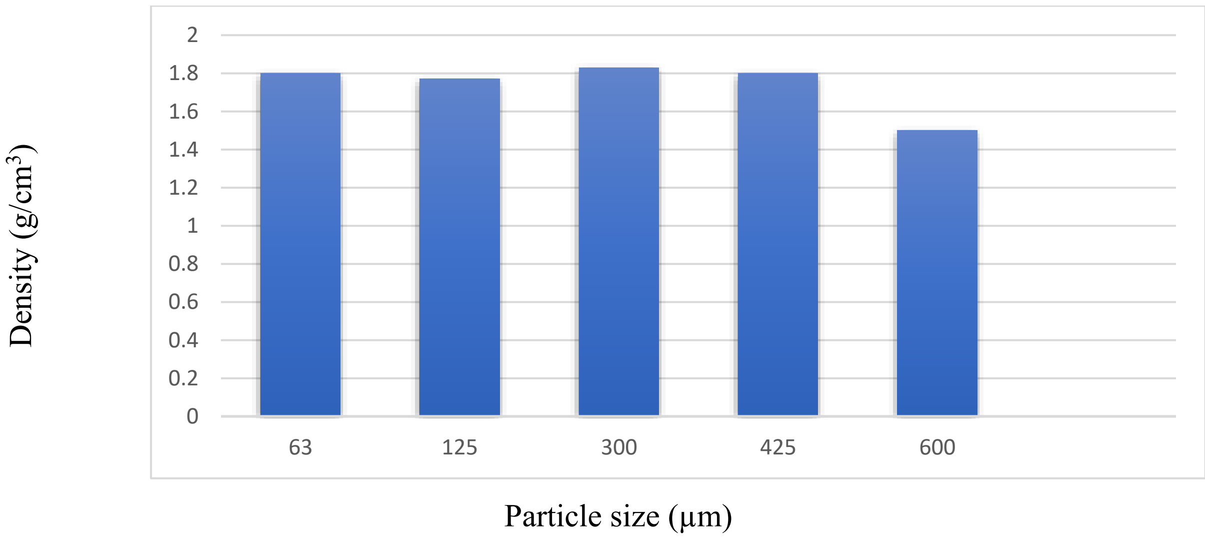

Figure 3. Density of brake pads at different filler particle sizes.

with snail shell powder (600 µm) exhibited the least density (1.50) while the other formulations had densities that lie in the range, 1.79 – 1.83. The low density of brake pads developed with snail shell powder (600 µm) could be attributed to particle size effect. The greater the particle size of filler, the less the packing efficiency, the greater the sizes of pores, and the less the density of the developed brake pads. Particle size of the filler did not have profound effect on the densities of brake pads developed with snail shell powder of sizes, 63, 300, and 1.80 µm as they exhibited similar densities. The control brake pad exhibited higher density (1.71) than that of brake pad of snail shell powder particle size, 600 µm. The decrease of density of brake pads with filler content has been reported in the literature [20]. The present study has demonstrated that developing automotive brake pads with snail shell powder (600 µm) can lead to les s weighting of its components. Using lighter brake pads can lead to lower fuel consumption in internal combustion engine since less weight needs to be carried by the vehicle. This will ultimately benefit the vehicle owner. Reduction in vehicle mass can also, reduce the emission of greenhouse gas (GHG) during vehicle use as less heavy weight vehicles cut CO_2 emissions. Generally, reducing the weight of a vehicle can be achieved by using light engineering materials or modification of the construction processes [35, 36].

3.2.2 Thermal Conductivity

The thermal conductivity of the developed automotive brake pads illustrated in

Figure 4 exhibited two types of behaviour: at lower filler particle sizes (63, 125 µm), the

thermal conductivity was the same (0.02 W/mK); at particle sizes above 125 µm (300, 425,

600 µm), the thermal conductivity of the brake pads was higher, and the same as that of the

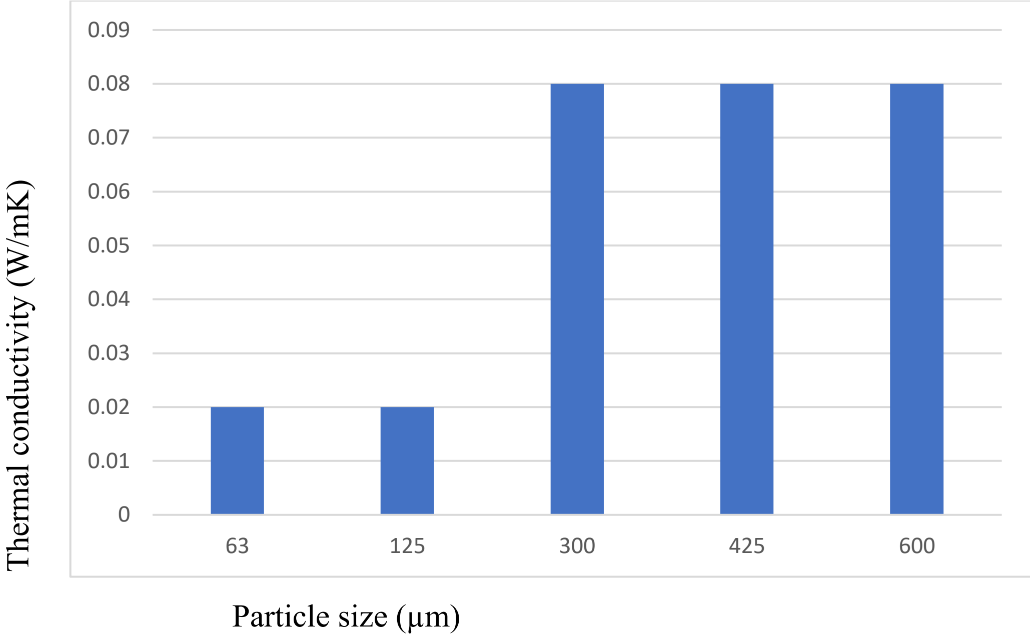

Figure 4. Thermal conductivity of developed automotive brake pads

control brake pad (0.08 W/mK). Generally, the dissipation of heat by brake pad material is essential in maintaining consistent performance, and preventing brake fade which occurs when heat builds up in the braking system to the extent that the brake pad losses its ability to generate adequate friction. The present study shows that brake pads developed with snail shell powder of particle sizes 300, 425, and 600 µm performed well as a friction material just as the control brake pad. The increase of thermal conductivity of brake pads with filler content has been reported [35].

3.2.3 Hardness

Figure 5 shows the effect of snail shell powder particle size on the hardness of developed automotive brake pads. The hardness was observed to decrease with filler particle size. The highest brake pad hardness (99.11 BHN) was recorded for snail shell powder of particle size, 600 µm while the least (67.33 BHN) was for particle size, 600 µm. The increase of brake pad hardness with decrease in filler particle size is attributed to increased filler particle surface area which resulted to increased interfacial bonding with the epoxy resin matrix. The control brake pad exhibited Brinell hardness of 101.30 which was slightly higher than the hardness of brake pad developed with snail shell powder of particle size, 63 µm. The hardness of automotive brake pad is an important property that affects braking performance, and wear of brake pads. Harder brake pads are expected to offer better resistance during application while softer ones will wear faster. The automotive brake pad developed with snail shell powder (63 µm) is expected to perform well in service just as the control brake pad. Aigbodion et al. [8] in their study on bagasse brake pad reported decrease of brake pad hardness with increasing bagasse filler particle size. Similarly, Osterle et al. 2001

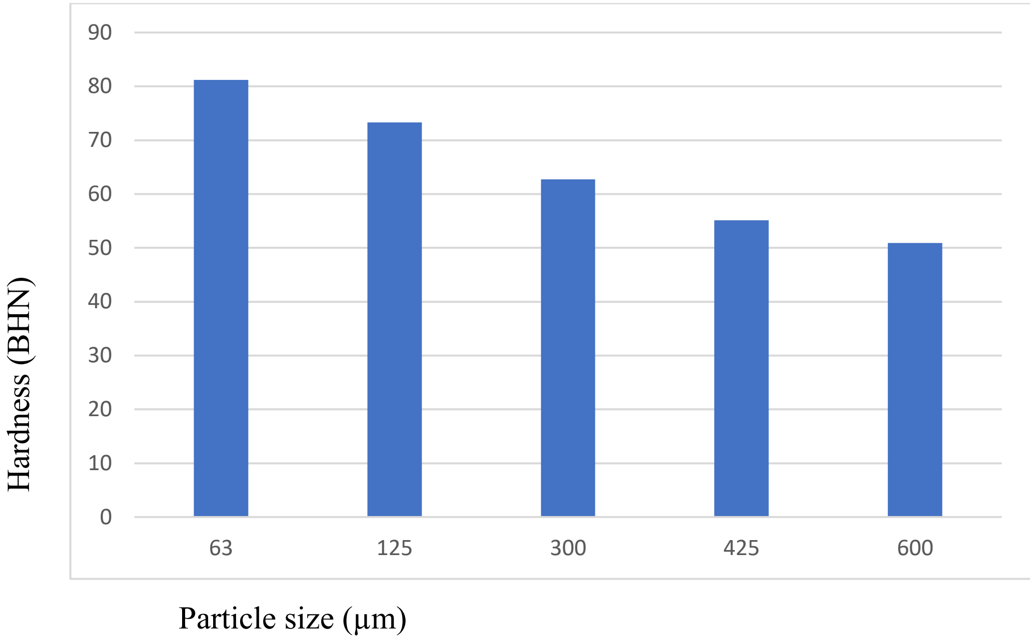

Figure 5. Hardness of developed automotive brake pads.

3.2.4 Liquid Absorption The water, and engine oil absorbed by the developed automotive brake pads are illustrated in Figure 6. The brake pads absorbed lower water, and engine oil compared to the control that absorbed 0.60, and 0.38 % water, and oil respectively. The results indicate that the developed

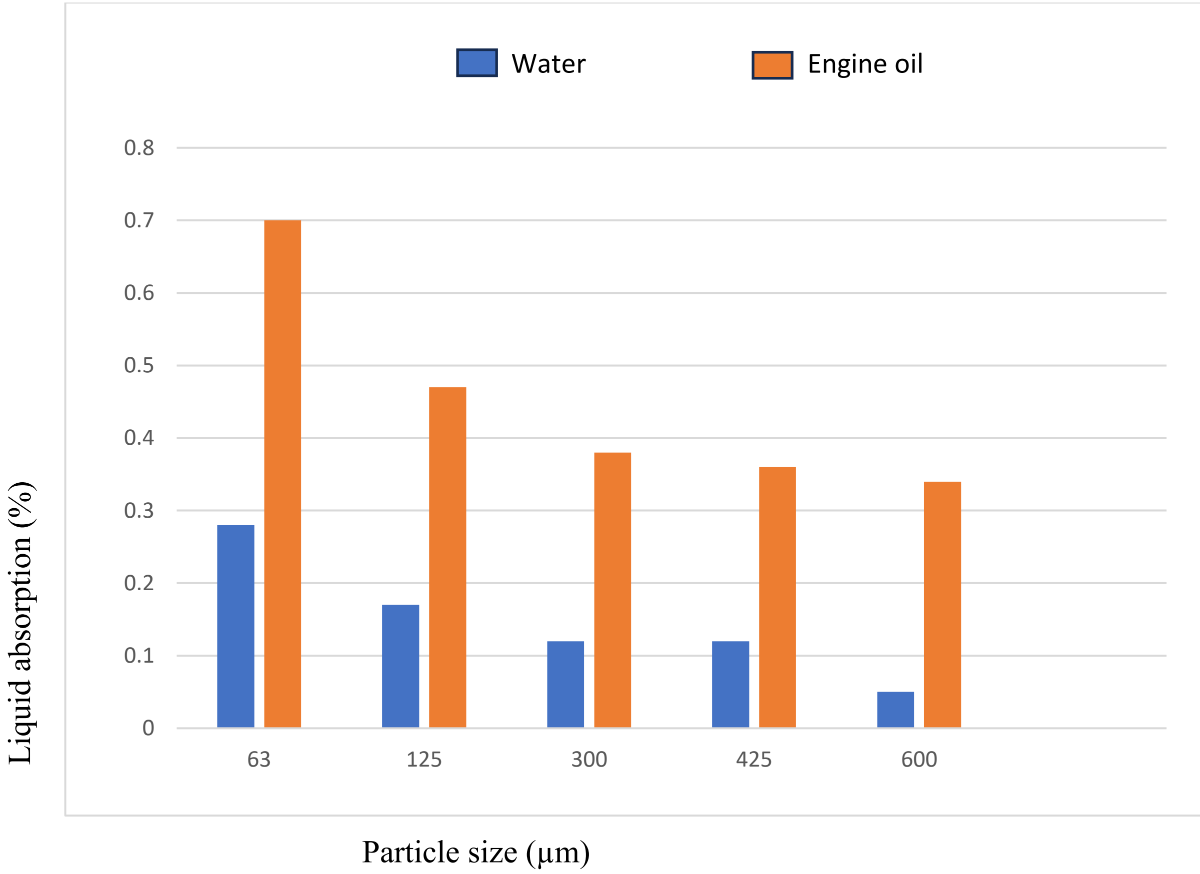

Figure 6. Liquid absorption by developed automotive brake pads.

brake pads will perform better in wet environments as occur in flooded areas or when there is oil leakage that gets to the brake pads. The water, and oil absorbed by the brake pads generally increased with snail shell powder particle size. Thus, brake pads developed with snail shell powder (63 µm) absorbed the least amount of water, and engine oil as a result of more closely parking of particles which reduced the available pores in the brake pads leading to cumulatively reduced liquid absorption. The figure shows that the brake pads absorbed more water than engine oil at any filler particle size considered. The following factors may be responsible: (i) the formation of polymer layer by epoxy resin that slows the absorption of the oil, (ii) the formation of water - proof layer on the brake pads surface and its additives increasing the adhesion between the particles thereby, decreasing the number of pores in the brake pads [10], and (iii) the high kinematic viscosity of the engine oil which is higher than that of water will slow down oil absorption. It is important to note that the diffusion coefficient of engine oil is 200 times lower than that of water [38]. This translates to water having a lower viscosity than engine oil and subsequently, diffuses more into the automotive brake pads. Similar to our findings, Aigbodion et. al [8] who worked on bagasse brake pads reported increased water, and oil absorption by the fabricated brake pads with filler content. Sunardi *et. al* [10] who worked on dimensional stability of egg shell particles developed brake pads reported the absorption of more water than engine oil by the brake pads.

3.2.5 Compression Strength

The variation of compression strength of the developed brake pads with filler particle size is illustrated in Figure 7. The figure shows a general decrease of compression strength with

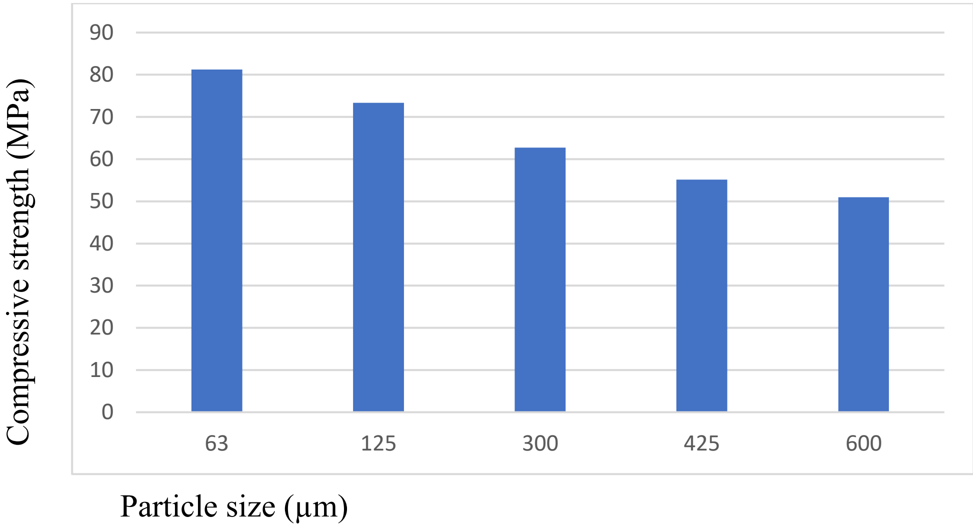

Figure 7. Compressive strength of developed automotive brake pads.

filler particle size. Thus, the automotive brake pad formulated with filler of particle size, 63 µm exhibited the highest strength of 81.20 Mpa while that for snail shell powder of particle size, 600 µm was the least (50.93 Mpa). The decrease of compression strength with filler particle size is attributed to decrease in interfacial bonding between the larger sized particles of snail shell powder, and the polymeric matrix resulting to lower strength values. Such decrease of brake pad compression strength with filler particle size has been reported in the literature [32, 34, 37]. The compressive strength of the control brake pad (83.0 Mpa) was similar, although, slightly higher than that of brake pad of snail shell powder particle size, 63 µm (81.20 Mpa), an indication that the latter brake pad will also, perform well under usage as that of control brake pad. The compressive strength is an important factor that affects the performance, and durability of brake pads since they are formulated to withstand compressive forces during braking. The strength is affected by the type of materials used in the formulation, and production process.

3.2.6 Wear Rate

The wear rate of the automotive brake pads illustrated in Figure 8 decreased with increased snail shell powder particle size. The brake pad developed with snail shell powder (63 µm)

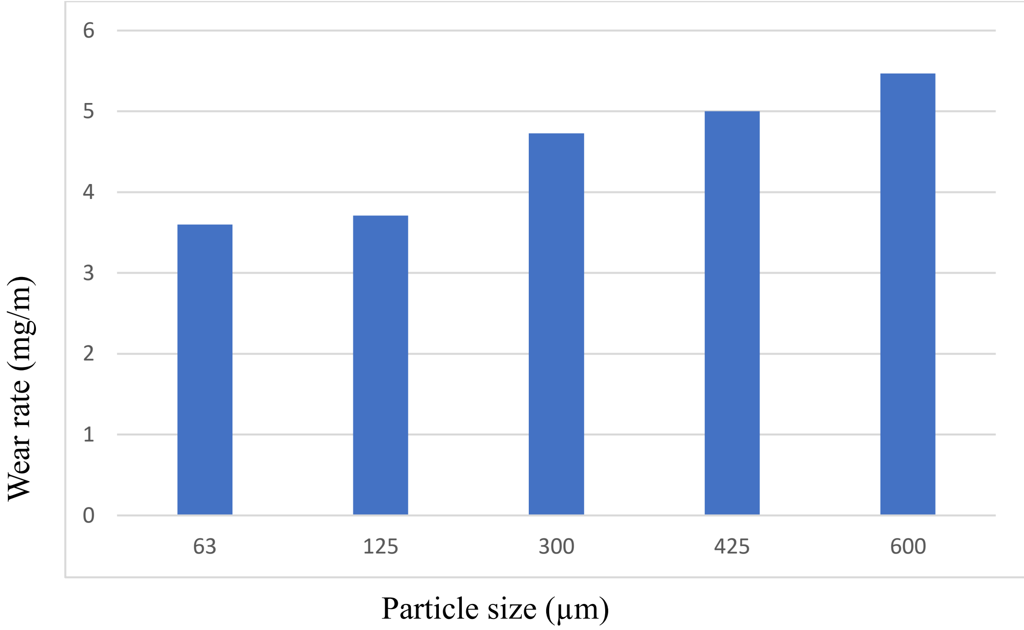

Figure 8. Wear rate of developed automotive brake pads.

exhibited the least wear rate (3.60 mg/m) which was higher than the wear rate of the control brake pad (2.81 mg/m). The decrease of wear rate of the automative brake pads with filler particle size followed the same trend as brake pad hardness in conformity with the Archard model [39]. Ekpruke et al [41] in their investigations on waste Thais Coronata seashell reinforced brake pads reported decrease of brake pad wear rate with seashell particle size. This was explained as due to the arrangement of particles where small particles fixed themselves closely thereby, minimizing the presence of voids. This resulted to the composite being compact. Generally, the lower the wear rate, the longer the application life of the friction material [40]. Ossia and Big - Alabo [33] who investigated brake pads formulated with giant African snail shell reported decrease of brake pad wear rate with snail shell particle size. This was attributed to poor thermal conductivity of the brake pads that made them to be thermally unstable during frictional heating of the rubbing contacts. Lower wear rate of brake pads is essential in maintaining automobile brake efficiency as it is capable of withstanding abrasion during operation without appreciable loss in material.

4. CONCLUSION

Snail shell powder was successfully used to develop automotive brake pads. The hardness, and compressive strength of the brake pads decreased with snail shell powder particle size while the wear rate, water and oil absorption, and thermal conductivity increased with snail shell powder particle size.

The water and oil absorption of the developed brake pads were lower compared to the control pad. Similarly, brake pad developed with snail shell powder (600 µm) exhibited lower density than the control brake pad.

The brake pad developed with snail shell powder (63 µm) exhibited similar hardness, and compressive strength to the control brake pad indicating similarity in performance. The thermal conductivity of brake pads developed with snail shell (300, 425, 600 µm) was the same as that of control pad. The wear rate of the control brake was 2.81 mg/m which was lower than the lowest brake pad wear rate obtained (3.60 mg/m) with snail shell powder of particle size, 63 µm.

The present study has highlighted the potentials of snail shell powder as an alternative filler to carcinogenic asbestos in developing eco – friendly wear materials, the automotive brake pads. Fortunatively, the filler is readily available, biodegradable, easy to process, and non – toxic.

CONFLICT OF INTEREST

The authors declare no Conflict of Interest in this study.

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