Thermophysical And Mechanical Behaviour of Nanosized Periwinkle Shell Ash Reinforced Low-Density Polyethylene Composite: Long-Term Salt-Water Aging Influence

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Abstract- The utilization of marine and agricultural waste into a more useful and promising alternatives to conventional materials commonly used for construction, fabrication and insulation in the civil engineering industry, Oil & Gas industry, maritime industry etc. This experimental investigation of the thermal and mechanical characteristics of periwinkle shell nanoparticle and low-density polyethylene to come up with a new novel material with predictable thermophysical properties that will be able to with some terrain with specific chemical composition. Three samples k1, k2 and k3 were collected, exposed and fabricated by thermoforming their homogenous mixture at a very high temperature with the following composite - polymer percentage composition of 15% periwinkle shell nanoparticle and 85% polyethylene, 25% periwinkle shell nanoparticle and 75% polyethylene, and 35% periwinkle shell nanoparticle and 65% polyethylene, in order to ascertain the impact of increasing concentration of periwinkle shell nanoparticle on the characteristics of reinforced composite. All samples were tested for thermal conductivity, friction wearing, water absorption and long-term acid aging. Thermal conductivity of the reinforced composite increases as the percentage of concentration of the periwinkle shell nanoparticle increases of the polyethylene in the composite. As concentration of the periwinkle shell nanoparticle increases over the polyethylene in the composite, the frictional wear coefficient of the composite decreases. Also, the rate at which water is absorbed by various samples of the composite decreases as the concentration of periwinkle shell nanoparticle increases in the reinforced composite.

Indexed Terms- Periwinkle Shell, Low-Density Polyethylene, Acid Aging, Water Absorption, Thermal Conductivity

I. INTRODUCTION

The material requirements of modern constructions and fabrications has overflown beyond the boundaries of what natural and first stage homogenous materials have to offer. Modern materials needed for constructions and fabrications now require hybrid materials with specific and sensitive density, ductility, tensile strength, crystalline structure as well as other thermophysical, mechanical and chemical properties for the construction of products that are meant to withstand certain sensitive and extreme condition. Hence material reinforcement will enable material scientists, researchers and engineers to come up with samples and prototypes of novel materials that will satisfy certain technological and engineering requirements. Material reinforcement is the subjection of composites and fiber matrix under extreme force and temperature in order to transform them into another homogenous material with specific and special thermal, physical, mechanical and chemical properties.

Several attempts have been made towards harnessing the periwinkle shell as a composite, which is consequently a means of recycling the shell from posing an unpleasant odour and sight, enabling the growth of possible diseases causing bacteria's and fungi as well as other unhealthy challenges on the environment. To enable other research scientist and engineers to understand the chemical composition of the periwinkle shell (Oyawoye *et al*, 2019) characterizes the periwinkle shell which shows that the periwinkle shell is very rich in calcium that displays itself in various samples of the calcium and calcium related compounds, and they further concluded that the periwinkle shell will be suitable for the production of soda ash, gas desulphurization, sugar refining, and the results obtained were later compared with the novel commercial limestone. (Atta et al, 2018) investigated the impact of sulphuric acid on a mixture of periwinkle shell ash and cement at some selected percentage composition.In the investigation of the use of abrasive properties of periwinkle shell particle with the binding efficiency of polyester resin on the periwinkle shell particle at a significant level of concentration were conducted. The following abrasive characteristics considered are coefficient of friction, hardness testing, and compressive strength testing (Obot *et al*, 2017). In their study, the cement component was replaced by 0, 5, 10 15 and 20% with the periwinkle shell ash, and their result shows that the compressive strength of the mixture increases as the age increase, and decreases as the periwinkle shell ash content increases, their results further revealed that when exposed to sulphuric acid, it was observed that the compressive strength of the sample decreases as the age increases, also as the periwinkle shell ash increases, as well as the sulphuric concentration (Etim, 2018). The periwinkle shells were considered as a partial replacement for sand dust in the molding of hollow sandcrete block (Oluwarotimi *et al*, 2023), in a study in which they partially replace sand and stone dust at 5, 10, 15 and 20% with crushed periwinkle in a sandcrete block mixed at a constant water-cement ratio at 0.35. the water absorption test was observed on the mixture after 28days. That the compressive strength, weight and density of the sample was determined. Observation of the results revealed that Increased in crushed periwinkle shell in the sample leads to increase in water absorption rate. And the result of the compressive strength of their sample suggest that it can be used as a particle substitute for sand as a constant stone material, the periwinkle shell ash was propose to be a possible replacement of cement, having considered properties like moisture content, specific gravity, finesse and bulk density in a study of the assessment of the physico-chemical properties of periwinkle shell ash as a partial replacement of cement in concrete (Ubong and Godwin, 2017) the results of the chemical composition of periwinkle shell ash they obtained were compared with the American Society of testing and materials. Results further shows that the compressive strength of the sample with the percentage of replacement of 10, 20. 30 and 40% done at 28days on a ratio of 1:1:2 and 1:1:4 with periwinkle shell calcined at 800 and 1000ºC shows some satisfactory result, and hence was recommended to be a partial replacement for cement and concrete preparation. Periwinkle shell and low-density polyethylene was developed using compression molding method. Under the different filler weight stated in the study of composite materials for particle board production (Ibrahim and Sylvester, 2018), in their study the water absorption volume, swelling, modulus of elasticity, rupturing modulus, percentage elongation, ultimate tensile strength, and tensile modulus were obtained and presented in the study and result further shows the result obtained satisfy the least specification for particle board production. Other studies involving the use of the low-density polyethylene matrix as polymer has also been carried out by research who considered the coconut coir husk, the whistling pine seed as their composites (Obada *et al*, 2022; Aneke and Egbo, 2024).

To investigate the thermal behaviour, physico-mechanical characteristics and how they are affected by a long-time acid aging of the periwinkle low-density polyethylene composite. To determine the thermal properties of the reenforced periwinkle shell low-density polyethylene composite. To observe and analyze the acid aging rate of the periwinkle shell low-density polyethylene composite. To compute the density, water absorption rate, friction and wear test of our periwinkle shell low-density polyethylene composite.

II. MATERIALS AND METHOD

- Materials

The periwinkle shell is collected from the dump where those that sells the periwinkle meat has disposed them. This is then crushed using the 1200A multi-function high-speed miller that was powered for 350sec (i.e for 6min) to ensure that it is properly crushed and sieved with a nanosized mesh. Industrial sodium chloride acid (NaCl) and Hydrochloric acid (HCl) used for the washing and treatment of the periwinkle shell was purchased from chukson chemical Ltd, 5 cherubim road, off building materials mile 3 diobu Port Harcourt, Rivers State, Nigeria. The low-density polyethylene matrix was collected from the refuse dump site beside the Bonny magistrate court located at the back of the Federal Polytechnic of Oil and Gas Bonny Island, Bonny, Rivers State, Nigeria.

- Composite Exposure

A handful of the periwinkle shell was gathered and first soaked with warm water before also been soaked with diluted sodium chloride acid for 72hrs (3days) before being subjected to machine washer where it was washed for 25mins. The samples of the periwinkle shell were then dried up in an oven for 50mins at 120ºC, before been treated with 6.0% wt of NaOH solution which is 15M in aqueous solution, to ensure the complete removal of alkali and traces of any sort of residual compound or elements. The periwinkle shell is then dried up again in an oven at a temperature of 120ºC for 5hrs. it was then crushed into 70 – 100nm particle size using the multi-function high speed miller of 1200A power capacity. While the low-density polyethylene matrix was shredded using a plastic crushing machine. Three samples of the reinforced composite with varying percentage of composite – polyethylene matrix composition of distribution of 15% periwinkle shell nanoparticle and 85% low density polyethylene labelled k1, 25% periwinkle shell nanoparticle and 75% low density polyethylene matrix labelled k2, and 35% periwinkle shell nanoparticle and 65% low density polyethylene matrix labelled k3 were all mixed to get a homogenous mixture. Finally, all samples of the composite were subjected to hot pressing machine for them to thermoform.

- Composite exposure condition

In order to test our composite samples for acid aging, our samples were immersed completely into NaCl solution whose pH value is within the range of 7.5mg/L to 7.88 mg/L. the choice of the chemical properties of our acid compound is associated to the bonny terrain. All composite samples were allowed to stay in the acid solution for 81 days to properly represent long term acid aging.

Material Characterization

Frictional wear testing

The two main devices used in the friction and wear testing of our periwinkle shell composite are the pin-on-disc type tribometer (DRTB-70090) and ICC-50-DM-750 LEICA optical microscope device. The pin-on-disc type tribometer is the device use to test the frictional and wear testing coefficient of the composites. To carry out this testing the composite samples will be pre-rubbed to enable our samples to get a good contact with device. The ambient temperature and relative atmospheric humidity under which the testing was carried out are 25±2ºC and 45±7% respectively. A load of 9N was applied directly on top of the sample that is placed on a rotating disc whose angular speed is kept constant at 15cm/s with a sliding displacement of 12.50m. the testing time was carried out for an interval of 370sec, the radius is configured at 7min. the testing was done on all samples of the periwinkle shell – low density polyethylene composite before and after acid aging, as well as before and after the water absorption testing. The optical microscope device is then used to capture and keep track of the wearing image of the samples collected.

- Water absorption testing

If the volume (*V*) of our reinforced periwinkle shell low density polyethylene composite is obtained from the rectangular dimensions, and the mass (*M*) is obtained by measuring the weight using a spring balance. The density (ρ) of our reinforced composites is given by the expression

$$\rho_{k_i} = \left(\frac{M}{V}\right)_{k_i} \qquad 1$$

The densities of the samples of our composite will be obtained and recorded before the water absorption testing, and the acid aging testing. To test for water absorption, the samples are cleaned, and dried up in an oven at a temperature of 50ºC for 4mins, and it's then allowed to cool down to the room temperature before being immersed completely in a bath filled with pure sample of water. The sample will be tested for 6days, but it is removed after every 24hrs, dried up using a clean hand towel, weighed and measured within 60sec before sending it back to the water bath. The values of the densities of various composition of the reinforced composite samples before water absorption testing and after water absorption testing is recorded.

- Thermal Conductivity Testing

The guarded heat method is used to test the thermal conductivity of the 40mm by 10mm by 7mm reinforced periwinkle shell – low density polyethylene composite. Each sample of the reinforced composite is subjected to the guarded heat flow meter, and the time it takes the quantity of heat q to flow through the length from the temperature T_1 to the temperature T_2 is given by the expression.

$$Q_{k_i} = \left(\frac{ql}{T_2 - T_1}\right)_{k_i} \qquad 2$$

Where Q_{ki} is the thermal conductivity of the k_i sample of the reinforced periwinkle shell composite.

III. RESULTS AND DISCUSSION

- Thermal Conductivity

Results of the thermal conductivity testing of the varying percentage composition of periwinkle shell – low density polyethylene composite is presented in Table 1. Result obtained shows that as the percentage of periwinkle shell increase over the percentage of polyethylene matrix in the composite, the thermal conductivity coefficient increases correspondingly.

Table 1: Result of the coefficient of thermal conductivity of all samples of our composite

	Thermal conductivity		
Composite samples	K_1	K_2	K_3
Values	0.570W/mK	0.620W/mK	0.690W/mK

Coefficient of Friction before and after acid aging

The numerical values of result of the coefficient of friction of the various samples of periwinkle shell - polyethylene composite obtained is presented in the Table 2. Results presented shows that the coefficient of friction of the various samples of reinforced composite $K_1 = 57\mu$, $K_2 = 63\mu$ and $K_3 = 72\mu$ decreases respectively by 42.7%, 39.4% and 31.9% after the 81days acid aging testing into $K_1 = 32.66\mu$, $K_2 = 38.18\mu$, and $K_3 = 49.03\mu$. the physical implication of the result is that, the coefficient of friction of the various samples of reinforced composite increases as the percentage of periwinkle shell nanoparticle increases over the polyethylene matrix. Further implication is that, samples of lower concentration of the periwinkle shell nanoparticle will demonstrate a fast acid aging. Hence, the periwinkle shell nanoparticle dampens the rate of materials acid aging in an acid dominated environment.

- Density of Composites Before and After Water Absorption Testing

Results of the water absorption testing of the various samples of periwinkle shell – polyethylene reinforced composite conducted every 24hrs for a total of 144hrs (6days). Results of the densities of all samples before and after water absorption testing is presented in Table 2 and Table 3 respectively, and they reveal that in the first 24hr the densities of K_1, K_2 and K_3 respectively increase by 1.92%, 1.69% and 1.21%, in the second 24hr (after 48hrs) results presented shows the respective samples increases by 2.03%, 1.89% and 1.34%, on the third 24hrs (after 72hrs), the following increase in densities of the respective samples were recoded 1.71%, 1.54%, and 0.98%, on the fourth 24hrs (after 96hrs) the increase in densities of the respective samples are 1.73%, 1.62% and 1.01%, and the fifth 24hrs (after 120hrs) respective samples increase by 1.75%, 1.63% and 1.03%, and in the last 24hr (144hr) the increase in densities of the selected samples are 1.77%, 1.70% and 0.93% respective.

Table 2: Densities of the composite samples before water absorption testing

$K_1 (kg/m^3)$	$K_2 (kg/m^3)$	$K_3 (kg/m^3)$
3.47	4.44	4.98

Table 3: values of density of composite samples after every water absorption stages.

Duration(hrs)	$K_1 (kg/m^3)$	$K_2 (kg/m^3)$	$K_3 (kg/m^3)$
24	3.54	4.40	5.04
48	3.61	4.48	5.11
72	3.67	4.55	5.16
96	3.73	4.62	5.21
120	3.79	4.69	5.30
144	3.86	4.77	5.35

The implication of the results presented is that increasing concentration of periwinkle shell nanoparticles decreases the rate of water absorption of reinforced composite.

CONCLUSION

Following the thermophysical properties of the binary samples of the periwinkle shell and the low-density polyethylene used as matrix in this study, and the experimental condition under which they were characterized and exposed, the key conclusions were made;

- Thermal conductivity of the reinforced composite increases as the percentage of concentration of the periwinkle shell nanoparticle increases of the polyethylene in the composite.
- As concentration of the periwinkle shell nanoparticle increases over the polyethylene in the composite, the frictional wear coefficient of the composite decreases.
- The rate at which water is absorbed by various samples of the composite decreases as the concentration of periwinkle shell nanoparticle increases in the reinforced composite.

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