Development of a Periwinkle Shell Reinforced Epoxy Composite for Military Protective Helmet

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Abstract: The potential of using periwinkle shells as a reinforcing material of a composite for the development of military protective helmets has been studied and reported in this work. 210µm grounded powder of periwinkle shell was used to develop a composite of varying concentrations with epoxy resin. ASTM standard samples for mechanical and physical properties tests were machined from the developed composites and were evaluated. It was found that epoxy with a 30% periwinkle shell has the best tensile result of 2.5 Mpa, hardness result of 133 BHN, and some physical properties. However, the values obtained are smaller than the values required for a good protective helmet. Therefore, it is concluded that periwinkle shell can be used as a filler material for the development of a hybrid composite for military ballistic helmet application.

I. INTRODUCTION

Biodegradable materials are also classified as composite since it is made up of resin and natural fibers. Composites are engineered materials as a result of a combination of two or more materials in which tailored properties can be achieved. Composite materials have been reported to offer a high strength-to-weight ratio and good corrosion resistance, and are highly competitive against conventional materials (Mamoon et al., 2022). Recently, natural fibers have received the global attention of researchers due to growing environmental concerns, thereby prompting the quest for new green and environmentally friendly options [i](Mousa et al., 2023). Periwinkle (Littorina littorea) is a species of small edible sea animal, a marine gastropod mollusk. These periwinkle shells are natural fiber and makeup over 70% of the weight of the animal, have no identified use, and are found littered around markets and homes (Onuoha et al., 2017).

Nowadays, periwinkle has become attractive due to its widespread thereby making it available and cheap. A lot of research has been conducted on the use of periwinkle shells for composite development. Njoku et al., 2011 used the hand lay-up method in producing composite laminate of periwinkle shell-reinforced polyester composite and studied the tensile strength and Young modulus by varying the particle size and weight fraction. They reported that the properties of the composites improved with decreasing particle size. Another research by Sadiq et al., 2020 studied the influence of periwinkle shell microparticles on the mechanical properties of epoxy polymer composite. The powder particle size was varied and concluded that the dispersion of periwinkle shell powder has a significant effect on the mechanical strength of the epoxy polymer.

The basic function of a military helmet is to protect against shrapnel and ballistic threats. The ballistic performance of a material can be measured using the ballistic limit (Kulkarni et al., 2013). The design and materials utilized in the development of ballistic helmets have changed over time as new ballistic materials have been discovered. Studies on natural fibers on ballistic properties have been performed on jute, hemp, and textile hemp-reinforced composites produced using hot compression molding. However, very little research has been reported on the potential use of natural fiber such as periwinkle shells for the development of ballistic helmets, which is hereby proposed

II. MATERIAL & METHODOLOGY

Material

The main materials used in this research include (a) Periwinkle Shell (b) Epoxy Resins, and (c) Epoxy Resin Hardener. The epoxy and hardener were procured from a chemical supply company in Abuja, Nigeria. Whereas the periwinkle shells were purchased from a local market at Bakin Dogo Central Market of Kaduna State, Nigeria.

Material Preparation

The periwinkle shells (PWS) were washed thoroughly to remove dirt. The washed PWS were dried in the sun and then milled. The milled PWS powder was sieved with an ASTM standard sieve of 210µm. the particles

were collected in plastic bags and tied up to prevent them from absorbing moisture. The PWS particles were characterized to determine their chemical composition and is as shown in Table 1:

Table 1: Composition of Periwinkle Shell

%SiO$_2$	%SnO$_2$	%Cr$_2$O$_3$	%MnO	%Fe2O3	%Al$_2$O$_3$	%TiO$_2$	%CuO
0.987	0.027	0.006	0.360	0.108	2.357	0.046	0.031
%ZnO	**%Ag$_2$O**	**%Cl**	**%ZrO$_2$**	**%SO$_3$**	**%CaO**	**%MgO**	**%K$_2$O**
0.024	0.009	1.115	0.027	0.282	91.169	3.440	0.098

Method:
Physical Properties of Periwinkle Shell
The periwinkle shell powder was used to determine its moisture content and moisture absorption. PWS of 2g was measured using an electronic scale and placed in a Petri dish of 56.76g, where it was heated for one hour (1hr) at a temperature of 130°C, the sample was then placed in a desiccator to cool. Upon cooling the sample was reweighed to get the weight after drying. The relationship below was used to calculate the moisture content.

$$MC = \frac{(\text{weight of sample before drying}) - (\text{weight of sample after drying})}{\text{weight of sample}} \times 100 \text{ ------(1)}$$

As for the determination of the moisture absorption, the specimens were then immersed in water at agreed-upon conditions often 23°C for 24 hours. The specimens were removed and dried with a clean cloth and weighed. The relationship below was used to calculate the moisture absorption.

$$\%MA = \frac{(\text{weight of wet sample}) - (\text{weight of dry sample})}{\text{weight of dry sample}} \times 100 \text{------------------(2)}$$

Composite Preparation
The hand layup technique was employed in the development of the composites by combining a mixture of the reinforcement and the matrix while varying their percentages yet maintaining a fixed total mass of the mixture at 100 grams. Firstly, only the matrix without the reinforcement of 100grms was taken as the standard to serve as the control after which the reinforcement was introduced gradually by increasing their mass with a uniform increment of 10grms until five samples were obtained. The various masses were measured using a Mettler balance, with the mix vigorously stirred to ensure homogeneous dispersion of the periwinkle particles in the resin. The prepared composite samples were used to develop test specimens by cutting to stipulated ASTM and ISO standard sizes for various experiments.

Physico-Mechanical Properties Tests of Composites
Each of the samples was subjected to mechanical properties tests such as Brinell hardness and tensile strength tests as well as physical properties tests such as water absorption and density tests of the developed composites.

Brinell Hardness Test
This test was carried out on 5 x 5 cut specimens prepared according to ASTM E10 standard and with a Brinell scale relationship given in equation (3). The Brinell hardness values were calculated for the various samples.

$$HBS = 0.102 \frac{2F}{\pi D(D - \sqrt{(D^2 - d^2)})} \text{ …………………... (3)}$$

Tensile Strength Test
The samples for these tests were prepared in accordance with ASTM D638 standard test. The tensile test was conducted based on Mosanto Tensometer. The maximum load at which the material fails is recorded and used to evaluate the tensile strength using equation (4).

$$Tensile\ strength = \frac{maximum\ load\ (N)}{original\ area\ (mm^2)} \text{ ……………….. (4)}$$

Water Absorption Test

The water absorption test was conducted according to ISO 62. The mass of the dry samples was measured using an electronic scale and the masses were recorded, after which they were immersed in distilled water at room temperature for 24 hours. The samples were then removed sequentially and partly dried with a clean cloth and reweighed using the same electronic scale, hence the masses were also recorded accordingly. Water absorption is expressed as the increase in weight percent as given by equation 4:

$$\% \ water \ absorption = \frac{wet \ weignt - dry \ weight}{dry \ weight} \ x \ 100 \dots\dots\dots\dots\dots (5)$$

Density Evaluation of Periwinkle-Epoxy Composite

Density of a material is defined as the ratio of the volume and mass of the material, this is determined mathematically for both the dry and wet masses. The dry masses were measured as well as the corresponding wet masses, which are then evaluated along with their respective determined volumes. These were evaluated using Equation 6.

$$\rho = \frac{M \ (kg)}{V \ (m^3)} \dots\dots\dots\dots\dots (6) \qquad\qquad\qquad where, \ V = L \ x \ W \ x \ T,$$

Thus: L= length of the sample, W= width of the sample, T= thickness of the sample, V= volume, ρ= density of the composite sample.

III.   RESULT & DISCUSSION

Moisture Content and Absorption of Periwinkle Shell

Weight of sample=2g, Weight of crucible=56.76g

Therefore, the weight of the sample + weight of the crucible before drying=58.76g

Weight of sample + weight of crucible after drying=58.404g

Using equation ----------1

$$\%MC = \frac{58.76 - 58.404}{2} \times 100$$

$$= \frac{0.356}{2} \times 100 = 17.8\%$$

As for moisture absorption, the weight of the wet sample=20g, the weight of the dry sample= 9.81g

Therefore, using equation--------- 2

$$\%WA = \frac{20 - 9.81}{9.81} \times 100 \ = 10.39\%$$

Brinell Hardness Result

From the result of the hardness test shown in Figure 2, the hardness value of the composite increases as the fiber content increases. Again, a sample with a fibre content of 30% in 70% resin has the highest hardness among all samples. This may be because there is a strong bonding between the fiber and resin. Similarly, it can be seen that the addition of reinforcement greatly affects the hardness properties. The finding of our work is in agreement with the findings of earlier published works on the effect of periwinkle shell particles on polymers (Njoku et al., 2011, Onuoha et al., 2017). Moreover, a drop in hardness was noticed when the reinforcing material became too much that the resin available was not enough to bond them which resulted in a loose composite with lower hardness.
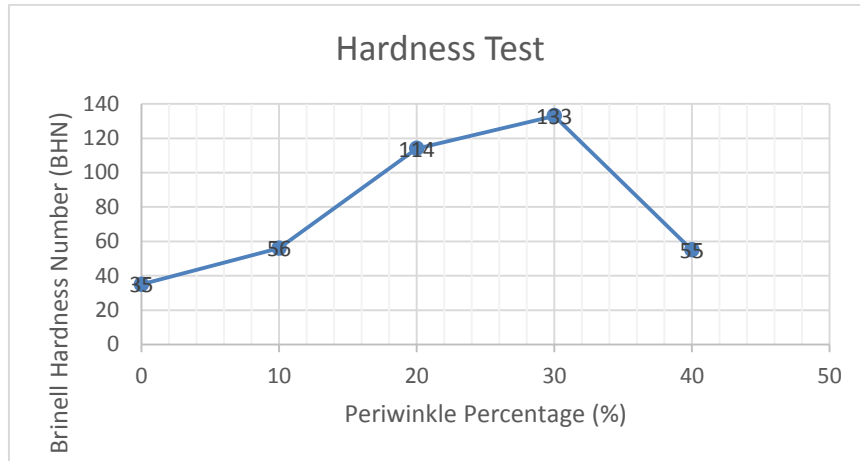
Figure 1: Hardness Test Result

Tensile Result

From the result of the tensile strength test in Figure 3, the tensile strength follows the same pattern as the hardness result, with a steady increase as the fiber content increases. The sample with 30% reinforcement similarly shows better tensile strength than all the other samples. This result corroborates that the sample with 30% reinforcement has better mechanical properties and the addition of the fibers to the epoxy affects the tensile strength of the resin. This shows that periwinkle shell reinforcement enhances and improves the hardness and tensile strength of epoxy resin.
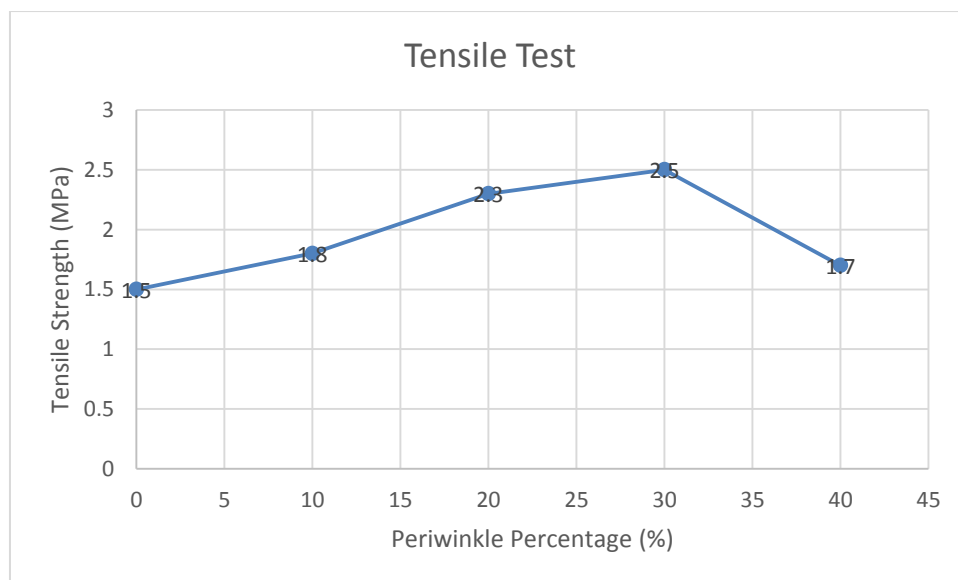

Figure 2: Tensile Test Result

IV.   CONCLUSION

From the various tests conducted on the Periwinkle shell and the composite, the following conclusions are made.

1. 30g reinforced periwinkle shell composite has the best mechanical properties i.e. hardness and tensile strength.
2. The moisture absorption of the periwinkle shell composite was found to be lower than that of epoxy/hardener.

In conclusion, therefore, it can be derived from the various results obtained above that epoxy resin with a 30% periwinkle shell has the best mechanical and physical properties and can be used as reinforcement in composite development for military helmet applications. However, the addition of a periwinkle shell greatly affected the physical and mechanical properties of the developed composite by increasing both the hardness and tensile strength as well as decreasing the density of the developed composite. However, the values of the

properties of the composites obtained is not closed to the values required for a military protective helmet. Therefore, it is recommended that a hybrid composite should be developed using a combination of synthetic fibre i.e. aramid and periwinkle shell fibre for possible use as a military protective helmet material.

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