HYBRID EFFECT ON THE MECHANICAL PROPERTIES OF SISAL FIBER AND E-GLASS FIBER REINFORCED POLYESTER COMPOSITES

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Abstract

The hybrid effect of incorporating periwinkle shell particles into sisal fiber- and E-glass fiber reinforced polyester composite was studied. Hybrid composites of sisal/periwinkle shell and E-glass/periwinkle shell were prepared at a fixed fiber to polyester ratio of 30:70 and variable ratios of the two reinforcements namely 30:0, 20:10, 15;15, 10:20, 0:30 by weight. Experimental samples were produced using the hand lay-up method. Tensile, hardness and flexural tests were performed on these samples and the results showed that the addition of periwinkle shell particles improved the mechanical properties of sisal fiber reinforced composite while it reduced those of E-glass fiber reinforced polyester composite. Improvement in strength of the sisal/periwinkle hybrid composite was attributed to the ability of the periwinkle shell particles to transfer load to the sisal fibers in the hybrid composite.

Keywords: Hybrid effect, sisal fiber, periwinkle shell particles, E-glass fibers, polyester, mechanical properties

1. Introduction

Polymer composites are engineered materials comprised of continuous, high strength fibers impregnated with a polymer matrix to form a reinforced layer (ply) which is subsequently bonded together with other layers under heat and pressure to form an orthotropic laminate [1]. Generally, the mechanical properties of a polymer composite are dependent upon the properties of the matrix and reinforcement, amount, type, and arrangement of fibers within the composite, the interface between the polymer matrix and reinforcing phase and formation process [2].

Fibers predominantly used for composite reinforcement are high strength glass, aramid, carbon/graphite and boron. E-glass fibers are the most commonly used synthetic fiber materials as a result of their relatively low cost of production and reasonably good mechanical and physical properties [3].

Natural fibers and particulate reinforcements have, however, been developed to ameliorate some of the negative effects of synthetic fibers. Composite materials have gained considerable applications in the aircraft and automotive industries and as roofing materials in low cost housing projects as a result of their low density, high specific strength and modulus, and high corrosion resistance [4].

Synthetic fibers like glass are less hydrophilic and more compatible with hydrocarbon polymeric matrices and thus have better mechanical properties than the natural fibers and are more predominantly used. This has a tendency to decline because of the adverse health and environmental impact of glass fibers and other synthetic fibers[5]. According to Yang [6], the greatest problem of the E-glass fibers is that they are non-degradable, cannot be burned nor recycled and hence, they pose serious threat to the environment at the end of their service life.

Recent trend towards environmentally friendly polymer composite systems have been focusing on the use of lingo-cellulosic (natural) fibers such as flax, hemp, sisal, jute, coil, oil palm and waste silk etc as replacements for glass fibers [7]. These natural fibers have some ecological advantage over glass fibers since they are renewable and can be incinerated. The use of natural fiber-reinforced plastic composites is gaining popularity in the automotive, cosmetic and plastic lumber applications [6, 7]. Natural fibers offer economical and environmental advantages over traditional inorganic reinforcements and fillers. The growing interest in using natural fibers as a reinforcement of polymer-based composites is mainly due to their advantages such as low cost, renewability, acceptable specific properties, lower density, ease of preparation, lower energy requirement for processing, biodegradability, wide availability and relative non-abrasiveness over traditional reinforcing fibers such as glass and carbon [8].

However, despite their attractive properties, lingo-cellulosic fibers are used only to a limited extent in industrial practice due to the difficulties associated with surface interactions. The primary drawback of agro-based fibers is associated with their inherent polar and hydrophilic nature and the non-polar characteristics of most thermoplastics. This results in difficulties in compounding the filler and the matrix and, therefore, in achieving acceptable dispersion levels, which ultimately gives rise to composites with low performance capabilities [9]. Again the hydrogen bonding of lingo-cellulosic fibers results in high moisture absorption and swelling of fibers resulting in poor fiber-matrix interface which induces a decrease in mechanical properties [10].

This work has explored the possibility of improving the mechanical properties of sisal fiber reinforced polymer composite through hybridization with periwinkle shell particle fillers. It has also studied the hybrid effect on the mechanical properties of E-glass fiber/periwinkle shell polyester composite. Njoku et al [11] investigated the effects of variation of particle size and weight fraction on tensile strength and modulus of periwinkle shell reinforced polyester composite and reported that periwinkle shell particles strengthened the polyester matrix as their sizes are reduced and weight fraction increased.

Jamal [12] defined a hybrid composite as a material made by combining two or more different types of fibers or reinforcements in a common matrix. Hybridization offers a range of properties that cannot be obtained with single kind of reinforcement. Hybrid composites have long taken the attention of many researchers as a way to enhance the mechanical properties of composites.

However, hybrid composites using natural fibers are less rigorously studied and in such studies, the hybrid composite often consists of one natural and one non-natural fiber [13]. Studies on hybrid composites with particulate reinforcing constituents are extremely rare.

1.1. Rule of hybrid mixtures equation

The rule of hybrid mixtures (RoHM) equation is used to predict the strength and modulus of hybrid composites. The modulus of hybrid a composite is evaluated from the RoHM equation by neglecting the interaction between two systems as:

$$E_C = E_{C1} + V_{C1} + E_{C2} + V_{C2} \qquad (1)$$

Where E_C is the elastic modulus of the hybrid composite. V_{C1} and V_{C2} are the relative volume fraction of the first system and the second system respectively.

$$V_{C1} = \frac{V_{F1}}{V_t} \text{ and } V_{C2} = \frac{V_{F2}}{V_t} \quad (2)$$

V_t is the total reinforcement volume fraction and equals $V_{f1} + V_{f2}$. V_{f1} and V_{f2} are volume fractions of fibers 1 and 2 respectively.

The basic rule of mixtures can also be used to determine the average stiffness of the reinforcement as indicated in the following equation:

$$E_F = \frac{E_C - E_m V_m}{V_F} \quad (3)$$

Where E_F, E_C and E_m are the elastic moduli of the reinforcement, the hybrid composite and the matrix respectively. V_F and V_m are the volume fractions of the reinforcement and matrix respectively.

2. Materials and Method

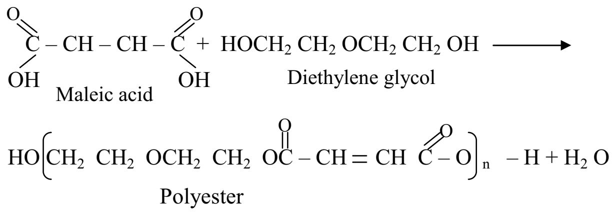
2.1. Materials

2.1.1. Sisal fiber

The sisal plant used in this work was obtained locally from Idah in Kogi State of Nigeria. The fiber was extracted from the leaf of the plant, "Agave sisalana" which is abundantly grown in this part of Nigeria. It is traditionally used in making twine and rope. The fiber was extracted by crushing the sisal leaves between rollers and scrapping of the epidermis and pithy materials from the fibers. The fibers were, thereafter, soaked in sodium hydroxide solution to modify their physic-chemical properties and finally washed in water.

2.1.2. Periwinkle shell

The periwinkle shell is a naturally occurring outer shell covering of a small edible marine gastropod mollusk known as littorina littorea. The periwinkle shell is typically made of calcium carbonate which is bonded in a protein-based organic matrix known as conchiolin [14]. The periwinkle shells used were sourced from Eket in Akwa Ibom State of southern Nigeria. The shells were dried in the sun, ball-milled and classified using hand sieves.



2.1.3. E-Glass fiber

The principal constituent of E-glass fibers is silica (SiO_2). Other oxides such as B_2O_2 and Al_2O_2 are added to modify the network structure of SiO_2, as well as improve its workability.

2.1.4. Polyester resin

A polyester resin is an unsaturated (reactive) polyester solid dissolved in a polymerisable monomer. Unsaturated polyesters are long chain, linear polymers containing a number of carbon double bonds. They are made by a condensation reaction between a glycol and an unsaturated dibasic acid (maleic or fumaric). The structure of a typical polyester is shown above.

2.2. Hybrid composite preparation

The hand lay-up technique was utilized in producing the composite laminates used in this work. 70:30 weight ratios of polyester and reinforcement were maintained. Periwinkle particle size of 600μm was used. Small quantities of methylethyketone and cobalt nephthenate were added to polyester resin to act as catalyst and accelerator respectively. Proportionate amount of periwinkle shell particles was added and the "mix" was vigorously stirred and poured into a mould. Appropriate quantities of fibers (sisal or E-glass) were impregnated in the "resin mix" which ultimately cured to give a solid laminate.

2.3. Tensile test

Standard tensile specimens were cut from the hybrid and non-hybrid composite laminates using ASTM D638 standard and tested in a Hounsfield Monsanto universal tensometer using a maximum beam load of 2500N.

2.3.1. Hardness test

The hardness of the hybrid composite specimens was determined using the Brinell Hardness Testing Machine. A ball indenter diameter of 20mm and maximum load of 4000N were used during the test. The formula used to determine the Brinell Hardness Number (BHN) of the specimens is given below:

$$BHN = \frac{P}{A} \tag{4}$$

Where P is the load applied to the specimen and A is the cross sectional area of the indentation.

$$A = \frac{\pi D}{2}(D - (D^2 - d^2))^{1/2} \tag{5}$$

Where D and d are the diameters of the ball indenter and indentation respectively.

2.3.2. Flexural test

The flexural strength of the hybrid composite samples was determined by subjecting the specimens under load in a three-point bending set-up in accordance with ASTM D790M standard. The test was performed using a Universal Hounsfield Monsanto tensometer. Flexural strength of the coupons was calculated using the formula below.

$$\sigma = \frac{3FL}{2bd^2} \tag{6}$$

Where F is the load at the fracture point, L is the length of the support, b is the width of sample and d is the thickness of the sample.

3. Results and Discussion

3.1. Hybrid effect on tensile strength and modulus of composite materials

Figure 1 and 2 show the tensile strength and moduli of different hybrid and non-hybrid

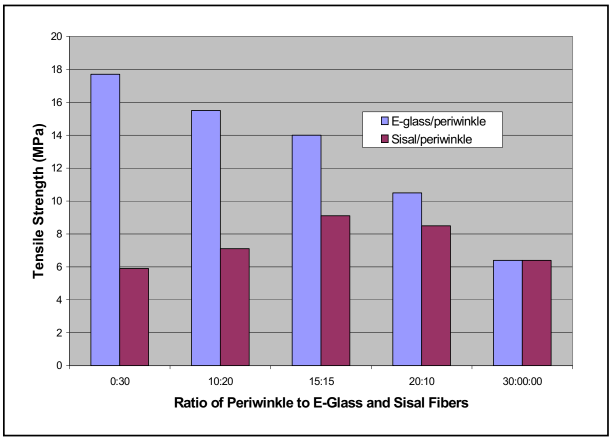


Figure 1: Hybrid Effect on Tensile Strength of Periwinkle/E-glass and Periwinkle Fiber Reinforced Polyester Composite.

composites respectively. The total reinforcement loading of the composite is maintained at 30 wt.%. The figures indicate that the tensile strength and modulus of the sisal fiber reinforced polyester composite was improved as periwinkle shell particles were added to form a hybrid composite. Optimum hybrid effect occurred at a sisal/periwinkle weight percent ratio of 15:15. However, further increase in the weight percent of periwinkle decreased the tensile strength and modulus of sisal/periwinkle hybrid polyesters composite. Conversely, the strength and modulus of the E-glass/periwinkle hybrid composite continuously decreased as the weight fraction of periwinkle particles was increased.

A critical analysis of the strength behaviour of the composite materials shows that there was 54% gain in strength in the sisal/polyester composite as it was hybridized with periwinkle shell particles at 15:15:70 sisal, periwinkle and polyester ratio. Also the strength of this hybrid composite is one half of the strength of E-glass/polyester composite as against that of sisal/polyester nonhybrid composite which is only one-third.

The improvement in tensile strength and modulus of the sisal/periwinkle polyester hybrid composite is probably due to the fact that

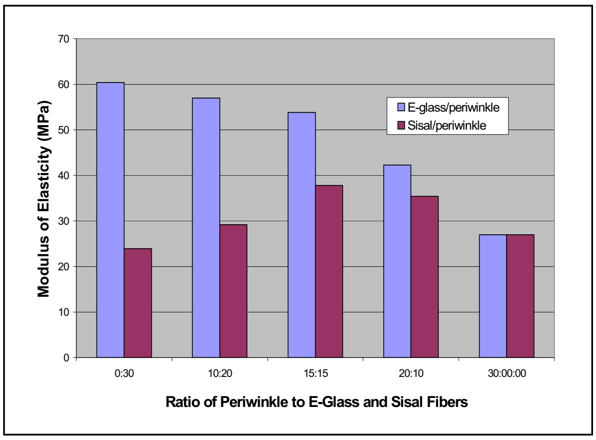


Figure 2: Hybrid Effect on Youngs Modulus of Periwinkle/E-glass and Periwinkle Fiber Reinforced Polyester Composite.

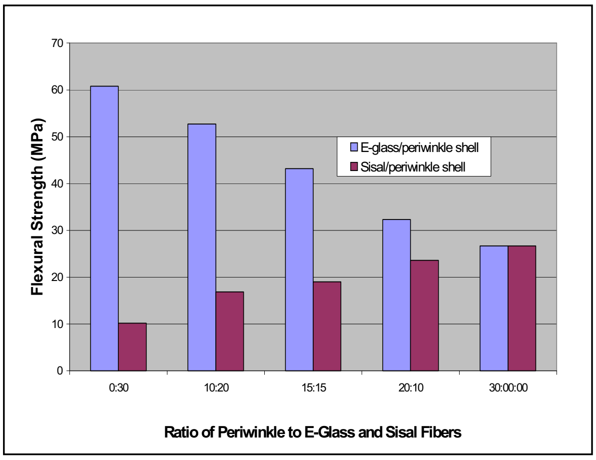


Figure 3: Hybrid Effect on Flexural Strength of E-glass/ Periwinkle Shell Particles Reinforced Polyester Composite.

sisal and periwinkle are compatible with one another resulting in the periwinkle shell particles, effectively transferring load to the sisal fiber [15].

3.2. Hybrid effect on flexural strength and hardness

Variation of flexural strength and hardness upon hybridization of the glass and sisal fiber reinforced plastic is shown in Figures 3 and 4 respectively. Notably, the flexural strength and hardness of sisal polyester composite continuously increased as the weight fraction of periwinkle shell particles in the hybrid composite is increased. However, these properties (flexural strength and hardness) reduced with the incorporation of periwinkle shell particles into the E-glass fiber polyester composite. Addition of 10wt.% of periwinkle shell particles increased the flexural strength of sisal-polyester composite by 65% and the hardness by 36%. In flexural loading condition, various mechanisms such as tension, compression and shearing take place simultaneously. The flexural strength increased with increasing periwinkle shell particles probably because periwinkle has greater resistance to shearing than sisal but has lesser resistance to shearing than E-glass fiber. In a three-point flexure test, failure occurs due to bending failure and shear failure [15].

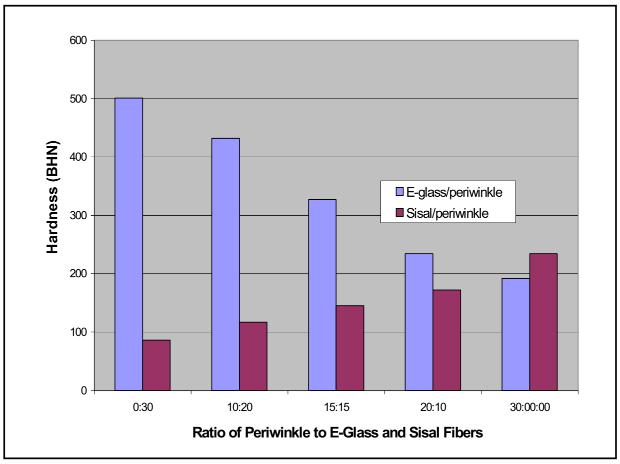


Figure 4: Hybrid Effect on Hardness of E-glass/Periwinkle Shell Particles Reinforced Polyester Composite.

4. Conclusions

In this paper, mechanical properties of sisal/periwinkle and E-glass/periwinkle reinforced polyester composites have been described. The tensile, flexural and hardness properties of sisal fiber reinforced polyester composite are observed to have improved by the incorporation of periwinkle shell particles, showing positive hybrid effect. Optimum hybrid effect on tensile strength and modulus was found at 15:15:70 weight ratios of sisal, periwinkle and polyester. Addition of periwinkle continuously improved the flexural and hardness properties of sisal-polyester composite. It is also observed that periwinkle shell particles produced negative hybrid effect on the E-glass fiber-polyester composite. Thus sisal/periwinkle shell particle-reinforcements in polyester resin resulted in composites having encouraging mechanical properties.

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