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Some Mechanical Properties of Coconut Fiber Reinforced Polyethylene Composite to Control Environmental Waste in Ghana

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Abstract

Polymer products have been applied in all spheres of life and their disposal after use has been a problem. In Ghana, non-biodegradable polymer products in the form of used water-sachet bags is littered everywhere. Coconut husk, which is a natural fiber, is also available as waste. We explore a means of recycling sachet-water bags and coconut husk to yield a useful product. A composite was formed by melting the polyethylene, into which was dispersed coconut fiber, and then allowed to set. Varied masses of fiber were added after which water absorption test, hardness/compressive and flexure tests were conducted on the composite product. The absorption rate of the composite increased with increasing composition of fiber, meaning that the porosity of the material was influenced by the amount of fiber. Increasing the fiber content increased the load needed to compress the sample, indicating an increase in the strength of the composite. The load-bearing capacity increased by 120 % when 450.5 g of fiber was added to the control sample, and further increased to 800 % when the fiber mass was increased to 804.4 g. With an amount of 100 g of fiber added to the polyethylene, the flexure increased by about 5.73 % and by about 31.46 % when 450 g of fiber was added. There was therefore improvement in the mechanical properties of the composite formed, and consequently such waste products can be put to use in applications like the production of ceilings, partition boards, automobile interiors and the likes.

Keywords: coconut, composite, environment, husk, polyethylene

1. Introduction

The engineering world today is characterized by the recycling, discovering and engineering of new materials from everyday convectional materials such as metals, ceramics and polymers (Camann, Dragsbaek, Krol, Sandgren, & Song, 2011). Plastics have consequently become the ideal material choice for many applications (Hull &Clyne, 1981). They can be easily molded into varied shapes and as such, perfect for packaging food, drinks and virtually all products. Plastics used for food storage preserve freshness and flavor as a result of their ability to seal-out contaminants. They are also useful over a wide range of temperature, being used in the storage of frozen foods and in microwavable packages. Plastics are also widely used due to their chemically inert nature (Callister Jr., 2007). The production of plastic products have increased over the years to meet the varied increasing demand in their usage, and so has there been an increase in the production of its waste after use, and therefore the need for its proper disposal. Waste management is a problem for many countries and Ghana is no exception. Plastic waste has ironically contributed enormously to this problem despite the fact that it has many benefits. A number of investigations have been carried out to assess the potential of natural fibers as being used for reinforcement in polymers. According to a previous study, reinforcements provide rigidity, thereby helping to support structural load, as the matrix supports and holds the fiber in place (Hill & Khalil, 2000). The study by Joshi et al. (2004) investigated the life cycle of natural fiber and glass fiber in relation to key drivers compared to their environmental performance. They realized that natural fiber composites were potentially environmentally superior, with their production having relatively lower environmental impacts as compared to glass fiber production. In relation to improvement in fuel efficiency and emissions, they suggested that the light–weight natural fiber composites were the best, especially when used in automobile applications (Joshi, Drzal, Mohanty& Arora, 2004). According to (Geethamma, Kalaprasad, Gabriel, &Sabu, 2005), several groups have successfully tested coir fiber polyester composites being used in the fabrication of helmet, roofing sheets and post boxes

while others have developed composite materials for building using natural fibers. A previous study evaluated the mechanical properties of sisal fiber and established that the mechanical property did not show an appreciable change with an increase in diameter of the fiber but rather with increase in length. Another study investigated the mechanical properties of samples using natural coir fiber with epoxy resin and compared the results with glass fiber reinforced with plastics (Geethamma, Kalaprasad, Gabriel, & Sabu, 2005).

Plastics are materials that can occur naturally or produced artificially and are susceptible to changes in shape. The latter are often produced from petrochemicals. Plastics are composed of polymers which are large molecules consisting of monomers. The focus of this study will be on polyethylene plastic bags, the repeating units of which are ethylene, or ethene. When ethylene molecules are polymerized to form polyethylene, they form long chains of carbon atoms in which each carbon is bonded to two hydrogen atoms (Lajeunesse, 2004; Belmares & Monjaras, 1983). According to Lajeunesse (2004), while plastic materials have made our lives easier in many ways, they are often not disposed-off properly, resulting in most of it ending up in landfills. Due to their light nature, they are then easily carried away onto the streets (where they litter), into gutters (where they chock) and into streams and the sea where they pose a serious threat to most marine species (fishes and animals such as turtles). This is because some of such species are strangled by these plastic bags, while some ingest them because they resemble jellyfish and other food items they are familiar with (Lajeunesse, 2004).

The preparation of composite materials, which involves the combination of two or more conventional materials, have been the result of many engineering activities. Furthermore, the quest to produce biodegradable and eco-friendly materials have brought about the inclusion of natural reinforcement materials into the many composites being produced (George, Sreekala, & Thomas, 2001). The use of composites have several applications which includes the manufacturing of aircraft parts, sporting equipment, marine equipment, in the construction industry and transportation industry (Mohammed, Ansari, Pua, Jawaid, & Islam, 2015).

This work seeks to report on the possibility of producing a polymer reinforced composite from polyethylene (polymer) and a natural fiber (reinforcement). Specifically, this involves the use of water sachet bags (plastic) and coconut fibers. In Ghana, these are both wastes, and therefore pose a lot of problems when it comes to their disposal. Water sachets, for instance, can be found littered virtually in every corner of our environment, while the accumulation of coconut husks principally along our beaches has turned into fertile breeding spots for mosquitoes. The useful application of these wastes is the motivation behind this work.

2. Materials and Methods

a b c

Figure 1. (a) The soaked coconut coir, (b) the dried coconut coir after soaking in water for 48 hours to soften, (c) the extracted fine fibers obtained after beating and combing the coconut coir

Raw materials and tools used:

- Coconut fiber (coir)
- Used empty water-sachet bags (polyethylene)
- Wooden mold
- Petroleum jelly
- Brush

2.1 Fiber Preparation

The coconuts were obtained from the open market, the fruits de-husked with a knife and retted (soaked in water to soften) for 48 hours. The fibers were extracted and separated into strands by continuously beating the

de-husked coir with a stick. The fibers were then combed to draw them out completely and make them long and hair-like. Figure 1 is a composite picture showing these distinct processes. Figure 1a shows the soaked coconut husks after drying; Figure 1b shows the husks after retting; Figure 1c shows the extracted fibre after beating and combing the cocoanut coir.

2.2. Composite Preparation

The preparation of the composite was carried out using the hand lay-up method. This involved the coir fiber being used to reinforce the polyethylene. The polyethylene matrix was obtained by melting the water-sachets in an aluminum saucepan. The test composite material had a composition of 30 wt% of fiber, and the rest being polyethylene.

Sample preparation and calculation

For this work, we considered the test composite to be structured as 30 wt% coconut fiber and 70 wt % polyethylene. Table 1 gives the densities of the components used in making the composite. We prepared a mold box made of wood with dimensions 30 cm × 20 cm × 2.5 cm. With these dimensions, the volume of the mold V_{mb} is given in equation (1). Petroleum jelly was used as a release agent to prevent the composite from sticking on the walls of the wooden mold. Figure 2 is a composite figure in which Figure 2a shows the mold box, and Figure 2b shows how the release agent was applied (by hand) to the interior and cover of the mold.

Table 1. Densities of fiber and polyethylene used to prepare the composite (Chawla, 2012)

Materials	Density (g/cm^3)
Coconut fiber	1.305
Polyethylene	0.910

$$V_{mb} = 30\ cm\ x\ 20\ cm\ x\ 2.5\ cm = 1500\ cm^3 \quad (1)$$

a b

Figure 2. (a) The wooden box used as mold, (b) application of the release agent to the interior of the mold

Consider a composite of components A and B. If W_A is the weight percent of A, W_B is the weight percent of B, ρ_A is the density of A and ρ_B is the density of B, then the volume fraction of A can be calculated using equation (2) (Callister Jr., 2007) as:

$$Volume\ fraction\ of\ A = \frac{{}^{W_A}/_{\rho_A}}{{}^{W_A}/_{\rho_A} + {}^{W_B}/_{\rho_B}} \quad (2)$$

Let A represent the coconut fiber (cf) content and B the polyethylene (p) content. Equation (2) was used to calculate the volume fractions used to calculate the masses of the individual composites.

Calculating the mass of coconut fiber needed:

$$Volume\ fraction\ of\ coconut\ fiber\ (\upsilon_{cf}) = \frac{0.300/1.305}{0.300/1.305 + 0.700/0.910}$$

$$= 0.2301$$

$$Volume\ of\ coconut\ fiber\ V_{cf} = \upsilon_{cf} \times V_{mb}$$

$$= 0.2301 \times 1500$$

$$= 345.2\ cm^3$$

$$\text{Mass of fiber } M_{cf} = V_{cf} \times \rho_{cf}$$
$$= 345.200\,\text{cm}^3 \times 1.305\,\text{g/cm}^3$$
$$= 450.500\,\text{g}$$

Calculating the mass of polyethylene needed:

$$\text{Volume fraction of polyethylene } \upsilon_p = 1 - \upsilon_{cf}$$
$$= 1 - 0.2301$$
$$= 0.7699$$

$$\text{Volume of polyethylene } V_p = \upsilon_p \times V_{mb}$$
$$= 0.7699 \times 1500$$
$$= 1154.85\ \text{cm}^3$$

$$\text{Mass of polyethylene } M_p = V_p \times \rho_p$$
$$= 1154.85\,\text{cm}^3 \times 0.910\,\text{g/cm}^3$$
$$= 1050.910\ \text{g}$$

These masses yield the 30 wt% fiber and 70 wt% polyethylene and are presented in Table 2

Table 2. Mass constituents of coconut fiber and polyethylene matrix used

Composite	Mass Used (g)
Coir	450.50
Polyethylene	1050.91

2.2.1 Natural Fiber Reinforced Polyethylene

Matrix serves several functions in a composite which includes protecting the fiber from the environment, holding the fiber together, distributing an applied load evenly between the fibers so that all fibers are subjected to the same amount of strain, and improving impact and fracture resistance of a component (Smith & Hashemi, 2009). The randomly oriented natural fiber reinforced polyethylene was obtained using the following procedure:

The waste water-sachet bags were washed to remove all impurities and dried to allow water evaporation from their surfaces. Melting was done on a gas stove in an aluminium pot at a temperature of about 110 ^{0}C using an electro-thermal 9100 melting-point apparatus. After the polyethylene bags (which served as the matrix) were melted, the fiber was added and stirred continuously to yield a uniform mixture. It was then left to cool. During cooling, a roller was used for about 10 minutes to make the composite compact and reduce porosity; and a brush used to level the composite. After the fabrication processes the final product was left to cool under ambient conditions in the mold for about an hour and then removed. Figure 3 is a composite figure in which Figure 3a shows the waste water-sachet being dried, Figure 3b shows the uniform composite mixture (in the mold box) after the addition of the fibre, and Figure 3c shows the final product after cooling.

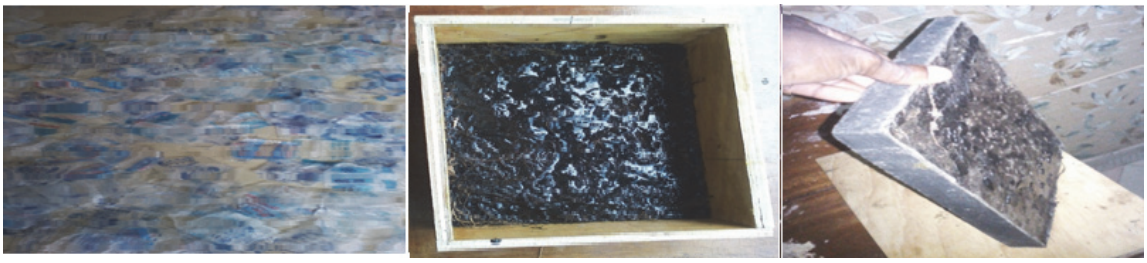

Figure 3. (a) shows the waste water-sachet being dried, (b) the uniform composite mixture (in the mold box) after the addition of the fibre, (c) the final product after the fabrication process

Samples of the final composite product were then subjected to water absorption, compressive (using CONTROLS hardness testing machine), and flexure (using CONTROLS Flexure testing machine) tests. The

machines used for the hardness tests are shown in Figures 4a and 4b respectively.

Figure 4. (a) CONTROLS compressive hardness testing machine used to test the hardness of the final composite product and (b) CONTROLS Flexure testing machine used to test the flexure of the final composite product

3. Results

The preparation of the composite, which involved the mixing of the fibers with the melted polyethylene, was challenging as it was flaming during the process. To overcome this, we employed a completely random orientation by weaving a fine mesh of uniform mesh count so as to add the fibers in an entirely random orientation. Weaving the mesh proved to be efficient since it guaranteed strength in diverse directions. A unidirectional arrangement of fibers would not have been satisfactory enough since it guaranteed strength only in directions of the fiber, thus facilitating easy crack propagation as a result of easy movement of cracks along grain boundaries. Employing a completely random arrangement of the reinforcement proved to be effective and also guaranteed good strength irrespective of the direction of load. In composites, load is generally transferred from the matrix to the reinforcement. It has been established that interfacial reactions ensure the transfer of load to the matrix interface and then to the fiber (Camann et al., 2011). We prepared composites with varying amounts of fiber content. The normal melting temperature range of polyethylene is 115 – 135 ^{0}C. However, with the use of the electro-thermal 9100 melting-point apparatus, it was realized that the sachet bags (polyethylene) melted at 110 ^{0}C. We attributed this reduction in melting point to the potential presence of additives in the polyethylene which were so included during the processing of the sachet bags.

3.1 Water Absorption Test

Water was used to conduct absorption tests on the final products with varying fiber contents (30 and 50 wt%). The weights of the various samples were measured and then immersed in a basin containing water for 24 hours. They were then retrieved and their new weights determined. The change in weight was calculated as a percentage of the initial weight. The results are presented in Table 3.

Table 3. Results for water absorption test

Composite	Weight percent of fiber (wt %)	Absorption of water (%)
A	0	0.01
B	30	0.02
C	50	0.03

It can be deduced from Table 3 that there were no significant additions to the weight of the fiber over the 24-hour period. Although small, the absorption rate of the composite increased slightly with increasing composition of fiber. This implies that the porosity of the material is influenced, to some extent, by the amount of fiber in it. We increased the fiber weight percentage to a maximum of 50 wt% since the polyethylene was to remain the host. A plot showing the variation of the Absorption of water with weight percent of fiber is presented in Figure 5. From the graph, it can be deduced that the positive slope of 3.94737×10^{-4} calculated after fitting the points confirm that increasing the fiber weight within the composite increases its absorption rate.

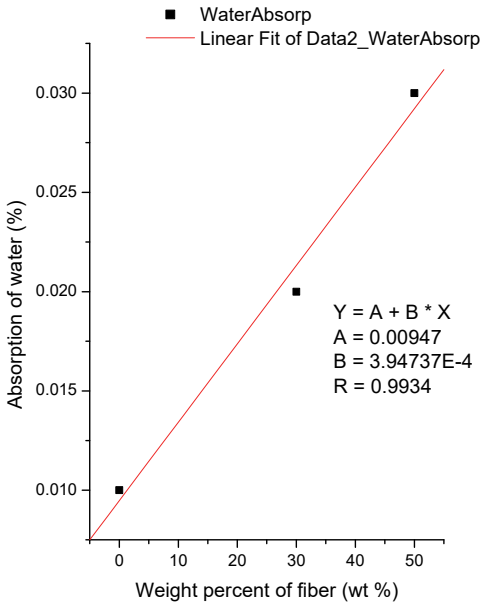

Figure 5. Graph showing the variation of the Absorption of Water (%) with Weight percent of fiber (%) present in the composite

3.2 Compressive Test

Results of the compressive test on the composites with varying fiber contents (30 and 50 wt%) are presented in Table 4.

Table 4. Results for compressive test

Composites	Thickness (mm)	Weight Percentage of Fiber (Wt%)	Mass of Fiber (g)	Load (kN)
A	2.5	0	0.0	0.05
B	2.5	30	450.5	0.11
C	2.5	50	804.4	0.45

It can be deduced from Table 4 that as the fiber content increased, the load needed to compress the sample increased correspondingly, indicating an increase in the strength of the composite. This is confirmed by the data collected for the control sample with no fiber content. The load bearing capacity increased by 120 % when 450.5 g of fiber was added to the control sample, and further increased to 800 % when the fiber mass was increased to

804.4 g. A graph showing an increase in the load when the weight percentage of fiber is increased is presented in Figure 6.

3.3. Flexure or Bending Strength Test

The final test conducted was flexure testing and involved a determination of the bending strength of the samples. For this test, all the samples were fabricated to have the same dimension, but with varying contents of fiber. The dimensions used were as follows:

L= length = 0.110 m; B = breadth = 0.100 m; D = depth = 0.025 m. F is the breaking load in kN.

Equation (3) was used to calculate these flexure values and the results shown in Table 5.

$$\text{Flexure} = \frac{3FL}{2BD^2} \tag{3}$$

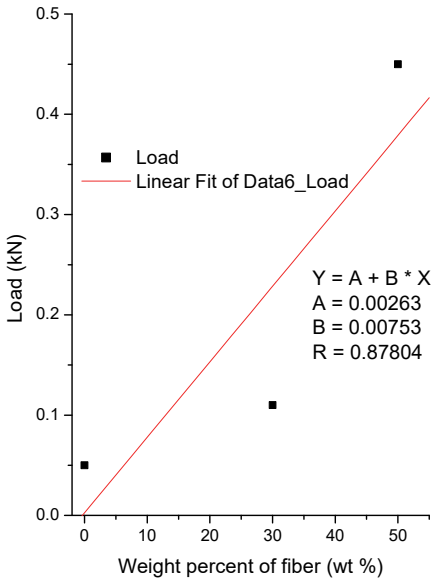

Figure 6. Graph showing the variation of the load with the weight percent of fiber (%) present in the composite.

Table 5. Results for flexure testing

Fibre content in composite (g)	Load dial reading	Load (kN)	Flexure
0	70	0.2880	7603.2
100	74	0.3045	8038.8
150	80	0.3291	8688.2
400	86	0.3380	9340.3
450	92	0.3786	9995.0

With the addition of 100 g of fiber to the polyethylene, the load increased by about 5.73 % with respect to the control, and by about 31.46 % when 450 g of fiber was added to the control. The flexure increased by the same percentages (5.73 % and 31.46 % respectively) for the two masses. This means that an increase in the fiber composition resulted in an increase in the flexure. This observation is depicted in the double y-graph in Figure 7.

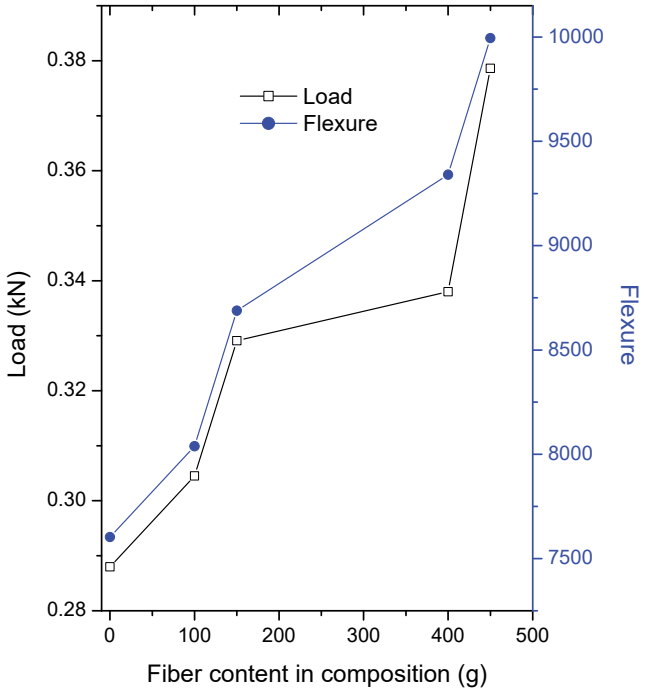

Figure 7. Double y-axis graph depicting an increase in load and flexure as the fiber content in the composite is increased

4. Discussion

With reference to the water absorption test it can be said that the porosity of the composite was affected by the amount of fiber present. This is because the ability of the composite to absorb water increased linearly with the amount of fiber. Other properties of the composite that changed by increasing linearly as the amount of fiber was increased were the load needed to compress the composite (according to the compressive test) and the bending strength of the sample (according to the flexure or bending test). The reinforced composites showed increased strength with increase in fiber content. This makes them good resources in the production of everyday materials such as ceilings, partition boards and automobile interiors. Such waste materials which are causing havoc to our environment therefore have the potential to be put to good use, and the negative effect to the environment avoided.

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