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Mechanical Properties of Coir Fiber Reinforced Epoxy Resin Composites for Helmet Shell.

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Abstract

Various filler loadings (10,20,30,40 & 50 weight%) of coir fiber/ epoxy resin composites have been formulated for possible helmet shell fabrication. The fiber length was 30mm and the ratio of epoxy resin: hardener was 1:0.8. A total of 50 numbers of short beams of 4 mm x 19 mm x 300 mm were produced and tested in flexure using universal testing machine. Impact test and tensile test were also carried out. The impact strength, tensile strength and tensile modulus were then calculated. It was observed that the tensile strength of coir fiber/epoxy resin composites was maximum at 30 wt% filler loading (23.68 N/mm^2). The charpy notch impact strength was also maximum at 30 wt.% (26.43KJ/m^2). The value however began to decrease as the filler loading increased. Currently, industrial helmet shell is fabricated from Polycarbonate (PC) and Acrylonitrile butadiene styrene (ABS). Their tensile strengths are PC; 60 N/mm^2 and ABS; 46 N/mm^2 while their charpy notch impact strengths are PC; 20.00-30.00 KJ/m^2 and ABS; 10.00-29.00 KJ/m^2. The values of coir/ epoxy resin composites fabricated are close to those of PC and ABS. Again, the tensile modulus of coir/epoxy resin composites was found to increase with an increase in filler loadings as follows: 10 wt.%. (900.00N/mm^2), 20 wt.% (977.80N/mm^2), 30 wt.% (1000.00N/mm^2), 40 wt.% (1066.67 N/mm^2) and 50 wt.% (1733.3 N/mm^2). On the other hand, tensile modulus for ABS is 1,910 MPa. Hence, coir/epoxy resin composite was used in industrial helmet fabrication using hand lay- up technique to save cost.
Keywords: coir fiber, helmet shell, mechanical properties.

1. Introduction

Coir has been tested as filler or reinforcement in different composite material (Choudhury et al., 2007, Corradini et al., 2006, Geethamma, et al., 1998, Owolabi et al., 1985 and karthikeyan et al.p, 2012). Coconut coir is the most interesting product as it has the lowest thermal conductivity and bulk density. The mechanical properties of coir toughened unsaturated polyester with different reinforced body forms, namely; coir non- woven needle mat, coir mesh and coir rope has been studied by Yao et al., 2013. From the study, the tensile strength of coir non-woven is the highest among the three with a value of 24.97 MPa at 20 wt.% coir content. The effect of fiber orientation on the mechanical properties of helmet made from coir/ epoxy resin with 10 wt.% coir and 90 wt.% epoxy only, was studied (Yuhazri et al., 2007). The work reported improved mechanical performance of the helmet. It also reccomended that the percentage of coconut fiber in the matrix must be more than 10 wt.% for better results. Misra et al., 2007, investigated fire retardant coir epoxy micro- composites. The coir fiber was treated with saturated bromine water for increasing the electrical properties and then mixed with stannous chloride solution for improving the fire retardant properties, it was observed that only 5% of fire retardant filler reduced the smoke density by 25% and the LOI value increased to 24%. The mechanical properties of the composites were not affected much after the incorporation of fillers and their flexural strength and flexural modulus increased tremendously.

Almeida et al., 2008, investigated the structural characteristics and mechanical properties of coir fiber/ polyester composites. The as-received coir fiber was characterised by scanning electron microscopy and X-ray dispersion analysis. Composites were prepared with two moulding pressures and they noted that with 50 wt.% fiber, rigid composites were obtained and with higher content the composites performed more like flexible agglomerates. Bensely et al., 2009, investigated and evaluated the mechanical properties of coir fiber composites using scanning electron micrographs obtained from fractured surfaces to evaluate the interfacial properties of coir/epoxy and compared with glass fiber epoxy. The results indicate that coir fiber can be used as a potential reinforcing material for making low load bearing plastic composites. Junior et al., 2010, studied the tensile properties of post-cured polyester matrix composites incorporated with the thinnest coir fibers. Tensile specimens with up to 40 vol.% of long and aligned coir fibers were tested and their fracture surfaces analysed by scanning electron microscopy. A relative improvement was found in the tensile properties. Zuradia et al., 2011, investigated the effect of fiber length on mechanical properties of coir fiber reinforced cement- album composites. They noted that by increasing the length of fiber, the flexural strength increased. But incorporation of long fiber into cement paste reduced the workability of the paste and thus introduced voids that resulted in the increase in water absorbtion. Verma et al., 2010, reviewed the use of coir fiber, a natural fiber abundantly available in India and Africa and explored the potentials of the coir fiber polymer composites and its mechanical properties as well as being a reinforcement in polymer matrix. They noted its wide application especially in packaging and furniture. Studies have shown that fiber modification improves resistance to moisture induced degradation of interface and composite properties (Josep et al., 2000). Ruhul Khan et al., 2012, studied the mechanical properties of coir fiber ethylene glycol dimethacrylate base composites. Tensile strength (TS), Young's modulus (YM) and elongation at break (Eb%) of virgin coir fibers were found to be 152 MPa, 5.3 GPa and 36% respectively. Coir fibers were treated with ultraviolet (UV) radiation and were found to improve the mechanical properties significantly. Coir fiber-reinforced ethylene glycol dimethacrylate (EGDM)-based composite was prepared and characterized. The surface of the coir fibers was modified with monomer EGDMA under UV radiation. Soaking time, monomer (EGDMA) concentration and radia intensities were optimized over mechanical properties. The highest values of TS, YM, Eb and polymer loading (PL) were found for 50 wt.% EGDMA at 125th pass of UV radiation for 7 minutes soaking time. Pre-treatment with UV radiation on the coir fiber was found to be more effective for the increment of its mechanical properties. The surface of the fiber was also mercerized (alkali treatment) using aqueous NaOH solutions (5-50%) at varied time and temperature. It was found that TS of the mercerized composites increased with the increase in NaOH solutions (up to 10%) and then decreased. The composites made using mercerized fibers treated with EGDMA showed further increase in TS. Pre-treatment with mercerization + UV treatment of coir fiber showed significant improvement in the mechanical properties of coir fiber- based composites.

Helmet shell is currently fabricated from Acrylonitrile Butadiene Styrene copolymer (ABS) or Polycarbonate (PC) by injection moulding process. However, ABS and PC are expensive and are uncommon with very high tooling cost. Some countries have their standard for helmet specification. For example, Europe: ECE 22.05, Japan: JIST 8133: 2000 and USA: SNELL M2000. Natural fiber polymer composite have recently had a great resurgence of interest for several reasons, among which are cost advantage and environmental preservation. Hand lay- up process which does not require expensive tooling can be adopted as an alternative to the injection moulding method using suitable polymers for this method, like epoxy resin and unsaturated polyester with very cheap, available and renewable natural fibers.

In Nigeria, coir fiber is harvested from coconut palm and is an abundant waste material. Large quantities of this waste are left in the field as under utilized. Information based on utilization of coir fiber for helmet production are limited. Hence, in this research, efforts have been made to treat the coir fiber before incorporating into epoxy (bisphenol A diglycidyl ether) polymer matrix. Test materials have been prepared and series of filled epoxy composites with coir fiber loading (10- 50 wt.%), was used to study the effect of the filler content. The aim of this work is to study the mechanical properties of epoxy filled modified coir fiber composite for helmet shell production.

2. Experimental

2.1 Materials

The coir fibre was sourced locally in Awka, Anambra State and the epoxy resin purchased from a chemical store.

Figure 1. Coir from coconut husk

2.2 Material Preparation

The coir fibers were extracted by retting process. This involves soaking the coconut husks in water and extracting the fibers manually from the husks. The coir fibers were treated with alkaline treatment using 0.5% NaOH. This was to remove wax, lignin, oils and other fiber constituents that may reduce adhesion between the matrix and fibers thereby constituting a weak boundary layer.

2.3 Composite Fabrication

Hand lay-up technique was employed in the composite fabrication using epoxy resin and coir fiber. Epoxy resin and hardener were mixed using the ratio of 10:8 parts by weight, as indicated in the product data sheet. The epoxy resin and hardener were weighed separately and stirred till the mixture became warm (exothermic reaction). A portion of the mixture was then poured into the mould cavity and the fiber introduced. 10, 20, 30, 40 & 50 grams was spread in turn over the polymer matrix in the mould. Dead weights were then placed on the ceramic slabs so as to expell excess matrix material from the mould cavity and also to avoid formation of voids that could be caused by air spaces. The composite was cured under a load of 50kg for 24 hours at atmospheric temperature before the mould was demounted. The composites (Fig. 2) were then removed from the mould and post cured in the air for another 24 hours.

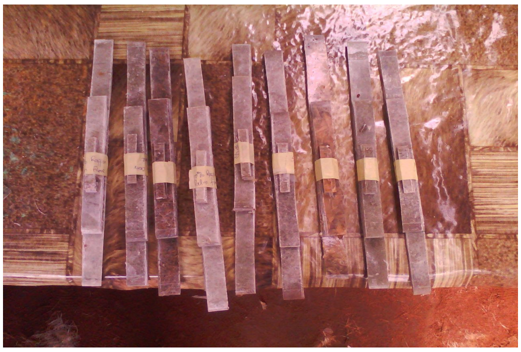

Figure 2. Fabricated Coir/ Epoxy resin composites

2.3.1 Tensile Strength

The test was done using a universal testing machine (Monsanto Tensometer, Wiltshire, England) (Figure 3) and performed according to ASTM D-3039. The test specimen size was 160 x 19 x 4mm.

The equation stated below was used to calculate the tensile properties of the fabricated composites:

Tensile strength = Maximum stress (Nm^{-2} or MPa)

Stress = Load/ Cross Sectional Area (1)

Strain = Change in length/ Original length (2)

Tensile Modulus = Stress/ Strain (3)

Figure 3. Monsanto Tensometer

Figure 4. Flexural Testing Machine

2.3.2 Flexural Strength

Flexural test for the samples was performed using a universal testing machine (Fig. 4). The three point flexural test was conducted according to ASTM D-790 and the specimen size was 300 x 19 x 4mm. Flexural strength was calculated using equation (4).

Flextural strength (MPa) = $3PL/2bd^2$ (4)

Where P = applied load (N), L = Span length(mm), b = width of specimen (mm),
d = thickness of specimen(mm)

2.3.3 Impact Strength (Charpy)

Charpy Impact Test was carried out to determine the toughness of the composites samples according to ASTM D-256 using Charpy principle.

2.3.4 Fabrication of Helmet Shell

It was found from test results of the composites that at 30 wt.% composition, the optimum value for impact strength was achieved. Hence that composition was used for the fabrication of helmet shell.

An industrial helmet shell mould was manufactured using hand lay- up technique. An existing helmet shell was used as the mould for the process. The mould was prepared for the process by first cleaning with a cloth after which universal mould release wax was applied with a soft brush on the inner portion of the mould. After a few minutes, poly vinyl alcohol (PVA) was also applied. The wax and PVA served as mould releasing agents in order to facilitate the removal of the molded component. Coir fibers were cut to 30mm length to ensure proper circulation of the matrix. The total volume of fiber used for the fabrication was 228 cm^3 and the density of coir was 1.15g/cm^3. Gel coat was prepared from epoxy/ hardener mixture and very little amount of sage green epoxy pigment added for aesthetic effect. The gel coat was applied gently with a soft brush and allowed for some minutes to become stagnant (to stop flowing and stick to the mould surface). Care was taken while applying the gel coat to avoid peeling off the thin PVA layer, since this could impart difficulties in removing the product. The mixed epoxy/ hardeners were impregnated with coir fibers (30 wt. %) on the mould surface. The set up was left for 18 hours before the helmet shell was detached from the mould. The mould thus produced was used to fabricate as many helmet shells as possible.

Figure 5. Helmet Shell Fabricated from Coir/ Epoxy resin composites

2.4 Test on Fabricated Helmet

2.4.1 Compressive Strength

The test was conducted using Universal Testing Machine, Cat. 019 by Controls, Milan Italy, serial number 98062563 and capacity of 1000KN, at the Civil Engineering workshop Nnamdi Azikiwe University, Awka, Nigeria. The helmets were tested in one- direction (Y-axis) of compressive load (Fig. 6). The test speed was 10mm/sec. Five helmets were tested under compression and the results averaged.

Figure 6. Compression Test on Coir/epoxy helmet shell

3. Results and Discussion

Table 1. Mechanical properties of coir/epoxy resin composites

Filler Loading (Wt. %)	Tensile Strength (MPa)	Tensile Modulus (N/mm^2)	Flexural Strength (KJ/m^2)	Impact Strength (N/mm^2)
10	23.37	900.00	46.63	21.80
20	23.03	977.80	32.64	24.76
30	23.68	1000.00	25.65	26.43
40	21.05	1066.67	13.99	23.54
50	18.42	1733.33	6.22	20.12

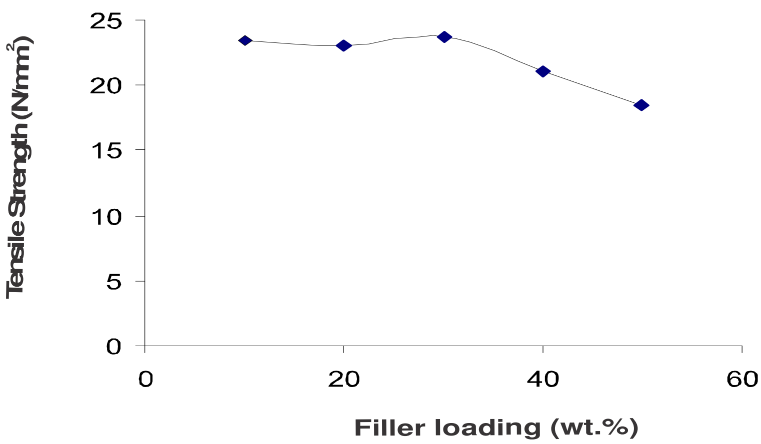

Fig. 7: Tensile Strength of Coir/Epoxy Resin Composites

Fig.7 shows that the tensile strength of coir/epoxy composite first increased with increase in filler loading up to

30 wt.% (23.68N/mm^2), after which a decrease in tensile strength was observed as the filler loading increased to 50% (18.42N/mm^2). The increase in tensile strength up to 30 wt.% could be due to proper adhesion between the epoxy matrix and the coir fibers, which contributes to improved tensile strength, since the coir fibers were treated using mercerization. This increases the maximum stress that the composite can withstand. However, the decrease in tensile strength of the composite after 30 wt.% filler loading could be due to poor circulation of the epoxy matrix around each individual coir fiber, leading to reduction in matrix-reinforcement interaction (poor adhesion) thereby reducing the maximum stress that the composite can withstand. The tensile strength of 23.68N/mm^2 obtained in this work is comparable to those of PC (60 N/mm^2) and ABS (40 N/mm^2) that are usually used for helmet shell (Rimdusit et al., 2012).

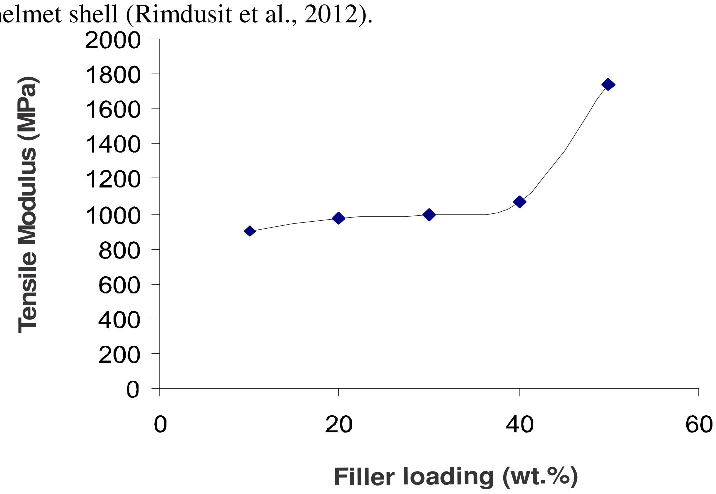

Fig. 8: Tensile Modulus of Coir/Epoxy Resin Composites

Table 1 also shows that the tensile modulus of coir/epoxy composites increased from 900 to 1733.33 MPa for 10 to 50 wt.% filler loading. This is also depicted in Fig. 8.
The increase could be due to improvement in the resistance to extension as the coir filler loading increased, thereby increasing the stiffness of the composite. The tensile modulus value obtained in this work is higher than that obtained in the work by Yuhaziri et al., 2007 and is in agreement with that for ABS (1,910 MPa) (Rimdusit et al., 2012).

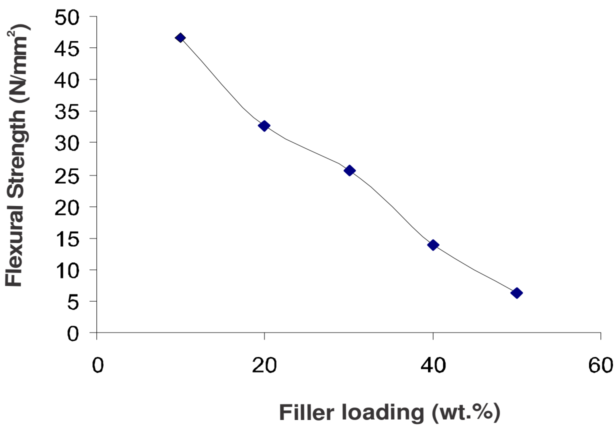

Fig. 9: Flexural Strength of Coir/Epoxy Resin Composites

Fig.9, and Table 1 show that the flexural strength of coir/ epoxy composite decreased as the filler loading increased. This may be due to reduction in the composites ability to resist deformation under load as the filler loading increased. The value of 25.65 N/mm^2 obtained in this work at 30 wt.% filler loading is lower than that obtained by Rimdusit, et al, 2012, with PC (100 N/mm^2) and ABS (72 N/mm^2).

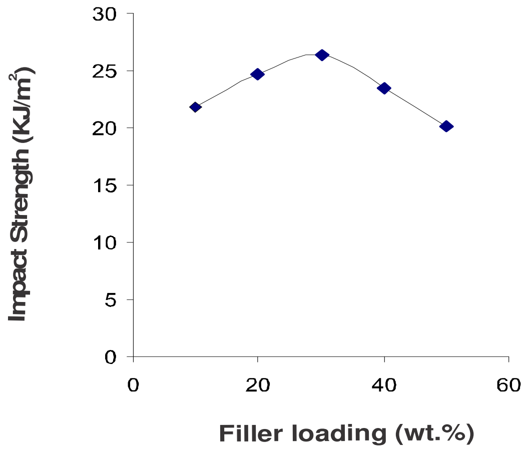

Fig.10: Impact Strength of Coir/Epoxy Resin Composite

Impact property is an important property to consider in helmet shell. The helmet is meant to protect the skull in the event of an accident therefore should have good impact strength.

Table 1 and Fig. 10 show that the impact strength of the coir /epoxy composite first increased with increase in filler loading up to 30 wt.% (26.43KJ/m^2), after which a decrease in impact strength was observed. The increase in impact strength of the composite (from 10 to 30 wt.% filler loading) could be as a result of proper adhesion between the matrix and fibers and also due to proper absorption and distribution of impact energy. However, the drop in impact strength (from 30 to 50 wt.%) could be due to inadequate circulation of epoxy matrix around each coir fiber, leading to poor matrix- fiber interaction which resulted in reduction in the amount of impact energy absorbed per unit area. The optimum impact strength (26.43 N/mm^2) at 30 wt.% is comparable to past related work, Yao et al., 2013, (24.97MPa). However, the achieved result in the present work is less than those of ABS plastic and hybrid reinforced composite developed by Murali et al, 2014, (53.06 J/m) and hybid composite by Ademoh et al, 2015, 41.11 J/m.

3.1 Compressive Test Result On Fabricated Helmet.

Compressive strength of helmets tested in Y- direction was found to be 920 N on the average. The result is in line with compressive strength of related work, (Marsyahyo et al., 2011,), which was found to be 1026 N on the average which is in agreement with result requirement of EN 397.

4. Conclusion.

Research on material and helmet shell production has been studied. Hand lay up process was employed to produce industrial helmet from renewable sources. Coir fiber of 10, 20, 30, 40 and 50 wt.% were introduced separately into epoxy resin matrix and their mechanical properties investigated. The composite material made with 30 wt.% coir fiber gave the highest impact strength 26.43 N/mm^2 and was therefore selected for helmet fabrication. The produced helmet shell has acceptable compressive strength and reduced weight. The 50 wt.% coir fiber/ epoxy composite have the least impact strength of 20.12 N/ mm^2 followed by that with 10 wt.% coir. It has shown that 30 wt.% coir/ epoxy reinforced composite material has sustainable strength for the application of industrial safety helmet and their mechanical properties compare well with those of ABS and PC plastic which is commonly used in the production of helmet. For further research, other matrix materials such as polyester resin can be suggested and mechanical tests such as impact test and penetration test should be carried out on the helmet prototype. Helmet shell needs a specially designed mould. In this research, mould is fabricated using already made helmet shell. This posed the difficulty of not having positive and negative mould. From literature, helmet shell mould can be fabricated from concrete mould or aluminium mould, but the problem is that it needs higher capital and longer time to fabricate. Mould made from concrete and aluminium can be used more than once and is suitable for large- scale production.

Apart from helmet, the coir/epoxy resin composite fabricated could also find application in building construction such as partitioning.

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