Mechanical Behaviour Of Nigerian Long Bamboo Fibre-Reinforced Polymer Composite (Nlbfrpc).

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***Abstract*—The high cost of synthetic fibres such as glass, carbon, kevars etc, results in high cost of production and products derived from these materials which has necessitated alternative means of materials development. This has also informed the utilization of locally available long bamboo fibre for composite materials development.**

Natural fibre has emerged as a renewable and cheaper substitute to synthetic materials such as glass, carbon and aramid, which are used as reinforcements. In this work, the objective was to develop, investigate and analyze the mechanical properties of a composite material using Nigerian long bamboo fibre-reinforced with a thermoset polymer. The long bamboo fibre was extracted using chemical digestion and maceration methods. The fabrication of the composite was carried out using Bisphenol-A-diglycidyl ether (BADGE) as the matrix and the long bamboo fibre as reinforcement. Tests were carried out to determine the mechanical properties such as tensile and compressive strengths. The tensile strength of the composite was 65.79N/mm^2 which can be compared to the tensile strength of Ductile iron (grade 100-70-03) which is 68.9N/mm^2 and tensile strength of Malleable iron (grade 80002) which is 65.5N/mm^2 . The compressive strength was not significantly affected. Therefore the material developed can be used in structural applications with strong dependence on its mechanical properties.

Keywords—long bamboo, fibre, tensile strength, compression strength, Bispenol-A-diglycidal ether

INTRODUCTION

In addition to these naturally occurring composite, there are many other engineering materials that are composite in general ways and have been in use for a long time. They include carbon black in rubber, Portland cement or asphalt mixed with sand, and glass fibres in resin etc.

Since the early 1960's, there have been an increasing demand for materials that are stiffer and stronger yet higher in fields as diverse as aerospace, energy, civil and mechanical constructions. The demand placed on materials for better overall performance is so great and diverse that no one material can satisfy them. This limitation has led to a resurgence of the ancient concept of combining different materials in an integrate-composite materials to satisfy the user requirement, this composite material system result in a performance that cannot be attained by individual constituent which offer a great advantage of a flexible design [2].

Again as this advancement in technology continues the uses and applications of metallic and non-metallic alloys also becomes limited. Therefore there arose the need for corrosion resistant materials, low electrical and thermal conductivity or insulation materials, materials that can easily be joined, casted and formed into complex and intricate shapes including having wide range of choice of appearance, colour and transparencies although the disadvantages of these category of materials such as low strength, low useful temperature, less dimensional stability over a time-creep effect, aging effect as there harden and becomes brittle over time, sensitivity to environment, moisture and chemical, and poor machinability cannot also be undermined[14].

It becomes imperative to consider these materials as alternative to metallic and non metallic materials for the above reasons.

Again the limitation of these materials is seen from their disadvantages which have also brought about the modification. These materials are called plastic or polymers.

Reinforcements provide strength and rigidity, assisting in supporting structural loads. The matrix or binder which could be organic or inorganic material maintains the position and orientation of the reinforcement. Significantly constituents of the composite retain their individual physical and chemical properties whereas together they combine to produce qualities that individual constituents cannot produce alone. Reinforcements have extensively been made of inorganic (man-made fibre) such as glass and organic fibres such as carbon and amid [5]

Recently, the rapidly increasing environmental awareness, geometrically increasing crude oil prices, growing global waste problem and high processing cost triggered the development concept of sustainability and reconsideration of renewable resources. The use of natural fibres derived from annually renewable resources, as reinforcing fibres in both thermoplastic and thermosets matrix composites provides positive environmental benefits with respect to ultimate disposability and raw material utilization.

Natural fibres are now regarded as a serious alternative to glass fibre for use as reinforcements in composite materials. Their advantages include low cost, low density, high strength-to-weight ratio, and resistance to breakage during processing, low energy content and recyclability. The properties of natural-fibre-based composites can be affected or modified by a number of factors such as fibre combinations, processing method, fibre volume fraction, aspect ratio, water absorption, etc. The process parameters and their influence on the final properties vary with different fibre-matrix combinations. The fabrication method has a significant impact on the resulting properties. Various processing methods, e.g. compression moulding, injection moulding, extrusion moulding, and hand lay-up, are available for natural fibre composite materials. Injection moulding improves the fibre dispersion, hence increasing the tensile and flexural properties. However, extrusion and injection moulding have detrimental effects on the properties of natural fibers [6, 16].

The advantages associated with use of reinforcement from natural fibres in polymer are their availability, non-abrasive nature, low energy consumption, biodegradability and low cost. Also natural fibres have low density and high specific properties. The specific properties of these fibres are comparable to those of traditional reinforcement. A number of investigations have been carried out to assess the potentials of natural fibres as reinforcements in polymers.

Nowadays, natural fibre-reinforced polymer composites are increasingly being used for various engineering applications due to their numerous advantages. Natural fibres have been used to reinforce materials for over 3,000 years, more recently they have been employed in combination with plastics. Many types of natural fibres have been investigated for use in plastics including flax, hemps, jute, straw, wood fibre, rice husk, wheat, barley, oats rye, cane (sugar and bamboo), grass reeds, kenaf, ramine, oil palm empty fruit bunch, sisal, coir, water hyacinth, pennywort, kapok, paper-mulberry, raphia, banana fibre, pineapple leaf fibre and papyrus. They all have the advantages of renewable resources and low cost.

Natural fibres are increasingly used in automotive and packaging materials, in some countries of the world that are solely agricultural dependent for instance Pakistan, Malaysia etc, thousands of tons of different crops are produced but most of their waste do not have any further utilization. These agricultural wastes include wheat husk, rice husk and straw, hemp fibre and shells of various dry fruits.

The mechanical properties of different natural fibres such as sisal, vakka, banana, bamboo were compared and it was found that the bamboo fibers have much higher tensile and flexural properties than other fibers [12, 13].

Bamboo fibres have emerged as a renewable and cheaper substitute for synthetic fibres such as glass and carbon, which are used as reinforcement in making structural components. They have high specific properties such as stiffness, impact resistance, flexibility and modulus, and are comparable to those of glass fibre.

Bamboo can be used for reinforcement such as the whole bamboo, section, strips and the fibers. These various forms of bamboo have been used in applications such as low rise construction to resist earthquake and wind loads, bamboo mats composite in combination with wood for beam, and shear wall in low rise construction in addition bamboo fibre can be used as reinforcement with various thermoplastic and thermoset polymer.

Fillers are materials added to plastics to improve their physical properties or in some cases to give cheaper products by acting as extenders. The term filler is very broad and encompasses a very wide range of materials that play important role in the improvement of the polymer performance and their composites [8, 9,11].

MATERIALS AND METHODS

Materials

The materials used here included but not limited to the following; Hydrogen peroxide, concentrated acetic acid, enamel bowl, oven, ladle, bamboo chips, weighing scale, water, plastic cup, bisphenol-A-diglycidlyl ether, poly vinyl alcohol, brush, polish (gel), metal bars of 300mm x 3mm, metal sheet, flat sheet of 300mm x 200mm x 3mm, weight of 8kg, thermometer, pH meter and a graduated cylinder.

Fibre Material

Fibre is the reinforcing phase of a composite material. In this work, bamboo fibre is taken as the reinforcement in the epoxy matrix to fabricate composites. Bamboo is available everywhere around the world and is an abundant natural resource. It has been a conventional construction material since ancient times. The scientific name of the type of bamboo used for this work is *Bambusa Vulgaris* (Ahmed and Kamke, 2005). This is one of the predominant species of bamboo in Nigeria, West Africa and Western Ghats in India. In the present work, long bamboo fibres (prepared in the department of Wood Products Engineering in the Cross River University of Technology, Calabar) were used as the reinforcing material in all the composites. Blemish free bamboo columns were obtained from CRUTECH environment and were chipped to 25 mm in length. The moisture content of the bamboo was determined using gravitational method and the average moisture was calculated to be 20.5% as shown in Tables 3.1 and 3.2 below.

Matrix Material

Among different types of matrix materials, polymer matrices are the most commonly used because of cost efficiency, ease of fabricating complex parts with less tooling cost and they also have excellent room temperature properties when compared. Polymer matrices can be either thermoplastic or thermoset. The most commonly used thermoset resins are epoxy, vinyl ester, polyester and phenolics.

Among them, the epoxy resins are being widely used for many advanced composites due to their advantages such as excellent adhesion to wide variety of fibres, good performance at elevated temperatures and superior mechanical and electrical properties. In addition to that they have low shrinkage upon curing and good chemical resistance. Due to several advantages over other thermoset polymers as mentioned above, epoxy (LY 556) was chosen as the matrix material for the present research work. It chemically belongs to the 'epoxide' family and its common name is Bisphenol-A-Diglycidyl-Ether (BADGE) or Diglycidyl of ether Bisphenol- A-(DGEBA).

There are several methods of fabricating composite, the method employed here was the hand lay-up method.

The resin (Bisphenol-A-diglycidyl ether) was obtained from Bristol Scientific Company Limited Lagos.

A mould having dimensions of 300 x 300 x 3mm was used. Polyvinyl alcohol and wax were used to polish the surface of the mould, they served as releasing agents that made it easy during demoulding of the composite. The resin, Bisphenol-A-diglycidyl ether (BADGE) and the hardener were measured in a ratio of 2:1.

The fibers (Figure 1.0) were distributed across the mould. The resin was added in the mould, while the brush was used to impregnate the fibers until they were saturated. The cast was post cured using a light load of 8.72KN/mm^2.

The mould was closed for curing at a temperature of 25°C for 24 hours at constant pressure. The cast was post cured again in air for 24hours after removal from the mould. Samples were prepared according to ASTM standard for each mechanical parameter and tested. Utmost care was taken to maintain uniformity and homogeneity of the composite since reproducibility is somewhat difficult in hand layup method that was used.

Fig. 1: Bamboo fibre

Tensile Test

According to ASTM D5083 tensile test measures the force required to break a reinforced thermoset plastic specimen and the extent to which the specimen stretches or elongates to that breaking point.

Tensile test is used to measure the force required to break a material and the extent to which the specimen elongates to breaking point. Tensile test produces a stress-strain diagram which is used to specify a material or design parts to withstand applications of force and quality control check. Tensile test is used to determine the tensile strength of a material with unit as N/mm^2 or MPa.

The specimens were prepared according to ASTM D5083, 160mm longx19mm wide x 2mm -14mm thickness this standard is recommended for tensile testing of reinforced thermosetting plastics. The sample was placed in the grips of the universal testing machine and pulled until deformation occurred. An extensometer was used to determine the elongation. The tensile strength was calculated using the following relation;

Tensile Strength for Reinforced Composite

The formula for tensile strength is given as:

$\frac{maximum\ tensile\ force}{cross\ sectional\ area}$.....(1)

Maximum tensile force=200N, length =160mm and breath=19mm

Cross sectional area is given as=length x width,

this gives 160mm x 19mm =3040mm^2

Ultimate tensile strength is given as $\frac{200}{160\ X\ 19}$ = 65.79N/mm^2 or 65.79MPa

Tensile Strength for Unreinforced Composite

Tensile strength is given as:

$\frac{maximum\ tensile\ force}{cross\ sectional\ area}$...... (2)

Maximum tensile force = 100N

Cross sectional area =160 x 19 = 3040mm^2

Ultimate tensile strength is given as $\frac{100}{3040}$ = 32.89 N/mm^2 or 32.89MPa

To plot the stress-strain graph the stress and strain was calculated using the formula

STRESS = Force/ Area

STRAIN = Extension/Original length.

Compression Test

This test was carried out using ASTM D3410. The specimen was dimensioned 144mm long x 12mm width and 30mm thickness. The sample was loaded into the machine and a force was gradually applied until the sample deformed.

Compressive test determines the behavior of materials under crushing loads. Compressive stress and strain was calculated and used to plot a stress-strain graph which can be used to determine elastic limit. The compressive properties that can also be determined from the data are; ultimate compressive strength, ultimate compressive strain, compressive Poisson's ratio etc.

Compression strength of Reinforced Composite:

$$\text{Compressive strength} = \frac{maximum\ compressive\ force}{cross\ sectional\ area} = \frac{F}{A} \quad \ldots(3)$$

Maximum compressive force = 3050N

The cross sectional area is given as 19x3.2 = 60.8mm^2

Ultimate compressive strength is given as $\frac{3050}{60.8}$ = 50.17N/mm^2 or 50.17MPa

Compression strength of Unreinforced Composite

$$\text{Compressive strength} = \frac{maximum\ compressive\ force}{cross\ sectional\ area} = \frac{F}{A} \quad \ldots(4)$$

Maximum compressive force = 3300N

The cross sectional area is given as 19x3.2 = 60.8mm^2

Ultimate compressive strength is given as $\frac{3300}{60.8}$ = 54.28N/mm^2 or 54.28MPa

RESULTS AND DISCUSSION

The results and discussion of the mechanical properties of Nigerian long bamboo fibre reinforced epoxy (Bisphenol-A-diglycidyl ether) composites are presented. The mechanical behaviour of long bamboo fibre reinforced epoxy composites with different loading parameters of fibre and filler are also presented.

Tensile Test Results

The tensile values of the reinforced and matrix composites recorded during the tensile test are shown in Figure 1.0.

The stress-strain relationship of the tensile loading behavior is also shown in Figure 2.0.

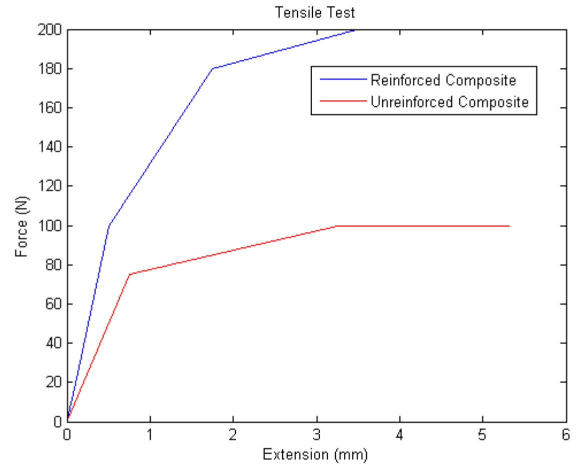

Fig. 2: Tensile graph for the developed composite material for reinforced and unreinforced composite

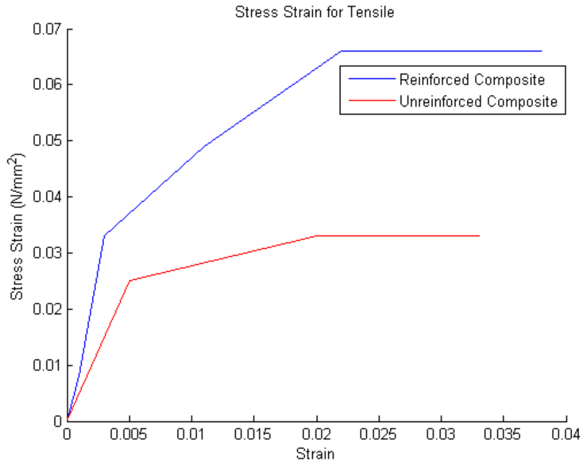

Fig. 3: Stress versus strain graph for long bamboo fiber reinforced and unreinforced composite.

Compression Test Result

The compression result for the reinforced and unreinforced composite are as plotted in Figure 4.0

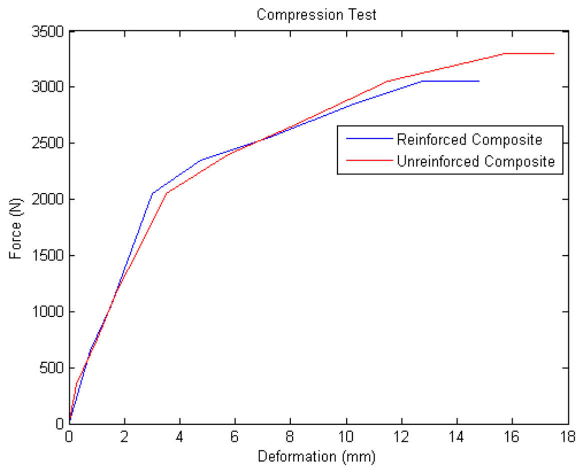

Fig. 4: Applied force versus deformation for long bamboo fibre-reinforced and unreinforced composite under compression loading.

Stress –Strain for reinforced and unreinforced composite were calculated from the compressive values obtained and plotted in Figure 5.0

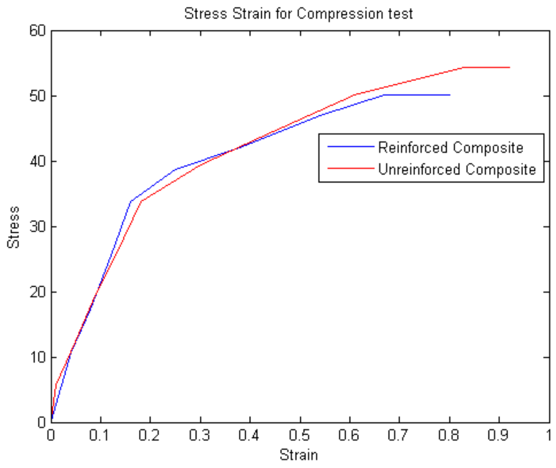

Fig. 5: Stress-strain for reinforced and unreinforced compressed developed composite material

DISCUSSION OF RESULTS

Tensile Strength: The tensile strength of the developed material was determined through the data generated during tensile test. This was for both the reinforced and the unreinforced materials. The test data for the tensile force versus extension is shown in Figure 2.0 for unreinforced and the reinforced material. Basically, tensile load increased linearly with increasing strain until the point of ultimate load, when bamboo fibres underwent breakage exhibiting brittle fracture.

The tensile strength of the reinforced material was determined to be 65.79N/mm^2. This shows that between the values of 100N and 200N load applied to the materials, there is great resistance to stretching force till the failure finally occurs. Theoretically the maximum allowable load that can cause permanent deformation to this epoxy material is 100N. From the foregoing it shows that the long bamboo fiber reinforced composite can withstand twice the strength of the unreinforced composite before fracture while in service. This result is in agreement with [4] who found that the tensile strength of natural fibre increased with reinforcement of natural fiber.

Stress and Strain: The stress and strain values for the developed reinforced materials were obtained from the tensile loading and represented in Figure 3.0. The result shows that for the reinforced material increase in strain was proportional to stress. This observation is in agreement with[10] who said that tensile strength of polymer increases with polymer chain length due to cross linking of polymer chains. This also is in agreement with [7] who said according to the stress-strain curves for different types of polymers by Carswell and Nason polymers (Epoxies) are characterized by high yields, high tensile strength and high elastic moduli and that they elongate considerably by necking.

Compressive strength: The compressive strength was carried out to determine the force that can deform the material. The result of the compressive test is shown in Figure 4.0 for reinforced and unreinforced materials respectively. Comparing the values that caused complete deformation in tensile and compression loadings, it was observed that those in the compression were higher agreeing with[3] who said that polymers compressive strengths are higher (about 20%) than those in tension.

Stress-Strain under Compressive Loading: Stress-Strain values for both developed and the matrix materials were calculated and plotted as shown in Figure 5.0. The values obtained from the matrix material shown significant strain effect on the compressive loading than the reinforced material. This indicates that the long bamboo fiber has low compressive strength.

Conclusion

Natural fibres, when used as reinforcement, compete with such conventional fibres as glass fibre. The advantages of the conventional fibres are good mechanical properties; which vary only little, while their disadvantage is difficulty in recycling. Several natural fibre composites reach the mechanical properties of glass fibre composites, and they are already applied, e.g., in automobile and furniture industries. Till date, the most important natural fibres are Jute, flax, bamboo and coir. Natural Fibres are renewable raw materials and they are recyclable.

The tensile and flexural properties of epoxy (Bisphenol-A-diglycidyl ether-BADGE) composites reinforced with long bamboo fibre have been studied and discussed. The following conclusions can be drawn from the present research.

It has been noticed that the mechanical properties of the composites such as tensile strength and compression strength of the composites are also greatly influenced by the fibre fraction and type.

This work shows that successful fabrication of long bamboo fibre reinforced epoxy composites is possible by simple hand lay-up technique.

The bamboo is known in Nigeria only for domestic use, this research has proved that it can be successfully utilized to produce composite by bonding with suitable resins for value added products.

The surface modification of fibre significantly improves the fiber matrix adhesion which in turn enhances the mechanical properties of the composite.

The developed long bamboo fibre reinforced composite (LBFRC) can be used in different engineering applications based on the available data provided by this research report.

Recommendations

Composite materials show excellent performance for manufacturing of sports goods. It is due to their light weight, high stiffness-to-weight ratio and strength-to-weight ratio, and potentially high resistance to environmental degradation. These result in higher life-cycle.

Some recommendations for future research include:

The developed long bamboo fibre reinforced composite (LBFRC) can be used in different engineering applications based on the available data provided by this research report.

Possible use of ceramic/metallic fillers, polymeric resins other than epoxy(Bisphenol-A- diglycidal ether) and natural fibres in the development of new hybrid composites

In the present investigation a hand lay-up technique was used to fabricate the composite. However there exists other manufacturing process for polymer matrix composite. The result provided by this research can act as the basis for the utilization of this fibre.

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