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Study on Chemical Treatments and Fabrication of Jute Fibre Reinforced Polyester (JFRP) Composites Suitable For Motorcycle Crash Helmet Production

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Abstract: The demand for natural fibers in polymer reinforcement has gained serious attention due to the fact that they are biodegradable and possess qualities similar to synthetic fibers. Chemical treatments have been successfully used to improve qualities and performance of natural fibers like jute fiber. This has made natural fiber reinforced polymer gain wide application in the production of structural engineering components. In this study, jute fiber was treated with 5% concentrated sodium hydroxide (NaOH), Potassium permanganate (KMnO4) and unsaturated polyester as binder. Hand lay-up method of compounding composites was used for the fabrication process. The composite and specimens were produced in a collection of workshops at Technology Incubation Centre (TIC) Nnewi, Anambra State, Nigeria. Replicate samples of JFRP composites were formed. Result showed that density, elongation, tensile strength, young modulus, tensile strain, flexural strength, flexural modulus, and flexural stain increased as a result of chemical treatment. Chemical treatment also improves its hydrophobic and chemical stabilities of the jute fiber and made it more suitable for motorcycle crash Helmet and other structural applications. The composite formulation was also observed to have high potentials for production of related engineering components like car bumper, dash board, military and industrial safety helmets etc.

Keywords: chemical treatment, jute fiber reinforced, polyester, crash helmet, production

INTRODUCTION

There is high demand for motorcycle crash helmets in Nigeria by commercial motorcycle riders, following the strict compliance of the directives of the Federal Road Safety Commission (FRSC) with the directive by the federal government. The need for motorcycle crash helmet cannot be over emphasized as the shell is usually hard and helps resist objects from penetrating during impact thereby preventing direct injury on skull. The foam liner help absorb most of the impact energy. Most helmets are made from resins or plastics reinforced with fibers like aramid. Helmets protect user head by absorbing mechanical energy and protect against penetration. The structure and protective capacity are altered in high-energy impact. However, most of the crash helmets available in Nigerian market are imported and need to improve on their qualities to enable them withstand the maximum impact force required using natural fiber. Hence, it becomes imperative to build local capacity for the production of cost effective crash helmets in Nigeria. The present research was undertaken to fabricate a composite suitable for production of a motorcycle crash helmet using jute fiber reinforced polyester based composites that can withstand the maximum impact force required for motorcycle crash helmet. Chizoba and Edith [1], fabricated coir fiber reinforced epoxy composite for helmet shell using hand layup technique. The weight percentages of coir fiber were 10, 20, 30, 40 and 50 the fiber length 30mm. The authors compare the impact strength, tensile strength and flexural strength of the developed composites with existed material of industrial helmet shell made of polycarbonate (PC) and acrylonitrile butadiene styrene (ABS). They observed that the maximum impact strength of coir fiber reinforced epoxy composite 26.43 KJ/m2 and tensile strength 23.68N/mm2 at 30 wt. % of coir fiber. The impact strength for PC was 20-30 KJ/m2 and for ABS was 10-29 KJ/m2 and the tensile strength for PC was 60N/mm2 and for ABS is 46N/mm2. They concluded that 30 wt. % coir fiber reinforced composite has good properties for industrial safety helmet as compared to PC and ABS material. Murali *et al.* [2] fabricate the sisal/banana/jute particle reinforced epoxy composite for industrial safety helmet using hand layup technique. The authors compared the weight, impact strength and flexural strength of sisal/banana/jute particle reinforced composite with ABS Plastic and they observed that the weight, impact strength and tensile strength of sisal/banana/jute are 252 gm, 53.06J/m and 0.12KN and for ABS Plastic 370 gram, 50J/m and 1.10KN. They concluded that sisal/banana/jute particle fiber reinforced epoxy composite helmet weight was less as compared to the ABS plastic helmet so sisal/banana/jute particle fiber reinforced epoxy composite material would be used as an alternate material of ABS plastics for industrial helmet. Stephen *et al.* [3] fabricate a military helmet using coir fiber reinforced epoxy composite. The weight percentage of fiber for different composition is 20, 40, 50, 60, 70, 80, and 85 taken. The authors observed that the specimen having 70 wt. % of fiber had maximum impact strength (8.733 J/mm2), hardness (30.03 HRF) and flexural strength (31.88 N/mm2). They concluded that the composite having 70 wt. % of fiber volume could be used as an alternate material to fabricate military helmet. Yogesha *et al*. [4] fabricate the jute/glass fibers reinforced polyester composite by varying the weight fraction of jute/glass as 50/50, 40/60, 30/70. The tensile strength, flexural strength and impact strength of the developed composite were examined and the authors concluded that tensile strength (84.59 MPa) and impact strength (7.12 J) of 50 wt. % jute and 50 wt. % glass fiber reinforced polymer was found higher as compared to other developed compositions and the flexural strength (113.93 MPa) of 40 wt. % of jute and 60 wt. % of glass fiber reinforced polyester composite was found higher other developed composite. Terano *et al*. [5] examined the mechanical properties of woven jute fabric reinforced polylactic acid composites. The authors concluded that woven structure exhibited excellent behaviour under tensile, flexural and impact loading as compared to non-woven composites. Mishra *et al*. [6] fabricate the bi-directional jute fiber reinforced epoxy composites using hand layup technique. The authors concluded that the formation of voids decreases with the increase in fiber volume fraction. The hardness, tensile strength and impact strength of bi-directional jute fiber reinforced epoxy composite increased with increase in fiber volume fraction. The flexural strength, first decreases with increase in weight percentage of fiber content and then increased by the increase in weight percentage of fiber. The void content greatly affects the flexural strength and inter-laminar strength of the composite. Berhanu *et al*. [7] fabricated jute fiber reinforced polypropylene composites using compression moulding technique by varying weight percentage of fiber as 30, 40, 50. The authors concluded that 40 weight percentage of jute fiber reinforced polypropylene composite exhibit maximum tensile and maximum flexural strength. Nuhu [8] fabricate the anti-crash helmet using the male bunch stalk fiber of palm oil treat with concentrated 5% sodium hydroxide (NAOH) and polyester as a matrix material using hand layup technique. The authors observed that the impact strength (24.22 J/m) hardness (71 No) and toughness (3.28J). The result showed that the treatment of male bunch stalk fiber with sodium hydroxide improved the mechanical properties of the composite. The 20 wt. % of bunch stalk fiber of oil palm reinforced polyester composite has suitable material for the production of anti-crash helmet. Research has shown that Jute fiber like any other fiber has good qualities like durability, low weight and good thermal conductor, low cost, low density, high specific strength and modulus, no health risk, easy availability, renewability and much lower energy requirement for processing Debiprasad *et al***.** [9]**.** Symington *et al*. [10], studied the effect of moisture content on tensile properties of natural fibers: jute, kenaf, flax, abaca, sisal, hemp and coir and concluded that jute fiber exhibited better mechanical properties than other fibers This can serve a great deal as a reinforcement of matrixes in modern technology and also be in hybrid with synthetic fiber. Jute fiber as a reinforcing material in polyester matrix offers good mechanical properties for producing indigenous products. This research was to improve, encourage and promote indigenous technology and reduces drastically importation of foreign helmets thereby causing savings on foreign exchange and helps create employment opportunities for youths. This will reduce incineration of agro-waste that release greenhouse gases that deplete the ozone layer. Apart from using jute fiber composite to manufacture local motorcycle crash helmet, the developed composite can also be used in producing related mechanical engineering components like car bumper, dashboard, military and industrial safety helmets. Finally the new developed composite will be of immense important to the following industries:

- Automobile industries
- Construction industries
- Luggage and packaging materials
- Building and furnishing materials and Textile industries etc.

MATERIALS AND METHODS (METHODOLOGY)

Materials

The materials used in this study include: Jute fiber, which are used for reinforcement, Polyester resin which serves as the matrix, Hardener, sodium hydroxide (NaOH), Potassium permanganate ($KMnO_4$) solid and Acetone liquid are used for chemical process treatments, Digit weighing balance for measuring weight of chemicals, rectangular glass mold and wax for fabrication of composite, impactor machine for the determination of impact strength universal testing machine for testing of tensile strength etc. Figure 1: is a rectangular glass mold, figure 2: is a wax, and figure 3: is a jute fiber.

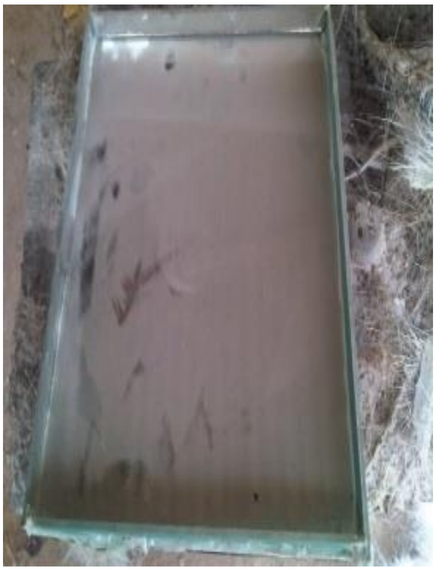

Fig-1: Rectangular glass

Fig-2 : wax.

Fig-3 jute fiber

Extraction of jute fiber

Jute fibers used in this work were sourced from the stem of jute plant through a process called Retting. Freshwater retting was employed in this experiment. Jute stems were soaked in bucket of water with some biodegradable material which helps to increase the pace of decomposition, thereby reducing the retting period to two month instead of normal three months. After the retting process, extracted fibers (jute stems) were separated and washed by removing some residue in water until all slipperiness was lost.

The clean Jute fibers are spread to naturally dry in the sun. Figure 4 is Jute fibers being dehydrated after retting process. In order for proper fiber treatment to take place, suitable chemicals such as Aqueous Sodium Hydroxide (NaOH) which was prepared by dissolving Sodium Hydroxide Pellets in water and Potassium Permanganate ($KMnO_4$) solution was made by also dissolving Potassium Permanganate ($KMnO_4$) solid in Acetone liquid were used. This was based on the recommendation of [11].

Chemical treatments/processing

Mechanical properties of composites were strongly influenced by the adhesion between the matrix, the fibers, and interphase properties. Due to the presence of hydroxyl groups in natural fibers, this makes the fiber to be of high moisture absorption and leads to the poor wettability and weak interfacial bonding between fibers and hydrophobic matrices. Therefore, in order to produce a composite with better mechanical strength, a modification on the fiber surface by using chemical treatments is needed to make the fibers more hydrophobic. Nurul [12]. Chemical treatments have been successfully used to improve the qualities and performance of natural fibers. This has made natural fiber reinforced polymer gain wide applications in the production of structural component. Chemical treatment greatly improved the mechanical properties, hydrophobic and chemical stabilities of the natural fibre and made them more suitable for various applications Nuhu and Olasoji [13].

The hydrophilic jute fiber was difficult to combine directly with the hydrophobic polyester matrix in jute fiber reinforced polyester composites. To bring about a reinforcing effect, the surface of the jute was changed from hydrophilic to hydrophobic. This was achieved by subjecting the jute fiber to alkali treatment and permanganate treatment among other chemical treatments types such as Alkaline treatment, Silane treatment, Acetylation, Benzoylation, Acrylation & Acrylonitrile Graphting Coupling agents, Isocyanate treatment, Permanganate treatment, Peroxide treatment, Sodium Chlorite treatment etc. Alkali treatment, also known as Mercerization, is a common chemical method of fiber treatment that is extensively used by researchers *Meheddene et al*, [14]

Fig-4: dehydrated Jute fiber

Aim of chemical treatments

Chemical treatment of fiber is aimed at improving the adhesion between the fiber surface and the polymer matrix and not only modify the fiber surface but also increase fiber strength and reducing water absorption by composites (increasing moisture resistance) & improving mechanical properties of the composite materials. Xue *et al*.[11]. Jute fibers were subjected to the surface treatments also to improve Interfacial adhesion between jute fiber and polyester resin matrix

Alkaline Treatment

Alkaline treatment or mercerization is one of the most used chemical treatments of natural fibers. When used to reinforce thermoplastics and thermo sets removes a certain amount of lignin, wax and oil covering the external surface of the fiber cell wall and exposes the short length crystallites. Disruption of hydrogen bonding in the network structure took place, thereby increasing surface roughness. The treatment changes the orientation of the highly packed crystalline cellulose order, forming an amorphous region. It has been reported that alkaline treatment has two effects on the fiber namely:

- It increases surface roughness resulting in better mechanical interlock.
- It increases the amount of cellulose exposed on the fiber surface [11].

In alkalization, fibers were cut to 260 mm of length and were soaked in 5% aqueous NaOH solution at room temperature maintaining a liquor ratio of 15:1 for 12hours for proper depolymerisation of cellulose, removal of lignin and better strength of jute fiber. The fibers were then washed several times with fresh water to remove any NaOH sticking to the fiber surface. Fibers were neutralized with dilute acetic acid and finally washed again with distilled water afterwards the treated fibers were carefully spread on mat and then finally air-dried. Figure 5 is the alkaline treated Jute fibre.

Fig-5: Alkaline treated Jute Fiber

Permanganate treatment

Permanganate treatment leads to the formation of cellulose radical through MnO_3 ion formation. In this study, the alkaline treated jute fibers were dipped in 50% permanganate acetone solution for 20 minutes with liquor ratio 15:1. Fibers were dried at 40 °C for 5 hours to remove excessive solvent and moisture by spreading on mat and then finally air dried. As a result of permanganate treatment, the hydrophilic tendency of the jute fiber was reduced, and thus, the water of JFRP composite decreased.

Composite Fabrication/Compounding

The materials used in fabrication/compounding process are:

- Natural fibre (Jute fibre 60g)
- Matrix (Polyester Resin)
- Rectangular Mould glass
- Wax and catalyst
- Acetone, roller and gloves
- Catalyst and Accelerator
- Poly vinyl acetate etc.

Figure 6 is samples of measured treated jute fiber in grams (48g 97g and 146g) to be used for fabrication of composite.

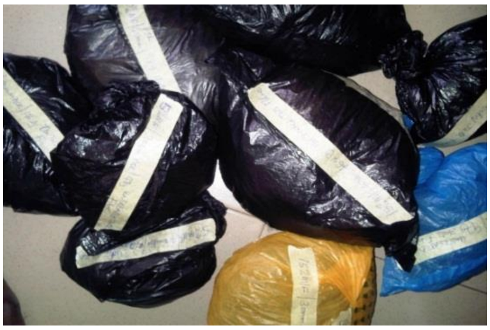

Fig-6: samples of measured treated jute fiber

Composite preparation after permanganate of treated and untreated jute fibers were carried out in an open rectangular glass mold of 246x29x3mm using hand lay-up method in a matching group of 10%, 15% and 20% mass fraction and 20, 30, 40 (mm/mm) aspect ratio based on design matrix of table 3.2 [15]. The process was compared with other methods like compression molding, vacuum molding. Pultrusionit was discovered that hand layup method aids fast product development sequence due to simplicity of fabrication, lower cost. This was in agreement with the findings of [16]. Before starting the formation of the composite, the mold was properly polished. Poly Vinyl Acetate (PVA) mold release agent was applied on its surface before the fabrication to facilitate easy removal of products. Afterwards, the binding mixture resin system consisting of unsaturated orthophthalic polyester, methyl ethyl ketone peroxide (MEKP) catalyst and cobalt naphthanate accelerator was prepared and used for the composites formation. The resin mixture was then poured into the well dispersed jute fiber placed in the glass Mold. The composite were conditioned at 110◦C for 12hours to remove moisture and polyester resin was also conditioned at the same temperature. The jute fiber was placed in a mold and the resin added by hand lay-up method to fabricate the JFRPC. Figure 7 is the picture of the hand layup process of jute fiber fabrication. Figure 8 Composite being prepared from jute fiber reinforced with polyester.

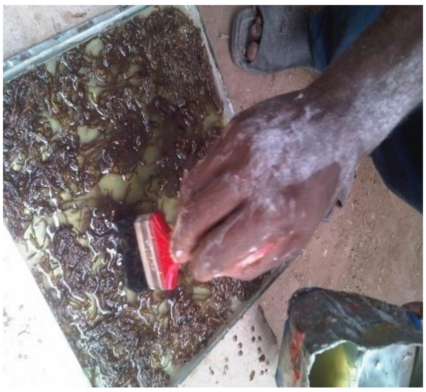

Fig-7: Hand Layup process of jute fiber fabrication

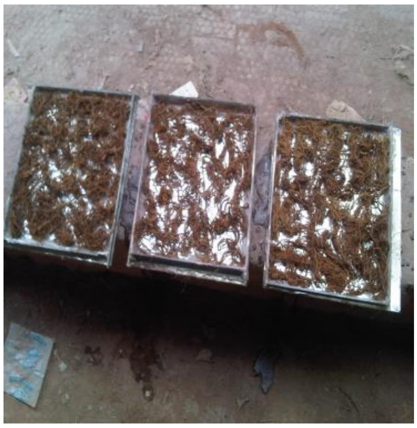

Fig-8: Composite being prepared from jute fiber reinforced with polyester.

The JFRP composite were pressed with a roller to avoid any air trap. When the jute fiber were completely wet by the resin, the mold was closed with a polished and poly vinyl acetate PVA release agent surface-coated cover after the fabrication then pressed and cured at room temperature. At the time of curing, a compressive pressure of 50KPa was applied and maintained on the mold and the composite specimens were cured for 12 hours. The composite and specimen were produced in a collection of workshops at Technology Incubation Centre (TIC) Nnewi, Anambra State of Nigeria. Replicate samples of JFRP composites were formed. After curing, the required untreated and treated composites were obtained as shown in figure 9. Table 1 is the Constituent materials and formulation for the composite

Fig-9: untreated and treated composites

Table-1: Constituent materials and formulation for the composite

S/N	Role of Constituent	Composition (%)	Name of Constituent
1.	Matrix	70	Unsaturated polyester
2.	Reinforcement	20	Jute Fibre
3.	Filler	8	Calcium carbonate
4.	Accelerator	1	Cobalt
5.	Methylethyl Ketone peroxide	1	Naphthate

Mechanical Testing of Composite Specimens

Impact tests were carried out on the jute reinforced polyester composite JFRP samples according to ASTM D256 standard using Ceast Resil impactor machine. Five Samples were cut to a dimension of 85 x 8 x 3 mm each as required by the machine specification. Each sample was set as vertical cantilever and broken with a single swing of the hammer at a Speed of 3.4 m/s and hammer of 4J and the average taken. The impact strength (J/m) was calculated by dividing average energy absorbed (J) with thickness of specimen (m). Hardness test was carried out on according to ASTM (D2240) standard using the Shore D durometer. Tensile test of composite samples was carried out according to ASTM D638 standard using the universal testing machine. The following results were obtained as shown in table 2.

Table-2: mechanical properties of untreated and treated jute fiber

Mechanical properties of untreated an treated jute fiber		
Properties	Untreated jute fiber	Treated jute fiber
Density in (g/cm^3)	1.38	1.10
Elongation in (%)	1.20	1.80
Tensile strength in (MPa)	26.01	29.12
Young modulus in (GPa)	23.01	30.23
Impact strength (J/mm)	8.01	8.73
Tensile Strain (%)	4.01	4.78
Flexural strength (MPa)	34.60	36.90
Flexural modulus (GPa)	3.40	3.90
Flexural Strain (%)	2.30	2.90

RESULT AND DISCUSSION

This study shows that chemical treatments performed on natural fiber like Jute fiber was crucial it improved the surface characteristics. Chemical treatments eliminates some portion of hemicelluloses, lignin, pectin, wax and oil covering materials thereby controlling the mechanical properties of jute fiber this tends to be controlled by the cellulose content and micro fibril angle based on the morphology and fiber composition. Thus fiber surface became more homogeneous due to elimination of micro voids. Stress transfer capacity between alternate cell Improved and increase effective fiber surface area for good adhesion with matrix. It decrease hydrophilic nature of fiber by raising its cellulose content and stabilized the material. The moisture content of treated fiber was removed from the fiber reducing its weight and increasing its mechanical properties such as density, elongation, tensile strength, young modulus, tensile strain, flexural strength, flexural modulus, and flexural stain. After fabrication of composites and testing, it was discovered that treated fiber was good for the manufacture of Motorcycle crash Helmet.

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CONCLUSION

The mechanical properties of Jute Fiber Reinforced Polyester Composites Studied depend immensely on alkali and permanganate treatments of

Jute fiber reinforcement combinations. The treated JFRP exhibits better and stronger mechanical properties which are highly recommended for fabrication of local motorcycle crash helmet than untreated JFRP due to some reasons which include the following: 1.Treated Jute fiber has better hydrophobic nature. 2. It has increase fiber Strength, rough surface characteristics and pits disclosure of the chemically treated jute fiber thereby enhances and improve the composite formation. 3. The mechanical properties such as density, elongation, tensile strength, young modulus, tensile strain, flexural strength, flexural modulus, and flexural stain increased thereby making it suitable for the manufacture of Motorcycle crash Helmet.

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