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BIO-DESIGN AND FABRICATION OF BIO-COMPOSITE HELMET USING (SISAL, BANANA, JUTE AND COCONUT COIR)

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ABSTRACT

Recently, bio composite materials are synthesized using natural cellulose fibers as reinforcements together with matrix, which have attracted the attention of researchers due to their low density with high specific mechanical strengths, availability, renewability, degradable and being environmental-friendly. The presentwork attempts to make an improvement in the current existing helmet manufacturing methodology and materials used to have better mechanical properties as well as to enhance the compatibility between fibers and the matrix. The bio-composite are prepared with the unsaturated polyester matrix and fibers such as jute, sisal, coconut, areca and banana using hand lay-up method with appropriate proportions to result in helmet shell structure. The fabricated helmet are planned to evaluate its mechanical properties such as tensile strength, impact strength and compression strength

Keywords: Bio-composite, Sisal, banana, jute, coconut coir

INTRODUCTION

Over the last thirty years composite materials, plastics and ceramics have been the dominant emerging materials **[1]**. The volume and number of applications of composite materials have grown steadily, penetrating and conquering new markets relentlessly. Modern composite materials constitute a significant proportion of the engineered materials market ranging from everyday products to sophisticated niche applications **[2]**. While composites have already proven their worth as weight-saving materials, the current challenge is to make them cost effective. The efforts to produce economically attractive composite components have resulted in several innovative manufacturing techniques currently being used in the composites industry **[3]**. It is obvious, especially for composites, that the improvement in manufacturing technology alone is not enough to overcome the cost hurdle **[4]**. It is essential that there be an integrated effort in design, material, process, tooling, quality assurance, manufacturing, and even program management for composites to become competitive with metals **[5]**.

The composites industry has begun to recognize that the commercial applications of composites promise to offer much larger business opportunities than the aerospace sector due to the sheer size of transportation industry **[6]**. Thus the shift of composite applications from aircraft to other commercial uses has become prominent in recent years. Increasingly enabled by the introduction of newer polymer resin matrix materials and high performance reinforcement fibers of glass, carbon and aramid, the penetration of these advanced materials has witnessed a steady expansion in uses and volume **[7]**. The increased volume has resulted in an expected reduction in costs. High performance FRP can now be found in such diverse applications as composite armouring designed to resist explosive impacts, fuel cylinders for natural gas vehicles, windmill blades, industrial drive shafts, support beams of highway bridges and even paper making rollers **[8]**. For certain applications, the use of composites rather than metals has in fact resulted in savings of both cost and weight. Some examples are cascades for engines, curved fairing and fillets, replacements for welded metallic parts, cylinders, tubes, ducts, blade containment bands etc. Further, the need of composite for lighter construction materials **[9]**.

and more seismic resistant structures has placed high emphasis on the use of new and advanced materials that not only decreases dead weight but also absorbs the shock & vibration through tailored microstructures **[10]**. Composites are now extensively being used for rehabilitation/ strengthening of pre-existing structures that have to be retrofitted to make them seismic resistant, or to repair damage caused by seismic activity **[11]**. Unlike conventional materials (e.g., steel), the properties of the composite material can be designed considering the structural aspects. This chapter outlines some of the recent reports published in literature on mechanical behavior of special emphasis on natural fiber reinforced polymer composites **[12]**. Persistence of plastics in the environment, the shortage of landfill space, the depletion of petroleum resources, concerns over emissions during incineration, and entrapment by and ingestion of pack-aging plastics by fish, fowl and animals have spurred efforts to develop biodegradable/bio based plastics **[13]**. This new generation of biobased polymeric products is based on renewable bio based plant and agricultural stock and form the basis for a portfolio of sustainable, eco-efficient products that can compete in markets currently dominated by products based on petroleum feedstock in applications such as packaging, automotives, building products, furniture and consumer goods **[14]**. It is not necessary to produce 100% biobased materials as substitutes for petroleum-based materials immediately **[15]**. Available solution is to combine petroleum and bioresources to produce a useful product having the requisite cost-performance properties for real-world applications **[16]**. Biopolymers or synthetic polymers reinforced with natural/biofiber frequently termed 'biocomposites' can be viable alternatives to glass fiber reinforced composites. The combination of biofibers like kenaf, industrial hemp, flax, jute, henequen, pineapple leaf fiber, sisal, wood and various grasses with polymer matrices from both non-renewable (petroleum-based) and renewable resources to produce composite materials that are competitive with synthetic composites such as glass- polypropylene, glass-epoxies, etc., is gaining attention over the last decade **[17]**. The use of natural fibers for the reinforcement of the composites has received increasing attention both by the academic sector and the industries. Natural fibers have many significant advantages over synthetic fibers currently, many types of natural fibers have been investigated for use in plastics including flax, hemp, jute straw, wood, rice husk, wheat, barley, sisal, coir, bamboo etc. **[18]**. The chemical composition of natural fibers varies depending upon the type of fibers. The chemical composition as well as the structure of the plant fibers is fairly complicated. Plant fibers are a composite material designed by nature. The fibers are basically a rigid, crystalline cellulose microfibril- reinforced amorphous lignin and/or with hemicellulosic matrix **[19]**. Most plant fibers, except for cotton, are composed of cellulose, hemicellulose, lignin, waxes, and some water- soluble compounds, where cellulose, hemicelluloses, and lignin are the major.

constituents. The properties of the constituents contribute to the overall properties of the fiber. Hemicellulose is responsible for the biodegradation, microabsorption and thermal degradation of the fiber as it shows least resistance, whereas lignin is thermally stable but prone to UV degradation. The percentage composition of each of these components varies for different fibers. Generally, the fiber contains 60-80 % cellulose, 5-20 % lignin and up to 20 % moisture **[20]**. The cell wall of the fibers undergoes pyrolysis with increasing processing temperature and contributes to char formation. These charred layers help to insulate the ligno-cellulose from further thermal degradation.

MATERIALS AND METHODS

Step 1: Selection of matrix material

Epoxy LY-556 resin belonging to the Epoxide family was taken as the matrix. HY 951 was used as the hardener.

Step 2: Selection of reinforcement and Natural fibers

Natural fibers such as Sisal, Coconut coir, Arecanut, Ridge gourd and Tamarind were taken to fill as reinforcements in the Polymer composite.

Step 3: Extraction of fibers

Sisal Fiber:

- Sisal is Commercially available.
- Sisal is a natural fiber (Scientific name is Agave sisalana) of Agavaceae (Agave) family yields a stiff fiber traditionally used in making twine and rope.
- Sisal is fully biodegradable and highly renewable resource.
- Sisal fiber is exceptionally durable and a low maintenance with minimal wear andtear.

Areca Nut:

- Areca nut is also known as Betel nut.
- The areca nut husk fibers are predominantly composed of cellulose and varying proportions of hemicelluloses, lignin, pectin and proto-pectin.

The fibers adjoining the inner layers are irregularly lignified group of cells called hard fibers,

- and the portions of the middle layer below the outermost layer are soft fibers.

Jute Mat Fiber:

- Jute is a long, soft, shiny plant fiber that can be spun into coarse, strong threads. It is produced from plants in the genus Corchorus.
- Jute is one of the cheapest natural fibers, and is second only to cotton in amountproduced and variety of uses.
- Jute fibers are composed primarily of the plant materials cellulose and lignin. Jute is a rainy season crop, growing best in warm, humid climates.
- It is 100% bio-degradable & recyclable and thus environment friendly.

- **Banana fiber:** Banana Fiber contains cellulose, hemicelluloses and lignin. Available at reasonable prices, our Banana Fiber is widely appreciated for its characteristics such as high strength, strong moisture absorption, good luster, lightweight, fast moisture absorption and release, small elongation, easy degradation and many more.
- **Coconut Coir Fiber:**

  Coconut coir- Coconut fruit peel were gathered and soaked in water. Later clean fibers were drawn manually from them. Show in **Figure 2**.

Step 4: Surface treatment of fibers

Freshly drawn fibers generally include lots of impurities that can adversely affect the fiber matrix bonding. Consequently the composite material made from such fibers may not possess satisfactory mechanical properties. Therefore it is desirable to eliminate the impurity content of the fibers and perhaps enhance the surface topography of the fibers to obtain a stronger fiber-matrix bonding. The fibers were left to treat with 5% NaOH for 3-4 hrs. Later they were drawn and dried under sunlight for 1-2 hours. Show in **Figures 3a-d**.

Figure 1: Jute mat Fiber

Figure 2: Coconut Coir

(a) 5% NaOH solution

(b) Fibers in NaOH solution

(c) Water Treatment

d) Drying at room temperature

Step 5: Wet Hand lay-up technique

Hand lay-up technique is the simplest method of composite processing. The infrastructural requirement for this method is also minimal. The processing steps are quite simple. First of all, a release gel is sprayed on the mold surface to avoid the sticking of polymer to the surface. Thin plastic sheets are used at the top and bottom of the mold plate to get good surface finish of the product. Reinforcement in the form of woven mats or chopped strand mats are cut as per the mold size and placed at the surface of mold after perspex sheet. Then thermosetting polymer in liquid form is mixed thoroughly in suitable proportion with a prescribed hardner (curing agent) and poured onto the surface of mat already placed in the mold.

Properties of Natural Fiber:

Plant Fibers	Density (Kg/m^3)	Tensile Strength (MPa)	Young'sModulus (GPa)
Jute Fiber	1300-1500	200-450	20-55
Sisal Fiber	1300-1500	80-840	9-22
Coconut Coir	1150-1250	106-175	6-8
Areca Nut	1050-1150	300-530	30-60

RESULT AND DISCUSSION

The natural fibers have been successfully reinforced with the epoxy resin by simple wet hand lay-up technique. The aim of this project is to find the tensile, Bending, ILSS and impact strength of natural fiber reinforced bio-composites. The fibers like jute fibers, coconut coir, areca nut fibers, sisal fibers were successfully used to fabricate bio-composites with varying the fiber percentage. The new hybrid composite produced with natural fibers as reinforcements gives good mechanical properties as compared with pure matrix material. These hybrid-bio-composite can be used in Aerospace and automobile applications.

TESTING AND RESULTS

Specimen preparation as per ASTM standards

The samples are cut to the following dimensions as per ASTM standards for testing shown in **Table 1**.

Mechanical Testing of Composite Laminates

Mechanical properties such as Ultimate tensile strength (UTS), Young's modulus, Flexural strength (FS), Flexural modulus, Inter laminar shear strength (ILSS) of carbon and glass fiber reinforced vinyl ester composites are computed from the test conducted using universal testing machine (UTM) in accordance to ASTM standards for specimen preparation. The 10 ton capacity UTM machine is supplied by Kalpak instruments and controls, Pune, India. UTM Specifications are shown in **Table 2**.

Flexural Testing of Composites

ASTM D 790: Standard Test Method for Flexural Properties of Polymer Composite. The samples are cut to the dimensions as per ASTM standards for flexural testing. The test specimen geometry as specified in the above standard for balanced symmetric carbon and glass fiber composites (0/90) are , width 12.7 mm, length 127 mm, thickness 6 mm.

The test is conducted at a strain rate of 0.5mm/minute. The Test Setup and the details of test specimen are given. Flexural test is done using a three point bend setup. The distance between the two supports are maintained at 100mm. The ultimate load carrying capacity of the composite laminates is recorded.

Flexural strength, strain and flexural modulus of the composites are determined using the formula 5.3,5.4 and 5.5 respectively.

$$\sigma_f = \frac{3PL}{2bd^2} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (5.3)$$

Strain $\boldsymbol{\varepsilon f} = 6Dd/L^2$…….. (5.4)

Flexural modulus X = $\boldsymbol{\sigma f / \varepsilon f}$ …… (5.5)

Where,

P = peak load in N,

L = span length in mm,

b = width of specimen in mm,

d = thickness of specimen in mm,

D = Deflection from no load condition in mm.

Test Result of Bio Composite Helmet

The drop weight impact tests were performed on the fabricated bio-composite helmet. Although, the maximum permissible limit of 19.5 kN (as per BIS standard) impact load is required for drop weight impact analysis, due to limitation of test rig, we performed the test with drop mass of 430 N. Figure 3, shows the impact load against displacement for tested bio-composite helmet. It could be observed that maximum permissible load withstood by the helmet is 68.57 KN and the impact energy absorbed by the helmet was found to be 1397.913 KJ by post processing the experimentally acquired data as shown in **Figure 4**.

Table 1: ASTM Standards for sample dimensions

Sl. No	ASTM Code	Mechanical Test	Sample Dimensions (mm)
1	ASTM-D790	Flexural	80 × 8 × 3
2	ASTM-D256	Impact	65 ×12.5× 3

Table 2: Specifications of Universal Testing Machine

Parameter	Specifications
Capacity	10 tones
Load frame	Mild steel C channel with double ball screw mechanism pre-loaded ball screw with zero backlash covered with bellow
Mounting	Free standing
Load range	1 kg-1000 kg using 1 ton load cell 1 kg-10000 kg using 10 ton load cell
Length measurements	Rotary encoder mounted on to the screw rod
Length resolution	0.01 mm
Cross head speed	0.1 to 100 mm/min
Controls	Emergency off, up and down key
Input power	220V±10% VAC,50 HZ,1500 VA
Net weight	225 kg
Grippers	Tensile, Compression, Three point Bending
Length accuracy	±0.1 mm

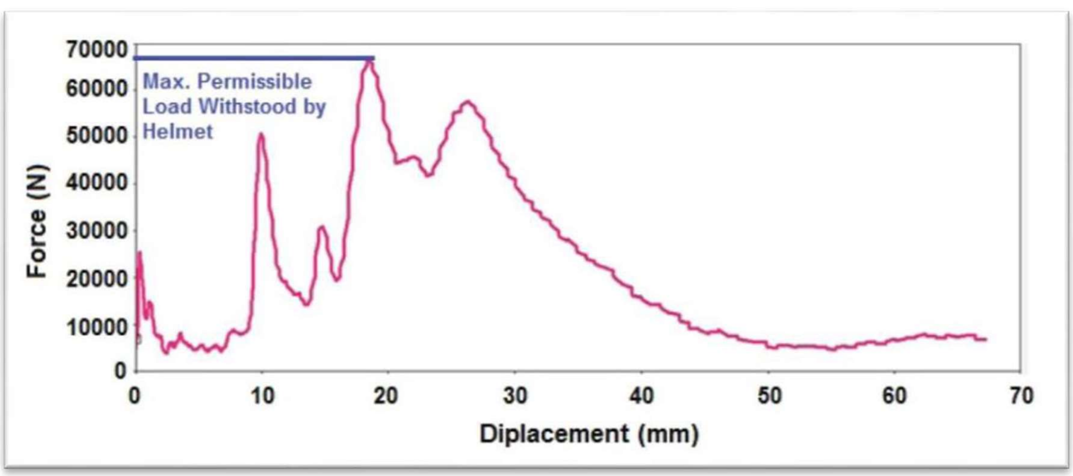

Figure 4: Impact load against displacement for tested bio-composite helmet

CONCLUSIONS

In the present work, bio-composite with multiple natural fibers such as jute fibers, Coconut coir, areca fibers, sisal fibers, banana fibers have been successfully reinforced with the epoxy resin by simple and inexpensive hand lay-up technique. The mechanical testing results of fabricated bio composite helmet indicate that, concept of using multiple natural fibers is viable for helmet application. However, there is a scope to optimize the volume fraction of natural fibers as reinforcements to achieve enhanced mechanical properties of helmet. So, it is clearly indicates that reinforcement of natural fibers have good and comparable mechanical properties as conventional composite materials.

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