EXPERIMENTAL ANALYSIS OF MECHANICAL PROPERTIES OF NATURAL FIBER COMPOSITES

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***Abstract*: Composite materials play a major role in day to day life. These composite materials are used mainly due to their light weight and high strength when compared to synthetic fibers. These natural reinforced fiber composites are used in automobile parts, window panels, cupboards, furniture. These natural fibers have high physical properties than the synthetic fibers. Researches show that synthetic fibers possess less tensile strength and impact strength. Natural fibers have the advantages that they are renewable resources and easily available in nature. Hand lay-up method followed by compression molding was adopted for composite fabrication. Mats of uniform thickness were prepared from chopped banana fibers and glass fibers of particular fiber length. The mats were impregnated in resin and the pre-preg was kept at room temperature up to semi cured stage. Different composite sheets are prepared varying the fiber length and volume fractions. In this project the tensile strength and impact strength of reinforced fibers of banana tree fiber and cotton fiber are determined the banana fibers and cotton fibers are selected due to their abundance availability and less cost. These fibers are fabricated by hand lay-up method process using polyester as resins for reinforcement by two forms as continuous strand mat and woven mat. The fibers are tested by varying the composition of the fiber and the resin.**

IndexTerms*: Micro-mechanics, Composites, fiber, resins.(keywords)*

I. INTRODUCTION

Composites consist of two or more phases that are usually processed separately and then bonded, resulting in properties that are different from those of either of the component materials. Polymer matrix composites generally combine high-strength, high-stiffness fibers (graphite, kevlar, etc.) with low-density matrix materials (epoxy, polyvinyl, etc.) to produce strong & stiff materials that are lightweight. Laminates are generally built up from multiple layers of lamina; the fibers within each lamina are generally parallel, but laminates usually contain lamina with their fibers oriented in various directions. Each lamina is an anisotropic layer with properties varying as a function of fiber angle. Loading along the fibers (longitudinal) is modeled as Iso-strain while loading perpendicular to the fibers (transverse) is modeled as Iso-stress; these two directions generally represent the extremes in material behavior. Fiber and matrix material property data can be used to predict/approximate the properties of laminated composites using the Rule of Mixtures. In this investigation, the elastic modulus of composites loaded at various angles with respect to the fiber direction will be predicted, tested and discussed.

This module introduces basic concepts of stiffness and strength underlying the mechanics of fiber-reinforced advanced composite materials. This aspect of composite materials technology is sometimes terms "micromechanics," because it deals with the relations between macroscopic engineering properties and the microscopic distribution of the material's constituents, namely the volume fraction of fiber. This module will deal primarily with unidirectional-reinforced continuous-fiber composites, and with properties measured along and transverse to the fiber direction.

II. PROPERTIES OF NATURAL FIBERS

1. Properties:

The needs or desired properties of the matrix which are important for a composite structure are as follows:

• Reduced moisture absorption.

• Low shrinkage.

• Low coefficient of thermal expansion.

• Good flow characteristics so that it penetrates the fiber bundles completely and eliminates voids during the compacting/curing process.

• Reasonable strength, modulus and elongation (elongation should be greater than fiber).

• Must be elastic to transfer load to fibers.

• Strength at elevated temperature (depending on application).

• Low temperature capability (depending on application).

• Excellent chemical resistance (depending on application).

• Should be easily processable into the final composite shape.

• Dimensional stability (maintains its shape).

2. Factors considered for selection of matrix:

The matrix must have a mechanical strength commensurate with that of the reinforcement i.e. both should be compatible. Thus, if a high strength fiber is used as the reinforcement, there is no point using a low strength matrix, which will not transmit stresses efficiently to the reinforcement. The matrix must stand up to the service conditions, viz., temperature, humidity, exposure to ultra-violet environment, exposure to chemical atmosphere, abrasion by dust particles, etc.

The matrix must be easy to use in the selected fabrication process.

• Smoke requirements.

• Life expectancy.

• The resultant composite should be cost effective

3. Selection of natural fibers and resins:

Fibers - Banana fiber, Cotton fiber
Resins - Polyester
Accelerator - Cobalt Napthalate
Catalyst - Methyl Ethyl Ketone Peroxide

4. **Banana fiber**
With growing environmental awareness, ecological concerns and new legislations, bio-fiber-reinforced plastic composites have received increasing attention during the recent decades. The composites have many advantages over traditional glass fiber or inorganic mineral filled materials, including lower cost, lighter weight, environmental friendliness and recyclables. The snap of banana fiber is shown in figure 6.1. Because wood and other bio-fibers easily undergo thermal degradation beyond 200°C, thermoplastic matrix used in the composites is mainly limited to low melting- temperature commodity thermoplastic resins, like polyethylene (PE), and polypropylene(PP). However, the inherently unfavourable thermo mechanical and creep properties of the polyolefin matrix limit some structural applications of the materials. Banana fiber is extracted from the waste product of banana cultivation. Due to high cellulose content, it has superior mechanical properties, especially tensile strength and modulus. It is thus considered as a promising candidate for replacing conventional glass fibers in the fiber-reinforced composites. The figure 1 shows the sample banna fiber selected for analyzing the mechanical properties.

Figure 1. Banana Fiber

4.1 Banana fiber collection process:
In banana plantations, after the fruits are harvested, the trunks or stems will be discarded. These wastes provide obtainable sources of fibers, which leads to the reduction of other natural and synthetic fibers' production that requires extra energy, fertilizer, and chemical. The properties of banana fiber are good absorbent highly breathable; quickly dry with high tensile strength. Banana trunk from the plantation has been shown in figure 2.

Figure 2. Banana trunk from the plantation

4.2 Banana fiber collection process:

Historically, banana fiber was extraction by hand. The process requires a long period of time and skilled practice to collect fibers. This research employed an invented motor-driven machine as extraction tool. Figure 3 demonstrates the Banana fiber after extraction.

Figure 3. Banana fiber after extraction

Properties of banana fiber:

Table 1 Properties of banana fiber

PROPERTY	**BANANA FIBER**
Tensile strength	529-914 Mpa
Density	1300 – 1350 kg/m^3
Young's Modulus	27 – 32 GPa
Moisture content	-
Failure strain	1-3 %

5. Cotton fiber extraction:

Preparing Fabric Cotton fibers don't shrink, but cotton fabric does, so preshrink the yardage. To preshrink, wash the fabric the same way you intend to launder the finished garment. Make sure the fabric is on-grain; that is, that the crosswise and lengthwise threads are truly perpendicular to each other. If the cotton has a permanent finish, it's not possible to straighten the grain. If the fabric has a print and the grain is off, the print may be skewed once you straighten the fabric. Avoid print fabrics unless the threads are truly on-grain. If it's difficult to tell the right side of the fabric from the wrong side, mark the wrong side with chalk to avoid confusion and a finished garment with shading differences. Cotton fibre drawing frame used for the purpose is shown in figure 4.

Figure 4. Cotton fibre drawing frame

Properties of cotton fiber:

Table 2 Properties of cotton fiber

PROPERTY	COTTON FIBER
Tensile strength	300 - 700 Mpa
Density	1550 kg/m^3
Young's Modulus	6 - 10 GPa
Moisture content	8.5
Failure strain	6-8%

6. Resins:

Matrix resins bind glass-reinforcing fibers together, protecting them from impact and the environment. Glass fiber properties such as strength dominate in continuously reinforced composites. When glass is used as a discontinuous reinforcement, resin properties dominate and are enhanced by the glass. Figure 5 deals with the resin materials used.

Figure 5. Resins

Properties of Polyester resin:

Table 3 Properties of polyester resin

PROPERTY	POLYESTER RESIN
Viscosity at 250C	250 – 350 cP
Density	1.09 g/cm
Heat Distortion Temperature (HDT)	85°C
Modulus of Elasticity	3.3 GPa
Flexural strength	45 MPa

Table 4. Chemical composition

Element	Chemical composition (%)			
	SiO_2	Al_2O_3	Fe_2O_3	CaO
Cordierite (C)	45.52	28.10	1.23	3.70
Talc (T)	62.20	3.11	1.25	1.07

2.7 Thermosets

With their track record of performance, thermosets have become the matrix of choice in continuously reinforced glass fiber composites and plastic parts made with glass filler. Especially popular are unsaturated polyester resins**,** which are relatively inexpensive, easy to handle, and have good mechanical, electrical and chemical resistance. Polyesters can be used in multiple fabrication processes, from spray-up boats and spas to compression moulding and resin transfer moulding (RTM) for making auto body parts, as well as injection moulded electrical components. Polyester is also the primary resin matrix in bulk moulding compounds (BMC) and sheet moulding compounds (SMC) used in compression moulding.

2.8 Thermoplastics

While thermosets are more widely used, thermoplastic resins are available in a significantly wider range of matrix choices. Higher in cost, they are also high-performance, withstanding temperatures up to 400º F and beyond. Besides elevated temperature performance, thermoplastic resins have better toughness/damage resistance and higher compressive strength. In advanced composites, they also exhibit high vibrational damping, viscoelasticity (important in failure resistance) and low CTE.

2.9 Polymeric material

Few polymers are thermally stable by comparison with metals or ceramics and even the most stable, like the polyimides, or poly ether ether ketone (known as PEEK) are degraded by exposure to temperatures above about 300°C.There is nothing that reinforcement can do to combat chemical degradation, but the associated fall in strength and increase in time-dependent (creep or visco-elastic) deformation, a feature common to all polymers, though less serious in cross-linked resin systems than in thermoplastics, can be delayed by fiber reinforcement. Polymers are traditionally insulators and in their application as such strength is usually a secondary consideration. The electrical conductivity of plastics reinforced with carbon fibers is of importance in many aeronautical applications, however, where protection of avionics systems from external electrical activity (*eg.* lightning strike) is of importance.

III. METHODOLOGY

1. Hand Lay-up method

Fiberglass (typically E-glass) continuous strand mat and/or other fabrics such as woven roving is manually placed in the mold. Each ply is sprayed with catalyzed resin (1000-1500 cps). Brushes and rollers are used to work the resin into the fiber, wetting out and compacting the laminate. For example, fabric might first be placed in an area exposed to high stress. A spray gun then applies chopped glass, completing the part. Balsa or foam cores may be inserted between the laminate layers in either process. Typical glass fiber volume ranges from 15-35%, with spray-up at the lower end and hand lay-up at the higher end. Fiber content can be increased up to 50% by curing the part in a vacuum bag at 2-14 psi vacuum pressure and a cure temperature below 350º F. It can be increased up to 70% by using vacuum-assisted resin transfer molding or infusion molding. The applied vacuum compacts the preform while helping the resin penetrate and wet-out the fiber. Spray-on surface materials, are available to finish parts made through Open or Closed Mold processes. This spray-onsurfacing material bonds to fiberglass and other materials.

2 Fabrication Process Involved

Step 1: Preparation of Mat

A mat is constructed as a blanket of continuous strands laid down as a continuous thin flat sheet. Continuous strand mats are prepared with less binder because of increased entanglement, which provides inherent integrity. Continuous strand mats can be moulded into complicated shapes without ant tearing. The mat is prepared by taking both banana fiber and cotton fiber in the ratio of 3:2. Initially, a square wooden frame is taken so as to support the fibers. Then, the cotton fiber is closely knitted and then tightened at both the ends using small nails. Similar to this fashion, banana fiber is also knitted and tightened at the both ends perpendicular to the cotton fiber in the aforementioned ratio. This configuration has higher resistance to shear distortion.

Figure 6. composite mat

Step 2: Moulding box preparation

The moulding box is constructed in order to prepare the required mould. The moulding box is prepared by using sheet metal in the dimension of 25*25*2.5 centimeters. The moulding box has to be wrapped on the outside with an OHP sheet in order to arrest the leakage of the prepared resin mixture. The moulding box has also needs to be covered on the inside with OHP sheet to ensure that the prepared resin does not undergo any kind of chemical reaction with the moulding box. It is mandatory for the natural fiber reinforcement to get dried prior to resin impregnation, to avoid poor wetting and moisture entrapment within the composite.

Figure 7. Mould

Step 3: Applying relieving agent

We apply gel coating on top of the OHP sheet and on top of the moulding metal box. The gel coat used is PVA (Poly Vinyl Acetate).

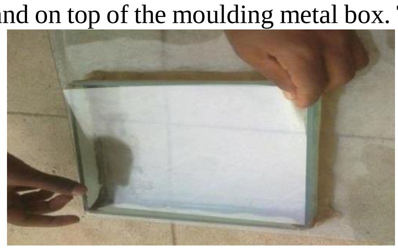

Figure 8. Relieving agent

Step 4: Preparation of resin

Resin used here is polyester resin. Catalyst used is Methyl ethyl ketone peroxide and accelerator here is cobalt naphthalate. Initially, 250 ml of polyester resin is taken in two beakers and mixed with, catalyst in the ratio of 10 ml per litre of the polyester resin and accelerator in the ratio of 15 ml per litre of the polyester resin.

Figue 9. Resin preparation

Step 5: Moulding process-mat

Initially, 250 ml of the resin mixture is poured over the moulding box and is allowed to remain in that state for 2 minutes. Then, the continuous woven fiber is placed over resin and remaining 250 ml of resin is poured over the fiber. The prepared mould then is pressed with a hand roller to eliminate the air bubbles and the excess resin. Finally, the mixture is allowed to remain undisturbed for 24 hours.

Figure 10. Moulding Process – mat

Step 6: Removal of moulded fiber

After 24 hours, the moulded fiber is removed from the moulding box. The moulded fiber can be taken out with the help of the reliving agent applied before the preparation of the resin.

Step 7: Preparation of chopped formation

The mat is constructed as a blanket of chopped strand laid down as a thin flat sheet. The strands are evenly distributed in a random pattern, and are held together by mechanically bonding. A chopped-strand composite is formed by randomly depositing chopped fibers onto the prepared resin mixture. In this method of formation, banana fiber and cotton fiber are mixed together in the ratio of 2:1. 20 grams of chopped banana fiber is mixed with 10 grams of cotton fiber.

Step 8: Moulding Process - chopped

Initially, 600 ml of the resin mixture is poured over the moulding box and is mixed vigorously with the mixed fiber. The prepared mould then is pressed with a hand roller so as to eliminate the air bubbles and the excess resin. Finally, the mixture is allowed to remain undisturbed for 24 hours. The image of finished material is shown in figure 11.

Figure 11. Moulding Process - chopped

IV. RESULTS

1. Testing of natural Fibers

Table 5 ASTM standards

TYPE OF TEST	STANDARD
FLEXURAL TEST	ASTM D 790
IMPACT TEST	ASTM D 256
TENSILE TEST	ASTM D 638

BARCOL HARDNESS	ASTM D 2583

Impact specimen dimensions and impact testing specimen are specified in figure 12 and figure 13.

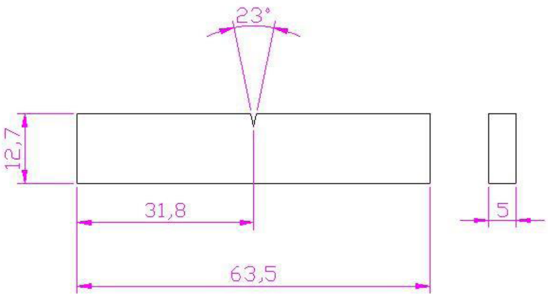

Figure 12. Impact specimen dimensions

FIgure 13. Impact testing specimens

Figure 14 shows the flexural testing specimen used for testing purpose and figure 15 shows the tensile testing specimen.

Figure 14. Flexural testing specimen

Figure 15. Tensile testing specimen

2. Flexural testing

The flexural test measures the force required to bend a beam under three point loading conditions. The data is often used to select materials for parts that will support loads without flexing. Flexural modulus is used as an indication of a material's stiffness when flexed. Since the physical properties of many materials (especially thermoplastics) can vary depending on ambient temperature, it is sometimes appropriate to test materials at temperatures that simulate the intended end use environment.

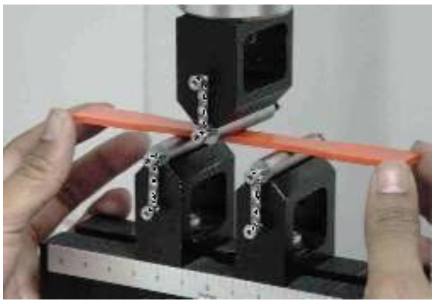

FIgure 14. specimen arangement

Below calculations show the flexural strength.

Table 6 Flexural testing results

TYPE OF ARRANGEMENT	FLEXUAL STRENGTH (MPa)
Net (Mat)	14
chopped	5.5

3. Tensile testing

Tensile testing is done so as to determine the tensile strength of the material. Tensile strength can be termed as the capacity to withstand loads that tend to elongate the material. Ultimate Tensile Strength is measured by the maximum stress that a material can withstand while being stretched.

Tensile Strength is measured as force per unit area.

Table 7 Tensile testing result

TYPE OF ARRANGE MENT	MAX. FORCE APPLIED (kN)	TENSILE STRENGT H (MPa)
Net (Mat)	2.11	14.18
chopped	2.44	28.49

4. Hardness testing

Hardness testing is done so as to determine the hardness of the material. Hardness is a measure of resistance to permanent shape change when compressive force is applied. Barcol hardness test is chosen due to the usage of thermosetting resin in composite preparation process.

Table 8 Hardness testing result

TYPE OF ARRAN GEMEN T	BARCOL HARDNESS		
	TRIAL 1	TRIAL 2	TRIAL 3
Net (Mat)	29	35	40
chopped	19	22	24

V. CONCLUSION

In flexural test, banana/cotton combination with woven orientation sustains more elongation than chopped orientation, with small but considerable difference in maximum load of both samples. In tensile test also banana/cotton with chopped orientation has more elongation than woven orientation and hence the tensile strength of chopped orientation is more than woven orientation.

In impact test, the composite with chopped orientation has more strength than composite with woven orientation and it can be said from result that the impact strength of chopped composite is more. So, it is clearly indicates that inclusion of natural fibers improves the load bearing capacity (tensile strength) and the ability to withstand bending (flexural strength) of the composites but the strength changes with orientation of fibers.

By comparing the flexural strength, tensile strength and impact strength of the composites, we can conclude that the chopped composite fiber material is best suited for works that will experience tensile and impact loads and net composite fiber material is best suited for works that will experience flexural load.

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