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Mechanical Properties of Luffa Cylindrica and Coconut Coir Reinforced Epoxy Hybrid Composite

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Abstract: In the current day scenario all the researchers and engineers are searching for a better and cheaper alternative for the current engineering materials. The project deals with the low cost, light weight and biodegradable composites and their use in the current industries. Substituting the legacy fiber reinforced composites with the low-cost natural plant- based fibers reinforced composites help us achieve comparative mechanical properties. India has a quite rich source of natural plant-based fibers which can be used for the production of natural fiber reinforced composites. In this project we used a combination of luffa fibers and coir fibers to produce an epoxy hybrid composite. The current project explores two different problems related to the natural fiber reinforced hybrid composite:

1) ***Study of mechanical properties of the hybrid thermosetting composite.***
2) ***Study of possibilities of use of natural fiber reinforced epoxy hybrid composites in the different industries.***

I. INTRODUCTION

Humans have been crafting things out of certain materials throughout the history of their presence on earth. In the Paleolithic age they used to use stones (mainly quartzite) for producing spear heads, hand axes, grinder, etc. later in Mesolithic age they started to produce microliths (small stone blades), much later in the Neolithic age which was the final segment of the Stone Age humans moved on to producing utensils out of clay and canoes out of wood. This went and the humans started switching to better materials such as using bronze (in the Bronze Age) and iron (in the Iron Age) for the production of equipment and weapons.

This goes to show how we humans have always looked for a better substitute for the materials which would be lighter and more durable from its predecessor. Such pursuit has led the modern age scientist, engineers and researchers to improve the legacy materials or produce new materials which would satisfy the norms of being lighter, cost effective and having high strength values.

Materials such as ceramic and plastics have been dominating as being a cost effective and strong materials. For around two decades development of composite materials has almost taken over these such dominating synthesized materials and have made their way into the everyday products and appliances. Composite materials have become an integrated part of the several industries such as Automobile industry, Aerospace industry, Construction industry, etc. and due to its affiliation to such big industries composites has seen several innovations in the composite production techniques. Such feat has been achieved by composites due to their traits such as high strength and light weight. Composites such as carbon fiber composites and glass fiber composites are already being used for the production of bicycle frames, frames of cars, boats, helicopter blades, helmets, aircraft components, etc.

Composites are also creeping into Indian industries as there is an abundance of natural fiber sources such as, banana, jute, bamboo, sisal, coconut, luffa cylindrica, etc. The main focus is on lowering the cost of production of composite materials and replacing the already depleting conventional materials.

A. What are Composites?

A composite material is formed when two or more than two insoluble constituent materials with physical and chemical traits differing from one another are brought together to form a single element. The final element that is formed in the process has the combined traits of its constituents and the constituents are distinct to one another making the end product different from a mixture.

The constituents may be categorized as reinforcements and matrix. Reinforcements maybe in the form of either fibers or particles, and can come either from natural or from artificial sources. On the other hand, the matrix is the component that acts as an adhering agent to combine the reinforcements and provide an even surface to the composites. These matrices are mostly polymer plastics which can have the properties of either thermosetting plastics or thermoplastics. The reinforcement fibers have good tensile strength and the matrices have good compressive strength and the combination of these traits make a composite strong.

The fibrous reinforcements that are typically used in the production of composites are mostly carbon fibers, glass fibers, aramid fibers (such as Kevlar® and Twaron®), SiC (silicon carbide), etc. The matrices used are mostly polymeric plastics, metals, ceramics (for high temperature environments), etc.

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One of the most widely used composite material today is Carbon Fiber composite which has carbon fiber strands woven to form a cloth as a reinforcing constituent and a thermosetting plastic as a matrix making it lighter in weight and stronger.

Glass fiber composites are also widely used for production of automobile components. RCC (reinforced cement concrete) which has concrete cement as a matrix and steel bars as reinforcements, is widely used as a composite for making buildings.

It has been noticed that the composites where first used in 1500 BC in the Egyptian and Mesopotamian settlements where the mixture of mud and straws wereused as a composite to make buildings from them. Mud acts as a matrix for the straws which are the reinforcing component in the composite.

B. Why is there a Need for Composites?

As the need for production of strong and durable objects goes on increasing the researchers have been busy in production of better and durable materials which can be flexible in design and can be molded into intricate shapes. It is true that metals are isotropically strong but composites can be designed to withstand forces or stresses in a specific direction.

The fibers as a separate entity are not so strong when compared to other engineering materials and are susceptible to water retention which can further degrade their performance when used alone, to overcome these shortcomings when the fibers are added to the matrix the byproduct produced is tough and strong and most notably are low in cost.

Some of the major advantages of composites are;

1) Low cost of production
2) Low material cost
3) Ability to mold easily
4) Resistance to chemicals
5) High impact strength
6) Lighter weight
7) Excellent electrical resistance
8) Toughness

The major advantages of composite are their light weight and strength. These composites can easily be produced for specific application just by using the right combination of reinforcement and matrix. The composites also give the freedom to be molded into any shape.

C. Materials that Constitute Composites

As stated earlier the constituents used in production of composites are mainly reinforcement materials and continuum matrix, but these are not the only constituents used in the composites. Materials like fillers/additives are also used not only to enhance the bond between the matrix and reinforcement but also the appearance of the composites.

1) *Matrix:* The matrix is a continuous material which gives the structural support to the reinforcement fibers which are embedded within the matrix. A matrix also acts as an adhering agent that holds together the final structure of composites. A matrix can be mainly classified into;

a) Metal matrix
b) Ceramic matrix
c) Polymer matrix

Metal matrix composites although not being widely used in the current time can show attributes like high strength and toughness. The composites made out of these matrices can withstand high temperatures. The only drawback is the weight of the matrix. Some of the metals that can be used for producing metal matrix composites are Titanium, Aluminum and Magnesium. Alloys of such metal are also used as a matrix.

Ceramics are solid materials comprising of metals or non- metals which are kept together by covalent and ionic bonds. Although these are the least used matrices, ceramics exhibit a high tolerance to heat, resistance to corrosion and high compressive strength. Ceramics can withstandtemperatures well above 1500^{o}C.

Polymer matrix is the most widely used matrix due to its low cost and light weight. The two main kinds of polymers are thermosets and thermoplastics. Thermosets once cured cannot be molded into a different shape, when exposed to high heat they tend to decompose rather than melting whereas thermoplastics have ability to be melted and reshaped. Thermosets tend to have thermal and chemical stability whereas thermoplastics tend to undergo deformation when exposed to high heat.

Thermosets are the most widely used polymer matrices and are used from aerospace industries to automobile industries. Thermosets can be classified further mainly into three types;

- Epoxy resins
- Phenolic polyamide resins
- Polyester

Epoxy resins are widely used in aerospace and automobile components. These remain stable when exposed to chemicals. Epoxy is classified as a copolymer which is formed when the two chemicals, "resin" and "hardener" are mixed in the proper proportion which then form a covalent bond and after curing gives the final thermoset matrix. While curing these exhibits low shrinkage and do not emit any volatile gases. Most of these compounds cannot withstand temperatures above 130^{o}C and might degrade when exposed to such or higher temperatures. Being a two- part compound, it makes epoxy resins more expensive than the other thermosets in most cases.

Phenolic resins are a product of reaction between phenol and formaldehyde. These are very efficient materials when there is application in high temperature areas.

Bakelite is one of the most popular phenolic resin which is mostly used worldwide as a material for making handles of kitchen utensils. These are not as strong as epoxy or polyester resins but their property of being fire retardant makes them suitable for high temperature applications.

Polyester resins are polymeric compound made up of dibasic organic acids (both saturated and unsaturated acids) and polyhydric alcohols (such as ethylene glycol). Fiber glass composite uses glass fibers as reinforcement and polyester resin as matrix and is one of the most popular composites. Polyester resin is low in cost, dimensionally stable, easy to handle and has good mechanical and electrical resistance.

2) *Reinforcements:* Reinforcement materials are used to improve tensile and flexural strength of the composite although they might not be as strong when used alone. Reinforcement materials are mostly non-reactive/inert and maybe in the form of fibers, particles, flakes, etc. Reinforcement material can totally change the failure mechanism of a composite.

The two main types of reinforcements are;

a) Fibrous reinforcement
b) Particulate reinforcement

Fibers are long, strong and stiff compounds. These type of reinforcement materials have their crystal lattice aligned in the same direction which makes them strong in their longitudinal direction. Fibers have low density which makes them suitable for use in composites. Their performance is optimum in longitudinal direction and is poor when the stress is applied in any other direction.

Most of the composites today are formed using fibers such as carbon fiber and glass fiber. Natural fibers like banana fiber, coir, sisal fiber, oil palm fiber, etc. are also being used and tested in several institutions today to bring the cost of composite further down as natural fibers are obtained from plants and trees and can be easily obtained al low to no cost.

Particulates are mostly used in the metal matrix composites. The sizes of particles are in the order of few microns. These strengthen the composite by arresting the motion within the composite which in turn take a lot of energy to take the material to failure. Their shape and size may vary from each other. Particulates have higher densities and hence are mostly useful only in metal matrix composites. Their shape and diameter may influence the strength of the composite that is produced.

3) *Additives/Fillers:* Additives or fillers are modifiers that are added to the polymer matrix to enhance several properties of the polymer in the composite. Fillers/ additives may help with the below mentioned tasks:

a) Reduce the cost
b) Increase or decrease viscosity of polymer matrix
c) Enhance weatherability
d) Flame retardation
e) Enhanced electrical conductivity
f) Releasing agent

Additives like thixotropes which are compounds like fumed silica and certain clays may help in elevating the viscosity of the polymers. Similarly, alumina trihydrate (ATH), bromine, chlorine and phosphorus act as fire retardant agents.

Fillers like calcium carbonate, kaolin and calcium sulfate may help in bringing down the cost of production and enhance the strength of composites. Among these calcium sulfate may act as a fire retardant also.

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4) Prepreg: Prepreg is "pre-impregnated" fibers that are impregnated with thermoset matrix beforehand and are partially cured composites. The fibers are mostly woven or sometimes unidirectional. Prepregs are stored in cold region (below 18^{o}C) to prevent further curing as heat acts as a catalyst to the curing process. These pre-impregnated fibers can easily be handled and molded into desired shapes.

D. Classification of Composites

Composites can basically be classified on thebasis of two distinct components, namely matrix and reinforcements.

1) Classification on the Basis or Reinforcement

On the basis of reinforcement used, composites can be classified into three classes:

a) *Particulate Reinforced Composites:* As the name suggests particulate reinforced composites are made up from small particulate material. These particles can be cuboidal, spherical or some irregular shape. Particulate reinforcement gives strength to the composite by the means of hydrostatic coercion in the matrix. These reinforcements are mostly used in metal and ceramic matrices. Particulate reinforcements can increase then stiffness of the matrix to some extent. The properties of matrix can influence the behavior of particles and vice- versa. The size of particulates is in order of few microns.
b) *Fiber Reinforced Composites:* Fibers are characterized by their high length to cross-section diameter ratio. Both organic and inorganic fiber can be used as reinforcement materials. Organic fiber mostly has low density and low elasticity, whereas inorganic fiber has high modulus and are somewhat elastic most of the times. Some of the frequently used fiber reinforcement materials are namely glass fiber, carbon fiber, silicon carbide fibers, alumina fibers, steel fibers, graphite fibers, boron fibers, etc. Fibers provide an increase in tensile strength in the direction of orientation when inside the composite structure. Asingle crystal grown with no defect turns into a short fiber known as whiskers are also used as reinforcement in a composite. The typical length of whisker ranges from 3 to 50 nm range. Although whiskers are short in length yet they have capability to withstand extreme loads.
c) *Laminate Reinforced Composites:* Laminate reinforced composites are two or more thin fiber reinforced composites that are stack on top of one another. These thin composites are called laminas, so two or more than two lamina stacked together males up a laminate. The fibers maybe long or short, place in uniform direction or in random order but the fiber embedded in one thin layer of matrix continuum forms a lamina. Laminas with different fiber orientations can be stacked together to improve performance of laminate in more than one direction.

2) Classification on the basis of matrix

On the basis of matrix used, composites can be classified into three classes:

a) *Metal Matrix Composites (MMCs):* Metal Matrix Composites are very popular among the researchers but yet these have not made their way into the real-world applications as widely as the Polymer Matrix Composites. These composites can attain high toughness, high strength and stiffness. Metals like Titanium, Magnesium and some alloys exhibit high strengthto weight ratio and can be suitably used as the matrix material in a composite. Adding reinforcement may further enhance the stiffness and strength of the matrices. Some advantages of metal matrix are high thermal and electrical conductivity and high isotropic strength.
b) *Ceramic Matrix Composites (CMCs):* Ceramic Matrix Composites have ceramic compounds as the matrix in which the reinforcement materials are embedded. Ceramics are made up of metallic or non- metallic compounds which are held together with covalent and ionic bonds, ionic bond being the primary one. Alumina, zirconia, carbide, boride, etc. are a few examples of ceramic compounds. Ceramic matrix can withstand high temperatures (even temperatures above 1500^{o}C). Ceramics are mostly immune to any chemical reaction have good strength are brittle in nature and are prone to fracture on application of tensile stress. Most commonly materials like carbon, silicon carbide (SiC) and mulite (Al_2O_3-SiO_2) are used as reinforcement materials inside the ceramic matrices. Addition of reinforcement materials increases the fracture toughness and improve thermal shock resistance.
c) *Polymer Matrix Composites (PMCs):* Polymer Matrix are made up of thermosets or thermoplastics. The compounds are easy to work with as they are in the form of liquid before they cure so they are easy to form into a certain shape inside a mold. On curing, these compounds become hard and have high strength and stiffness. Polymers can provide high surface finish. Thermosets like Epoxy resins and Polyester resins are mostly used in composites due to their low cost and machinability. Polyethylene, polystyrene, polyamides, nylon, etc. are few thermoplastics that are used as polymer matrix in composites but are seldom used due to their tendency to deform when exposed to high temperatures. These provide structure to the fibrous reinforcements and on combining the fiber and polymer the composite produce has high tensile and compressive strength.

E. Plant Based Natural Fibers as reinforcements

Artificial or man-made fibers like glass fibers and carbon fibers are widely accepted as a prime fiber for composite material due to their capability to endure high tensile loads. These fibers can complement the matrix material very well providing strength to the composite but are very costly and are difficult to produce.

Natural fiber on the other hand is cheap, renewable and easy to produce. Plant based natural fibers mostly comprise of Lignin, Alpha-Cellulose and Hemicellulose. Natural fibers also have low density and have satisfactory mechanical properties. Fibers like sisal fibers, hemp fibers, jute fibers, luffa fibers, coir, banana fibers, cotton fibers, etc. are some popular plant-based fibers that have fascinated researchers and engineers today due to their low cost and wide applications in the development of new composite materials. Natural fibers can be a better alternative to the artificial fibers as natural fibers are biodegradable and are also renewable. They can have application in several fields like aerospace and automotive industries or in building and furniture.

These natural fibers can also be combined with other natural or artificial fibers to produce a hybrid composite which may have better properties when compared to single kind fiber system.

F. Some Fields of Application of Plant Based Natural Fibers

1) *Automobile Industry:* Frames of cars, trucks and motorcycle.
2) *Marine Industry:* Small boats and hull of ships.
3) *Electronic Industry:* Frames of appliances and circuit boards.
4) *Aerospace Industry:* Components of airplanes, helicopters, rockets, etc.
5) *Sporting Goods Industry:* Durable and lightweight sports equipment.
6) *Construction Industry:* Walls, roof, panels, doors, door frames, window frames, tiles, etc.
7) *Logistics:* Freight containers, packaging, etc.

Natural fiber composite can also replace the material that day-to-day things such as helmets, furniture, storage cases, etc. are made with.

G. Luffa Cylindrica Fibers

Luffa cylindrica is a scientific name for sponge gourd. The plant is an annual vine cultivated mostly for its fruit. Luffa cylindrica belongs to the family of *Cucubitaceae* and is native to South Asia. The fruit of the plant can grow up to 60 cm in length, is cylindrical in shape and contains several seeds. The plant can be found growing in large quantity in India.

The fibers are held together the resinous plant tissues to form a network of fibers in multi-direction. The fibers of the fruit are composed of 11.2% Lignin, 19.4% Hemicellulose, 63.0% Cellulose, 82.4% Holocellulose and 0.4% Ash [1].

The fibers from dried Luffa cylindrica fruit are used as one of the reinforcement materials in this project for the production of Hybrid Polymer Matrix Composite with Epoxy Resin as the polymer matrix.

H. Coconut Coir Fibers

Coconuts are a fruit of coconut trees. The coconut tree falls under the family *Arecaceae* and are native to mostly tropical and subtropical regions. These trees can grow up to 30 m tall and have fruits at the top along with the leaves.

The seeds or the fruits has several purposes such as, the immature fruits are harvested for the “coconut milk” which is present inside the endosperm of the fruits, ripe coconuts have “coconut water” in them as well as have the flesh of endosperm which is edible, the husk can be obtained from the covering of the endosperm which can give coir (coconut fibers) and coco peat. Coco peat is used for gardening and coir are mostly used for decorative purposes. Coir are long strands of fibers which have exceptional strength and can be used in the development of modern-day composites. Percentage of chemical components that make up coir fibers are 32.8% Lignin, 44.2% Alpha-Cellulose, 56.3% Holocellulose and 2.2% Ash [2].

Coir fibers are used in this project for the production of Fiber Reinforced Hybrid Composite with epoxy resin matrix.

II. LITERATURE ANALYSIS

This is a list of researches that have been carried out in the field of natural fiber composites. These research goes to show the effect that natural have on the mechanical, thermal and electrical behavior of the composite materials. Some research also covers stacking of different types of fibers to produce Hybrid composite and the effect it has on the behavior of the composite thus produced.

These researches have been carried out to study the effect of natural fibers in a composite and to their capability of replacing the artificial fibers like glass and carbon fibers. These literatures contain most of the research that has been done till this date to study the properties of natural fiber and their possibilities for future composites.

Tanobe *et al.* [1] carried out a comprehensive characterization of the chemical compounds present in the luffa cylindrica fibers. The chemicals components like lignin, alpha-cellulose, hemicellulose, etc. where characterized. The fibers were treated with NaOH (2%) and some distinct fibers were treated with methacrylamide (1- 3%). The alkali treatment turned out to be good for the fibers as it modified the fiber surfaces whereas, the methacrylamide treatment severely damaged the fibers.

D'Almaeida *et al.* [2] carried out derivatization treatment of the luffa fibers by acetalyzation. It was noticed that the process increased the surface roughness of the fibers due to the removal of the outer layer of the fibers. The process also increased the hydrophobic nature of the fibers and decreased the content of lignin and hemicellulose in the fibers.

Lassad Ghali et al. [3] compared the changes in mechanical and hygrothermal behavior of alkali treated and acytalated luffa fiber polymer composites to the untreated luffa fiber polymer composites. They noticed that acetalysation of luffa fibers enhanced the mechanical properties of the polymer composite and decreased the hydrophilic nature of the fibers and also decreased the hygrothermal properties of the composite. Whereas, the alkali treatment of luffa fibers removed the outer layer of the fiber's cell wall and made the fibers more hydrophilic in nature. Highest water absorption was noticed in the alkali treated luffa fibers.

Khalil *et al.* [4] have studied the chemical composition of the Malaysian plant waste fibers, namely oil palm frond (OPF), coconut (coir), pineapple leaf (PALF), and banana stem (BS) fibers. Among the four fibers coir fibers contained the highest amount of lignin (32.8 %) which is still lower than wood fibers, and the lowest amount of alpha- cellulose (44.2 %) content. They concluded that all types of agro fibers cell walls are made up of primary and secondary layers.

Hill *et al.* [5] studied the effects of acetalization of several plant fibers on their properties. Fibers like coir, oil palm, flax and jute fibers went under acetalization using acetic anhydride. It was observed that acetalization of fibers at 120^{o}C damaged the fiber structure and resulted in poor mechanical properties of the fibers. Whereas, at 100^{o}C acetalization improved the performance of the fibers. It was observed that the tensile strength of the coir fibers was increased by this process.

S.K. Saw *et al.* [6] carried out a study on the effects of alkali treatment (5% NaOH) and furfuryl alcohol grafting of the luffa fibers on the properties of the luffa fiber reinforced epoxy composite. The grafting of fibers with furfuryl alcohol followed by oxidation with $NaClO_2$ resulted in enhanced surface area and better hydrophobic traits. Grafting by furfuryl alcohol resulted in better extraction of lignin and hemicellulose from the fibers than the alkali treatment. They concluded that grafting method can be used to obtain composites with better mechanical and thermal properties.

S. Harish *et al.* [7] investigated the mechanical properties of coir reinforced epoxy composite and compared the results with that of glass fiber reinforced epoxy composite. According to their results the coir fiber epoxy composite presented the tensile strength of 17.86 MPa, flexural strength of 31.08 MPa and impact strength of 11.49 kj/m^2. These results are quite mediocre in respect to the glass fiber epoxy composites which showed high strength properties. It was also noticed that the coir fibers exhibited poor interfacial bonding to the epoxy resin matrix.

R. Panneerdhass *et al.* [8] studied the mechanical properties of alkali treated and untreated luffa fiber reinforced epoxy composites. The study was carried out on the composites with three different percentages of fibers in the composite namely 30%, 40% and 50%. The tensile strength varied from 9 MPa to 20 MPa, compressive strength varied from 75 MPa to 105 MPa, flexural strength varied from 15 MPa to 140 MPa and impact energy was registered varying from 0.25 joules to 1.45 joules. The most superior mechanical properties were noticed in alkali treated luffa reinforced composite with 40 % composition of fibers in the composite. The water absorption test indicated the good compatibility of fibers with the epoxy resin matrix.

N. Venkateshwaran *et al.* [9] carried out a study of tensile properties of short, randomly oriented sisal and banana fiber reinforced epoxy hybrid composite. The overall volume fraction of the combination of fibers was 0.4 of the total volume of composite. Banana/sisal fibers were taken in the following ratios; 40:0, 30:10, 20:20, 10:30 and 0:40. The tensile properties were predicted using the Rule of Hybrid Mixtures (RoHMs) and the results were compared to the experimental values which indicated that the RoHMs values were slightly higher than the experimental results due to the chances of formation of micro voids in the structure of the composite.

M. Sakthivel *et al.* [10] carried out a study on the characterization of luff/coir reinforced polypropylene composite. In their study four samples were prepared;

1) Composed of purely polypropylene
2) Composed of 80% polypropylene and 20% coir
3) Composed of 80% polypropylene and 20% luffa fibers
4) Composed of 80% polypropylene, 10% luffa and 10% coir

It was seen that the second sample had the best tensile strength while the third sample exhibited the best flexural strength and impact energy. The study concluded that the luffa/coir reinforced polypropylene composite might be useful in the automobile industry.

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N. Mohanta *et al.* [11] investigated the mechanical properties of luffa/glass fibers reinforced epoxy hybrid composite. Six different composite laminates were produced using different stacking orders;

a) LLLL
b) LGLG
c) GLGL
d) LGGL
e) GLLG
f) GGGG

Where, L means luffa fibers and G means glass fibers

The tensile and flexural strengths of the hybrid composite were found to be maximum in the fifth stacking order with tensile strength being 35.34 MPa and flexural strength being

108.36 MPa. The results are way higher than the luffa reinforced composite but quite less than the glass fiber reinforced composite.
R. Panneerdhass *et al.* [12] studied the mechanical properties of luffa and groundnut fiber reinforced epoxy polymer hybrid composite. The group carried out the study with alkali treated luffa fibers and groundnut fibers (in ratio of 1:1) with volume fractions of 10%, 20%, 30%, 40% and 50%. The results indicate that the composite with 40% volume fraction of fibers possesses the highest values among all. And it was learned that the alkali treatment of fibers resulted in enhancement of the mechanical properties of the composite. This extensive literature analysis indicates the future possibilities for the natural fiber reinforced hybrid composites and their several applications in the different industries. However, there is still a large scope of research in the field of natural fiber composites. The search for a better and cheaper alternative will always strive in the industries.

III. RAW MATERIALS USED AND THEIR PROPERTIES

The raw materials that were used for the fabrication of the composite in this project are mentioned below:

A. Luffa Fiber

Luffa fiber is obtained from the fruit of luffa cylindrica or “sponge gourd” plant. The fibers are in a system of network and are held together with the resinous plant tissues. Fibers are perfectly interlinked and give great resistance to the tensile load in their natural netting form. So, this attribute makes them quite useful for use in composites.
The fibers have quite low density. Lignin, Hemicellulose, Holocellulose and Alpha-Cellulose are the main chemical components that constitute the fiber of luffa cylindrica fruit. Lignin binds together the cellulose component of the fiber structure. The outer covering can be removed off of the fruit to expose the fibers. The fibers can be cut along the length to produce a fibrous mat.


(a) Dried sponge gourd. (b) Sponge gourd without outer(c) Short luffa fibers

B. Coir Fibers

Coir fibers are obtained from the husk that makes up the outer covering of the endosperm of the coconut fruit. The husk has coir and coco peat as the two components that constitute the husk. When coco peat is removed from the husk the long strands of fibers that remain are known as coir.
Coir is composed of chemical compounds such as Lignin, Alpha-Cellulose, Holocellulose and Ash. The long strands of fibers are useful as reinforcement materials inside a composite due to their strength and stiffness. The fibers have density when compared to other fibers which is an advantage over other fibers.

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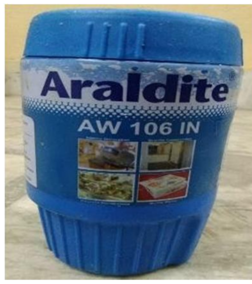
C. Resin

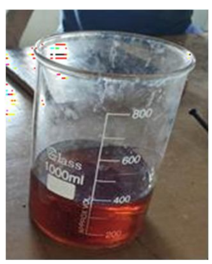
The resin used for this project is Araldite AW 106 IN. The resin has following Properties:

1) Color: Creamy
2) Appearance: Viscous liquid
3) Specific Gravity: 1.17
4) Viscosity: 50,000 cP (at 25^{o}C)



D. Hardener

The hardener used in the project is Araldite HV 953 IN. Hardener has the following properties:
Color: Amber
Appearance: Liquid Specific
Gravity: 0.92
Viscosity: 35,000 cP (at 25^{o}C)




E. Properties of Epoxy Resin

1) Exceptional bonding to other materials including metals, ceramics and wood
2) Electrical insulation
3) No release of volatile constituents
4) High shear strength
5) Room temperature curing
6) Good resistance to static and dynamic loads
7) Combined viscosity of 45,000 cP (at 25^{o}C)
8) Little to no shrinkage

F. Recommended Cure Schedule of Epoxy Resin

Temperature	Minimum Cure Time
20^{o}C	15 Hours
25^{o}C	12 Hours
40^{o}C	3 Hours
70^{o}C	50 Minutes
100^{o}C	10 Minutes
150^{o}C	5 Minutes

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IV. PREPARATION METHODS

A. Preparation of Fibers

The ripe fruits of Luffa cylindrica and Coconut are firstly dried in the sun to remove any moisture.

The outer covering of luffa cylindrica is removed, also the seeds are removed from the fruit. The ridge fibers inside the fruit are cut along a line along the length of the fruit and a mat of network of fibers is produced. Luffa fibers are then roughly chopped into 1*1 cm^2 fibers and are further dried in an oven to remove excessive moisture. The husk of the ripe coconut is peeled off and then the coco peat is removed with hands to obtain the useful coir fibers. These long strands of fibers are then cut into 2 cm long strands and are then dried in an oven to remove excessive moisture.

B. Density Measurement of the Fibers

Densities of the fibers are measured using a pycnometer using the following formula:

$$\rho = \frac{(W_2 - W_1)}{(W - W) - (W - W)} * Density\ of\ kerosene$$

Where, W_1 is the weight of an empty pycnometer flask,

W_2 is the weight of the pycnometer flask filled with fiber,

W_3 is the weight of the pycnometer flask filled with kerosene, and

W_4 is the weight of the pycnometer flask filled with both kerosene and the fiber.

The densities of the fibers obtained from the above relation are:

Luffa Fibers: 0.525 gm/cc

Coir Fibers: 0.98 gm/cc

C. Preparation of the Molds

The molds are made on a square plywood and the boundaries of the molds are made up of solid wood with square cross-section. The mold is made to be closed with a square plywood lid with the help of cast iron clamps. The dimensions of the molds are 220*220*15 cm^3. The surfaces of the mold were sanded down with a sand paper to remove uneven surfaces. The figure below shows one of the molds that was created of production of Fiber Reinforced Composite.

D. Preparation of Samples

1) *Preparation of Lamina:* The samples were prepared with 5 different compositions of fiber and epoxy resin. The compositions were done in respect to volume. The following table shows the various composition distribution of the matrix and reinforcement fibers.

Composition	Percentage of Fibers (Luffa + Coir)	Percentage of Epoxy Resin
1	0 %	100 %
2	1.25 %	98.75 %
3	2.5 %	97.5 %
4	5 %	95 %
5	10 %	90 %

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It should be noted that the ratio of volume of luffa fibers to coir fibers are 1:1 and that of the resin and hardener is also 1:1.

The short fibers of both luffa and coir in ratio of volume of 1:1 for every composition were mixed together thoroughly and then were mixed in the resin after which the hardener was mixed and the final mixture was poured in the mold which was sprayed on with a mold release spray for easy removal of the composite formed. Care was taken to pour the mixture inside the mold before it started to solidify and the plywood lid put on top of the mold and was fixed in place with screw clamps. Clamps also put pressure on the lid of the mold to make sure that there was no air gap inside the mold and some of the epoxy and fiber mixture leaked out. The composite was left to totally cure for more than 96 hours after which it was removed from the mold for inspection. The dimension of the composite came out perfect and there were no cracks in the composite. The figure below shows the composite that was produced in the process.

2) *Preparation of Test Samples:* The laminae of different composition of fibers were cut into desired dimensions with the help of a saw for the purpose of testing.

These dimensions accord with ASTM standards.

a) *Tensile Test:* Samples were formed into the dog bone shape with the dimensions of the test region were 42 mm * 10 mm * 5 mm.
b) *Flexural Test:* A rectangular samples of dimensions 140 mm * 15 mm * 5 mm were used for flexural testing.

V. TESTING OF SAMPLES COMPRESSIVE TEST

Compressive test was carried out on a computerized UTM (Universal Testing Machine). The samples of dimension 200 mm * 15 mm * 15 mm were placed between the two test surfaces of the machine. At the point of breakage of the sample the values of compressive strength were shown on the computer screen. Fig. 5.3 shows the sample loaded in the UTM for compressive testing.

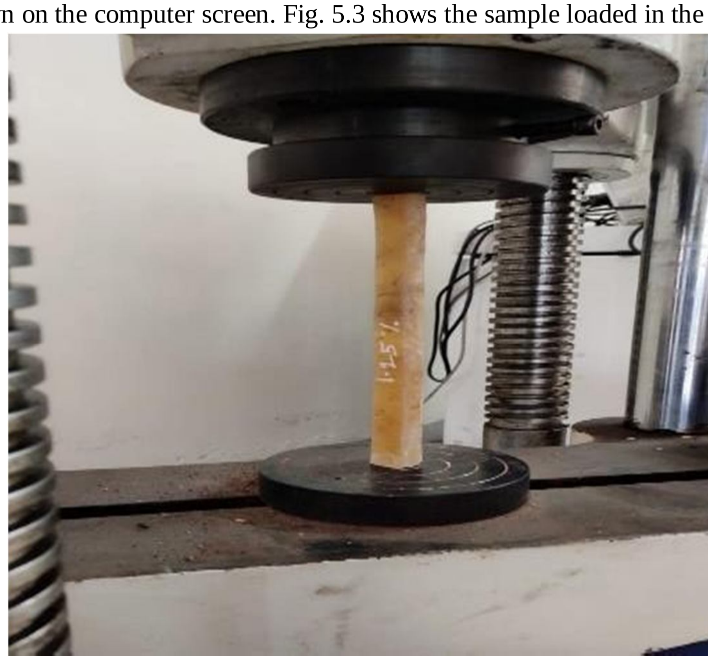

Fig. 5.3 Flat Sample Placed in the UTM for Compressive Test

VI. RESULTS AND DISCUSSIONS

A. Tensile Test

A tensile test is carried out to know the lateral strength of a material. Tensile test is commonly carried out on a flat dog bone shaped sample. Fig. 4.4 shows the sample produced for the purpose of carrying out tensile test. Tensile test was carried out according to the ASTM D 3039-76 standards with samples having span of 42 mm and width of 15 mm. All the tensile tests were done on a computerized UTM (Universal Testing Machine). All the tensile tests were performed with a uniform strain rate of 2mm/min.Tensile tests were carried out on the UTM with the samples of test area dimensions of 42 mm * 15 mm * 10 mm. the table 6.1 below shows the result of tensile test for all the samples.

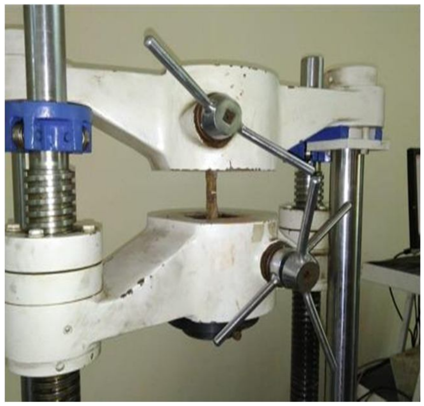

Fig. 5.2 UTM Loaded with a Sample for Tensile Test

Table 6.1 (Tensile Test Results)

Sample	Tensile Strength (MPa)
S1	38.33
S2	40.47
S3	27.857
S4	23.56
S5	23.434

Where, S1 is the sample with fiber volume fraction of 0%, S2 is the sample with fiber volume fraction of 1.25%, S3 is the sample with fiber volume fraction of 2.5 %, S4 is the sample with fiber volume fraction of 5% and S5 is the samples with fiber volume fraction of 10%. The results show that the sample S2 with 1.25% volume fraction possesses the highest tensile strength among all the samples. Whereas the tensile strength decreases with an increasing volume fraction of fibers. This may be due to poor adhesion of epoxy and fibers or the poor impregnation of epoxy into the fibers.

The increase in tensile strength in the composite is seen with an addition of small amounts of fibers in the epoxy. With a better impregnation of epoxy in the higher volume fraction of fibers better results can be achieved.

B. Compressive Test

The samples of dimension 200 mm * 15 mm * 15 mm were loaded between the two testing surfaces of the UTM. A load was applied on the samples and the results were captured on the computer at the point of failure of the samples. The table below shows the results from the compressive test.

Where, S1 is the sample with fiber volume fraction of 0%, S2 is the sample with fiber volume fraction of 1.25%, S3 is the sample with fiber volume fraction of 2.5 %, S4 is the sample with fiber volume fraction of 5% and S5 is the samples with fiber volume fraction of 10%.

It can be seen that addition of 1.25% volume fractions of fiber increased the compressive strength of the sample S2 dramatically but further addition of fibers see a decrease in the values of compressive strength of the composite samples.

The addition of small amount of fibers no doubt increased the compressive strength of composite but the performance of latter samples might be poor due to the poor adhesion of epoxy and fibers or production of void might be an issue.

VII. CONCLUSIONS

This report is the documentation of work carried out for the preparation of a new fiber reinforced epoxy hybrid composite. The testing of the mechanical properties of the composite revealed the following aspects:

A. A new fiber reinforced epoxy hybrid composite was successfully produced using luffa fibers, coir fibers and epoxy resin.
B. The tensile tests revealed that the addition of 1.25% volume fraction of reinforcement (Sample S2) increases the tensile strength of the composite but further addition of fibers results in decreasing strength of the composite which might be due to poor adhesion of the matrix and the reinforcements or poor impregnation of epoxy in the fibers.
C. The compressive tests indicated a dramatic increase in the value of compressive strength of the sample S2 with 1.25% volume fraction of the fibers over the neat epoxy sample (S1). The value of compressive strength jumped from 25.068 MPa for the neat epoxy (S1) to the 37.87 MPa for the sample with 1.25% volume fraction of fibers. The further samples with increasing volume fractions of fibers witnessed a fall in the values of compressive strength. The decreasing values might be caused due to voids present inside the samples or the poor adhesion of the matrix and the reinforcements.
D. Natural fiber composites can possibly replace the use of wood and other materials in industries like construction industry, logistics, automobile industry, etc. And can be used for production of home appliances and storage units.
E. Further test may give a better understanding of the other mechanical properties of the hybrid composite.

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