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Development and Analysis of Hybrid Polymer Composite from Bagasse and Coconut Coir

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Abstract: ***Lot of research is going on today in the field of material science to develop newer materials. Natural fibres are getting much attention of researchers, engineers and scientists as reinforcement in the epoxy matrix to develop natural fibre reinforced epoxy composites. In the present work an attempt has been made to develop a systematic approach to evaluate tensile impact and hardness strength of coir and bagasse fiber reinforced hybrid composites. The composite panel was fabricated using hand lay-up method to the size of 300mmx200mmx10mm of natural fibres namely coconut coir (5 wt %) and bagasse as a fibre (45 % by volume) reinforced in epoxy resin. The test criteria determine modulus, percentage elongation, ultimate strength, hardness and impact strength.***

Keywords: Composite, Bagasse Fibre, Coir Fibre

1. Introduction

Composites made of conventional fibres (glass, carbon, graphite, boron, Kevlar etc.) have a high cost. If made of inexpensive fibres, they will cut-down the cost of components for which they are used. Natural fibres are such materials, they are not only inexpensive, but are available in abundance also. They are light weight and they possess high specific strength and low specific weight, and are eco-friendly too. Their strength is not as high as those of synthetic fibres. Hence, natural fibre composites are likely to be a blend of lightweight and strong material. [1]

Polymers are used in almost every area of society such as packaging, transport, construction and casings. Polymers are easily shaped by extrusion, injection moulding, vacuum forming or foaming. It is durable, environmentally resistant, tough and light. Tailoring mechanical polymer properties for specific purposes often require fibre reinforcement. Common synthetic fibres include carbon, aramid and glass while natural fibres such as wood, hemp and sisal are have also been shown to be effective. An alternative to the aforementioned fibres is fibre recovered from chicken feathers, as they are widely available and has good mechanical properties. [2]

There are enormous mechanical advantages for using composite materials. Natural Fibre Composite (JFRC) illustrates the specific properties benefits of the composites structural use over traditional industrial materials. Fibres reinforced organic matrix composite materials specific-properties can double or triple the load carrying capacity over the traditional metals. This material's benefit enables structural designs that out-perform the conventional application limitations commensurately improving system performance such as reducing weight, increasing fuel efficiency or increasing speed. [3]

1.1 Composite

Composite materials are materials made from two or more constituent materials with significantly different physical or chemical properties, that when combined, produce a material with characteristics different from the individual components. The individual components remain separate and distinct within the finished structure. The new material may be preferred for many reasons: common examples include materials which are stronger, lighter or less expensive when compared to traditional materials.

- Typical engineered composite materials include:
- Composite building materials such as cements, concrete
- Reinforced plastics such as fibre-reinforced polymer
- Metal Composites
- Ceramic Composites (composite ceramic and metal matrices)

Composite materials are generally used for buildings, bridges and structures such as boat hulls, swimming pool panels, race car bodies, shower stalls, bathtubs, storage tanks, imitation granite and cultured marble sinks and counter tops. The most advanced examples perform routinely on spacecraft in demanding environments.

1.2 Types of Composite

Composite materials are commonly classified at following two distinct levels:

Figure 1.2: Composites are formed by combining materials together to form an overall structure that is better than the sum of the individual components

The first level of classification is usually made with respect to the matrix constituent. The major composite classes include Organic Matrix Composites (OMCs), Metal Matrix Composites (MMCs) and Ceramic Matrix Composites (CMCs). The term organic matrix composite is generally assumed to include two classes of composites, namely

Polymer Matrix Composites (PMCs) and carbon matrix composites commonly referred to as carbon-carbon composites.

The second level of classification refers to the reinforcement form - fibre reinforced composites, laminar composites and particulate composites. Fibre Reinforced composites (FRP) can be further divided into those containing discontinuous or continuous fibres.

1.3 Hybrid Fibre Composite

Composites containing two or more different reinforcing materials bound in the same matrix are commonly known as hybrid composites. Hybridization allow designers to tailor the composite properties to the exact needs of the structure under consideration. In most cases, the purpose of hybridization is to obtain a new material retaining the advantages of its constituents, and hopefully overcoming some of their disadvantages. Another desired achievement is related to the cost, with one of the two components being generally cheaper than the other one.

There are several types of hybrid composites, depending on the way the constituent materials are mixed, ie: (i) interply hybrids where layers of the two (or more) homogeneous reinforcements are stacked; (ii) intraply hybrids in which tows of the two (or more) constituent types of fibres are mixed in the same layer; (iii) intimately mixed (intermingled) hybrids where the constituent fibres are mixed as randomly as possible so that no concentrations of either type are present in the material; (iv) selective placement in which reinforcements are placed where additional strength is needed, over the base reinforcing laminate layer; (v) super hybrid composites which are composed of metal foils or metal composite plies stacked in a specified orientation and sequence[5]

Classification of Hybrid Composites

Hybridization is commonly used for improving the properties and for lowering the cost of conventional composites. There are different types of hybrid composites classified according to the way in which the component materials are incorporated.

Hybrids are designated as

- **Sandwich**: One material is sandwiched between layers of another.
- **Interply:** Alternate layers of two or more materials are stacked in regular manner.
- **Intraply**: Rows of two or more constituents are arranged in a regular or random manner.
- **Intimately mixed:** Constituents are mixed as much as possible so that no concentration of either type is present in the composite material.

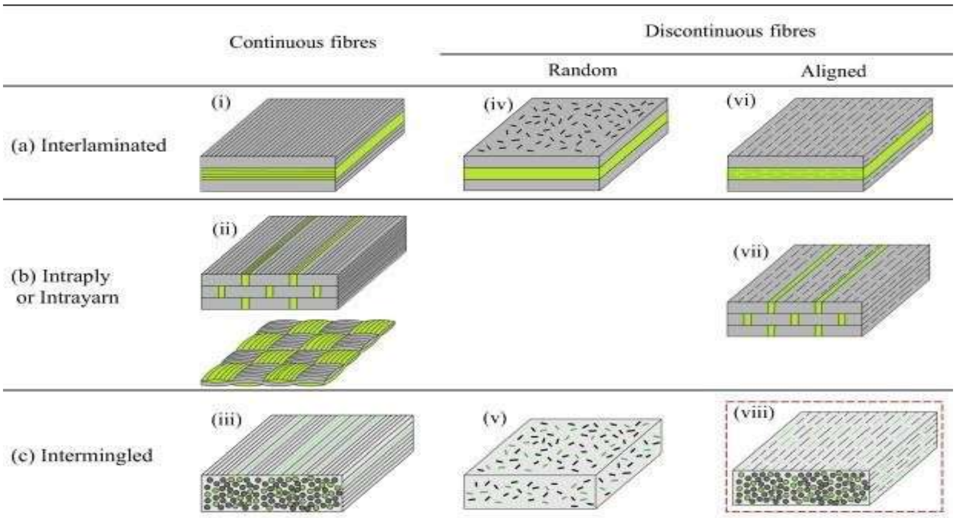

Figure 1.3: Types of Hybrid Composite

Table 1: List of Hybrid Composites fabricated by Hand Lay Up Technique

Hybrid Fibre	Resin	Process
Sisal/Silk	Polyester	Hand lay-up technique
Kenaf/Glass	Polyester	Hand lay-up and cold press
Woven Jute/Glass	Polyester	Hand lay-up
Glass/Glass	Epoxy	Hand lay-up technique
Carbon/Glass	Epoxy	Hand lay-up technique
Banana/Sisal	Polyester	Hand lay-up method
Jute/Glass	Polyester	Hand lay-up technique

1.4 Fabrication Methods

Fabrication of composite materials is accomplished by a wide variety of techniques, including:

- Vacuum bag moulding
- Pressure bag moulding
- Autoclave moulding
- Resin transfer moulding (RTM)
- Hand layup technique
- Advantages of Composite Material:

a) **Light Weight** – Composites are light in weight, compared to most woods and metals. Their lightness is important in automobiles and aircraft, for example, where less weight means better fuel efficiency (more miles to the gallon). People who design airplanes are greatly concerned with weight, since reducing a craft's weight reduces the amount of fuel it needs and increases the speeds it can reach. Some modern airplanes are built with more composites than metal including the new Boeing 787, Dream liner.

b) **High Strength** – Composites can be designed to be far stronger than aluminum or steel. Metals are equally strong in all directions. But composites can be engineered and designed to be strong in a specific direction.
c) **Corrosion Resistance** – Composites resist damage from the weather and from harsh chemicals that can eat away at other materials. Composites are good choices where chemicals are handled or stored. Outdoors, they stand up to severe weather and wide changes in temperature.
d) **High-Impact Strength** – Composites can be made to absorb impacts—the sudden force of a bullet, for instance, or the blast from an explosion. Because of this property, composites are used in bulletproof vests and panels, and to shield airplanes, buildings, and military vehicles from explosions.
e) **Design Flexibility** – Composites can be molded into complicated shapes more easily than most other materials. This gives designers the freedom to create almost any shape or form. Most recreational boats today, for example, are built from fiberglass composites because these materials can easily be molded into complex shapes, which improve boat design while lowering costs. The surface of composites can also be molded to mimic any surface finish or texture, from smooth to pebbly.
f) **Low Thermal Conductivity** – Composites are good insulators—they do not easily conduct heat or cold. They are used in buildings for doors, panels, and windows where extra protection is needed from severe weather.
g) **Durable** – Structures made of composites have a long life and need little maintenance. We do not know how long composites last, because we have not come to the end of the life of many original composites. Many composites have been in service for half a century.

Limitations of Composites:
Some of the associated disadvantages of advanced composites are as follows:
- High cost of raw materials and fabrication.
- Composites are more brittle than wrought metals and thus are more easily damaged.
- Transverse properties may be weak.
- Matrix is weak, therefore, low toughness.
- Reuse and disposal may be difficult.
- Difficult to attach.
- Materials require refrigerated transport and storage and have limited shelf life.
- Hot curing is necessary in many cases requiring special tooling.
- Applications of Composites
- Aerospace
- Automotive Engineering
- Bio engineering
- Civil/ Structural engineering
- Domestic
- Marine Engineering
- Sport

1.5 Natural Fibre

Natural fibres are classified into three categories. These are plant fibres, animal fibres and mineral fibres. Plant fibres are important types of natural fibres and these are generally comprised mainly of cellulose, hemi-cellulose, lignin, pectin.

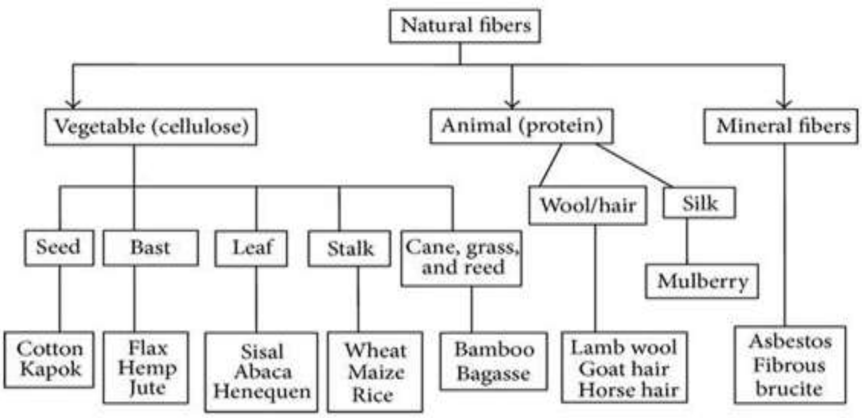

Figure 1.5: Classification of natural fibre

Prominent natural fibers are cotton, jute, flax, ramie, sisal and hemp. Cellulose fibres are mainly used in manufacturing of paper and cloth. This fibre is categorized into seed fibres, leaf fibres, bastfibre/ stem fibre, fruit fibre, stalk fibre.

1.6 Plant Fibre

Plant fibres are a composite material designed by nature. The fibres are basically a rigid, crystalline cellulose micro fibril-reinforced amorphous lignin and/or with hemicellulosic matrix. Most plant fibres are composed of cellulose, 24emicelluloses, lignin, waxes, and some water-soluble compounds. The percentage composition of each of these components varies for different fibres. Generally, the fibre contains 60-80 % cellulose, 5-20% lignin and up to 20 % moisture (Taj et al., 2007; Wang et al., 2008). During the biological synthesis of plant cell walls, polysaccharides such as cellulose and 24 emicelluloses are produced simultaneously. Lignin fills the space between the polysaccharide fibres, cementing them together. This lignifications process causes a stiffening of cell walls and the carbohydrate is protected from chemical and physical damage (Taj et al., 2007). The chemical composition of natural fibres varies depending upon the type of fibres. The chemical composition as well as the structure of the plant fibres is fairly complicated. Hemicellulose is responsible for the biodegradation, micro absorption and thermal degradation of the fibre as it shows least resistance, whereas lignin is thermally stable but prone to UV degradation.

- **Seed fiber:** Fibers collected from the seed and seed case e.g. cotton and kapok.
- **Leaf fiber:** Fibers collected from the leaves e.g. sisal and agave.
- **Skin fiber**: Fibers are collected from the skin or bast surrounding the stem of their respective plant. These fibers have higher tensile strength than other 11 fibers. Therefore, these fibers are used for durable yarn, fabric, packaging, and paper. Some examples are flax, jute, banana, hemp, and soybean.
- **Fruit fiber**: Fibers are collected from the fruit of the plant, e.g. coconut (coir) fiber.
- **Stalk fiber:** Fibers are actually the stalks of the plant. E.g. straws of wheat, rice, barley, and other crops including bamboo and grass. Tree wood is also such a fiber.

The natural fibers can be used to reinforce both thermosetting and thermoplastic matrices. Thermosetting resins, such as epoxy, polyester, polyurethane, phenolic, etc. are commonly used today in natural fiber composites, in which composites requiring higher performance applications. They provide sufficient mechanical properties, in particular stiffness and strength, at acceptably low price levels. Considering the ecological aspects of material selection, replacing synthetic fibers by natural ones is only a first step. Restricting the emission of green house effect causing gases such as CO_2 into the atmosphere and an increasing awareness of the finiteness of fossil energy resources are leading to developing new materials that are entirely based on renewable resources.

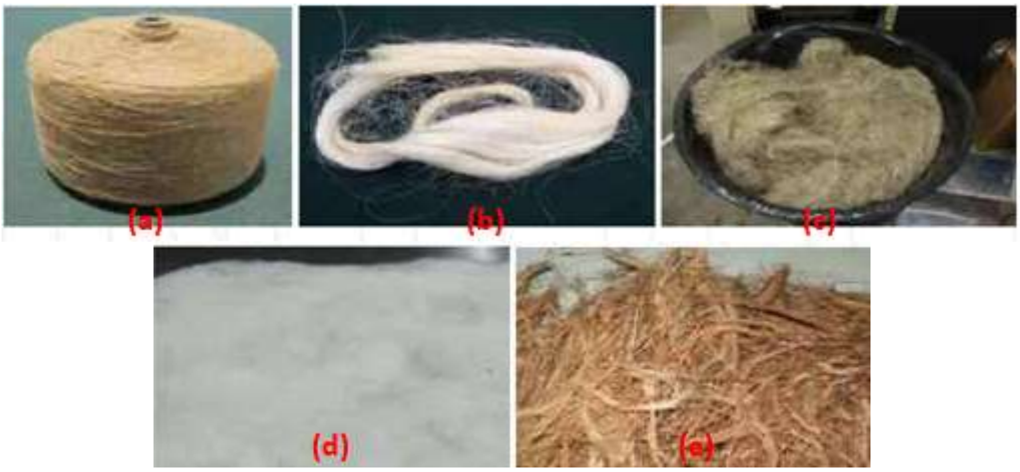

Figure 1.7.1: (a) Jute yarn (b) Sisal fibre (c) Hemp fibre (d) Cotton fibre (e) Coir fibre

1.7 Bagasse

Bagasse is the fibrous residue which remains after sugarcane stalks are crushed to extract their juice. It is mainly used as a burning raw material in the sugar mill furnaces. The low caloric power of bagasse makes this a low efficiency process. Also, the sugarcane mill management encounters problems regarding regulations of clean air from the Environmental Protection Agency, due to the quality of the smoke released in the atmosphere. Presently 85% of bagasse production is burnt. Even so, there is an excess of bagasse. Usually this excess is deposited on empty fields altering the landscape. Approximately 9% of bagasse is used in alcohol (ethanol) production. Ethanol is not just a good replacement for the fossil fuels, but it is also an environmentally friendly fuel.

SCB wastes are chosen as an ideal raw material in manufacturing new products because of its low fabricating costs and high quality green end material. It is ideal due to the fact that it is easily obtainable given the extensive sugar cane cultivation making its supply constant and stable. The associated costs of extraction, chemical modifications and/or other pre-treatments of SCB in the transformation process to ready-to-be used materials are potentially reduced as the complex processes are simplified by the mere usage of Bagasse. When appropriate modifications and manufacturing procedures are applied, bagasse displays improved mechanical properties such as tensile strength, flexural strength, flexural modulus, hardness, and impact strength. Bagasse is also found to be easily treated and modified with chemicals besides blending well with other materials to form new types of composite materials.

1.8 Composition of bagasse

The bagasse fiber reinforced polymer composites performance depends on several factors, including fibers chemical composition, cell dimensions, microfibrillar angle, defects, structure, physical properties, and mechanical properties, and also the interaction of a fiber with the polymer. In order to expand the use of bagasse fibers for composites and improved their performance, it is essential to know the fiber characteristics. Bagasse consists of approximately 50% cellulose and 25% each of 26 emicelluloses and lignin. Chemically, bagasse contains about 50% α-cellulose, 30% pentosans, and 2.4% ash. Because of its low ash content, bagasse offers numerous advantages in comparison to other crop residues such as rice straw and wheat straw, which have 17.5% and 11.0%, respectively, ash contents, for usage in microbial cultures.[6]

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Figure 1.8: Figure of bagasse fibre

Properties The physical properties of bagasse fiber are critical, and include the fiber dimensions, defects, strength and structure.

Table 2: Physico-mechanical properties of bagasse fibers

Properties	Values
Tensile strength (MPa)	290
Young's modulus (GPa)	17
Density [g/cm^3]	1.25

1.9 Coconut fibre

It is extracted from the outer shell of a coconut. The common name, scientific name and plant family of coconut fibre is Coir, Cocosnucifera and Arecaceae (Palm), respectively. There are two types of coconut fibres, brown fibre extracted from matured coconuts and white fibres extracted from immature coconuts. Brown fibres are thick, strong and have high abrasion resistance. White fibres are smoother and finer, but also weaker. Coconut fibres are commercial available in three forms, namely bristle (long fibres), mattress (relatively short) and decorticated (mixed fibres). These different types of fibres have different uses depending upon the requirement.[7]

In engineering, brown fibres are mostly used. According to official website of International Year for Natural Fibres 2009, approximately, 500 000 tonnes of coconut fibres are produced annually worldwide, mainly in India and Sri Lanka. Its total value is estimated at $100 million. India and Sri Lanka are also the main exporters, followed by Thailand, Vietnam, the Philippines and Indonesia. Around half of the coconut fibres produced is exported in the form of raw fibre.

There are many general advantages of coconut fibres e.g. they are moth-proof, resistant to fungi and rot, provide excellent insulation against temperature and sound, not easily combustible, flame-retardant, unaffected by moisture and dampness, tough and durable, resilient, springs back to shape even after constant use, totally static free and easy to clean.

Fig. 1. Coconut Tree, Coconut and Coconut fibres

Figure 1.9: Longitudinal and Cross-Section of a Fibre Cell

Properties of Coconut Fibres.

Chemical Composition of Coconut / Coir Fiber:

Composition	Percentage (%)
Lignin	45.84
Cellulose	43.44
Hemi-Cellulose	00.25
Pectin's and related Compound	03.00
Water soluble	05.25
Ash	02.22

Table 3: Chemical Composition of Coir Physical Properties of Coconut / Coir Fiber:

Properties	Value
Length in inches	6-8
Density (g/cc)	1.40
Tenacity(g/Tex)	10.0
Diameter in mm	0.1-1.5
Rigidity of Modulus	1.8924 dyne/cm2
Swelling in water (dia)	5%
Moisture at 65% RH	10.50%
Breaking elongation%	30%

2. Fabrication and Testing

There are several method for making of natural fibre composites. Most of the techniques commonly used for making glass fibre composites are applicable for making natural fibre composites. However, the well-known method for composites making are as followings: Hand Lay-up/Spray up is one of the cheapest and most common processes for making fibre composite products. In this process, the mold is waxed and sprayed with gel coat and cured in a heated oven. In the spray up

Figure 2(a): Mould

process, catalyzed resin is sprayed into the mold, with chopped fibre where secondary spray up layer imbeds the core between the laminates resulting a composite. In hand layup processing, both continuous fibre strand mat and fabrics are manually placed in the mold. Each ply is sprayed with catalyzed resin and with required pressure compact laminate is made.In this study chickenfibre-reinforced epoxy resin composites were moulded by the hand lay-up technique using naturally available chickenfibre and a matrix .

Figure 2 (c): Bagasse fibre

Figure 2(b): Roller

The fibres (bagasse and coconut coir) were collected from local area. Bagasse and coir fibre were washed several times with warm water in order to remove the cellulose content and other impurities and then were soaked in 5% NaOH concentrated water for 30 minutes. The soaked fibres were then washed with detergent water followed by pure water then were dried in sun rays. Clean fibres from dirt and impurities are obtained.

Figure 2(d): Cocunut coir

Figure 2(e): Fabrication process

Figure 2(f): Hybrid Composite Sheet

3. Result and Discussion

Testing performed: - There are two types of testing are performed on the chicken feather composite sheet

- Mechanical Testing
- Tensile test
- Izod Test
- Hardness test
- Thermal Testing
- Differential Scanning Calorimetry (DSC) test
- Thermo Gravimetric Analysis (TGA) test

3.1 Tensile Testing

Tensile testing, also known as tension testing, is a fundamental materials science test in which a sample is subjected to a controlled tension until failure. The results from the test are commonly used to select a material for an application, for quality control, and to predict how a material will react under other types of forces. Specimen are prepared as per ASTM D3039

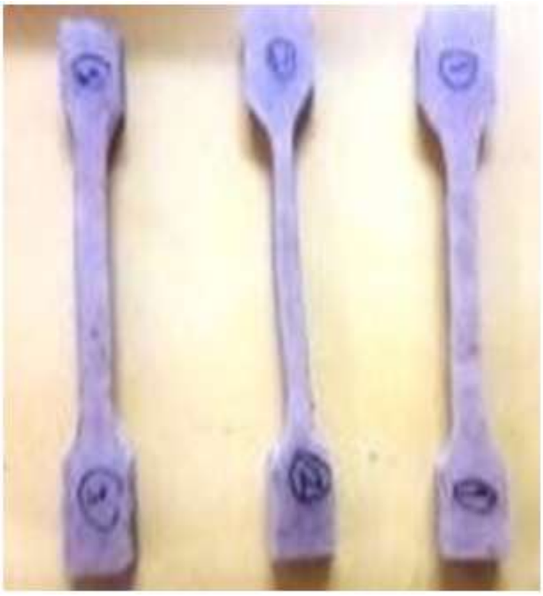

Figure 3.1: Specimen Before Fracture

Figure 3.2: Specimen After Fracture

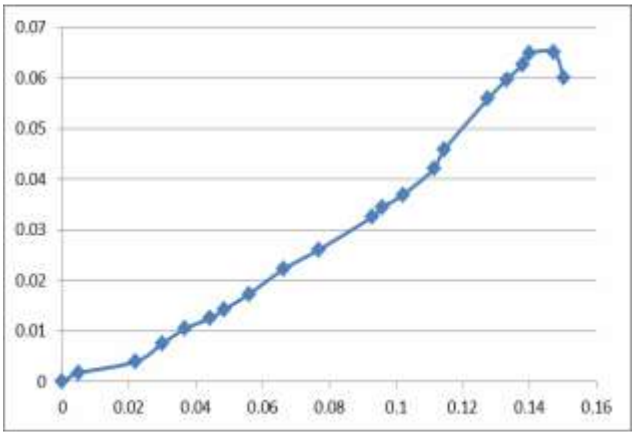

Figure 3: Stress strain curve of tensile test

Conclusion from Tensile test:
To obtain the value of modulus of elasticity, Elongation and Ultimate stress of the hybrid composite material the tensile test is performed tensile testing machine (AST 40) and the following result is obtained.

Mean Value of Modulus of Elasticity	=	4.32GPa
Mean Value of Elongation	=	1.5 %
Mean Value of Ultimate stress	=	64.81 MPa

3.2 Impact test

Impact test are perform to assess shock absorbing capability of the material subjected to suddenly applied shock load. This capability is expressed as impact strength of the material.
Summary of Impact testing

Table 4.1: Summary of Impact test

S. No.	Name of the test	Testing method	Test value (J/m)
1	IZOD 1	ASTM-D256	29.90
2	IZOD 2	ASTM-D256	30.20
3	IZOD 3	ASTM-D256	30.36

Conclusion from Impact test
To obtain the impact strength of hybrid composite material IZOD test is performed as per ASTM D256 standard. The mean value impact strength of this composite material is found to be 30.15 J/m. Which shows better impact strength than plain epoxy sheet.

3.3 Hardness Test

Hardness test is performed on hybrid composite on digital hardness testing machine as shown

Table 4.2.2: Result of Hardness test

S.No	Test valve
Sample 1	47.6
Sample 2	45.9
Sample 3	46.8

Average hardness of Composite = 46.767 HRM

3.4 Water Absorption Test

Testing Procedure
Water absorption test conducted in which specimen is immerged in the for 36 hours at room temperature under normal condition and each 4hours their weight would be measured .

A rectangular test piece of dimension (60mm×40mm×10mm) was dipped in a glass containing water 250ml for 36 hrs. Initial weight of the specimen was 25 g measured by the weighing balance (manufactured by Ohaus) whose least count is 0.01g. The weight of the specimen was measured at a time interval of 6 hrs till 36 hrs. the specimen absorbed water only upto 24 hrs. The specimen weight increased upto 0.55g in 24 hrs only and after that the specimen weight shows that there is no increase in weight that is specimen weight is constant. After 24 hrs, the samples were taken out from the moist environment and all surface moisture was removed with the help o-f a clean dry cloth or tissue paper.

Figure 4.4.1: Water Absorption Test

Table 4.4: Result of water absorption test

Weight(g)	25.00	25.20	25.30	25.50	25.55	25.55	25.55
Time(Hr)	0	6	12	18	24	30	36

4. Conclusions

- In the present investigation a hybrid composite (bagasse and coconut coir) is made with polymer matrix (Epoxy Resin). Various mechanical tests are performed as per ASTM standards .
- There is 74.67% increase in tensile strength of hybrid composite by adding coconut coir fibre with bagasse in comparison to aloevera – bagasse natural hybrid composite
- There is slight improvement (1.06%) in impact strength of hybrid Composite as compared to hybrid composed of bagasse and chicken fibre.
- There is improvement (1.54%) in hardness of hybrid Composite in comparison to CRFC (Chicken reinforced fibre composite).
- Initial degradation temperature of hybrid composite was 150^0C and final degradation temperature was 600^0C. The maximum rate of weight loss was observed in the range of 150^0C– 600^0C. The amount of residue left is 0.33%.
- The glass transition temperature (Tg) of hybrid composite increases as compared to plain epoxy. The baggase as a fiber and Coconut coir as particulate form are aided to plain epoxy enhanced the glass transition temperature (Tg) is up to 190^0C.
- Natural fiber reinforced hybrid composite material can be used in smart structure, false ceiling, automobile interior and in packaging industry.

5. Future Scope

Based on the limitation following are the some suggestions:

1) Further research can be carried out by using different types of fibre such as chicken feather, human hair (as a waste) used in hybrid composite for enhancing the mechanical and thermal property.
2) In the present research we used hand lay-up technique to fabricate hybrid composite material, in future different technique of fabrication can be used.
3) In present investigation we used 5% by weight of coconut coir for making of hybrid composite material, in future we can study the behavior of composite material at varying its proportion.
4) By using the design of experiment(DOE) different process parameter can be optimized by different method such as response surface methodology (RSM), artificial neural network(ANN), genetic algorithm (GA)
5) Same work can be extended for other thermosetting and thermoplast materials.

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