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Study on Mechanical Behavior of Bio-Fiber Reinforced Polymer Matrix Composite

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Abstract

Presently polymer matrix composites reinforced with fibers such as glass, carbon, aramid, etc. are being used more because of their favorable mechanical properties in spite of they being more expensive materials. Nowadays natural fibers such as sisal, flax, hemp, jute, coir, bamboo, banana, etc. are widely used for environmental concern on synthetic fibers. This coming generation of engineered bio-composites must provide construction materials and building products that exceed current expectations, such as lower cost, greater adaptability and reliability and lower maintenance. These engineered bio-composites are opening new markets in the field of commercial construction, automotive, aerospace and also reducing effects on the environment such as energy, air, water, and waste. In this investigation, a Cissus fiber is reinforced with Epoxy matrix and composites have been developed by compression moulding technique. The fiber percentages (15%, 20%, 25% and 30% by weight) were used for the preparation of composites. These natural fiber reinforced composites were then characterized by mechanical tests. The results showed increase in the tensile strength as the fiber percentage increased; however, after a certain percentage of fiber reinforcement, the tensile strength decreased. And also the maximum flexural strength and maximum impact energy absorbed was obtained for 30% of the fiber reinforced.

Keywords: Natural fiber reinforced composites, Cissus fibers, fiber percentages by weight, Mechanical Properties..

Introduction

Fibers are class of hair-like materials that are continuous filaments or in discrete elongated pieces, similar to piece of thread. They can be spun into filaments, thread or rope. They can be used as a component of composite materials. Fibers are of three types such as natural fibers, cellulose fiber and synthetic fiber. Natural fibers are made from plant, animals and mineral sources. Natural fibers can be classified according to their origin. Vegetable fibers are generally comprised mainly of cellulose. Fiber-Reinforced composites consist of thin fibers of a material, which are embedded in a matrix of another material. Matrix is the medium or the substance in which the fibers are embedded. Matrix helps distribute the stress across the fibers and then continuous or discontinuous fibers provide strength of the composites. The matrix also provides toughness to the fiber reinforced structure.

Mechanical properties of the composites treated with both grades of coupling agents were significantly superior to those of untreated ones, due to the stronger interfacial bonding between the fiber and the matrix polymer [1]. Woven sisal fibers were used untreated and thermal treated, and the composites were processed by compression molding. The present work study tensile behavior at four composites: dry sisal/polyurethane, humid sisal/polyurethane, dry sisal/phenolic and humid sisal/phenolic resin. The moisture content influences of sisal fibers on the mechanical behaviors were analyzed. Experimental results showed a higher tensile strength for the sisal/phenolic composites followed by sisal/polyurethane, respectively. In this research, sisal composites were also characterized by scanning electron microscopy [2].

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The alkali-treated roselle and sisal fibers were used as reinforcement fillers for thermosetting matrix with the aim of obtaining better mechanical properties and machinability of natural fiber hybrid polyester composite. However, their mechanical properties and machinability were compared with untreated fiber composites. The roselle and the sisal fibers were subjected to a 10% sodium hydroxide solution treatment at different duration of 2, 4, 6, and 8 h. Besides, the fractured surfaces of composite specimen were investigated using scanning electron microscopy. Drill hole profiles were analyzed using a profile projector and machine vision inspection system. An improvement in strength and stiffness combined with high toughness was achieved by treating the fibers using 10% NaOH solution [3].

All composite models contain the Young's modulus or the tensile strength of the reinforcing fibers. Therefore the essential pre-requisite to come to an agreement between the theoretical approaches and the practical results is the exact measurement of these parameters. Some aspects of the measurement of the natural fiber E-modulus are discussed. Furthermore a new process to produce long fiber reinforced thermoplastic granules is presented. These long fiber granules can be processed by conventional plastic equipments [4].

Okra technical fibers are extracted from the stem of a plant of the Malvaceae family (Abelmoschus esculentus). Their use as potential reinforcement in polymer composites requires the understanding of their microstructure and mechanical properties. This work investigates the morphology of the technical fibers through optical and electron microscopy and their thermal behavior through thermo gravimetric analysis. Single fiber tensile tests were performed in order to obtain their mechanical properties and the results were analyzed through a two-parameter Weibull distribution. The fracture modes of okra fibers were also addressed [5].Morphology of natural fibers was correlated with their mechanical properties via image analysis. Jute, sisal, curaua, coir and piassava fibers were tested under direct tension in a universal testing machine and the cross-sectional areas of the fibers were calculated using images obtained in a scanning electron microscopy [6].

An investigation of the extraction procedures of vakka (Roystonea regia), date and bamboo fibers has been undertaken. The cross-sectional shape, the density and tensile properties of these fibers, along with established fibers like sisal, banana, coconut and palm, are determined experimentally under similar conditions and compared. The fibers introduced in the present study could be used as an effective reinforcement for making composites, which have an added advantage of being lightweight [7]. The degree of fiber–matrix adhesion and its effect on the mechanical reinforcement of short henequen fibers and a polyethylene matrix was studied. The surface treatments were: an alkali treatment, a silane coupling agent and the pre-impregnation process of the HDPE/xylene solution. The presence of Si–O–cellulose and Si–O–Si bonds on the lignocelluloses surface confirmed that the silane coupling agent was efficiently held on the fiber surface through both condensation with cellulose hydroxyl groups and self-condensation between silanol groups [8].

The nature of representative stress strain curves and fracture at different strain rates have been analyzed through SEM. Natural fibers present important advantages such as low density, appropriate stiffness and mechanical properties and high disposability and renewability. Moreover, they are recyclable and biodegradable. There has been lot of research on use of natural fibers in reinforcements. Banana fiber, a ligno-cellulosic fiber, obtained from the pseudo-stem of banana plant (Musa sepientum), is a bast fiber with relatively good mechanical properties [9].

Problem identification

Now a day's natural fibers such as sisal, flax, hemp, jute, coir, bamboo, banana, etc. are widely used for environmental concern on synthetic fibers (such as glass, carbon, ceramic fibers, aramid etc.). Engineered bio-composites are needed to meet the needs of users for construction and commodity products which will simultaneously maximize the sustainability of natural resources. This coming generation of engineered bio-composites must provide construction materials and building products that exceed current expectations, such as lower cost, greater adaptability and reliability and lower maintenance. These engineered bio-composites are opening new markets in the field of commercial construction, automotive, aerospace and also reducing effects on the environment such as energy, air, water, and waste.

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Methodology

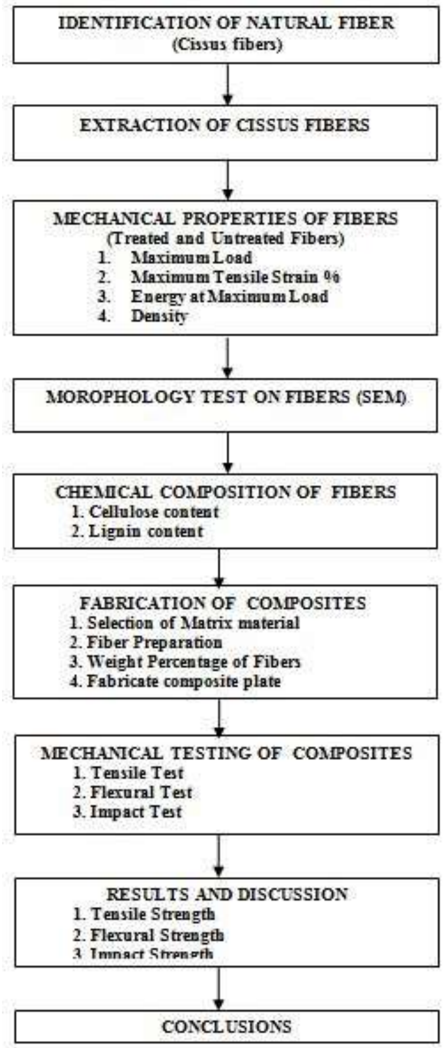

Fig.1 Methodology

Processing of cissus fibers

The Cissus were collected and immersed in water for 7 days until it become decay. Then the plant was washed in water to remove the fibers present inside. Then Cissus fibers were dried in shadow.

Fig.2 Cissus Plant

Fig.3 Decay Cissus Plant

Fig.4 Cissus fibers

Chemical treatment of fibers

Fibers were treated with 5% aq. NaOH solution and washed in distilled water. Then these fibers were washed with very dilute acid (HCL) to remove any particles of alkali. Then the fibers were washed with in water. Finally these fibers were washed with distilled water until the fibers were alkali free. Then the washed fibers were dried in shadow.

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Tensile testing of fibers

The percentage of elongation and mean breaking strength were determined using universal testing machine (INSTRON5500R) at cross head speed of 10mm/min and gauge length of 50mm.Twenty samples were used and average values were reported.

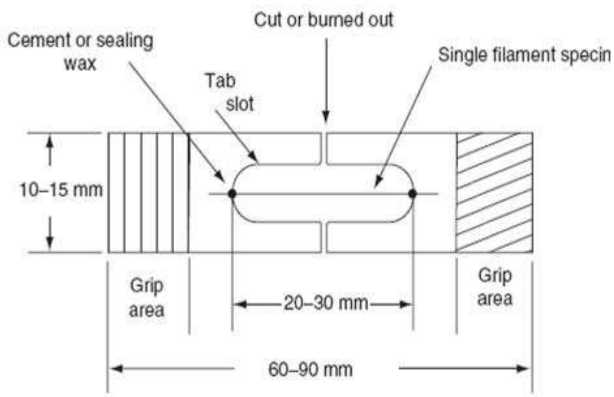

Fig.5 Fiber Testing-Mounting Tab for Tensile Testing Of Single Fiber

Mechanical properties of fibers

Tensile strength test for untreated fiber

The Tensile strength test report given by SITRA for untreated fiber.

Instrument Name : INSTRON 5500R
Type of Fiber : Untreated Fiber
Gauge Length : 50 mm
Cross Head Speed : 10.0 mm/min

Table.1 Test reports for untreated fiber (Mean Values)

Maximum Load (kgf)	Maximum Tensile Strain (%)	Energy at Maximum Load (J)
243.97	8.57	0.00641

Table.2 Test reports for treated fiber (Mean Values)

Maximum Load (kgf)	Maximum Tensile Strain (%)	Energy at Maximum Load (J)
238.10	8.57	0.00632

Table 3 Density of treated fiber and untreated fiber

Properties	Treated fiber	Untreated fiber
Density (g/cc)	1.6565	1.7688

Morphology test on fiber (sem)

A Scanning Electron Microscope (SEM) is the instrument used to perform scanning electron microscopy, also known as SEM analysis or SEM microscopy. The SEM uses a focused beam of high-energy electrons to generate a variety of signals at the surface of solid specimens. Scanning electron microscopy is performed at high magnifications, generates high-resolution images and precisely measures very small features and objects. SEM microscopy is used very effectively in microanalysis and failure analysis of solid materials. The signals generated during analysis produce a two-dimensional image and reveal information about the sample including external morphology (texture).The mean diameter of treated and untreated fibers were found out from SEM test.

Table.4 Diameter of Untreated Fiber and Treated Fiber

Fiber	Mean diameter (mm)	Cross sectional area (mm^2)
Untreated Fiber	0.2435	0.0466
Treated Fiber	0.1210	0.0115

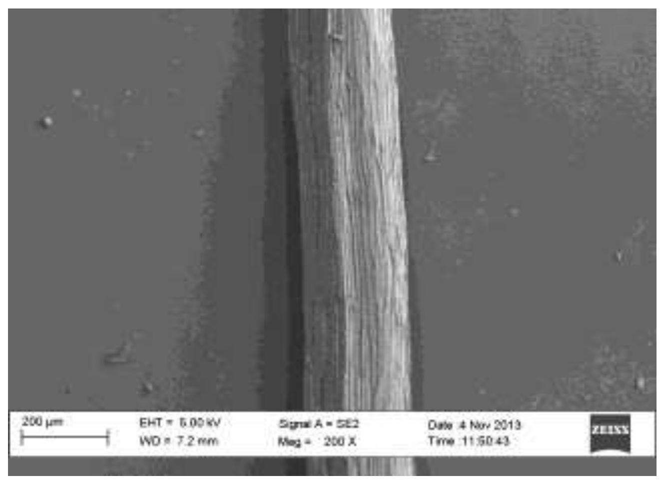

Fig.6 SEM images of untreated fiber at 200 µm magnification

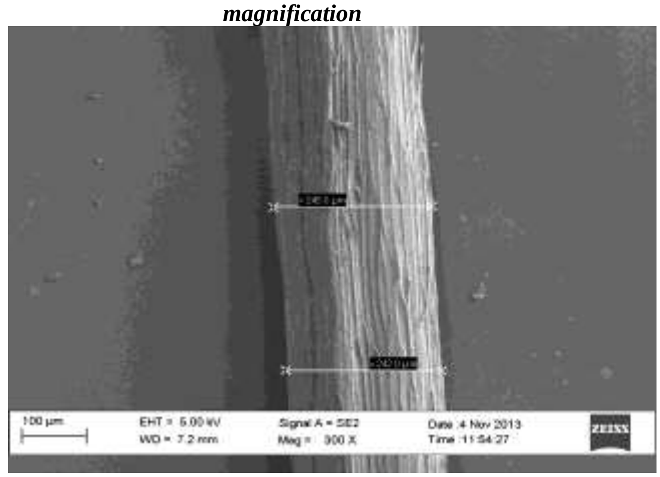

Fig.7 SEM images of untreated fiber at 100 µm magnification

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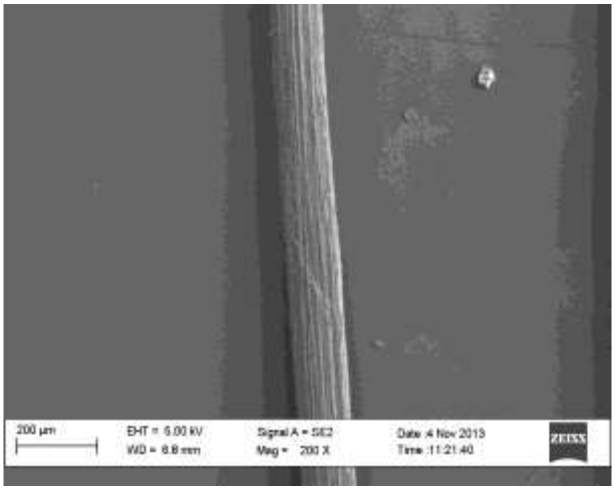

Fig.8 SEM images of treated fiber at 200 μm magnification

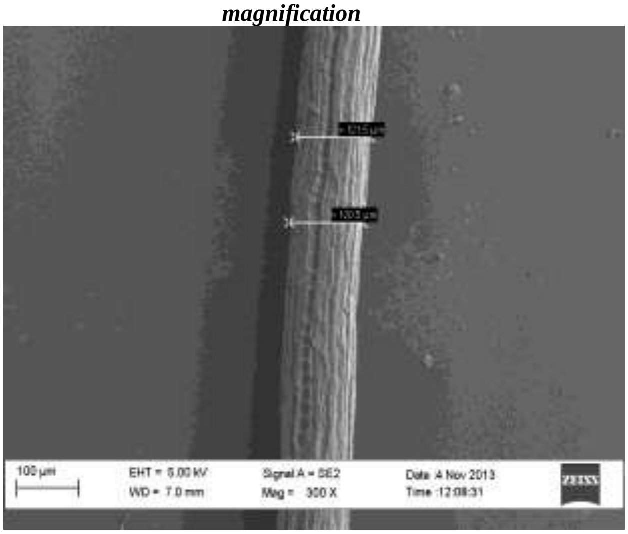

Fig.9 SEM images of treated fiber at 100 μm magnification

Chemical composition of cissus fiber

Cellulose content and Lignin content is a molecule comprised of carbon, hydrogen, and oxygen, and is found in the cellular structure of virtually all natural fibers.

The mechanical properties of natural fiber depend on Cellulose content and Lignin content. The Cellulose content in the untreated fiber is more than treated fiber.

Table.5 Chemical composition of Cissus fiber

Percentage	Treated fiber	Untreated fiber
Cellulose content	63.63 %	71.54 %
Lignin content	18.47 %	12.92 %

Fabrication

Selection of matrix material

Epoxy is a thermosetting polymer that cures (polymerizes and cross links) when mixed with a hardener. Epoxy resin of the grade Ly-556 with a density of 1.1–1.5 g/cm3 was used. The hardener used was HY-951. The matrix material was prepared with a mixture of epoxy and hardener HY-951 at a ratio of 10:1.

Fiber preparation

The Cissus were collected and immersed in water for 7 days until it become decay. Then the plant was washed in water to remove the fibers present inside. Then Cissus fibers were dried in shadow.

The composite material was made of polymer matrix reinforced with Cissus fibers. The fibers were chopped uniformly at a length of 10mm these fibers were mixed thoroughly with the ratio of based on the rule of mixture. ***They were arranged in discontinuous randomly oriented configuration.***

Weight percentage of fiber

The natural Cissus fibers was used in varying weight percentages of 15%, 20%, 25% and 30%, for the fabrication of composite plate.

Table.6 Weight percentage of fiber

Sl.No	Fiber percentage	Matrix percentage
1	15% Fiber	85% (Epoxy + Hardener)
2	20% Fiber	80% (Epoxy + Hardener)
3	25% Fiber	75% (Epoxy + Hardener)
4	30% Fiber	70% (Epoxy + Hardener)

Fabrication of composite plate

The composites were prepared by varying the fibers volume fraction from 15%, 20%, 25% and 30% by weight. ***In the first process of preparing the composite, a release agent was used to clean and dry the mould before the*** Epoxy resin ***can be laid up on the mould.***

The Epoxy resin ***was then mixed uniformly with the Cissus fibers by using a special rod in the mixed*** container***. The mixture was poured carefully into the moulds and flattened appropriately by using the roller. The wet composites were then lightly compressed to squeeze out the excessive resin. Finally after the composites were fully dried, they were separated off from the moulds and 24 hours curing time was used to obtain an optimum composite hardness and shrinkage.***

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Fig.10 Configuration of 15% Fiber by weight

Fig.11 Configuration of 20% Fiber by weight

Fig.12 Configuration of 25% Fiber by weight

Fig.13 Configuration of 30% Fiber by weight

Mechanical testing of composites

Three important mechanical properties, tensile strength, flexural strength and impact strength were tested. All test specimen dimensions were according to the respective ASTM standards. All tests were performed at room temperature. Five specimens of each type were tested and five replicate values were taken as an average of tested specimens. The Universal Testing Machine was used for finding tensile strength and flexural strength.

Tensile strength test

Tensile tests were conducted using universal testing machine with across head speed of 5mm/min. In each case, five samples were tested and average value tabulated. Tensile test samples were cut as per ASTM D638 test procedure. Tests were carried out at room temperature and each test was performed until tensile failure occurred.

Table.7 ASTM D638 Dimension

Description	**Dimensions (mm)**
Thickness (T)	3
Width of narrow section (W)	13
Length of narrow section (L)	57
Width Overall (WO)	19
Length Overall (LO)	168
Gage length (G)	50
Distance between grips (D)	115

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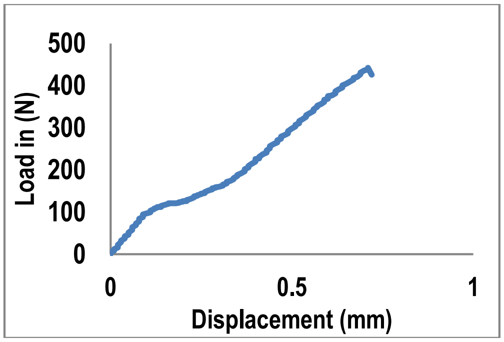

Fig.14 Load Vs Displacement Curve For 15% Fiber

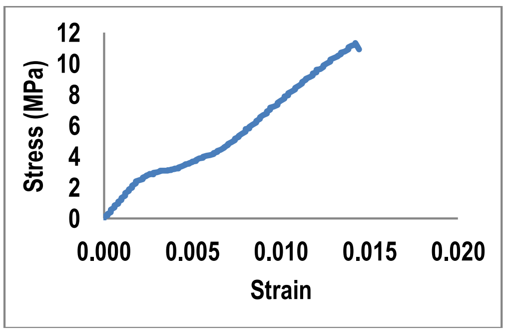

Fig.15 Stress Vs Strain Curve For 15% Fiber

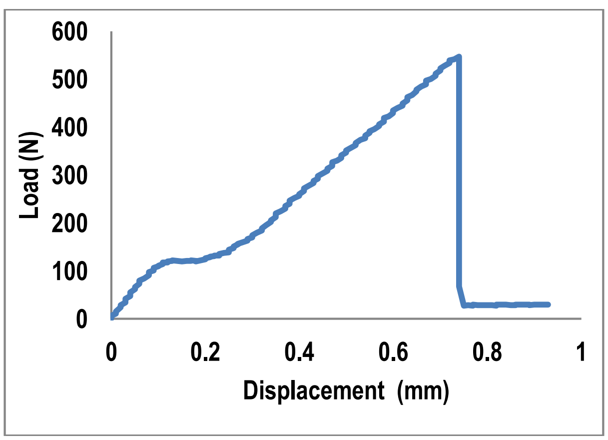

Fig.16 Load Vs Displacement Curve For 20% Fiber

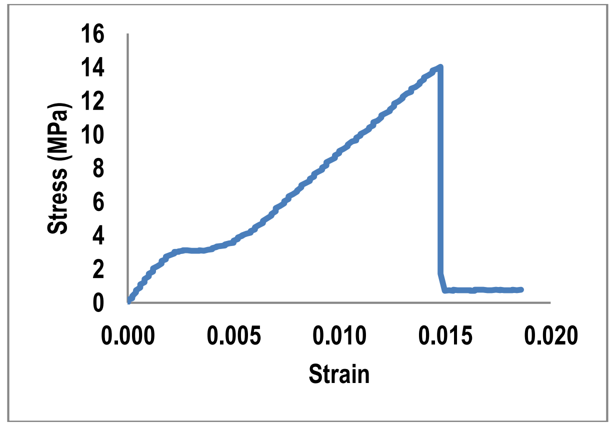

Fig.17 Stress Vs Strain Curve For 20% Fiber

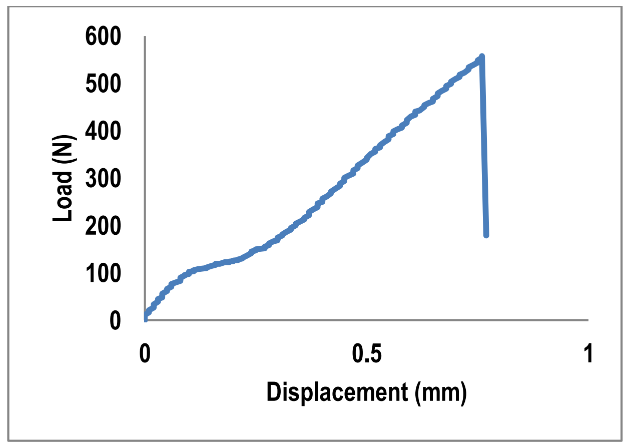

Fig.18 Load Vs Displacement Curve For 25% Fiber

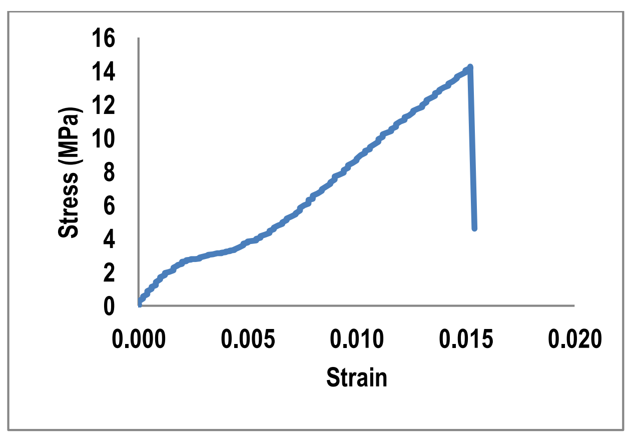

Fig.19 Stress Vs Strain Curve For 25% Fiber

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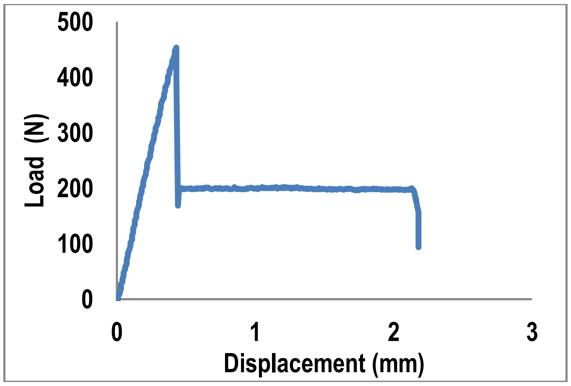

Fig.20 Load Vs Displacement Curve For 30% Fiber

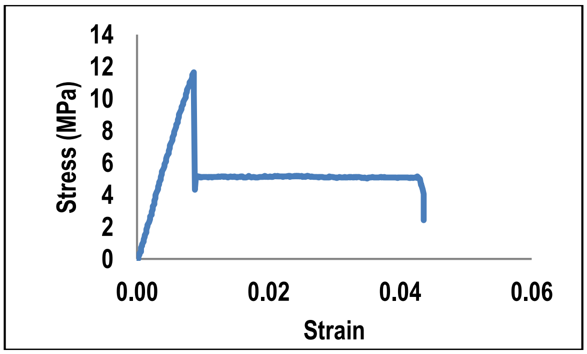

Fig.21 Stress Vs Strain Curve For 30% Fiber

Table.8 tensile test results for different fiber configurations

Fiber type	Cross sectional area (mm^2)	Peak load (N)	Break load (N)	Elongation (%)	Ultimate tensile strength (N/mm^2)
15%	39	442.196	426	1.26	11.34
20%	39	546.809	426	1.8	14.018
25%	39	557.286	179	1.56	14.293
30 %	39	453.624	94	4.38	11.635

Flexural strength test

Flexural analysis was carried out at room temperature through three-point bend testing as specified in ASTM D 790, using universal testing machine. The speed of the crosshead was 2 mm/min. five composites specimens were tested for each sample and each test was performed until failure occurred.

Fig.22 Flexural Strength Test specimen

ASTM D 790

Flexural strength was calculated from the Equation.

$$\sigma_f = (3FL) / (2bd^2)$$

Where,

- F = Load at a given point on the load deflection curve in Newton (Peak load)
- Support span (L) = 130mm
- Width of the samples (b) = 13mm
- Thickness of the samples (d) = 3mm

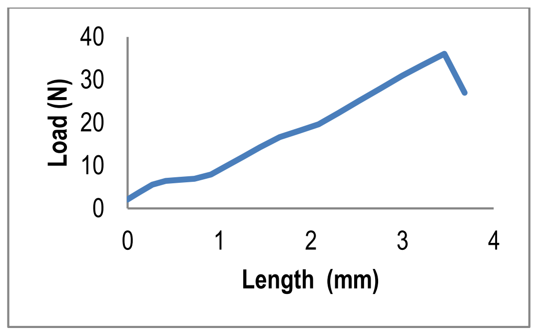

Fig.23 Load Vs length curve for 15% fiber

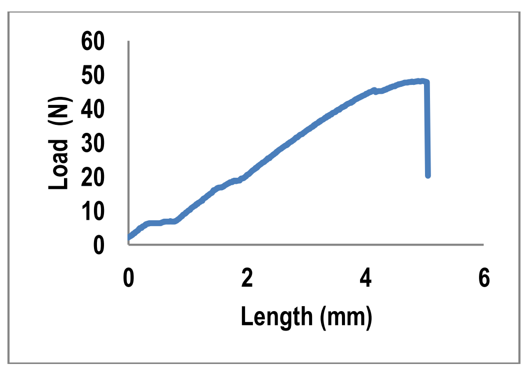

Fig.24 Load Vs length curve for 20% fiber

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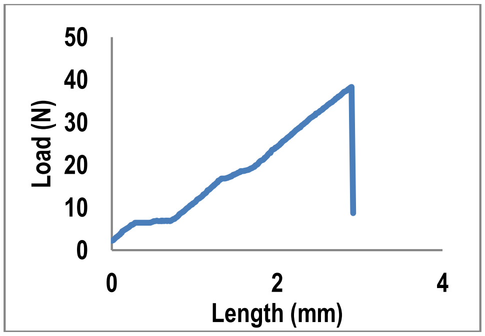

Fig.25 Load Vs length curve for 25% fiber

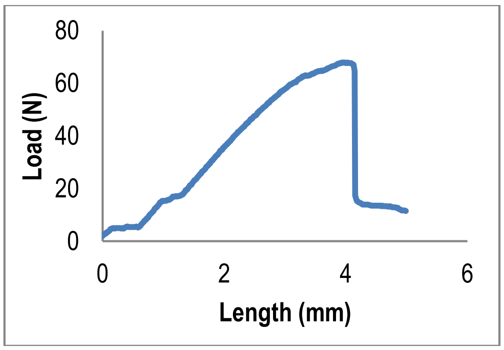

Fig.26 Load Vs length curve for 30% fiber

Table.9 Flexural test results for different fiber configurations

Fiber type	**Cross sectional area (mm²)**	**Peak load (N)**	**Break load (N)**	**Flexural strength (N/mm²)**
15%	39	36.042	27	29.11
20%	39	48.117	20	38.91
25%	39	38.259	9	30.90
30%	39	67.866	9	54.82

IZOD impact test

Izod impact test was performed on Cissus fibers reinforced epoxy composite specimens as per ASTM-D256. Five samples were tested at ambient conditions and the average of Impact Strength was calculated.

Fig.27 Izod impact test specimen ASTM D 256

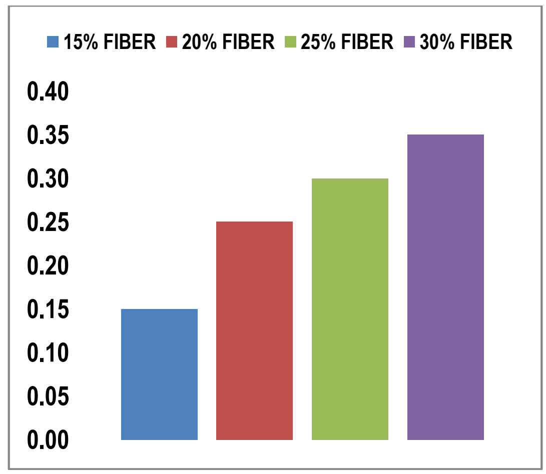

Fig.28 Impact strength for composites

Results and discussion

Chemical composition of Cissus fiber

Table.10 Chemical composition of Cissus fiber

Percentage	**Treated fiber**	**Untreated fiber**
Cellulose content	63.63 %	71.54 %
Lignin content	18.47 %	12.92 %

Mechanical properties of Cissus fiber

Table.11 Mechanical properties of Cissus fiber

Properties	**Treated fiber**	**Untreated fiber**
Mean Breaking Strength (g)	238.100	243.97
Mean Elongation (%)	8.75	8.75
Density (g/cc)	1.6565	1.7688
Mean Diameter (mm)	0.1210	0.2435

Twenty samples were taken randomly for the testing and the results were tabulated. The load Vs strain curves were plotted. According to the test report Mean Breaking Strength of treated fiber was less than

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the untreated fiber and there is no change in mean elongation.

The Density of the treated fiber was less than that of untreated fiber .The Cellulose content in the untreated fiber was more than treated fiber. The Lignin content in the treated fiber was more than untreated fiber.

As per the test report there was the minimum difference between the properties of treated and untreated fiber, so the untreated fiber was used for the fabrication composite plate as per ASTM standards.

Mechanical properties of composites

Development of Bio-fiber composites made from natural fibers with increased strength, stiffness and durability requires necessary understanding of mechanical behaviors. The mechanical properties of Bio-fiber composites depend on the fiber strength, fiber modulus, fiber length, fiber orientation, and fiber–matrix interfacial bond strength. A strong fiber–matrix interface bond plays a vital role in establishing high mechanical properties of composites. A good interfacial bond is required for effective stress transfer from the matrix to the fiber by which maximum utilization of the fiber strength in the composite can be obtained. This leads to developing an alternative material to wood. The analysis of mechanical properties of composites is important for understanding the behavior of composite materials.

It is a well-known fact that the mechanical properties of fiber-reinforced composites depend on the nature of matrix material, the distribution and orientation of the reinforcing fibers and the nature of the fiber-matrix interfaces. A change in the physical and chemical structure of the fiber for a given matrix will result in drastic changes in the overall mechanical properties of composites.

Tensile strength of composites

Tensile tests were conducted using universal testing machine for the Cissus fiber reinforced polymer matrix composite by varying fiber percentages of 15%, 20%, 25% and 30%. Stress strain curve for the composites is shown in the Fig.29 and also by comparing the Ultimate Tensile Strength of Composites, 25% fiber composite is maximum is show in the Fig.30 which can be used for product application.

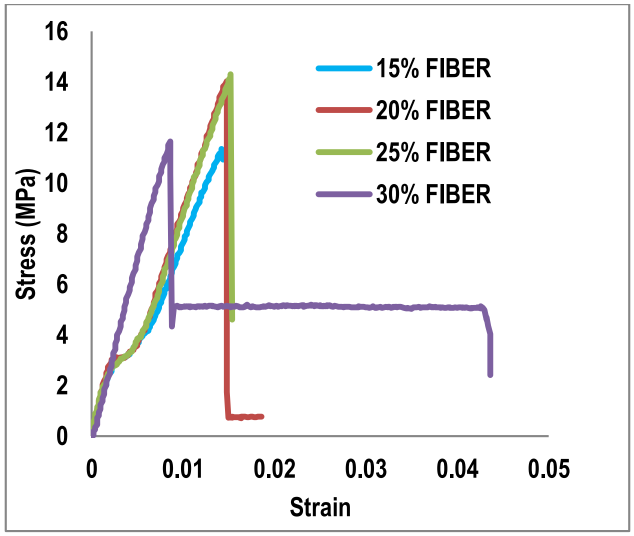

Fig. 29 Stress strain curve for composites

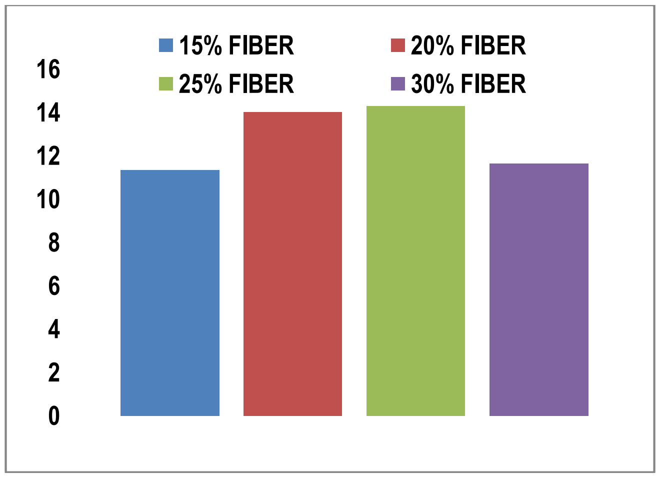

Fig.30 Ultimate Tensile Strength of Composites

Flexural strength of composites

Flexural strength of the Bio-fiber composites as a function of fiber loading (weight percentage). The stresses induced due to the flexural load are a combination of compressive and tensile stresses.

The Flexural strength of 30% fiber composite is maximum is shown in the Fig.31.

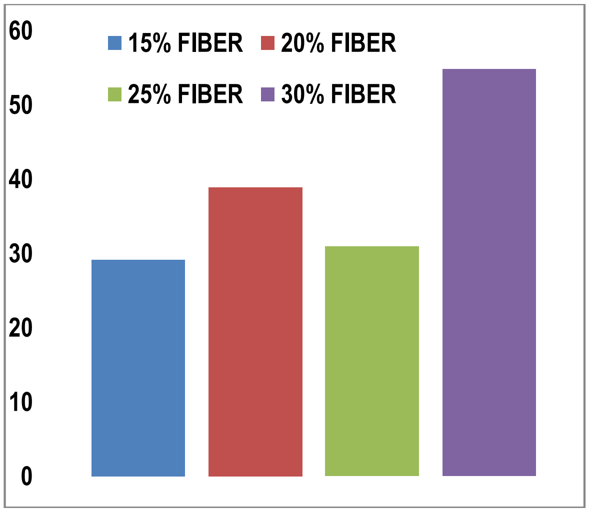

Fig.31 Flexural Strength of Composites

Impact strength of composites

Impact strength is the ability of a material to absorb energy under a shock load or the ability to resist the fracture under load applied at high speed. Impact behavior is one of the most widely specified mechanical properties of the Engineering materials. The variations of impact strength with respect to fiber loading (weight fraction) is as shown in Fig.32 for Izod method of impact test. The maximum impact energy absorbed was 30% fiber composite.

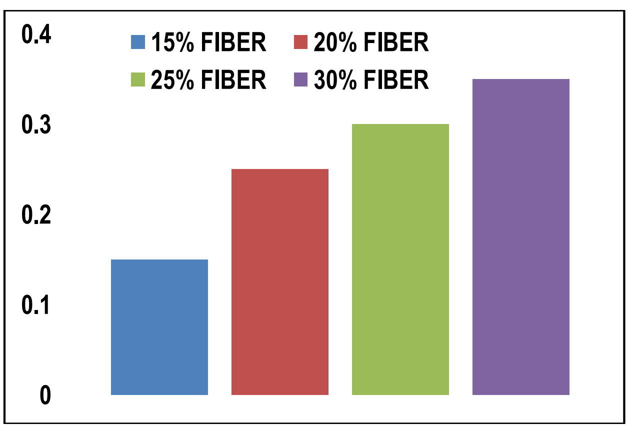

Fig.32 Impact Strength of Composites

Conclusions

The results in the investigation indicate that, it is possible to enhance the properties of Cissus fiber reinforced composites through varying the fiber and matrix percentage. The Tensile Strength, Flexural Strength and Impact strength of natural fiber composite improved by varying the fiber percentage. It is also noticed that the Tensile Strength of the natural composites increases with increase in volume fraction of fiber in the natural composites. It is found that the natural fiber composites show maximum mechanical properties between 25% - 30% of the fiber reinforcements. The enormous availability (Cissus fibers) cheaper and good strength of the composites leads way for the fabrication of lightweight materials that can be used in automobile body building, office furniture, packaging industry, partition panels, and others compared to wood based plywood or particle boards.

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