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A STUDY OF MECHANICAL PROPERTIES OF BANANA-COIR HYBRID COMPOSITE USING EXPERIMENTAL AND FEM TECHNIQUES

T. Hariprasad[1,] G. Dharmalingam[2] and P. Praveen Raj[3]

[1]Department of Mechanical Engineering, Sree Vidyanikethan Engineering College
Tirupati, Andhra Pradesh - 517102
Email: thprasads@gmail.com
[2]Department of ME SRM University,Chennai
[3] Department of ME, Thanthai Periyar Government Institute of Technology
Bagayam, Vellore, Tamil Nadu, India-632002

ABSTRACT

The use of natural fibers as reinforcement in polymers has gained importance in the recent years due to the eco-friendly nature. In this connection, an investigation has been carried out to make use of banana-coir, a natural fiber abundantly available in India. Natural fibers are not only strong and lightweight but also relatively very cheap. Composite plates were prepared with resin 392gm, coir 54gm, and banana 69gm. The purpose of this work is to establish the tensile, flexural and impact properties of banana-coir reinforced composite material with a thermo set for treated and untreated fibers. The resin used was epoxy (EP306). The tensile and impact tests showed that treated banana-coir epoxy hybrid composite have high tensile strength and impact strength than untreated composite. At the same time the flexural strength is higher in untreated fiber composite than treated fiber composite. The FEA software Ansys has been successfully executed to evaluate the properties. The stresses at the banana-coir matrix interfaces induced due to the different loading condition were applied to predict the tensile, impact and flexural properties from the FEA models. The value of model was compared with the experimental results and was found to be close. This analysis is useful to realize the advantage of hybrid fiber reinforced composites in structural applications and to identify the varying loading conditions with the reasons where the stresses are critical to damage the interface.

Keywords: Banana-fiber, coir-fiber, tensile, flexural, impact, FEA Model.

INTRODUCTION

Usually the fiber reinforcement is done to obtain high strength and high modulus. Hence it is necessary for the fiber to possess higher modulus than the matrix material. So the load is transferred to the fiber from the matrix more effectively. Fiber reinforced composites are popularly being used in many industrial applications because of their high specific strength & stiffness. Nowadays natural fibers are very fast replacing the traditional manmade fibers as Reinforcements and have several advantages over manmade fibers (Wallenberg and Weston, 2004). A number of investigations have been conducted on several types of natural fibers such as kenaf, hemp, flax, bamboo, and jute to study the effect of these fibers on the mechanical properties of composite materials (Umar et al., 2012; Gowda et al., 1999; Ibrahim et al., 2012; Hardinnawirda and SitiRabiatull Aisha, 2012; Bhaskarand Sharief, 2012). Among this banana and coir is gaining more importance. The main chemical constituents of banana fibers are hemi cellulose and lignin. Hemi cellulose and cellulose are present in the form of holocellulose in banana fibers, which contributes more than 70 % of the total chemical constituent present in banana fiber. Another important chemical constituent present in banana fiber is lignin. Lignin acts as a binder for the cellulose fibers and also behaves as an energy storage system. Coir is an abundant, versatile, renewable, cheap, and biodegradable lignocelluloses fiber used for making a wide variety of products .Coir has also been tested as filler or reinforcement in different composite materials. Coconut coir is the most interesting products as it has the lowest thermal conductivity and bulk density (Prasanna and Subbaiah, 2011). Multi component composite materials comprising of two or more families of fibers have been attracting the attention of researchers these years. This is because, the usage of one type of fiber alone has proved to be inadequate in satisfactorily tackling all the technical and economic problems confronted by them while making fiber reinforced composites. These types of composites introduce additional degrees of compositional freedom for providing yet another dimension to the potential versatility of fiber reinforced composite materials. Therefore the ultimate strength of the system is the stress level at which the elongation of the system has reached the ultimate elongation of the fiber family. Attempts have been made by other researchers for the preparation of hybrid composites of natural fiber and synthetic fiber to improve the mechanical properties of the composites.

An investigation was carried out to make use of coir, Banana fiber (BaF)-filled composites based on high density polyethylene (HDPE)/Nylon-6 blends. It was studied for properties (Khanam et al., 2010). The hybrid composites of coir/silk unsaturated polyester-based hybrid composites were studied for the effect of fiber length on mechanical behavior of coir fiber reinforced epoxy composites (Liu et al., 2009; Bachtiar et al., 2010).Variations in tensile and impact properties of banana fiber reinforced polyester Composites caused by the addition of glass fiber have been analyzed **(**Adebisi et al., 2011; Maleque et al., 2007; Jeffrey et al., 2011**)**. Coir yarn-reinforced polypropylene (PP)-based unidirectional composites were prepared by compression molding. Coir yarn content in the composite was optimized and 20% yarn content showed higher mechanical properties. Jute yarns (20%—100%) were incorporated into the coir-based composites (Pothan et al., 2012).

Banana FRP composites having fiber length of 30 mm and a fiber content of 40 vol% showed the maximum tensile strength. The highest tensile strength values was obtained for an intimate mixture of banana and glass fibers of composite samples prepared from interleaving layers of banana fiber and glass fiber (Haydaruzzaman et al., 2010). A light weight composite material was prepared using banana empty fruit bunch fiber (banana- EFB) as reinforcement in polyester resin matrix, and its mechanical properties studied (Srinivasababu et al., 2009). There has been a lot of research work on different combination of natural fiber. But none has reported on the combination of banana-coir epoxy composite, which individually has gained lot of attraction. Keeping this in view the present work has been undertaken to develop a polymer matrix composite (epoxy resin) using banana-coir fiber as reinforcement and to study its mechanical properties. The composites were prepared with 30% volume fraction of fibers. (Kulkarni et al., 1983).

MATERIALS AND METHODS

Banana Fibers

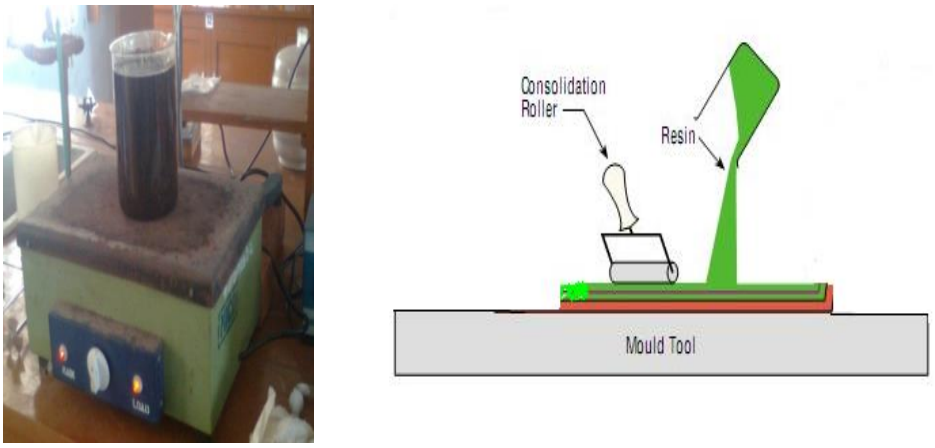
The pseudo-stem banana woven fabric reinforced epoxy composite was prepared by the hand lay-up method. The fibers were extracted from banana stems by hand and dried in sunlight for 12 hours until all the moisture was removed from the fiber. The Woven Banana Fabric used for the study is shown in Figure 1.

a) Banana woven fiber b) Banana fiber immersed in 6%NaoH solution

Figure 1. Banana woven fiber.

Coir Fiber

Coir is a coarse fiber extracted from the fibrous outer shell of a coconut. The individual fiber cells are narrow and hollow, with thick walls made of cellulose. It has been traditionally used in tropical regions of Asia, Africa and South America in a variety of simple item such as rugs, couch and mattress stuffing as well as gardening pots. The coir fibers used for study are shown in Figure 2.



(a) Coir fiber treated in heater (b) Hand layup method

Figure 2. Experimental set up.

Epoxy Resin

Epoxy or polyepoxide is a thermosetting polymer formed from reaction of an epoxide "resin" with polyamine "hardener". Epoxy has a wide range of applications, including fiber-reinforced plastic materials and general purpose adhesives. The resin consists of monomers or short chain polymers with an epoxide group at either end. Most common epoxy resins are produced from a reaction between epichlorohydrin and bisphenol-A, though the latter may be replaced by similar chemicals. The hardener consists of polyamine monomers, for example Triethylenetetramine (TETA). When these compounds are mixed together, the amine groups react with the epoxide groups to form a covalent bond. Each NH group can react with an epoxide group, so that the resulting polymer is heavily cross linked, and is thus rigid and strong. The process of polymerization is called "curing", and can be controlled through temperature and choice of resin and hardener compounds; the process can take minutes to hours. Some formulations benefit from heating during the cure period, whereas others simply require time, and ambient temperatures. Industrial Specifications and Notifications of Materials (M/s Roto Polymers., Chennai.) are shown in Table 1.

Table 1. Properties of materials.

	Company code	Color	Specific gravity	Viscosity	Epoxy Value
Diglycidyl Ether Of bisphenol-A	EP 306	Transparent, sticky liquid	1.14 - 1.19@ 25 ºC	9500 – 12500cps @ 25 ºC	5 –5.5
Di Ethyl Tetra Amine	EH 758	Transparent, liquid	0.95 – 1.05@ 25 ºC	20 -50 cps @ 25ºC	--

Chemical Treatment

Alkali treatment of natural fibers, also called mercerization, is the common method to produce high-quality fibers. Mercerization leads to fibrillation which causes the breakdown of the composite fiber bundle into smaller fibers. Mercerization reduces fiber diameter, thereby increases the aspect ratio which leads to the development of a rough surface topography that results in better fiber-matrix interface adhesion and an increase in mechanical properties. Moreover, mercerization increases the number of possible reactive sites and allows better fiber wetting. Mercerization has an effect on the chemical composition of the flax fibers, degree of polymerization. The degree of polymerization, or DP, is the number of repeat units in an average polymer chain at time *t* in a polymerization reaction. The length is in monomer units. The degree of polymerization is a measure of molecular weight and molecular orientation of the cellulose crystallites due to cementing substances like lignin and hemicelluloses, which were removed during the mercerization process. As a result, mercerization had a long-lasting effect on the mechanical properties of flax fibers, mainly on fiber strength and stiffness.

Properties of HARDENER

In the present work hardener (EH758) has been used. The properties of the hardner are shown in Table1.

Banana Fiber Treatment

Banana fibers were immersed in 6%NaoH solution for 2 hours at room temperature as shown in Figure 1(b). After the alkali treatment, the fibers were thoroughly washed by immersion in water tanks, followed by running water. The material was then filtered and dried at 80°C for 24 hours. The Banana fiber immersed in 6%NaoH solution. Banana fiber obtained after the final washing are shown in Figure 1(a).

Coconut Fiber Treatment

All fibers were pre-washed with large amount of distilled water and dried at 50ºC until constant weight, prior to treatment. The mercerization process consisted of immersing coir fibers (200 g) in a 10% (w/v) sodium hydroxide aqueous solution (2 L) for 3 hours at 70ºC with occasional shaking followed by washing with distilled water several times to remove any absorbed alkali. Then it was dried at sun light. The Coir fiber was treated in heater as shown in Figure 2(a).

Fabrication of Composites

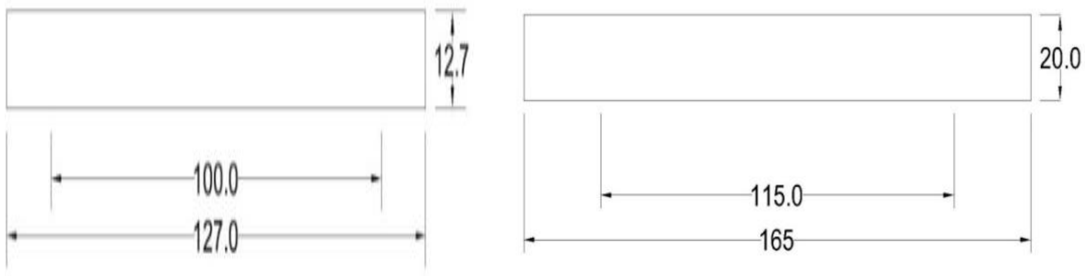
There are a wide variety of FRP processes. The choice of process is dependent on many factors, such as type of reinforcement and matrix materials, size, shape, quantity and cost. There are many specialized processes available, but only the most commonly used commercial processes hand layup has been used in the preparation of composite. The experimental setups are shown in Figure 2(b). A weight press was needed for the Hand lay-up method. The base plate was cleared of rust by scrubbing with an abrasive paper. Then the surface was allowed to dry after cleaning it with a thinner solution. After drying, the surface was coated with silicon gel. The surface was given a few minutes to get it set for the mold lay-up. The company codes for the epoxy semi polymerized resin and the Hardener/Curing agent were EP-306 and EH-758 respectively. They were mixed in the proportion of 10:1 (EP-306 and EP-758). The curing time or the pot life, which is how it is usually notified in the laboratory charts, was 20 minutes once mixed. Care was taken so that the resin does not cure in the curing pot itself. A constant watch over the blend in the pot was made with the aid of a stop watch.

A plate of dimensions 300×300×8 mm was fabricated by this process. First the epoxy-banana-coir composite was fabricated. The matrix material was poured into the mould slowly in order to avoid air trapping. The mixture was left for 2 minutes so that it becomes a little tacky. After that, the banana fiber ply was laid unidirectional on the matrix layer, which was covered by another layer of matrix by pouring the mixture slowly onto the surface of the fiber ply. A small pressure was applied using a roller to distribute the matrix material and to avoid void formation. Then chopped coir fiber (30-50 mm) was laid on the matrix layer. Likewise banana-coir-banana-coir-banana layer plate was fabricated. The set up was cured under the loaded condition of 25 Kg for about 24 hours.

MATERIAL TESTING

Tensile Test

A tensile test, also known as tension test, is probably the most fundamental type of mechanical test performed on material. Tensile tests are simple, relatively inexpensive, and fully standardized. As the material is being pulled, we can find its strength along with how much it will elongate. The point of failure is of much interest and is typically called its "Ultimate Strength" or UTS on the chart. For some materials (e.g., metals and plastics), the departure from the linear elastic region cannot be easily identified. Therefore, an offset method to determine the yield strength of the material tested is allowed. These methods are discussed in ASTM E8 (metals) and D638 (plastics). An offset is specified as a % of strain (for metals, usually 0.2% from E8 and sometimes for plastics a value of 2% is used). The stress (R) that is determined from the intersection point when the line of the linear elastic region (with slope equal to Modulus of Elasticity) is drawn from the offset becomes the Yield strength by the offset method. The tensile curves of some materials do not have a very well-defined linear region. In these cases, ASTM Standard D638 provides for alternative methods for determining the modulus of a material, as well as Young's Modulus. These alternate modules are the secant modulus and tangent modulus. One of the properties that can be determined about a material is its ultimate tensile strength (UTS). It is the maximum load the specimen sustains during the test. The UTS may or may not equate to the strength at break. This all depends on what type of material is being tested. Brittle, ductile, or a substance that even exhibits both properties. Sometimes a material may be ductile when tested in a lab, but, when placed in service and exposed to extreme cold temperatures; it may make a transition to brittle behavior. The tensile test was conducted in UTM Lloyd LR100K Testing Machine. The 10kN two columns LR 100K incorporates the latest advanced technology and quality engineering. The material was loaded in the machine. Then the load is applied at increasing rate until it reaches the maximum tensile load. When the load reaches the maximum tensile load it breaks.The load at this point is used to calculate the maximum tensile strength of the composite material. According to the ASTM D 638 standards five test specimens were made as shown in Figure 3(a).



(a) ASTM D638 standard specimen 1 (treated)

(b) ASTM D790 standard specimen 2 (untreated)

Figure 3. Specimen used.

Flexural Test

Flexural strength, also known as modulus of rupture, bend strength, or fracture strength, a mechanical parameter for brittle material, is defined as a material's ability to resist deformation under load. The transverse bending test is most frequently employed, in which a rod specimen having either a circular or rectangular cross-section is bent until fracture using a three point flexural test technique. The flexural strength represents the highest stress experienced within the material at its moment of rupture. It is measured in terms of stress. The flexural strength would be the same as the direct tensile strength (see Ultimate tensile strength) if the material was homogeneous. In fact, most materials have small or large defects in them which act to concentrate the stresses locally, effectively causing a localized weakness. When a material is bent only the extreme fibers are at the largest stress so, if those fibers are free from defects, the flexural strength will be controlled by the strength of those intact 'fibers'. However, if the same material was subjected to direct tension then all the 'fibers' in the material are at the same stress and failure will initiate when the weakest fiber reaches its limiting tensile stress. Therefore it is common for flexural strengths to be higher than direct tensile strengths for the same material. Conversely, a homogeneous material with defects only on it surfaces (e.g. due to scratches) might have a higher direct tensile strength than flexural strength.

In mechanics, the flexural modulus is the ratio of stress to strain in flexural deformation, or the tendency for a material to bend. It is determined from the slope of a stress-strain curve produced by a flexural test (such as the ASTM D 790), and uses units of force per area. It is an intensive property. Flexural modulus are given by the Eq. (1).

$$E(\text{bend}) = \frac{L^3F}{4wh^3d} \tag{1}$$

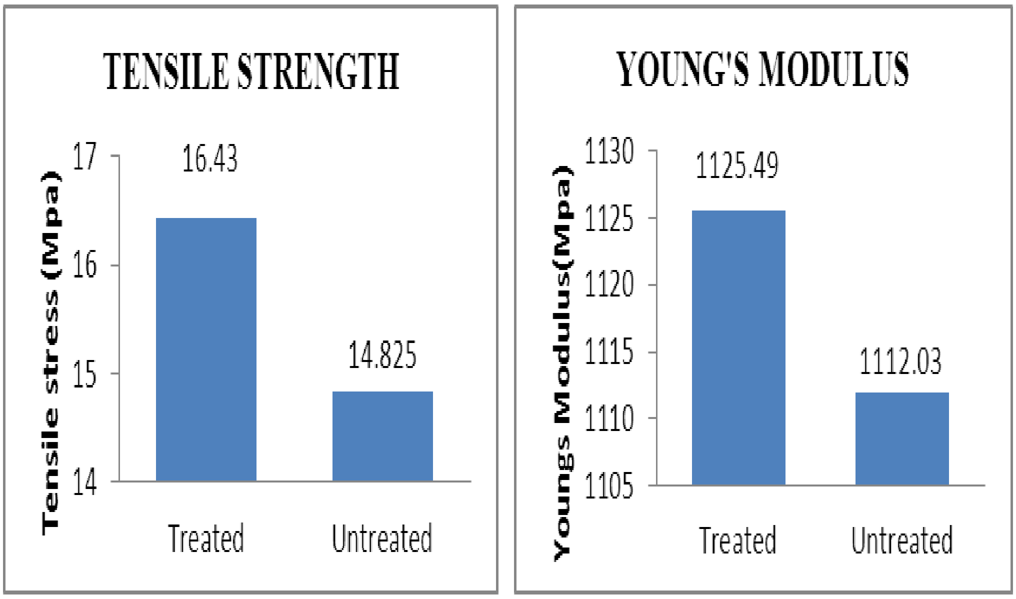
For a 3-point deflection test of a beam, where w and h are the width and height of the beam, L is the distance between the two outer supports and d is the deflection due to load F applied at the middle of the beam. According to the ASTM D 790 standards five test specimens were made as shown in Figure 3(b).

Impact Test

A test designed to give information on how a specimen of a known material will respond to a suddenly applied stress, e.g. shock. The test ascertains whether the material is tough or brittle. A notched test piece is normally employed and the two methods in general use are either the Izod or Charpy test. The result is usually reported as the energy in ft.lbs. or KJ required to fracture the test piece. Molded-in stresses, polymer orientation, weak spots (e.g. weld lines or gate areas), and part geometry will affect impact performance. Impact properties also change when additives, e.g. colouring agents, are added to plastics. The Charpy impact test, also known as the Charpy v-notch test, is a standardized high strain-rate test which determines the amount of energy absorbed by a material during fracture. This absorbed energy is a measure of a given material's toughness and acts as a tool to study temperature-dependent brittle-ductile transition. It is widely applied in industry, since it is easy to prepare and conduct and results can be obtained quickly and cheaply. But a major disadvantage is that all results are only comparative. The test specimen size was prepared as per the standard IS 867.

FINITE ELEMENT ANALYSIS

To study the elastic behavior of the plastics and predict some of the resulting important mechanical properties, a finite-element analysis (FEA) was carried out. Although most of these properties can be obtained through experimentation, the elastic-plastic transition behavior in plastics was not easy to study under experimental conditions, hence a need for theoretical modeling. In addition to validating experimental findings, the theoretical prediction of these properties can shorten the cycle time for determining optimum filler quantities that will maximize the resulting composite properties. A finite element model of the experimentally molded specimens was created using ANSYS 11.0 software. Preliminary results from tensile, flexural, impact tests indicated that the composite material was very brittle but exhibited linear deformation in its elastic state. Thus the model was developed using a SOLID 20 node186 element, using an elastic material, with mechanical characteristics. Because thermosetting plastic was considered with granular additives, behavior was fairly uncertain. SOLID 20 node186 elements permit irregular shapes, and its 20 nodes allow for any spatial orientation. Models of treated and untreated were tested with simulated different loading conditions (Otieno et al., 2006). The FEA model of the untreated and treated test specimens are shown in Figures 6- 8.



a) Tensile Strengths comparison b) Young's modulus comparison

Figure 4. Comparison of Tensile Strengths and young's modulus

RESULTS AND DISCUSSION

Tensile Test Results

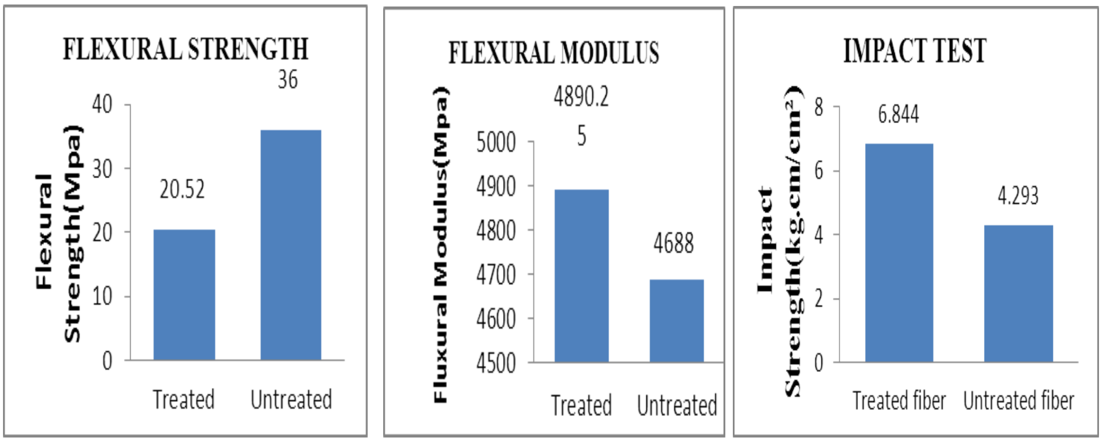
The results obtained from the tension test for treated and untreated banana-coir composite are tabulated as shown in the Table 2. The tensile properties of Treated and Untreated Banana-coir Epoxy composite were measured and tabulated as Shown in Table 2. Tensile strength of these composites was compared using the bar chart as shown in the Figure 4. It was found that the treated composite has more Tensile strength than the untreated composite. The tensile strengths of these materials are compared as shown in Table 2. As such the young's modules were also compared using the bar chart as shown in the Figure 4. It was found that Treated composite has more Young's modulus than the Untreated composite.

Table 2. Measured properties of banana- coir epoxy composite (treated @Untreated).

		Trail-1	Trail-2	Trail-3		Average
Treated Specimen	Width (mm)	21.1	19.3	20.1		-
	Thickness (mm)	7.1	7.1	6.8		-
	Max load (N)	2760	2520	1710		2330
	Tensile strength (MPa)	18.4	18.4	12.5		16.43
	Young's modulus (MPa)	1257.9	1450.1	668.5		1125.4
	Extension at break (mm)	1.68	1.46	2.15		1.76
Untreated Specimen	Width (mm)	20.1	18.8	19.0		19.0
	Thickness (mm)	8.7	8.7	8.5		8.9
	Max load (kgf)	257	265	253		235
	Tensile strength (MPa)	14.42	15.89	15.36		13.63
	Young's modulus (MPa)	1176.09	1427.61	905.84		938.59
	Extension at break (mm)	1.41	1.28	1.95		1.67
	Width (mm)	13.00	13.80	13.70	13.75	-
	Thickness (mm)	8.60	7.12	7.02	7.03	-
	Max load (kgf)	198	177	196	145	-
	Flexural strength (MPa)	30.74	37.94	43.47	31.86	36.00
	Flexural modulus (MPa)	3120	5486	5192	4954	4688
Treated Specimen	Width (mm)	12.65	12.12	12.80	12.70	-
	Thickness (mm)	8.49	8.45	8.62	8.62	-
	Max load (N)	123	109	105	166	-
	Flexural strength (MPa)	20.16	18.95	16.59	26.38	20.52
	Flexural modulus (MPa)	5148	3625	4609	6179	4890.25

Flexural Test

The results obtained from the flexural test for treated and untreated banana-coir composite was tabulated as shown in the Table 2. The flexural properties of untreated Banana-coir Epoxy hybrid composite and treated Banana-coir Epoxy hybrid composite were measured and tabulated as shown in Table 2 and also the flexural strength of these composites was compared using the bar chart as shown in the Figure 5(a). It was found that the Untreated Banana-coir Epoxy composite has more Flexural strength than the Treated one. The Flexural strengths of these materials were compared. As such the young's modules were compared using the bar chart as shown in the Figure 5(b). It was found that Treated Banana-coir-Epoxy composite has more Young's modulus than the Untreated Banana-coir- composite.



a) Flexural Strength b) Flexural modulus c) Impact Strength

Figure 5. Comparison of flexural strength, flexural modulus and impact strength.

Impact Test

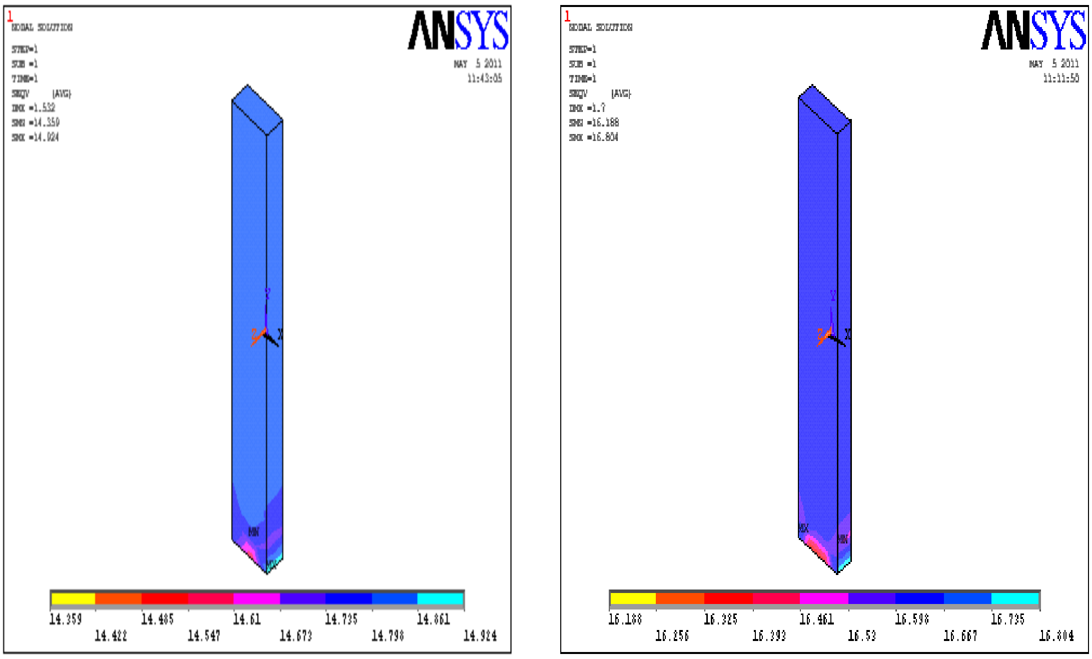
The results obtained from the Impact test for treated and untreated banana-coir composite was tabulated as shown in the Table 3. The Impact strengths of these materials were compared using the bar chart as shown in the Figure 5(c). It is found that Treated Banana-coir Epoxy composite has more Impact strengths than the untreated composite.

Table 3. Measured properties of banana-coir epoxy composite (treated and untreated))

Untreated Specimen	Width (cm)	Thickness (cm)	Impact energy (dj)	Impact strength (kg.cm/cm^2)	Average (N-m)
Trail-1	1.31	0.66	4	4.718	0.36
Trail-2	1.39	0.69	3	3.191	
Trail-3	1.30	0.69	4	4.548	
Trail-4	1.31	0.66	4	4.718	
Treated Specimen					
Trail-1	1.08	0.85	5	5.556	0.76
Trail-2	1.30	0.85	10	9.231	
Trail-3	1.30	0.86	6	4.561	
Trail-4	1.21	0.84	11	8.028	

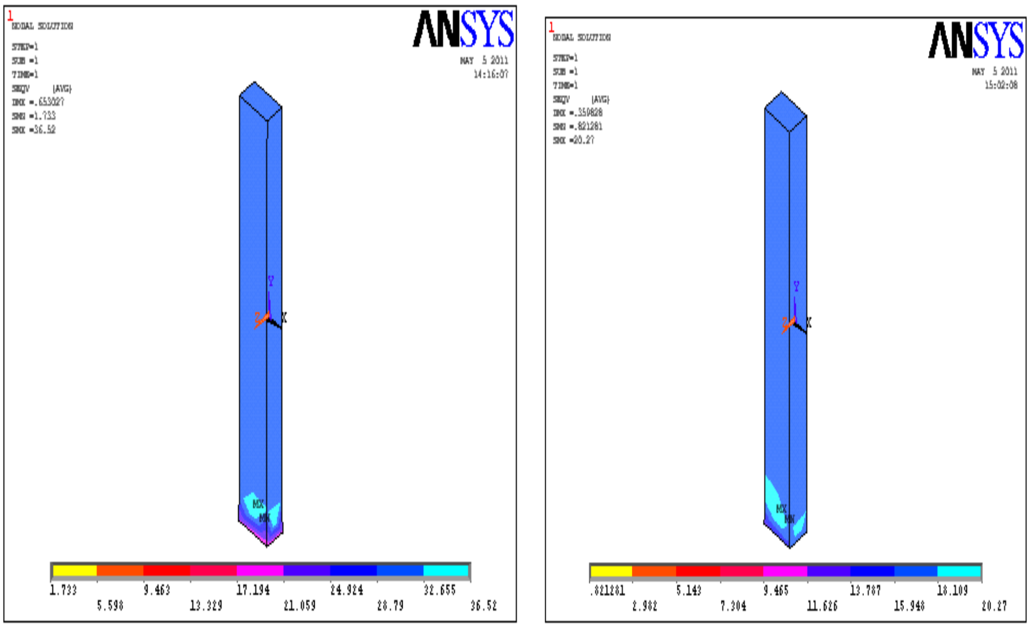
Simulation Results

The simulated stress distribution for mechanical properties of banana - coir hybrid treated and untreated at different loading conditions was performed. The maximum stresses are averages of the values of the center elements used in the FEA. The plots of the nodal solutions showing simulated stress distributions for banana - coir hybrid treated and untreated are shown below in Figs 6-8 respectively. As the results indicate, tensile strength, impact strength of treated increased, and flexural decreased. Table 4 summarizes the numerical results of the predicted stress data for these specimens. Comparing simulated with actual results, it appears that the model was fairly accurate. The results obtained from the experimental testing and simulations have been compared as shown in the Table 4.



(a)untreated plate (b)treated plate

Figure 6. Tensile stress distribution.

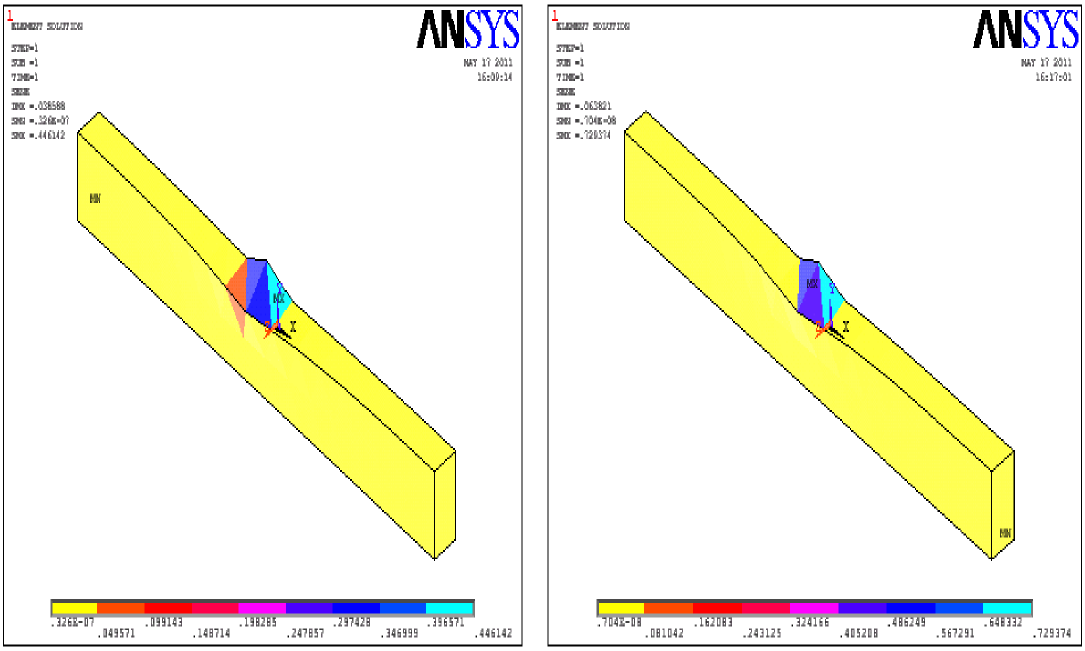


(a)untreated plate (b)treated plate

Figure 7. Flexural stress distribution.

Table 4. Comparison of experimental and simulation results.

S.No	Mechanical properties	Treated	FEA Treated	Untreated	FEA Untreated
1	Tensile strength(MPa)	16.43	16.80	14.82	14.92
2	Flexural strength(MPa)	20.52	20.27	36	36.52
3	Impact strength (J)	0.76	0.72	0.36	0.44



(a)untreated (b)treated plate

Figure 8. Impact stress distribution

CONCLUSION

It is concluded that alkali treated banana-coir epoxy hybrid composite has more tensile and impact strength than untreated banana-coir epoxy hybrid composite. At the same time alkali treated banana-coir epoxy hybrid composite has less flexural strength than untreated banana-coir epoxy hybrid composite. The properties were improved by alkali treating process. In this study fiber weight fraction of 20% has been used. This can be further increased to find out the optimum filler volume fraction depending on applications. The simulated stress distribution for mechanical properties of banana - coir hybrid treated and untreated under different loading conditions was obtained. The maximum stresses are averages of the values of the center elements used in the FEA. These results indicate tensile strength and impact strength of treated banana fiber increased and flexural strength decreased. It was found out the discussed FEA model results are close to be experimental and hence can be used for predicting properties required for different applications.

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