International Journal of Applied Engineering Research
ISSN 0973-4562 Volume 10, Number 10 (2015) pp. 27283-27299

http://www.ripublication.com

Study on Mechanical Properties of Natural Fiber Reinforced Sisal-Coir-Glass Hybrid Epoxy Composites Using Experimental Method

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Abstract

In this work the natural fibers are used as reinforcing components for both thermoplastic and thermoset matrices, because of their ideal benefits. The benefits of natural fibers are convenient renewability, biodegradability and environmentally friendliness. Effort has been taken to utilize the advantages offered by the renewable resources for the development of hybrid composite materials based on epoxy resin and synthetic & natural fibers. Here Coir fiber, sisal fiber and glass fiber are used as reinforcing components. Due to the high specific strength of glass fiber, an investigation has been carried out to make use of sisal-coir-glass fiber. Sisal and coir fiber combined with glass is an excellent method for making cost effective composite material. Sisal and coir fibers are made into woven mat structure and glass fiber is made into chopped fibers. Composite plates are prepared with resin 780gm, coir 100gm, and sisal 80gm, glass 60gm. The composite material plates are fabricated using treated and untreated fiber of coir, sisal and glass using hand layup technique. The resins used are epoxy (EP526) and hardener (HY951). Fiber treatments are done using alkali and fiber neutralization is done using acetic acid in hot water. The purpose of this work is to establish the mechanical properties of sisal-coir-glass reinforced composite materials with a thermo set for treated and untreated fibers. The tensile, impact, compressive, hardness tests showed that treated sisal-coir-glass epoxy hybrid composite has higher tensile strength, impact strength, compressive strength and hardness than untreated composites. This analysis is useful for realizing the advantages of hybrid fiber reinforced composites in structural applications.

Keywords: Coir, Sisal, Glass fiber, Epoxy, Hand layup, Tensile strength, impact strength, compressive strength, Hardness.

Introduction

Nowadays composite materials comprise of two or more families of fibers and that is attracting the attention of researcher community. This is because, the usage of one type of fiber is inadequate for tackling all the technical and economic problems confronted while making fiber reinforced composites. These types of composites introduce additional degrees of compositional freedom for its making and provide yet another dimension to the potential versatility of fiber reinforced composite materials. Combination of a high performance and a low performance fiber provides versatility in the performance of the product. Various reports of hybrid composites of natural fibers reveal reduction in the material cost. It is due to the low cost of the natural fibers and due to the growing interest in the use of natural materials. Cellulosic fibers as reinforcing fillers for commodity plastics has received much attention because of its advantages such as good specific strength, high toughness, good thermal insulation, less abrasion, minimal dermal and respiratory irritation, biodegradability, and natural abundance . Nowadays, natural fibers are replacing traditional manmade fibers as reinforcements because they have several advantages (Wallenberg &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 effects of these fibers on the mechanical properties of composite materials (Gowda, Naidu, & Chhaya,1999 [1]. The effect of Alkali and Sodium Lauryl Sulphate treatment on bio- composites and woven hybrid composites were studied by several researchers. The natural fibres are treated with 10% of sodium hydroxide (NaOH) and 10% Sodium Lauryl Sulphate (SLS) showed improved mechanical and morphological properties by Thiruchitrambalam. M [2]. The development of composite materials reinforced with natural fibers has emerged in the last decade[3].The hybrid composites of coir/silk unsaturated polyester based hybrid composites were studied for the effects of fiber length on the mechanical behavior of coir-fiber-reinforced epoxy composites (Liu, Wu, & Zhang, 2009) [4]. A lightweight composite material was prepared using banana empty fruit bunch fibers as reinforcement in a polyester resin matrix and its mechanical properties studied (Srinivasababu, Rao, &Suresh Kumar, 2009)[5].The natural fibers such as sisal, coir, jute, ramie, pineapple leaf, and kenaf have the potential to be used as reinforcement materials in composites. Investigations on lingo cellulosic fibre composites shows that the properties of the fibre can be better utilized in hybrid composites [6]. An investigation was performed using coir, banana-fiber-filled composites based on high-density polyethylene (HDPE)/Nylon-6 blends. It was studied for its properties (Haydaruzzaman, Khan, Hossain, Khan, & Khan, 2010[7].The analysis of variation in thermal conductivity and diffusivity of Banana fiber reinforced polyester composites caused by the addition of glass fiber have been presented in this paper (RajniAgarwal,2003)[8]. Variations in the tensile and impact properties of banana-fiber-reinforced polyester composites, caused by the addition of glass fiber, have been analyzed (Maleque, Belal, & Sapuan, 2007) have studied the mechanical properties of coir-glass hybrid composites contains various amounts of glass fiber. Studies on sisal-glass in polyester have shown that there is linear increase in the work of fracture by varying the volume fraction of the glass at the core [9]. The mechanical properties of thermoplastic matrix material (HDPE/PCL 80:20 blend and LDPE/PCL 70:30 blend) were improved by introducing untreated or alkali-treated short banana fibers Shaktawatetal[10].An investigated the temperature dependence of thermo-mechanical properties of banana fiber reinforced polyester composites and found the alkali treated composites had the maximum phase transition temperatures. Zaman et al. [11].An investigated the influence of acrylic monomer and starch on the fiber/low density polyethylene(LDPE)composites. They prepared banana fiber-reinforced low density polyethylene composites by using the fibers treated with monomer solution. They found that there was a remarkable improvement on properties of the composites after monomer treatment. Aseer et al. [12].The prepared chemically treated banana fiber composites and evaluated the physical, thermal and morphological properties. The results indicated that, the NaClO treated banana fibers showed good physical properties and low moisture absorption characteristics with respect to untreated raw banana fiber.The surface treatment results indicated that treated banana fibers can be a good choice as reinforcement in the manufacture of bio-composites. Sathasivam et al [13].The prepared the banana trunk fibers and polyvinyl alcohol blended composite films and examined their physical characteristics. They found that the increase in the fiber content improved the physical characteristics and decreased the degree of swelling when compared to unblended films. They suggested that these films can be used as an alternate replacing material for food packaging materials.Biswal [14-16, 17]. In the present study sisal-coir-glass fiber reinforced polymer composites are prepared and its mechanical properties are tested.

Materials and Methods

Matrix Material

Epoxy Resin (EP 526)

Epoxies are polymer materials that begin as liquids and are chemically changed into solid state. An epoxy based polymer is mechanically strong, chemically resistant to degradation of the chemical elements in the solid form and highly adhesive during conversion from liquid to solid. Epoxies have been used extensively due to their excellent properties such as adhesion, high strength, good corrosion resistance, low shrinkage(as compared to polyester resin), and processing versatility. In addition, the processing of epoxy resins does not involve toxic gases like styrene. The range of operating temperatures of epoxy resins can be up to 140°C. This is better than polyesters but lower than that of polyamides. On the other hand, epoxies have higher viscosities than polyesters. Epoxy coatings are used because of their outstanding chemical resistance, durability, low porosity and strong bond strength. Epoxies are known for their excellent adhesion, chemical and heat resistance, good to excellent mechanical properties and very good electrical insulating properties. Epoxy resin was mixed with hardener in the ratio 10:1. The mixture thus formed was a strong covalent bond so that the resulting polymer would be heavily cross linked, 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.

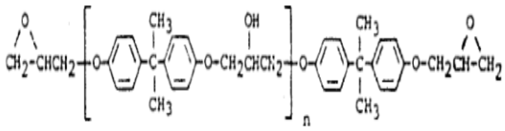


Figure 1: The Basic Epoxy Molecule With Two Epoxy Groups At Two Ends

Hardener (HY 951)
Hardener HY-951 is usually a yellowish-green liquid and has slight odour. It was used as Curing Agent. Hardener was mixed with resin in 10:1. When these two components were mixed, they will react chemically and bond together. Once the chemical reaction was finished, a strong and rigid plastic material was formed. Epoxy Hardener was a phenolic curing agent to use with epoxy. Coatings made with Epoxy Hardener exhibit the excellent chemical resistance and mechanical properties for which phenolic-cured epoxy coatings were noted.

Adhesive (326)
It was added to resin and the hardener mixture to improve the bonding and smoothing the surface.

Reinforcing Element
Reinforcing agents were added to the resin to improve the mechanical strength and wear properties.

Sisal Fiber
Sisal is a natural fiber (Scientific name is Agave sisal Ana) of Agavaceae (Agave) family yields a stiff fiber traditionally used in making twine and rope. The fibre composed of numerous elongated fusi form fibre cells that taper towards each end. The fibre cells are linked together by means of middle lamellae, which consist of hemicellulose, lignin and pectin. Sisal fiber was extracted by the process known as decortications, where leaves were crushed and beaten by a rotating wheel set with blunt knives, so that only fibers would remain. A good sisal plant yields about 200 leaves with each leaf having a mass composition of 4% fibre, 0.75% cuticle,8% other dry matter and 87.25% moisture. Thus a normal leaf weighing about 600g yields about 3% by weight of fibre with each leaf containing about 1000 fibres removal was accomplished by scraping away the pulpy material, generally by a mechanical decortications process and by hand stripping. The sisal fiber that was used for treated and untreated had been studied as shown in below figure2, 3.

Figure 2: Untreated sisal Fiber

Figure 3: Treated sisal Fiber

Coir Fiber

Coconut Coir is a lingo-cellulosic natural fiber. It is a seed-hair fiber obtained from the outer shell, or husk of the coconut, the fruit of Cocos-nucifera.The coarse, stiff, reddish brown fiber is made up of smaller threads, each about 0.03 to 0.1 cm long and 12 to 24 micrometre in diameter coir is composed of lignin, a woody plant substance, and cellulose. The coir fiber is relatively waterproof and is the only natural fiber resistant to damage by salt water. The individual fiber cells are narrow and hollow, with thick walls made of cellulose. Mature brown coir fibers contain more lignin and less cellulose than fibers such as flax and cotton and are thus stronger but less flexible. Coir fibre was extracted by Wet Milling Operation and Dry Milling Operation.

Figure 4: Untreated coir Fiber

Figure 5: Treated coir Fiber

Glass Fiber

The glass fiber is also called as fiberglass. It is made from extremely fine fibers of glass. The fiber glass is a lightweight, extremely strong, and robust material. Although, the strength is lower than carbon fiber and it is less stiff, the material is typically far less brittle, and the raw materials are much less expensive. Its bulk strength and weight properties are also very favorable when compared to metals, and it can be easily formed using moulding processes. Glass fibers are useful because of their high ratio of surface area to weight. However, the increased surface area makes them much more susceptible to chemical attack. Glass fibers make good thermal insulation, with a thermal conductivity of the order of 0.05 W/ mK. The glass fiber is classified into four types A, C, E, and AE. The most common glass fiber used in composites is E glass because it is inexpensive when compared with other types.

Figure 6: Glass Fiber

Fiber geometry

Continuous & Aligned geometry were used in the fabrication of composite material.

Aligned: The properties of aligned fiber-reinforced composite materials are highly anisotropic. The longitudinal tensile strength will be high whereas the transverse tensile strength can be less than the matrix tensile strength. It depends on the properties of the fibers and the matrix, the interfacial bond between them and the presence of voids.

Continuous & Aligned

The fiber length should be longer than critical length which is the minimum length, so that the entire load is transmitted from the matrix to the fibers. If they are shorter than the critical length then, only some of the loads are transmitted. If the fiber length is 15 times greater than the critical length then it is considered as optimal. Aligned and continuous fibers give the most effective strength for fiber composites as shown in figure7. Continuous reinforcements include unidirectional, woven cloth, and helical winding. Continuous-fiber composites are often made into laminates by stacking single sheets of continuous fibers in different orientations to obtain the desired strength and stiffness properties with fiber volumes as high as 60 to 70 percent. Fibers produce high-strength composites because of their small diameter.

a)Mat of coir **b)Mat of sisal**

Figure 7: Mat Structure of Coir and Sisal

Chemical Treatment

Alkaline treatment is one of the most commonly used chemical treatments for natural fibers when used to reinforce thermoplastics and thermosets. The important modification done by alkaline treatment is the disruption of hydrogen bonding in the network structure, thereby increasing surface roughness. This treatment removes certain amount of lignin, wax and oils covering the external surface of the fiber cell wall, depolymerizes cellulose and exposes the short length crystallites. Alkali treatment leads to an increase in amorphous cellulose content at the expense of crystalline cellulose. It is reported that alkaline treatment has two effects on the fiber.

It increases surface roughness resulting in better mechanical interlocking; and it increases the amount of cellulose exposed on the fiber surface, thus increasing the number of possible reaction sites. Consequently, alkaline treatment has a lasting effect on the mechanical behaviour of sisal fibers, especially on fiber strength and stiffness [15]. It is reported that alkaline treatment gives upto 30% increase in tensile properties (both strength and modulus) for Sisal fiber–epoxy composites and coincided with the removal of pectin. Alkaline treatment also significantly improved the mechanical, impact fatigue and dynamic mechanical behaviours of fiber-reinforced composites. The alkali concentration should be minimum otherwise it causes excess delignification of natural fiber, resulting in a weaker or damaged fiber. The tensile strength of the composite decreased drastically after certain optimum alkali concentration.

Sisal Fiber Treatment

Sisal fibers were immersed in neutral soap powder solution. In the sisal fiber treatment, the neutral soap was used as an alkali medium. The alkali solution was prepared with 2gm/l neutral soap powder and 1gm/l sodium bi carbonate in Hot water. The fibers were immersed in prepared hot alkali solution for one hour and periodic stirring was done at regular intervals. After the alkaline treatment, fibers were thoroughly washed with hot water and cold water to remove the absorbed alkali. Neutralizing of fiber was done by Acetic acid i.e. 1cc/l of Acetic acid was added to the hot water and treated fiber was immersed in the solution for an 1 hour to remove the absorbed alkali from the fiber as shown in figure 8. Again neutralized fiber was washed with cold water and it is oven dried or sun dried at 60°C for 2 hours. Similarly has been prepared coir fiber as shown in figure 9. PH should be neutral after neutralizing i.e. PH value should be 7(neutral).

a)Sisal Fiber **b)Alkali Solution** **c)Sun Dried sisal Fiber**

Figure 8: Sisal Fiber Treatment

Coir Fiber Treatment

All fibers are pre-washed with large amount of distilled water and dried at 50ºC until constant weight, prior to treatment. Pre- washed fibers were immersed in neutral soap powder solution.

a)Coir Fiber **b)Alkali Solution** **c) Sun Dried Coir Fiber**

Figure 9: Coir Fiber Treatment

Fabrication Method

Fabrication Flow Process

Raw Material collection
↓
MAT Formation using fibers
↓
Preparing Mould
↓
WAX Coating
↓
Resin Preparation
↓
Arrangements of fiber layer
↓
Curing process
↓
Final Product

Figure 10: Fabrication Process (Sisal-coir- glass)

There are wide varieties of FRP process. 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 the most commonly used is hand layup process. So the hand layup process was used in the preparation of the composite. Weight press was needed for the Hand lay-up method as shown in figure11.The base plate was cleared from rust by scrubbing with abrasive paper. Then the surface was allowed to dry after cleaning it with a thinner solution. After drying, the surface was coated with wax. The surface took few minutes to get set into mold lay-up form. The company codes for the epoxy semi polymerized resin and the Hardener/Curing agent are EP-526 and EH-951and adhesive 326 respectively. They were mixed in the proportion of 10:1 (EP-526& EP-951). The curing time or the pot life was based on how it was usually notified in the laboratory charts, i.e. 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.

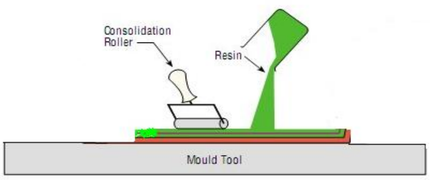


Figure 11: Handlayup method

A plate with the dimensions 200×200×15 mm was fabricated by this process. The matrix material was poured into the mold slowly in order to avoid air trapping. The mixture was left for 2 minutes so that it becomes little tacky. After that, coir fiber woven mat was laid on the matrix layer, which was then covered by another layer of chopped glass matrix and then resin mixture was poured slowly on to the surface of the glass fiber, finally rolling was done with help of roller on the surface of the glass fiber to spread the resin evenly in the fiber matrix.A small pressure was applied using a roller to distribute the matrix material and to avoid void formation. Then sisal mat fiber was laid on the matrix layer. Likewise treated sisal-coir-glass layer plate was fabricated. The set up was cured under the loaded condition of 25 Kg for about 24 hours.

Result and Discussions

Testing and Experimental Results

Tensile Test

A tensile test is also known as tension test, the most fundamental type of mechanical test performed on materials. Tensile tests are simple, relatively inexpensive, and fully standardized. As the material is being pulled, we can find its strength and how much it can elongate. The point of failure is much interest and it is typically called its "Ultimate Strength" or UTS on the chart. Specimen for tensile test was made according to the ASTMD638 standards as shown in below Figure 12.

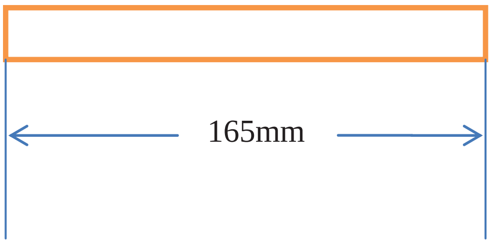
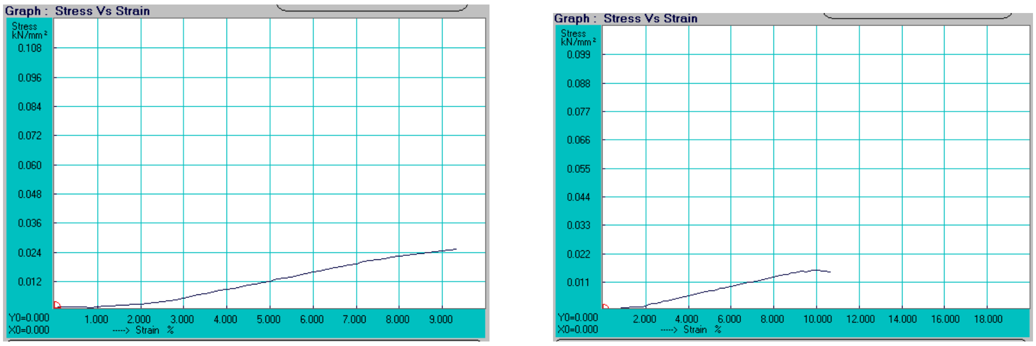


Figure 12: Tensile Test Specimen

Tensile Stress-Strain Curve

The tensile Stress and Strain Curve of Treated and Untreated sisal-coir-glass fiber filled with epoxy resin. All tests were conducted as per ASTMD638 in Universal Testing Machine as shown in figure 13.



a) Treated fiber **b) Untreated fiber**

Figure 13: Tensile stress and Strain Curve

Tensile Strength

Tensile Strength of the treated and untreated sisal-Coir-Glass fiber filled epoxy resin hybrid composite materials were obtained and calculated by tension Test. Tensile strength of these composites were compared using the bar chart as Shown in the Figure 14.

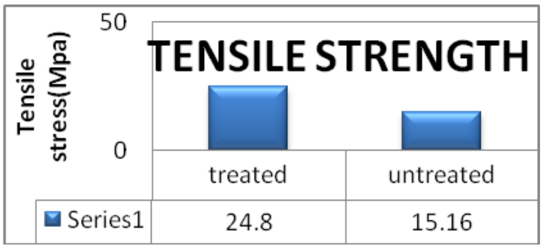


Figure 14: Tensile Strength

It had been found that the Treated composite have more Tensile strength than the Untreated composite.

Tensile Properties

The tensile properties of treated and untreated sisal-coir-glass fiber reinforced composite along with epoxy resin are tabulated below.

Table 1: Measured tensile properties of sisal-coir-glass epoxy composite (treated and untreated)

		Trail-1			Trail-1
	Width (mm)	25		Width (mm)	25
	Thickness (mm)	15		Thickness (mm)	15
Treated Specimen	Max load (N)	6040	**Untreated Treated** Specimen	Max load (N)	3655
	Tensile strength (Mpa)	24.81		Tensile strength (Mpa)	15.16
	Young's modulus (Mpa)	2702.23		Young's modulus (Mpa)	1454.01
	Extension %	9.33		Extension %	10.66

Young's Modulus

The tensile strengths of the treated and untreated materials are compared as shown in Table 1. The comparison of the young's modules is also done using the bar chart as shown in the Figure 15. It had been found that Treated composite has more Young's modulus than the Untreated composite.

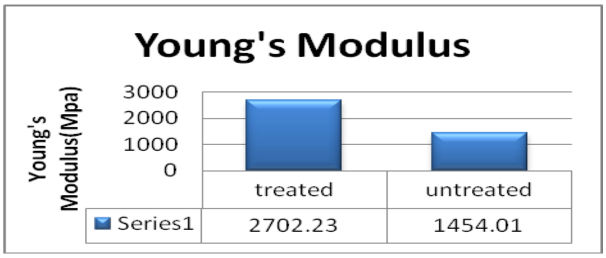


Figure 15: Young's Modulus of treated and untreated (sisal-coir-glass)

Flexural Test

Flexural strength is 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. Specimen for Flexural test is made according to the ASTM D790 standards as shown in below Figure 16.

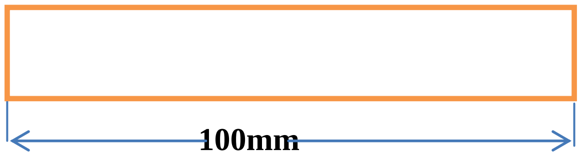


Figure 16: Flexural Test Specimen

Flexural Strength

Flexural strength is 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 flexural strength of these composites was compared using the bar chart as shown in the Figure17. It was found that the untreated sisal-coir-glass Epoxy composite has more Flexural strength than the Treated.

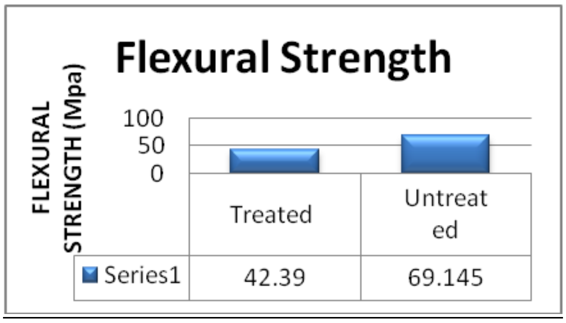


Figure 17: Flexural Strength

Flexural Properties

The flexural properties of treated and untreated sisal-coir-glass fiber reinforced composite along with epoxy resin are tabulated below.

Table 2: Measured flexural properties of sisal-coir-glass epoxy composite (treated and untreated)

Treated Specimen	width (mm)	12.7	**untreated** Specimen	width (mm)	12.7
	Thickness (mm)	15		Thickness (mm)	15
	Max load (N)	1115		Max load (N)	2025
	Flexural strength (Mpa)	42.39		Flexural strength (Mpa)	69.14

Impact Test

A test is 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 methods in use are either the Izod or Charpy test. The result is usually reported as the energy in ft.lbs. Or KJ required fracturing the test piece. The impact test specimens are prepared according to the required dimension and the ASTM-A370 standard. The impact tested specimen as shown in figure 18.

Figure 18: Impact Strength Tested Specimen

Impact Strength

The obtained Impact strengths of the materials were compared using the bar chart as shown in the figure19. It is found that Treated sisal-glass-coir Epoxy composite has more impact strengths than the untreated sisal-glass-coir composite.

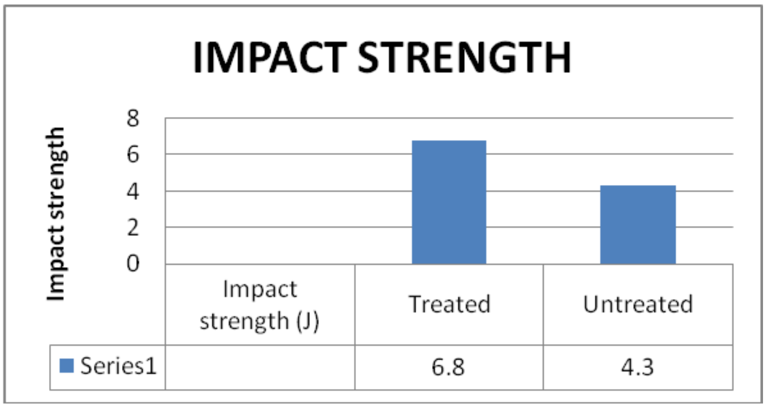


Figure 19: Impact strength

Compressive Strength

Compressive Strength of the treated and untreated sisal-Coir-Glass fiber filled epoxy resin hybrid composite materials were obtained by tension test and compressive strength is calculated. The compressive strength of these composites was compared using the bar chart as shown in the Fig.20. It was found that the treated sisal-coir-glass Epoxy composite has more compressive strength than the untreated.

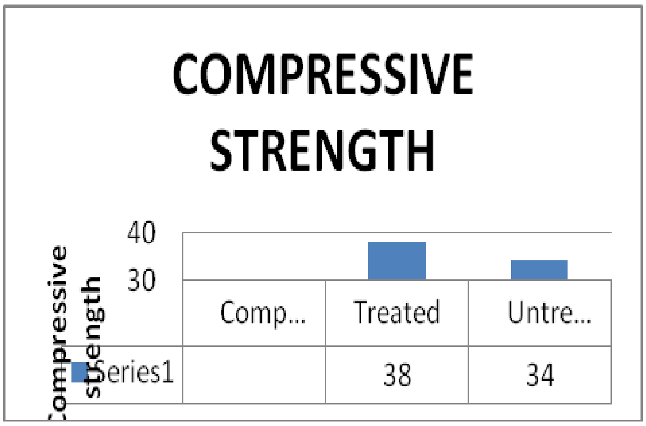


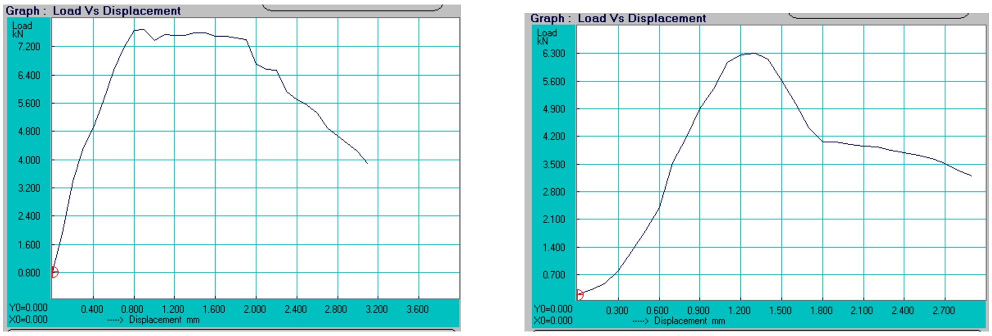
Figure 20: Compressive Strength

Compressive Properties

The Compressive Properties of Treated and untreated sisal-glass-coir fiber reinforced composite along with that of epoxy resin are tabulated3 and compressive properties curve is shown in figure21. It was found that the treated sisal-coir-glass Epoxy composite has more compressive strength than the untreated.

Table 3: Measured compressive properties of sisal-coir-glass epoxy composite (treated and untreated)

Un Treated Specimen		Trial-1	**Treated** Specimen		Trial-1
	width (mm)	25		width (mm)	25
	Thickness (mm)	15		Thickness (mm)	15
	Max load (N)	7680		Max load (N)	6310
	Compressive Strength (Mpa)	34		Compressive Strength (Mpa)	38



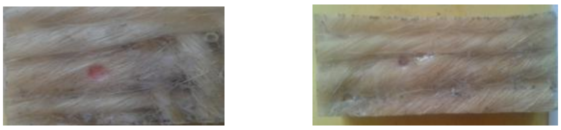
a)Treated compressive (load Vs displacement) **b) Untreated Compressive (load Vs Displacement)**

Figure 21: Compressive Properties Curve

Hardness Test

The Brinell hardness test method is used to determine Brinell hardness is defined in ASTM E10. Mostly it is used to test materials that have a structure that is too coarse or that have a surface that is too rough to be tested using another test method, e.g., castings and forgings. Brinell testing often use a very high test load (3000 kgf) and a 10mm wide indenter so that the resulting indentation averages out most surface and sub-surface inconsistencies. A Brinell hardness result measures the permanent width of indentation produced by a carbide indenter applied to a test specimen at a given load, for a given length of time. The resulting measurement is converted to a Brinell value using the Brinell formula or a conversion chart based on the formula.

$$BHN = \frac{2P}{\pi D\left[D - \sqrt{D^2 - d^2}\right]}$$



a)Treated specimen **b) Untreated specimen**

Figure 22: Brinell hardness Tested Specimens

Brinell hardness number

The hardness of treated and untreated sisal-coir-glass fiber reinforced composite along with epoxy resin are tabulated below. It was found that the treated sisal-coir-glass Epoxy composite has more hardness than the untreated.

Table 4: Measured BHN of sisal-coir-glass epoxy composites (treated and untreated)

Samples	**Load**	**Hardness value**
Treated sisal-coir-glass	500kgf	539.254 BHN
Untreated sisal-coir-glass	1000kgf	398.231 BHN

Conclusion

It can be concluded that an alkali-treated sisal-coir-glass epoxy hybrid composite have greater tensile strength and hardness than an untreated sisal-coir-glass epoxy hybrid Composite. The Tensile strength of alkali treated sisal-coir-glass Epoxy composites and untreated sisal-coir-glass epoxy composites were found to be 24.80MPa and 15.16MPa and the Young's modules of these composites were found to 2702.23MPa and 1454.01MPa. However, the alkali-treated sisal-coir-glass epoxy hybrid composite have less flexural strength than the untreated banana-coir epoxy hybrid composite. The properties were improved by the alkali treatment process. The impact strength and compressive strength of Alkali treated sisal-coir-glass Epoxy composites and untreated sisal-coir-glass epoxy composites were found to be 6.8J , 4.3J and 38Mpa,34Mpa .The brinell hardness of alkali treated sisal-coir-glass epoxy composite is more than the untreated sisal-coir-glass epoxy composites the hardness were found to 539.25 BHN and 398.23 BHN . In this study, the fiber weight fraction of 20% has been used. This can be further increased to establish the optimum filler volume fraction depending on the application.

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