International Journal of Mechanical and Production Engineering Research and Development (IJMPERD)
ISSN (P): 2249-6890; ISSN (E): 2249-8001
Vol. 8, Issue 3, Jun 2018, 39-50

MECHANICAL BEHAVIOUR OF TREATED AND UNTREATED SISAL-KENAF HYBRID COMPOSITE MATERIALS

G. DHARMALINGAM[1], V. KUMAR[2] & A. SENGOLERAYAN[3]

[1]Vel Tech Rangarajan Dr.Sagunthala R&D Institute of Science and Technology, Department of Mechanical Engineering Avadi, Chennai, Tamil Nadu, India

[2,3]SRM Institute of Science and Technology, Department of Mechanical Engineering, Vadapalani, Chennai, Tamil Nadu, India

ABSTRACT

In recent trends, replacement of complex metal extracts from naturally available fiber composites has become a keen in every industrial application. These natural composites are most likely to inherit all the properties of metals and serve their purpose a better way. The aim of this paper is to study the mechanical behavior of treated and untreated sisal-kenaf fiber composite materials. The composites are prepared from sisal fiber (33cm, 3layers), kenaf fiber (33cm, 3layers) .The resin used was epoxy (LY 556) and gardner (HY 951). Hand lay-up method was used for fabrication of fibers. Chemical treatment of the composites is done using NaOH solution by the mercerization process. The Mechanical properties were determined using experimental techniques. Results showed that the chemically treated composite sample exhibits better mechanical stability than untreated sample. This is because of chemical treatment eliminates the cellulose matter present between the fibers providing among them better bonding strength. This bonding strength of fibers affects the overall properties of the composite. This analysis gives an essence of the properties of the composite under varying loading conditions.

KEYWORDS: Sisal-Kenaf, Hand Lay-up Method, Treated, Untreated & Epoxy

Received: Mar 07, 2018**; Accepted:** Mar 27, 2018; **Published:** Apr 24, 2018; **Paper Id.:** IJMPERDJUN20185

Original Article

INTRODUCTION

Natural fibers due to their excellent tensile and mechanical properties and their ease of availability in abundance provide excellent scope of research opportunities for preceding generations. Due to their ease of manufacturing and reliability properties, form substitutes for many complex artificial composites and metals. The main preference of the study is considering natural fibres are eco-friendly and can be renewed, biodegradable and replaced in a limited period. By reinforcement of the fibre composite the tensile properties exhibited by increase drastically as reinforcement of fibres promotes growth in flexural strength and tensile modulus [1]. Chemical treatment of natural fiber composite improves the strength and provides better bonding ability among the fibres in the composite [2]. Andressa Cecília Milanese et.al concluded that naturally available fibers like sisal can be used as a substitute for glass fibers in making of composites as sisal fiber composite exhibit excellent tensile properties and can be synthesised easily [3]. Vivek Mishra et.al studied the properties of jute-epoxy composite in fiber loading conditions. The conclusions are that the hardness, tensile properties and impact strength of the jute-epoxy composites increases with the increase in fiber loading and the properties like flexural strength and inter-laminar shear strength is greatly influenced by the void content of the composites [4]. M.Ramesh et.al studied the

strength of sisal fiber composite through experimental examination, in this study the tensile and mechanical properties of sisal-glass epoxy and jute-glass epoxy composites were determined and conclusions made here are that sisal fiber composite exhibit better tensile properties than jute fibre composites [5-12]. According Li, et.al to modify the fiber surface structure in order to enhance the bond strength between fiber and matrix and reduce water absorption of sisal fiber chemical and thermal treatment are used [13]. There are many reports about sisal fibers composites, Paiva Frollini et.al [14] studied unmodified and modified surface sisal fibers by mercerization (alkali treatment) using NaOH 10%,esterification (succinic anhydride) and ionized air treatment on phenolic and lignophenolic matrixes. The study showed an improvement on fiber/matrix interfacial adhesion by mercerization and esterification when compared to ionized air treatment. Mwaikambo Rong et.al [15-17] also observed the fiber surface topography and crystallographic index changes with mercerization treatment. However they observed yet that depending on the NaOH concentration a reduction of fiber thermal resistance is promote. Bismarck et al. [18-20] reported that the sisal fibers thermal stability is not affected by dewaxing treatment while the mercerization and methyl methacrylate grafting increases the maximum decomposition temperature by 10ºC as compared to untreated fibers.

Present investigations have been carried out on combinations of natural fibers (sisal-kenaf) of different compositions but there are no reports concerning the sisal-kenaf epoxy resin composites. So considering sisal-kenaf fibers as reinforcements and using epoxy as the resin a lightweight composite plate was prepared and tests were conducted on the specimen to determine its mechanical properties under varying loading conditions.

MATERIALS AND CHEMICALS USED

Sisal Fiber

Sisal fiber is one of the most widely used natural fibers and it has obtained from sisal plant. Each leaf contains a number of long, straight fibers which can be removed in a process known as decortications. During decortications, the leaves are beaten to remove the pulp and plant material, leaving the tough fibers behind. The fibers can be spun into thread for twine and textile production, or pulped to make paper products. It is fully biodegradable, green composites were fabricated with soy protein resin modified with gelatine. Sisal fiber modified soy protein resins, and composites were characterized for their mechanical and thermal properties. It is a highly renewable resource of energy. Sisal fiber is exceptionally durable and a low maintenance with minimal wear and tear. It is used in automotive friction parts (brakes, clutches), where it imparts green strength to performs, and for enhancing texture in coatings.

Figure 1: Sisal Fiber

Kenaf Fibers

Kenaf is known as Hibiscus cannabinus L has a cellulosic source with both economic and ecological advantages. Kenaf has been used as a cordage crop to produce twine, rope, and sackcloth. Kenaf has good mechanical properties and can grow quickly as it takes only 150 days to harvest. The kenaf fibers can also serve as a virgin fiber for increasing

recycled paper quality and paper strength. A variety of additional uses has developed for the bast fiber strands. In recent years, with increasing concerns for environmental protection, kenaf has found more applications. These include use in automobile dashboards, carpet padding etc. The breakthroughs and advances in environmental technology have resulted from intensive testing and research in the kenaf industry. Kenaf fiber/plastic compounds based on kenaf can replace glass reinforced plastics in many applications such as automotive industry, construction and housing industry, food packaging industry, oil and chemical 8 absorbents, animal bedding and poultry litter, and soil-free potting mix. The compounds have the good mechanical strength characteristics of glass filled plastics but are less expensive and in many instances are completely recyclable.

The fibers, resin and hardener and their composition that were used in making a composite plate are as follows

- **Reinforcements:** Sisal and Kenaf fibers
- **Matrix material:** Araldite LY 556
- **Hardener:** Aradur Hy 951

Sisal and Kenaf Fibers

Sisal fibers have good strength and are highly resistant to wear and tear. Sisal fiber composites modified with soy protein resins are characterized for their mechanical and thermal properties. The compositions of various elements present in sisal fiber are as shown in table 1

Table 1: Composition of Elements in Sisal Fiber

Cellulose	Hemi cellulose	Lignin	Waxes	Total
65%	12%	9.9%	2%	100%

Kenaf fiber is known for its binding strength. It has its wide range of applications as pulp for paper. Its ability to make strong bonds with other fibers makes it a good form of reinforcement fiber in making a composite. The compositions of various elements in kenaf fiber are as shown in table 2

Table 2: Composition of Elements in Kenaf Fiber

Cellulose	Hemicellulose	Lignin	Waxes	Total
43.7%	24.7%	11.5%	3%	100%

Resin and Hardener

The resin material that is considered here for fabrication process is Araldite LY 556 and hardener is Aradur HY 951. The properties of these materials are listed below table 3and 4

Table 3: Properties of Resin and Hardener

Property	Specification	Units	Araldite LY 556	Aradur HY 951
Viscosity at 25^{o}c	ISO 12058	MPa.s	10,000-12,000	10-20
Density at 25^{o}c	ISO 1675	gm/cc	1.15-1.20	0.97-0.99
Flash point	ISO 2719	^{o}C	>200	>180

Table 4: Properties of the Mixed Solution

Viscosity at 25°C	Viscosity at 40°c	Gel Time at 25°C	Gel Time at 40°C	Usable Life Time at 1500 MPa.s
1700 MPa.s	650 MPa.s	120-80 minutes	30 minutes	10 minutes

EXPERIMENTAL SETUP

Chemical Treatment

Sisal and kenaf fibers are completely immersed in a solution of 6%NaOH solution. This process of treatment of natural fibers with alkali is known as mercerization. Mercerization reduces fiber diameter, thereby increasing 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.

Sisal and Kenaf Fiber Treatment

Initially, these two fibers are immersed in NaOH solution separately for two hours at room temperature. In the later stage, the fibers are washed thoroughly by immersing them in water tanks. This obtained material is then filtered and dried at an optimum temperature for 48 hours. These obtained fibers are treated and were produced for further stages of testing.

Fabrication of Sisal-Kenaf Fiber Composite

At present with the increase in technological facilities, a number of fabrication methods have been developed into existence. Each of the methods gained its importance based upon the material to be fabricated and the type of resin, hardener used to fabricate a composite. In this study hand, lay-up method is considered for fabrication of sisal-kenaf fibers with epoxy resin as the binding material.

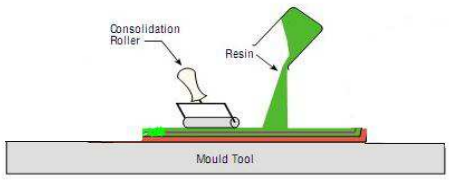

Figure 2: Hand Lay-up Method

Before fabrication, the base plate is to be 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 is coated with silicone gel. The surface is then given a few minutes to set before the mold lay-up. The resin and hardener used are Araldite LY-556 and Aradur HY-951. These are mixed in proper proportions in a ratio of 10:1 wt% and adequate time are given for the solution to cure. Then the process of fabrication is started by pouring the cured matrix material slowly into the mold to avoid trapping air. The mixture was left for 2 minutes until it became a little tacky. In the later stage, the sisal fiber ply was laid unidirectionally on the matrix layer, which is preceded by another layer of matrix poured slowly onto the surface of the fiber ply. A small pressure was applied by using a roller to distribute the matrix material and to avoid the formation of voids. Then, kenaf fibers (33 mm) were laid on the matrix layer. Thus layers of sisal-kenaf-sisal-kenaf-sisal are repeated simultaneously to produce a required composite plate as shown in figure 3.

Figure 3: Fabricated Sisal-Kenaf Composite

MATERIAL TESTING

Tensile Test

The main purpose of conducting the tensile test is to estimate the ultimate strength that can be exhibited by any metal or material. In tensile test as the material is being pulled, we can establish its strength together with how much it will elongate. The point of failure of the material is of significant interest and it is typically called its "Ultimate Tensile Strength" (UTS). For some materials (e.g., metals and plastics), the departure from the linear elastic region cannot be identified easily. These methods are discussed in ASTM E8 (metals) and D638 (plastics). An offset is specified as a percentage of strain (for metals, it is usually 0.2% from E8, and sometimes for plastics, a value of 2% is used). The stress that is determined from the intersection point, when the line of the linear elastic region (with slope equal to the Modulus of Elasticity) is drawn from the offset, becomes the Yield Strength by the offset method. The tensile test was conducted in a UTM Lloyd LR100K Testing Machine. The 10kN(2000 lbf) two column LR100K incorporates the latest technology and quality engineering. The material was loaded into the machine and the load applied at an increasing rate until it reached the maximum tensile load. When the load reached the maximum tensile load, the sample broke. The load at this point is used to calculate the maximum tensile strength of the composite material. According to the ASTM D 638 standards, test specimens dimensions are in mm.

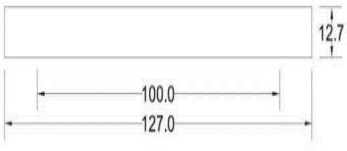

Figure 4a: ASTM D790 Standard Specimen 1 (Treated)

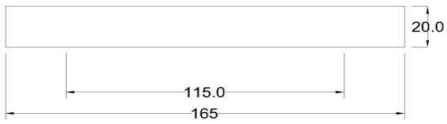

Figure 4b: ASTM D790 Standard Specimen 2 (untreated)

Flexural Test

To determine the rupture, bend strength or fracture strength of a brittle material, the flexural test is conducted on the specimen. In flexural testing process, transverse bending method is the most frequently adapted technique as it is simple, non-time consuming and easy to perform. In this method, a rectangular cross-section, is bent until fractures a three-point flexural test technique were used. The flexural strength represents the highest stress experienced within the material

at its moment of rupture. It is measured in terms of stress. When a material is bent, only the extreme fibers experience maximum stress, therefore, 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 is 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. The flexural modulus of the composite specimen determined by three-point deflection test is given by the following equation

$$E(\text{bend}) = \frac{Fl^3}{4bh^3d}$$

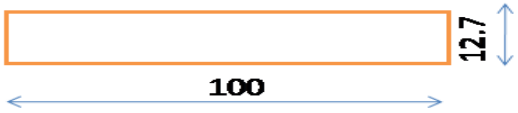

Figure 5: Flexural Test Specimen

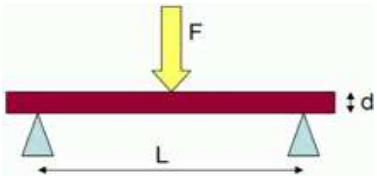

Figure 6: Flexural Test

Where b 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. These sizes are considered from composites prepared according to the ASTM D 790 standards. All dimensions are in mm.

Impact Test

The impact test is conducted to determine the stress response characteristics of the metal or material when it is subjected to sudden or shock loads. A notched test piece is normally employed and the two methods in general use are the Izod and the Charpy test. The result is usually reported as the energy in ft.lbs. or kJ required to fracture the test piece. Properties of material such as internal stresses, polymer orientation, weak spots (e.g., weld lines or gate areas), and part geometry will affect the impact laid on the material. 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 the toughness of a given material and acts as a tool to study temperature-dependent brittle-ductile transitions. It is applied widely in industry, because it is easy to prepare and conduct, and because the results can be obtained quickly and cheaply. However, a major disadvantage is that all results are only comparative. The test specimen size was prepared as per the standard IS 867.

Compression Test

To examine the deformation of the composite when compressive forces are applied on it compression test is conducted. Compressive Strength of the treated and untreated sisal-kenaf fiber filled epoxy resin hybrid composite materials was obtained by tension test and compressive strength is calculated. The compressive strength of these composites was compared using the bar chart as shown in Figure 10. It was found that the treated sisal-kenaf Epoxy composite has more compressive strength than the untreated.

Hardness Test

To determine the extent of the hardness of the total composite prepared, hardness test is conducted on the obtained specimen. Factors such as toughness, a durability of the fibers are determined by this test. In this study, Rockwell hardness testing method is considered for determining the hardness of treated and untreated fiber composite.

RESULTS AND DISCUSSIONS

Tensile Test Results

The results obtained from the tension test for the treated and untreated sisal-kenaf composite are tabulated in Table 5. The tensile strength of these composites was compared using the bar chart is shown in Figure 7. It was found that the treated composite has greater tensile strength than the untreated composite. The Young's modulus of these materials is compared in Table 5. It was found that the treated composite has a higher Young's modulus than untreated composite.

Table 5: Measured Tensile Properties of Sisal - Kenaf Epoxy Composite

Specimen Considered	Properties of Sisal – Kenaf Composite	Trail 1	Trail 2	Trail 3	Average
Treated specimen	Width(mm)	21.5	21.5	20	-
	Thickness(mm)	6.5	6.8	7.2	-
	Max.load(N)	4300	4330	4390	-
	Tensile strength(MPa)	30.76	29.61	30.48	30.28
	Young's Modulus(MPa)	1300	1500	1600	1544.72
	Extension at break(mm)	1.8	1.6	2.5	1.966
Untreated specimen	Width(mm)	20.5	20.5	20.5	-
	Thickness(mm)	6.5	6.5	7.2	-
	Max.load(N)	3345	3340	3300	-
	Tensile strength(MPa)	25.10	25.06	22.35	24.17
	Young's Modulus(MPa)	1200	1150	1159	1248.66
	Extension at break(mm)	1.8	1.4	2.7	1.966

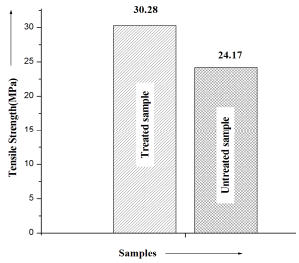

Figure 7: Tensile Strength Comparison Between Treated and Untreated Sisal-Kenaf Fiber Sample

Flexural Test Results

The results obtained from the flexural tests for the treated and untreated sisal-kenaf composites. The flexural properties of the untreated sisal-kenaf epoxy hybrid composite and the treated sisal-kenaf epoxy hybrid composite were measured and tabulated, as shown in Table 6 and the flexural strength of these composites was compared using the bar chart, as shown in Figure 8 . The flexural strengths of these materials were compared and it was found that the untreated sisal-kenaf epoxy composite has greater flexural strength than the treated. The values of the Flexural modulus were shown in table 6. It was found that the treated sisal-kenaf epoxy composite has a higher Flexural modulus than the untreated sisal-kenaf composite**.**

Table 6: Measured Flexural Properties of Sisal-Kenaf Epoxy Composite

Specimen Considered	Properties	Trail 1	Trail 2	Trail 3	Average
Treated Specimen	Width (mm)	12.48	12.09	12.8	-
	Thickness (mm)	8.29	8.65	8.82	-
	Max load (Kgf)	123	109	105	-
	Flexural strength (MPa)	30	30.2	35	31.77
	Flexural modulus (MPa)	5500	5600	6200	5766.66
Untreated Specimen	Width (mm)	13	13.65	13.8	-
	Thickness (mm)	8.5	7.65	7.02	-
	Max load (Kgf)	198	177	196	-
	Flexural strength (MPa)	33.64	40	46	39.88
	Flexural modulus (MPa)	3200	5900	5400	4833.33

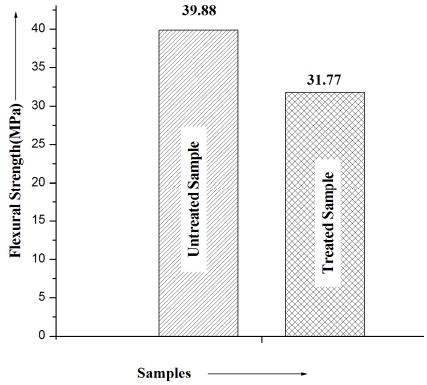

Figure 8: Flexural Strength Comparison Between Treated and Untreated Sisal-Kenaf Fiber Sample

Impact Test Results

The results obtained from the impact tests for treated and untreated sisal-kenaf composite are tabulated in 7. The impact strengths of these materials were compared using bar chart shown in figure 9. It is found that the treated sisal-kenaf epoxy composite has greater impact strength than the untreated composite

Table 7: Measured Impact Properties of Sisal-Kenaf Epoxy Composite

Specimen	Width (mm)	Thickness (mm)	Impact Energy(J)	Impact Strength (J/mm^2)
Un Treated	1.5	0.8	7	5.83
Treated	1.5	0.8	12	10

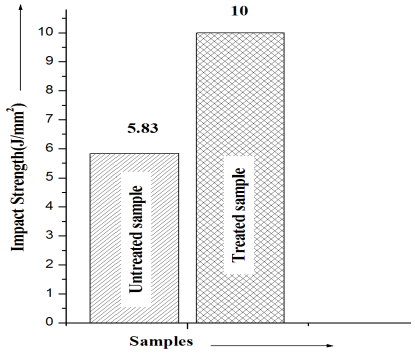

Figure 9: Impact Strength Comparison Between Treated and Untreated Sisal-Kenaf Fiber Sample

Compression Test Results

The compressive properties of treated and untreated sisal- kenaf reinforced composite along with epoxy resin are tabulated 8 and the compressive properties are shown in Figure 10. It was found that treated sisal-kenaf epoxy composite has more compressive strength than the untreated

Table 8: Measured Compressive Properties of Sisal-Kenaf Epoxy Composite (Treated and Untreated)

Untreated Specimen		**Trail-1**	**Treated Specimen**		**Trail-1**
	Width(mm)	25		Width(mm)	25
	Thickness(mm)	15		Thickness(mm)	15
	Max.load(N)	7850		Max.load(N)	8942
	Compressive Strength(MPa)	26.16		Compressive Strength(MPa)	29.80

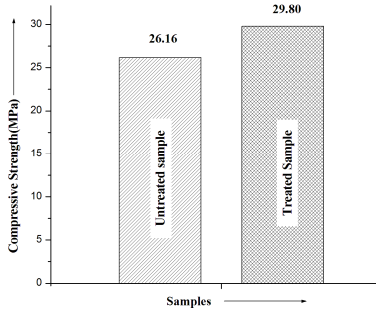

Figure 10: Compressive Strength Comparison of Treated and Untreated Sample

Results of Rockwell Test

The Rockwell hardness test method as used to determine the hardness of the composite and defined in ASTM E10. The 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. In this study, Rockwell testing often used a load (60 kg) and a ¼ inch steel ball indenter and dwell time is 5seconds, so that the resulting indentation averages out the most surface and sub-surface inconsistencies. A Rockwell hardness result measures the permanent width of indentation produced by a steel ball indenter applied to a test specimen at a given load, for a given length of time. It was found that treated sisal-kenaf epoxy composite has more Hardness than the untreated sisal-kenaf epoxy composite as shown in figure11

Table 9: Comparison of Rockwell Hardness for Treated and Untreated Samples

S.No	Hardness	Trail 1	Trail 2	Trail 3	Average	Scale
1	Untreated sample	93.4	92.7	81.8	89	L
2	Treated sample	98.8	100.9	92.1	97	L

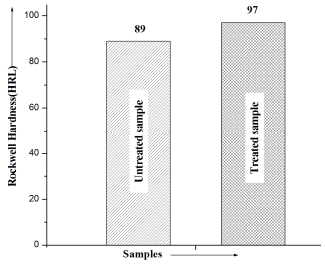

Figure 11: Rockwell Hardness Comparison of Treated and Untreated Sample

CONCLUSIONS

From the obtained experimental results it can be concluded that chemically treated sisal-kenaf epoxy composite exhibited better mechanical properties than untreated sample. The Tensile strength of alkali treated sisal-kenaf epoxy composites and untreated sisal-kenaf epoxy composites were found to be 30.28MPa and 24.17MPa and Young's modulus of these composites were found to 1544.72MPa and 1248.66MPa. The flexural strength of untreated sisal-kenaf epoxy composite was found to be greater than that of the treated sisal-kenaf epoxy composite. The properties were improved by the alkali treatment process. The impact energy and compressive strength of Alkali treated sisal-kenaf epoxy composites and untreated sisal-kenaf epoxy composites were found to be 10J/mm^2, 5.83J/mm^2 and 29.80MPa, 26.16MPa. The Rockwell hardness of alkali treated sisal-kenaf epoxy composite is more than the untreated sisal-kenaf epoxy composites the hardness were found to 97RHL and 89 RHL. These excellent mechanical properties of treated sisal-kenaf epoxy composite contribute its involvement as a substitute element for many artificial composites and metals exhibiting similar characteristics. In this study, the fiber weight fraction of 30% has been used. This ratio can be modified as per the requirements in the application purposes and composite can be remodified.

ACKNOWLEDGEMENT

The authors would like to sincere thanks to the Hon'ble Chairman, Vel Tech Rangarajan Dr.Sagunthala R&D Institute of Science and Technology, Chennai, India for providing the research facilities and also to publish the research paper.

REFERENCES

1. *Pruttipong Pantamanatsopa a, Warunee Ariyawiriyanan a*, Tawatchai Meekeaw a and Hiroyuki Hamada, Effect of Modified Jute Fiber on Mechanical Properties of Green Rubber Composite; (2014),pp.641-647.*
2. *Ajith Gopinath a, Senthil Kumar.Mb, Elayaperumal, Experimental Investigations on Mechanical Properties Of Jute Fiber Reinforced Composites with Polyester and Epoxy Resin Matrices; (2014) pp.2052 – 2063.*
3. *Andressa Cecília Milanese*, Maria Odila Hilário Cioffi and Herman Jacobus Cornelis Voorwald,Mechanical behavior of natural fiber composites; (2011) pp.2022–2027.*

4. *Vivek Mishra*, Sandhyarani Biswas: Physical and Mechanical Properties of Bi-directional Jute Fiber epoxy Composites; (2012) pp.561-566.*

5. *M.Ramesh a*, K.Palanikumar b, K.Hemachandra Reddy c: Comparative Evaluation on Properties of Hybrid Glass Fiber-Sisal/Jute Reinforced Epoxy Composites; (2012) pp.745-750.*

6. *T. Hariprasad, G. Dharmalingam and P. Praveen Raj study of mechanical properties of banana-coir hybrid composite using experimental and fem techniques, International journal of mechanical engineering and sciences,(2013) pp.518-531.*

7. *Rajni Agarwal 1, N . S. Saxena 2, K . B. Sharma 2, S. Thomas 3 & Laly A Pothan 4: Thermal conduction and diffusion through glass-banana fiber polyester composites; (February 2003) pp.448-452.*

8. *Haydaruzzaman, Khan, A. H., Hossain, M. A., Khan, M. A., & Khan, R. A. Mechanical properties of the coir fiber reinforced polypropylene composites effect of the incorporation of jute fiber. Journal of Composite Materials, (2010). 44(4), pp.401-416.*

9. *Wallenberg, F. T., & Weston, N. (2004). Natural fibers, plastics and composites natural.Texas: Materials Source Book.*

10. *Adebisi, A. A., Maleque, M. A., & Rahman, M. M. Metal matrix composite brake rotor: historical development and product life cycle analysis. InternationalJournal of Automotive and Mechanical Engineering, (2011), pp.4471-480.*

11. *Mwaikambo L Y, Ansell M P. Chemical modification of hemp, sisal, jute, and kapok fibers by alkalization. J Appl Polym Sci (2002),pp: 2222-2234.*

12. *Palanethra, Pratheek, and Vl Jagannatha Guptha. "Experimental Investigation Of Stress Concentration Factor in a Unidirectional Carbon/E-Glass Fiber Hybrid Composite."*

13. *Thiruchitrambalam, M., Alavudeen, A., Athijayamani, A., Venkateshwaran, N. and Elaya Perumal,A. "Improving mechanical properties of banana/kenaf polyester hybrid composites using sodiumlaulryl sulfate treatment", Material Physics and Mechanics, (2009)Vol.8, pp.165-173.*

14. *Jacob M, Varughese KT, Thomas S. Novel Woven Sisal Fabric Reinforced Natural Rubber Composites: Tensile and Swelling Characteristics. Journal of Composites Materials 2006; 40(16): 1471-1485.*

15. *Li Y, Mai Y, Ye L. Sisal fibre and its composites: a review of recent developments. Compos Sci and Technol 2000; 60(11):2037-2055.*

16. *Mishra S, Mohanty AK, Drzai LT, Misra M, Hinrichsen G. A review on pineapple leaf fibers, sisal fibers and their biocomposites. Macromol Mater Eng 2004; 289(11); pp.955-974.*

17. *Paiva JMF, Frollini E. Unmodified and modified surface sisal fibers as reinforcement of phenolic and lignophenolic matrices composites: thermal analyses of fibers and composites. Macromol Mater Eng 2006; 291(4): pp.405-417.*

18. *Mwaikambo L Y, Ansell M P. The effect of chemical treatment on the properties of hemp, sisal, jute and kapok forcomposite reinforcement. Die Angewandte Makromolekulare Chemie. 1999; 272(1):pp. 108-116.*

19. *Mwaikambo L Y, Ansell M P. Chemical modification of hemp, sisal, jute, and kapok fibers by alkalization. J Appl Polym Sci 2002; 84(12):pp. 2222-2234.*

20. *Rong MZ, Zhang MQ, Liu Y, Yang GC, Zeng HM. The effect of fiber treatment on the mechanical properties of unidirectional sisal-reinforced epoxy composites. Composites Science and Technology 2001; 61(10):pp. 1437-1447.*

21. *Bismarck A, Mohanty AK, Aranberri-Askargorta I, Czapla S, Misra M, Hinrichsenb G, Springera J. Surface characterization of natural fibers; surface properties and the water up-take behavior of modified sisal and coir fibers. Green Chem 2001;3: pp.100-107.*