ISSN No.: 2455-6130
Volume 2, Issue 4, 2017, pp. 18-27

website: www.ijoetr.com

International Journal of Emerging Trends in Research

Effect of Lay-up Angle on Mechanical Behavior of Sisal Fibre reinforced Composites

Kapil Goyal, Abhishek Kamboj

Haryana Engineering College, Jagadhri, Haryana, India

Abstract

Presently the fast development in research and advancement towards the natural fiber reinforced composite (NFRC) can be observed globally due to their benefits over synthetic fiber reinforced composites (SFRC). The advantages are analogous mechanical properties, lower ecological impact, low cost and usability across a broad series of applications. The current investigation endeavour mainly related with the fabrication, testing and comparison of sisal reinforced polyester composites fabricated at two different fiber orientations (0° and 45°) fabricated with hand layup process. ASTM D-3039 and ASTM D-7264 standards have been used to test the specimen for their tensile and flexural properties, respectively. It has been observed that unidirectional natural fiber reinforced composite has much better effect on mechanical properties as compared to inclined or cross plied natural fiber reinforced composite.

Keywords: fiber reinforcement; synthetic fiber composites; NFRC; SFRC

1. Introduction

Materials can be broadly divided into three main groups: metals, ceramics, and polymers. These materials can be classified on the various chemical, physical and mechanical properties as well as on atomic structure, but mostly materials fall into one distinct group or another. A composite material is considered to be one that contains two or more distinct constituents with significantly different macroscopic behavior and a distinct interface between each constituent [1]. These materials consist, two or more different phases, i.e., chemical and physical, separated by a distinct interface. A schematic diagram of composite is shown in Fig. 1.

The continuous element, which holds the structure and generally present in the larger fraction in the composites, is termed the matrix and works as a binding agent. The other phase is coined as reinforcement, which provides mechanical properties and strength to collective structure. Composites may have a ceramic, metallic, and polymeric matrix. Other constituents are referred as reinforcement phase or reinforcements, as it increases the properties of the matrix material. It is generally harder and stronger than the matrix material.

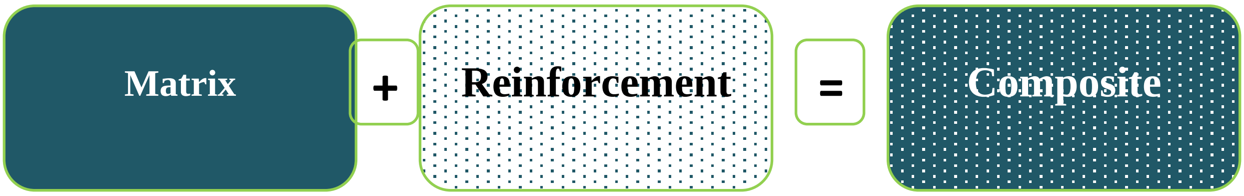


Fig. 1: Schematic view of Composite material

Composites can be modified for desired properties by rightfully choosing their components, proportions and interface between components. Due to their strong tailor-ability, composite materials make them to gratify the needs of various industries, relating to civil and construction, aerospace, automobile, biomedical, electronics and packaging. As a result composite materials comprise of the most commercial engineering materials.

Polymer matrix composites consist of of thermoplastic or thermoset matrix resins reinforced with fibers, which are much stronger and stiffer than the matrix. There are of two types of polymer matrices used for manufacturing of polymer matrix composites i.e, thermoset and thermoplastics. A thermoset is similar to a low-viscosity resin that reacts with its hardening agent in a suitable environment and cures during processing and then solidifies due to chemical reaction among the resin and hardening agent. As thermoset resin sets up and cures during processing due to some chemical reactions involved, it cannot be reprocessed by reheating. A thermoplastic is a high-viscosity resin that is melted by heating it above its melting temperature and formed in the preferred shape and solidifies usually at room temperature.

In common applications, reinforcement in composite is in form of wire, fibers or particulates. The length/diameter (l/d) ratio is rather higher in case of wire and fiber as compared to particulate form. Fibers are small in diameters and their materials are generally polymeric, natural or metallic. Now days, there are two kinds of fibers used in engineering sector, first, which they get from natural sources and others which are man-made.

a) Man-made fibers are called as synthetic fibers. Synthetic fibers can be fabricated by synthesizing the polymers. The compounds used to make these fibers usually come from petroleum based chemicals or petrochemicals as raw materials. The most common examples of synthetic fibers are Glass fibers, Carbon fibers, Aramid fibers and Basalt fibers, etc.

a. Glass fiber *b. Carbon fiber* *c. Aramid fiber* *d. Basalt fiber*

Fig. 2: Different types of Synthetic fibers

b) Fibers which are obtained from natural sources or processed from natural source are called natural fibers. Natural fibers are lingo cellulosic and void in nature and having comparable mechanical, thermal and structural properties. Generally, some mechanical properties of these fibers are quite lower than the synthetic fibers, but can be made almost equivalent by suitable treatment of fibers i.e. alkalization, acetone treatment etc. Hemp, sisal, cotton, silk, wool, etc. are some examples of natural fibers.

Table 1: Various natural fibers and their grouping based on their space of origin [2]

Classification of Natural Fibers					
Bast	**Leaf**	**Seed**	**Fruit**	**Stalk**	**Wood**
Flax	Sisal	Cotton	Coconut	Bamboo	Hardwood
Hemp	Manilla	Kapok	Coir	Wheat Husk	Softwood
Jute	Banana			Rice Husk	
Kenaf	Palm			S.Grass	
Banana	Pineapple			Barley	
Cane	Abaca			Corn	
Nettle	Henequen			Rye	
Kudzu	Piassava			Alfa	

In terms of geometry, natural fibers are non-regular monofilament cylinders like carbon and glass, but bundles of elementary fibers which consist of voids and defects with uneven cross-sections. In terms of chemical organization, natural fibers have varying surface energy and available bonding sites along their fiber length due to the various natural polymers which create these bundles of elementary fibers. Each of these considerations for various natural fiber types will be discussed in vast detail to begin this review to show why composite fabricators cannot just treat natural fibers as conventional engineered fibers [3].

Sisal fiber is obtained from the leaves of the plant named Agave sisalana. It was firstly originated from Mexico and is now largely cultivated in East Africa, Brazil, Haiti, India and Indonesia. It comes under the category of the “hard fibers” amongst which it is placed second to manila in durability and strength. A good sisal plant gives around 200 leaves with every leaf comprises of 4% fibre, 0.75% cuticle, 8% other dry matter and 87.25% moisture. So, a simple leaf weighing about 600g yields about 3% by weight of fibre with each leaf containing about 1000 fibers. [4]

Many researchers have formulated their work on various combinations of natural fiber and matrices. Bajpai et al. [2] compared the mechanical properties of many natural fibers with PLA as reinforcement which were manufactured by different processes. It is resulted that the mechanical properties of various composites depend upon various parameters like percentage of fiber reinforcement, interfacial adhesion, aspect ratio and additives (coupling agents), which are used to enhance the compatibility between fiber and matrix.

H Ku et al. [5]calculated the mechanical properties of natural fiber reinforced polymer composites and concluded that the tensile properties of natural fibre reinforced polymer composites can be enhanced therefore it can be suitably used for industrial works. Sahari and Sapuan[6]Studied natural fiber reinforced bio degradable polymer composites and gave an overview about the origin and properties of bio composites where the polymer matrices were derived from renewable resources such as poly lactide acid (PLA), starch (TPS) and cellulose. They did experiments to evaluate the properties of natural fiber reinforced biodegradable polymer composites. It was formulated that these materials are capable of full degradation as well as compatible with the environment. Akova [7] experimented and developed natural fiber reinforced polymer composites, reinforced with hop fibers. Calculations concluded that mechanical properties with fatigue strength increased by using hop fibers and water absorption reduced with respect to conventional fiber reinforced composites. Maries Idicula et al [8] investigated the mechanical properties of banana/sisal hybrid fiber reinforced polyester composites by taking volume fraction of the fiber as prime factor and observed that the highest tensile and flexural modulus at 0.4 volume fraction and also formulated that the sisal/polyester composite was having maximum damping value and impact strength than banana fiber polyester hybrid composites.

The same specimens were fabricated by Venkeshwaram et al. [9] with different ratios by taking 0.4 volume fraction and tensile properties of these hybrid natural fiber composites are tested by using Rule of Hybrid Mixture (RoHM). It was formulated the RoHM equation gives the tensile properties of the hybrid composites slightly better than the experimental values. Nguong et al. [10] presented a summary on natural fibers; he used locally available fibers and pineapple leaf in his research work. It was found that the use of a confined waste natural fiber for manufacturing of polymer is an eco-friendly better choice. It also revealed that, natural fibers soak up water which affects the engineering properties poorly. He suggested that nano-clay can be mixed for increasing the engineering properties of composites. Faruk et al. [11] conducted testing on bio composites reinforced with natural fibers and calculated mechanical properties and behavior of bio composites. It was found that performance of bio composites in tensile, compression and flexural properties of natural fiber-reinforced polymer improved with respect to polymer composites. Mukherjee and Kao [12] carried out tests on bio composites reinforced with natural fibers; the matrix they used was biodegradable Poly Lactic Acid (PLA) and locally available fibers like hemp, sisal, jute and ken are used for making bio polymer. It was revealed that performances of bio composites were enhanced and their bio degradability improved compare to the polymer composites. Ahmad et al. [13] conducted tests on water soaking performance of natural fiber composites, and used Bagasse flour as reinforcement with matrix as recycled high density polyethylene (HDPE).Bagasse flour was mixed in various proportions by weight. The resultant composite was fabricated by injection molding technique. The experiment concluded that water soaking for bagasse flour with proportion 20% was the minimum value.

Along with the fabrication, secondary processing in terms of drilling is also considered by some researchers. Sisal-epoxy and sisal-PP laminates were fabricated and their drilling performance was experimentally investigated by Debnath et al. [14]. It was realized that the drilling characteristics of natural fiber reinforced composites are irregular as compared to the synthetic fiber based composites due to the irregularities. The same composite (Sisal/PP), was investigated experimentally by Bajpai et al. [15] but with different types of drill point geometries (twist drill and trepanning). Visual examination of the drilled holes also exhibited that almost damage free holes were fabricated with trepanning tool as compared to the twist drill. Yet, the torque values were found for the trepanning tool was observed on the higher side, but the thrust force was observed as considerably lesser for the same.

2. Materials and Methods

Unsaturated polyester resin i.e. a low viscosity resin has been procured from local vendor, suitable for fabricating composites by hand lay-up (HLU) process. Proper wetting of fiber and better interfacial bonding between the fiber and the matrix can only be made possible by the low viscosity property of the polyester resin. Cobalt accelerator was used as curing agent and methyl-ethyl-ketone peroxide (MEKP) as the initiator/ catalyst. Cobalt salt is mixed in white spirit and styrene to produce cobalt accelerator. First the accelerator and resin is mixed and then the MEKP initiator is added. Then curing of the resin is allowed to occur for a reasonable time (depending upon the grades) in order to allow sheets of resin to be molded before gelation occurs.

Unidirectional Sisal fiber sheet has been procured from Women Development Board, Dehradun. The sheet contains sisal fiber strands in a single direction, loosely warped with yarn to reduce mingling of the fibers and to provide direction to sisal fiber strands.

2.1 Processing of Sisal Fibre

Sisal fibers are extracted from the leaves of sisal plant. A hand extraction machine composed of serrated knives is used to extract these fibers. The peel is clamped between the wood plank and knife and hand-pulled through, removing the resinous material. The fibers thus extracted are sun-dried. Once dried, the fibers are prepared for knotting. Each fiber is divided on the basis of their fiber sizes and then grouped accordingly. To knot the fiber, each fiber is separated and knotted to the end of another fiber manually. The separation and knotting is repeated until bunches of unknotted fibers are finished to form a long continuous strand.

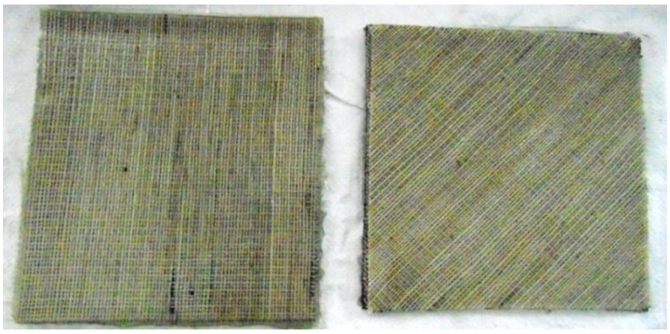
Fig.3: Processing of Sisal Fibre

2.2 Fabrication of Unidirectional composite specimen

Two plates of mild steel (300 mm x 300 mm x 10 mm) are used to ease the fabrication of composite. Thin plastic sheets of polyester (transparency film 100 microns) are placed at the top and bottom of the mold plate to get good surface finish of the product and for ease of removal. Woven fabric are cut as (220mm x 220mm) per the mold size and placed at the surface of mold. For preparing the matrix, the polyester resin was mixed with cobalt accelerator and MEKP catalyst (97: 2: 1) in a glass flask and stirred with glass rod for 3-4 minutes for proper mixing of the components. A layer of this resinous mixture is coated on the mold and then woven mat is placed over it. The resin is spread uniformly with the help of a brush. Then another coat of resin is made and another layer of woven mat is placed over it. This process has been repeated four times and then another sheet of polyester is placed on the top layer of the resin and a roller is moved over the layers to remove any air entrapment and to remove excess polymeric resin. Then the whole setup is covered with another mold plate and a pressure of 400 kgf is applied over it. After curing for 6 hours, the load is removed and composite plates are removed from the mold.

2.3 Fabrication of Cross Plied composite specimen

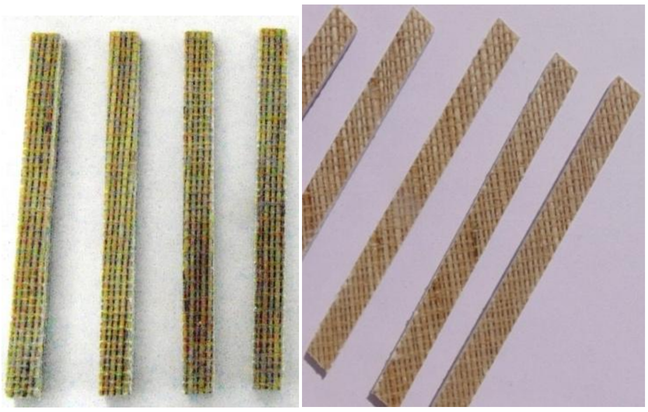
To fabricate cross plied composite, four sheets of size 220 mm x 220 mm has been cut from sisal fiber sheet at an angle of 45° from the direction of strands. The composite has been fabricated by the same method as normal one but the direction of stands were taken as (-45°/ +45°/ -45°/ 45°) to fabricate cross plied composites. Fabricated composite laminates are shown in Fig. 4 (a) and (b).



a. Unidirectional SFRP *b. Inclined Cross plied SFRP*

Fig 4: Fabricated polyester plate and composite laminate

After removal of the composite laminate plates, the specimen has been prepared as per the ASTM 3039 and ASTM 7264 standard for testing purpose. The specimens are prepared as per the required size using a bend saw machine for polyester and composite laminates respectively. Then all the specimen sides and edges has been rubbed on an emery paper (Grit size: 1200) to remove notch and irregularities, which may cause stress concentration while testing of composites. Fabricated specimens are shown in Fig. 5 (a), (b)



(b) Unidirectional SFRP *(c) Inclined cross plied SFRP*

Fig 5: Specimen for mechanical testing

3. Testing of Composites

Tensile Test: The tensile test has been carried out as per ASTM D3039 standards with a length of 150mm, width of 15mm and thickness of 4mm for the laminate sisal fiber composites (unidirectional and cross plied). The test has been performed on the universal testing machine with a crosshead speed of 2mm/ min with a gauge length of 50 mm. The surrounding temperature has been measured as 35ºC.

Flexural Test: Flexural testing has been carried as per ASTM D7264 standard with a length of 150mm, width of 15mm and thickness of 4mm for both laminate sisal fiber composite unidirectional and cross plied. Test specimens of each laminates have been tested by applying the 3 point flexural load on universal testing machine (UTM). The results of flexural strength, modulus and displacement of each specimen has been observed and calculated for comparison. The gauge length is taken as 50mm with a constant crosshead speed of 2mm/ min.

SEM (Scanning Electron Microscopy): The micro-structural examination of the fiber and fractured composite surface is carried on scanning electron microscope. The composite samples prepared, dried and then gold particles are sputtered to form a layer of 100 Å thickness to make

Volume 2, Issue 4, 2017, pp. 18-27

the specimen as electrical conductor. This conductivity enhances the visibility and reduces noise while examining under SEM. The gold sputtering is carried with a sputter ion coater and then specimens were observed in SEM at 15 kV applied voltage.

4. Results & Discussions

The results obtained from micro-structural and mechanical tests are mentioned and discussed in this section. Also, the effect of change in direction of reinforcement and possible causes of variation in physical and mechanical characteristics was analyzed.

4.1 Mechanical properties of the developed composites

When loaded under tensile testing conditions, Tensile strength and tensile modulus as well as are calculated based on the data for various specimens. The average values of tensile properties and flexural properties for unidirectional and cross plied composite specimen are shown in Fig. 6 and Fig. 7.

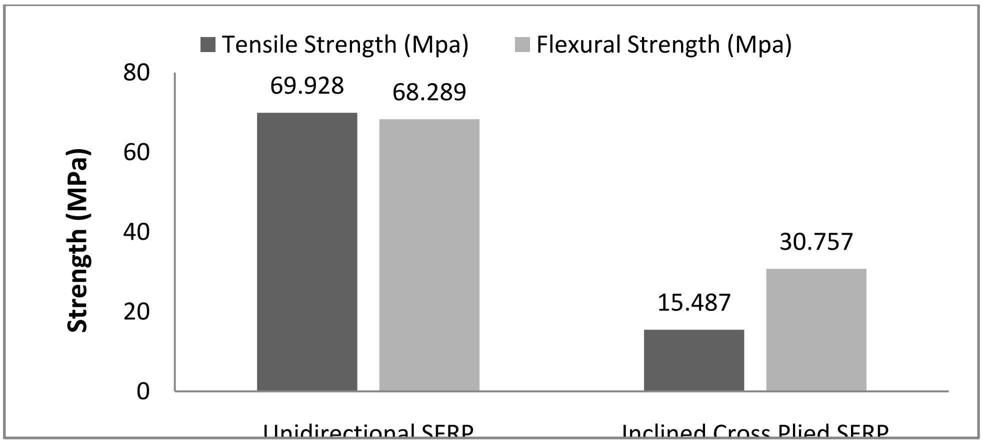


Fig 6: Mechanical strength of unidirectional and cross plied composite

In unidirectional sisal fiber reinforced composite, an increase of more than 400 % (15.48 MPa to 69.92 MPa) has been observed in tensile strength, when compared with inclined sisal fiber reinforced composite. This represents that the unsaturated polyester resin is not able to penetrate deeply in the sisal fiber strands due to comparative high viscosity and close packing of fibers in strands. the peripheral fibers and the matrix is high. In case of flexural strength again there is more than 200% (30.8 MPa to 68.29 MPa) increase in unidirectional sisal fiber reinforced composite as compared to inclined or cross plied sisal fiber reinforced composite.

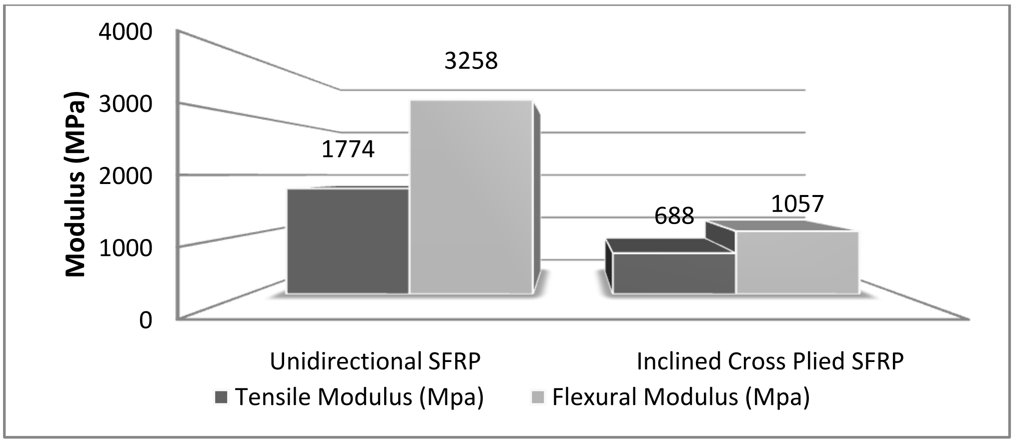


Fig 7: Mechanical strength of unidirectional and cross plied composite

An increase of about 250% (688 MPa to 1774 MPa) was also observed in tensile modulus for the unidirectional sisal fiber reinforced composite when compared with inclined or cross plied sisal fiber reinforced composite and the change in % elongation at break is observed as 11% only.

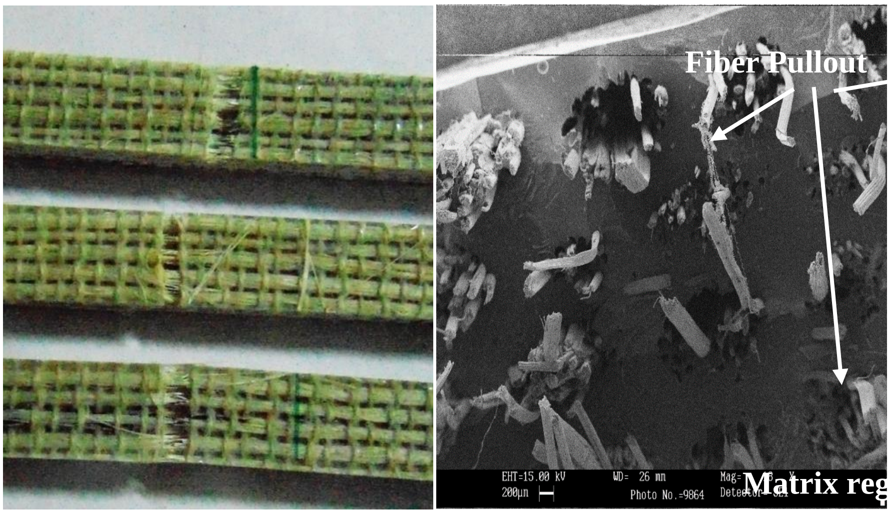


Fig. 8: Fractured specimen and SEM image of surface of unidirectional SFRP

In case of inclined cross-plied sisal fiber reinforced composite laminates a slight increase of 17% was observed. The main reason for this is observed as the non-contribution of fiber strands when tested under tensile condition. Also the tensile load on the fiber strand resulted in nonlinear fracture of the specimen. Fractured specimen and SEM images of the fractured surface for the same are shown in Fig. 8. It can be observed from the images that only matrix fracture took place when loaded under tensile conditions. The effective length of the fiber strands has been observed as 16mm which is quite shorter than the gauge length. But an increase of 52% was observed in tensile modulus, which exhibits that the fiber strands and the inter surface bonding also have a contribution in the same.

Fig. 9: Fractured specimen and SEM image of surface of inclined cross plied SFRP

It can be observed from the above results that although the % reinforcement is same for both of the composite laminates (0° and +45°/-45°), but there is a visible difference in their mechanical properties. The main reason for the above is that when in inclined position the fibers are not playing a major role in deciding the properties. It can be seen in tensile testing that most of the fibers are not in the gauge length, therefore the main load bearing agent is polyester only, which itself possess lower mechanical properties. Fiber pullout can be seen in unidirectional SFRP but no fiber pull or fiber cracks are visible in SEM images of the inclined cross plied composite laminates. The crack direction is perpendicular to the direction of the fibers in case of unidirectional SFRP while parallel to the fibers in inclined cross plied composite laminates (fig 9). The same phenomenon can be applied over flexural properties as well.

5. Conclusion

Based on the experimental investigation, the following points can be concluded, which are mention mentioned below;

- Unidirectional SFRP composites laminates exhibit better mechanical properties when compared to inclined cross plied composite laminates, even for the same volume percentage of reinforcement.
- The fiber doesn’t plays a major role in deciding the mechanical properties, if the inclination angle is higher than a certain value, as the effective length of the fibers are shorter than the gauge length, while testing.
- Matrix material (Polyester, in this case) is main load bearing agent, when the effective length of the fiber is shorter than the gauge length.

The above research leaves a wide scope for further research on the effect of inclination angle of cross plied composite laminates.

References

[1] D. Chandramohan, “Tensile and hardness tests on natural fiber reinforced polymer composite material”,*Int J Adv Engg SciTech*, Vol 6 (1), 097 – 104 (2011).

[2] E. Zini and M. Scandola, "Green composites: An overview.” *Polym Compos*, Vol 32 (12), 1905-1915 (2011).

[3] H. J. Kim and D.W. Seo “Effect of water absorption fatigue on mechanicalproperties of sisal reinforced composite”,*Int J Fatigue.* Vol28, 1307-1314 (2006).

[4] H. Ku, H. Wang, N. Pattarachaiyakoop and M. Trada, “A review on the tensile properties of natural fibre reinforced polymer composites”,*Compos Part B*; Vol 42, 856- 873(2011).

[5] H. S. George,“Laminar Composites”. Butterworth-Heinemann, ISBN: 9780128024003 (1999)

[6] J. Sahari and S.M. Sapuan, “Natural fibre reinforced bio degradable polymer composites”, *Rev Adv Mater Sci*,Vol 30, 166-174 (2011).

[7] K. Debnath, I. Singh, A.Dvivedi and P Kumar,“Natural fiber reinforced composites for wind turbine blades: Challenges and opportunities”*Recent Advances in Composite Materials for Wind Turbine Blades*,ISBN 978-0-9889190-0-6,25–40 (2013).

[8] M. A. Fuqua, S. Huo and C. A. Ulven, “Natural Fiber Reinforced Composites”,*Polym Rev*, Vol 52, 259–320 (2012).

[9] M. Ramesh, K. Palanikumar, K. H. Reddy,“Mechanical property evaluation of sisal–jute–glass fiber reinforced polyester composites”,*Compos Part B*; Vol 48, 1–9(2013).

[10] O. Faruk, A.K.Bledzki, H. P. Fink and M. Sain, "Biocomposites reinforced with natural fibers: 2000–2010",*ProgPolymSci*, Vol 37, 1552– 1596(2012).

[11] P. K.Bajpai, I. Singh and J. Madaan, “Development and characterization of PLA-based green composites: A review”,*J Thermoplast Compos Mater*, Vol 27(1), 52–81 (2014).

[12] P.K. Bajpai andI. Singh, “Drilling behavior of sisal fiber reinforced polypropylene composite laminates. *JReinfPlast Compos*, Vol32 (20), 1569–1576 (2013).

[13] R.Codispoti, R. Fangueiro, P. B. Lourenço and R. S. Olivito and D. V. Oliveira, “Experimental behavior of natural fiber based composites used for strengthening Masonry Structures”,*International Conference on Natural Fibers-Sustainable Materials for Advanced Applications*, DOI: 10.1155/2013/539856 (2013).

[14] S. Matthys, G.Deschutter, andL. Taerwe,“Influence of transverse thermal expansion of FRP reinforcement on the critical concrete cover”.*2nd International Conference on Advanced Composite Materials in Bridges and Structures, Montréal (Canada),* 11-14 August 1996.

[15] T. Mukherjee and N. Kao, “PLA based biopolymer reinforced with natural fiber: A review”,*JPolymEnvir*. Vol19(3), 714-25 (2011).

[16] V.G.Geethamma,K. M. Thomas,R. Lakshminarayanan and S. Thomas. “Composite of short coir fibres and natural rubber: effect of chemical modification, loading and orientation of fibre”,*Polymer*. 39, 1483–1491 (1998).