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Mechanical behavior of woven sisal fiber reinforcement on polyester composites

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Abstract

Currently a rapid growth in research and innovation towards the natural fiber composite (NFC) can be observed worldwide due to their advantages over synthetic fiber composites (SFC). The advantages are comparable mechanical properties, lower environmental impact, low cost and applicability across a wide range of applications. The current research endeavor mainly associated with the fabrication and testing of sisal reinforced polyester composites fabricated with Hand layup process. ASTM D-3039 and ASTM D-7264 standards has been used to test the specimen for their tensile and flexural properties, respectively. It has been observed that reinforcement of sisal fiber in woven form has a positive effect on all the mechanical properties. An increase of 150%-428% has been observed in tensile and flexural properties of the developed composite after reinforcement SEM has been carried out to study the fracture behavior of the developed composites, and this has been observed that higher fiber roughness results in better interfacial bonding among fiber and matrix and plays a major role in deciding the mechanical properties of the composites.

Keywords: mechanical behavior; fiber reinforcement; synthetic fiber composites

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. There are also some intermediate materials, which are generally termed as alloys or composites.

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 constituent, which holds the structure and generally present in the greater fraction in the composites, is termed the matrix and works as a binding agent. The other phase is termed as reinforcement, which provides mechanical properties and strength to combined structure. For example wheat straw, jute and sun fibers have been used with clay and mud for making strong

walls and floors in the ancient time. Other examples are concrete in which reinforcement is provided for improving the properties, rubber is reinforced by black carbon, in wood cellulose fiber are mixed with lignin matrix , similarly in bone collagen fibers are combined with apatite matrix.

Composites may have a ceramic, metallic, and polymeric matrix. Other constituents are referred as reinforcement phase or reinforcements, as it enhances the properties of the matrix material. It is generally harder and stronger than the matrix material. Composites can be tailored for desired properties by suitably choosing their components, proportions and interface between components. Due to their strong tailor-ability, composite materials make them to satisfy the needs of various industries, relating to civil and construction, aerospace, automobile, biomedical, electronics and packaging. As a result composite materials constitute most commercial engineering material.

Fig. 1: Schematic view of Composite material

Polymer matrix composites comprise of thermoplastic or thermoset matrix resins reinforced with fibers, which are much stronger and rigid 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 like 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 desired shape and solidifies generally at room temperature.

Table 1: Commonly used thermoplastics and thermosets

Thermoplastics	Thermosets
Polyethylene (PE)	Epoxy
Polyvinyl Chloride (PVC)	Polyester
Polypropylene (PP)	Urea
Polystyrene (PS)	Melamine
Polyethylene Terephthalate (PET)	Phenolic
Acrylonitrile Butadiene Styrene (ABS)	Poly-Urethane
Styrene Acrylonitrile (SA)	

Polymer matrix composites are now a day very popular due to their low density and simple fabrication methods *[2]*. In general application, PMCs has high specific strength and stiffness, but weaker in impact and corrosion resistance. Now-a-days, natural fibers are getting attraction from the industries, because of their mechanical properties, low densities, low cost and high modulus. Also the production of synthetic fiber is associated with the need of high energy and environmental pollution, governments and private interest groups throughout the world have been developing regulatory laws and general societal awareness on pollution, energy, and raw material

waste which have stimulated a rapid growth of more novel uses of natural fibers as reinforcements in plastics to replace traditional composite, metallic, and wood structures.

Natural fibers are lingo cellulosic and hollow 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 comparable by proper treatment of fibers i.e. alkalization, acetone treatment etc. In terms of geometry, natural fibers are not uniform monofilament cylinders like carbon and glass, but bundles of elementary fibers which consist of voids and defects with irregular cross-sections. In terms of chemical structure, 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 geometrical and chemical considerations for various natural fiber types will be discussed in great detail to begin this review to demonstrate why composite designers cannot simply treat natural fibers as conventional engineered fibers [3].

Table 2: Mechanical properties of some green and synthetic fibers [3]

Fiber	Density (g/cm^2)	Specific Modulus	Tensile Strength	E-Modulus (GPa)	Elongation at Break (%)
Flax	1.5	50	344	27	1.5-1.8
Pineapple	1.56	40	170	62	-
Sunhemp	1.07	32	389	35	1.6
Jute	1.3	38	393	55	1.5-1.8
Ramie	1.55	-	400-938	61.4-128	1.2-3.8
Sisal	1.5	22	510	28	2-2.5
Abaca	-	-	430-760	-	-
Cotton	1.5-1.6	-	287-800	5.5-12.6	7-8
Coir	1.15-1.46	-	131-220	4-6	15-40
E-glass	2.55	28	3400	73	2.5
Kavlar	1.44	-	3000	60	2.5-3.7
Carbon	1.78	-	3400-4800	240-425	1.4-1.8

Natural fibers are grouped into best fibers (jute, hemp, kenaf, flax), hard fibers from leaf (sisal, pineapple), fibers derived from seed (cotton), fibers derived from fruits, stalk, wood, husk/hull, and processed or by-products (bagasse), each of which is having different mechanical and physical properties. Mechanical and physical properties of some natural and synthetic fibers are shown in table 2.

Various researchers have reported their work on various combination of natural fiber and matrices. Bajpai et al. *[4]* compared the mechanical properties of various natural fibers with PLA as reinforcement which were fabricated by different processes and reported 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. Ramesh et al. *[5]*investigated the tensile, flexural and impact properties of natural fibers and synthetic fibers reinforced polymer

composites with different fiber volume fractions and indicated significant improvements in mechanical properties as well as revealed that the process of hybridization reduces the risks of environmental pollution. Ku et al. *[6]* experimentally shown that the tensile properties of natural fibre reinforced polymer composites can be improved therefore it can be suitably used for industrial works.

Sahariand Sapuan*[7]* presented an overview about the genesis and properties of bio composites where the polymer matrices were derived from renewable resources such as poly lactide acid (PLA), starch (TPS) and cellulose. Chandra mohan et al. *[8]*studied and developed natural fiber reinforced composites by using locally available natural fibers with bio epoxy resin. Tensile and Hardness Tests were also analyzed; economically required quantity of fiber with matrix was obtained by Taguchi method. Some experimentation on properties of composite materials used for retrofitting work for civil engineering applications has been carried out and reported better mechanical properties of the composite mortar*[9]* and FRP bars *[10]*.Zini et al. *[11]* studied and compared natural fiber composites with synthetic fibre reinforced composites in terms of environmentally superiority. Faruk et al.*[12]*carried experimentation on bio composites reinforced with natural fibers and studied mechanical properties and behavior of bio composites. It was observed that performance of bio composites in tensile, compression and flexural properties of natural fiber-reinforced polymer improved with respect to polymer composites. Kim andSeo*[13]* worked and developed experimental set up for natural fiber(sisal) reinforced polymer composites by using sisal fiber as reinforcement and carried out experiments on effect of water absorption, fatigue and other mechanical properties of developed NFRC.

Mukherjee and Kao*[14]* carried experimentation on bio composites reinforced with natural fibers; the matrix used was biodegradable Poly Lactic Acid (PLA)and locally available fibers like hemp, sisal, jute and kenafused for making bio polymer. 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 behavior was experimentally investigated by Debnath et al. *[15]*. 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.*[16]* but with different types of drill point geometries (twist drill and trepanning). Visua lexamination of the drilled holes also exhibited that almost damage free holes were produced 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 asconsiderably lesser for the same.

2. Materials and Methods

Unsaturated polyester resin has been procured from local vendor, which is a low viscosity resin, which issuitable forfabricating composites by hand lay-up (HLU) process. Low viscosity of the polyester resin helps in proper wetting of fiber and better interfacial bonding between the fiber and the matrix. The curing agent used was Cobalt accelerator and methyl-ethyl-ketone peroxide (MEKP) as the initiator/ catalyst. Cobalt salt is diluted in white spirit and styrene to produce cobalt accelerator. First the accelerator is mixed into the resin and then the MEK Pinitiator 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.

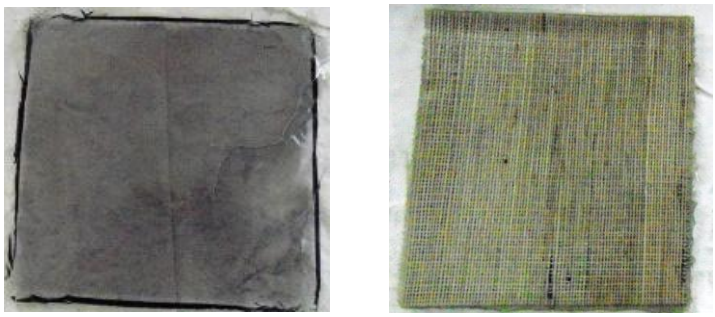
Unidirectional Sisal fiber sheet has been procured from Women Development Board, Dehradun. The sheet contains sisal fiber strands in a single direction, loosely warped with yarn to reduce mingling of the fibers and to provide direction to sisal fiber strands.

2.1. Fabrication of pure polyester specimen

Initially to fabricate pure polyester specimen, a mild steel mold with a cavity has been used. The size of the mold cavity was 200mm x 200 mm x 4mm. Unsaturated polyester is mixed in a glass flask with cobalt accelerator and MEKP catalyst with a ratio of 97:2:1 (as per resin's manufacturer guidelines). This mixture is then stirred with a glass rod for 2-4 minutes for proper mixing of the components. A polyester film is placed on the bottom of the mold cavity to remove surface asperities due to the mold surface, to get better surface finish and ease of removal after curing. Then this mixture is poured in the mold cavity and the covered and placed on a flat surface for 5 to 6 hours for curing. After curing, the fabricated polyester plate is removed from the cavity and cutting has been performed to get desired size of the specimen. Fabricated plates and specimen image is shown in fig. 2 (a).

2.2. Fabrication of composite specimen

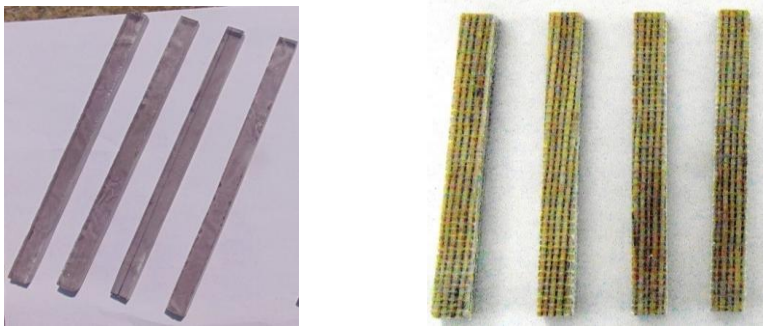
Two plates of mild steel (300 mm x 300 mm x 10 mm) are used to ease the fabrication of composite. Thin plastic sheets of polyester (transparency film 100 microns) are placed at the top and bottom of the mold plate to get good surface finish of the product and for ease of removal. Woven fabric are cut 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. Fabricated composite laminate is shown in figure 2 (b). 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 specimen are prepared as per the required size using a bend saw machine with a width of 11mm and thickness of 8mm and 6mm for polyester and composite laminates respectively.



a. Polyester plate *b. Unidirectional SFRP composite*

Fig 2: Fabricated polyester plate and composite laminate

Then all the specimen sides and edges has been rubbed on an emery paper (Grit size: 1200) to remove and notch and irregularities, which may cause stress concentration while testing of composites. Fabricated specimens are shown in fig. 3(a) and (b).



(a) *Polyester* *(b) Unidirectional SFRP*

Fig 3:Specimen for mechanical testing

3. Mechanical Testing

3.1 Tensile Test

The tensile test has been carried out as per ASTM D3039 standards for pure polyester and the laminate fiber composite. 4 specimens of all three samples (Pure Polyester and Unidirectional SFRP) have been used for testing the tensile behavior of the developed composites. 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.

3.2 Flexural Test

Flexural testing has been carried as per ASTM D7264 standard. 3-5 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 63mm with a constant crosshead speed of 2mm/ min. The same method has been applied to all the samples/ specimen to get the mean flexural properties and comparison of results.

3.3 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 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 and Discussion

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

4.1 Micro-structural Analysis

The SEM images of the sisal fibers used are shown in fig. 4. The surface quality also leads to mechanical bonding between fiber and reinforcement by means of roughness. By the images, we can easily observe that the surfaces roughness of sisal fiber is higher, which may lead to better inter surface bonding and thus lead to improved mechanical properties. The same can be verified by the result obtained.

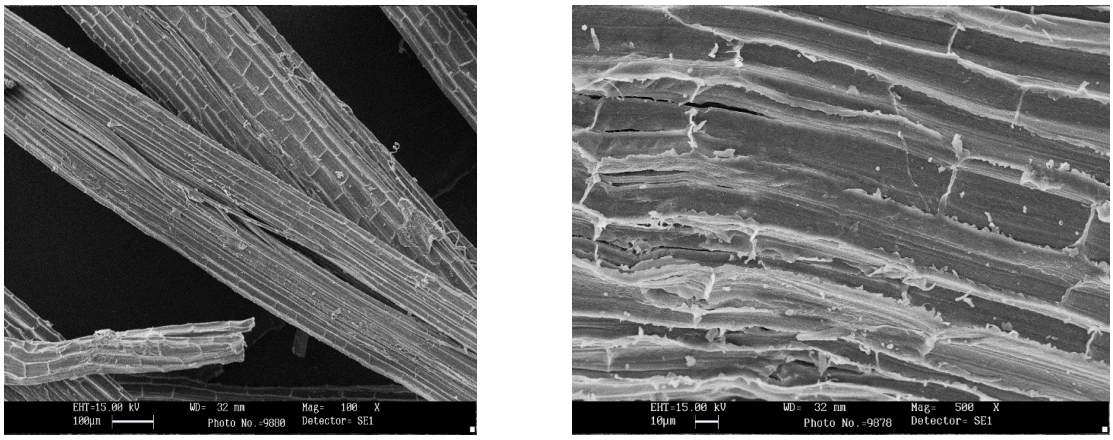


Fig 4: SEM images for the sisal fiber at different magnification

4.2 Mechanical properties of the developed composites

When loaded under tensile testing conditions, Tensile strength and tensile modulus are calculated based on the data for various specimens. Fractured specimen of polyester specimen under tensile loading conditions and their SEM images are shown in Fig5(a) and (b). A brittle fracture was observed in polyester specimen, when tensile load was applied and an elongation of 21.4% was observed for a gauge length of 55mm.

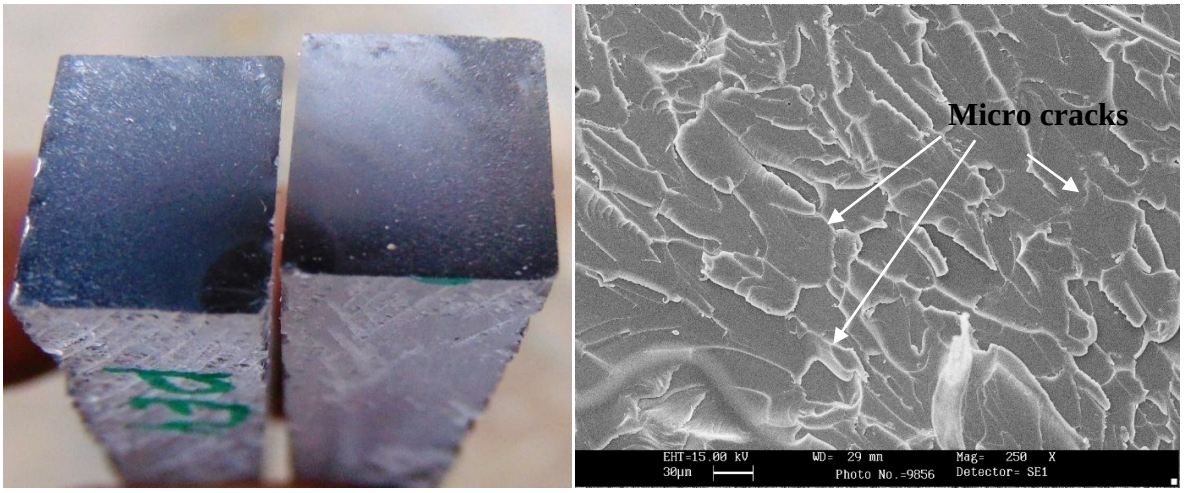


Fig 5: Fractured polyester specimen under tensile loading conditions and its SEM image

The average values of tensile properties for polyester and composite specimen are shown in Fig 6. In sisal fiber reinforced composite, an increase of more than 400 % (13.22 MPa to 69.92 MPa) has been observed in tensile strength, when compared with pure polyester specimen. A lot of fiberpullouts has been observed in tensile specimen when under SEM microscope, which is also shown in fig 7. This also represent 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.

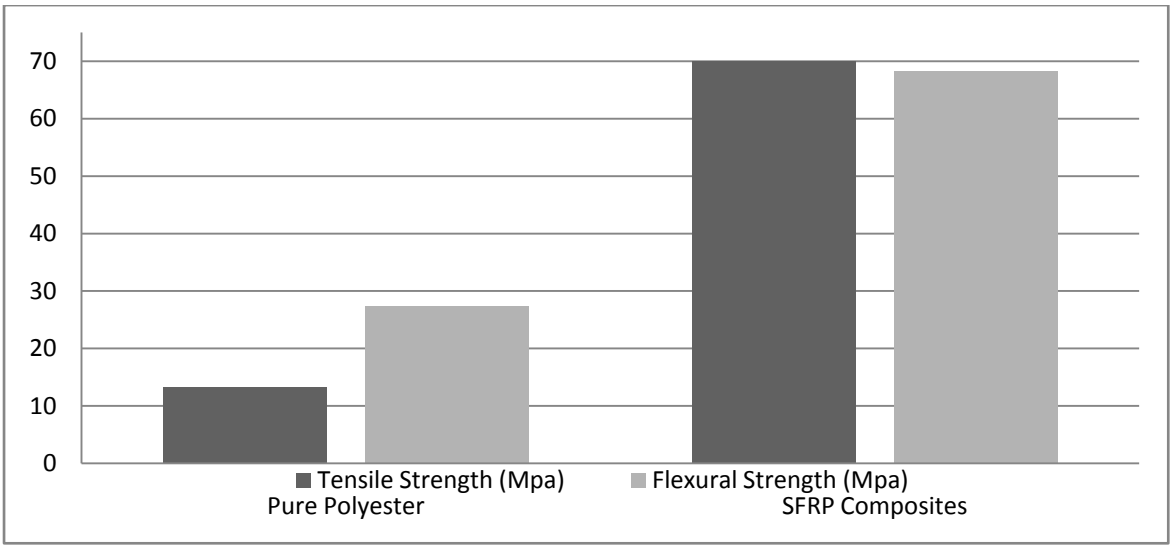


Fig 6: Mechanical strength of pure polyester and developed composite

Fiber fracture in the same specimen also reveals that inter surface bonding between the peripheral fibers and the matrix. An increase of about 300% (452MPa to 1774 MPa) was also observed in tensile modulus for the same composite when compared with pure polyester specimen and the change in % elongation at break is observed as 11% only. An elongation of 20-25% in both the cases exhibits that there is almost no change in the phase of the matrix

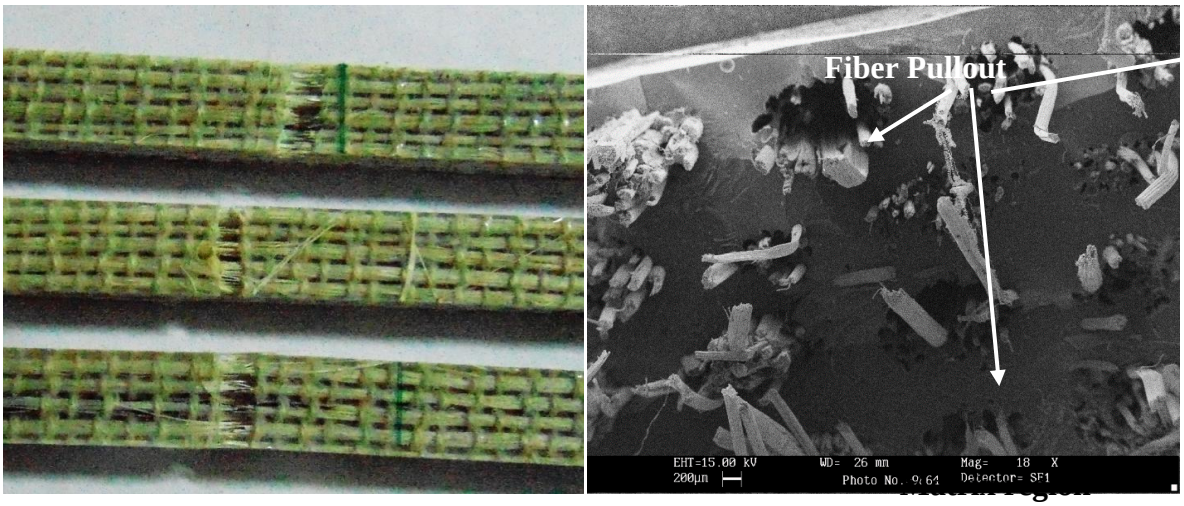


Fig.7: Fractured specimen and SEM image of surface of unidirectional SFRP

In SEM images (Fig 4), it is clear that the surface of sisal fiber is not smooth; this surface roughness propagates the mechanical bonding among fibers and matrix as well as helps in good mechanical properties. Still some voids were also visible, which may be due to air entrapment between the gap of the warps and the viscosity of the polyester resin. This air entrapment also reduces the effective area to bear the tensile load which results in comparatively low tensile properties.

Materials, when used in structural applications, are prone to fail in bending and therefore the development of new composites with comparable flexural characteristic is essential. The outcome of flexural strength and flexural modulus of developed composite showed a significant increase in both the values as compared to neat polyester (Fig 6). Brittle fracture was observed in polyester specimen, when loaded under flexural conditions with a bending distance or extension of 15.10%.

In case of composite specimen, micro crack were developed while applying the bending load and this crack propagation reached at a certain level, where drop in flexural stress was observed. The maximum load, at which the flexural stress is maximum, is treated as flexural strength. The images of failed specimen under flexural loading are shown in figs. 8 and 9.

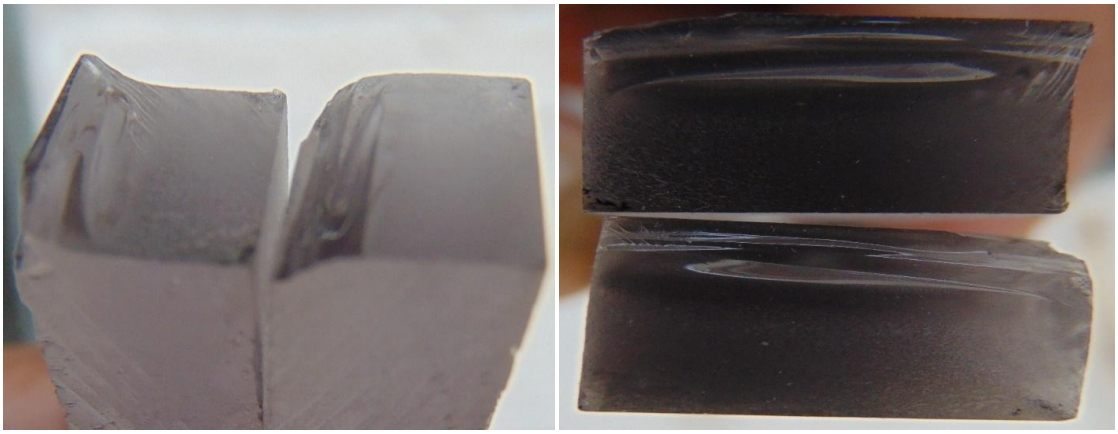


Fig. 8: Fractured polyester specimen under flexural loading

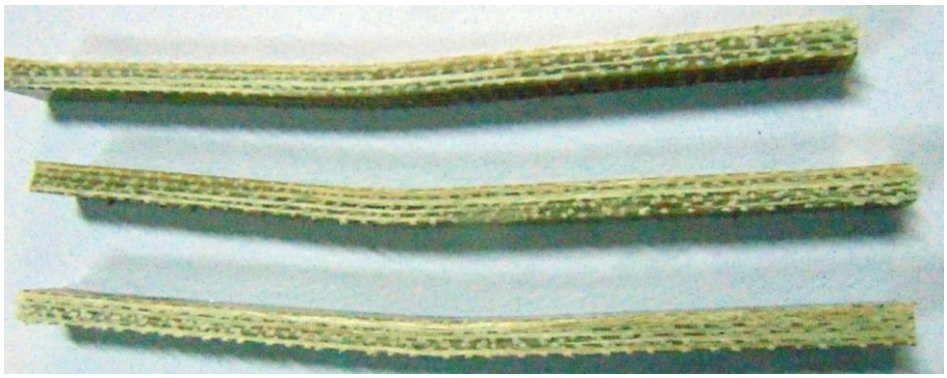


Fig. 9: SFRP specimen failed under flexural loading

An increase of about 150% (27.42 MPa to 68.28MPa) was observed in case of unidirectional sisal fiber reinforced composite as compared to pure polyester when tested under similar conditions. Tests also revealed that an increase of more than 400% (628 MPa to 3.258 GPa) in case of unidirectional fiber composite as the whole fiber strand is contributing in the load distribution under loading condition. The results obtained revealed that the sisal fibers reinforced composites laminates are much better than pure polyester resin.

5. Conclusion

The result reveals an increase in tensile and flexural properties for all the developed composites. The properties can be much better if some chemical treatment can be done for enhancement of surface properties for better wettability of the fibers. Also viscosity of the matrix also plays a role in deciding the mechanical properties by wetting the fiber surfaces and to generates some inter-surface bonding among matrix and fibers. The air entrapment, which leads to poor mechanical properties by reducing effective are to bear the load, can be minimize by reducing the viscosity of matrix as well as applying more pressure while fabricating composites.

By observing the different characteristics of the developed composites, these can be used in all the application areas, where pure epoxy is used. It has been observed that in plastics are mainly subjected to flexural loading in most of the cases, so natural fiber reinforced composites may be

another option for this type of application. The same properties are desirable in case of furniture and other domestic products. The examples of components, where the developed material configuration can be used for are:

Automobiles: Body parts, Buttons, Bumper, Interiors etc.
Household items: Table, Chairs, Door etc.
Miscellaneous products: Domestic coolers, corrugated roof sheets etc.

The present research leaves a wide scope for further investigation to explore many other aspects on processing of natural fiber composites.

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