Review on Mechanical Properties of Sisal Fibre Reinforced Composites

3 authors:

Subhan Ali
Muhammad Nawaz Shareef University of Agriculture

Naman Jain
ABES Engineering College

V. k. Singh
G. B. Pant University of Agriculture and Technology, Pantnagar

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Subhan Ali[1], Naman Jain[2] and V.K. Singh[3]

[1,2] Research Scholar, [3]Professor

Department of Mechanical Engineering

College of Technology, G.B. Pant University of Agri. & Tech, Pantnagar

Mail Id: subhanali3794gmail.com, contact no: 7409653386

ABSTRACT

Sisal fibre is a promising reinforcement fibre for use in composites on account of its low cost, low density, high specific strength and modulus, no health risk, easy availability in some countries and renewability. In recent years, there has been an increasing interest in finding new applications for sisal-fibre-reinforced composites that are traditionally used for making ropes, mats, carpets, fancy articles and others. This review presents a summary of recent developments of sisal fibre and its composites. The properties of sisal fibre itself interface between sisal fibre and matrix, properties of sisal-fibre-reinforced composites and their hybrid composites have been reviewed. Suggestions for future work are also given.

INTRODUCTION

Sisal Fibre is one of the most widely used natural fibre and is very easily cultivated. It is obtain from sisal plant. The plant, known formally as Agave sisalana. Sisal fibre has short renewal times. [3] Nearly 4.5 million of tons of sisal fibre are produced every year all over the world. [2] Brazil has a great production of sisal and export for the entire world, with a yearly production of 151.6 thousands of tons, in 2015. It is also responsible for 56% of the worldwide production [12]. The main producer's states are Bahia - 93.5%, Paraíba - 3.5% and Rio Grande do Norte - 3%, semiarid region [6]. The other leading countries that produce sisal in the world are Madagascar, People's Republic of China, India, Mexico, and Haiti accounting for 19.1, 16.8, 12.0, 11.9 and 9.1 thousand tons respectively produced in 2016. The importance of sisal to these countries is that its production not only enhances economic growth but is also a source for employment opportunities. A sisal plant produces about 200 - 250 leaves and each leaf contains 1000-1200 fibre bundles which is composed of 4% fibre, 0.75% cuticle, 8% dry matter and 87.25% water.So normally a leaf weighing about 600 g will yield about 3% by weight of fibre. [3,16]. These plants produce rosettes of sword-shaped leaves which start out toothed, and gradually lose their teeth with maturity. The processing methods for extracting sisal fibres have been described by Chand et al.; Mukherjee n Stayanarayana. Each leaf contains a number of long, straight fibers which can be removed in a process known as decortication. in decortication leaves are brushed away, beaten and crushed by a wheel that rotates with knives that aren't sharp. What remains is thus the fiber. In the case of sisal fiber, after decortication only approximately 4% of the whole sisal leaf is used, leaving the remaining 95% as residue [8] which is separated in a rotating sieve leaf residues that can be used to generate bioenergy. During decortication, the leaves are beaten to remove the pulp, and wash the fibre, and assist in the removal of leaf tissue . Fibre is taken to drying, where it is spread on to wires and left to dry for a period of 24 hours .when the roughly dry the fibre is taken to brush room where it is brushed to separate the individual fibres, and prepare then for grading. the fibre is graded according to length colour, and blemishes after sorting the different grades of fibre are placed in boxes which are delivered to a balling place where the fibre is compressed and consolidated into bales ready for shipment considerable attention is given grading and quality control with higher grade fetching a better price the main grades produced in East America and Mexico, Brazil, East Africa and many other countries [12].

Sisal fiber

The sisal leaf mainly contains three types of fibres [12], which are mechanical, ribbon and xylem. The mechanical fibres are mostly extracted from the periphery of the leaf. They have a roughly thickened-horseshoe shape and seldom divide during the extraction processes. They are the most commercially useful of the sisal fibre. Ribbon fibres occur in association with the conducting tissues in the median line of the leaf. Fig. 1 shows a cross-section of a sisal leaf and indicates where mechanical and ribbon fibres are obtained [12]. The related conducting tissue structure of the ribbon fibre gives them considerable mechanical strength. They are the longest fibres and compared with mechanical fibres they can be easily split longitudinally during processing. Xylem fibres have an irregular shape and occur opposite the ribbon fibres through the connection of vascular bundles. They are composed of thin-walled cells and are therefore easily broken up and lost during the extraction process.

2. Chemical Composition of Sisal Fibre: Sisal fibre cell walls were reinforced with spirally oriented cellulose in a hemi cellulose and **lignin** matrix. So, the cell wall in a composite structure of **lignocellulosic** material reinforced by helical **microfibrillar** bonds of cellulose. Microfibrillar means a small fibril in the cytoplasm or wall of a cell, visible only under an electron microscope, and typically aggregated into coarser fibrils or structures.[10] Sisal composed of many chemical

Table 1. Properties of some natural fibres (Mukherjee & Satyanarayana)

Fibre Type	Diameter (mm)	density (g cm-3)	cellulose %	lignin %	l/d ratio*	cell wall Thickness (mm)	microfibrillar Angle (deg)
Sisal	100-300	1.450	70	12	100	12.	20-25
Banana	50-250	1.350	83	5 1	50	1.25	11-12
Coir	100-450	1.150	37	42	35	8.	30.45

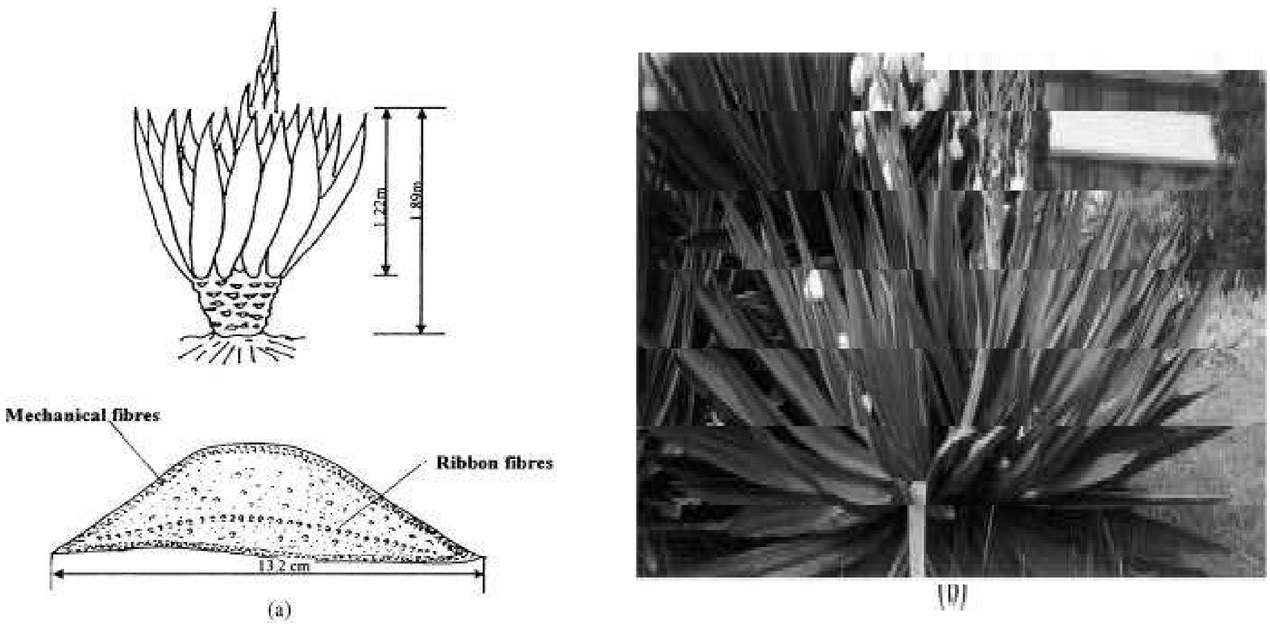

Fig.1. (a) A sketch of sisal plant and the cross-section of a sisal leaf. [3]; (b) photograph of a sisal plant

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component. Cellulose is main comonent of sisal fibre. Here, I have presented the chemical composition of sisal fibre. The chemical compositions of sisal fibres have been reported by several groups of researchers [6-8]. For example, Wilson [6] indicated that sisal fibre contains 78% cellulose, 8% lignin, 10% hemi-celluloses, 2% waxes and about 1% ash by weight; but Rowell [5] found that sisal contains 43-56% cellulose, 7-9% lignin, 21-24% pentose and 0.6-1.1% ash. More recently, Joseph et al. [16] reported that sisal contains 85-88% cellulose. These large variations in chemical compositions of sisal fibre are a result of its different source, age, measurement methods, etc. Indeed, Chand and Hashmi [7] showed that the cellulose and lignin contents of sisalvary from 49.62-60.95 and 3.75-4.40%, respectively, depending on the age of the plant. The length of sisal fibre is approximately between 1.0 and 1.5 m and the diameter is measured about 100-300 mm. [8] the fibre is actually a bundle of hollow sub-fibres. Their cell walls are reinforced with spirally oriented cellulose in a hemi-cellulose and lignin matrix. So, the cell wall is a composite structure of lignocellulosic material reinforced by helical microfibrillar bands of cellulose. The composition of the external surface of the cell wall is a layer of lignaceous material and waxy substances which bond the cell to its adjacent neighbours. Hence, this surface will not form a strong bond with a polymer matrix. Also, cellulose is a hydrophilic glucan polymer consisting of a linear chain of 1, 4-â -bonded anhydroglucose units and this large amount of hydroxyl groups will give sisal fibre hydrophilic properties. This will lead to a very poor interface between sisal fibre and the hydrophobic matrix and very poor moisture absorption resistance [9]. Here we have some natural fibre which is sisal .banana, coir. And properties comparison table 1 which is given below.

3. Uses/Application of Sisal Fibre: Traditionally sisal was the leading material for agricultural twine (“binder” and “baler” twine) but the importance of this has now diminished (with competition from polypropylene and other techniques) although there is still a major business between Brazil and the United States. Apart from ropes, twines and general cordage sisal is used in both low-cost and specialty paper, dartboards, buffing cloth, filters, geotextiles, mattresses, carpets and wall coverings, handicrafts, wire rope cores and macramé [3]. Other products developed from sisal fiber include spa products, cat scratching posts, lumbar support belts, rugs, slippers, cloths and disc buffers. Sisal is used by itself in carpets or in blends with wool and acrylic for a softer hand.

It is also used as a binding material for plaster moldings as well as in the construction industry to reinforce plaster in ceilings and walls [20]. A new potential application is for manufacture of corrugated roofing panels that are strong and cheap with good fibre resistance [5].In recent years sisal has been utilized as a strengthening agent to replace asbestos and fiberglass and is increasingly a component used in the automobile industry, where its strength, “naturalness” and environmentally friendly characteristics are greatly appreciated.

During the past decade (2005-2015), the determine of new areas for this cost effective material has become demanding work. Mostly sisal fibre play important role as reinforcement in composites, and it is become an outstanding reinceforcement, and many scientists and engineers are interested, to work with sisal fibre because they had many ecpectations.

The main delibrerates on sisal fibre accomplish during this 10-year period can be widely divided in to the following main material:

4. Properties of sisal fibre

Here we have three main properties of sisal fibre which is given below.

Mechanical, thermal and dielectric have been deliberated in detail. X-ray, diffraction,

Table 2. Properties of sisal fibres reported by different researchers

Density (kg/m3)	Moisture content (%)	Tensile strength (MPa)	Tensile Modulus (GPa)	Maximum strain (%)	Diameter (mm)	Reference
1450	11	604	9.4-15.8	-	50-200	[14]
1450	-	530-640	9.4-22	3-7	50-300	[2]
-	-	347	14	5	-	[65]
1030	-	500-600	16-21	3.6-5.1	-	[28]
1410	-	400-700	9-20	5-14	100-300	[44]
1450	-	450-700	7-13	4-9	-	[43]
-	-	530-630	17-22	3.64-5.12	100-300	[1]
1450	-	450-700	7-13	4-9	-	[53]

Fibre. Which is helpfull in processing and application of the sisal fibre based composite?

4.1 Interface properties of sisal fibre and matrix

Here our objective is to increase the properties of sisal fibre. Specially upper surface structure with the help of chemical and thermal treatment methods. Which is very usefull to increase the bond strength between fibre and matrix? And moreover it is play important role to minimize water absorption of sisal fibre.[1]

Sisal/glass-fibre-reinforced hybrid composites:

If we want to take benefit of both sisal and glass fibre, they have been combined to the matrix so that desire, admirable but efficient composite can be gained. The hybrid effect of sisal/glass fibre on the mechanical virtue have been deliberated and interpreted. [19]

4.2. Properties

Generally, the strength and stiffness of plant fibres depend on the cellulose content and the spiral angle which the bands of micro fibrils in the inner secondary cell wall make with the fibre axis. That is, the structure and properties of natural fibres depend on their source, age, etc. [11]. The tensile properties of sisal fibre are not uniform along its length [12]. The root or lower part has low tensile strength and modulus but high fracture strain. The fibre becomes stronger and stiffer at mid- span and the tip has moderate properties. Table 2 shows the properties of sisal fibres as reported by different researchers. Note that except for the struc- ture and properties of the natural fibre itself, experimental conditions such as fibre length, test speed, etc., all have some effects on the properties of natural fibres [13,20]. Mukherjee and Satyanarayana [3] studied the effects of fibre diameter, test length and test speed on the ten- sile strength, initial modulus and percent elongation at the break of sisal fibres. They concluded that no significant variation of mechanical properties with change in fibre diameter was observed. However, the tensile strength and percent elongation at the break decrease while Young's modulus increases with fibre length. With increasing speed of testing, Young's modulus and tensile strength both increase but elongation does not show any significant variation. However, at a test speed of 500 mm/min, the tensile strength decreases sharply. These results have been explained in terms of the internal structure of the fibre, such as cell structure, microfibrillar angle (20-25_), defects, etc. In rapid mechanical testing, the fibre behaves like an elastic body, i.e. thecrystalline region shares the major applied load resulting in high values of both modulus and tensile strength. When the testing speed decreases, the applied load will be borne increasingly by the amorphous region. However, at very slow test speeds, the fibre behaves like a viscous liquid. The amorphous regions take up a major

Portion of the applied load giving a low fibre modulus and a low tensile strength. But at very high strain rates (_500 mm/min), the sudden fall in tensile strength may be a result of the presence of imperfections in the fibre causing immediate failure. In Ref. [1], the microfibrillar angle and number of strengthening cells in the sisal fibres did not show any appreciable variation in fibre diameter. Hence, no appreciable change in values of Young's modulus and tensile strength were observed. As the test length increases, the number of weak links or imperfections also increases, thus resulting in reduction in tensile strength. However, with increasing fibre length, sisal offers a higher resistance to applied stress as a result of the involvement of more oriented cellulosic fibres. This probably also accounts for the higher modulus of the fibres at longer test lengths. The reason for such behavior by the characteristics of natural fibres such as multi-cellular structures, visco-elastic nature and non uniform structural inhomogeneity [11]. Reported the effects of testing speed and gauge length on the mechanical properties of other kinds of natural fibres (sun-hemp fibres). Their results support the finding of Ref. [1], though the magnitudes are much lower than those of sisal fibres. (For example, when the gauge length is 50 mm and testing speed is 50 mm/min, the tensile strength of sisal fibre is 759 MPa. However, for sun-hemp fibre, the tensile strength is only 283 MPa.) The mechanical properties of sisal fibres obtained from different age at three different temperatures were investigated by Kim JT, Netravali AN [14]. The tensile strength, modulus and toughness (defined as energy absorption per unit volume) values of sisal fibre decrease with increasing temperature. The relative effect of plant age on these mechanical properties is less prominent at 100oC than at 30oC. This is attributed to the more intense removal of water and/or other volatiles (at 100oC) originally present in the fibres, which otherwise act as plasticising agents in the chains of the cellulose macromolecules. It is, however, noted that at 80oC both tensile strength and modulus decrease with age of the plant. This trend is different to testing at 100oC. Table 3 shows the results of sisal fibers of diff age at different temperature.

Comparisons of mechanical properties of sisal fibres with different age at different temperature [14]

To make good use of sisal fibre reinforcement in composites, fibre-surface treatment must be carried out to obtain an enhanced interface between the hydrophilic sisal fibre and the hydrophobic polymer matrices. Modifications of interfaces between sisal fibre and polyester, epoxy, polypropylene, etc.

4.2.1. Sisal/polyester composites

The properties of sisal fibre-reinforced polyester composites can be improved when sisal fibres were suitably modified with surface treatment [15].

4.2.2. Sisal/epoxy composites for the interface

Age of plant	Toughness per unit volume (MJ/m3)			Tensile strength (MPa)			Tensile modulus (GPa)		
	30^{o}C	80^{o}C	100^{o}C	30^{o}C	80^{o}C	100^{o}C	30^{o}C	80^{o}C	100^{o}C
3	4.8	4.9	4.1	452	350	303	26	29	21
5	5.5	7.8	4..3	508	355	300	29	-	22
7	6.0	5.2	4.7	500	300	280	34	22	17
9	7.4	5.4	5.2	581	316	339	37	17.5	21

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between sisal fibres and epoxy,

[2] adopted silane treatment methods to improve the adhesion and moisture resistance properties.

4.2.3. Sisal/phenol formaldehyde composites

Yang et al. [2] using NaOH, silane (3-aminopropyltriethoxy silane), chemical grafting and thermal treatment methods studied the effects on sisal/phenol formaldehyde composites.

4.2.4. Sisal/polyethylene composites Owing to the increasing use of thermoplastics, sisal fibre reinforced-thermoplastics have become increasingly important.

CONCLUSIONS

Sisal fibre is an effective reinforcement of polymer, rubber, gypsum and cement matrices. This has created a range of technological applications beyond its traditional usage as ropes, carpets, mats, etc.

The mechanical and physical properties of sisal fibre not only depend on its source, position and age which will affect the structure and properties, but also depend on the experimental conditions, such as fibre diameter, gauge length, strain rate and test temperature. Different matrix systems have different properties.

The mechanical and physical properties of sisal-fibre- reinforced composites are very sensitive to processing methods, fibre length, fibre orientation and fibre volume fraction. Sisal and glass fibres can be combined to produce hybrid composites which take full advantage of the best properties of the constituents. Almost all the mechanical properties show 'positive' hybrid effects.

FUTURE WORK

From this review, it is clear that chemically treated or modified sisal-fibre-reinforced composites are potential structural materials as a result of their good mechanical, environmental and economic properties The following areas of research are, however, needed to realise wider applications of sisal fibres in engineering:

η Sisal-textile-reinforced composite is an important area in which little work has been done [3]. Sisal fibres can be woven into textile performs and impregnated with resins by resin transfer moulding (RTM) or resin film infusion (RFI) to make superior but more economical composites.

η Microstructure of the interface between sisal fibre and matrix still needs to be investigated and the interfacial properties should be studied with more rigorous single fibre pullout and fragmentation tests. The relationship between interface and bulk composite properties should be established.

η Fracture toughness and fracture mechanisms of sisal-fibre composites do not seem to have been studied in any depth in previous published works. This is important if new improved materials are to be developed for safe usage against crack growth.

η Mechanical properties of sisal-fibre composites measured from tests quite often disagree with the rule of mixtures. A full can only be obtained if the interface strength and the failure mechanisms are known. Further work is needed particularly to explain 'hybrid' effects in sisal/glass composites.

η Economical processing methods must be developed for the composites because of the very low price of sisal fibres. The relationship between mechanical properties and processing methods should be established.

η New applications should be found for sisal-fibre- based composites. Hybrid fibre composites with sisal and other fibres rather than glass may open up new applications. For example, from the economics point of view, sisal fibres may be hybridised with carbon or aramid fibres to reduce the costs of these expensive fibres reinforced composites whilst maintaining their good mechanical performance. Recycling (including burning) characteristics and methods of sisal-fibre-reinforced composites are important aspects of this new material but there are very few published data to date. Recycling is an attractive future research direction that will provide socio-economic benefits.

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