The Mechanical Properties of Natural Fibre Reinforced Polymer Composites: A Review

Dr. Rajashekar Patil
BOE Mechanical Department
Reva School of Engineering
Reva University, Bangalore-560064
Karnataka, India

Ganesh Kalagi
Mechanical Department
Shri Madhwa Vadhiraja Institute of Technilogy
Bantakal, Udupi-574115
Karnataka, India

***Abstract*— Natural fibers have been used to reinforce materials for over 3,000 years. More recently they have been employed in combination with plastics. Many types of natural fibers have been investigated for use in plastics including Flax, hemp, jute, straw, wood fiber, rice husks, wheat, barley, oats, rye, cane (sugar and bamboo), grass reeds, kenaf, ramie, oil palm empty fruit bunch, sisal, coir, water hyacinth, pennywort, kapok, paper-mulberry, raphia, banana fiber, pineapple leaf fiber and papyrus. Natural fibers have the advantage that they are renewable resources and have marketing appeal. The Asian markets have been using natural fibers for many years e.g., jute is a common reinforcement in India. Natural fibers are increasingly used in automotive and packaging materials. Agricultural wastes include wheat husk, rice husk, and their straw, hemp fiber and shells of various dry fruits. These agricultural wastes can be used to prepare fiber reinforced polymer composites for commercial use.**

This report examines the different types of fibers available and the current status of research. Many references to the latest work on properties, processing and application have been cited in this review.

Keywords*— Natural composites, polymers, hybrid fibres, mechanical properties.

I. INTRODUCTION

Composites are materials that comprise strong load carrying material (known as re-enforcement) imbedded in weaker material (known as matrix). Reinforcement provides strength and rigidity, helping to support structural load. The matrix or binder (organic or in-organic) maintains the position and orientation of the reinforcement. Significantly, constituents of the composites retain their individual, physical and chemical properties; yet together they produce a combination of qualities which individual constituents would be incapable of producing alone [1].

Wood [2] is natural three-dimensional polymeric composite and consists primarily of cellulose, hemicelluloses and lignin.

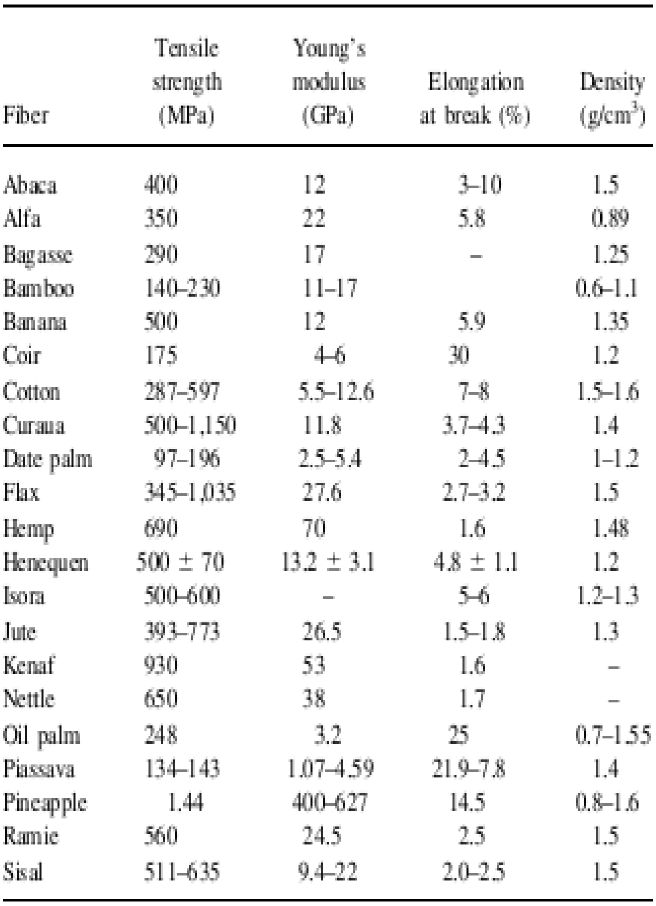
Historical examples of composites [3] are abundant in literature. Significant examples include the use of reinforcing mud walls in houses with bamboo shoots, glued laminated wood by Egyptians (1500 BC) and laminated metals in the forging of swords (1800 AD). In the 20th century, modern composites were used in 1930s, where glass fibers reinforced resins. Boats and aircrafts were built out of this glass composites, commonly called fiberglass. Since the 1970s, the application of composites has widely increased due to development of new fibers such as carbon, boron and aramids, and new composite systems with matrices made of metal and ceramics.

Natural fibers have recently attracted the attention of scientists and technologists because of the advantages that these fibers provide over conventional reinforcement materials, and the development of natural fiber composites has been a subject of interest for the past few years. These natural [4–7] fibers are low-cost fibers with low density and high specific properties. These are biodegradable and nonabrasive, unlike other reinforcing fibers. Also, they are readily available and their specific properties are comparable to those of other fibers used for reinforcement.

II. NATURAL FIBRE

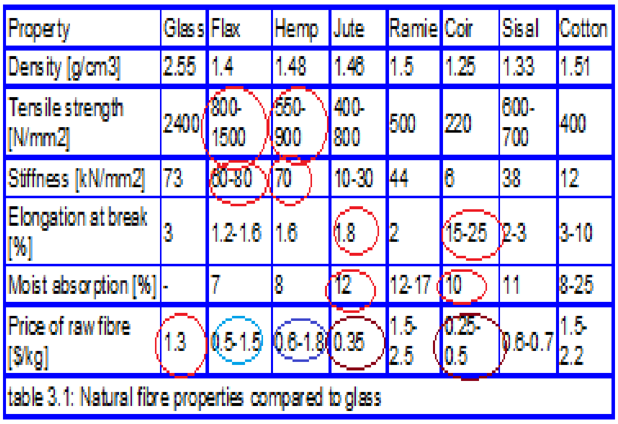
The use of natural fiber for the reinforcement of the composites has received increasing attention both by the academic sector and the industry. Natural fibers have many significant advantages over synthetic fibers. Currently, many types of natural fibers [8] have been investigated for use in plastics including flax, hemp, jute straw, wood, rice husk, wheat, barley, oats, rye, cane (sugar and bamboo), grass, reeds, kenaf, ramie, oil palm empty fruit bunch, sisal, coir, water, hyacinth, pennywort, kapok, paper mulberry, raphia, banana fiber, pineapple leaf fiber and papyrus. Thermoplastics reinforced with special wood [2] fillers are enjoying rapid growth due to their many advantages; light-weight reasonable strength and stiffness. Some plant proteins are interesting renewable materials, because of their thermoplastic properties. Wheat gluten [9] is unique among cereal and other plant proteins in its ability to form a cohesive blend with viscoelastic properties once plasticized. For these reasons, wheat gluten has been utilized to process edible or biodegradable films or packing materials. Hemp [10] is a bast lingo cellulosic fiber, comes from the plant Cannabis sativa and has been used as reinforcement in biodegradable composites.

TABLE 1: MECHANICAL PROPERTIES OF NATURAL FIBRES [11]



Fiber	Tensile strength (MPa)	Young's modulus (GPa)	Elongation at break (%)	Density (g/cm^3)
Abaca	400	12	3–10	1.5
Alfa	350	22	5.8	0.89
Bagasse	290	17	–	1.25
Bamboo	140–230	11–17		0.6–1.1
Banana	500	12	5.9	1.35
Coir	175	4–6	30	1.2
Cotton	287–597	5.5–12.6	7–8	1.5–1.6
Curaua	500–1,150	11.8	3.7–4.3	1.4
Date palm	97–196	2.5–5.4	2–4.5	1–1.2
Flax	345–1,035	27.6	2.7–3.2	1.5
Hemp	690	70	1.6	1.48
Henequen	500 ± 70	13.2 ± 3.1	4.8 ± 1.1	1.2
Isora	500–600	–	5–6	1.2–1.3
Jute	393–773	26.5	1.5–1.8	1.3
Kenaf	930	53	1.6	–
Nettle	650	38	1.7	–
Oil palm	248	3.2	25	0.7–1.55
Piassava	134–143	1.07–4.59	21.9–7.8	1.4
Pineapple	1.44	400–627	14.5	0.8–1.6
Ramie	560	24.5	2.5	1.5
Sisal	511–635	9.4–22	2.0–2.5	1.5

TABLE 2: NATURAL FIBRE PROPERTIES COMPARED TO E-GLASS [12]

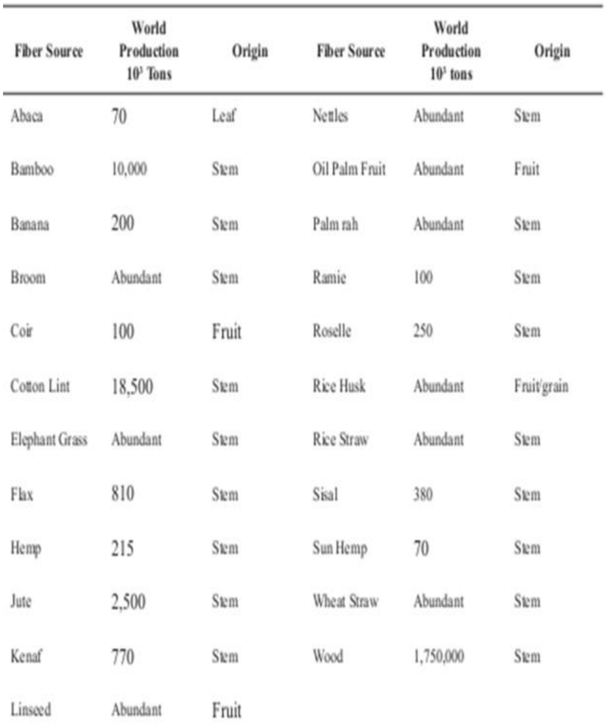


Property	Glass	Flax	Hemp	Jute	Ramie	Coir	Sisal	Cotton
Density [g/cm3]	2.55	1.4	1.48	1.46	1.5	1.25	1.33	1.51
Tensile strength [N/mm2]	2400	800-1500	550-900	400-800	500	220	600-700	400
Stiffness [kN/mm2]	73	60-80	70	10-30	44	6	38	12
Elongation at break [%]	3	1.2-1.6	1.6	1.8	2	15-25	2-3	3-10
Moist absorption [%]	-	7	8	12	12-17	10	11	8-25
Price of raw fibre [$/kg]	1.3	0.5-1.5	0.6-1.8	0.35	1.5-2.5	0.25-0.5	0.6-0.7	1.5-2.2

table 3.1: Natural fibre properties compared to glass

In the above table natural fibres are presented and compared to the properties of E-glass fibre. With respect to the natural fibres one has to keep in mind that large variation in properties exists due to natural circumstances.

TABLE 3: ANNUAL PRODUCTION OF NATURAL FIBRE AND SOURCES

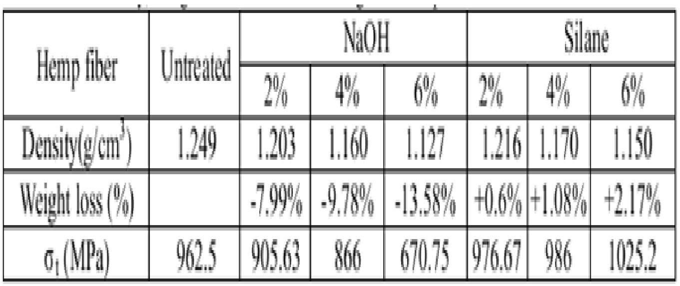


Fiber Source	World Production 10^3 Tons	Origin	Fiber Source	World Production 10^3 tons	Origin
Abaca	70	Leaf	Nettles	Abundant	Stem
Bamboo	10,000	Stem	Oil Palm Fruit	Abundant	Fruit
Banana	200	Stem	Palm rah	Abundant	Stem
Broom	Abundant	Stem	Ramie	100	Stem
Coir	100	Fruit	Roselle	250	Stem
Cotton Lint	18,500	Stem	Rice Husk	Abundant	Fruit/grain
Elephant Grass	Abundant	Stem	Rice Straw	Abundant	Stem
Flax	810	Stem	Sisal	380	Stem
Hemp	215	Stem	Sun Hemp	70	Stem
Jute	2,500	Stem	Wheat Straw	Abundant	Stem
Kenaf	770	Stem	Wood	1,750,000	Stem
Linseed	Abundant	Fruit			

Incorporation of hemp fibres into the polyester resin resulted in negligible improvement in tensile strength of the neat polyester resin but almost doubled the tensile modulus to 7.2 GPa. The addition of a small proportion of glass fibres to the hemp, producing a hybrid composite, resulted in almost 50% improvement in tensile strength and 10% improvement in tensile modulus.[13]

The effects of chemical surface treatment on the hemp fibers and mechanical properties of hemp fiber composites were investigated. After chemical treatment of the fiber, the density and weight loss were measured. The surface morphologies of fibers were observed using SEM, and FT - IR was utilized to characterize the chemically modified fiber s. Among the tested samples, the 4 wt% NaOH- treated fiber composites demonstrated the best mechanical properties [13].

Table4: The Density, Weight Loss and Tensile Strength of Hemp Fibre after Chemical Treatments



Hemp fiber	Untreated	NaOH			Silane		
		2%	4%	6%	2%	4%	6%
Density(g/cm^3)	1.249	1.203	1.160	1.127	1.216	1.170	1.150
Weight loss (%)		-7.99%	-9.78%	-13.58%	+0.6%	+1.08%	+2.17%
σ_1 (MPa)	962.5	905.63	866	670.75	976.67	986	1025.2

The tensile properties of natural fiber reinforce polymers (both thermoplastics and thermosets) are mainly influenced by the interfacial adhesion between the matrix and the fibers. Several chemical modifications are employed to improve the interfacial matrix–fiber bonding resulting in the enhancement of tensile properties of the composites. In general, the tensile strengths of the natural fiber reinforced polymer composites increase with fiber content, up to a maximum or optimum value, the value will then drop. However, the Young's modulus of the natural fiber reinforced polymer composites increase with increasing fiber loading. The tensile strength and Young's modulus of composites reinforced with bleached hemp fibers increased incredibly with increasing fiber loading[15].

Natural fibers are potentially a high-performance non-abrasive reinforcing fiber source. In this study, pulp fibers [including bleached Kraft pulp (BKP) and thermo mechanical pulp (TMP)], hemp, flax, and wood flour were used for reinforcing in polypropylene (PP) composite. The results show that pulp fibers, in particular, TMP-reinforced PP has the highest tensile strength, possibly because pulp fibers were subjected to less severe shortening during compounding, compared to hemp and flax fiber bundles[16].

With introduction of 5 layered hemp reinforcement (26% fibre volume fraction) into the polyester, the peak load and total energy absorbed no longer increased but decreases slightly compared to 4 layered (21% fibre volume fraction) of hemp reinforcement. This trend of decreasing peak load and total absorbed energy would be expected to continue if an additional layer of hemp was introduced. [17]

This may be due to the resin being less able to 'wet' the fibres. This indicates that 'the threshold fibre volume fraction of this composite system is approximately 21%. Beyond this, the load bearing and energy absorption capabilities of the composite system would not increase even if the volume fraction of the fibre reinforcement were increased. [17]

The strength and stiffness of hemp fibre reinforced unsaturated polyester composites in this study were found to be lower than comparable chopped strand E-glass fibre reinforced polyester composites. However, the impact test results show that the total impact energy absorbed by 21% fibre volume (4 layered) hemp rein-forced specimen is comparable to the total energy absorbed by 21% fibre volume chopped strand mat E-glass reinforced specimens.[17]

The mechanical behavior high density polyethylene (HDPE) reinforced with continuous henequen fibres (Agave fourcroydes) was studied.[18]

It was observed that the increase in stiffness from the use of henequen fibres was approximately 80% of the calculated values. The increase in the mechanical properties ranged between 3 and 43%, for the longitudinal tensile and flexural properties, whereas in the transverse direction to the fibre, the increase was greater than 50% with respect to the properties of the composite made with untreated fibre composite. In the case of the shear strength, the increase was of the order of 50%. From the failure surfaces it was observed that with increasing fibre-matrix interaction the failure mode changed from interfacial failure to matrix failure. [18]

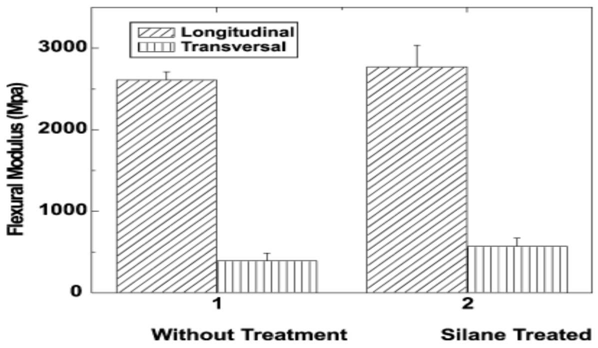


Fig1: effect of various fibre treatments on the tensile strength of HDPE-henequene composites. [18]

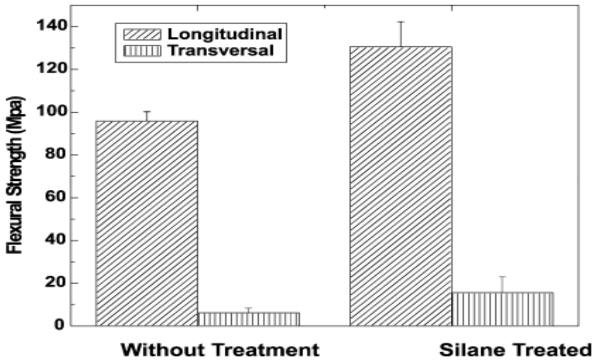


Fig2: effect of various fibre treatments on the tensile modulus of HDPE-henequene composites. [18]

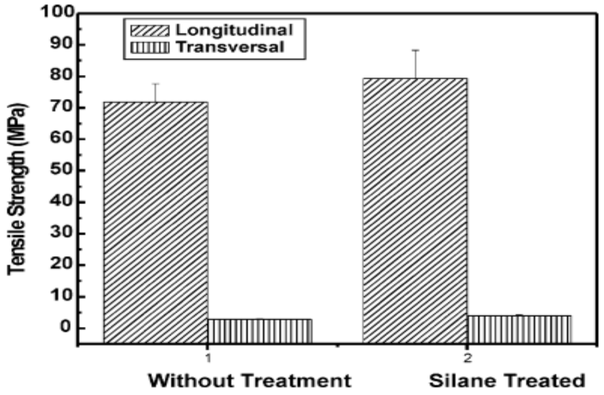


Fig3: effect of various fibre treatments on the flexural strength of HDPE-henequene composites. [18]

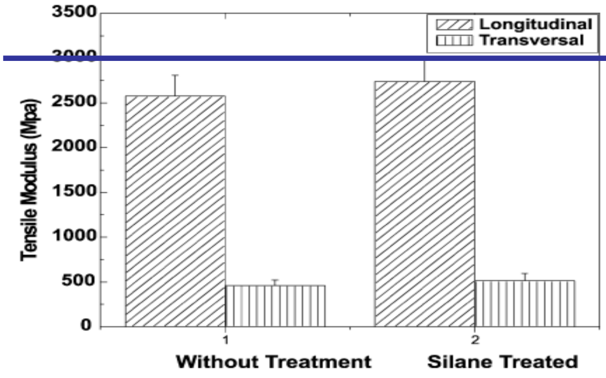


Fig4: effect of various fibre treatments on the flexural modulus of HDPE-henequene composites. [18]

The mechanical properties of the natural fibre composites tested were found to compare favorably with the corresponding properties of glass mat polypropylene composites. The specific properties of the natural fibre composites were in some cases better than those of glass. This suggests that natural fibre composites have a potential to replace glass in many applications that do not require very high load bearing capabilities. [19]

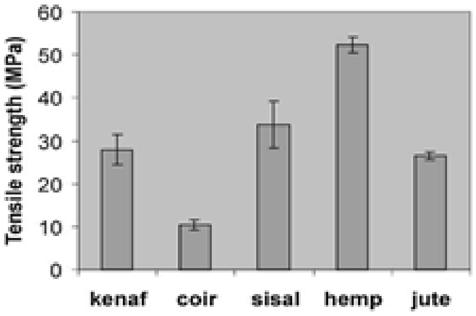


Fig5: tensile strength of Fibre reinforced polymer composites [19]

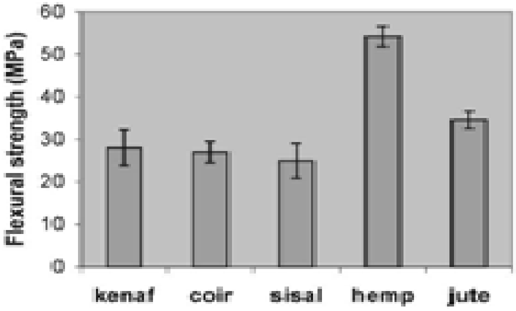


Fig6: flexural strength of Fibre reinforced polymer composites [19]

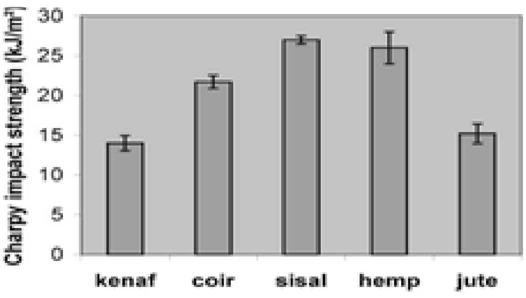


Fig7: charpy impact strength of fibre reinforced polymer composites [19]

The experiments are carried out to determine tensile, flexural and impact properties of jute and hemp reinforced with epoxy and polyester hybrid composites for 30^{o}, 45^{o}, and 90° fibre orientations. From the obtained results following conclusion have been drawn. [20]

Composite with polyester resin as matrix give more tensile, flexural and impact strength than epoxy based hybrid composites. [20]

The tensile, flexural and impact strength is observed to be maximum at 90° orientation in both epoxy and polyester based composites. [20]

Composite rotor blade built from flax/polyester and E-glass/polyester has been investigated. It is found that the flax/polyester blade is 10% lighter than the E-glass/polyester blade (fiber mass saving 45%). In conclusion it was proposed that flax is suitable structural replacement to E-glass for similar composite small wind turbine blade applications. [21]

III. TECHNICAL APPLICATIONS OF NATURAL FIBER REINFORCED COMPOSITES

Natural fibers are replacing synthetic fibers as reinforcement in various matrices. The composites so prepared can effectively be used as substitute for wood and also in various other technical fields, e.g. automotive parts.

Seventy years ago, nearly all resources for the production of commodities and many technical products were materials derived from natural textiles. Textiles, ropes, canvas and also paper, were made of local natural fibers, such as flax and hemp. Some of these are still used today. As early as 1908, the first composite materials were applied for the fabrication of large quantities of sheets, tubes and pipes for electronic purposes (paper or cotton to reinforce sheets, made of phenol or melamine-formaldehyde resins). For example in 1996, aero plane seats and fuel tanks were made of natural fibers with small content of polymeric binders. The last decade has seen a multiplicity of applications of natural fiber composites due to their impressive properties such as biodegradability and high specific properties. Currently, a revolution in the use of natural fibers, as reinforcements in technical application, is taking place mainly in the automobile and packaging industries (e.g., egg boxes). In the automotive industry, textile waste has been used for years to reinforce plastics used in cars, especially in the Trabant.

The use of natural fibers within composite applications is being pursued extensively throughout the world. Consequently, natural fiber composite materials are being used for making many components in the automotive sector. These materials are based largely on polypropylene or polyester matrices, incorporating fibers such as flax, hemp, and jute. Thus in the future cars may be molded from cashew nut oil and hemp. Even golf clubs may be built around jute fibers, and tennis racket may be stiffened with coconut hair. Bicycle frames may derive their strength from any one of the 2000 other suitable plants. The high-tech revolution in use of natural fibers could end in replacement of synthetic materials.

The diverse range of products now being produced, utilizing natural fibers and biobased resins derived from soybeans, is giving life to a new generation of biobased composites for a number of applications. These include not only automotive vehicles (including trucking) but also hurricane-resistant housing and structures, especially in the United States [22]. The construction sector and the leisure industry are some of the other areas where these novel materials are finding a market. In Germany, car manufactures are aiming to make every component of their vehicles either recyclable or biodegradable [23].

IV. CONCLUSION

Natural fibers, when used as reinforcement, compete with such technical fibers as glass fiber. The advantages of technical fibers are good mechanical properties; which vary only little, while their disadvantage is difficulty in recycling. Several natural fiber composites reach the mechanical properties of glass fiber composites, and they are already applied, e.g., in automobile and furniture industries. Till date, the most important natural fibers are Jute, flax and coir. Natural Fibers are renewable raw materials and they are recyclable.

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