*Available online at*www.ijpab.com

DOI: http://dx.doi.org/10.18782/2320-7051.5876

ISSN: 2320 – 7051

Int. J. Pure App. Biosci. **5(5):** 509-514 (2017)

Research Article

International Journal of Pure & Applied Bioscience

OPEN ACCESS

Natural Fibre Composites- An Opportunity for Farmers

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Received: 5.09.2017 | Revised: 7.10.2017 | Accepted: 13.10.2017

ABSTRACT

Previously farmers have limited choice to earn, only edible and cash crops were grown and used. But nowadays other plantations excluding cash crops offer a better alternative to earn their livelihood. The idea of combining two or more different materials resulting in a new material with improved properties exists from ages. Fibre is a unit of matter characterisedby flexibility, fineness and a high ratio of length to thickness. Because fibres have a high surface to volume ratio, they can be extremely strong materials.The composite materials have the combined advantages of each individual material. For time immemorial, man has been using fibres along with a binder or matrix for stronger materials. The usage of plant fibres for strengthening and preventing bricks and pottery from cracking were practisedby the Pharaohs of Egypt and the ancient Incan and Mayan civilisations. The natural fibres used due to its low cost, high specific modulus, lightweight, lower energy requirement means less wear and tear in processing, wide availability, biodegradability and resistance to deforestation. The use of natural fibres as a reinforcing agent in both thermoset and thermoplastic polymer composites gained inroads from automotive, aerodynamic to biomedical engineering materials.

Key words: *Natural Fibre, Composites, Farmers, Engineered Materials, Plant Fibre*

INTRODUCTION

Natural plant fibres as a sustainable alternative to man-made fibres as composites fillers. The properties of natural plant fibres are dimensional stability, reaction to fire and mechanical properties of the fibre. The natural plant fibre shows high variability of properties depending upon fibre characteristics, the coupling between fibre/matrix, type of matrix, production process and possible additives.These natural plant fibre also shown dependence on the service conditions[4].

What are Composites?

As per TIFAC, "Composite materials are formed by the combination of two or more materials that retain their respective characteristics when combined to achieve properties (physical, chemical, etc.). that are superior to those of individual constituents. The main components of composites are reinforcing agents and matrix".

The fibres, particulates and whiskers act as the reinforcement and provide most of the stiffness and strength.

Cite this article: Bhardwaj, S. and Sharma, R., Natural Fibre Composites- an Opportunity for Farmers, *Int. J. Pure App. Biosci.* **5(5):** 509-514(2017). doi: http://dx.doi.org/10.18782/2320-7051.5876

The matrix binds the reinforcement together thus affecting the load transfer from matrix to reinforcement. Other substances such as fillers are used to reduce the cost and improve processability and dimensional stability.

Why Composites?

Composites can meet diverse design requirements with significant weight savings as well as a high strength-to-weight ratio as compared to conventional materials. The properties and advantages were quoted from TIFAC.

- The tensile strength of composites is four to six times greater than that of steel or aluminium.
- Improved torsional stiffness and impact properties
- Composites have *higher fatigue endurance limit* (up to 60% of the ultimate tensile strength).
- Composite materials are 30-45% lighter than aluminium structures designed to the same functional requirements
- Lower *embedded energy* compared to other structural materials like steel, aluminium etc.
- Composites are *less noisy* while in operation and provide *lower vibration transmission* than metals.
- Composites are *more versatile* than metals and can be tailored to meet performance needs and complex design requirements.
- Long life offers excellent fatigue, impact, environmental resistance and reduced maintenance.
- Composites enjoy *reduced life-cycle cost* compared to metals.
- Composites exhibit excellent *corrosion resistance* and *fire retardancy*.
- Improved appearancewith smooth surfaces and readily incorporable integral decorative melamine are other characteristics of composites.
- Composite parts can eliminate joints/fasteners, providing part simplification and integrated design compared to conventional metallic parts

Plant fibres includebast (or stem or soft sclerenchyma) fibre, leaf or hard fibre, seed, fruit, wood, cereal straw and other grass fibres. These parts of plants are primarily used for natural fibre as composite materials. Mainly cellulose and lignocellulose natural fibres will be obtained from the plants and farm crops. Table 1 demonstrates the natural cellulose/lignocellulose fibres derived from parts of the plant.

Table 1: Cellulose and Lignocellulose Natural fibres[3]

Natural Fibres						
Bast	***Leaf***	***Seed***	***Fruit***	***Wood***	***Stalk***	***Grass/reeds***
Flax	Sisal	Kapok	Coir	Softwood	Rice	Bamboo
Hemp	Banana	Cotton	Oil Palm	Hardwood	Wheat	Bagasse
Jute	Abaca	Loofah			Barley	Corn
Ramie	PALF	Milk Weed			Maize	Sabai
Mesta	Henequen				Oat	Rape
Kenaf	Agave				Rye	Esparto
Rosella	Raphia					Canary

Mechanical Properties of the Natural Fibres Composite:

Natural fibre (such as kenaf, jute, hemp) reinforced polymer composites reflects outstanding, comparable mechanical and dynamic mechanical properties of steel and aluminium, leading to extending its application for special engineering materials such as automotive, aerospace industry and construction structures[7]. Table 2 describes the natural fibre strength and their mechanical properties for their application as a reinforcing agent in the thermoset and thermoplastic polymer composites and their mechanical and physical properties were given in table 4 for comparison. A variety of natural fibre based polymer composites materials has been developed using modified synthetic strategies to extend its application. Natural fibres such as: coconut, sisal, jute, ramie bast, eucalyptus pulp, malva, banana, hemp, kenaf bast, flax, pineapple leaf, sansevieria leaf, abaca leaf, bamboo, date, palm, sugarcane fibre and cotton are being commonly used reinforced in the polymer system to complement the certain specific properties in the final products.

Natural fibres, as a substitute for glass fibres in composite components currently were used in the housing sector. Fibres like flax, hemp or jute are cheap, have better stiffness per unit weight and have a lower impact on the environment as given in table 4. Structural applications are rare since existing production techniques are not applicable and availability of semi-finished materials with constant quality is still a problem.

Because of moderate mechanical properties of natural fibres giving obstraction for their use in high-performance applications (e.g. where carbon reinforced composites were used previously), but for many reasons, they can compete with glass fibres. Advantages and disadvantages determine the choice. As shown in table 4, low specific weight, which results in a higher specific strength and stiffness than glass is suitable for flexural design where moderate to high stiffness of the material is required. The physical and mechanical properties of the plant fibre were given in table 4 for comparison with other man-made composites and advantages they offer.

Recently the use of natural fibres for composite applications is being investigated intensively in Europe. As a result, many components of the industry now produced in natural composites, mainly based on polyester or polypropylene fibres like flax, jute, sisal, banana or ramie. The use of renewable natural fibres contributes to sustainable developments.The incorporation of natural fibres as a reinforcing agent in both thermoset and thermoplastic polymer composites was described in table 2.

Table 2: Natural Fibres Based Polymer Composites[7]

Reinforcement	**Matrix**
Thermoset polymer composites	
Ramie fibre	Epoxy
Banana Fibre	Polyester
Untreated and alkali-treated jute fibre	Vinyl-ester
Sansevieria cylindrical fibre	Polyester
Eucalyptus wood cellulose fibre	Phenolic
Oil Palm empty fruit bunch fibre	Epoxy
Untreated and treated coconut sheath fibre	Epoxy
Treated and untreated agave continuous fibre	Epoxy
Jute fibre	Polyester
Sisal fibre	Epoxy
Kenaffibre	Polyester
Thermoplastic polymer composites	
Short coir fibre	Natural rubber
Kenaffibre	HDPE
Short hemp fibre	Polypropylene
Short sisal fibre	Polystyrene
Wood flour	Polypropylene
Pineapple leaf fibre	Polypropylene
Jute fibre	Polypropylene
Sisal fibre	Rubber seed oil polyurethane
Oil palm microfibril	Natural rubber
Bio-composites	
Modified jute fibre	Biopol
Kenaffibre	Poly(lactic acid)\Thymol
Woven hemp fibre	Poly(lactic acid)
Short ramie fibre	Poly(lactic acid)
Wood-fibre	Polylactide
Cotton stalk bastfibre	Poly(butylene succinate)
Flax fibre	Poly(lactic acid)

Natural fibre composites can be used as a substitute for timber as well as for some other applications. Natural fibres composites maybe moulded into sheets, boards, gratings, pallets, frames, structural sections and many different shapes. As per TIFAC, Natural Fibres composites maybe used as a substitute for wood, metal or masonry for partitions, false ceilings, facades, barricades, fences, railings, flooring, roofing, wall tiles etc.

TIFAC used natural fibre composites in pre-fabricated housing, cubicles, kiosks, awnings, sheds/shelters. Natural fibres due to their adequate tensile strength and suitable specific modulus enjoy the right potential for usage in composites thus ensuring a value-added application avenue. The maximum tensile, impact and flexural strengths for natural fibre composites reported so far are 104.0 MN/m^2 (jute-epoxy), 22.0 kJ/m^2 (jute-polyester) and 64.0 MN/m^2 (banana-polyester) respectively. (Source: *http://tifac.org.in/.)*

Although the tensile strength and Young's modulus of natural fibre like jute are lower than those of glass fibres, the specific modulus of jute fibre is superior to that of glass, and on a modulus per cost basis, jute is far superior. The specific strength per unit cost of jute, too, approaches that of glass.

The need for using jute fibres in place of the traditional glass fibre partly or wholly as reinforcing agents in composites stems from its lower specific gravity (1.29) and higher specific modulus (40 GPa) of jute compared with those of glass (2.5 and 30 GPa respectively). Apart from much lower cost and renewable nature of jute, the much smaller energy requirement for the production of jute (only 2% of that for glass) makes it attractive as a reinforcing fibre in composites. (Ref. TIFAC)

Regarding tensile properties, bamboo and flax perform better than coir fibres in absolute terms. But in comparison to glass fibre composites, natural fibre composites perform less in compression. Strength ratio of natural fibre composites is about 60%to 80% as per Vuure *et al.*[10]and if we compare the flexural and impact strength of the natural fibre, the flax shows highest flexural and impact strength. Table 3 list the flexural and impact strength of few fibres quoted in the literature. Flexural and impact strength properties of fibre are of great use in structural component design and have broader applications but due to brittleness, the variability of the properties and moisture absorption, this property was found difficult to inclusion in composites.

Table3: Flexural and Impact Strength of the Natural Fibre[2]

Fibre	Flexural strength in MPa	Flexural Modulus in GPa	Impact strength in KJ/m^2
Bamboo	40-50	4-5	
Sisal	29.28-62.50	1.29-3.16	8.76
Coir			13.11
Jute	60-80	6-8	13.44
Banana	57.33	8.9	
Kenaf	19.43	18.22	
Flax	200-250	20-25	70-80
Hemp			7.41
Coconut			8.36
Rice Husk	19.43	2.86	
Palmyra	59.19	3.59	
Curaua	200-250	12-20	
Pineapple	80.2	1.3	
Banana	57.33	8.9	

The natural fibre shows low levels of embodied energy compared to synthetic fibre. They have high specific properties, the specific energy absorption of the plant fibre composites is critical to maintaining a low mass. The natural fibres show high values of specific energy absorption[5] experimentally quotes the specific energy absorption of unwoven hemp 54.3 J/gm, woven flax 48.5 J/gm and woven jute 32.6 J/gm. The property of specific energy absorption of natural fibres was affected by fibre volume fraction, higher the fibre volume fraction more will be the specific energy absorption of plant fibre. This property of the fibre is necessary to absorb the impact, wear and tear.

The variability or uncertainty in the plant fibre composites is a significant cause of concern in their use[8]. Detailed out the standardisation of the mechanical properties of the plant fibre is necessary. The use of statistical tools and possibility distribution (probability-distribution-neutral representation of the uncertainty associated with a physical quantity) minimises the risk associated with variability of mechanical properties of the plant fibre composites. The variability of elastic modulus, strength and failure strain shows less variation in long natural fibre composites (jute, flax etc.) whereas in short fibre composites they exhibit a high order of scattering as suggested by Torres *et al*[9].

The moisture absorption in the plant fibre composites is another evil in reducing the mechanical performance of the plant fibre composites. The moisture absorption in the plant fibre composites is dependent on the fibre content, fibre length, fibre treatment/coupling agent and fibre arrangement. It also found that moisture absorption is different depending upon on its salt content in the fibre[6].

RESULTS AND DISCUSSION

The above facts are not conclusive, more and more research exists in natural fibre composites, this paper states the use of plant fibre as composites and discusses the possible manufacturing and processing of plant fibre at the village level. The main mechanical properties of natural fibre while selecting the crop or plantation will be a flexural strength, compressive strength, tensile strength and moisture abortion of the fibre. The specific properties of the natural fibre composites will be another important criterion for use in automotive and aero industry. Biopolymer could be an another frontier for natural fibre for their vastness in varieties available in plants.

Table 4: Physical and Mechanical Properties of the Natural Fibres[3]

Fibre	Density (g cm^{-3})	Length (mm)	Diameter (μm)	Strain at break (%)	Tensile Strength (MPa)	Young's Modulus (GPa)	Specific strength (MPa)	Specific modulus (GPa)	Moisture content (%)	Price(kg^{-1}) (USD)
Cotton	1.21	15-56	12-35	2-10	287-597	6-10	194-452	4-6.5	33-34	~$1.5-$2.2
Jute	1.23	0.8-6	5-25	1.5-3.1	187-773	20-55	140-320	14-39	12	~$0.926
Flax	1.38	10-65	5-38	1.2-3	343-1035	50-70	345-620	34-48	7	~$3.11
Sisal	1.20	0.8-8	7-47	1.9-3	507-855	9-22	55-580	6-15	11	~$0.65
Ramie	1.44	40-250	18-80	2-4	400-938	61.4-128	590	29	12-17	~$2
Hemp	1.35	5-55	10-51	1.6-4.5	580-1110	30-60	210-510	20-41	8	~$1.55
Coir	1.2	0.3-3.0	7-30	15-25	175	6	92-152	5.2	10	~$0.2-$0.4
Kenaf	1.2	1.4-11	12-36	2.7-6.9	295-930	22-60	246-993	18-50	6.2-12	~$0.378
Banana	1.35	0.9-0.4	12-30	5-6	529-914	27-32	392-677	20-24	10-11	-
Pineapple	1.5	3-8	8-41	1-3	170-1627	60-82	287-1130	42-57	10-13	~$0.40-$0.55
Abaca	1.5	4.6-5.2	10-30	2-9	430-813	31.1-33.6	-	-	14	~$0.345
Bamboo	0.6-0.11	1.5-4	88-25	1.3-8	140-441	11-36	383	18	11-17	~$0.5
Nettle	1.51	5.5	20-80	1.7	650	38	-	-	-	-
Hardwood	0.3-0.88	3.3	16	-	51-120.7	5.2-15.6	-	-	-	~$0.44-$55
Softwood	0.3-0.59	1.0	30	4.4	45.5-11.7	3.6-14.3	-	-	-	~$0.44-$55

CONCLUSION

TIFAC states on its website about the potential of natural fibre composites as"Globally, composite technology and its applications had made tremendous progress during the last two decades or so, as evident from the present level of consumption of composite materials at about 2.2 million MT, with the Asia-Pacific region accounting for about 24% of this usage.Currently, approximately 40,000 composite products are in use for an array of applications in diverse sectors of the industry all over the world. While China and India started making use of composites almost simultaneously about 30 years ago, the progress made in China is some what astounding with a consumption level of nearly 2,00,000 MT, as compared to about 30,000 MT in India."

With more and more realisation on the conversation of nature and natural resources, scarcity of wood looms large for the construction and housing sector. Farmer's attention required for an immediate consideration for developing suitable wood substitutes. Wood substitution, natural fibre composites would enjoy wider acceptance. India enjoys a niche for the natural fibre composites as the country has abundant varieties of natural fibre.

The products when locally manufactured would become cost competitive for other wood substitutes. Natural fibre will be an excellent opportunity for small farmers to setup natural fibre composites factories in their villages and surrounding areas just to create new composites component to cater the need of different industries like construction, automobile, etc. instead of making a new composites material. If further research is proceeding, then the invention of new biomaterial composites at a village level may be a reality for farmers.

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