Structural Composites from Natural Fibres

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Natural fibres are emerging as low cost, lightweight and environmentally superior alternative in composites. Different fibres will exhibit different properties that are fundamentally important to the resultant composites. In this paper an attempt is made to give an overview of different fibres most commonly used in composites, their extraction methods, characterization and treatments to improve fibre performance, composite manufacture and mechanical properties.

Bio composites are composite materials comprising at least one major component derived from a biological origin. The bio materials that are long textile fibres used as reinforcements are Flax, Jute, Hemp and Ramie and short fibres like wood fibres and recycled fibres. The polymer matrix used is biopolymers, but most of them are in the developmental stage. Vast majority of the composites are made from the combination of biofibres and petrochemical based matrices.

The growing interest in the field of bio composites are due to the environmental and health concerns, sustainability and lighter weight constructions. Wood based composites have been used in building construction like decking. The low mass density of the natural fibres (1.4 - 1.5gms/cm3 for flax and jute fibres compared to 2.5gms/cm3 for glass fibres) used in automobiles leads to reduced vehicle weight which in turn leads to reduced fuel consumption. Natural fibre composites used in automobiles provide better acoustic and thermal insulation.

Table 1: Examples of automotive parts produced from natural fibres

Vehicle Part	Material Used
Interior glove box	wood/cotton/sisal/flax
Door panels	flax/sisal with thermoset resin
Seat covers	leather/wool backing
Trunk panel	cotton fibre
Insulation	cotton fibre
Exterior floor panel	Flax mat with polypropylene

The hydrophilic nature of natural fibres cause poor interfacial adhesion with hydrophobic polymer matrices and hence poses some limitations in automotive uses. The most prominent natural fibres used in composite applications are plant fibres because of their high stiffness (Young's Modulus), strength and available volumes.

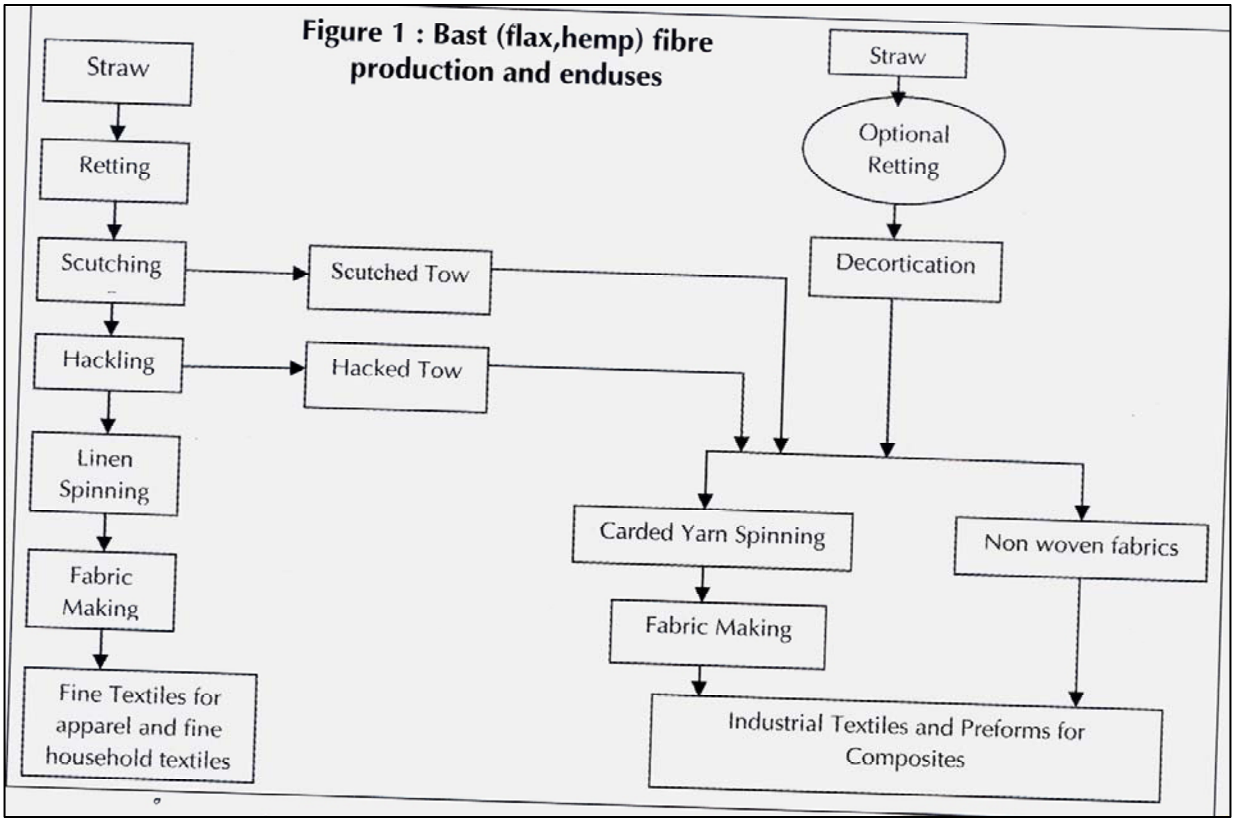
Table 2: Use of natural fibres in automotive applications

Fibre	Flax	Jute	Hemp	Sisal	Others
Percentage	64.2%	9.0%	11%	7%	7%

From the above table we see that flax occupies a major component in the usage as fibre in the manufacturing of composites.

Fibre Production

Most of the bast fibres are produced by the traditional method of fibre extraction called retting followed by manual stripping or mechanical scutching to remove the fibres from the stem. High quality flax fibres are obtained by hackling and are made into fine count yarn by wet spinning method. Both hackling and scutching produce waste fibres called tows that are used for producing coarse count yarn by dry spinning method which are used for making industrial products like sags, ropes and twines.



One thousand kilograms of flax stalks produce 30kgs of woven fabrics and 140kgs polished twines. Generally the long fibre extraction and linen spinning processes are too expensive for the production of natural fibre composites. Hence for producing natural composites waste tows are used that is competitive with glass fibres.

Retting

It is the process of removing the fibres from the woody matter and the cellular tissues that hold the fibres in the plant stem. Under suitable conditions various fungi and bacteria present in the atmosphere colonize the stalks and their enzymes attack pectic elements. Retting makes the removal of fibre from the stalk easier so that less mechanical actions are required in fibre extraction. Retting can be done by dew, water and chemical methods. Water retting is banned in Europe, but it carried out is Asia. Chemical like caustic soda sodium carbonate soaps and dilute mineral acids.

Nowadays enzymes like pectinases and hemicellulases are used for retting within a short period. In the steam explosion process the raw material is first impregnated in alkali. After subjecting to steam pressure for a short period of time, the material is blown apart when the pressure is suddenly released. The disadvantage in this method is loss of strength because of exposure to high temperature involved in this process.

Table 3: Influence of Retting on fibre properties

Level of Retting	Average Fibre length (mm)	Fineness (tex)	Tear Strength (cN/tex)
Hemp, freshly harvested	66	14.9	33.8
Hemp, less retting	95	8.1	38.9
Hemp, retted	140	7.4	43.2

The use of ultrasonic waves is used to detach bast fibres from the stalk. Partially retted stalk is first mechanically broken between rollers and then it is subjected to ultrasonic treatment under water. The ultrasonic bubbles help in separating the fibres from the stalk.

The influence of retting on the characteristics of fibre is shown in the above table. In unretted fibre more cuticle and epidermal tissue remains attached to the fibre tissue. Hence if unretted fibre is used there are chances that these two tissues are susceptible to breakdown over time, limiting the useful life of resultant composites. It would be therefore be an advantage if the epidermal tissues can be removed. From Table 3 the fibres obtained from unretted stems contain more impurities and are shorter due to more severe decorticating action applied and. has less tensile strength. Lack of retting did not significantly change the reinforcing capabilities of hemp fibres.

Fibre Characterization

The fundamental equation in composite material engineering is the rule of mixtures equation for the composite elastic modulus Ec is:

$$Ec = Vf\ Ef + (1-Vf)\ Em$$

where Vf is the fibre volume fraction, Ef is the fibre elastic modulus and Em is the composite elastic modulus. The reinforcing fibres used in composites normally possess mechanical properties several times higher than the matrix and thus the fibre volume fraction ratio and the fibre mechanical properties dominate the properties of the final composites.

Tensile Properties

The commonly used a stress unit (Pascal or N/m^2 and MPa or GPa) to describe the mechanical properties. In Table 4 the tensile strength and elastic modulus of major natural and manmade fibres are given which are used in composites.

It is Evident from Table 4 that E-glass fibre is superior in tensile strength and elastic modulus compared to all other natural fibres.

Table 4: Properties of Natural and Manmade Fibres.

Fibre	Density g/cm^3	Elongation %	Tensile Strength cN/tex	Modulus cN/tex
Flax	1.5	2.7-3.2	54	1800
Hemp	1.47	2-4	47	2170
Jute	1.3	1 .5-1 .8	31	1720
Ramie	-	3.6-3.8	59	1460
E glass	2.5	0.5	75	2940
Carbon	1.4	1 .4-1 .8	-	-

The tensile properties measured on bundles of elementary fibres are considerably influenced by testing conditions, especially gauge length. Tensile strength tested at small clamping length (<3mm) could be three times as much as that tested at long clamping lengths (>25mm). This is because when the testing length is greater than the length of the elementary fibres, the fibres fail because of low shear strength of pectin binder instead of the strength of elementary fibres.

Moisture Uptake and Interfacial Bonding

Unlike glass fibre and carbon fibre, natural plant fibres can take up considerable amount of moisture when exposed to humid conditions. The moisture present in fibres can affect the resultant natural fibre composite in several ways like,

- Low fibre-matrix bonding strength
- Dimensional and shape instability
- Restriction in end use environment
- Rapid product degradation

All natural fibres are strongly hydrophilic owing to the presence of hydroxyl groups in the cellulose molecules. This caused incompatibility with hydrophobic polymer matrices. Chemical modification of natural fibres like acetylation or silylation and other treatments are reported to reduce fibre moisture sensitivity.

Preforms Architecture

Fibre volume fraction is the single most important factor in the rule of mixtures, with most mechanical properties increasing with increase in the fibre volume fraction but up to a certain limit. It has been found that for flax and hemp the fibre volume fraction achievable with random oriented fibre assemblies (non wovens) is 40% and in case of parallel fibre assemblies of yarns and rovings it could be 60%.

Fibre based Preforms

Fibre based preforms are produced by converting staple fibres into nonwoven mats. The fibres are processed in the normal spinning route till carding machine. The carded web is then folded into a batt. The carded web may be laid into a thicker batt by laying them in parallel direction or cross-laying. In parallel laying technique the carded web is placed one over the other in the same direction and in the case of cross-laid web each carded web is laid in perpendicular direction.

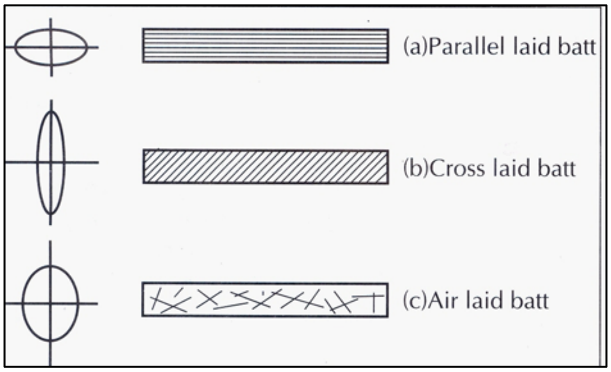


Figure 2: Architecture of nonwoven mats formed by different laying methods and their preferential fibre orientation

Preferential fibre orientation impacts significantly on the anisotropy of the mechanical properties of the resulting composites. Elastic modulus and failure stress along the carding direction was about 20-40% higher than the perpendicular to the carding direction. On the other hand there is little difference in the moisture uptake along these two directions.

Mat consolidation

The batt thus formed is very bulky and have less mechanical strength. They have to be consolidated or bonded to ensure easy handling and convenient use as preforms for composite production. Several methods to bond these fibres are chemical bonding, thermal bonding, stitching, needle punching and hydro entanglement. The most commonly used method is the needle punching.

In needle punching, barbed needles are forced through the thickness of the fibre batt to drive a small portion of the fibre batt to the other side so as to interlock the fibres together. The level of batt densification depends on the number of needle punches per unit area, the depth of needle penetration and fibre locking efficiency of the barbed needles. Increasing needle density and needle penetration depth do cause mechanical damage to the fibres. The modulus and impact resistance of the fibre composites in general peaked at a needle density of approximately 200 needle punches/cm^2.

Composite Manufacturing Technology

A survey conducted by German Automobile Industry showed that in 2005 over 60% of the natural fibre composites were manufactured by thermoplastic press moulding and 65% by thermoset press moulding. The cellulose structure of natural fibres begins to degrade at 180200°C. The most widely used thermoplastic forming methods is the hot press moulding of natural fibre nonwoven mat thermoplastics to make interior components for the automotive industry. Fibres are combined with maleicanhydride -modified Polypropylene either by blending PP fibres into the nonwoven preforms wit~ polymer sheets. Components are press bonded at 180°C briefly, because long residence time will damage the fibres. Pultrusion technology has been adopted for processing Flax/PP blended fibres into thermoplastic profiled composites.

Thermosetting polymers such as epoxy, polyester and phenolic resins have been found to penetrate and wet out easily in natural fibre preforms. The thermoset composites are made by resin infusion methods. Across the literature the fibre volume fraction generally lie in the range of 35-50%. However fibre quality, type, architecture, refinement level and moisture content affect product properties enormously.

Life Cycle Assessment

Natural fibre composites are superior to synthetic/glass fibre composites for the following reasons:

(1) Natural fibre production has low environmental impact compared to glass fibre production;
(2) Natural fibre composites have high fibre content for equivalent performance, reducing more polluting base polymer content;
(3) The light weight natural composites improve fuel efficiency and reduce emissions in the use phase of the component in automobile applications; and
(4) End of life incineration of natural fibre results in recovered energy and carbon credits. The Life Cycle Assessment (LCA) standards ISO 14040-43 include the ecological implications of the whole life cycle of the product as well as its by-products. LCA focuses on the entire life cycle of a product from raw material to final product disposal, its environmental effects, damage to ecosystems and human health. The properties of composites are mainly determined by the fibres, but the environmental impact of the composites is determined by the matrix.

Conclusion

The use of natural fibres in composites has experienced a rapid growth with still some major technical and economical challenges ahead. Majority of the natural fibre composites contain too much short fibres and they are suitable for nonwoven processing and finally end up in manufacturing of composites with moderate mechanical properties. Fibre orientation plays a major role in achieving maximum fibre fraction ratio and fibre utilization efficiency in the resulting composites. A high moisture absorption property of natural fibres is a disadvantage in composite applications. Biocomposites are typically made from a combination of natural fibres and petrol based resins.

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