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A Review on Natural Fiber Composites and Its Applications

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ABSTRACT

The high demand for environmental friendly materials from natural resources gains attention from last decades. Synthetic materials can be replaced by the natural fibers which lead to prepare the cost effective, bio-degradable, toxic free materials. In this paper, we were focusing on a detailed review of the different types of natural fibers and their physical properties and compositions, chemical and surface treatments. We summarize major findings from the literature and the treatment effects on the properties of the natural fibers are being highlighted.

Key Words: Natural Fibers, Mechanical Properties, Chemical Treatment, Composites.

1. INTRODUCTION

The present world is facing a problem on usage of plastic which are non biodegradable, toxic and harmful to the world. To eradicate this difficulty natural fibers are the best option. Natural fibers are playing a vital role in the process of replacement of plastics. Due to the vital advantages of natural fibers namely cost effective and surplus in nature, blending with matrix makes its effective in the case of thermal, physical, chemical and mechanical properties to be used for applications.

Natural fiber:

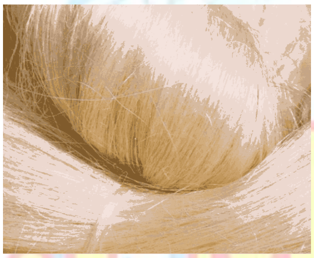
Natural fibers are elongated substances produced by the plants and animals that can be spun into filaments, thread or rope. They can be used as a component of composite materials, where the orientation of fibers impacts the properties. Natural fibers may be classified according to their sources as cellulosic (from plants), protein (from animals) and minerals. Plants fibers may be seed hairs, such as cotton; bast fibers, such as linen; leaf, such as sisal; and husk fibers, such as coir from the coconut. Animal fibers include wool, hair, fur and secretions, such as silk. The only important mineral fibers are asbestos; but due to its associated health problems, it is of little economic consequence present days. Among them, plant fibers are popularly used to reinforce composites (Thi Thu et.al 2018).

Plant Fibers:

- Seed Fiber: The seeds and fruits of plants are attached to hairs or fibers or encased in husk that may be fibrous. These fibers are collected from the seeds of the various plants. These are cellulosic based fibers.


Example: Cotton Fiber, Coconut Fiber/Coir Fiber, Bamboo Fiber, Milkweed Fiber, Coffee Fiber etc.

- **Leaf fiber:** leaf Fibers are a type of plant fiber mainly used for the production of rope. These are typically hard, rigid fibers collected from the cells of a leaf. The toughness is due to their increased lignin content when compared to the other group of plant fibers.

Example: Abaca, Cantala, Henequen, Sisal etc

- **Bast Fiber:** it is a type of plant fiber collected from the phloem or bast surrounding the stem of certain dicotyledonous plants. These are obtained either from cultivated herbs or wild plants.


Example: Flax, Jute, hemp, Ramie, Kenaf etc.

- **Animal Fiber:** these are the natural fibers that can be sourced to animals. These are consisting of different kinds of protein, extracted from different animals usually they have different properties.


Example: silk, wool, hair/fur , feathers etc.

Some of the difference between natural and synthetic fiber

Aspects	Natural fiber	Synthetic fiber
Density	Low	High
Renewability	Low	Double
Recyclability	Yes	No
Consumption of energy	Low	High
Biodegradability	Yes	No
Carbon dioxide	No	Yes
Health risk	No	Yes
Eco friendly	Yes	No

Types of Natural Fiber

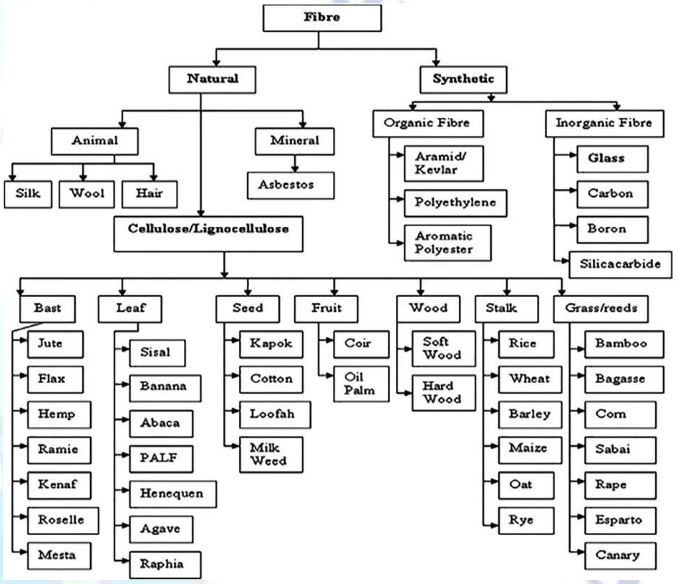


Fig 1. Classification of natural fiber(Ramengmawii Siakeng, Mohammad Jawaid et.al 2018)

Composites:

Composites are simply a combination of two or more constituent materials with different physical or chemical properties. When combined, they produce a material with characteristics different from their original properties. The two main components within a composite are the matrix and fiber. The most widely used meaning is the following one, which has been stated by Jartiz "Composites are multifunctional material systems that provide characteristics not obtainable from any discrete material. They are cohesive structures made by physically combining two or more compatible materials, different in composition and characteristics and sometimes in form". Beghezan defines composites as, "The composites are compound materials which differ from alloys by the fact that the individual components retain their characteristics but are so incorporated into the composite as to take advantage only of their attributes and not of their short comings", in order to obtain improved materials. Van Suchetclan explains composite materials as heterogeneous materials consisting of two or more solid phases, which are in intimate contact with each other on a microscopic scale. They can be also considered as homogeneous materials on a microscopic scale in the sense that any portion of it will have the same physical property. (D. Chandramohan1*& .K. Marimuthu2 et.al 2011).

Types of Composites:

Composites are usually classified by the type of material used for the matrix. The four primary categories of composites are

- Polymer Matrix Composites (PMCs)
- Metal Matrix Composites (MMCs)
- Ceramic Matrix Composites (CMCs) and
- Carbon Matrix Composites (CAMCs).

Merits of Composites:

Advantages of composite materials over conventional ones are as follows:

- Tensile strength of composites is four to six times greater than that of steel or aluminum (depending on the reinforcements).
- Improved tensional stiffness and impact properties.
- Higher fatigue endurance limit (up to 60% of ultimate tensile strength).
- 30% - 40% lighter for example any particular aluminum structures designed to the same functional requirements.
- Lower embedded energy compared to other structural metallic materials like steel, aluminum 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.

Composition of Natural Fiber:

There are three main ingredients in natural fiber: hemi-cellulose, lignin, and cellulose. Cellulose is a biopolymer available on earth; plants are composed of this material. It is considered as a linear organic compound with formula $(C_6H_{10}O_5)n$.& Hemicelluloses are heterogeneous bi-polymers are made of monomers (with a degree of polymerization from 200 to 300). The strength and hardness of the plant fibers are intrinsically linked with the percentage and extent of monomers in the polymers. Examples of monomers are mannose, arabinose, galactose, glucose, and xylose. Besides these monomers, acidic sugars like glucuronic and its acids also exist in hemicellulose polymers. Legnin is a combination of heterogeneous tri- polymers. Lignin is polymers based on basically three monolinguals: p-coumaryl, sinapyl, and coniferyl alcohol. (AL-Oqla, F. M., & Salit, M. S. (2017). Physical & mechanical properties of natural fibers are enriched with low density and high tensile strength.(Pacheco-Torgal et al (2011)). The percentage composition of each of these components varies for different fibers. The percentage composition of each of these components varies for different fibers. Generally, the fibers contain 60 – 80% cellulose, 5 – 20% lignin, and up to 20% moisture.(D. NABI SAHEB and J. P. JOG et.al 1999).

Table1. Chemical compositions of some natural fibers
(Kabir et al (2012))

Type fibers	Cellulose (wt.%)	Lignin (wt.%)	Hemicellulose (wt.%
Jute	61-71.5	12-13	13.6-20.4
Flax	71	2.2	18.6-20.6
Hemp	70.2-74.4	3.7-5.7	19.9-22.4
Ramie	68.6-76.2	0.6-0.7	13.1-16.7
Sisal	67-78	8.0-11.0	10.0-14.2
Cotton	82.7	0.7-1.6	5.7
Palf	70-82	5-12	--
Bamboo	49-50	23	18-20

The disadvantage of natural fiber composites includes poor fiber- matrix interfacial bonding, poor wet ability, water absorption, and moisture absorption. The hydrophilic nature of the natural fibers caused poor interfacial interaction between the polymer matrix and the fiber. Hence, it is required to optimize the fibers by chemical treatments and surface treatments. (Thyavihalli Girijappa et.al 2019).

Table 2. Mechanical Properties of Some Natural Fibers (d. Nabi saheb and j. P. Jog et.al 1999).

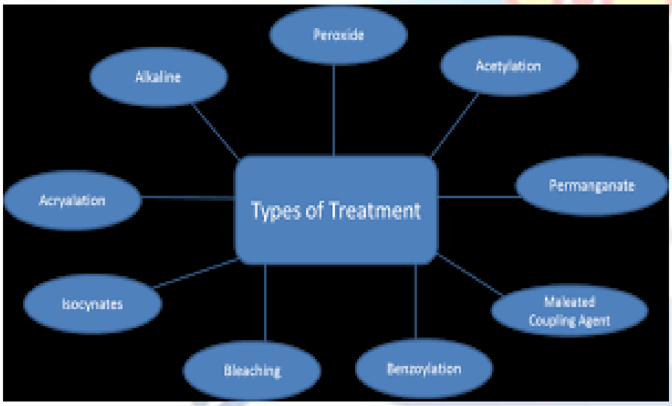
Fiber	Specific Gravity	Tensile Strength (MPa)	Modulus (GPa)	Specific Modulus
Jute	1.3	393	55	38
Sisal	1.3	510	28	22

Flax	1.5	344	27	50
Sun hemp	1.07	389	35	32
Pineapple	1.56	170	62	40
Glass Fiber-E	2.5	3400	72	28

The above table indicates that, the tensile strength of glass fibers is substantially higher than that of natural fibers even though the modulus is of the same order. However, when the specific modulus of natural fibers (modulus/specific gravity) is considered, the natural fibers show values that are com- parable to or better than those of glass fibers.

Treatment of Natural Fibers:

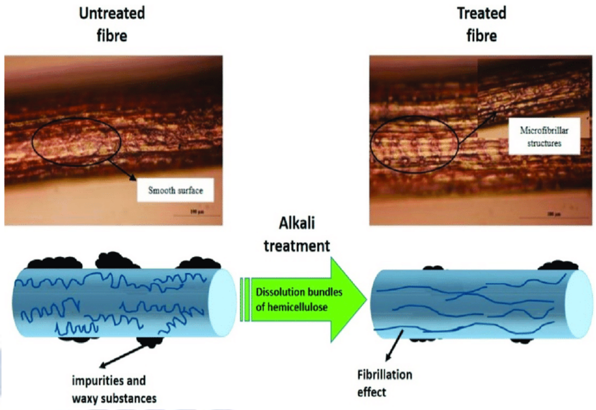
Several research studies have been carried out on the surface modification and treatments of natural fibers to achieve the desired qualities. However, the mechanical performance of a composite material also depends on the orientation and nature of fibers and matrix, while the fibers-matrix bonding plays a very important role as well. Chemical, physical, or biological treatments of natural fiber helps remove the impurities from the fiber surface and can reduce its hydrophilicity, while increasing fiber/matrix compatibility.



Chemical Treatment:

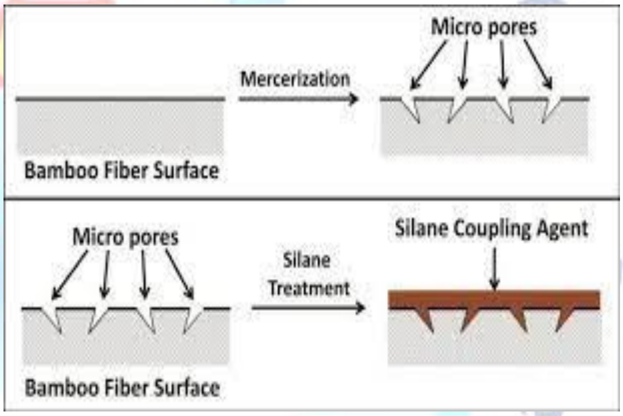
- **Alkali treatment**

  It reduces fiber diameter by breaking the fiber bundle, thereby increases the surface are of fiber which results in good adhesion with the matrix and improves mechanical and thermal behaviors of the composite.

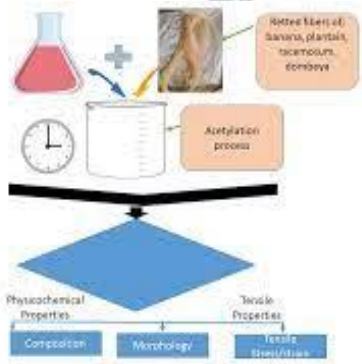


- **Silane treatment :**

  It is one of the most effective coupling agents for natural fibers surface modification. It is a multifunctional molecule which deposit on the fiber surface which makes better linkage with the matrix through a siloxane bridge. It improves the fiber matrix adhesion and stabilizes the composite properties.

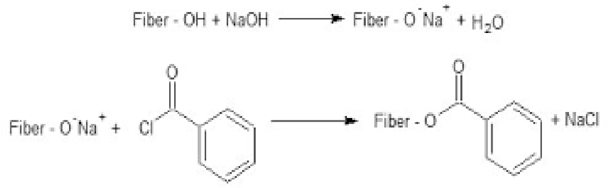


- **Acetylation treatment:**This treatment is known as esterification process for plasticizing natural fibers. The reaction of Acetyl group (CH3CO) with the hydroxyl groups (–OH) reduce the hydrophilicity of natural fiber and improves dimensional stability of the composites.

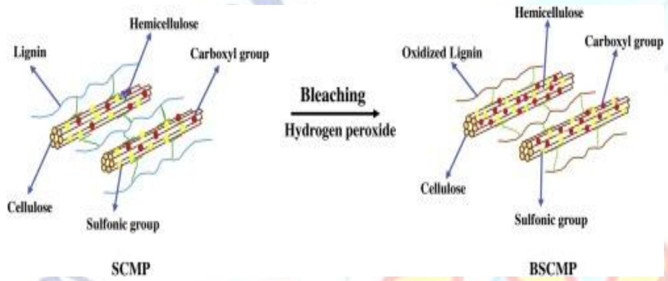


- **Benzoylation Treatment:**

  Benzoyl chloride is used as an agent to decrease hydrophilic nature of the natural fibers and improve its compatibility with the matrix, which therefore enhance the thermal stability and strength of the composite.

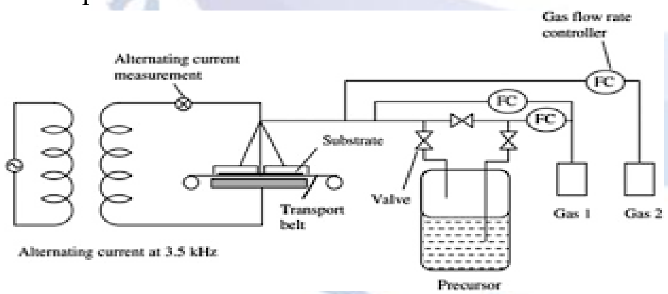


- **Peroxide treatment:**
  It improves the interfacial adhesion, thermal stability and reduces the moisture absorption of fiber and matrix.

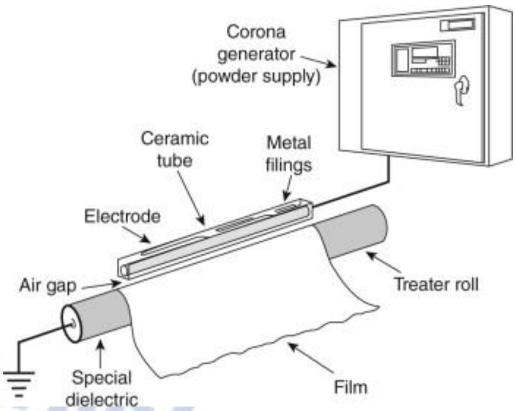


Physical Treatments

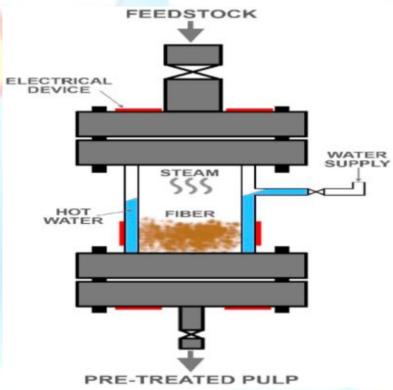
- **Plasma Treatment**
  It offers a unique approach of modifying the physio-chemical structures fiber surfaces without altering the bulk structures and characteristics of the composites. Plasma has been regarded as a clean and dry method for fiber treatments and it resulted in increased surface roughness, which facilitates better dispersion within the matrices.



- **Corona discharge**
  It is a green technique for modification of fibers and the subsequent reinforcement into composites that tend to show significant improvements in mechanical properties.



- **Steam explosion**
  Steam explosion involves heating of natural fiber materials at high temperatures and pressures followed by mechanical disruption of the pre-treated material by violent discharge (explosion) into a collecting tank. It results in fiber properties improvements which include smoother surface, reduced stiffness, improved bending properties and dispersion in the matrices.



Biological treatments

- **Enzymatic Treatment :**
  Enzyme treatments have been shown to be an effective method of treating natural fibers to improve the interface between the fibers and the matrix, leading to improved mechanical properties of the composites. However, it is expensive and limited to pilot scale only.
- **Fungal Treatment :**
  It removes non-cellulosic components and lignin from the fiber surface by the action of specific enzymes as well as increases hemicelluloses solubility and thus reduce hydrophobic tendency of the fiber.

Applications of Natural Fiber Composites:

- Electric devices: **Super-capacitors**, electrical appliances, pipes, etc.

- Used as insulating material.
- Used in Packaging industries.
- Used in Medical fields
- Military applications
- Lampshades, suitcases, helmets, etc.
- Interior of automobiles and railway coach interior, boat, etc.
- Used as fiber cements for constructions, ceiling, structural applications.
- The reasons for the application of natural fibers in the automotive industry include:
  - Low density: which may lead to a weight reduction of 10 to 30%
  - Acceptable mechanical properties, good acoustic properties.
  - Favorable processing properties, for instance low wear on tools, etc.

CONCLUSION :

A lot of research has been conducted on natural fiber composites. This work highlighted the chemical and physical composition of the natural fiber. In future, this paper will helful to reseracher to select respective natural fibers for their work based on the composition.

Conflict of interest statement

Authors declare that they do not have any conflict of interest.

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