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Chemical Treatments on Plant-Based Natural Fibers for Natural Fiber - Reinforced Polymer Composites: A Review

Shivam Panjgotra[1], Rajiv Kumar[2]

[1]Post Graduate Student, School of Mechanical Engineering, Shri Mata Vaishno Devi University, Katra, India

[2]Assistant Professor, School of Mechanical Engineering, Shri Mata Vaishno Devi University, Katra, India

Abstract: ***Natural fiber reinforced composites are the material which swaps the synthetic fiber reinforced composites due to its low cost, light- weight, low density, low health hazards, recyclability and can be decomposed easily which may be not possible in case of man-made fibers. Researchers use different types of natural fibers to make polymer composites and study their mechanical properties. It is found that the interfacial bonding between the plant based fiber and the matrix plays a vigorous role to get good mechanical properties of composites but due to the presence of lignin, cellulose and hemicelluloses in natural fibers the interfacial bonding between the fiber and matrix results into the poor interface. In order to remove this limitation, we need to do chemical treatment on natural fibers. In this paper, different types of chemical treatments on natural fibers such as silane, alkali, benzoylation, acetylation, isocyanates, and peroxide will be discoursed to advance the interface adhesion properties.***

Keywords: natural fiber, synthetic fiber, composites, chemical treatment, lignin, cellulose

1. Introduction

Natural fibre-reinforced composites consist of the polymer as a matrix and fiber as reinforcement. Natural fibres are take out from plants such as banana, sisal, hemp, coconut, ramie, jute, palm, bamboo and sugarcane [1].

Polymer used for making composites may be of thermoplastic or thermoset type. The thermoplastic polymer is a polymer that turns into moldable when heated and become inelastic on cooling [2]. A few examples of thermoplastics are PVC, nylon and PLA. Thermoplastic materials can be changed into different shapes when they are in softened or melted. Thermoplastic has low thickness, low weight. In contrast, thermosetting polymer is the polymer which is very rigid, not moldable easily and soften when they are heated. Commonly used thermosetting polymer is epoxy. They have many advantages, such as better grip on different materials, good electrical safety and good mechanical properties.

Polymer composites find its applications in automobiles, aerospace, marine, sporting goods, packaging, electronic Industries and construction industries. It is found that the automobile companies in Germany such as Mercedes, Audi, BMW, Volkswagen, etc. are the leading companies that make use of natural fiber reinforced polymer composites for making different parts of automobiles[3].

Good knowledge of interfacial bonding and chemical composition of different fibers is important for making natural fiber reinforced composites. The composition of various types of natural fibers are shown in table 1.

Table 1: Compositions of natural fibers[4]

Fibers	Cellulose (wt%)	Hemi cellulose (wt%)	Lignin (wt%)	Moisture (wt%)	Waxes
Cotton	85-90	5.7	-	7.85-8.55	0.60
Bamboo	60.80	0.5	33	-	-
Flax	71	18.5-20.5	2.03	8-12	1.7
Hemp	70-75	17.8-20.4	3.7-5.5	6.2-12	0.80
Jute	61.1-71.50	13.5-20.5	12-13	12.5-13.7	0.50
Kenaf	45-47.5	21.50	8-13	-	-
Ramie	68.4-76.20	13.1-16.7	0.6-0.8	7.5-17	0.30
Sisal	66-78	10-15	10-14	10-22	2-3
Coir	32-43	0.15-0.25	40-45	8-9	
Banana	63-64	19	5	10-12.5	-

2. Chemical treatments

Due to the hydrophilic nature of fibers, it cannot be used directly for making composites. Researchers have found a way to reduce the hydrophilic nature of fibers by doing chemical treatment on these fibers which result in increased adhesion properties between the fiber and the matrix[5]. Not only but also due to chemical treatment, waxy and pectin which covers the outward layer of fibers can be removed easily. Different researchers used different types of chemical treatments to improve the adhesion properties of fiber with the matrix.

2.1 Alkali Treatment

Alkali treatment is one of the most common and simplest methods used for the chemical treatment of fibers. Alkali treatment is used to disordering the hydrogen bonding in the fiber structure and results in an increase in the surface roughness of the different fibers[6]. It also used to detach the lignin, oil and wax content from the outer surface of the fibers, break down the cellulose into monomers and the hydroxyl group gets ionized to the alkoxide.

$$\text{Fiber - OH} + \text{NaOH} \Rightarrow \text{Fiber - O - Na} + \text{water}$$

For alkali treatment, we need to submerge the fibers in NaOH solution for a certain amount of time.

V. Fiore et. al.[7] used NaOH solution for surface modification of kenaf fibers for 48 h and found that the mechanical properties of the composites are increased with the help of good adhesion properties between fiber and matrix.

A.M. Mohd Edeerozey et. al.[8] used NaOH solution on kenaf fibers with concentration (3%, 6% and 9%) for a time period of 3 h and then dehydrated for 48 h. It was found that 6% concentration shows improved results than 3% and 9% concentration of NaOH.

Laly A. Pothan et. al.[9] performed NaOH treatment on banana fibers with concentration 0.5 and 1% and found that the tensile strength of banana fibers increases from 58 Mpa to 70 Mpa

Jacob et al.[10] performed NaOH treatment on sisal fibers having a concentration (0.5,1, 2, 4,6 and 10%) and found that 4% NaOH concentration shows a maximum increase of tensile strength at room temperature.

Mishra et al.[11] examined NaOH treatment on sisal fibers with 5% and 10% NaOH employed sisal fibers with 5% and 10% NaOH and results show that 5% NaOH solution gives good adhesion properties as compared to 10% NaOH. It also removes wax and oil from the outer surface of the fibers.

Tao Yu et. al.[12] immersed the ramie fibers in NaOH solution having 5% concentration for 3h and then dried for 72 h in air. Chemical treated fibers shows better properties than untreated fibers.

2.2 Silane Treatment

In this type of treatment, silane can be used which is a multifunctional molecule and act as a coupling agent to change the fiber surface. Silane coupling agent forms a chemical link between fiber and the matrix to increase the adhesion properties between fiber and the matrix.

P.J. Jandas et. al.[13] used 3-amino propyltriethoxysilane (APS) silane coupling agent (5 wt%) for 3h and then air and vacuum dried for 48h and 12h respectively. It is found that the chemical treated fiber composites show better results than untreated fibers.

Rong et al. performed silane treatment on sisal fiber with 2 wt% aminosilane in 95 wt% alcohol for 5 minutes and dried for 30 minutes.

Van de Weyenberg I et. al. used 3 aminopropyl trimethoxy silane (1% in acetone and water) for 2 h to improving the surface of flax fibers.

2.3 Benzoylation Treatment

In benzoylation treatment, researchers use benzoyl chloride to reduce the hydrophobic nature of plant-based fibers. For benzoylation treatment, we need to do alkali pretreatment so that the hydroxyl groups will be stimulated. After that, the fiber will be immersed in C6H5CH2Cl for some time. It is found that the adhesion between fiber and the matrix will be increased and the strength of composites will also be increased.

Chandra Rao et. al.[14] performed benzoylation treatment on coir fiber by means of pretreating the fiber with 10% NaOH and then immersed in C6H5CH2Cl. After that, the treated fibers were immersed in ethanol to remove excessive C6H5CH2Cl.

Nair et. al.[14] treated the sisal fibers with NaOH and C6H5CH2Cl. It is found that by means of the assistance of benzoylation, the adhesion properties will be increased.

2.4 Peroxide Treatment

Peroxide originated free activists which react with the hydroxyl group of plant-based fibers and matrix. With the help of this, the adhesion properties will be improved and improves thermal stability.

Joseph et al.[15] used 6% of benzoyl peroxide and 4% dicumyl peroxide on sisal fibers and found that the composite shows good mechanical properties and adhesion properties.

$$RO - OR \Rightarrow 2RO$$
$$RO + Cellulose - H \Rightarrow R - OH + Cellulose$$

2.5 Isocyanate Treatment

In this type of treatment, the functional group of isocyanate reacts with the hydroxyl group of lignin and cellulose and forms a chemical linkage between fiber and the matrix. Due to this linkage, the mechanical properties of composites will be heightened.

Wu et al.[16] treated the carbon fibers with isocyanate to reduce the water absorption properties of fibers and to enhance interface adhesion between fiber and the matrix.

George et al.[17] use C15H10N2O2 at 50 degrees for 30 minutes for surface modification of pineapple fiber.

2.6 Acetylation Treatment

Acetylation treatment is also called an esterification method triggering of fibers. In this, CH3CO rejoins with OH group of fiber and removes all the moisture content from fiber which results in the good interlocking of fibers with matrix and dimensional stability.

$$Fiber - OH + CH3 - C(=O) - O - C(=O) - CH3$$
$$\Rightarrow Fiber - OCOCH3\ CH3COOH$$

Nair et al.[18] used 18% NaOH for pretreatment on sisal fiber and then immersed the fibers in glacial acetic and in acetic anhydride having 2 drops of H2SO4. Results show that the treated fibers have lots of voids and become rough that provides good adhesion..

3. Conclusion

Natural fibers can be used as reinforcement in place of synthetic fibers for making composites due to its advantages like low cost, abundant in nature, low density, environmentally friendly and a lot more but the main problem with natural fibers is that it consist of a hydrophilic group which makes it incompatible with the polymer matrix. However, the researchers found a way to reduce the hydrophilic nature of natural fibers by doing different types of chemical treatments on it. Although with the help of chemical treatment, there is a bad influence on economics but it makes the fiber compatible for making composites. Not only this but also it improves moisture absorption properties and improves the thermal steadiness of composites. Nowadays a huge number of chemical treatments are available, yet chemical treatment has attained various heights of success for surface modifications of fiber.

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Author Profile

Shivam Panjgotra completed his B.Tech in Mechanical Engineering from Swami Vivekanand Subharti University, Meerut.

He is currently pursuing M.Tech from Shri Mata Vaishno Devi University, Katra under the guidance of Mr. Rajiv Kumar. His current area of research is natural fiber-reinforced polymer composites.