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EXPLORING NATURAL FIBERS AS SUBSTITUTES FOR SYNTHETIC FIBER-REINFORCED POLYMER COMPOSITES: AN IN-DEPTH REVIEW ON CHARACTERIZATION STUDIES

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ABSTRACT

Researchers and academics are increasingly focusing on natural fibers for their ecofriendly and sustainable qualities, particularly in the realm of polymer composites. The review manuscript aims to cite a thorough overview of the optimal and extensively developed natural fiber-reinforced polymer composites (NFPCs) along with their utilization. Additionally, it offers an overview of different surface modifications on natural fibers and their impact on NFPC properties. The characteristics of NFPCs exhibit variations based on attributes such as type of fiber, source, and structure. The review delves into the nature of chemical treatments on the mechanical and thermal attributed of natural fiber-fortified thermosetting and thermoplastic composites. The primary discovery indicates that treating natural fibers chemically enhances the bond between the fiber surface and the polymer matrix. This enhancement ultimately results in improved physico-mechanical and thermochemical characteristics of NFPCs.

Keywords: Natural Fibers, Extraction, Characterization studies, Green Composites.

1. INTRODUCTION

The active pursuit of environmentally friendly and biodegradable materials is aimed at meeting the evolving requirements of next-generation composite products. This endeavor is spurred by worldwide environmental issues and a growing recognition of naturally occuring green sources. The heightened integration of natural reinforcements in composites has played a crucial role in reducing the emissions of greenhouse gases and the related carbon impact of these materials.

Despite the benefits associated with green materials, challenges remain, including issues like the constrained compatibility of matrices and reinforcing natural fibers and the comparitively elevated moisture intake of these fibers.

Environment friendly composites show promise as a substitute for materials derived from petroleum. Before being widely used, there are a few obstacles that need to be overcome, such as weak fire resistance, low impact strength, reduced durability, poor interfacial adherence among matrix and natural fibrils, and moisture intake concerns.
Extensive research has focused on unraveling the characteristics of natural fiber composites, leading to the advancement of numerous processes for altering both natural fibrils and resins.

A modern survey covering lignocellulose fiber from various sources, alteration and handling methods, physical and mechanical ways of behaving, employment, life-cycle evaluation, and other important attributes of green composites becomes pivotal to fulfill the developing need for eco-accommodating materials in assorted applications. An intensive investigation like this is important to work on our understanding of the way of behaving and potential purposes of green composites.

2. Literature Review

The analysis on the physical, chemical, and thermal properties of Coccinia grandis fiber [1] as an eco-friendly alternative to harmful synthetic fibers. Tensile tests revealed that the fiber exhibited higher specific strength, attributed to its elevated cellulose content. Optical microscopic images further indicated the presence of a porous surface, facilitating improved bonding within polymer composites.

The physico-chemical analysis of Cissus quadrangularis root fiber [2]. The physical properties of CQRF are intricately linked to its chemical composition and cell wall structure,

influencing parameters like density, elongation, tensile strength, and Young's modulus. Chemical analysis revealed the presence of cellulose, hemicelluloses, lignin, wax, and moisture content. The high cellulose content in CQRF was identified as a contributing factor to its enhanced mechanical properties. Despite its favorable mechanical characteristics, the density of CQRF remains comparatively lower than that of synthetic fibers.

The physical and mechanical properties of natural fibers [3] including jute, sisal, and curaua fibers. Their analysis revealed a high cellulose content in these natural fibers through chemical composition examination, leading to minimal deformation during tensile tests. The authors emphasized that the geometric and mechanical properties of these fibers were comparable to those of other fibers commonly used in industrial applications for fiber-fortified composites.

The comprehensive analysis of several characteristics of Kigelia africana fiber [4]. In contrast to synthetic fibers, Kigelia africana fiber showcased a low density of 1.316 g/cc, making it suitable for lightweight applications. Additionally, the fiber displayed consistent thermal stability within the temperature of 212°C to 340°C, suggesting its potential use in hightemperature applications.

The characterization studies on fibers extracted from Ficus racemose [5], revealing a cellulose content of 72.63%, hemicelluloses content of 11.20%, and lignin content of 10.45% by weight. The fiber showed a tensile strength of 270 MPa with 2.57% elongation and Young’s Modulus of 67.45 GPa. The crystallinity index was determined to be 57.32%, and the fibers demonstrated thermal stability. Morphological studies indicated a fiber diameter in the range of 200-300 μm, with a roughness value of 6.763 nm as obtained from Atomic force microscopy. The conclusion drawn was that these fibers are adaptable for fortifying polymers.

In the case of Aristida adscensionis fibers [6], the authors highlighted their potential as reinforcements. With a low density value of 790 kg/m3, thermal stability up to 250°C, and cellulose content and crystallinity index of 70.78% and 58.9%, respectively, these fibers are suggested for use as polymeric reinforcements. The researchers concluded that these fibers could find applications in various household products.

The characterization of Areca Fruit Husk [7] (AFH) fibers, derived from tobacco industrial waste. The study involved analyzing the lignin, cellulose, and hemicellulose contents of the fibers, along with their physical characteristics, including density, diameter, and length. The presence of high cellulose content and low wax was identified as contributing

to increased mechanical strength and bonding properties. These characteristics position AFH fibers as promising reinforcements in biopolymer composites and potential alternatives to conventional man-made glass fibers.

The experiment on silane-treated corn stalk fiber [8] (CSF) at various weight percentages (1 wt%, 5 wt%, 9 wt%, and 13 wt%). FTIR analysis confirmed the elimination of hemicelluloses and pectin from the CSF surface, with the presence of Si-O-Si vibration stretching observed at 9 wt% and 13 wt% silane treatment. XRD results indicated that the crystallinity index (CI) and Crystallinity Size (CS) of 5 wt% silane-treated CSF were 69.7% and 5.3 nm, respectively, which were higher compared to raw CSF.

The cellulose fibril extraction from the legume of Senna auriculata [9] to assess their potential as polymer reinforcements. The studied physical properties and chemical composition uncovered that the fibers had a cellulose content of 59.6% by weight, a moisture content of 27.36% by weight, and a density of 0.3708 gm/cm3—comparatively lower than many fibers reported in the literature. FTIR analysis displayed prominent peaks corresponding to the presence of biopolymers. X-ray diffraction analyses indicated a crystallite size of 2.75 nm, a Crystalline Index of 49.6%, and thermal stability up to 205°C according to Thermo-gravimetric analysis. Surface characterization revealed densely packed fibers with a surface roughness of 79.997 nm. The study concluded that cellulose content depends on the age of the fibers and does not vary with the height of the plant, making these fibers excellent reinforcements for polymer matrices and suitable for producing lightweight components.

The characterization of Dracaena reflexa fibers [10] and proposed their potential use as fortification in polymer composite structures, emphasizing the importance of green fiber composite materials. The authors performed physical, chemical, and morphological analyses of Dracaena reflexa fibers. Chemical analysis indicated that the fiber contained 70.32% cellulose, with hemicelluloses and lignin at 11.02% and 11.35% by weight, respectively, making it a promising candidate for reinforcement. The observed crystallinity index was 57.32%. FTIR studies revealed the presence of chemical functional groups. Dracaena reflexa fiber exhibited chemical stability up to 230°C, surpassing the processing temperature of thermoplastic resin. Due to its low density and higher tensile properties, the fiber is recommended as a viable replacement to synthetic fibers in composite manufacturing.

The dynamic mechanical analysis performed on epoxy composites reinforced [11] with natural fibers (Jute/Hemp/Flax). The results indicated a significant enhancement in the

thermal stability of the neat epoxy under dynamic loading conditions. The dynamic mechanical characteristics, such as storage modulus, loss modulus, and damping capability, exhibited notable dependence on natural fibers and their hybridization with the epoxy polymer.

The investigation into the composition of Acacia leucophloea bark fibers [12], revealing cellulose (68.09 wt.%), hemicelluloses (13.6 wt.%), lignin (17.73 wt.%), and wax (0.55 wt.%) content. The reinforcing efficiency of natural fibers is significantly influenced by the nature and crystallinity of cellulose. Through optimal alkali treatment, the cellulose content was observed to transform from 68.09 wt.% to 76.69 wt.%. Alkali treatment also resulted in variations in hemicellulose (13.60 to 3.81 wt.%) and lignin (17.73 to 13.67 wt.%). The reduced wax (0.13 wt.%) and moisture (6.31 wt.%) content after alkali treatment contribute to enhanced interfacial bonding of optimally treated Acacia leucophloea bark fibers in polymeric matrices.

The DTG curve of Barbata fiber [13], revealing two prominent intensity peaks characteristic of natural fibers. The peak at 254°C is attributed to suberin, while the peak at 324.6°C corresponds to the degradation of cellulose content. Initial weight loss is primarily associated with the evaporation of moisture, water-soluble hydroxyl, and carboxyl groups present in the fiber. The gradual degradation profile between 210°C and 290°C indicates the breakage of glycosidic bonds. The decomposition of α-cellulose occurs in the second degradation profile between 280°C and 340°C. Above 600°C, the decomposition of residual products displays a slow degradation profile. The identified residual content of 13.62% includes ash and dust matters absorbed by the fiber.

The Pigeon pea fiber [14] exhibits thermal stability up to 225°C, aligning with other natural fibers like bagasse, kenaf, cotton stalk, rice husk, and wood-maple, which display temperatures of 222.3°C, 219°C, 221.6 °C, 223.3°C, and 220.9°C, respectively. Thermal stability is a crucial consideration during the reinforcement of composites with natural fibers. The analysis of thermal behavior involved assessing the percentage loss of mass in the sample through thermogravimetric analysis. The initial mass loss in the temperature range of 25°C to 125°C was contributed to the elimination of water content.

The significance of Atomic Force Microscopy (AFM) in determining the matrix boundary surface free energy of flax fibers [15]. Understanding the surface characteristics of flax fibers in their natural state is crucial for manufacturing bio-composite materials. AFM enables the prediction of adhesion force, aiding in the prediction of the surface wettability of

individual flax fibers. Hence, AFM serves as a valuable tool for assessing the fiber-matrix bonding in natural fiber composite materials.

The AFM characterization was employed to analyze the cross-section of Angustifolia kunth fibers [16]. The microfibrils of Angustifolia kunth fibers are oriented longitudinally, providing excellent resistance to tension. The imprints on these fibers displayed minimal stacking and no sinking. Characterization revealed that the application of 5% NaOH removes surface irregularities and enhances the fiber's roughness.

The alkali treatment [17] improves the chemical composition of Thespesia populnea bark fiber and Coccinia grandis fiber (CGF) compared to untreated fibers. This treatment leads to the elimination of impurities and amorphous content, resulting in a reduced cross-sectional area of the fiber. For NaOH modifed Thespesia populnea bark fiber, the crystallinity index (CI) increases from 48.17% to 67.52%. Additionally, the thermal degradation of alkali-treated fiber is reduced by 5.57% compared to untreated fiber.

The study on the thermal decomposition behaviour [18] of cellulose fiber-fortified polyester composites. The research involved uniformly heating one side of the surface of a flat laminate to determine the behavior and damage profile of the composite. The examination included the charring of fibers, interface decomposition, and matrix heating. The findings indicated that at the onset of degradation temperature, the fiber-matrix interface remained intact, with the fiber color changing from light grey to light red-orange. As the temperature increased, fiber shrinkage and the development of voids in the fiber region led to interface separation. A compact adhesion among the fiber and matrix was found to enhance heat conduction, while effective air control inside the composite increased the insulation layer. The degradation of lignin contributed to the disintegration which was influenced by the primary cell wall of the fiber. of the fiber-matrix interface, and the degradation of lignin and hemicellulose in the secondary cell wall resulted in the formation of voids.

A study on the fiber derived from Derris scandens plant [19] stems and characterized them. They proposed that these stem fibers could serve as a novel alternated for detrimental synthetic fibers in polymer composites. An anatomical study revealed the traditional hierarchical cell structure of the fiber wall. The fiber composition analysis showed cellulose, hemicelluloses, and lignin content to be 63.3%, 11.6%, and 15.3% by weight, respectively. The size of crystalline cellulose was determined to be 11.92 nm, and the crystallinity index was measured at 58.15%. SEM and AFM studies estimated an average roughness of 10.95 nm. Single fiber tensile strength showed a mean Young’s modulus of 13.54 GPa and tensile

strength of 63.87 MPa, respectively. Thermal stability was observed up to 230°C in TGA. The study concluded that Derris scandens plant stems not only have the potential for medical use but can also be utilized in the field of composites as fortification element in polymer matrix composites.

The surface-tailored natural cellulosic fibers retted from Ficus religiosa trees were characterized for their suitability as reinforcement in natural fiber composites. The characterization included fundamental properties of Ficus religiosa root fibers [20]. The cellulose content was found to be nominal, and the crystallinity index was determined to be 42.92% through X-ray diffraction tests. Morphology studies indicated that the fibers were rough, and TGA results demonstrated better thermal stability. These findings suggest that fibers from the root of Ficus religiosa trees as novel fortification in composites.

The various properties of Guettarda speciosa bark fibers [21] to assess their suitability for reinforcing polymers compared to synthetic fibers. The cellulose contribution in the fibers was around 72.59%, and the crystallinity index was 52.99%, comparable to many fibers. FTIR confirmed the existence of amorphous contents. The density of the fibers was measured at 905 kg/m3. Thermal degradation studies showed that the maximum degradation occurred at 353.37°C, and the kinetic activation energy was determined to be 89 kJ/mol. These concluded that the fibers can be utilised as an alternate for glass fibers to reinforce polymers.

3. CONCLUSION

a. The vast array of plant sources in nature provides a rich pool of potential remedies, including fibers for structural applications. Exploring additional sources of natural fibers can lead to diverse applications with economic benefits.
b. Characterization processes involve analyzing the physical and chemical parameters, as well as the material content of fibers. Techniques such as Fourier Transform Infrared methods (FTIR), X-ray diffraction (XRD) studies, Thermo Gravimetric Analysis (TGA), and Scanning Electron Microscopy (SEM) are employed to characterize natural fibers. The study aims to verify trends related to fiber strength concerning variations in fiber length. Surface morphological studies offer insights into fibrillation, lignin presence, hemicellulose content, among others.
c. To improvise the mechanical and adhesion characteristics of natural fibers, researchers have explored various chemical treatments, including the use of alkali solutions like NaOH. Treated fibers exhibit increased stability and mechanical

strength. Composites made from natural fibers often demonstrate stiffness and mechanical properties comparable to or better than those made with synthetic fibers.

d. Surface treatments, such as alkaline, silane, potassium permanganate, sodium hydroxide, have been applied to natural fiber composites to enhance performance and reduce water absorption. Hybrid modification, involving the combination of different fibers in varying quantities, is another approach to achieving desired composite properties. The sequence of positioning different types of laminae is recognized as crucial in achieving improved proportions. Identifying prospective natural fibers for processing and creating successful composites remains an ongoing societal need.
e. Identifying potential natural fibers for processing and creating successful composites addresses a growing societal need. The literature cited highlights a promising scope for utilizing natural materials in the manufacturing of polymer composites.

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