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Review Article

Study on Water Absorption Characteristics, Various Chemical Treatments, and Applications of Biological Fiber-Reinforced Polymer Matrix Composites

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This study presents an extensive survey of the many surface treatments that may be given to natural fibers for use in advanced composites. When put into reality, the primary disadvantages of working through biological fibers are the increased level of moisture intake that natural fibers possess as well as their low dimensional stability. The fundamental purpose of applying surface treatments to natural fibers is to optimize the bonding strength as well as the pressure transferability in composites made of biological natural fibers. Natural fiber-strengthened polymer composites (NFPC) have overall mechanical qualities that are strongly dependent on the morphological, aspect ratio, hydrophilic propensity, and high stiffness of the natural fibers that are employed in the composite. Cellulosic fibers are being studied for their effects both before and after being used as reinforcements for thermoset and thermoplastic polymers. Some of the chemicals utilized in treatments include alkalis, silane, acetyl, benzoylation, acrylation and polyamide grafting, maleated linking agents, ammonium nitrate, peroxide, phenoxy, stearic acid, potassium chalcopyrite, triazine, synthetic derivatives of fatty acids (oleoyl chloride), and fungi. After chemical treatment, composites made from organic fibers are stronger and more dimensionally stable than the untreated sample.

1. Introduction

Natural fibers can be used instead of man-made fibers in fiber-reinforced composites, which have led to more research and new business opportunities. Natural fibers are cheap, can be broken down by nature, and have a low density. Natural fiber composites are moisture-absorbent and incompatible with the matrix. As a result, biochemical behaviors are taken into consideration while trying to modify the fiber surface qualities. This article discusses the various chemical modifications that can be made to natural fibers for them to be used in natural fiber-reinforced composites. They include alkalis, silanes (acetylation and benzoylation), and other chemical treatments such as isocyanates and permanganates in their discussion. Fiber surface modification and fiber strength both can be enhanced through chemical treatment targeted at enhancing adhesion between the superficiality of the fiber and the polymer matrices. Composite materials have enhanced mechanical characteristics and have lower water absorption rates than their predecessors. In this study, the chemical modification of the fiber, bonding characteristics, mechanical and water absorption behavior, and applications of various chemically treated natural fiber-reinforced composites have been studied.

2. The Effect of Chemical Modification on the Thermal and Mechanical Properties of Polymer Composite Materials with Banana Fibers

The purpose of this study is to investigate the heat transmission, tribological, and degrading behavior of banana fiber-reinforced polypropylene composites that have been treated with alkaline. Extrusion–injection molding processes were used to develop composites that contained BF at a ratio of 20% by weight-to-weight and had been treated with an aqueous solution of NaOH containing 5% by weight of the solvent's volume. Following the application of the chemical treatment, the composite demonstrates increases in its tensile strength of 3.8%, flexural strength of 5.17%, and impact strength of 11.50%, respectively. Fiber pull-out and fiber fracture are the primary causes of the nonsuccess of advanced composite material when subjected to ductile and impression loading, according to SEM inspection of evaluated specimens [1]. For the degradation studies, the samples were put in two different environments for 5 weeks: they were submerged in water or buried in the soil. The deterioration of composites was assessed in terms of both their weight and their mechanical characteristics of ductile, malleability, and withstands behavior. The composites that had been buried under soil showed the greatest amount of deterioration based on the mechanical behavior characterization [2]. The composite experienced a decrease in tensile strength of 7.69%, flexural strength of 12.06%, and impact strength of 3.27%. Due to their low weight, exceptional qualities, low production costs, and applicability for a variety of goods, organic fiber-reinforced polymer hybrids (NFPC) have become inescapably used in transportation practices. However, the most significant drawbacks associated with the utilization of these fibers are their low-dimensional space stability and excessive hydrophilicity. When it comes to figuring out the composite's physical behavior, the interfacial attachment between the reinforcement and the matrix is quite important. Various chemical treatments can be used to improve fiber–matrix adhesion, leading to composites with improved mechanical properties. Composites are being researched as a possible alternative to more conventional, high-density materials for use in transportation and aircraft. As a result, the plane's overall weight would be reduced and its performance enhanced. This page provides an in-depth introduction to biocomposites, discussing their many potential uses and the many chemical modifications that can be made to them [3].

3. Treatment Effects on the Moisture Intake Characteristics of NFRPC

A review was done on the effects that the treatment had on the water-absorbing capabilities of the natural fiber-reinforced polymer composites (NFRPC). It has been found that a variety of chemical treatments work well to minimize the hydrophilic nature of composites. One thing remains the same across the whole of the treatment, and that is the primary objective, which is to reduce the number of hydroxyl groups that are found in the fibers while concurrently raising the level of attachment between matrices and the fibers. The amount of moisture that the NFRPC could absorb was also significantly affected by its fiber composition and dimensions. Additionally, the polymer used in the manufacturing of NFRPC is significant, since several studies have discovered that PP-based hybrids have superior water absorption properties compared to PE-based composites. The extent to which the NFRPC's absorption capacity improves as a result of therapy is very sensitive to the kind of chemicals used. Treatment with sodium hydroxide had the worst effect on NFRPC's water absorption improvement among the chemicals examined. The treatment with acrylic acid, ethoxy, and potassium permanganate demonstrated a higher degree of effectiveness in increasing the water-absorption characteristics of the NFRPC. Chemical treatments such as sulfuric acid and hydrochloric acid are less effective at improving fiber-matrix interfacial adhesion and compatibility than peroxide preparation using benzoyl and dicumyl peroxides [4]. To lessen the amount of water that is absorbed by NFRPC, the majority of the research efforts have been directed toward developing a treatment that will lessen the amount of moisture that is absorbed by the fiber. It improves the adhesion that exists between the matrix and the fiber. According to Kakroodi et al. [5], NFRPC water absorption was linked to two key mechanisms. The first factor was the naturally occurring hygroscopic property of the natural fiber, which contributed to extending the improvement in the hydrophilic behavior of the composites. The second problem was that the structural inhomogeneity that existed between natural fibers reinforcement led to the creation of voids that were able to trap water at the interface. Because of this, it is expected that stronger adhesion and compatibility between the phases will minimize the likelihood of both mechanisms. When it comes to water absorption, the NFRPCs' interfacial adhesion, the type of fibers used to strengthen them, and the number of voids in those composites are all important factors that need to be taken into account, according to Pandian et al. Composites reinforced with various fiber types and matrices have varying degrees of water absorption, and the results of this investigation are summarized. Several distinct chemical processes were used to treat the fibers that were utilized as the reinforcing material. Sisal and bamboo were treated by Venkatesh et al. [6] by soaking them in a 10% NaOH solution for 24 hr at room temperature. After that, the natural fiber moisture content was removed by a hot air oven and then dried in the air for 24 hr each. According to the findings, the water absorption rate of polyester composites produced from untreated fiber had a value of 19.6%, whereas the value of treated fiber's water absorption rate was 9.1%. Similar outcomes were discovered by Gupta and Srivastava [7] because sisal and jute filaments were submerged in a 5% NaOH solution and then dried in the oven at 70°C for 24 hr. When associated with composites made from unprocessed treatment fibers, the epoxy composites made from treated fibers demonstrated a water absorption rate that was 1.58% points lower than those made from untreated fibers (2.79% 6.09%). Epoxy composites reinforced with bagasse had a water absorption value of 8% after the fibers were treated with 1% alkali for 30 min and then submerged for 1 hr in 1% acrylic acid [8]. This is compared to 12% for untreated composites. Black sugar palmer was used to reinforce polypropylene composites by Zahari et al. [9], who observed that composites reinforced from vinyltrimethoxy silane-treated fiber exhibited somewhat reduced water absorption. This was the case when comparing treated fiber to a composite made from untreated fiber. The water absorption of a polypropylene composite that was reinforced with wood fiber and wheat husk and then subjected to a benzylation treatment was found to be much lower [10] than that of a composite that was manufactured from fiber that had not been treated. After being treated with pristine and NaOH, jute fiber was saturated with 5% by weight of both PP-maleic acetic anhydride and PE-maleic epichlorohydrin, and then it was dried at 80°C for 8 hr. A decrease in the amount of water that the composites absorbed after being implanted with PP-maleic acetic anhydride and PE-maleic epichlorohydrin was seen as a consequence of this change. In comparison to composites based on PE, PP-based composites showed a much lower water absorption rate [11]. In addition to the fibers being pretreated, the NFRPC being post-treated demonstrated significant improvement in water behavior. Post-treatment of a coir-reinforced polypropylene composite by Ali et al. [12] was carried out at a temperature of 70°C for 4 hr using a solution in which phenylhydrazine was saturated in ethanol. According to the findings, 0.18% water absorption of the composite after treatment was less than that of the composite before treatment (0.32%).

4. Different Treatments for Natural Fibers

The increasing demand of renewable materials, there are many industries using these eco-friendly materials. Biocomposites have seen a renaissance in the previous two decades as a material for a wide variety of goods, even those in the transportation, packing, sports, and construction sectors [13]. The hydrophilicity of these filaments must be diminished through the use of surface treatments that also enhance their characteristics and interfacial interaction with polymer matrices. Chemical, physical, and biological procedures are the three broad classifications that best describe these approaches. Chemical techniques involve the utilization of chemical reagents to bring about the desired decrease in the hydrophilic propensity of the filaments and, consequently, an improvement in their interaction with the matrix. They also enhance efficient interaction with the matrix by exposing more aromatic rings on the fiber surface. The chemical makeup of the fibers is not drastically altered by the physical approaches, but the altered superficial and structural properties of the fibers do distress the interfacial adhesion by matrices [14]. In comparison to chemical approaches, they are less complicated and produce fewer side effects. To alter the characteristics of the fiber's exterior, biological techniques employ organisms such as fungi, enzymes, and bacteria. These techniques are neither harmful to the environment like chemical procedures nor energy-consuming like physical ones [15].

4.1. Physical Treatments. To appreciate how lignocellulosic fiber may be used in high-performance industrial applications, it is crucial to recognize how the features of the cell wall segments rely on the properties of the fiber. With this information, you will be able to grasp the potential applications of lignocellulosic fiber. Hydrophobicity is typically lacking in natural fibers, which result in poor chemical resistance, weak mechanical properties, and a porous structure. Because of these properties, natural fibers can only be used for so many technical tasks. The hydrophilicity of textile products also restricts their usability, particularly in the transportation and packaging industries [16]. The various treatments that are used in the creation of NFRPCs are another key aspect that virtually influences the characteristics and interfacial behavior of the NFRPCs. Before natural fibers undergo any chemical processing, they go through many different physical processes first. Corona discharge, plasma, ultraviolet light, fiber beating, and heat are all examples of such treatments. The use of a corona discharge as a method for activating surface oxidation is probably the most exciting of all of the available options. This treatment modifies the interfacial tension of the cellulose filaments, which increases the fibers' compatibility with the hydrophobic matrix [17].

The use of plasma treatment has proven to be a successful method for removing pollution and dust particles from the fibers, which has resulted in an enhanced surface for the fibers. For the processing to go smoothly, the type of gas, the pressing factor, and the concentration all need to be properly managed. In recent years, ultraviolet (UV) light has gained popularity as a novel method for cleaning the exterior of plant fibers of any accumulated dust. Some aspects of UV therapy, such as the stream and the type of gas used, cannot be regulated. To oxidize the fibers' surfaces, the strands are placed in a special chamber before the treatment begins. Also, the UV treatment increases the polarization on the surface of the fibers. This makes the fibers easier to wet, which makes the NFRPCs stronger [18].

4.2. Chemical Treatments. Natural fibers-fillers are becoming increasingly popular as a component of composite materials due to their low cost and abundant availability. Natural fibers have several uses that are limited by their difficulty to cling to surfaces and their propensity to get mineralized. Natural fibers cannot be used in composites until they undergo a treatment that at the very least enhance their surface properties. Biochemical (alkaline, silane, acetylation, etc.), physical (corona, plasma), and biological therapies are all examples (enzymes). However, the benefits of each treatment, taking into consideration energy consumption and effluent formation, should be evaluated in greater depth [16]. To suggest a more sustainable treatment in the treatment section in the manufacturing of natural fibers–polymer composites, this study conducted a literature review to compare the mechanical properties, energy consumption, and created pollutants of chemical methods (NaOH, silane, acetylation, and maleated connection) (gate-to-gate). During this review study, it was demonstrated that maleated interactions are a more environmentally friendly method because it does not require any particular form of energy during the primary treatment, it does not produce any effluent, and it consistently enhances the mechanical property performance of composites [19].

5. Natural Fiber-Reinforced Polymer Uses

The strict rules imposed on the environment and the search for more sustainable materials have pushed researchers in the direction of developing environmentally friendly materials. Exceptional NFPCs are needed in today's economy, particularly in the automotive and civil infrastructure sectors. Natural fiber reinforcement is a great option for polymer composites since it is inexpensive to produce, has superior thermal and acoustic qualities, and is processed in an eco-friendly manner. NPCs have a promising prospect in load-bearing applications due to the great qualities that they possess. As a significant portion of the natural materials and their respective polymer mixes have not been investigated, there appears to be a massive amount of untapped potential. Exploration of the many native species that can be used to make natural fibers is also something that should be done. The study of hybrid polymer composites as well as the synergistic effect of a variety of natural fibers is something that could be pursued in further research in the future. To broaden the range of applications for NFPCs, it is necessary to find solutions to the problems of temperature stability and moisture absorption. An important step forward in polymer composites research will be taken as a result of this paper [20].

5.1. Natural Fibers in Car Structural Applications. Natural fibers are becoming increasingly popular in the car industry, thanks to both the global trend toward lighter materials and the tightening of environmental regulations. Although there are a wide variety of natural fibers available, only a select handful of them are utilized in the production of vehicle components. Throughout the entirety of the European automobile industry's history, NFPCs have been deployed. The most recent piece of law that was established by the European Union mandates that by the end of year 2006, 80% of an automobile must be either recyclable or reusable, and by 2015, that number should be increased to 85% [21]. The growing popularity of eco-friendly automobiles has stoked interest in studying natural fiber composites (NFPCs). It is normal practice in the German auto industry to use natural fiber composites based on polyester and polypropylene when producing car parts [22].

Natural fiber composites are used almost exclusively for side panels, the rear package compartment, seat covers, and various other parts connected to dampening and insulation, among other uses. Al-Qureshi [23] was the one who conceived and carried out the design and fabrication of the banana-reinforced polymer composite. He concluded that the connection between the fiber matrixes was very strong and that there were no signs of delamination or delamination anywhere in the structure. The mechanical properties of the aforementioned element were improved thanks to the utilization of a hybrid composite that was constructed out of kenaf and glass fiber-reinforced epoxy as framed structures in automobile bumper beams [20]. As a result of the discovery that the composite possessed a greater elasticity and compressive than the standard material utilized in automotive bumper beams, the door was opened for the composite material to be utilized as engineered structures in some bumper sticker beams. Jute fibers were used as an alternative to glass fibers in the frontal hood of a vehicle to evaluate their impact on a variety of factors, including the environment, society, technology, and the economy. Except for the technical aspects, the performance that jute fibers deliver for these structural purposes is superior to that of glass fibers [22, 24, 25]. Pineapple and cassava flours were mixed into the biopolymers PLA and PBS to see how much of a contribution they made to the total emissions of volatile organic compounds (VOCs). Pineapple, cassava/PLA, and PBS-based composites were shown to significantly reduce smell emissions, and this characteristic is particularly beneficial in automobile interior components. the mechanical characteristics of hybrid composites consisting of abaca, jute, and fiberglass were investigated in all three cases [26]. The maximum fiber volume percent was set to 0.4 for all three composites. According to the findings of the research conducted, the tensile strength of the hybrid composite was significantly different from that of other composites. According to the authors, abaca-based composites have greater impact and flexural strengths than jute and hybrid composites. The authors correspondingly determined that hybrid composites are good replacements [27]. In addition, when there is a demand for higher impact strength, the usage of a composite made from abaca can be an option. The scientists also indicated that abaca and cotton fibers can be employed as reinforcements in polymeric composites, which can then be used to produce vehicle components like mudguards and engine covers. The compression molding technique is used to create a composite made of sisal and urea-formaldehyde. The authors researched to determine how fiber loading affected the mechanical properties of the material [28]. The study found that composites produced with 30% sisal fiber had the highest flexural strength and 50% had the highest impact strength. How many jute layers affect the mechanical qualities of a compression-molded jute/epoxy composite? The number of fiber layers affects a material's mechanical properties [29]. According to the findings of the study, composites consisting of five sheets of fiber had superior mechanical capabilities. According to the findings of the study, NFPCs offer significant benefits in a variety of structural applications within the Indian Railway industry. NFPCs are used in the construction of berths, dividers, floor and ceiling panels, and modular toilets in the railway sector. If low power consumption, low weight, low inertia, and low track wear are among the desired outcomes, then natural fibers should be employed in railway construction. The authors also mentioned that agave fiber is another viable contender for these purposes and that it may be used in those ways [30, 31].

The efforts that DaimlerChrysler has made toward sustainability have prepared the path for technology transfer programs in South America, the Philippines, and South Africa that entail the use of environmentally friendly materials. Bio-based automotive supply chains will begin with farmers and conclude at car distributors as the organization emphasized the use of renewable sources rather than traditional fossil fuels to promote international sustainability. NFPCs are currently being utilized in the production of a variety of different components by virtually all of the major car manufacturers [13].

5.2. Natural Fiber Applications in Building. Natural fiber and polymer matrix biocomposite materials are a class of man-made composites with a wide range of uses. More and more people are using these materials because they are easy to design with, have good properties, and look good. However, the interaction at the fiber–matrix interface determines the biocomposite's application. This document summarizes the most recent published studies on the fiber–matrix interface. A quick introduction to biocomposite materials is given. The alteration of natural fibers and its impact on fiber–matrix interfacial adhesion and characteristics are the primary topic of this review. The impact of chemical modification on fiber structure and fiber–matrix interfacial adhesion mechanism is also explored [32]. When used as the primary component in biocomposite construction materials, natural fibers that have been reclaimed from annual agricultural waste have the potential to confer many distinct benefits. Fibers like hay as well as other nonwood fibers have the lowest price when compared to certain other natural fibers that may be found on the market for industrial use. Densification of agro-fibers, building plans for specific uses, and production methods are all included in this research. The composite material was made by combining natural fibers with three different types of biopolymers. A polyamide, a thermoplastic, and an elastic thermosetting polymer were all present among these biopolymers. This allowed for varying final designs and geometries but necessitated modifying fabrication methods accordingly. Mechanical qualities and an assessment of their impact on the environment were investigated to provide evidence that the newly produced items had practical applications [33]. The natural fiber composites, also known as NFCs, in which polymeric resins serve as the matrix components are the primary subject of this chapter. At least one key component of NFCs has a renewable biological origin, making them biodegradable. The fundamentals of NFC materials, including reinforcements preforms, matrix polymers, composite production procedures, characterization, and quality assurance, are described in this article. Since NFC materials made from renewable resources can be used to make low-cost structural parts and sustainable and environmental alternatives to traditional structural materials in the automotive and construction industries, microbially structural composites are also being looked at for use in the construction and automotive industries [22]. To evaluate the acoustic absorption capabilities of a set of 21 elastic material high-frequency resonant construction (HFRC) prototypes, the impedance tube method was applied. Natural and synthetic fiber polymeric components, including polyamide, lignocellulose, keratin, and alginate biopolymer, were recovered from postconsumer and end-of-life industrial wastes to generate the nanocomposite blends. The discussion focuses on two significant environmental pollution issues, namely urban sound and waste fibers, as well as how these wastes can be converted into construction materials. The end goal is a two-pronged solution that has positive effects on the environment, the economy, and society. Creating high-end, nontoxic solutions for acoustical structures help to facilitate the removal of valuable fiber components from landfills [34, 35]. Although urban vibration is a major contributor to pollutants in industrialized metropolitan areas, the focus of this work is on the sound-absorbing qualities of HFRCs. The results showed the modest absorption at mid-frequencies (500 Hz to 2.4 kHz) and considerable absorption at higher frequencies (2.4–6.5 kHz). Low-density prototypes with small filler-matrix interfacial gaps and natural fibers with hierarchical intraparticle microstructure achieved 0.79 peak sound absorption. These novel reduced materials from wastes provide an environmentally friendly alternative to standard commercial synthetic products for improving indoor quality by reducing noise, especially in dense urban areas [36].

6. Conclusion

Numerous researchers have been inspired to develop innovative materials as a result of the deteriorating state of the atmosphere, rising concerns about the state of the environment, and the requirement for increased levels of innovation.

(1) Researchers from all around the world are efficiently responding to worries about the environment by moving their focus toward materials that are biodegradable and sustainable. Since this is the case, NFRPCs are rapidly replacing other materials in a wide variety of industrial settings.
(2) An uptick in inquiries on NFRPCs inspired this study of natural fibers, their production, chemical processing, and many applications. Chemical treatments were examined in depth as a means of improving surface qualities such as hydrophobic nature and adherence among fibers and polymeric materials.
(3) The choice of natural fibers is determined by factors such as their availability, weight, and cost, as well as their mechanical qualities. The degree to which the fibers adhere to one another is the primary factor that determines the material characteristics of NFRPCs. The pretreatment of the fibers can result in an improvement in this characteristic.
(4) It is possible to use alkali treatment because it is regarded as the method that is the most successful for all NFRPCs. Other treatments, such as those

consisting of alkali and silane, can also be employed in conjunction. Significant improvements in the fibers' mechanical characteristics are brought about as a result of both the increased chemical concentration and the lengthened soaking time. New developments in NFRPCs can be seen as a promising material for numerous applications in the future.

(5) The interfacial connection of natural fibers with the matrix continues to be the most important issue in terms of inclusive performance. In all of the chemical treatments that have been researched, the alkali treatment stands out as the most straightforward, time-honored, and successful method for treating many types of fibers. This treatment, which can be carried out on virtually every type of natural fiber, can improve the interfacial bond of the fibers. The phenomena of biodegradation or the possible igniting of NFRPCs is just somewhat new. As a result, researchers should also examine how NFRPCs decompose.

(6) Biodegradation and deterioration time must be accurately accounted for to make an informed decision. It is likely that in the not-too-distant future, similar NFRPCs will achieve total biodegradability and mechanical qualities that are comparable to those of composites reinforced with synthetic fibers.

(7) Improvements in NFRPC composite materials are projected to focus on mass production, as well as their application in the large-scale market, soon. Furthermore, the incorporation of nanocellulose (possibly nanoclay) into NFRPC can improve a variety of beneficial qualities, and finally, the investigation of NFRPC tribological properties should be one of the primary topics of focus in larger prospective studies.

Data Availability

The data used to support the findings of this study are included within the article.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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