Research Article

Mechanical Characterization and Water Absorption Behavior of Waste Coconut Leaf Stalk Fiber Reinforced Hybrid Polymer Composite: Impact of Chemical Treatment

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Abstract

In recent times, there has been a significant enhancement in the focus on composite materials that are reinforced with natural fibers, primarily driven by the growing environmental awareness. Naturally occurring fibers offer several advantages, that includes renewability, cost-effectiveness, complete or partial reusability, and biodegradability. The utilization of agricultural waste fibers for the fabrication of polymer composites has commercial potential. This study focuses on the production of polymer composites using coconut leaf stalk fibers to investigate their mechanical properties, including tensile, flexural, impact strengths, as well as their water absorption characteristics. The impact of chemical treatment is being investigated through the utilization of sodium hydroxide on the fibers of coconut leaf stalks. The findings indicate that untreated fiber composites demonstrate superior mechanical properties, including tensile strength, flexural strength, and impact strength, as well as water absorption behavior, compared to alkali-treated fiber composites. These findings would help to accelerate the applications of biofibers based composite materials.

Keywords: Chemical treatment, Coconut leaf stalk, Composite materials, Mechanical properties, Water absorption

1 Introduction

Composite materials have garnered considerable attention in various industries, including automotive, aerospace, construction, packaging, and others. These properties can be attributed to their superior strength and stiffness-to-density ratios, resistance to corrosion, ability to manage thermal expansion, and greater design freedom in comparison to traditional solid materials such as metals and plastics. By altering the composition of the matrix and reinforcing elements, the characteristics of composites can be customized to fulfill precise technical specifications. Natural fiber-reinforced polymer composites are now recognized as a significant category of composite materials. They possess numerous advantages compared to synthetic composites, including reduced density, decreased cost, biodegradability, and sustainability. The uses of natural fibers, such as jute, hemp, and bamboo are increasing in composites as a means of partially substituting energy-intensive synthetic fibers like glass and carbon fibers.

Natural fibers exhibit favorable mechanical characteristics and have the ability to improve the properties of the polymer matrix when used in small amounts [1]–[4]. Thus, natural fiber composites offer a promising ecological and commercially feasible alternative for items that do not necessitate exceptionally high mechanical performance. The utilization of composite materials that are strengthened with natural fibers has become increasingly prevalent in contemporary times, primarily due to heightened environmental consciousness and the pursuit of more ecologically sustainable materials. Natural fibers possess various benefits, including renewability, cost-effectiveness, and partial or complete biodegradability [5]–[9]. Furthermore, the utilization of agricultural waste fibers in the fabrication of polymer composites can result in commercial benefits, while also contributing to their environmental sustainability.

The emergence of natural fiber-reinforced composites has presented prospects in diverse sectors such as the automotive, aerospace, construction, and packaging industries [10]–[13]. Panels, seat backs, door trims, package trays, and other interior components are just some of the applications in which these materials are put to use. The impetus behind the heightened environmental awareness regarding natural fiber composites arises from their capacity to diminish dependence on non-renewable resources, decrease carbon emissions in the manufacturing process, and enable recycling or biodegradation at the end of their useful life. Furthermore, the output of their production has the potential to facilitate the exploitation of agricultural by-products, thereby mitigating waste disposal and augmenting sustainability in agricultural methodologies. In general, the increased focus on composite materials that are strengthened by natural fibers is consistent with the escalating attention to ecological sustainability and the aspiration to diminish the environmental impact of diverse sectors.

Currently, a variety of commercial fibers are accessible, including glass, carbon, and Kevlar 49 [14], [15]. Despite the exceptional mechanical and thermal properties exhibited by synthetic fiber composites, they are associated with environmental challenges such as disposal. In recent times, there has been a growing consciousness of the environment, leading to the exploration of natural fibers as a substitute for synthetic fibers in polymer composites for reinforcement purposes [16]. Natural fibers possess several advantages in comparison to conventional fibers, including their widespread availability, reduced cost, lighter weight, biodegradability, and renewability. In contemporary times, natural fibers such as coir, sisal, hemp, jute, and others have been employed as substitutes for synthetic fibers in the context of reinforcement. India possesses abundant natural fiber resources such as jute, silk, cotton, sisal, banana, coir, and others, which are widely distributed throughout the country [17], [18]. The nation exhibits a range of agro-climatic conditions and consumer preferences, resulting in the cultivation of a diverse array of agricultural fibers [19].

In recent times, there has been a growing focus on ecologically friendly materials that can alleviate the strain on the ecosystem and establish a more sustainable material life cycle. The appeal of these materials lies in their comparatively safer handling and workability, as well as their environmentally conscious properties. The swift advancement of eco-composite materials can be attributed mainly to enhancements in process technology and economic considerations. The utilization of natural, biodegradable materials in the production of composite materials, commonly referred to as “eco-composites” or “green composites,” has been extensively researched in the field. These materials are being explored as a potential substitute for traditional composites that are manufactured using thermoplastics and engineering fibers, such as glass fiber/polypropylene. The escalation of fossil fuel expenses has expedited the pace of advancement of these composites possessing comparable mechanical characteristics. Although glass fiber-reinforced plastics exhibit exceptional thermal and mechanical characteristics, the development of appropriate disposal techniques for these materials remains challenging. The disposal and recycling of glass fiber-reinforced plastics (GFRP) have gained significant attention due to numerous environmental issues.

The utilization of natural fiber composites presents a promising prospect for a wide range of applications in various fields, including but not limited to consumer goods, low-cost housing, civil structures, and other commonplace applications. This is particularly advantageous in situations where the current high cost of reinforcements hinders the use of conventional lightweight reinforced plastics. Over the last ten years, there has been a development of natural fiber composites that utilize various natural fibers, including but not limited to ramie, hemp, jute, sisal, bamboo, banana, and oil palm fibers, as replacements for glass fibers in reinforcement applications [20]. The modification of fiber surface properties is achieved through the implementation of chemical treatments. The utilization of differential hydroxyl group can potentially augment the bond strength between the fiber and matrix, while concurrently reducing the water absorption of the natural fiber. Several scholars have conducted research on the chemical treatment of natural fibers. The conventional chemical methodologies encompass alkaline, H_2SO_4, and acetylated treatments. The alkaline treatment method is a commonly employed technique for natural fibers utilized as reinforcement in thermoplastics and thermosets [19]. The application of chemical treatment to natural fibers results in increased hydrophobicity, thereby enhancing the compatibility of the polymer with the matrix. The structural and compositional characteristics of fibers are directly impacted by chemical modification [21]. Coconut is a significant worldwide agricultural product that is widely grown in tropical coastal areas. The coconut palm is regarded as an essential crop because of its versatile value in providing sustenance, energy, housing, and fiber. The annual global coconut production exceeds 60 million tons. The residual materials from coconut harvesting, such as leaf stalks and husks, are predominantly disposed of as agricultural waste. There is an increasing body of research focused on harnessing the potential of these coconut biomass materials that have not been fully utilized.

The coconut leaf stalks account for approximately one-third of the overall weight of a coconut palm tree. Every year, a substantial amount of dried coconut leaf stalks, amounting to billions of tons, is generated. However, the majority of this biomass is either incinerated or allowed to decompose in fields. Using the fiber derived from this readily accessible, renewable, and inexpensive biomass for purposes such as strengthening composites can enhance its worth. Nevertheless, before coconut leaf fibers can be efficiently utilized, it is imperative to tackle technological obstacles such as significant moisture absorption, limited heat stability, inadequate surface adhesion, and incompatibility with polymer matrices. Appropriate physical and chemical treatments are essential for eliminating surface contaminants and wax, enhancing surface roughness, and altering the surface chemistry of the fiber. This can aid in overcoming obstacles and promoting enhanced mechanical interlocking and bonding between the hydrophilic fiber and hydrophobic polymer matrix.

The utilization of coir fiber is prevalent in the fields of agriculture and horticulture. The substance in question possesses noteworthy properties as a growth medium and soil enhancer, as it exhibits a capacity for moisture retention, aeration promotion, and maintenance of a consistent pH level. The utilization of coir fiber encompasses its application in hydroponics, potting mixes, seed germination, and as a substrate for plants. The utilization of coconut leaf stalk fiber has been observed in various erosion control and land reclamation initiatives. The stabilization of slopes and banks aids in the prevention of soil erosion, while also promoting vegetation growth in regions that are susceptible to erosion. The utilization of coir fiber as a material is environmentally sustainable. The material under consideration is characterized by its biodegradability, renewability, and sourcing from a byproduct of the coconut industry, thereby reducing waste. The utilization of coconut leaf stalk fiber is conducive to sustainability as it diminishes the dependence on synthetic materials and bolsters the agricultural economy in regions where coconut cultivation is prevalent. In general, coir fiber, also known as coconut leaf stalk fiber, is a multifaceted and eco-friendly organic substance that possesses a diverse array of potential uses. The popularity of this material in diverse industries such as agriculture, horticulture, construction, textiles, and crafts can be attributed to its robustness, longevity, and environmentally sustainable characteristics.

Epoxy is a widely utilized polymer matrix material due to its exceptional strength, favorable wetting characteristics, and low volatility during the curing process. Epoxy is a commonly employed material in various applications owing to its cost-effectiveness, minimal shrinkage, and exceptional adhesion characteristics. Epoxy exhibits sensitivity to moisture in both cured and uncured states. In comparison to polyesters, they typically demonstrate superior resistance to moisture and other environmental factors, while also providing lower shrinkage and improved mechanical properties [22]. The coconut fibers underwent a pre-treatment process using a 1% weight/volume solution of sodium hydroxide (NaOH). The composites were manufactured with a fiber content of 10%. The composite materials exhibited a reduction in fatigue life as a result of the presence of fractured fibers and inadequate bonding between the fibers and matrix, which was observed to occur at higher levels of applied tension [16].

The modification of the coir's surface topology and chemical composition can be accomplished through a pre-treatment process, such as boiling and washing. Research has demonstrated that the utilization of pre-treated coir is efficacious in eliminating impurities present on the surface of the coir. Furthermore, it has been observed that the mechanical properties and performance of pre-treated coir-based green composite are significantly superior to those of untreated coir-based green composite [23]. The impact of the inherent waxy surface layer of coconut on the establishment of a robust interfacial bonding between the coconut and polyethylene matrix. The elimination of the waxy layer led to a diminished interfacial adhesion, an augmentation in the critical length, and a reduction in both the tensile strength and modulus of the composite [24]. The composite materials were fabricated via injection molding technique, incorporating varying proportions of fiber content, specifically 20, 25, 30, and 35%. The findings indicate that the utilization of post-treated fiber composites resulted in superior properties when compared to raw fiber composites [21]. Tensile strength, flexural strength, and impact strength properties of the coir/epoxy composites were measured at 17.86, 31.08 MPa, and 11.49 kJ/m^2, respectively. These values were found to be lower than those of GFRP. The findings indicate that notable enhancements in both strength and fracture properties are necessary for this particular category of materials [20]. Incorporating inorganic materials, such as composites reinforced with glass fibers, has demonstrated superior properties. However, these materials are not biodegradable, leading to heightened environmental pollution, and their production can be cost-prohibitive. Therefore, there has been a growing interest in the utilization of natural materials for the production of composites in recent years, due to their advantageous properties, such as accessibility, affordability, and biodegradability [25], [26]. To date, there has been a lack of research conducted on composites made from natural fibers derived from coconut leaf stalks. Based on the analysis of existing research and identification of unexplored areas, this study proposes the utilization of coconut leaf stalk fiber in the development of a natural fiber composite, utilizing an appropriate epoxy as a bonding agent.

The current investigation initially aimed to fabricate a composite material utilizing mats composed of long coconut leaf stalk fibers. This work may lead to further developments in the areas of chemical treatment optimization for better fiber-matrix adhesion, hybridization with other natural fibers for the customization of particular features, durability research, and life cycle analysis. Strong applications that complement the biocomposite method, such as furniture for homes, car interior components, container crates, etc., would be made possible by favorable mechanical qualities and moisture resistance. Large-scale research on mass-production-ready compression molding fabrication at the industrial level is possible. This could pave the way for the commercial use of biocomposites reinforced with coconut leaf stalk fiber as a substitute for glass-fiber-reinforced plastics and wood-plastic composites in price-sensitive markets. Adoption can support sustainable materials technology and more efficient use of agricultural leftovers. However, due to unforeseen circumstances, the project was altered and instead, chopped coconut leaf stalk fibers were utilized as reinforcement in conjunction with epoxy resin at varying weight fractions to produce the composites. The specimens have been prepared for the purpose of evaluating the mechanical properties of natural composites, including but not limited to tensile, flexural, compression, and impact testing. The study observes the impact of treatment on the mechanical properties and moisture absorption characteristics of composites. In accordance with the American Society for Testing and Materials (ASTM) requirements, specimens of varying sizes and undergoing a variety of tests are created.

2 Materials and Methods

2.1 *Matrix material*

The present study employs epoxy resin as the matrix material [27]–[32]. Epoxy resin is a type of thermoset polymer that is commonly utilized in industrial settings due to its exceptional strength and mechanical adhesion properties [33]–[38]. The rationale behind utilizing this particular epoxy lies in its characteristics of possessing a moderate viscosity and non-crystallizing composition, which allows for curing at ambient temperatures [39]–[42]. The Lapox L-12 and K-6 hardeners were procured from Yuje Marketing, located in Bengaluru, India. The present experiment makes use of a hardener with a weight % that corresponds to a ratio of 10:1.

2.2 *Reinforcements*

The primary chemical composition of coconut leaf stalk fiber is shown in Figure 1. The coconut leaf stalk fiber, commonly referred to as coir fiber or coconut coir, is a naturally occurring fiber that is obtained from the external shell of coconuts. The material exhibits versatility and sustainability, rendering it suitable for diverse applications across multiple industries. The fiber derived from the stalk of coconut leaves is a type of lignocellulosic natural fiber. The fibers underwent a washing process using water and were subsequently subjected to a drying period of 72 h at ambient temperature. The fibers that have been dried are classified as untreated fibers. The fibers that have undergone a drying process are classified as untreated fibers. The fibers are truncated to achieve short fibers measuring between 2–3 mm in length, which is necessary for the fabrication of composites. The fibrous stalk of the coconut leaf exhibits robust mechanical properties, long-lasting durability, and notable resistance to decay, rendering it a viable material for diverse applications. The substance exhibits a rough consistency, a hue that is pale brown in nature, and a luster that is inherent.

2.3 *Chemical treatment on coconut leaf stalk fiber*

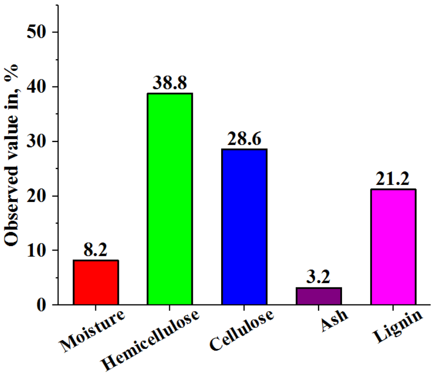

Figure 1: Chemical composition of coconut leaf stalk fiber.

Chemical treatment on coconut leaf stalk fiber will modify the surface properties by enhancing the bond strength between the fiber and matrix, and also to reduce the water absorption of the fiber. From the literature, it is observed that alkaline treatment is one of the most used treatments. Hence, NaOH treatment is made with 1% NaOH for a time duration of 1 h. After chemical treatment fibers are washed with deionized water and dried at room temperature.

2.4 *Fabrication*

As previously stated in the introduction, the fabrication of composites utilizing mats has been altered. The composite material was unable to undergo the drying process, thus necessitating the chopping of fibers to dimensions of 2–3 mm prior to composite preparation. Molds were prepared in accordance with the testing specifications to produce specimens for experimentation. At the beginning of the process, a releasing agent was applied to the mold interior surfaces to prevent composites from adhering to the mold walls. The coconut leaf stalk fibers were combined with epoxy and hardener in accordance with the predetermined weight ratio within a container and agitated thoroughly for 5–6 min. The mixer is prepared and subsequently poured into the molds, after which it is left to dry for 48 hours at ambient temperature. The samples (refer to Figure 2) were cut in compliance with the ASTM standards and subsequently, specimens were prepared according to the same standards. The composites that were prepared (Table 1) underwent an initial marking process in accordance with ASTM requirements and were subsequently cut using a wire saw. After the amputation of the cut edges, the specimens were subjected to abrasion against emery paper to eliminate any inconsistencies in the cuts and to achieve precise dimensions. Various examinations necessitate samples of varying sizes. The specimens underwent preparation procedures in accordance with the standards set by the ASTM.

Figure 2: Fabrication procedure of the composites.

Table 1: Details of specimens prepared as per the composition

Specimen Designation Code		**Specimen Epoxy Resin**	**Composition Coconut Leaf Stalk Fiber**
Untreated coconut leaf stalk fiber	Untreated F 30 %	70 %	30 %
NAOH –Treated coconut leaf stalk fiber	Treated F 25 %	75 %	25 %
	Treated F 30 %	70 %	30 %
	Treated F 35 %	65 %	35 %

2.5 *Moisture absorption test*

The present study involved conducting moisture absorption tests on composites reinforced with coconut leaf stalk fibers, both treated and untreated, using different water sources including river water, bore well water, and distilled water. The composite materials were submerged within a vessel containing various types of aqueous solutions. Following a 24 h period, the composites were extracted from the beaker and subjected to a drying process utilizing filter paper fold. Subsequently, the composites were weighed, and the percentage of water absorption was determined using the following equation.

$$\%\,of\ Water\ Absorption = \frac{Difference\,in\,Weight}{Initial\,Weight} \times 100$$

The composites underwent a repeated soaking process in water at 24 h intervals for 6 days. Moisture test specimens were prepared according to the ASTM D5226 standard. The specimen used is a rectangular bar of length 45 mm, width 25 mm and thickness 6 mm.

2.6 *Impact test*

The impact test is a widely employed method for assessing the durability and capacity to withstand abrupt loading of various materials, including composite materials such as composites made from coconut leaf stalk fibers. The present examination quantifies the amount of energy that a given material when exposed to a sudden and forceful impact of significant magnitude. It is noteworthy that the testing parameters, dimensions of the specimen, and testing criteria may differ based on the specific demands and relevant standards for composites made of coconut leaf stalk fibers. Impact test specimens were prepared according to the ASTM D256 standard. The specimen used is a rectangular bar of length 63.5 mm, width 12.7 mm and thickness 12.7 mm.

3 Results and Discussion

The examination of the mechanical properties and moisture uptake of composites holds paramount significance. The evaluation of mechanical behavior and moisture absorption in composites is contingent upon various factors, including the matrix material's characteristics, the distribution and orientation of the reinforcing fibers, and the nature of the interfaces between the fibers and matrix. Minor alterations in the structural characteristics of the reinforcement material incorporated within a matrix can yield significant modifications in the global mechanical response and moisture uptake of composite materials.

3.1 *Tensile strength of composites*

Figure 3 depicts a comparative analysis of the tensile characteristics of fiber composites with 30% fiber composition, both in their untreated and treated states. It can be seen from the graph that the untreated fiber composite can withstand loads of 1300 N, which is a greater amount than the treated fiber composite. Due to inadequate adhesion between the fiber and the matrix, treated fiber composites have a reduced load-bearing capability. The application of alkali treatment resulted

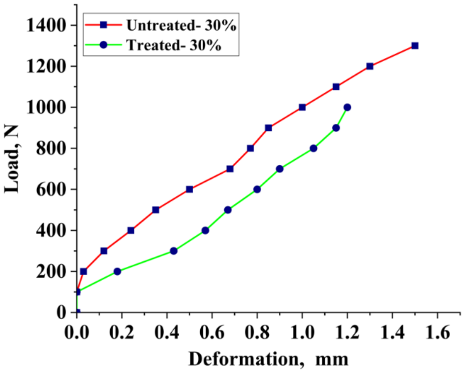

Figure 3: Effect of load on tensile strength of untreated and treated 30 % natural composite.

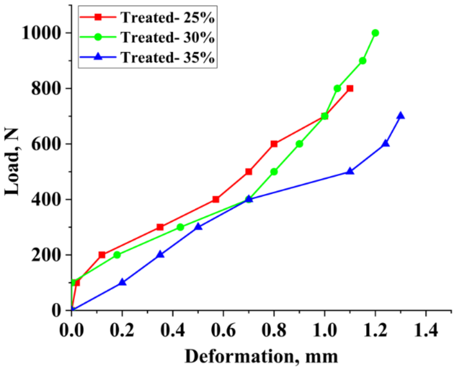

Figure 4: Effect of load on tensile strength of NaOH treated fiber with different weight fractions.

in a reduction in the tensile strength of the fibers. The observed outcome was ascribed to the cellular wall impairment and the over-extraction of lignin and hemicellulose, which serve as binding agents in the fiber structure. The administered treatment resulted in fibrillation, which refers to the division of the microfibers comprising the technical fiber. This phenomenon results in a reduction in diameter, and an increase in the dispersion of strength values [43]. The tensile test results in Figure 4 demonstrate the effect of varying coconut leaf stalk fiber weight fractions on the tensile strength of the alkali-treated fiber composites. It can be observed that the tensile strength increases progressively with fiber content up to 30 weight percentage (wt.%), beyond which a declining trend is seen for 35 wt.% fibers. The substantial improvement from 25 wt.% to 30 wt.% fibers (over 20% increase in tensile strength) indicates better stress transfer due to increased fiber contribution. However, excessive fibers tend to aggregate causing poor wettability and void formation. The reduced strength for 35 wt.% fibers suggests there is a threshold optimal fiber content between 30–35 wt.%. Exceeding this leads to inferior fiber dispersion, poor fiber impregnation and increased porosity in the composite. The irregular decline (over 60 MPa strength reduction) implies poor interfacial bonding strength and adhesion between the fiber and matrix for the 35 wt.% composite. This can arise from inadequate resin to wet and bind higher fiber content. Overall, 30 wt.% coconut leaf stalk fiber appears optimal for balanced fiber-matrix interaction. Further chemical modifications may help enhance compatibility for higher fiber fractions to obtain superior mechanical performance.

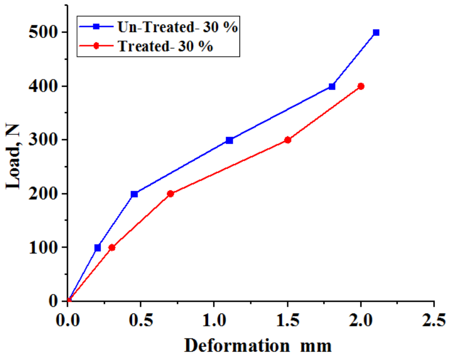

Figure 5: Effect of load on flexural strength of untreated and treated 30% natural composite.

3.2 *Flexural strength of composites*

The graph (Figure 5) portrays a comparison of the flexural strength of 30% fiber composites that have been treated and those that have not undergone treatment. The graph indicates that the untreated fiber composite is capable of sustaining a greater load than the treated fiber composite. The reduction in flexural strength observed in the treated fiber composite can be attributed to the impact of chemical treatment on the fiber. Enhancement of the interfacial strength between the fiber and matrix, as previously elucidated, results in a reduction of energy consumption by preventing the fiber pull-out. In this instance, the fracture of the material occurs with minimal alteration to the cracking plane, resulting in the rupture of the fibers as opposed to their extraction.

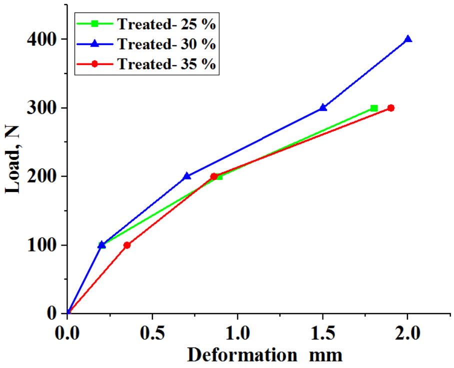

Figure 6: Effect of load on flexural strength of NaOH treated fiber with different weight fractions.

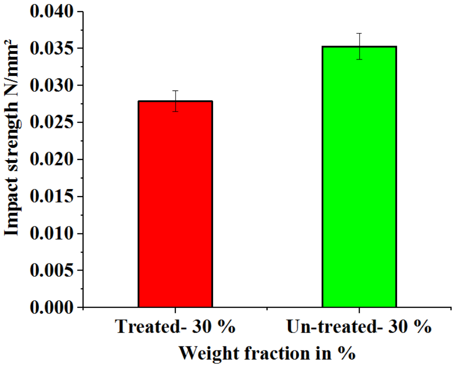

Figure 7: Effect of load on Impact strength of untreated and treated 30% natural composite.

Figure 6 presents a comparison of the flexural strengths of treated fiber composites that contain varying percentages of fiber content, such as 25, 30, and 35%. The graph indicates that the flexural load bearing capacity experiences a rise as the fiber content increases up to 30%. This can be attributed to the robust adhesion between the fiber and polymer matrix, as well as the reduced likelihood of void formation within the composite material. It has been observed that the flexural load bearing capacity does not increase beyond 30% fiber content. This is due to the fact that increasing the fiber content further results in reduced adhesion between the fiber and polymer. Moreover, the substantial quantity of fiber content relative to the weight fraction of the matrix, such as a 35% fiber composition, has the potential to generate voids within the composite. The flexural test findings reveal an interesting trend regarding the effect of alkali treatment on the mechanical performance of the composites. It is evident that the untreated coconut leaf stalk fiber composite demonstrably outperforms the treated composite in terms of flexural strength. Specifically, the untreated composite withstands almost double the load compared to the treated one before fracture occurs. This indicates that the raw fibers possess significantly better compatibility and adhesion to the polymer matrix, facilitating efficient stress transfer between the constituents. Whereas the intention behind chemically treating the fibers was to remove surface impurities and increase surface roughness to improve mechanical interlocking between the hydrophilic fibers and hydrophobic polymer, the results show the reverse effect. The alkali treatment appears to have disrupted the native structure of the fibers leading to poor interfacial bonding with the matrix. The considerable difference in flexural load bearing capacity highlights that chemical modifications do not necessarily improve fiber-matrix interaction for natural fiber composites. In fact, for coconut leaf stalk fibers, surface treatment seems detrimental to mechanical performance. Leaving the fibers in their raw, untreated state preserves their natural compatibility with reinforced composites. These insights are valuable from both a fundamental materials design perspective and for applied composite fabrication using this particular agricultural biomass. The findings can guide future work on tailoring coconut leaf stalk fiber composites for load-bearing applications without resorting to chemical interventions.

3.3 *Impact strength of composites*

The presented graph (Figure 7) depicts a comparative analysis of the impact strength exhibited by fiber composites that have undergone treatment and those that have not. The impact strength of untreated fiber composite is greater than that of treated fiber composite, with a difference of 0.0353 N/mm². The application of chemical treatment to the fiber composite results in a reduction of its impact strength.

The graphical representation in Figure 8 illustrates a comparative analysis of the impact energy of various rated fiber composites, specifically those with percentages of 25, 30, and 35%. The graphical representation indicates a positive correlation between the percentage of fiber and the energy absorbing capacity. Notably, the composite containing 35% fiber

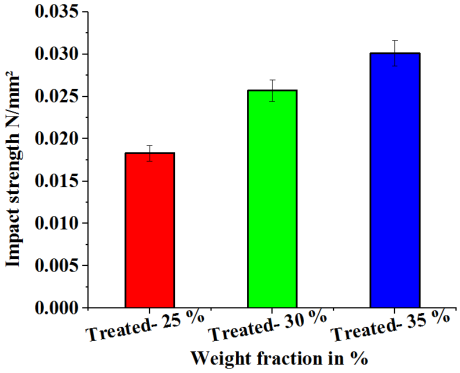

Figure 8: Effect of load on impact strength of NaOH treated fiber with different weight fractions.

exhibits a higher impact energy of 0.0301 N/mm² in comparison to the other composite combinations. The impact resistance of fiber-reinforced polymeric composites is contingent upon the characteristics of the fiber, polymer, and the bonding between the fiber and matrix. Furthermore, the enhanced strength exhibited by the composite containing 35 weight percent may be attributed to effective interfacial adhesion between the fiber and matrix. The fibers possess adequate quantities and function as a medium for transferring stress.

3.4 *Moisture absorption test for composites*

The graphs (Figure 9) presented depict the outcomes of a moisture absorption experiment conducted on river water, distilled water, and borewell water, respectively. In particular, Figure 9 shows the percentage of moisture absorption with various water sources. For all the instances, there was a positive correlation between the moisture absorption and the fiber content, indicating that an increase in fiber content led to a corresponding increase in moisture absorption. The observed behavior can be attributed to the amplification of micro void generation within the matrix resin. The graph illustrates a clear relationship between fiber content and the initial rate of water uptake, indicating that an increase in fiber content leads to a corresponding increase in the initial rate of water uptake. The enhanced water uptake can be attributed to the inherent hydrophilicity of the fiber and the amplified interfacial surface area between the fiber and the matrix. The initial stage of water absorption in all specimens follows a linear pattern, which gradually decelerates until it reaches the point of saturation [44].

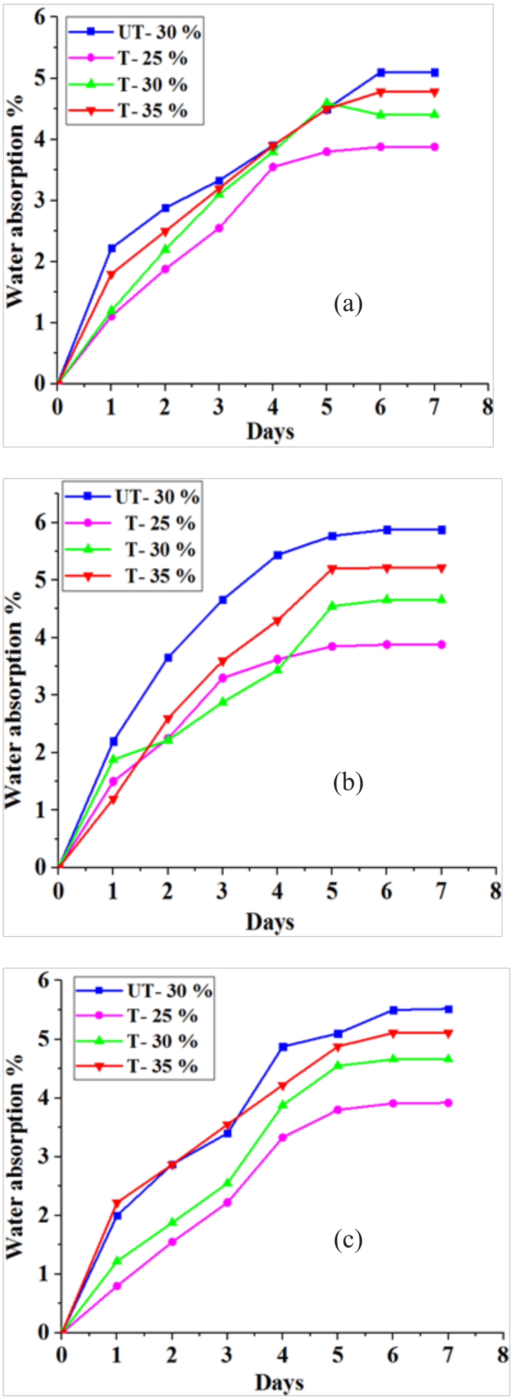

Figure 9: Comparison of moisture absorption property of untreated and treated coconut leafstalk fiber in (a) river water, (b) distilled water, and (c) borewell water.

The composite specimen exhibits a moisture absorption rate of approximately 4–5% of its weight. Based on the data presented, it can be observed that the chemically treated composites exhibit a lower water absorption rate in comparison to the untreated composites. The observed phenomenon could potentially be attributed to alterations in the fiber's surface topography resulting from chemical treatment. The application of chemical treatments resulted in the depletion of a significant proportion of hemicelluloses and lignin, leading to an increase in the hydrophobicity of coconut leaf stalk fiber. Consequently, the composites that were produced using the treated fiber exhibited reduced water absorption properties.

4 Conclusions

The demonstration of untreated coconut leaf stalk fibers providing superior mechanical performance compared to chemically treated fibers can enable more cost-effective and eco-friendly composite manufacturing avoiding alkali processing. Coconut leaf stalk fibers as a renewable agricultural waste material can yield low-cost, biodegradable composites for cost-sensitive industries like automotive interior parts, construction, packaging, etc. The characterization of the effect of fiber loading on mechanical properties provides guidance for tailoring coconut leaf stalk composites for specific strength and stiffness requirements. The composite's tensile strength of untreated fiber with a fiber content of 30% was measured to be 1300 N, indicating a high level of strength. The flexural strength of the specimen exhibits a positive correlation with the percentage of fibers, indicating that an increase in fiber content leads to an increase in flexural strength. The composite containing untreated 30% fiber exhibited a higher tensile strength of 500 N in comparison to the composite made with NaOH-treated fiber. The composites exhibited an increase in both tensile and flexural strength as the fiber loading was increased. In contrast to the 30% fiber loaded composites, the 35% fiber loaded composites exhibited reduced tensile flexural strength. The composite material consisting of untreated coconut leaf stalk fiber with a fiber content of 30% exhibits the highest impact strength, measuring at 0.0353 N/mm². The composites that underwent NaOH treatment exhibited reduced water absorption tendencies in comparison to the composites that were not treated. Insights from this work can aid in applying coconut leaf stalk fiber reinforced polymers as "green" substitutes to synthetic fiber composites in structural, coating, and other applications.

Author Contributions

All authors have participated in a) conception and design, or analysis and interpretation of the data; b) drafting the article or revising it critically for important intellectual content; and c) approval of the final version. All authors have read and approved the manuscript.

Conflicts of Interest

The authors declare no conflict of interest.

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