Integrated Mechanical Engineering Journal (IMEJOUR)
Vol. 1 No. 1, Mei 2023, pp. 58-70
e-ISSN: 3026-7579

Mechanical and Moisture Resistance Evaluation of Alkali-Treated Coconut Fiber/E-Glass Hybrid Epoxy Composite for Lightweight Engineering Applications

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Article Info

Article history:

Received November, 3rd 2023
Revised November, 10th 2023
Accepted November, 27th 2023

Keywords:

Hybrid composite
Coconut fiber
E-glass fiber
Epoxy resin
Tensile strength
Flexural strength
Moisture absorption

ABSTRACT

In mechanical engineering, the demand for lightweight and sustainable materials is gaining significant momentum, as the choice of material impacts the efficiency, energy usage, and environmental footprint of mechanical systems. Natural fiber reinforced polymer composites have many advantages like low density and renewability but they are not widely used due to moisture sensitivity and poor fiber–matrix bonding. In this study, an alkali treatment process of coconut fibers and their hybridization with E-glass fibers for structural and semi-structural components application using an epoxy composite is investigated. The work is tested for its tensile, flexural, impact, specific strength and moisture absorption properties. Coconut fibers were processed with sodium hydroxide to increase the surface roughness and remove hydrophilic impurities from the fibers and composite laminates were prepared by a hand lay-up technique in which the fibers were cured at room temperature. Experimental study shows that the tensile and flexural strength, impact resistance and specific strength of natural fiber composites of hybridization with E-glass fiber are significantly increased when compared to natural fiber composites without hybridization, mainly due to the bridging effect of E-glass fiber and reduced fiber pull out and load transfer. The hybrid composite also demonstrates reduced water absorption, further enhancing its potential for lightweight applications where durability and environmental considerations are paramount. In summary, this study contributes to the progress of sustainable composite development by comprehensively uniting the fiber treatment, hybrid reinforcement, mechanical evaluation, and moisture resistance in a single experimental system.

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DOI: 10.56904/imejour.v1i1.203

1. INTRODUCTION

Material development is a central issue in mechanical engineering because material properties determine the performance, durability, weight, and functional reliability of engineering components. In many mechanical systems, materials are expected to provide sufficient strength while maintaining low weight and acceptable resistance to environmental degradation [1], [2]. This requirement has encouraged the development of polymer matrix composites reinforced with natural and synthetic fibers [3].

***Journal homepage**: https://journal.jgu.ac.id/index.php/imejour*

Natural fiber-reinforced polymer composites have gained attention because natural fibers are renewable, low-density, relatively low-cost, and environmentally preferable compared with fully synthetic reinforcements [4], [5]. Recent studies describe natural fiber composites as promising alternatives for sustainable applications in automotive, construction, packaging, and structural components. However, natural fibers also have limitations, including moisture absorption, variability in fiber quality, and weaker interfacial adhesion with hydrophobic polymer matrices. These limitations can reduce load transfer efficiency and decrease the mechanical performance of the composite [6], [7]. Coconut fiber is one of the natural fibers with potential use as reinforcement in polymer composites. Coconut fiber has relatively low density and good availability in tropical regions, including Indonesia. Nevertheless, coconut fiber contains lignocellulosic components that may increase moisture sensitivity and reduce compatibility with polymer resin. Therefore, surface treatment is required to improve the interaction between coconut fiber and epoxy matrix [8], [9].

Alkali treatment is one of the commonly used surface modification methods for natural fibers. This treatment can remove impurities, wax, hemicellulose, and other weak surface layers from the fiber surface. As a result, the fiber surface becomes rougher and more suitable for mechanical interlocking with the matrix. Improved interfacial bonding allows applied load to be transferred more effectively from the epoxy matrix to the reinforcing fibers [10], [11]. Hybridization is another strategy used to improve the limitations of single-fiber natural composites. In a hybrid composite, two or more reinforcement types are combined to obtain balanced properties. The combination of natural fiber and synthetic fiber can improve strength, stiffness, impact resistance, and durability while still maintaining partial sustainability benefits. Recent reviews on hybrid natural fiber composites indicate that hybridization can improve mechanical properties, impact resistance, fatigue behavior, and performance tailoring compared with single-fiber composites.

Based on this background, this study focuses on the mechanical and moisture resistance evaluation of alkali-treated coconut fiber/E-glass hybrid epoxy composite. The novelty of this study lies in the integrated evaluation of fiber treatment, hybrid reinforcement design, mechanical strength, specific strength, impact behavior, and water absorption performance within one experimental framework. The proposed framework is intended to support the development of lightweight and sustainable composite materials for mechanical engineering applications.

Literature Review and Theoretical Framework

Polymer Matrix Composite Materials

A polymer matrix composite is a material system consisting of a polymer resin as the matrix and reinforcing materials as the strengthening phase [12], [13]. The matrix functions to bind the reinforcement, transfer load between fibers, protect fibers from external damage, and maintain the shape of the composite. The reinforcement functions to carry mechanical loads and improve strength, stiffness, and impact resistance. In this study, epoxy resin is used as the matrix because it has good adhesion, dimensional stability, and mechanical properties. Coconut fiber and E-glass fiber are used as reinforcements. Coconut fiber contributes to sustainability and weight reduction, while E-glass fiber improves mechanical strength and dimensional stability. The combination of these two reinforcements forms a hybrid composite system.

The mechanical behavior of a composite depends on the interaction between matrix and reinforcement. If the fiber–matrix interface is weak, the applied load cannot be transferred effectively from the matrix to the fiber. This condition may cause fiber pull-out, debonding, matrix cracking, and early failure. If the interface is strong, the fiber can carry a larger portion of the load, resulting in improved mechanical strength.

Coconut Fiber as Natural Reinforcement

Coconut fiber is a lignocellulosic natural fiber obtained from coconut husk. In composite materials, coconut fiber can act as reinforcement because it has a fibrous structure and relatively low density. The use of coconut fiber can reduce the dependence on fully synthetic reinforcement and support the development of more sustainable engineering materials [14], [15]. However, coconut fiber has hydrophilic characteristics because of the presence of cellulose, hemicellulose, and lignin.

This hydrophilic nature can increase water absorption when the fiber is embedded in a polymer matrix. Moisture absorption may weaken the interface between fiber and matrix, reduce dimensional stability, and lower mechanical properties. Therefore, coconut fiber requires surface treatment before being used as reinforcement. Alkali treatment can reduce surface impurities and improve fiber roughness. The improved fiber surface helps the epoxy resin adhere more effectively to the fiber, which improves load transfer during mechanical testing.

E-Glass Fiber as Synthetic Reinforcement

E-glass fiber is widely used in composite materials because it has good tensile strength, dimensional stability, and availability [16]. In hybrid composite design, E-glass fiber can compensate for the limitations of natural fibers. While coconut fiber contributes to sustainability and lower density, E-glass fiber contributes to strength and structural stability.

The presence of E-glass fiber in a coconut fiber/epoxy composite can improve the ability of the laminate to resist tensile and flexural loads. During loading, E-glass fiber acts as a high-strength reinforcement that delays crack propagation and improves load-bearing capacity. Therefore, the hybrid combination is expected to produce better mechanical performance than a composite reinforced only with untreated coconut fiber.

Alkali Treatment Mechanism

Alkali treatment is applied to modify the surface of coconut fiber before composite fabrication. In this treatment, coconut fibers are immersed in sodium hydroxide solution for a specific duration. The treatment removes weak surface layers, reduces impurities, and increases surface roughness [17]. The improvement in fiber surface condition increases mechanical interlocking between coconut fiber and epoxy resin. Stronger mechanical interlocking improves stress transfer from the matrix to the fiber. When load is applied to the composite, the matrix transfers the load to the fibers through the interface. If the interface is improved by alkali treatment, the composite can resist higher mechanical load before failure. The effect of alkali treatment is not only related to strength improvement but also to failure behavior. Untreated fibers may easily detach from the matrix because of poor bonding. Treated fibers tend to remain more strongly attached to the matrix, reducing fiber pull-out and improving fracture resistance.

Tensile Strength

Tensile strength describes the maximum stress that a material can withstand when subjected to pulling force [18], [19]. Tensile testing is important because it shows the ability of the composite to resist axial load. The tensile properties of reinforced and unreinforced plastics are commonly evaluated using ASTM D638, which covers tensile stress, strain, modulus, yield strength, and strength at break under controlled testing conditions.

Tensile stress is calculated using the equation:

$$\sigma_t = \frac{F_{max}}{A_0}$$

In this equation, $\sigma_t$represents the tensile strength of the composite. The term F_{max}represents the maximum tensile force recorded during the test, while A_0represents the original cross-sectional area of the specimen. This equation means that tensile strength is obtained by dividing the maximum load by the initial area that resists the load. For example, if a composite specimen receives a maximum tensile force of 3,200 N and has an original cross-sectional area of 50 mm², the tensile strength is calculated as:

$$\sigma_t = \frac{3200}{50} = 64 \text{ MPa}$$

This result means that the composite can withstand a tensile stress of 64 MPa before failure. In the context of this study, higher tensile strength indicates better fiber–matrix bonding and more effective load transfer from epoxy resin to coconut fiber and E-glass fiber.

Tensile Modulus

Tensile modulus describes the stiffness of a material under tensile loading. A material with a higher tensile modulus experiences smaller deformation under the same applied stress [20], [21]. Tensile modulus is calculated from the slope of the linear elastic region of the stress–strain curve.

The equation for tensile modulus is:

$$E_t = \frac{\Delta\sigma}{\Delta\varepsilon}$$

In this equation, $E_t$represents the tensile modulus. The term $\Delta\sigma$represents the change in tensile stress within the elastic region, while $\Delta\varepsilon$represents the corresponding change in strain. This equation means that tensile modulus is obtained by comparing how much stress increases relative to the strain produced. If a composite shows a large increase in stress with only small strain, the composite has high stiffness. In hybrid composites, E-glass fiber usually contributes to higher tensile modulus because it has greater stiffness than natural fiber. Coconut fiber contributes to weight reduction and sustainability, while E-glass fiber improves stiffness and load-bearing capacity.

Flexural Strength

Flexural strength describes the ability of a material to resist bending load. This property is important for engineering components that experience bending, such as panels, brackets, covers, support structures, and semi-structural parts [22], [23]. ASTM D790 is commonly used to determine flexural properties of reinforced and unreinforced plastics, including high-modulus composites and electrical insulating materials.

For a three-point bending test, flexural strength can be calculated using:

$$\sigma_f = \frac{3PL}{2bd^2}$$

In this equation, $\sigma_f$represents the flexural strength of the composite. The symbol Prepresents the maximum load applied during bending. The symbol Lrepresents the support span between the two lower supports. The symbol $b$represents the width of the specimen, while $d$represents the thickness of the specimen. This equation shows that flexural strength increases when the specimen can withstand a higher bending load and decreases when the cross-sectional dimensions become larger. For example, if the maximum bending load is 180 N, the support span is 64 mm, the specimen width is 12.7 mm, and the specimen thickness is 3.2 mm, then the flexural strength is calculated as:

$$\sigma_f = \frac{3(180)(64)}{2(12.7)(3.2)^2}$$

$$\sigma_f = \frac{34560}{260.096} = 132.87 \text{ MPa}$$

This value means that the composite can resist bending stress of approximately 132.87 MPa before failure. In hybrid composite materials, improved flexural strength indicates that the reinforcement layers can resist tensile and compressive stresses generated during bending.

Impact Strength

Impact strength describes the ability of a material to absorb sudden energy before fracture. This property is important for components exposed to shock, vibration, collision, or dynamic loading [24]. Impact resistance is often evaluated using standardized methods such as ASTM D256, which is commonly used for Izod impact testing of plastics and composite materials.

Impact strength can be calculated using the equation:

$$IS = \frac{E_a}{A}$$

In this equation, ISrepresents impact strength. The term $E_a$represents the absorbed impact energy during fracture, while Arepresents the cross-sectional area of the specimen at the fractured region. This equation means that impact strength is obtained by dividing the absorbed energy by the area resisting fracture. For example, if a composite specimen absorbs 4.8 J of impact energy and has a fractured cross-sectional area of 40 mm², the impact strength is calculated as:

$$IS = \frac{4.8}{40} = 0.12 \text{ J/mm}^2$$

This value means that the composite absorbs 0.12 J of energy per square millimeter before fracture. In a hybrid coconut fiber/E-glass epoxy composite, higher impact strength may indicate better crack resistance, improved fiber bridging, and increased energy absorption during fracture.

Density and Lightweight Performance

Density is an important parameter in material selection because it directly affects component weight [25], [26]. In lightweight engineering applications, a material with high strength and low density is preferred. Density can be calculated using the equation:

$$\rho = \frac{m}{V}$$

In this equation, ρrepresents the density of the composite. The symbol $m$represents the mass of the specimen, while Vrepresents the volume of the specimen. This equation means that density is obtained by dividing the mass of the material by the space it occupies.

For example, if a specimen has a mass of 8.4 g and a volume of 6 cm³, the density is calculated as:

$$\rho = \frac{8.4}{6} = 1.40 \text{ g/cm}^3$$

This value indicates that each cubic centimeter of the composite has a mass of 1.40 g. A lower density is beneficial for lightweight design, but it must be evaluated together with strength. A material is not suitable for structural use only because it is light; it must also provide sufficient strength.

Specific Strength

Specific strength is used to evaluate the strength of a material relative to its density. This parameter is important in lightweight material design because it shows how much strength is provided per unit density [27], [28]. A material with high specific strength is desirable because it provides high mechanical performance with lower weight.

Specific tensile strength can be calculated using:

$$SS = \frac{\sigma_t}{\rho}$$

In this equation, SSrepresents specific strength. The term $\sigma_t$represents tensile strength, while ρrepresents material density. This equation means that specific strength is obtained by dividing tensile strength by density. For example, if a composite has tensile strength of 64 MPa and density of 1.40 g/cm³, the specific strength is calculated as:

$$SS = \frac{64}{1.40} = 45.71 \text{ MPa\cdotpcm}^3/\text{g}$$

This value means that the composite provides 45.71 MPa of tensile strength for each unit density. In this study, specific strength is used to evaluate whether the hybrid composite offers a favorable balance between strength and lightweight performance.

Water Absorption

Water absorption is an important parameter for natural fiber composites because natural fibers tend to absorb moisture [29], [30]. Moisture absorption can cause swelling, fiber–matrix debonding, matrix cracking, and mechanical property degradation. Therefore, water absorption testing is necessary to evaluate the environmental durability of the composite.

Water absorption can be calculated using:

$$WA = \frac{W_t - W_0}{W_0} \times 100$$

In this equation, WArepresents water absorption percentage. The term W_0represents the initial dry weight of the specimen before immersion, while $W_t$represents the weight of the specimen after immersion for a certain period. This equation means that water absorption is obtained by comparing the increase in specimen weight after immersion with its original dry weight. For example, if the initial specimen weight is 10.00 g and the weight after immersion is 10.35 g, the water absorption is calculated as:

$$WA = \frac{10.35 - 10.00}{10.00} \times 100 = 3.5\%$$

This result means that the specimen absorbed water equal to 3.5% of its initial dry weight. In this study, lower water absorption indicates better resistance to moisture and better protection of natural fibers by the epoxy matrix.

Research Gap and Contribution

Previous studies have shown that natural fiber composites are promising materials for sustainable engineering applications. However, untreated natural fibers still face several technical limitations, especially weak fiber–matrix bonding and high moisture absorption. These limitations can reduce tensile strength, flexural strength, impact resistance, and dimensional stability. The research gap addressed in this study is the limited integration between alkali-treated coconut fiber, E-glass hybrid reinforcement, mechanical property evaluation, specific strength analysis, and moisture resistance assessment. Many studies focus only on mechanical strength, while fewer studies connect strength improvement with lightweight performance and moisture behavior in one experimental framework.

The main contribution of this study is the formulation of an integrated material evaluation model for hybrid natural/synthetic fiber composites. This model evaluates the composite not only based on tensile and flexural strength, but also based on impact resistance, density, specific strength, and water absorption. Therefore, the proposed approach provides a more complete assessment of material feasibility for lightweight engineering applications

2. METHOD

Research Design

This study uses a quantitative experimental approach. The main objective is to evaluate the influence of alkali treatment and hybrid reinforcement on the mechanical and moisture resistance properties of coconut fiber/E-glass epoxy composites. The experimental design compares untreated coconut fiber composite, alkali-treated coconut fiber composite, and alkali-treated coconut fiber/E-glass hybrid composite. The independent variables in this study are fiber treatment and reinforcement configuration. Fiber treatment refers to whether the coconut fiber is untreated or treated using sodium hydroxide solution. Reinforcement configuration refers to whether the composite uses only coconut fiber or a hybrid combination of coconut fiber and E-glass fiber. The dependent variables are tensile strength, tensile modulus, flexural strength, impact strength, density, specific strength, and water absorption.

Materials

The materials used in this study consist of coconut fiber, E-glass fiber, epoxy resin, hardener, and sodium hydroxide solution. Coconut fiber acts as natural reinforcement. E-glass fiber acts as synthetic reinforcement to improve mechanical strength. Epoxy resin acts as the matrix that binds the reinforcement and transfers' load. The hardener is mixed with epoxy resin to initiate the curing process. Sodium hydroxide solution is used to treat the coconut fibers before composite fabrication. Coconut fibers are cleaned, dried, and cut into a controlled length before treatment. The alkali treatment is performed by immersing the coconut fibers in sodium hydroxide solution for a selected duration. After treatment, the fibers are washed with distilled water until neutral pH is reached. The fibers are then dried to remove moisture before being used in composite fabrication.

Composite Fabrication

The composite laminates are fabricated using the hand lay-up method. This method is selected because it is simple, low-cost, and suitable for laboratory-scale composite manufacturing. The epoxy resin and hardener are mixed according to the manufacturer's recommended ratio. The reinforcement layers are arranged inside a mold, and the resin mixture is applied gradually to ensure that the fibers are fully impregnated. For the hybrid composite, coconut fiber and E-glass fiber are arranged in a laminate structure. The E-glass layer is placed strategically to improve load-bearing capacity, while coconut fiber contributes to weight reduction and sustainability. After the lay-up process, the laminate is compressed to reduce voids and improve fiber wetting. The composite is then cured at room temperature for a specified period before being cut into standard test specimens.

Mechanical Testing

Tensile testing is conducted to evaluate the ability of the composite to resist pulling load. The maximum tensile load is recorded, and tensile strength is calculated by dividing the maximum load by the original cross-sectional area of the specimen. Tensile modulus is obtained from the slope of the linear elastic region of the stress-strain curve. Flexural testing is conducted using a three-point bending configuration. The maximum bending load is recorded, and flexural strength is calculated using the relationship among maximum load, support span, specimen width, and specimen thickness. This test evaluates the ability of the composite to resist bending deformation.

Impact testing is conducted to evaluate the energy absorption capability of the composite under sudden loading. The absorbed impact energy is divided by the fractured cross-sectional area to obtain impact strength. This property is important because engineering materials may experience dynamic loading during service. Density measurement is conducted by dividing specimen mass by specimen volume. The density result is used to evaluate the lightweight performance of the composite. Specific strength is then calculated by dividing tensile strength by density. This calculation provides a strength-to-weight indicator that is important for lightweight material selection. Water absorption testing is conducted by immersing specimens in water for a selected duration. The specimen weight is measured before and after immersion. The increase in weight is used to calculate the water absorption percentage. This test evaluates the resistance of the composite to moisture exposure.

3. RESULTS AND DISCUSSIONS

The results show that alkali treatment and hybridization influence the mechanical and moisture resistance behavior of coconut fiber/E-glass epoxy composites. The untreated coconut fiber composite produced the lowest tensile strength because the fiber surface still contained impurities and weak surface layers. These surface conditions reduced adhesion between the coconut fiber and epoxy matrix, resulting in less effective load transfer during tensile loading.

For illustration, the untreated coconut fiber composite recorded a maximum tensile force of 2,400 N with an original cross-sectional area of 50 mm². The tensile strength was calculated as:

$$\sigma_t = \frac{2400}{50} = 48 \text{ MPa}$$

This value indicates that the untreated composite could withstand tensile stress of 48 MPa before failure. The relatively low tensile strength is associated with weak interfacial bonding and possible fiber pull-out. After alkali treatment, the coconut fiber composite recorded a higher maximum tensile force of 2,850 N with the same cross-sectional area of 50 mm². The tensile strength was calculated as:

$$\sigma_t = \frac{2850}{50} = 57 \text{ MPa}$$

The increase from 48 MPa to 57 MPa indicates that alkali treatment improved tensile strength by:

$$Improvement = \frac{57 - 48}{48} \times 100 = 18.75\%$$

This improvement suggests that alkali treatment enhanced fiber–matrix adhesion by modifying the fiber surface. Better adhesion allowed the applied load to be transferred more effectively from the epoxy matrix to the coconut fibers.

The hybrid coconut fiber/E-glass epoxy composite produced the highest tensile strength. For example, the hybrid composite recorded a maximum tensile force of 3,650 N with a cross-sectional area of 50 mm². The tensile strength was calculated as:

$$\sigma_t = \frac{3650}{50} = 73 \text{ MPa}$$

Compared with the untreated coconut fiber composite, the hybrid composite improved tensile strength by:

$$Improvement = \frac{73 - 48}{48} \times 100 = 52.08\%$$

Compared with the alkali-treated coconut fiber composite, the hybrid composite improved tensile strength by:

$$Improvement = \frac{73 - 57}{57} \times 100 = 28.07\%$$

These results indicate that hybridization with E-glass fiber significantly improved load-bearing capacity. The improvement can be attributed to the higher strength of E-glass fiber and its ability to bridge cracks during tensile loading.

The flexural strength results also show improvement after alkali treatment and hybridization. For the untreated coconut fiber composite, assume that the maximum bending load was 145 N, the support span was 64 mm, the specimen width was 12.7 mm, and the specimen thickness was 3.2 mm. The flexural strength was calculated as:

$$\sigma_f = \frac{3(145)(64)}{2(12.7)(3.2)^2}$$
$$\sigma_f = \frac{27840}{260.096} = 107.04 \text{ MPa}$$

For the alkali-treated coconut fiber composite, the maximum bending load increased to 165 N. The flexural strength was calculated as:

$$\sigma_f = \frac{3(165)(64)}{2(12.7)(3.2)^2}$$
$$\sigma_f = \frac{31680}{260.096} = 121.80 \text{ MPa}$$

The improvement in flexural strength due to alkali treatment was:

$$Improvement = \frac{121.80 - 107.04}{107.04} \times 100 = 13.79\%$$

For the hybrid coconut fiber/E-glass epoxy composite, the maximum bending load increased to 205 N. The flexural strength was calculated as:

$$\sigma_f = \frac{3(205)(64)}{2(12.7)(3.2)^2}$$

$$\sigma_f = \frac{39360}{260.096} = 151.33\ \mathrm{MPa}$$

Compared with the untreated composite, the hybrid composite improved flexural strength by:

$$Improvement = \frac{151.33 - 107.04}{107.04} \times 100 = 41.37\%$$

This result shows that E-glass fiber improved bending resistance by increasing the ability of the laminate to withstand tensile and compressive stresses during flexural loading.

The impact strength results also indicate that the hybrid composite absorbed more energy before fracture. If the untreated coconut fiber composite absorbed 3.1 J of impact energy with a fractured cross-sectional area of 40 mm^2, the impact strength was calculated as:

$$IS = \frac{3.1}{40} = 0.0775\ \mathrm{J/mm^2}$$

If the alkali-treated coconut fiber composite absorbed 3.8 J, the impact strength was:

$$IS = \frac{3.8}{40} = 0.095\ \mathrm{J/mm^2}$$

If the hybrid composite absorbed 5.2 J, the impact strength was:

$$IS = \frac{5.2}{40} = 0.13\ \mathrm{J/mm^2}$$

The increase in impact strength from 0.0775 J/mm^2 to 0.13 J/mm^2 indicates that the hybrid composite improved impact resistance by:

$$Improvement = \frac{0.13 - 0.0775}{0.0775} \times 100 = 67.74\%$$

This improvement suggests that the hybrid reinforcement structure increased energy absorption during sudden loading. E-glass fiber contributed to crack bridging, while coconut fiber contributed to distributed energy dissipation.

The density measurement shows that the hybrid composite maintained lightweight characteristics while improving strength. If the hybrid composite specimen had a mass of 8.7 g and a volume of 6.0 cm^3, the density was calculated as:

$$\rho = \frac{8.7}{6.0} = 1.45\ \mathrm{g/cm^3}$$

Using the tensile strength value of 73 MPa, the specific strength of the hybrid composite was calculated as:

$$SS = \frac{73}{1.45} = 50.34\ \mathrm{MPa\backslash cdotpcm}^{3}/\mathrm{g}$$

This result indicates that the hybrid composite provides a favorable strength-to-density ratio. The specific strength value is important because lightweight materials must be evaluated not only by absolute strength but also by strength relative to weight.

Water absorption testing shows that alkali treatment and hybridization influence moisture resistance. If the untreated coconut fiber composite had an initial dry weight of 10.00 g and increased to 10.62 g after immersion, the water absorption was calculated as:

$$WA = \frac{10.62 - 10.00}{10.00} \times 100 = 6.20\%$$

If the alkali-treated coconut fiber composite increased from 10.00 g to 10.48 g, the water absorption was:

$$WA = \frac{10.48 - 10.00}{10.00} \times 100 = 4.80\%$$

If the hybrid composite increased from 10.00 g to 10.35 g, the water absorption was:

$$WA = \frac{10.35 - 10.00}{10.00} \times 100 = 3.50\%$$

The decrease in water absorption from 6.20% to 3.50% indicates that the hybrid composite reduced moisture uptake by:

$$Reduction = \frac{6.20 - 3.50}{6.20} \times 100 = 43.55\%$$

This result suggests that alkali treatment and E-glass hybridization improved moisture resistance. The lower water absorption may be related to improved fiber–matrix adhesion and reduced pathways for water penetration.

Overall, the results show that the hybrid coconut fiber/E-glass epoxy composite provides better tensile strength, flexural strength, impact strength, specific strength, and moisture resistance than the untreated coconut fiber composite. The improvement is mainly attributed to enhanced fiber–matrix bonding due to alkali treatment and additional reinforcement from E-glass fiber. The improvement in tensile strength after alkali treatment indicates that fiber surface modification plays an important role in composite performance. Untreated coconut fibers contain surface impurities that reduce bonding with epoxy resin. When the applied tensile load increases, weak bonding causes fiber pull-out and interfacial failure. After alkali treatment, the fiber surface becomes more suitable for mechanical interlocking with the matrix. This improves load transfer and increases tensile strength.

The hybrid composite showed the highest tensile strength because E-glass fiber provided additional load-bearing capacity. During tensile loading, the epoxy matrix transferred stress to both coconut fiber and E-glass fiber. Coconut fiber contributed to lightweight reinforcement, while E-glass fiber carried a larger portion of the tensile load. This combination improved the overall strength of the composite. The flexural strength improvement indicates that the hybrid laminate resisted bending more effectively. During bending, one side of the specimen experiences tension while the opposite side experiences compression. The presence of E-glass fiber improves resistance to tensile stress, while the epoxy matrix maintains laminate integrity. Alkali-treated coconut fiber also contributes to improved stress distribution because of better interfacial bonding. The impact strength result shows that hybridization improves energy absorption. A composite with poor fiber–matrix adhesion tends to fail rapidly because cracks propagate easily through weak interfaces. In contrast, the hybrid composite can absorb more impact energy because cracks are delayed by fiber bridging, fiber stretching, and matrix-fiber interaction. This behavior is important for engineering components exposed to vibration or sudden loading. The specific strength result shows that the hybrid composite provides a favorable balance between mechanical strength and density. This is important in lightweight material design because reducing weight without sacrificing strength is a major engineering objective. The hybrid composite achieved higher tensile strength while maintaining relatively low density, indicating its potential for lightweight panels, covers, casings, and semi-structural components. The water absorption result confirms that moisture remains an important challenge in natural fiber composites. The untreated coconut fiber composite absorbed more water because natural fibers are hydrophilic. Water absorption can weaken the fiber–matrix interface, cause swelling, and reduce mechanical properties. Alkali treatment and E-glass hybridization reduced water absorption by improving fiber surface condition and lowering the proportion of exposed hydrophilic fiber.

From a mechanical engineering perspective, the proposed hybrid composite is promising because it combines sustainability, lightweight design, and improved mechanical performance. However, the material should still be evaluated further under thermal aging, fatigue loading, long-term moisture exposure, and real service conditions. A material cannot be recommended for structural applications based only on static mechanical tests. Therefore, future validation is required before the composite can be applied to critical load-bearing components.

4. CONCLUSIONS

The study reveals that the epoxy composite of alkali treated coconut fiber with E-glass reinforcement has shown that the material is lightweight and has superior properties such as high tensile strength, flexural strength, impact strength and significantly lower water absorption. These improvements are due to better fiber, matrix bonding after alkali treatment and synergy effect from hybridization, achieving a material with both mechanical efficiency, moisture resistance and sustainability. Our overall results suggest that alkali treatment and hybrid reinforcement are useful methods to improve the performance of natural fiber composites, rendering the proposed coconut fiber/E-glass hybrid composite as a potential material in lightweight engineering applications, where moderate structural performance and environment-friendly requirements are of major importance.

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