Journal of
Polymer & Composites

ISSN: 2321-2810 (Online)
ISSN: 2321-8525 (Print)
Volume 13, Special Issue 5, 2025
DOI (Journal): 10.37591/JoPC

https://journals.stmjournals.com/jopc

Research JoPC

Chemical Modifications and Tensile Properties of Areca Leaf Sheath Fiber Reinforced Polymer Composites: A Comprehensive Review

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Abstract

Areca leaf sheath (ALS) fiber is a promising eco-friendly material, offering a sustainable, lightweight, and cost-effective alternative for low-strength applications. Its natural biodegradability aligns well with the growing global demand for environmentally responsible materials. This review explores the transformative effects of chemical treatments, such as alkali, silane, and benzoylation, on the tensile properties of Areca leaf sheath fibers. Among these, alkali treatment consistently demonstrates the most significant improvement in tensile strength by eliminating surface impurities and enhancing fiber roughness, thereby facilitating superior matrix bonding. Silane treatment, while slightly less effective in tensile enhancement, offers improved moisture resistance. Other therapies, like benzoylation and peroxide, show moderate gains but are less consistent in performance. A critical balance must be maintained in alkali treatment, as excessive concentration or duration may degrade the fibers, underlining the importance of optimizing treatment conditions. Furthermore, the integration of chemically treated Areca leaf sheath fibers into polymer matrices, such as epoxy, polypropylene, polyvinyl alcohol, and hybrid composites, has significantly boosted composite performance. The effect of fiber loading also plays a crucial role: tensile strength increases in woven fiber composites due to enhanced load transfer. In contrast, short fiber composites exhibit reduced strength at higher loadings due to agglomeration and poor interfacial bonding. These findings emphasize the untapped potential of chemically modified Areca leaf sheath fibers for diverse applications, including electrical insulation, sustainable packaging, interior woodworking, and eco-friendly composite materials.

Keywords: Areca sheath fiber, tensile strength, epoxy, chemical treatments, hybrid composites

INTRODUCTION

Combining two or more materials with different physical and chemical properties makes a composite material. Collectively, it makes a material with better properties than each one alone. Composites consist of two primary components referred to as the matrix and reinforcement. Composite materials can generally be divided into two primary categories according to the types of matrix constituents and reinforcement constituents. According to matrix components, composites can be divided into metal matrix composites, ceramic matrix composites, and polymer matrix composites. Additionally, regarding reinforcement, composites are classified as fiber-reinforced composites, structural-reinforced composites, particulate-reinforced composites, and whisker-reinforced composites[1]. The fuse of at least two filaments inside the solitary framework of the subsequent materials is a mixed composite, regularly truncated to simply a hybrid composite[1]. Polymer metal matrix has matrix materials such as thermoplastic, thermosets, and elastomers, fiber

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Received Date: February 12, 2025
Accepted Date: May 24, 2025
Published Date: July 17, 2025

Citation: Kishor Budda, Madhu M G. Chemical Modifications and Tensile Properties of Areca Leaf Sheath Fiber Reinforced Polymer Composites: A Comprehensive Review. Journal of Polymer & Composites. 2025; 13(Special Issue 5): S94–S106p.

reinforcement composites, and fiber in the form of natural fiber or synthetic fiber. Fiber-reinforced polymer composites, recognized for their elevated specific strength and modulus, hold a significant position in various applications[2]. Artificial fibers, such as glass, carbon, and aramid, are broadly utilized in polymer composites due to their better strength and stiffness properties. Be that as it may, the appeal of using engineered filaments in polymer composites is blurring step by step for the following reasons: they are costly, non-biodegradable, and rough, accordingly making them unsafe to work with and additionally expanding the wear on handling hardware[3].

Agro-strands require almost no vitality to deliver, and because they have high calorific qualities, they can be burned at the end of their life for vitality recuperation[4]. All plant-determined filaments use carbon dioxide when developed and can be viewed as CO_2 characteristics, implying that they can be burned at the end of their existence without extra CO_2 being released into the atmosphere. Then again, glass filaments do not have CO_2 characteristics and require the consumption of petroleum derivatives to give the vitality expected to generate[5]. The destruction of petroleum derivative-based items discharges large amounts of CO_2 into the environment, and this phenomenon is accepted to be the primary source of the nursery impact and the climatic changes that are being seen on the planet today[6]. The comparative properties of areca fiber with other natural and synthetic fibers are shown in Table 1

Areca leaf sheath is one of the agricultural wastes that can be used for the most definable agrofiber in the natural fiber composite field [12]. India is the dominant country in producing the areca crop, which is a tropical crop. Areca is a palm tree in the family of arecaceae [13]. Karnataka is the leading state in the production of areca nuts. The areca leaf sheath is a complex, biodegradable, fibrous material. It is a readily available, cheap, and renewable resource of lignocellulosic agricultural material [14]. Areca leaf sheath fibers are lignocellulosic fibers that contain three main chemical constituents: cellulose, hemicellulose, and lignin [13]. The extent of these segments in a thread relies upon the region of generation, assortment, the development of the plant (age), and the extraction conditions used to acquire the tissues.

Areca sheath fiber gained scientific attention over the last decade due to its potential applications in various fields, including polymer composite materials[15]. Numerous investigations have assessed the chemical, physical, and mechanical characteristics of areca sheath polymer composites [15]. Natural fibers' energy consumption, price, and density are relatively low compared to synthetic fibers [16]. Natural fiber composites are attractive, but their modulus, strength, and, most importantly, moisture resistance are lower than those of synthetic fibers[17]. Physical and chemical techniques are used to successfully modify natural fiber to improve interfacial bonding and reduce moisture absorption[12]. Suggested that areca husk fiber composites are a good substitute for lightweight and moderate life for packing other general structural applications [18–20].

Table 1. Comparison of areca fiber properties with other natural and synthetic fibers[7]–[11].

Fiber	Cellulose (%)	Hemicellulose (%)	Lignin (%)	Moisture content (%)	Density (g/cm³)	Tensile strength (MPa)	Elongation (%)	Ref.
Abaca	56–64	25–29	11–14	15	1.5	717	3-10	[7]
sisal	65.8	12	0.8	10	1.41	350-370		[8]
Jute	64.4	12	0.2	10	1.3-1.49	393-800	1.5-1.8	[9]
kenaf	44.4	20.3	20.1		1.2	282.6	1.6	[10]
Bagasse	55.2	16.8	25.3	8.8	1.25	290	1	[11]
Areca	57-59	13-16	23-25	7.32	0.7-1.5	147-322	10.23	[11]
Aramid					1.4	3000	3.3-3.7	[11]
Carbon					1.7	2400-4000	1.4-1.8	[11]
E-Glass					2.5	2000	2.5	[11]
S-Glass					2.5	4570	2.8	[11]

Researchers are attempting to employ natural rather than synthetic fiber since it is more affordable, renewable, recyclable, requires less energy to produce, poses no health risks when inhaled, and is environmentally friendly and biodegradable[3]. This study compares the tensile strengths of areca sheath fiber reinforced with various polymer matrices and studies the impact of chemical treatment on areca sheath fiber tensile strength. Variables, including crystal index and microfibril angle, influence the initial modulus and strength of areca sheath fibers[21]. A reduced microfibril angle and higher crystallinity improve the mechanical properties of areca sheath fibers[21].

ARECA SHEATH FIBER EXTRACTION

The researcher has used their own extracted areca sheath fiber and areca sheath mat, which are available on the market. Extraction of areca fiber includes the areca leaves collected from the areca plant; there are around 8 to 10 fallen leaves of a mature areca palm per year, measuring 1 to 1.5 meters in length, and are called raw areca leaves. These leaves were cleaned with water and dried in the sunlight until the moisture content was removed. Then, these fresh leaves are soaked in water for ten days, which loosens the fiber for easy extraction[15]. The fibers are separated from the sheet using a metal wire brush and air dried at room temperature for a day. The extracted threads are known as unprocessed fibers. After these extracted fibers had been immersed in water once more for roughly a day, the waste material that stuck to the fibers was manually removed and allowed to dry at room temperature [22]. The areca leaf sheath fibers were chopped into the required length. Then, the chopped fibers were cleaned with distilled water and used to prepare composites [23]. Various shapes and orientations of a material might result in multiple absorption characteristics.[24].

CHEMICAL TREATMENTS

The fiber surface's composition and strength affect composites' mechanical and thermal properties [25]. Fiber treatments might be organic, physical, or synthetic and are performed to accomplish at least one of the following goals. The mechanical properties of fiber polymer composites are affected by their two main constituents, the matrix and the fibers[26]. Due to improved cellulose chain packing during lignin dissolution, composites with chemically processed fibers have better mechanical characteristics than unprocessed fiber-reinforced composites[27]. Chemically treating areca fiber to change its microstructure and morphological changes mainly enhances the fiber's mechanical and physical properties.[28].

The extent of Cellulose, hemicelluloses, and lignin in a fiber relies upon the region of generation, assortment, the development of the plant (age), and the extraction conditions used to acquire the tissues. As discussed, it is inevitable that conventional fiber-fortified polymer composites inalienably have poor mechanical properties because of the poor grip between the thread and framework. Facial attachment can be enhanced by adjusting the textures, lattice, fibers, and context using various physical and compound techniques. Lattice adjustments, by and large, include the expansion of compound coupling specialists and similarity to the polymer network, with the motivation behind enhancing the polymer reactivity and wetting of the reinforcing fibers. Fiber treatments might be organic, physical, or synthetic and are performed to accomplish at least one of the following goals.

Chemical treatments can clean the fiber surface, alter its chemical composition, prevent moisture absorption, eliminate irritating fiber components, and roughen the fiber surface[29]. Additionally, it improves the fiber's strength, elongation, resistance to shrinking, and cell life structure. The chemical treatment reduces irritants such as lignin, hemicellulose, oils, and wax, separating the individual fiber strands from their fiber bundle[29].

Alkali Solution

The unprocessed areca sheath fibers have been processed for the designated time at various temperatures using an appropriate percentage of sodium hydroxide (NaOH) solution, usually 5 to 10 %. Afterward, the fibers were allowed to cool to room temperature and cleaned with water to remove any remaining sodium hydroxide solution that might have stuck to their surface and maintain the pH value. After that, it dried for 12 to 24 hours at a set temperature in an oven and was used for manufacturing composites[30]. Macroscopically, it improves the natural fiber's tensile qualities and raises surface roughness [31]. The most popular and economical method is the Alkali solution [32]. Alkali solution enhances the fiber surface adhesion characteristics, improving the mechanical interlocking at the interface. This is accomplished by breaking up hydrogen bonds in the network structure and eliminating artificial and natural contaminants. Alkali solutions applied to natural fibers enhance the cellulose chain's molecular alignment and reduce the helical angle. Alkali solution creates a rougher texture on the fiber structure, enhancing the interfacial adhesion between the fiber and matrix. When impurities are eliminated using chemical treatment, the fibers' surfaces become rougher, improving the mechanical interlocking of the fibers with the matrix.

Silane Treatment

It involves agitating a silane solution that contains unprocessed fibers. Experimented with a 10% solution, including 20% ethanol and 80% water as a solvent mixture, prepared using tri-ethoxy-vinyl-silane [33]. After 4 hours of vigorous stirring, the fiber in the solution was cleaned in distilled water to eliminate any remaining silane, and it was then dried for 3 hours at 50 degrees Celsius in a hot air oven [33]. The fiber's diameter shrank, density rose, cellulose content rose, hemicellulose, lignin, and moisture content decreased following the silane treatment. Following silane treatment, the crystallite size and crystallinity index increased. The chemical treatment eliminated the extra amorphous component, which increased the alpha-cellulose proportionately. Fibrillation is the process by which the removal of hemicellulose, wax, and lignin separates the well-joined microfibrils. This results in an increase in surface roughness and improved interlocking with the polymer matrix. Furthermore, the modified fiber exhibited thermal stability [33][34]. The mechanical properties are increased in the modified fibers when soaked in the silane solution compared to the alkaline-processed fibers[35]. The natural fiber biocomposite processed with silane exhibits improved interfacial bonding strength and other changed features.

Benzoylation Solution

Benzoyl chloride solution has been used to treat Areca sheath fibers for the prescribed duration. Subsequently, the fibers were immersed in ethanol for a predetermined duration to remove benzoyl chloride from their surface altogether[31]. The fibers were dried in an oven at a predetermined temperature and cleaned with distilled water, and then the fibers were ready to prepare composites. Benzoylation improves the qualities of fibers, just like silane and Alkali solutions do [36]. Lignin and hemicellulose cannot be efficiently removed by an Alkali solution alone. Amorphous material and other contaminants are successfully eliminated from the fiber surface by benzoylation. Regarding the duration of benzoylation therapy, one study found that fiber characteristics degrade when treatment times exceed 15 minutes[36].

Acetylation Treatment

In acetylation, a chemical process that employs acetic acid to alter natural fibers' characteristics and surface features. Moisture absorption capacity is decreased when the acetic acid interacts with the cellulose fibers and removes hydroxyl groups[37]. In this chemical treatment, natural fibers were soaked in an acetic acid solution at different temperature ranges for a specific period and repeatedly rinsed with distilled water to remove excess acid. This method helps to improve dimensional stability and reduce the water absorption of natural fibers[38]. Additionally, acetylation chemical treatment has increased bond shear strength, stiffness, and tensile strength[35][39].

Among the various treatments applied to ALS fibers, alkali treatment consistently shows the most significant improvement in tensile properties by removing surface impurities and increasing fiber roughness for better matrix bonding. Silane treatment also enhances performance but is often slightly less effective than alkali treatment in terms of tensile strength improvement, though it may offer better moisture resistance. Other therapies like peroxide and benzoyl have shown moderate gains. While alkali treatment provides the highest strength gains, it can also lead to fiber degradation if concentration or duration is excessive, highlighting a trade-off between treatment intensity and fiber integrity.

CHARACTERIZATIONS OF ARECA SHEATH FIBER

Density Calculation

A material's density is expressed as its mass per unit of volume. Five Different methods are used to calculate the density of natural fiber. The density of the areca sheath fiber is determined as per Archimedes' principle. The fiber volume fraction plays a vital role in deciding composite properties. A typical fiber volume fraction is between 30% and 60 %. The first can determine a material's density by weighing it in water (W_w) and air (W_a). In this instance, the water's density is measured at standard room temperature, and the air's density is negligible. The specimen's volume is calculated using the known water density and the difference between the material's weight in air and water. The polymer composite density $\boldsymbol{\rho}_c$ is calculated by [2].

$$Composite\ density\ \rho_c = \frac{W_a}{\frac{W_a - W_w}{\rho_w}} = \frac{\rho_w\, W_a}{W_a - W_w}$$

$$\text{Theoretical Composite density } \rho_t = \frac{\text{Weight of the Composite}}{\text{Composite Volume}}$$

Single Fiber Pullout Test of Areca Sheath Fiber

An individual strand pullout investigation was carried out to determine the embedded strand length of the Areca leaf sheath used to manufacture the composite. Some samples were produced for each critical length, and the fair value was taken[15]. Single-fiber pullout tests assessed the interfacial shear strength between the fiber and the matrix material. [15]. The areca leaf sheath fiber was inserted in the matrix material while maintaining the embedded length and applying the force in another direction. Repeat the investigation with different embedded lengths to get the best load-carrying capacity of fiber[40][41].

Water Absorption

Water absorption is a crucial characteristic of natural fibers that influences the properties of composites, including strength and elongation. Absorption of water causes the fiber to swell [42]. Areca fiber consists of different proportions of cellulose, hemicellulose, lignin, and pectin. Fiber's water absorption is more likely to rise when cellulose concentration increases [42]. The moisture level of dried areca fiber is 14 – 16 %.[43]. The composite samples were dried at a predetermined temperature until the weight did not change. The testing was conducted two to five times, and the samples' beginning weight (W_1) and final weight (W_2) were precisely determined[18]. The dry sample weight was taken before and after immersing the samples in water for a day. Capillary transport into the gaps and flaws at the fiber-polymer interfaces is caused by incomplete wettability produced during the compounding process.

Moisture content is determined using the following equation

$$Moisture\ content\ in\ \% = \frac{W_2 - W_1}{W_1} X100$$

COMPARATIVE STUDY OF ARECA SHEATH TENSILE STRENGTH

Tensile Strength of Areca Sheath Fiber Composites

Researchers [44] [14] investigated the tensile strength of natural areca sheath fiber that had been processed with various chemical treatments, including alkali, benzoylation, acrylation, permanganate, and Peroxide solution, with each chemical concentration used at 5 % and 10 %. 15 % and 20 %. Specimens as prepared as per ASTM D3039. The tensile strength of areca sheath fiber processed with different chemicals and concentrations is detailed in Table 2, and the trend is visualized in Figure 1. Satisfactory tensile strength results were obtained at 5% alkali-processed areca sheath fiber. Compared to unprocessed areca sheath fiber[14], the fiber processed with benzoylation exhibited lower tensile strength.

Tensile Strength of Areca Husk and Areca Sheath Fiber Composites

Investigators [45] [46] used L 12 epoxy as the matrix, K-6 hardener blended in a 1:10 ratio, and 1% Alkali solution to create polymer composites of areca husk and areca sheath fiber. Fiber loading for composites is prepared using a random mixing technique of 45 %, 50 %, 55 %, 60 %, and 65 %.

Compared to areca husk polymer composites, areca sheath fiber polymer composites have a significantly higher tensile strength in all fiber loading concentrations. This comparison is presented in Table 3.

Table 2. Tensile strength values of processed areca sheath fibers[14].

Chemical concentration	**Tensile strength (MPa)**				
	Alkali solution	***Benzoylation solution***	***Acrylation solution***	***Permanganate solution***	***Peroxide solution***
5%	21.54	9.84	19.46	15.69	12.57
10%	7.37	8.33	9.08	12.69	4.81
15%	7.36	10.47	11.19	7.66	12.48
20%	10.26	12.17	11.64	6.88	3.79

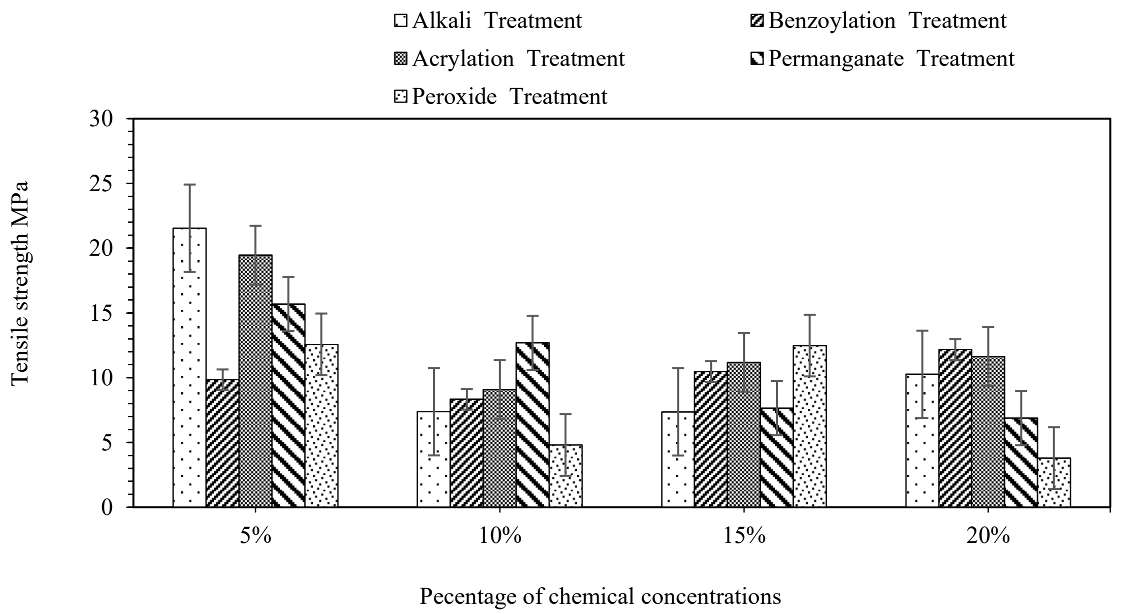

Figure 1. Tensile properties relative to different chemical concentrations of areca sheath fiber.

Table 3. Tensile strength values of alkali-processed Areca husk fiber and Areca sheath fibers.[46].

Percentage fiber loading (%)	**Tensile strength (N/mm^2) areca husk fiber composites**	**Tensile strength (N/mm^2) areca sheath fiber composites**
45	18.35	22.5
50	18.6	19.76
55	22.06	25.93
60	18.4	20.8
65	12.83	13.06

Tensile strength of Areca sheath fiber reinforced with Epoxy composites

Researchers [15] used discontinued short areca sheath fiber as reinforcement material and epoxy LY 556 as matrix material, mixing with hardener HY 951. The length of the fibers varies between 820 and 1400 mm, while the diameter fluctuates from 400 to 700 µm. The fiber proposition employed was manufacturing composites at 0 %, 12 %, 24 %, 36 %, and 48 % on a weight basis.

Based on tensile strength results obtained by the researcher, 48% of fiber-reinforced polymer composites possess significant tensile properties. The tensile performance at different loading percentages is summarized in Table 4, compared to other concentrations. Researchers get results that increase the fiber fraction concentration to increase the void fraction, but 48 % of fiber proposition reinforced polymer composites' void fraction is reduced by 0.029 % compared to 36 % of fiber proposition reinforced polymer composites.

The Researcher [47] [48] used randomly distributed short areca sheath fiber as reinforcement material and epoxy LY 556 as matrix material, mixing with hardener HY 951. The composite was manufactured using the hand layup technique with a fiber length of 10 mm. The fiber proposition was employed in manufacturing composites at 0 %, 12 %, 24 %, 36 %, and 48 % on a weight basis [48].

The contrasting effects of fiber loading on tensile strength arise from differences in fiber form and quality. In the woven fiber composite[15], tensile strength increased with fiber content due to improved load transfer and structural continuity. In contrast, the short fiber composite[48] decreased tensile strength at higher loadings, likely due to fiber agglomeration, poor dispersion, and weak interfacial bonding. The results of the short fiber composites are shown in Table 5. This highlights the critical role of fiber architecture and adhesion in tensile performance.

Tensile strength of Areca sheath fiber reinforced with Polypropylene composites

The researcher [23] developed short Areca-nut leaf sheath fiber as reinforcement material and Polypropylene granules as matrix materials. Polymer composites are manufactured using the compression molding method. The fiber proposition was employed to manufacture composites, which were 5 %, 10 %, 15 %, 20 %, and 25 %, on a weight basis [23]. This composition's tensile strength is tested in the universal testing machine as per ASTM standards.

Table 4. Tensile strength values of alkali-processed areca sheath fiber composites[15].

Percentage fiber loading (%)	Tensile strength (MPa)
0	43
12	68.26
24	88.68
36	96.82
48	104.46

Table 5. Tensile strength values of alkali-processed areca sheath fiber composites [48].

Percentage fiber loading (%)	Tensile strength (MPa)
0	43.68
12	32.24
24	24.02
36	15.82
48	14.02

Table 6. Tensile strength values of areca sheath fiber reinforced with polypropylene polymer composites[23].

Percentage fiber loading (%)	Tensile strength (MPa)
5	25.4
10	28.7
15	26.3
20	24.2
25	23.1

Table 7. Tensile strength values of areca sheath fiber reinforced with polyvinyl polymer composites[49].

Percentage fiber loading (%)	Tensile strength (MPa)
10	30.98
20	44.92
27	46.52
30	44.76
40	27.25

Compared to other percentages of fiber loading, the tensile strength of areca sheath fiber loaded with polypropylene at 10% is higher. The tensile strength values for different fiber loadings are shown in Table 6.

Tensile Strength Areca Sheath Fiber Reinforced with Polyvinyl Alcohol Composites

Polyvinyl alcohol thermoplastic was employed as the matrix material, and this investigation used randomly distributed short areca sheath fibers as reinforcement. Benzoyl chloride and 10% sodium hydroxide treated the fiber chemically. The fiber proposition was employed to manufacture composites at 10 %, 20 %, 27 %, 30 %, and 40 % on a weight basis. The shear and loss moduli increase, showing a significant difference in the low-frequency region and getting closer as the shear frequency increases [49].

The optimal tensile strength of randomly dispersed short areca sheath fiber reinforced with thermoplastic polymer matrix composites containing polyvinyl alcohol is demonstrated by fiber loading levels of 27 %. Detailed tensile strength values are presented in Table 7. The addition of fiber increases the viscosity of a composite.

Tensile Strength of Areca Fiber Mat Reinforced with Epoxy

The researcher [25] developed areca fine fiber fabric mat polymer composites using L 12 epoxy as a matrix with K-6 hardener mixed at a 10 ratio. 6% sodium hydroxide was used for the chemical treatment of the areca fine fiber fabric mat [25]. Tensile tests are performed according to the ASTM D 3039 standards. Compared to areca sheath fiber reinforced polymer composites, the tensile strength values for areca fine fiber fabric mat polymer composites are lower than those. The values are listed in Table 8.

Table 8. Tensile strength values of areca sheath fiber reinforced with polyvinyl polymer composites [25].

Sample	Tensile strength (MPa)
S 1	9.82
S 2	11.1
S 3	11.5

Table 9. Tensile strength values of areca sheath and banana fiber reinforced with epoxy polymer composites [50].

Specimens	Tensile strength (MPa)
S 1	24.4
S 2	23
S 3	21
S 4	26.48
S 5	20.5

Table 10. Tensile strength values of Areca sheath, jute, and E glass fiber reinforced with epoxy polymer composites [53].

Epoxy weight in %	Tensile strength (MPa)
73.52	8.51
71.94	27.3
72.99	15.13
72.46	46.99

Tensile Strength of Hybrid Composites Using Areca Sheath and Banana Fiber

The researchers [50] used natural banana fiber processed with 5% sodium hydroxide and areca sheath fiber with 1N NaOH as reinforcement materials, and epoxy Lapox L-12 was used as matrix material with K6 hardener mixed in a 1:10 proportion. The hand layup technique was used to develop laminated polymer composites[51]. Five tensile test specimens were prepared according to the ASTM D3039 standard, and two bidirectional mats were prepared with 1x1 weaving of 0-90^o orientation in the case of areca fibers and one mat of 0-90^o orientation of banana mat[50] [52].

Samples with more mat layers can be manufactured to provide better results. The individual tensile strengths of these samples are presented in Table 9.

Tensile Strength of Hybrid Composites Using Areca Sheath, Jute, and E-Glass

Researchers [53] use natural, areca sheath, jute, and synthetic fiber as E-glass reinforcement materials in this study. Epoxy LY556, used as matrix material with Hy951 hardener, was mixed in 1:10 proportions. Both Natural fibers are chemically processed with a 5% NaOH solution[53].

The hand layup technique was used to develop laminated polymer composites. Five different layers are used to manufacture four different types of laminated polymer composites with longitudinal and transverse directions. Glass fabrics were used for the top and bottom layers, and based on the specified composite, areca sheath, jute, or both fibers were used for the second, third, and fourth layers. Tensile test specimens are prepared as per ASTM D3039 standard.

Whereas the fourth combination of areca sheath (3.84 %), jute (9.09 %), and glass (19.35 %) based composites showed superior ultimate tensile strength, hybrid composites made from areca sheath, jute, and e-glass can provide an improved option for uses that demand lightweight, high-strength, and cost-efficient solutions. [53]. The tensile strengths of different hybrid combinations are shown in Table 10.

ALS fiber-reinforced composites show varying strengths depending on the matrix used. Epoxy-based composites typically achieve higher mechanical properties due to better fiber–matrix adhesion. In contrast, PP matrices often require compatibilizers like MAPP to improve bonding, and PVA, while more hydrophilic, generally results in lower strength due to its softer nature. ALS/epoxy composites can exceed 50 MPa in tensile strength at similar fiber loadings, compared to 30–35 MPa for ALS/PP and 25–30 MPa for ALS/PVA. These differences are mainly due to matrix polarity, bonding efficiency, and stiffness.

CONCLUSIONS

Areca leaf sheath fiber, an eco-friendly and quickly renewable resource, shows great potential as a sustainable option for low-strength applications. Its outstanding mechanical attributes, attainable via refined chemical treatments like alkali processing, emphasize its promise for various industrial applications. The individual fiber pullout test has shown the fiber's strong interface de-bonding energy and frictional sliding abilities within polymer matrices, highlighting its suitability for composite manufacturing. Crucial elements affecting its tensile strength, like chemical treatments, structure, and moisture levels, have been thoroughly researched, affirming its excellent mechanical properties.

Promising results from several composite uses, such as electrical insulation, environmentally friendly packaging, interior carpentry, and sustainable material manufacturing, indicate that areca leaf sheath fiber is a practical substitute for conventional materials. Enhancing its market potential necessitates more thorough and organized research to create scalable manufacturing techniques and build robust business cases.

This research reinforces the unrealized potential of areca leaf sheath fiber as a revolutionary resource in eco-friendly composite production, setting the stage for its incorporation into sustainable sectors and aiding in creating a greener future.

Conflicts of Interest

The authors state they have no conflicts of interest.

Acknowledgments

The authors extend their gratitude to the GITAM management for supporting the research.

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