

Surface Modified Coir and its Applications



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ABSTRACT: Coconuts (*Cocos nucifera*) are frequently cultivated in tropical locations for their fruits. The rising desire for sustainable, renewable, biodegradable, and recyclable materials has led to greater usage of coir fibre-reinforced bio-composites generated from coconut husks. Although these husks and shells are frequently disposed of as garbage, they may be important raw materials for manufacturing eco-friendly bio-composite materials utilized in diverse applications, including insulation, building, and automotive sectors. Coir fibres exhibit good mechanical and thermal characteristics. However, their hydrophilic nature generally restricts their application in industrial settings unless proper surface modification techniques such as acetylation and mercerization are employed, coupled with hydrophobic coatings produced from natural or synthetic latex. This article offers an overview of coir fibre's chemical, physical, mechanical, and thermal characteristics. It also analyses numerous surface modification methods performed by different researchers, their influence on coir's thermo-physical and mechanical properties, and identifies the practical uses for each approach.

KEYWORDS: *Cocos nucifera*, Mercerisation, Acetylation, Hydrophobic coatings.

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I. INTRODUCTION

Coconut coir is a coconut waste product widely available in tropical countries. Nigeria produces about 265,000 metric tonnes of coconut per year. (Owoyemi et al., 2022). The coconut's mesocarp (coir) is the fibrous layer in the fruit's centre (Figure 1). It is between the inner endocarp, the hard, stony layer, and the outer exocarp. The mesocarp of the coconut is inedible, unlike other portions of the fruit. (Mishra & Basu, 2020). It can be used as a filler in composites and for insulation applications, which reduces waste and meets the demand for fillers. Coconut coir is cost-effective, biodegradable, and non-carcinogenic compared to other artificial fillers. It belongs to the category of fibrous materials and has a high cellulose and lignin content, making it strong, durable and resilient (Oh *et al.*, 2024). Coir is a durable and stiff biodegradable lignocellulosic fibre obtained from the fibrous mesocarp of coconut fruits, which constitutes about 25% of the nut. The coconut, scientifically known as *Cocos nucifera*, is cultivated extensively in tropical countries, including Thailand, India, and Sri Lanka (Arumugam & Hatta, 2022; Ignacio & Miguel, 2021; Kumar & Kunhamu, 2022; Nuwarapaksha et al., 2022). Due to its high lignin content, coir fibres are known for their durability, weather resistance, and relative waterproof qualities, making them suitable for various applications. Additionally, these fibres exhibit significant elongation at break, meaning they can stretch beyond their elastic limit without breaking (Saba et al., 2019).

Biomass materials such as coir attract water because of the hydroxyl groups present in their functional groups. This emphasizes the urgent need to modify the surface of coir to enhance its thermal, physical, and mechanical properties. This paper will explore the composition of coir as discussed in various

studies, analyze the different types of surface modifications mentioned in the literature, and assess the suitability of each modification method for various applications.

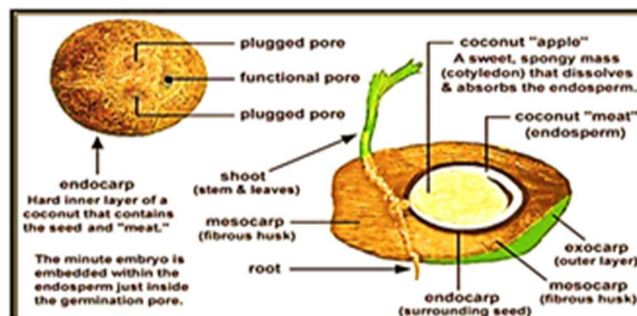


Figure 1: Photo Illustration of a Germinated Coconut (Mangat et al., 2023)

II. COMPOSITION AND PROPERTIES OF RAW COIR

A. Chemical Composition

Coir fibres, derived from the husk of coconuts, have a unique biochemical composition that is primarily made up of three key components: lignin, hemicellulose, and cellulose (Mishra & Basu, 2020). Lignin provides rigidity and strength to the fibres, making them durable and resilient, which is essential for their various applications. Hemicellulose, on the other hand, serves as a matrix that holds the cellulose fibres together and contributes to the overall flexibility and elasticity of the coir material. Cellulose is the main structural component of the fibres, contributing to their tensile strength and aiding in water

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retention. The specific ratios and quality of these components can vary significantly, leading to distinct physical and chemical properties in coir fibres. This variation is critical for determining their usability in different applications, ranging from horticulture and erosion control to the manufacturing of mats and ropes. (Fernando *et al.*, 2025). As presented in Table 1, numerous studies have illustrated the wide range of chemical compositions found in raw coir fibre, highlighting the influence of factors such as the source of the coconuts, processing methods, and environmental conditions. This variation underscores the importance of understanding the biochemical makeup of coir fibres to optimise their performance in various industrial applications. (Zin *et al.*, 2018).

Table 1: Chemical Composition of Coir

Cellulose (%)	Hemicellulose (%)	Lignin (%)	Reference
36-43	0.2	41-45	(Yan <i>et al.</i> , 2016)
43.4	0.25	42	(Oladele <i>et al.</i> , 2022; Verma <i>et al.</i> , 2013)
36-43	0.15-0.25	45.8	(Zhang <i>et al.</i> , 2014)
42.14	15–17	41-45	(Siakeng <i>et al.</i> , 2018)
32-43	0.15–0.25	35.25	(Yusoff <i>et al.</i> , 2016)
38-46	10–15	37–41	(Pérez-Fonseca <i>et al.</i> , 2016)
42.44	0.25	45.4	(Khan <i>et al.</i> , 2014)
32-43	0.15-0.25	40-45	(Zainudin <i>et al.</i> , 2014)
45.67	0.12-0.25	37-41	(Sudhakara <i>et al.</i> , 2013)
43.44	0.25	45.84	(Haque <i>et al.</i> , 2010)

Almost exclusively, the cellulose content invariably lies between 32% to 50%, suggesting a comprehensive contribution by this building block accounting for the strength and stability of the fibres it serves. Hemicellulose content varies from .15% to +15%, which means that it at least will make some contribution to adjusting flexibility and structural support. Lignin, another significant element, is about 30% to 46%. Coir fibres also hold about 3% to 4% pectin, which may be good for bonding and lots of water retention. (Bunsell *et al.*, 2021; Li *et al.*, 2022; Shadhin *et al.*, 2023).

The variations in chemical composition highlight that cellulose and lignin are the key components of plant fibres, which are important for agricultural and industrial applications. (Thapliyal *et al.*, 2023). Variations in the properties of the coir fibre can occur from multiple factors such as the particular coconut variety of plant from which the fibre comes and the extraction techniques that one can use (which may yield variation in purity & quality of the fibres) (Jahami *et al.*, 2024; Rahayu *et al.*, 2022). Coir is a lignocellulosic material which has a thermal conductivity range from 0.014-0.2797 W/mK (Cai *et al.*, 2022; Hoseini & Bahrami, 2017; Ndagi *et al.*, 2021; Thakur *et al.*, 2016). Due to the high lignin content, coir is very elastic, durable, and resistant to rotting. (Danso, 2017; Madueke *et al.*, 2024). However, the water absorption capacity of coir has also been found to be as high as 412%, this is due to the presence of

lignocellulosic compounds which make the fibre hydrophilic (Bhuvanewari *et al.*, 2022; Li *et al.*, 2023; Marakana *et al.*, 2021). The presence of these lignocellulosic compounds increases the coir's hydrophilicity, affecting its thermophysical and mechanical strength (Camillo *et al.*, 2023; Rangappa *et al.*, 2022; Setiyo *et al.*, 2024).

Coir can attract water, which is known as its hydrophilicity. (Ng *et al.*, 2024). This ability is affected by several factors. Firstly, coconut fibres have hydroxyl (-OH) groups on their surface, which makes them hydrophilic and enables them to interact with water molecules easily. (Hewson *et al.*, 2023; Mohammadi *et al.*, 2024). Secondly, coconut fibres primarily comprise cellulose, a naturally hydrophilic polymer, further enhancing their hydrophilicity. (Bi *et al.*, 2024; Rangappa *et al.*, 2022). Thirdly, the porous structure of coconut fibres allows water to be absorbed into the fibres, thereby increasing their water absorption properties. (Fernando *et al.*, 2025; Sutrisno *et al.*, 2021).

A. Physio-mechanical And Thermal Properties of Coir

The characteristics of composites are defined by the properties of their components and how these materials intermingle. Tensile, flexural, and impact strengths are critical mechanical properties that define a material's performance under various types of loading conditions. Tensile strength refers to the maximum stress a material can withstand while being stretched before breaking, whereas flexural strength indicates how well a material can resist deformation under bending loads. Impact strength measures a material's ability to absorb energy and resist fracture when subjected to sudden loads or impacts. In addition to these mechanical properties, several key physical characteristics are essential for understanding a material's behaviour. The diameter affects the cross-sectional area and, subsequently, the load-bearing capacity of cylindrical materials. Density, which is the mass per unit volume, plays an important role in determining the material's weight and buoyancy. Furthermore, water absorption can lead to an increase in mass and density, potentially altering the material's overall performance and durability. Understanding these properties is crucial for selecting the appropriate materials for specific applications.. (Mohd Bakhori *et al.*, 2022); Table 2 indicates the physical and mechanical properties with appropriate values of coir fibres described by some authors. Coir fibres typically possess a density ranging from 1.1 to 1.5 g/cm³, a Young's modulus (tensile strength) of 2 to 8 GPa, and a tensile strength between 105 and 593 MPa. They exhibit an elongation at break of 15 to 51% and a water absorption capacity of 10 to 180%. Variations in these properties are influenced by factors such as the source fiber, pretreatment methods, and extraction techniques. (Adeniyi *et al.*, 2019).

Table 2 Physical and Mechanical Properties of Coir

Average diameter (mm)	Water Absorption (%)	Density (g/cm ³)	Young Modulus (GPa)	Tensile Strength (MPa)	Elongation at break (%)	Reference
0.025	–	1.2	2.74	286	20.8	(Yan et al., 2015)
0.4	130–180	1.2	4–6	175	30	(Priya et al., 2014)
0.01–0.46	–	1.15–1.46	2.2–6	95–230	15–51.4	(Yan et al., 2016)
0.25	–	1.2	2.74	286	20.8	(Yan et al., 2015)
0.1–0.45	10	1.3–1.5	4–6	105–175	17–47	(Siakeng et al., 2018)
0.38	–	1.2	2	144	4.5	(Yusoff et al., 2016)
–	–	–	3.23	165.2	39.45	(Andiç-Çakir et al., 2014)
–	–	–	4–6	144	15–40	(Zainudin et al., 2014)
0.1–0.4	–	1.15	4–6	108–252	15–40	(Sanjay et al., 2018)
–	–	1.37	3.19–3.23	158–165	39–41	(Andiç-Çakir et al., 2014)
–	–	–	4–5	250	20–40	(Tran et al., 2013)
0.1–0.45	–	–	3–6	106–175	47 (max)	(Verma et al., 2013)
–	–	–	4–6	131–175	47.2	(Sudhakara et al., 2013)
0.2	–	1.3	3.11	144.6	32.3	(Saw et al., 2012)
–	93	1.17	8	95–118	–	(Sen et al., 2011)
–	–	1.2	4–6	593	30	(Saw, Sarkhel, & Choudhury, 2011)

Thermo-Gravimetric Analysis (TGA) can be used to investigate the thermal stability of any material. The term "thermal stability" refers to the highest temperature at which a fibre can withstand decomposition (Arrakhiz et al., 2012; Essabir et al., 2016). According to Morandim-Giannetti, Agnelli (Morandim-Giannetti et al., 2012), cellulose degrades between 240 and 350 C, lignin at 280–500 C, and hemicellulose at 200–260 C. The addition of coir fibres has also been found to decrease the thermal conductivity of composite specimens (Nechifor et al., 2022). Coir has been found to possess thermal conductivity properties that rival synthetic insulation materials such as polyurethane and polystyrene. In their research, Ndagi et al. (2021) summarised that coir and Sugarcane bagasse have lower thermal conductivity and thermal diffusivity than polyurethane, but performed poorly in the water absorption test compared to the control polyurethane sample, as shown in Table 3. Sieve size and density played important roles in the thermo-physical and mechanical performance of the bio-composite materials with a particle size of 1.0 mm having a higher density as coir percentage increased and performing better than 0.5 mm particle size in mechanical and thermal tests, 1.0 mm particle size sample containing 70 % coir and 30 % bagasse is the most favourable for use as low temperature thermal insulating material to replace the synthetic ones presently used in low-temperature insulation application. Density has been found to impact the thermal properties of insulation materials significantly. (Kumar et al., 2020; Owoeye et al., 2020; Pászatory, 2021).

Muthuraj et al. (2019) Compared thermal conductivities from several works of literature with their physical experiment and concluded that biomass materials can compare favourably with synthetic insulation materials. K. F. Hasan et al. (2021) created innovative insulating panels using a combination of coir short and long fibres reinforced with phenol-

formaldehyde polymeric bio-composites. Four composite panels with 360, 680, 800, and 1000 kg/m³ densities were created using the hot-pressing technique. An investigation was conducted to examine the composite panels' thermal conductivity and microstructural, mechanical, and physical characteristics. The composites exhibited insulating capabilities, with perceived thermal conductivity values ranging from 0.046280 (0.000494) to 0.062400 (0.001146) W/mK. Their research demonstrated that the mechanical and thermal characteristics of the composite panels were enhanced with increasing density. Out of all the low-density fibre boards, only the ones with a density of 1000 kg/m³ exhibited subpar performance due to fibre clumping. All of the composite panels constructed demonstrated potential as insulating materials. The Fourier Transform Infrared Spectroscopy (FTIR) study revealed a strong and effective bond between the cellulosic coir components and phenol-formaldehyde resin.

B. Morphological Properties of Coir

Several studies have examined the microstructural features of coir fibres using scanning electron microscopy (SEM) (Dharmaratne et al., 2021). Wang et al. (2023) conducted SEM analysis on the cross-sections of several coir fibres, revealing that each fibre contained a significant number of primary fibres with an amorphous shape. (Figure 2), a finding also noted by Dugvekar and Dixit (2022). Meanwhile, Jawaid (2022); Souza et al. (2022), reported that untreated raw coir fibres exhibited surface roughness and closely spaced pits under SEM. These pits, described as spherical voids were found to be reduced following chemical treatment (Wang et al., 2023). Figure 2 shows the SEM images obtained by Arpitha et al. (2024). In the SEM picture, Sample 2 shows a different layer of glass fibre and coir. The fibre breakdown in samples two and three were clean, suggesting a superior fibre-matrix interaction. Furthermore, a good fibre-matrix adhesion was demonstrated by the remaining matrix flakes that were

present around the fibre surfaces. Excellent load transmission is suggested by the components' strong adherence to one another, which might result in improved mechanical characteristics. More significantly, there are no cavities or gaps seen in the composite domain according to the SEM pictures. This shows that the glass fibres, charcoal particles, and coir fibres have all been adequately saturated by the epoxy matrix. Fibre pullout and matrix debonding are the main

causes of material failure, demonstrating damage to the fibre-matrix interface in Samples 1 and 3. The high mechanical properties obtained are probably as result of this full saturation. Lastly, the epoxy matrix's glass and coir fibres seem aligned and oriented correctly. This precise alignment further enhanced the mechanical performance of the composite.

Table 3: Physical and Thermal properties of coir

Sample	Ratio	Sieve Size (mm)	Thermal conductivity (W/mK)	Density (g/cm ³)	Reference
Polyurethane			0.01832	0.1670	(Ndagi et al., 2021)
Coir + bagasse	50:50		0.01472	0.2474	(Ndagi et al., 2021)
Coir + bagasse	60:40	0.5	0.01472	0.2765	(Ndagi et al., 2021)
Coir + bagasse	70:30		0.01472	0.2599	(Ndagi et al., 2021)
Coir + bagasse	50:50		0.01467	0.2453	(Ndagi et al., 2021)
Coir + bagasse	60:40	1.0	0.01467	0.2515	(Ndagi et al., 2021)
Coir + bagasse	70:30		0.01467	0.2494	(Ndagi et al., 2021)
Coir + Ferocement			0.22100		(Alavez-Ramirez et al., 2012)
Coir			0.04600		(Manohar & Technology, 2012)

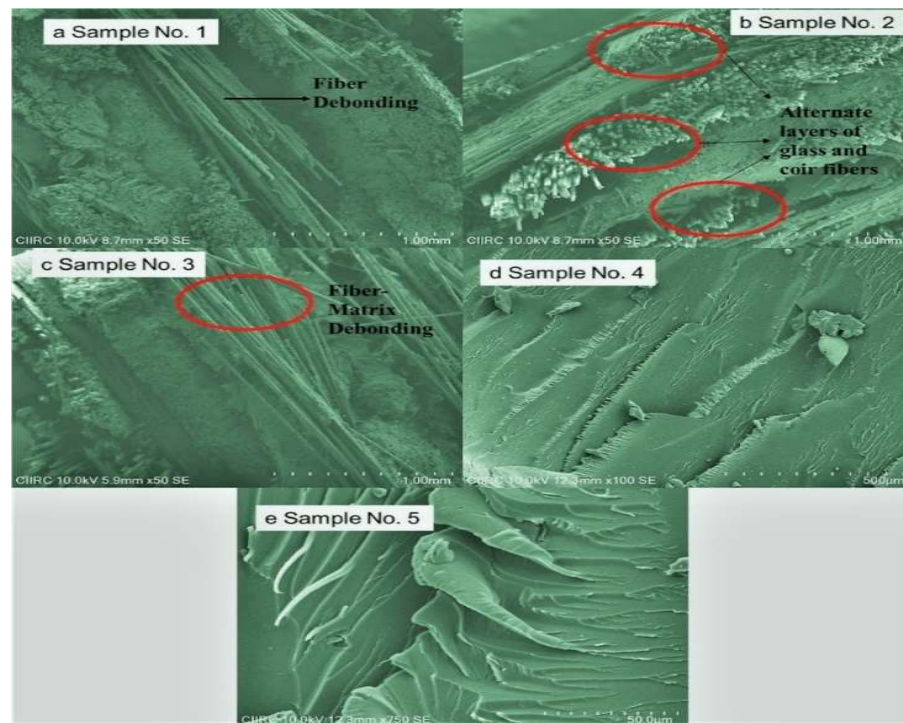


Figure 2 SEM images of **a** epoxy + hardener + three layers of coir fiber (C + C + C); **b** epoxy + hardener + alternate layers of glass and coir fibers (G + C + G + C); **c** epoxy + hardener + alternate layers of coir and glass fibers (C + G + C + G) + 1 wt% of charcoal; **d** epoxy + hardener + 2 wt% of charcoal; and **e** epoxy + hardener + glass fiber + 2 wt% of charcoal (Arpitha et al., 2024)

III. SURFACE MODIFICATION OF COIR

Coir has limitations like hydrophilicity, wettability, and poor adhesion to polymers (Madueke *et al.*, 2024). Surface modification techniques like physical and chemical treatments can improve these properties (Chhetri *et al.*, 2021). Physical methods like stretching and thermo-treatment alter fibre properties, while chemical treatments improve wetting and adhesion (Nwankwo *et al.*, 2025). Matrix modifications add coupling agents and compatibilizers (Nechifor *et al.*, 2022). Coir surfaces can be modified through several methods including Mercerization, Acetylation aminopropyltriethoxy silane method, microwave method and a combination of two or more methods stated above. (Aravind *et al.*, 2022; K. F. Hasan *et al.*, 2021). However, most researchers modify the coir surface to improve its hydrophobicity and enhance its surface adhesion properties to the polymer matrix to improve the mechanical and physical properties of composites. (Ali *et al.*, 2018; Arsyad *et al.*, 2015; Bakri, Naharuddin, *et al.*, 2018; 2021; Bui *et al.*, 2020; Cai *et al.*, 2022; Ekpenyong *et al.*, 2022; K. Hasan *et al.*, 2021; Mir *et al.*, 2013; Ng *et al.*, 2018; Rahman & Khan, 2007; Sahu *et al.*, 2020; Saw, Sarkhel, & Choudhury, 2011; Simimol *et al.*, 2020; Singh *et al.*, 2020; Sumi *et al.*, 2018; Thakur *et al.*, 2016). In their study, Mir *et al.* (2013) observed that, processing raw coir with chemicals such as NaOH results in the transformation of hydrophilic -OH groups into hydrophobic -OH Cr groups. As a result, the adhesion properties between the fibre surface and polymer matrix are enhanced. The treated surface underwent microstructural and chemical examinations, which corroborated these findings. Figure 3 shows the relation between the tensile strength of raw coir, 3-hour treated coir and 5-hour treated coir. The strength of the coir improved as hydrophobicity was substituted for hydrophilicity through chemical treatment. The level of success in cellulose removal is affected by the particle size of the coir and the period of immersion in the alkaline solution. (Rahayu *et al.*, 2022).

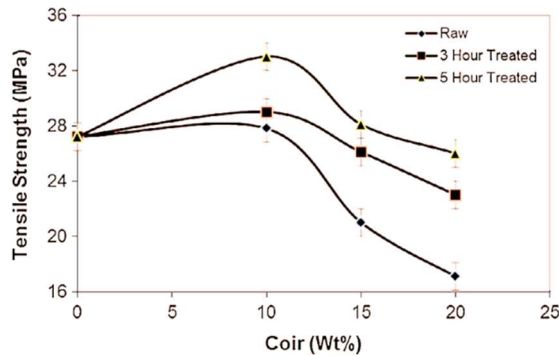
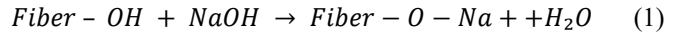


Figure 3: Variation of tensile strength of PP biocomposites reinforced with raw, 3 h-treated and 5 h-treated coir (Mir *et al.*, 2013).

A. Mercerisation (Alkaline Treatment)

The process of mercerisation is an Alkaline treatment of fibres often employed in textile industries by applying NaOH to the surface of the fibre, which causes the OH group present in the fibre to react with NaOH as shown in equation 1.



Fibres are immersed in sodium hydroxide solution of varying percentages of 5, 10, 15 and 20 and kept overnight with occasional stirring to neutralize the acid, they are then dipped into a 10% solution of HCl for half an hour, washed with running water and air dried. The water/liquor ratio was maintained at 1: 24 at room temperature. (Nurazzi *et al.*, 2021). Bakri, Naharuddin, *et al.* (2018) Characterized coir fibres after treatment in various solutions of NAOH and inside a microwave oven at different intervals, Coir fibres were soaked in sodium hydroxide (NaOH) solution 5 wt.% for 24 hours. After soaking, fibres were rinsed and dried at room temperature for 48 hours. They sought to improve the mechanical strength of treated coir fibres. Figure 4 shows that the tensile strength of treated coir fibres improved significantly after Alkali treatment and 10-minute heating inside the microwave. Their research also observed the crystallinity index of coir fibre Figure 5 based on the characterization of Fourier Transform Infrared Spectroscopy (FTIR) and X-ray diffraction (XRD).

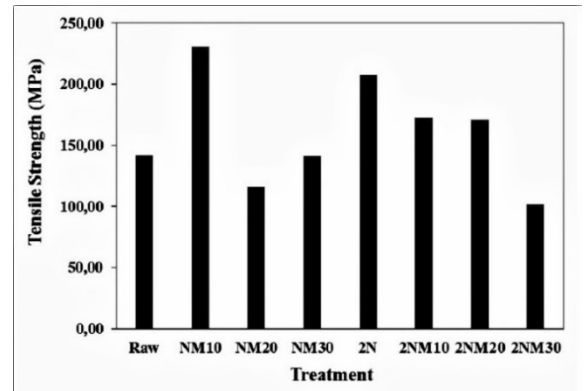


Figure 4 Tensile Strength of Raw and Treated Coir Fibres (Bakri, Naharuddin, *et al.*, 2018)

In Figure 5, the sample with the highest tensile strength (NM10) also had the highest crystallinity index of 43%. However, it was observed that with an increase in the concentration of sodium hydroxide, there is a decrease in the tensile strength and crystallinity of the coir fibres. (Arsyad *et al.*, 2015). Delignification of coir removes the brown colour of coir which is caused by the presence of lignin content. (Rahayu *et al.*, 2022). Simimol *et al.* (2020) enhanced the surface of flax fibres towards improving its mechanical and physical properties by chemically treating the fibre surfaces using two methods i.e., mercerization and acetylation.

Crystallinity index (%) of treated and untreated coir fibres

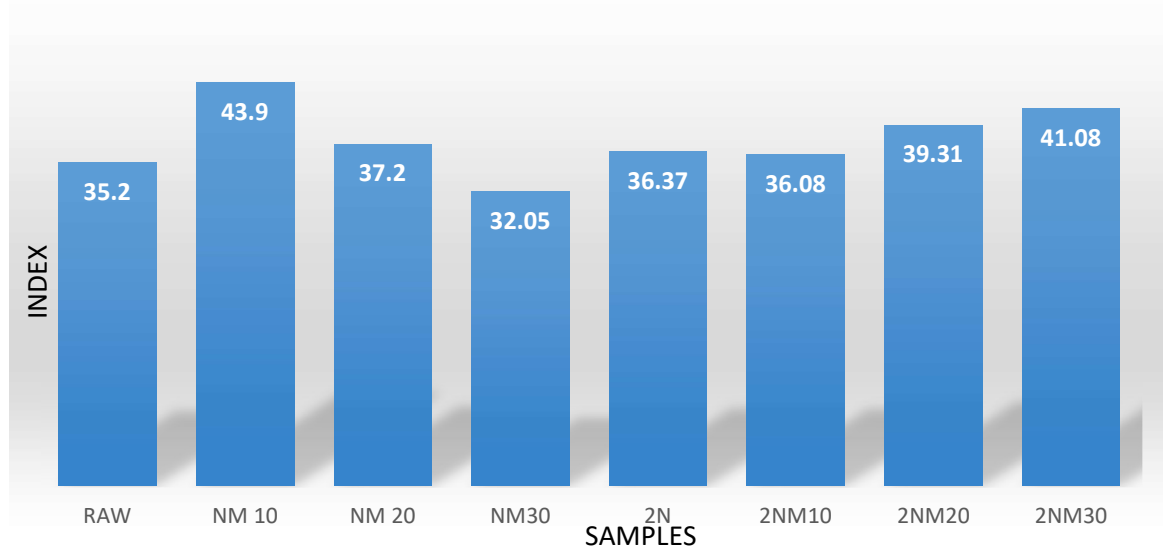


Figure 5: The crystallinity index of coir fibres (Bakri, Naharuddin, et al., 2018)

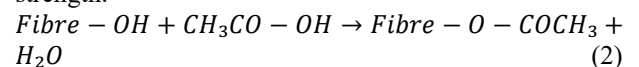
Studies have shown that untreated natural fibres tend to be coated with lignin, hemicellulose, wax, and oils. However, treating these fibres with alkali can produce a coarser and cleaner texture as some impurities are removed.

Bakri, Putra, et al. (2018) observed that micropores appear in the treatment of 8 wt.% and 10 wt.% NaHCO_3 . In the case of the 12% NaHCO_3 solution with a soaking time of 120 hours, only a few micropores were observed on its surface compared to the other samples. This may explain why the tensile strength of the 12 wt.% NaHCO_3 treated for 120 hours was the highest among all the samples examined. These results suggested that the appropriate density of NaHCO_3 and soaking time may enhance the tensile strength of coir fibre. The result also implied the potential characteristic of coir fibre to be used as reinforcement in matrix composite. The micropores, however, can serve as interlocking bonding between matrix the alkali treatment also causes the fibre surfaces to become more uneven, reducing their diameter and increasing their aspect ratio. This increase in aspect ratio ultimately strengthens the interfacial bonding. (Arsyad, 2019). Coir fibres subjected to NaOH treatment at various concentrations, time, and temperature parameters as ascertained by the Box-Behnken design (Method of optimization of process parameters) improve the surface crystallinity of the fibres. In their study, Panwar and Neelakrishnan (2022) surmised that The optimum parameters identified are 8% NaOH at 25°C for 480 min, which resulted in higher fibre crystallinity, rougher surface, and an increase in maximum tensile force. The variation in lignin and maximum tensile force was reduced by 22.415% and 39.571%, respectively. The effects of alkaline treatment on fibers include the extraction of various impurities such as wax, lignin, and oil. This process also leads to the initial dissolution of cellulose, resulting in the formation of shorter crystallites. Additionally, the treatment enhances the surface roughness of the fibers, which subsequently improves their

mechanical properties. Finally, it also increases the wettability of the fiber surfaces.

B. Acetylation

Acetylation involves the grafting of acetyl groups onto cellulose fibres using the esterification method to plasticize the surface of the cellulose fibre as shown in equation 2. Sahu et al. (2020) studied treated and untreated sisal fibre using the scanning electron microscope, the results from their research indicated that mechanical properties greatly improved after mercerization and acetylation treatment, however, samples that went through acetylation treatment had better flexural and water absorption properties while samples that went through the mercerization process had better tensile properties. The surface morphology of samples treated using the two chemical processes is shown in Figure 6 (a and b) with treated fibres having rougher surfaces compared to untreated fibre. The durability of treated natural fibre samples in Alkaline and Acidic environments over some time was discussed by Sumi et al. (2018). They conducted tests on multiple treated coir specimens, exposing them to both alkaline and acidic environments for 12 months. The findings indicated that the degradation rates were slightly elevated in alkaline conditions when compared to acidic ones. Samples that were subjected to saline conditions or alternate wetting and drying conditions experienced minor losses of tensile strength, which was less than 7%. However, geotextiles that underwent surface modification and were buried at lower depths of soil under field conditions maintained 70-80% of their original tensile strength.



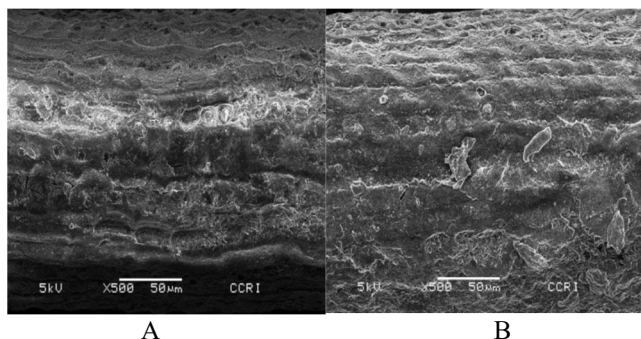


Figure 6: Micrograph Image of Fibres Treated in : (a) mercerisation (a) acetylation (Simimol et al., 2020)

C. Use of Coupling Agent

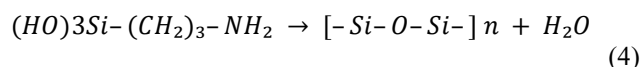
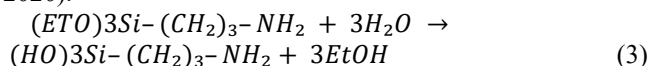
Coupling agents are substances that improve the compatibility and adhesion between two different materials, particularly between natural fibres and their matrix in composite systems (Aziz et al., 2021). They are often employed in conjunction with chemical treatments like mercerization to enhance the overall performance of fiber-reinforced composites

Coupling agents such as Silane, Malleated Polypropylene (MAPP), and Maleic Anhydride grafted copolymers are often used to enhance fibre compatibility with their respective matrix. Coupling agents are often used in conjunction with fibre chemical treatments like mercerisation. Essabir *et al.* (2016) Found that using a coupling agent (styrene-(ethylene-butene)-styrene) triblock copolymer grafted with 1.4-2% maleic anhydride (SEBS-g-MA) improved filler-matrix interfacial adhesion. The study examined how alkali, silane, and calcium hydroxide affect the thermal, tensile, structural, and morphological characteristics of coir fibre (CF) and enhance its adherence to a polylactic acid (PLA) matrix. Adding coupling agents significantly affects the physical and thermal characteristics of composites. (Arrakhiz *et al.*, 2012; Essabir *et al.*, 2016; Siakeng *et al.*, 2018). Several research have examined how coupling agents affect the characteristics of coir fibres and composites. (Anbupalani et al., 2020; Fernandes et al., 2013; Geethamma et al., 2005; Kurinjimalar et al., 2021; Pérez-Fonseca et al., 2016; Praveen et al., 2016; Verma et al., 2013).

D. Aminopropyltriethoxysilane

Aminopropyltriethoxysilane (APTES) is a crucial silicon compound in chemistry, used in the synthesis of materials. Metal oxide nanoparticles (MONP) are used for silanization, with amine incorporation improving dispersibility and antibacterial properties. APTES-MONPs are used in electrochemical sensors, catalysts, and pickering emulsions (Zhang & Lai, 2022). Aminopropyltriethoxysilane (APTES) is a silane compound with the chemical formula $C_9H_{23}NO_3Si$, used in the silanization process to functionalize surfaces with alkoxy silane molecules (Mishra, 2015). It plays a significant role in the covalent bonding of organic films to metal oxides, particularly silica and titania, which is crucial in biological and materials science applications (Piccinno et al., 2012). In the manufacturing of insulating materials like glass wool and mineral wool, APTES is added to the binder to improve

moisture resistance and boost compression resilience, which is vital for retaining insulating characteristics over time. (Rajan *et al.*, 2018). Aminopropyltriethoxysilane (APTES) is a useful silane molecule that can be synthesized through a sequence of chemical events. The process begins with aminopropyl groups reacting with triethoxysilane precursors, which requires careful temperature control and the presence of a catalyst to complete the reaction. The aminopropyl group is obtained by the interaction of ammonia with an alkyl halide, resulting in the creation of an aminopropyl halide. This intermediate is then treated with triethoxysilane in the presence of a base, such as triethylamine, which acts as a catalyst and aids the nucleophilic substitution reaction that connects the aminopropyl group to the silicon atom. (Miller & Shantz, 2020).



where

$(EtO)3Si$ represents the triethoxysilane group.

$(CH_2)_3-NH_2$ is the aminopropyl group.

$EtOH$ is ethanol, a byproduct of the hydrolysis reaction.

$[-Si-O-Si-]_n$ represents the polymeric siloxane network formed during condensation.

E. Microwave Oven Method

The microwave oven technique of surface modification is a technology that may be utilised to alter the surface characteristics of materials, such as coir. This technique utilises a microwave oven to generate plasma, which is subsequently employed for surface modification. (Barnes *et al.*, 2021). In the context of coir, Lai (2024) indicated that alkali-treated coir fibre properties may be changed by a silane coupling agent in a microwave oven. The application of microwave-assisted chemical treatments efficiently accelerated the esterification reaction, which improved the interfacial adhesion between the coir fibres and a PLA (polylactic acid) matrix. (Zhang et al., 2017).

The method normally involves the following steps:

- i. The sample is put into an Erlenmeyer flask.
- ii. The vacuum valve is opened, and a vacuum pump is used to evacuate the flask.
- iii. The valve is closed, and the vacuum hose is withdrawn.
- iv. The flask is transferred to the microwave oven.
- v. As the microwave is turned on, plasma is sparked to treat the surface for the chosen amount of time (Nemani *et al.*, 2018).

F. Hydrophobic Coatings

Hydrophobic coatings are surface treatments that enhance a material's resistance to water by lowering its surface energy (Bayer, 2020). Super-hydrophobic surfaces, on the other hand, repel water drops and have high apparent contact angles, low contact angle hysteresis, low sliding angle, and high stability of the Cassie model state (Zhang et al., 2021). These surfaces can be achieved using natural materials like lotus leaves, which exhibit natural waterproofing abilities (Collins & Safiuddin, 2022). Coating the surface of coir is a practical approach to enhancing its hydrophobicity, making it more water-resistant and durable for various uses. Surface modification techniques, such as the application of polymer thin films, can significantly improve coir's hydrophobicity (Aravind *et al.*, 2022). Wahby et al. (2020), created bio-based super-hydrophobic coatings by assembling nanoparticles in bio-based polymer matrices, increasing hydrophobicity and adhesion even when exposed to water. Combining silica nanoparticles with polydopamine has been shown to improve materials' water repellences, which could be applied to coir fibres (Mohammed *et al.*, 2022). Basic surface coatings, such as polyvinyl acetate, can transform water-attracting surfaces into water-repellent ones, suggesting that using this technology to treat coir holds promise. Water-based silicone-modified polyurethane dispersions were applied to generate superhydrophobic coatings that are free of fluorine and solvents, making them more environmentally sustainable (Liu *et al.*, 2022). Surface coating technology advancements provide numerous alternatives to improve coir fibre properties, increasing their flexibility and value for industrial applications (Aravind *et al.*, 2022). Latex coating is a process that enhances the properties of coir fibres, produced from coconut husk. It involves treating the fibres with sodium hydroxide and coating them with either synthetic or natural latex, resulting in a hydrophobic surface. This process not only enhances coir fibres' durability and performance but also contributes to environmental initiatives by reducing waste and providing a lightweight, eco-friendly alternative to synthetic materials (Dewri & Gnanamoorthy, 2023, 2024; Edirisinghe et al., 2015; Nair et al., 2011). Thakur et al. (2016). Studied the development of antibacterial and hydrophobic functionalities in natural fibres for fibre-reinforced composite materials, the mechanical properties of raw and biografted fibre composites were studied and their results show that, the biocomposites reinforced with biografted coconut fibers required more tensile load to break in comparison to neat polymer and raw coconut fiber reinforced biocomposites (Fig. 10a and b). The effect of fiber content on the mechanical properties of biocomposites. The biocomposite reinforced with 1% Biografted fibers showed maximum tensile strength (34.96 MPa) in comparison to biocomposites reinforced with 0.5% biografted fibres (23.18 MPa), 1% raw fibres (13.64 MPa) and 0.5% raw fibres (10.48 MPa). Similar results were observed in the case of the flexural strength of biocomposites.

IV. EFFECTS OF SURFACE MODIFICATION ON PROPERTIES OF COIR

Surface fibre modification plays a vital function in increasing the characteristics of coir utilised in composite materials. These adjustments enhance the mechanical properties of the final composites by boosting the compatibility of coir fibres with different matrices, including the epoxy resin (Karthik et al., 2024). Treatments such as alkali and silane considerably increase the interfacial contact between coir fibres and epoxy resin, which is crucial for the mechanical strength of the composites. Research reveals that some combinations of these treatments may considerably enhance withdrawal energy and interfacial shear strength, indicating a stronger link between the fibre and the matrix. Furthermore, varied immersion durations and concentrations of sodium bicarbonate greatly alter the mechanical characteristics of coir fibre/epoxy resin composites, including their strength, impact resistance, and tensile modulus. (Gouda et al., 2021; Islam et al., 2024; Singh et al., 2020). As coir is a natural and renewable resource, these adjustments not only increase the material's physical characteristics but also contribute to sustainability (Stelte et al., 2023). Current research shows that, with suitable surface treatments, coir fibres might successfully replace synthetic fibres in some applications, giving an ecologically benign alternative while still fulfilling performance demands (Mahmud et al., 2025; Siregar et al., 2024). Continued study and development in this subject are likely to uncover new uses for coir across numerous industries, therefore improving resource efficiency and environmental sustainability. The different types of surface modification methods, their effects and applications are summarised in Table 4. Each of these methods has its advantages and can be chosen based on the desired properties of the final composite material. It is important to consider the end-use application when selecting a surface modification technique for coir fibre.

The biocomposites reinforced with 1% biografted fibers showed maximum flexural strength (22.08 MPa) followed by biocomposites reinforced with 0.5% biografted fibers (14.18 MPa), 1% raw fibres (8.9 MPa) and 0.5% raw fibres (7.68 MPa). Tensile and flexural strengths were found to improve in the case of reinforcements with biografted fibres. In case of fibre contents, there was a huge improvement in mechanical properties, even with the slight enhancement in biografted fibre contents.

Table 4: Surface Modification Methods, Their Effect and Applications

Treatment Method	Effect	Application	References
Mercerisation	Removes impurities and increases the surface roughness of coir	Better mechanical interlocking. With a polymer matrix	(Chollakup et al., 2013; Rahman et al., 2007; Yusoff et al., 2016)
Acetylation	Alters the surface chemistry of coir	Reduces the moisture absorption of coir	(Dugvekar & Dixit, 2022; Ezeamaku et al., 2023; K. F. Hasan et al., 2021)
3-Aminopropyltriethoxysilane	Reacts with the fibre surface to form a stable bond	Improves the interfacial bonding between the fibres and the matrix	(Mahalingam & Babu, 2022; Ru et al., 2022)
Microwave	enhance the surface characteristics of coir fibres	Improved Mechanical strength	(Ahmad et al., 2021; Renreng et al., 2021; Subha et al., 2022)
Latex Coating	Improves frictional Properties of coir	Drastically reduces Water absorption of coir	(Dewri & Gnanamoorthy, 2023, 2024; Edirisinghe et al., 2015)

A. Effect of Surface Modification on Mechanical properties of coir

The alteration of coir fibres may greatly increase their mechanical characteristics, such as impact resistance, stiffness, tensile strength, flexural strength and compressive strength thereby making them more appropriate for usage in composite materials (Adeniyi et al., 2019). An overview of the mechanical properties of treated and untreated coir fibres used in composite preparation is shown in Table 5. A recent study by Schiavon et al. (2023) suggests that treating coir fibres with sodium bicarbonate solutions of varied concentrations and immersion periods may increase their compatibility with polymer matrices, such as epoxy resin. Specifically, soaking the fibres in a 15% sodium bicarbonate solution for five days resulted in maximum stiffness and strength. Conversely, a 5% solution concentration is optimum for improving strain and impact strength (Sobuz et al., 2024). Additionally, chemical treatments such as those using chromium sulphate followed by sodium bicarbonate can further boost the tensile strength of coir fibres (Kumar et al., 2020). This is corroborated by observations of cleaner and smoother surfaces under scanning electron microscopy(Windyandari et al., 2021). These breakthroughs in coir fibre treatment are opening the way for manufacturing more durable, sustainable, and cost-effective materials for numerous industrial applications.

The influence of fibre surface modifications on the mechanical, thermal and morphological properties of coir/carbon fibre-reinforced epoxy-based hybrid composite was investigated by Singh et al. (2020). They found that treating fibres with NaOH resulted in superior mechanical

properties compared to untreated samples. However, the tensile properties varied as the percentage of weight fibre loading decreased. The woven carbon fibre had the best tensile performance, with the maximum strength achieved at 10% fibre loading. SEM analysis confirmed the interfacial bonding of the Coir carbon fibre/epoxy hybrid composite. Moreover, compressive properties increased as the fibre loading increased from 10% to 30%. The hybrid composite achieved a maximum compressive strength of 0.23 MPa at 30% fibre loading, surpassing untreated coir fibre/carbon fibre/epoxy resin. The alkali treatment was responsible for the hybrid composite's increased

Table 5: Mechanical Properties of Epoxy-based Treated Coir Hybrid Composites (Arpitha et al., 2024)

	Tensile strength (N/mm ²)	Young's modulus (N/mm ²)	Flexural strength (N/mm ²)	Flexural modulus (N/mm ²)	Hardness (BHN)
1	5.9 ± 0.6	630.4 ± 65.3	22.4 ± 1.8	3114.05 ± 287.5	44.72 ± 3.5
2	35.0 ± 0.4	910.3 ± 93.2	107.1 ± 9.2	5120.46 ± 487.3	46.27 ± 4.2
3	37.1 ± 0.3	952.8 ± 91.2	49.0 ± 5.3	5178.78 ± 497.5	49.21 ± 5.1
4	3.3 ± 0.2	1072.6 ± 98.6	56.8 ± 5.1	4115.16 ± 377.6	18.25 ± 1.7
5	2.8 ± 0.3	990.7 ± 92.3	55.2 ± 4.5	3987.22 ± 321.1	17.89 ± 1.2

compressive strength. The removal of lignin from the surface structure of coir fibres has been found to hurt the tensile strength of the fibre. Bui et al. (2020) subjected different samples of coir fibres to alkali treatment and compared the

results to raw, untreated samples. Interestingly, samples were also subjected to boiling, and results indicated that the water absorption capacities of alkali-treated and raw fibre were found to be almost the same, but there was a remarkable reduction in the water absorption capacity of boiled fibre. The thermal conductivity decreased from 0.052 to 0.024 W/M. K with the increase in density of the fibre bundles from 30 to 120 kg/m³. They also concluded that reduction in lignin, Pectin, fatty acid and cellulose led to the reduced tensile strength of the treated fibres. By contrast, tensile strains at the failure of fibres were increased significantly by 18% and 51% after chemical and physical treatment, respectively. Their Study showed that treating fibres can increase their ductility, a consistent trend observed across all fibre types in Thermogravimetric analysis (TGA) and Differential Thermal Analysis (DTA) tests. Moreover, treated fibres exhibit greater thermal stability than their raw counterparts, as impurities are removed during treatment. At 90°C, the residue of treated fibres is also higher than that of raw fibres. Furthermore, applying these treatments enhances the chemical durability of the fibres, which was demonstrated by exposing them to a saturated solution of sodium hydroxide NaOH (10%) and calcium hydroxide (Ca (OH)₂). Based on the results, when exposed to sodium hydroxide solution and calcium hydroxide solution, the raw fibre undergoes a 37% and 20% mass reduction, respectively. Conversely, treated fibres experience a nearly 50% mass reduction compared to raw fibres. Notably, the concentration of NaOH and the treatment temperature significantly impact the physical and mechanical features of coir.

Ru et al. (2022) optimized coir at different NaOH concentrations and treatment temperatures and found that at a concentration of 4.12%, for 15.08 h and 34.21 °C, the coir exhibited optimum mechanical values of tensile strength of 97.14 MPa, elastic modulus of 2.98 GPa and elongation of 29.35%, which were 38.28%, 39.91% and 25.59% higher than that of untreated coir fibre. Water absorbability was reduced by coating with a hydrophobic substance, their results showed that samples exhibited contact angle values in the range of 84° to 146°, thermal conductivity values in the range of 0.0511 to 0.0861 W/mK and densities in the range of 0.678 to 0.99 g/cm³. As a result of the compressive and flexural strength tests, it was found that the compressive strength of the specimens was very high, the highest compressive strength was found as 32.8093 N/mm².

B. Effect of Surface Modification on Thermal properties of coir

Surface modification can significantly impact the thermal properties of coir fibre (Rahman et al., 2007). Adediran et al. (2021) used treated coir fibre and yam peel particulate to reinforce polypropylene composites, revealing that the composites had optimal mechanical properties. However, the thermal conductivity increased with fibre addition. Siakeng et al. (2018) investigated the effects of alkali, silane, and calcium hydroxide on the tensile, thermal, and fibre-matrix bond strength of coir fibres and pineapple leaf fibres to improve their interfacial bonding with

Poly(lactic Acid (PLA) matrix. Alkali-treated fibres yielded the lowest fibre diameter and highest Interfacial Stress Strength (IFSS), while silane-treated CF and alkali-treated PALF showed improved thermal stability. Thermogravimetric Analysis (TGA) showed improved thermal stability in these treatments. The study recommends optimizing surface treatments to improve fibre matrix bond strength and exploring new applications in different industrial sectors.

C. Effect Of Surface Modification on The Physical Properties of Coir

Water on natural fibres can cause bio-corrosion and fibre volume changes, leading to cracks in composite materials. Increased water absorption can arise from a high cellulose content and a greater presence of -OH (hydroxyl) molecules that interact with water (Arifuzzaman Khan et al., 2013; Arpitha et al., 2024; Sanjay et al., 2015). This indicates that untreated fibre composites are more susceptible to significant water absorption compared to treated counterparts, where the number of free hydroxyl groups has been reduced through the treatment process (Saw, Sarkhel, & Choudhury, 2011; Saw, Sarkhel, Choudhury, et al., 2011; Siddika et al., 2013). Shams-Ghahfarokhi et al. (2019) developed a new technique to prepare a polyester woven fabric that was both hydrophobic and thermal insulating using electro-spraying of nano-porous silica powder. The study showed that heat transfer decreased from 71.65% for the untreated fabric to 38.35% and 30.99% for the electro-sprayed fabrics after 16 and 24 hours, respectively. The presence of aerogel particles also improved the hydrophobic properties of the electro-sprayed samples. Sahu et al. (2020) found that alkali treatment is the most cost-effective and efficient way to improve the bonding between fibres and polymers, resulting in significant improvements in mechanical properties, water absorption resistance, fatigue resistance, thermal properties, electrical properties, wear, and friction resistance capacity. Many chemicals are available to treat textile materials to make them waterproof, but there are concerns about potential environmental and health risks associated with their use. Composite coatings are layers of particles applied to the surface of a textile to add new and beneficial properties.

V. CONCLUSIONS

The lignocellulosic nature of coir is responsible for its hydrophilicity, which makes it susceptible to weak mechanical, thermal and physical properties. This review paper establishes that surface modification plays a significant role in improving the physical, mechanical and thermal characteristics of coir fibres, allowing their specialized usage in numerous industrial applications. Each treatment procedure is specially developed to meet various properties and needs of the fibres. For example, treatments such as acetylation and latex coating are extremely successful in improving the hydrophobicity of coir fibres. By lowering their hydrophilicity, these approaches make the fibres more resistant to water absorption, which is especially useful in humid areas where moisture exposure is a problem. This improved water resistance may greatly improve the performance and lifetime of coir-based goods in applications

including roofing, insulation, and packaging. In instances where better mechanical qualities are necessary, alkali treatment is typically applied. This procedure improves the surface roughness of the coir fibres, hence improving their adherence to diverse matrices inside composite materials. Better adhesion is crucial for assuring the structural integrity and mechanical performance of composite materials, which are extensively employed in the construction and automotive industries.

Moreover, the introduction of coupling agents, such as silane, has been demonstrated to augment the tensile strength of coir fibres. These coupling agents strengthen the interfacial bonding between the coir fibres and the matrix, which is crucial to boosting the overall strength and durability of the composite material. Improved tensile strength is especially significant in applications needing load-bearing capabilities.

Chemical treatments, including mercerisation, are also applied to efficiently limit the moisture absorption capacity of coir fibres. By limiting moisture absorption, mercerisation increases the fibres' dimensional stability and endurance, making them appropriate for usage in situations with changing humidity and temperature conditions. This treatment is excellent for industries such as textiles and building materials where moisture management is critical.

Additionally, novel surface modification methods like microwave treatment may considerably increase the thermal stability of coir fibres. Treating the fibres with microwave radiation may strengthen their structural integrity, enabling them to sustain greater temperatures without deterioration. This feature makes coir fibres ideal for high-temperature situations, including automobile components and thermal insulation materials.

Overall, these diverse surface modification approaches allow the exact tuning of coir fibres' physical characteristics. This versatility enables coir fibres to suit the unique needs of numerous industrial applications, covering industries such as construction, automotive, packaging, and beyond.

REFERENCES

- Adeniyi, A. G., Onifade, D. V., Ighalo, J. O., & Adeoye, A. S. (2019). A review of coir fiber reinforced polymer composites. *Composites Part B: Engineering*, 176, 107305.
- Ahmad, F. H., Ibrahim, N., Mahmud, M. S., Alhadadi, W. A. M. H., Salleh, S., & Nurdin, S. (2021). Microwave Irradiation Optimization For Efficient Lignin Removal From Cocoa Shell Waste Using Alkali. *IIUM Engineering Journal*, 22(2), 21-30.
- Alavez-Ramirez, R., Chiñas-Castillo, F., Morales-Dominguez, V. J., & Ortiz-Guzman, M. (2012). Thermal conductivity of coconut fibre filled ferrocement sandwich panels. *Construction and Building Materials*, 37, 425-431.
- Ali, A., Shaker, K., Nawab, Y., Jabbar, M., Hussain, T., Militky, J., & Baheti, V. (2018). Hydrophobic treatment of natural fibers and their composites—A review. *Journal of Industrial Textiles*, 47(8), 2153-2183.
- Anbupalani, M. S., Venkatachalam, C. D., & Rathanasamy, R. (2020). Influence of coupling agent on altering the reinforcing efficiency of natural fibre-incorporated polymers—A review. *Journal of Reinforced Plastics and Composites*, 39(13-14), 520-544.
- Andiç-Çakir, Ö., Sarikanat, M., Tüfekçi, H. B., Demirci, C., & Erdoğan, Ü. H. (2014). Physical and mechanical properties of randomly oriented coir fiber-cementitious composites. *Composites Part B: Engineering*, 61, 49-54.
- Aravind, D., Senthilkumar, K., Diwahar, P., Chandrasekar, M., Kumar, T. S. M., Parameswaranpillai, J., ... & Siengchin, S. (2022). Review on coir fiber surface modification by various techniques. *Coir Fiber and its Composites*, 55-78.
- Arifuzzaman Khan, G. M., Alam Shams, M. S., Kabir, M. R., Gafur, M. A., Terano, M., & Alam, M. S. (2013). Influence of chemical treatment on the properties of banana stem fiber and banana stem fiber/coir hybrid fiber reinforced maleic anhydride grafted polypropylene/low-density polyethylene composites. *Journal of applied polymer science*, 128(2), 1020-1029.
- Arpitha, G. R., Raghu, M. J., Bharath, K. N., Jain, N., & Verma, A. (2024). Mechanical and micro-structural characterization of biodegradable coir fiber-glass sheet-charcoal reinforced polymer composite: an experimental approach. *Discover Polymers*, 1(1), 7.
- Arrakhiz, F. Z., El Achaby, M., Kakou, A. C., Vaudreuil, S., Benmoussa, K., Bouhfid, R., ... & Quaiss, A. (2012). Mechanical properties of high density polyethylene reinforced with chemically modified coir fibers: Impact of chemical treatments. *Materials & Design*, 37, 379-383.
- Arsyad, M. (2019, October). Sodium hydroxide and potassium permanganate treatment on mechanical properties of coconut fibers. In *IOP Conference Series: Materials Science and Engineering* (Vol. 619, No. 1, p. 012011). IOP Publishing.
- Arsyad, M., Wardana, I. N. G., Pratikto, & Irawan, Y. S. (2015). The morphology of coconut fiber surface under chemical treatment. *Matéria (Rio de Janeiro)*, 20(1), 169-177.
- Arumugam, T., & Hatta, M. A. M. (2022). Improving coconut using modern breeding technologies: Challenges and opportunities. *Plants*, 11(24), 3414.
- Aziz, T., Ullah, A., Fan, H., Jamil, M. I., Khan, F. U., Ullah, R., ... & Ullah, B. (2021). Recent progress in silane coupling agent with its emerging applications. *Journal of Polymers and the Environment*, 1-17.
- Bakri, B., Naharuddin, A. E. E., Renreng, I., & Arsyad, H. (2018). Characterization of coir fibers after alkali and microwave treatments. *ARPN J. Eng. Appl. Sci*, 13(4), 1335-1339.
- Bakri, B., Putra, A. E. E., Mochtar, A. A., Renreng, I., & Arsyad, H. (2018). Sodium bicarbonate treatment on mechanical and morphological properties of coir

- fibres. *International Journal of Automotive and Mechanical Engineering*, 15(3), 5562-5572.
- Banea, M. D., Neto, J. S., & Cavalcanti, D. K. (2021).** Recent trends in surface modification of natural fibres for their use in green composites. *Green composites*, 329-350.
- Barnes, B. K., Ouro-Koura, H., Derickson, J., Lebart, S., Omidokun, J., Bane, N., ... & Das, K. S. (2021).** Plasma generation by household microwave oven for surface modification and other emerging applications. *American Journal of Physics*, 89(4), 372-382.
- Bayer, I. S. (2020).** Superhydrophobic coatings from ecofriendly materials and processes: a review. *Advanced Materials Interfaces*, 7(13), 2000095.
- Bhuvaneshwari, V., Devarajan, B., Arulmurugan, B., Mahendran, R., Rajkumar, S., Sharma, S., ... & Eldin, E. T. (2022).** A critical review on hydrothermal and sound absorption behavior of natural-fiber-reinforced polymer composites. *Polymers*, 14(21), 4727.
- Bi, M., Qin, Q., Deng, B., & Chen, D. (2024).** Natural fibers as sustainable and renewable materials for green sample preparation. *TrAC Trends in Analytical Chemistry*, 117894.
- Bui, H., Sebaibi, N., Boutouil, M., & Levacher, D. (2020).** Determination and review of physical and mechanical properties of raw and treated coconut fibers for their recycling in construction materials. *Fibers*, 8(6), 37.
- Bunsell, A. R., Joannès, S., & Thionnet, A. (2021).** *Fundamentals of fibre reinforced composite materials*. CRC Press.
- Cai, J., Li, Q., & Wu, C. (2022).** Surface modification of recycled coir fibers with hybrid coating and its effect on the properties of ABS composites. *Materials Research Express*, 9(2), 025307.
- Camillo, M. D. O., Gonçalves, B. M. M., Candido, V. S., Dias, L. D. C., Moulin, J. C., Monteiro, S. N., & Oliveira, M. P. (2023).** Assessment of hydrothermal treatment effects on coir fibers for incorporation into polyurethane matrix biocomposites derived from castor oil. *Polymers*, 15(23), 4614.
- Chhetri, S., & Bougherara, H. (2021).** A comprehensive review on surface modification of UHMWPE fiber and interfacial properties. *Composites Part A: applied science and manufacturing*, 140, 106146.
- Chollakup, R., Smithipong, W., Kongtud, W., & Tantatherdtam, R. (2013).** Polyethylene green composites reinforced with cellulose fibers (coir and palm fibers): effect of fiber surface treatment and fiber content. *Journal of adhesion science and technology*, 27(12), 1290-1300.
- Collins, C. M., & Safiuddin, M. D. (2022).** Lotus-leaf-inspired biomimetic coatings: different types, key properties, and applications in infrastructures. *Infrastructures*, 7(4), 46.
- Danso, H. (2017).** Properties of coconut, oil palm and bagasse fibres: as potential building materials. *Procedia Engineering*, 200, 1-9.
- Dewri, S. P., & Gnanamoorthy, R. (2023, September).** Surface Modification of Coconut Fibers: Latex Coating. In *International Conference on Processing and Fabrication of Advanced Materials* (pp. 245-255). Singapore: Springer Nature Singapore.
- Dewri, S. P., & Gnanamoorthy, R. (2024).** Latex Coating. In *Processing and Fabrication of Advanced Materials: Proceedings of the 29th International Conference on Processing and Fabrication of Advanced Materials (29th PFAM), September 6-8, 2023* (Vol. 2, p. 245). Springer Nature.
- Dharmaratne, P. D., Galabada, H., Jayasinghe, R., Nilmini, R., & Halwatura, R. U. (2021).** Characterization of physical, chemical and mechanical properties of Sri Lankan coir fibers. *Journal of Ecological Engineering*, 22(6), 55-65.
- Dugvekar, M., & Dixit, S. (2022).** Chemical treatments for modification of the surface morphology of coir fiber: a review. *Journal of Natural Fibers*, 19(15), 11940-11961.
- Edirisinghe, D. G., Sampath, W. D. M., & Wettasinghe, P. C. (2015).** Effect of latex coated coconut fibre on cure characteristics and physico mechanical properties of natural rubber-coir composites. *Journal of the Rubber Research Institute of Sri Lanka*, 95.
- Ekpenyong, N. E., Umoren, G. P., Udo, I. E., & Yawo, O. J. (2022).** Assessment of thermophysical and mechanical properties of composite panels fabricated from untreated and treated coconut husk particles for structural application. *Journal of Brilliant Engineering*, 2, 4547.
- Essabir, H., Bensalah, M. O., Rodrigue, D., Bouhfid, R., & Qaiss, A. (2016).** Structural, mechanical and thermal properties of bio-based hybrid composites from waste coir residues: Fibers and shell particles. *Mechanics of Materials*, 93, 134-144.
- Ezeamaku, U. L., Nnanwube, I. A., Eze, I. O., & Onukwuli, O. D. (2023).** Effects of acetylation treatment on pineapple leaf fiber (*Ananas comosus*) reinforced with tapioca bio-based resin (cassava starch). *Cogent Engineering*, 10(1), 2229109.
- Fernandes, E. M., Correlo, V. M., Mano, J. F., & Reis, R. L. (2013).** Novel cork-polymer composites reinforced with short natural coconut fibres: Effect of fibre loading and coupling agent addition. *Composites science and technology*, 78, 56-62.
- Fernando, J. A., Yalagama, C., Fernando, N., Samarakoon, U. K., Edirisinghe, D., & Sampath, M. (2025).** Characterization of the coir fiber from different coconut varieties to enhance the performance of coir fiber-reinforced natural rubber composites. *Journal of Elastomers & Plastics*, 00952443251323933.

- Geethamma, V. G., Kalaprasad, G., Groeninckx, G., & Thomas, S. (2005).** Dynamic mechanical behavior of short coir fiber reinforced natural rubber composites. *Composites part A: applied science and manufacturing*, 36(11), 1499-1506.
- Gouda, K., Bhowmik, S., & Das, B. (2021).** A review on allotropes of carbon and natural filler-reinforced thermomechanical properties of upgraded epoxy hybrid composite. *Reviews on Advanced Materials Science*, 60(1), 237-275.
- Haque, M., Rahman, R., Islam, N., Huque, M., & Hasan, M. (2010).** Mechanical properties of polypropylene composites reinforced with chemically treated coir and abaca fiber. *Journal of reinforced plastics and composites*, 29(15), 2253-2261.
- Hasan, K. F., Horváth, P. G., Kóczán, Z., & Alpár, T. (2021).** Thermo-mechanical properties of pretreated coir fiber and fibrous chips reinforced multilayered composites. *Scientific Reports*, 11(1), 3618.
- Hasan, K. F., Horváth, P. G., Kóczán, Z., & Alpár, T. (2021).** Thermo-mechanical properties of pretreated coir fiber and fibrous chips reinforced multilayered composites. *Scientific Reports*, 11(1), 3618.
- Hewson, C., Acharya, M., Naderi, M., Guo, M., Molisso, S., & Burnett, D. (2023).** HYDROXYL GROUP ACCESSIBILITY IN CELLULOSE FIBER WITH DYNAMIC VAPOR SORPTION TECHNIQUE. In *BOOK OF ABSTRACTS* (p. 32).
- Hoseini, A., & Bahrami, M. (2017).** Effects of humidity on thermal performance of aerogel insulation blankets. *Journal of building engineering*, 13, 107-115.
- Ignacio, I. F., & Miguel, T. S. (2021).** Research opportunities on the coconut (*Cocos nucifera* L.) using new technologies. *South African Journal of Botany*, 141, 414-420.
- Islam, T., Chaion, M. H., Jalil, M. A., Rafi, A. S., Mushtari, F., Dhar, A. K., & Hossain, S. (2024).** Advancements and challenges in natural fiber-reinforced hybrid composites: a comprehensive review. *SPE Polymers*, 5(4), 481-506.
- Jahami, A., Zeaiter, N., & Cheaib, M. (2024).** Reviewing the potential: a comprehensive review of natural fibers (NFs) in structural concrete and their multifaceted influences. *Innovative Infrastructure Solutions*, 9(4), 102.
- Jawaid, M. (Ed.). (2022).** *Coir Fiber and Its Composites: Processing, Properties and Applications*. Elsevier.
- Karthik, K., kumar RAJAMANIKKAM, R., Venkatesan, E. P., Bishwakarma, S., Krishnaiah, R., SALEEL, C. A., ... & Bashir, M. N. (2024).** State of the art: natural fibre-reinforced composites in advanced development and their physical/chemical/mechanical properties. *Chinese Journal of Analytical Chemistry*, 52(7), 100415.
- Khan, A., Ahmad, M. A., Joshi, S., & Al Said, S. A. (2014).** Abrasive wear behavior of chemically treated coir fibre filled epoxy polymer composites. *American Journal of Mechanical Engineering and Automation*, 1(1), 1-5.
- Kumar, B. M., & Kunhamu, T. K. (2022).** Nature-based solutions in agriculture: A review of the coconut (*Cocos nucifera* L.)-based farming systems in Kerala, "the Land of Coconut Trees". *Nature-Based Solutions*, 2, 100012.
- Kumar, D., Alam, M., Zou, P. X., Sanjayan, J. G., & Memon, R. A. (2020).** Comparative analysis of building insulation material properties and performance. *Renewable and Sustainable Energy Reviews*, 131, 110038.
- Lai, T. S. M. (2024).** *Study on The Influence of Microwave Curing on Dielectric and Mechanical Properties of Banana Fiber Reinforced High-Density Polyethylene with Magnesium Oxide* (Doctoral dissertation, Swinburne).
- Li, C., Wu, J., Shi, H., Xia, Z., Sahoo, J. K., Yeo, J., & Kaplan, D. L. (2022).** Fiber-based biopolymer processing as a route toward sustainability. *Advanced Materials*, 34(1), 2105196.
- Li, X., Jin, X., Wu, Y., Zhang, D., Sun, F., Ma, H., ... & Xia, C. (2023).** A comprehensive review of lignocellulosic biomass derived materials for water/oil separation. *Science of the Total Environment*, 876, 162549.
- Liu, H., Xiong, H., Chang, Y., Xu, J., Xu, C., & Liu, Y. (2022).** Fabrication of superhydrophobic coating based on waterborne silicone-modified polyurethane dispersion and silica nanoparticles. *Polymers*, 15(1), 22.
- Madueke, C. I., Ekechukwu, O. M., & Kolawole, F. O. (2024).** A review on coir fibre, coir fibre reinforced polymer composites and their current applications. *Journal of renewable materials*, 12(12).
- Mahalingam, S., & Babu, A. S. (2022).** Characterization of 3-aminopropyltriethoxysilane treated stacked silicate nanoclay and red Matta-RHA biosilica woven ramie fibre epoxy composite. *Silicon*, 14(13), 8129-8139.
- Mahmud, M. Z. A., Rabbi, S. F., Islam, M. D., & Hossain, N. (2025).** Synthesis and applications of natural fiber-reinforced epoxy composites: A comprehensive review. *SPE Polymers*, 6(1), e10161.
- Mangat, A., Sureshkumar, P. K., & Niyas, P. (2023).** Structural analysis of coconut palm prior to the design of a coconut palm climber and derivation of allometric relationships-a study at KAU campus.
- Manohar, K. (2012).** Experimental investigation of building thermal insulation from agricultural by-products. *British Journal of Applied Science & Technology*, 2(3), 227.
- Marakana, P. G., Dey, A., & Saini, B. (2021).** Isolation of nanocellulose from lignocellulosic biomass: Synthesis, characterization, modification, and potential applications. *Journal of Environmental Chemical Engineering*, 9(6), 106606.
- Miller, P. J., & Shantz, D. F. (2020).** Covalently functionalized uniform amino-silica nanoparticles.

- Synthesis and validation of amine group accessibility and stability. *Nanoscale Advances*, 2(2), 860-868.
- Mir, S. S., Nafsin, N., Hasan, M., Hasan, N., & Hassan, A. (2013).** Improvement of physico-mechanical properties of coir-polypropylene biocomposites by fiber chemical treatment. *Materials & Design (1980-2015)*, 52, 251-257.
- Mishra, L., & Basu, G. (2020).** Coconut fibre: its structure, properties and applications. In *Handbook of natural fibres* (pp. 231-255). Woodhead Publishing.
- Mishra, M. (2015).** *Study and development of recyclable and reusable silica based organic-inorganic hybrid catalyst: a concept of green chemistry* (Doctoral dissertation, UPES).
- Mohammadi, M., Ishak, M. R., & Sultan, M. T. H. (2024).** Exploring chemical and physical advancements in surface modification techniques of natural fiber reinforced composite: a comprehensive review. *Journal of Natural Fibers*, 21(1), 2408633.
- Mohammed, M., Rahman, R., Mohammed, A. M., Adam, T., Betar, B. O., Osman, A. F., & Dahham, O. S. (2022).** Surface treatment to improve water repellence and compatibility of natural fiber with polymer matrix: Recent advancement. *Polymer Testing*, 115, 107707.
- Mohd Bakhori, S. N., Hassan, M. Z., Mohd Bakhori, N., Jamaludin, K. R., Ramlie, F., Md Daud, M. Y., & Abdul Aziz, S. A. (2022).** Physical, mechanical and perforation resistance of natural-synthetic fiber interply laminate hybrid composites. *Polymers*, 14(7), 1322.
- Morandim-Giannetti, A. A., Agnelli, J. A. M., Lanças, B. Z., Magnabosco, R., Casarin, S. A., & Bettini, S. H. (2012).** Lignin as additive in polypropylene/coir composites: Thermal, mechanical and morphological properties. *Carbohydrate Polymers*, 87(4), 2563-2568.
- Muthuraj, R., Lacoste, C., Lacroix, P., & Bergeret, A. (2019).** Sustainable thermal insulation biocomposites from rice husk, wheat husk, wood fibers and textile waste fibers: Elaboration and performances evaluation. *Industrial Crops and Products*, 135, 238-245.
- Nair, L., Ravi, P. K., & Sarma, U. S. (2011).** Enhancement of Properties of Coir Geotextiles by Natural Rubber Latex Coating. *Cord*, 27(1), 1-8.
- Ndagi, M., Kolawole, A. T., Olawale, F. M., & Sulaiman, A. (2021).** Investigation of the thermo-physical and mechanical properties of coir and sugarcane bagasse for low temperature insulation. *International Journal of Engineering Materials and Manufacture*, 6(4), 340-356.
- Nechifor, M., Tanasă, F., Teacă, C. A., & Şulea, D. (2022).** Maleated coupling agents for the surface treatment of natural fibers. *Surface treatment methods of natural fibres and their effects on biocomposites*, 95-123.
- Nemani, S. K., Annavarapu, R. K., Mohammadian, B., Raiyan, A., Heil, J., Haque, M. A., ... & Sojoudi, H. (2018).** Surface modification of polymers: methods and applications. *Advanced Materials Interfaces*, 5(24), 1801247.
- Ng, Y. R., Shahid, S. N. A. M., & Nordin, N. I. A. A. (2018, June).** The effect of alkali treatment on tensile properties of coir/polypropylene biocomposite. In *IOP Conference Series: Materials Science and Engineering* (Vol. 368, No. 1, p. 012048). IOP Publishing.
- Ng, Y. Y., Kiew, P. L., Yeoh, W. M., Lam, M. K., & Chee, H. L. (2024).** Valorization of Coconut Coir Fiber: Comparative Analysis of Treatments for Enhanced Oil Adsorption in Oily Water and Pure Oil. *Waste and Biomass Valorization*, 1-13.
- Nurazzi, N. M., Harussani, M. M., Aisyah, H. A., Ilyas, R. A., Norrrahim, M. N. F., Khalina, A., & Abdullah, N. (2021).** Treatments of natural fiber as reinforcement in polymer composites—a short review. *Functional Composites and Structures*, 3(2), 024002.
- Nuwarapaksha, T. D., Udumann, S. S., Dissanayaka, D. M. N. S., Dissanayake, D. K. R. P. L., & Atapattu, A. J. (2022).** Coconut based multiple cropping systems: An analytical review in Sri Lankan coconut cultivations. *Circular Agricultural Systems*, 2(1), 1-7
- Nwankwo, C., Mahachi, J., Olukanni, D., & Musonda, I. (2025).** Alkali treatment of flax fibres: effects on tensile strength, thermal performance, and moisture absorption. *Composite Interfaces*, 1-18.
- Oh, E., Godoy Zúniga, M. M., Nguyen, T. B., Kim, B. H., Trung Tien, T., & Suhr, J. (2024).** Sustainable green composite materials in the next-generation mobility industry: review and prospective
- Oladele, I. O., Adelani, S. O., Makinde-Isola, B. A., & Omotosho, T. F. (2022).** Coconut/coir fibers, their composites and applications. In *Plant Fibers, their Composites, and Applications* (pp. 181-208). Woodhead Publishing.
- Owoeye, S. S., Matthew, G. O., Ovienmhanda, F. O., & Tunmilayo, S. O. (2020).** Preparation and characterization of foam glass from waste container glasses and water glass for application in thermal insulations. *Ceramics International*, 46(8), 11770-11775.
- Owoyemi, J. M., Akinwamide, T. O., & Ibidokun, A. O. (2022).** Development of coconut plantation in Nigeria; Problems and prospects. *International Journal of Agriculture and Plant Science*, 4(1), 58-66.
- Panwar, A., & Neelakrishnan, S. (2022).** An experimental study on the effect of mercerization parameters on the variation in the chemical composition and mechanical properties of natural fibers: Coir. *Journal of Natural Fibers*, 19(15), 10383-10393.
- Pásztor, Z. (2021).** An overview of factors influencing thermal conductivity of building insulation materials. *Journal of Building Engineering*, 44, 102604.

- Pérez-Fonseca, A. A., Arellano, M., Rodrigue, D., González-Núñez, R., & Robledo-Ortiz, J. R. (2016).** Effect of coupling agent content and water absorption on the mechanical properties of coir-agave fibers reinforced polyethylene hybrid composites. *Polymer Composites*, 37(10), 3015-3024
- Piccinno, F., Gottschalk, F., Seeger, S., & Nowack, B. (2012).** Industrial production quantities and uses of ten engineered nanomaterials in Europe and the world. *Journal of nanoparticle research*, 14, 1-11.
- Praveen, K., Thomas, S., Grohens, Y., Mozetič, M., Junkar, I., Primc, G., & Gorjanc, M. J. A. S. S. (2016).** Investigations of plasma induced effects on the surface properties of lignocellulosic natural coir fibres. 368, 146-156.
- Priya, N. A. S., Raju, P. V., & Naveen, P. N. E. (2014).** Experimental testing of polymer reinforced with coconut coir fiber composites. *Int. J. Emerg. Technol. Adv. Eng*, 4(12), 453-460.
- Rahayu, A., Hanum, F. F., Amrillah, N. A. Z., Lim, L. W., & Salamah, S. (2022).** Cellulose extraction from coconut coir with alkaline delignification process. *Journal of fibers and polymer composites*, 1(2), 106-116.
- Rahman, M. M., & Khan, M. A. (2007).** Surface treatment of coir (*Cocos nucifera*) fibers and its influence on the fibers' physico-mechanical properties. *Composites science and technology*, 67(11-12), 2369-2376.
- Rahman, M. M., & Khan, M. A. (2007).** Surface treatment of coir (*Cocos nucifera*) fibers and its influence on the fibers' physico-mechanical properties. *Composites science and technology*, 67(11-12), 2369-2376.
- Rajan, R., Rainosalo, E., Thomas, S. P., Ramamoorthy, S. K., Zavašnik, J., Vuorinen, J., & Skrifvars, M. (2018).** Modification of epoxy resin by silane-coupling agent to improve tensile properties of viscose fabric composites. *Polymer Bulletin*, 75, 167-195.
- Rangappa, S. M., Siengchin, S., Parameswaranpillai, J., Jawaid, M., & Ozbakkaloglu, T. (2022).** Lignocellulosic fiber reinforced composites: Progress, performance, properties, applications, and future perspectives. *Polymer Composites*, 43(2), 645-691.
- Renreng, I., Bakri, B., & Chandrabakty, S. (2021).** Evaluation of mechanical and physical properties of pressed coir fiber/epoxy composite with NaOH and microwave treatment of fiber. *Journal of Renewable Materials*, 9(2), 325-335.
- Ru, S., Zhao, C., Yang, S., & Liang, D. (2022).** Effect of coir fiber surface treatment on interfacial properties of reinforced epoxy resin composites. *Polymers*, 14(17), 3488.
- Saba, N., Allothman, O. Y., Almutairi, Z., & Jawaid, M. (2019).** Magnesium hydroxide reinforced kenaf fibers/epoxy hybrid composites: Mechanical and thermomechanical properties. *Construction and Building Materials*, 201, 138-148.
- Yao, C., & Wanli, L. (2024).** Research progress on interfacial modification of plant fiber biocomposites. *New Chemical Materials*, 52(7), 45-50.
- Sanjay, M., Madhu, P., Jawaid, M., Senthamarakannan, P., Senthil, S., & Pradeep, S. J. J. o. C. p. (2018).** Characterization and properties of natural fiber polymer composites: A comprehensive review. 172, 566-581.
- Sanjay, M. R., Arpitha, G. R., & Yogesha, B. (2015).** Study on mechanical properties of natural-glass fibre reinforced polymer hybrid composites: a review. *Materials today: proceedings*, 2(4-5), 2959-2967.
- Saw, S. K., Sarkhel, G., & Choudhury, A. (2011).** Surface modification of coir fibre involving oxidation of lignins followed by reaction with furfuryl alcohol: Characterization and stability. *Applied Surface Science*, 257(8), 3763-3769.
- Saw, S. K., Sarkhel, G., & Choudhury, A. (2011).** Dynamic mechanical analysis of randomly oriented short bagasse/coir hybrid fibre-reinforced epoxy novolac composites. *Fibers and Polymers*, 12, 506-513.
- Saw, S. K., Sarkhel, G., & Choudhury, A. (2012).** Preparation and characterization of chemically modified jute-coir hybrid fiber reinforced epoxy novolac composites. *Journal of applied polymer science*, 125(4), 3038-3049.
- Schiavon, J. Z., & de Oliveira Andrade, J. J. (2023).** Comparison between alternative chemical treatments on coir fibers for application in cementitious materials. *Journal of Materials Research and Technology*, 25, 4634-4649.
- Sen, T., & Reddy, H. J. (2011).** Application of sisal, bamboo, coir and jute natural composites in structural upgradation. *International journal of innovation, management and technology*, 2(3), 186.
- Setiyo, M., Rejab, M. R. M., Jaafar, J., Fitriyana, D. F., & Dewi, R. (2024).** Advancements in sustainable material development: A Comprehensive review of coir fiber and its composites.
- Shadhin, M., Rahman, M., Jayaraman, R., Chen, Y., Mann, D., & Zhong, W. (2023).** Natural biomass & waste biomass fibers—structures, environmental footprints, sustainability, degumming methods, & surface modifications. *Industrial Crops and Products*, 204, 117252.
- Siakeng, R., Jawaid, M., Ariffin, H., & Salit, M. S. (2018).** Effects of surface treatments on tensile, thermal and fibre-matrix bond strength of coir and pineapple leaf fibres with poly lactic acid. *Journal of Bionic Engineering*, 15, 1035-1046.
- Siddika, S., Mansura, F., & Hasan, M. (2013).** Physico-mechanical properties of jute-coir fiber reinforced hybrid polypropylene composites. *Engineering and Technology*, 73, 1145-1149.
- Simimol, A. S., Sebastian, S., Ravindranath, D. A., & Jacob, A. (2020).** Enhancement of Physical, Mechanical and Morphological Properties of Coir by Mercerization and Acetylation. *International*

Journal of Innovative Science and Research Technology, 5, 530-535.

- Singh, Y., Singh, J., Sharma, S., Lam, T. D., & Nguyen, D. N. (2020).** Fabrication and characterization of coir/carbon-fiber reinforced epoxy based hybrid composite for helmet shells and sports-good applications: Influence of fiber surface modifications on the mechanical, thermal and morphological properties. *Journal of Materials Research and Technology*, 9(6), 15593-15603.
- Siregar, J. P., Cionita, T., Hadi, A. E., Setiyo, M., Rejab, M. R. M., Jaafar, J., ... & Dewi, R. (2024).** Advancements in sustainable material development: A Comprehensive review of coir fiber and its composites. *Mechanical Engineering for Society and Industry*, 4(3), 415-454.
- Sobuz, M. H. R., Datta, S. D., Akid, A. S. M., Tam, V. W., Islam, S., Rana, M. J., ... & Sutan, N. M. (2024).** Evaluating the effects of recycled concrete aggregate size and concentration on properties of high-strength sustainable concrete. *Journal of King Saud University-Engineering Sciences*, 36(3), 216-227.
- Souza, J. C., Fernandes, V., Correia, A., Miller, P., Carvalho, O., Silva, F., ... & Henriques, B. (2022).** Surface modification of glass fiber-reinforced composite posts to enhance their bond strength to resin-matrix cements: an integrative review. *Clinical oral investigations*, 1-13.
- Stelte, W., Reddy, N., Barsberg, S., & Sanadi, A. R. (2023).** Coir from Coconut Processing Waste as a Raw Material for Applications Beyond Traditional Uses. *BioResources*, 18(1).
- Subha, S. L., Isabel, W., & Priscilla, A. S. (2022).** Optimization and enhanced saccharification of coir pith by microwave irradiation using response surface methodology. *UTTAR PRADESH JOURNAL OF ZOOLOGY*, 43(12), 63-71.
- Sudhakara, P., Jagadeesh, D., Wang, Y., Prasad, C. V., Devi, A. K., Balakrishnan, G., ... & Song, J. I. (2013).** Fabrication of Borassus fruit lignocellulose fiber/PP composites and comparison with jute, sisal and coir fibers. *Carbohydrate polymers*, 98(1), 1002-1010.
- Sumi, S., Unnikrishnan, N., & Mathew, L. (2018).** Durability studies of surface-modified coir geotextiles. *Geotextiles and Geomembranes*, 46(6), 699-706.
- Sutrisno, S., Soenoko, R., Irawan, Y. S., & Widodo, T. D. (2021).** Effect of coconut fiber treatment with limestone water media on the fiber surface, wettability, and interface shear strength. *Eastern-European Journal of Enterprise Technologies*, 1(6), 109.
- Thakur, K., Kalia, S., Kaith, B. S., Pathania, D., Kumar, A., Thakur, P., ... & Totaro, G. (2016).** The development of antibacterial and hydrophobic functionalities in natural fibers for fiber-reinforced composite materials. *Journal of environmental chemical engineering*, 4(2), 1743-1752. The development of antibacterial and hydrophobic functionalities in natural fibers for fiber-reinforced composite materials. *Journal of environmental chemical engineering*, 4(2), 1743-1752.
- Thapliyal, D., Verma, S., Sen, P., Kumar, R., Thakur, A., Tiwari, A. K., ... & Arya, R. K. (2023).** Natural fibers composites: origin, importance, consumption pattern, and challenges. *Journal of Composites Science*, 7(12), 506.
- Tran, L. Q. N., Fuentes, C. A., Dupont-Gillain, C., Van Vuure, A. W., & Verpoest, I. (2013).** Understanding the interfacial compatibility and adhesion of natural coir fibre thermoplastic composites. *Composites Science and Technology*, 80, 23-30.
- Verma, D., Gope, P. C., Shandilya, A., Gupta, A., & Maheshwari, M. K. (2013).** Coir fibre reinforcement and application in polymer composites. *J. Mater. Environ. Sci*, 4(2), 263-276.
- Wahby, M. H., Atta, A. M., Moustafa, Y. M., Ezzat, A. O., & Hashem, A. I. (2020).** Hydrophobic and superhydrophobic bio-based nano-magnetic epoxy composites as organic coating of steel. *Coatings*, 10(12), 1201.
- Wang, B., Yan, L., Xu, R., & Kasal, B. (2023).** Microstructural analysis, physical, chemical components and tensile properties of coir fibre long-term exposed in Ca (OH) 2 as representative of concrete pore solution. *Journal of Cleaner Production*, 385, 135693.
- Windyandari, A., Kurdi, O., & Tauviqirrahman, M. (2021, February).** Scanning Electron Microscopy Observation of Coir Fibre with Alkali and Drying Method Treatment. In *IOP Conference Series: Materials Science and Engineering* (Vol. 1053, No. 1, p. 012031). IOP Publishing.
- Yan, L., Chouw, N., Huang, L., & Kasal, B. (2016).** Effect of alkali treatment on microstructure and mechanical properties of coir fibres, coir fibre reinforced-polymer composites and reinforced-cementitious composites. *Construction and Building Materials*, 112, 168-182.
- Yan, L., Su, S., & Chouw, N. (2015).** Microstructure, flexural properties and durability of coir fibre reinforced concrete beams externally strengthened with flax FRP composites. *Composites Part B: Engineering*, 80, 343-354. beams externally strengthened with flax FRP composites. 80, 343-354.
- Yusoff, R. B., Takagi, H., & Nakagaito, A. N. (2016).** Tensile and flexural properties of polylactic acid-based hybrid green composites reinforced by kenaf, bamboo and coir fibers. *Industrial crops and products*, 94, 562-573.
- Zainudin, E. S., Yan, L. H., Haniffah, W. H., Jawaid, M., & Alothman, O. Y. (2014).** Effect of coir fiber loading on mechanical and morphological properties of oil palm fibers reinforced polypropylene composites. *Polymer Composites*, 35(7), 1418-1425.

- Zhang, L., & Hu, Y. (2014).** Novel lignocellulosic hybrid particleboard composites made from rice straws and coir fibers. *Materials & Design*, 55, 19-26.
- Zhang, L., Sun, Z., Liang, D., Lin, J., & Xiao, W. (2017).** Preparation and performance evaluation of PLA/coir fibre biocomposites. *BioResources*, 12(4), 7349-7362.
- Zhang, W., & Lai, E. P. (2022).** Chemical functionalities of 3-aminopropyltriethoxy-silane for surface modification of metal oxide nanoparticles. *Silicon*, 14(12), 6535-6545.
- Zhang, W., Wang, D., Sun, Z., Song, J., & Deng, X. (2021).** Robust superhydrophobicity: mechanisms and strategies. *Chemical Society Reviews*, 50(6), 4031-4061.
- Zin, M. H., Abdan, K., Norizan, M. N., & Mazlan, N. (2018).** The Effects of Alkali Treatment on the Mechanical and Chemical Properties of Banana Fibre and Adhesion to Epoxy Resin. *Pertanika Journal of Science & Technology*, 26(1).