

Review

Developments in Chemical Treatments, Manufacturing Techniques and Potential Applications of Natural-Fibers-Based Biodegradable Composites

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Abstract: The utilization of synthetic materials stimulates environmental concerns, and researchers worldwide are effectively reacting to environmental concerns by transitioning towards biodegradable and sustainable materials. Natural fibers like jute and sisal have been being utilized for ages in several applications, such as ropes, building materials, particle boards, etc. The absence of essential information in preparing the natural-fiber-reinforced materials is still a challenge for future applications. Chemical treatments and surface modifications can improve the quality of the natural fibers. Natural-fiber-based composites are a potential candidate for many lightweight engineering applications with significant mechanical properties. In the view of the progressive literature reported in the field, this work aims to present the significance of natural fibers, their composites, and the main factors influencing these materials for various applications (automotive industry, for instance). Secondly, we aim to address different surface modifications and chemical treatments on natural fibers and finally provide an overview of natural fiber reinforced polymer composites' potential applications.

Keywords: natural-fiber-reinforced polymer composites; chemical treatments; natural fibers; manufacturing techniques; green composites

1. Introduction

The utilization of synthetic materials (Kevlar, carbon, and aramid fibers) stimulates environmental concerns. The production of composites reinforced with these synthetic fibers is costly [1]. Researchers around the globe are effectively reacting to environmental concerns and now shifting towards biodegradable and sustainable materials. The natural fiber-reinforced polymer composites (NFRPCs) are becoming a prime choice in several industrial applications [2,3]. For instance, considering the automotive sector, the overall car production rate is expanding every year. Restricted oil assets will elevate the oil-based items' costs soon [4]. It is assessed that a 25% decrease in vehicle weight would be equal to sparing 250 million barrels of unrefined petroleum. Utilizing the NFRPCs could prompt a weight decrease of 10–30%; thus, it is conceivable that producers will consider extending the utilization of NFRPCs in their new products [5]. Natural fibers are seen in many

applications, like in constructing sewage-system septic pipes, which triggering their use in many recyclable products [6]. The utilization of these natural fibers in the car business is now practiced. It can be seen in vehicles' interior, for example, seatbacks, bumpers, dashboards, truck liners, main events, decking, railing, windows, and casings.

Another crucial factor is the massive manufacturing of plastic which rapidly turns into waste and becomes an issue to the climate after its application. From 1950 to 2014, global plastic production has expanded from 1.7 million tons to more than 300 million tons. Plastics use around 8% of globally produced oil in their design as crude material and energy for their production. It was discovered that 95% of these synthetic plastic materials were situated on the seashore, seabed, and top of the ocean [7]. The fabrication of an enormous amount of synthetic-fiber-reinforced materials, such as glass/carbon-fiber polymer composites, is a severe threat to our environment, as reusing glass-fiber-reinforced composites is not straightforward [8]. Furthermore, the synthetic fiber-reinforced composite poses an estimated cost of for glass US\$1200–\$1800/ton for glass and 30 GJ/ton energy to create, and for carbon, it is US\$12,500/ton and 130 GJ/ton energy to deliver, whereas NFRPCs have a lower cost of US\$200–\$1000/ton and 4 GJ/ton energy to produce [9,10].

Two major challenges are hindering the vast utilization of NFRPCs. The first one is the inferior mechanical properties, compared to synthetic fiber composites [11], which usually is a consequence of the inconsistency between the fiber and the matrix [12]. The fibers' wettability is significantly lower than synthetic fibers (like glass fiber) [13]. Lower wettability is still a challenge for their extensive use in industries [14], even though the strength of these natural fibers is comparable to synthetic fibers [15,16]. The water-absorbing capacity is another factor restricting the enormous use of NFRPCs [17,18]. This behavior hinders the utilization of NFRPCs, since their mechanical properties decline in wet conditions. The opportunities to implement these new materials in open-air applications need to be considered, especially in damp climates [19], as these fibers retain water from the air and on direct contact with the earth, resulting in voids creation within the material [20,21]. Another factor is the exceptionally polar surface of natural fibers; this actuates an interfacial dissimilarity with non-polar polymers like polypropylene and polyethylene [22,23]. Briefly, natural fibers possess inferior hydrophilicity, as well as surface and mechanical properties, and have a porous structure, restricting their use in commercial applications [24].

Besides the full replacement of synthetic fibers as reinforcement to polymers, researchers widely use another technique to reinforce the polymers with a combination of natural and synthetic fibers, limiting the use of synthetic fibers. This technique is often termed hybridization. Khalid et al. [25] studied the effect of hybridization of jute and carbon fibers. Results revealed that the jute/carbon-reinforced composites provide sufficient tensile strength compared to merely carbon-fiber-reinforced composites, broadening the scope to use hybridized fiber-reinforced composites for various applications [26].

A vast majority of the research data published in recent years on natural fiber composites provide limited information on the classification of natural fibers [27], the effect of chemical treatments, and their applications [28–30]. Thus, comprehensive work is needed for the recent accomplishments in this field. This work aims to present the significance of natural fibers, their composites, and the main factors influencing these materials' choices for various applications (automotive industry, for instance). Secondly, this work aims to address different surface modifications and chemical treatments on natural fibers and finally provide an overview of potential applications of NFRPCs.

2. Composition and Mechanical Properties of Natural Fibers

The polymers containing natural fibers as reinforcement are called green composites or natural-fiber-reinforced polymer composites (NFRPCs) [31,32]. Green composites provide several benefits over synthetic-strands/fibers-based composites [9], for example, ease of availability, cost adequacy, modulus, biodegradability, sustainability, and handling simplicity [33–35]. The research interest in natural fibers is developing due to their potential use in modern applications [36]. They are sustainable, cheaper, totally/partially recyclable,

and biodegradable [37–39]. The natural fibers can be extracted from several sources, including animals, plants, and minerals [40]. The NFRPCs are also globally accepted sustainable materials [41]. Their brief classification, according to their source, is illustrated in Figure 1. Natural fibers are abundantly available in the South Asian region, specifically Pakistan, India, and Sri Lanka. Among all the natural fibers, jute, bamboo, coir, sisal, and hemp are most commonly reported in the literature.

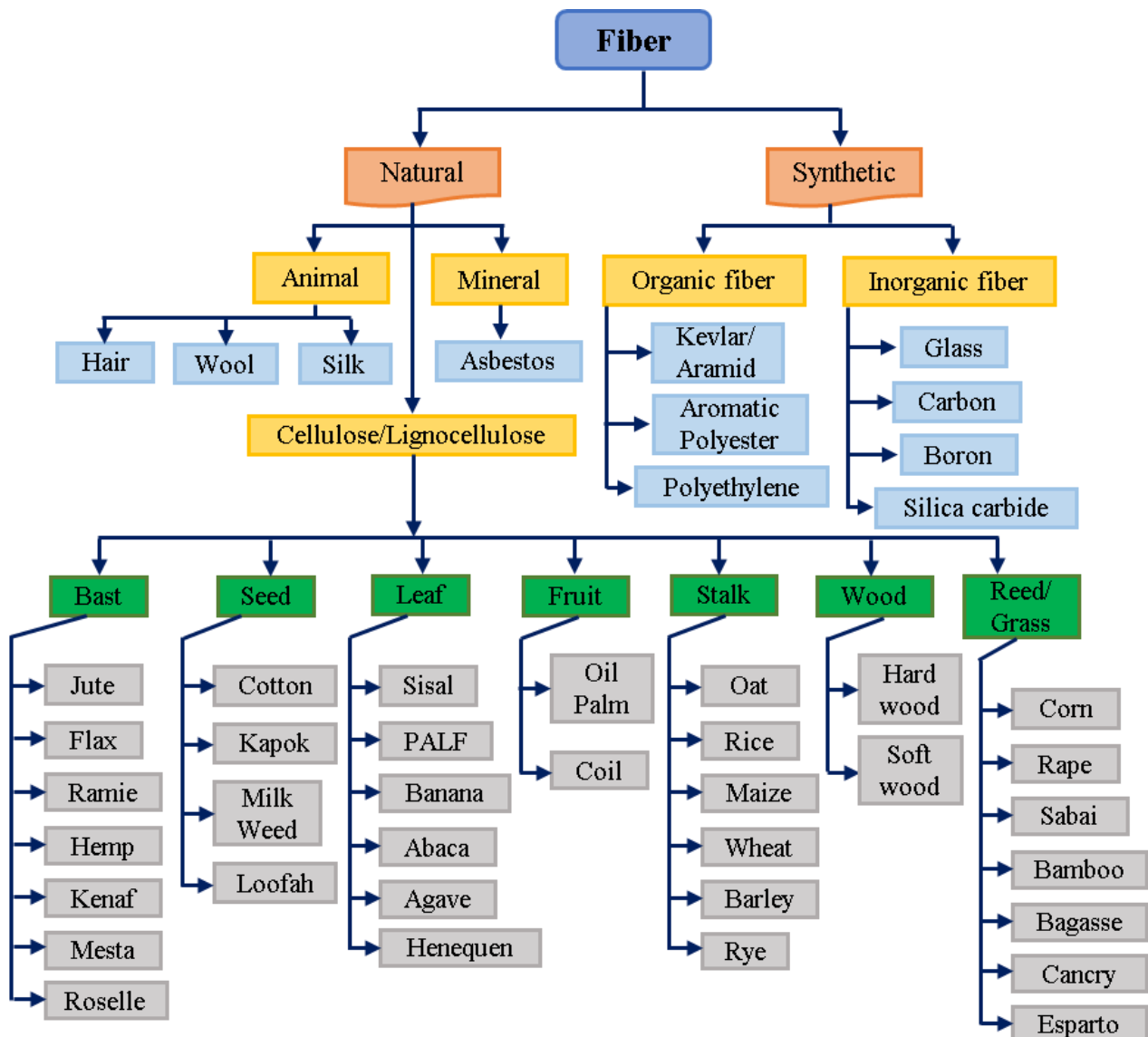


Figure 1. Classification of different types of natural fibers and their sources.

The fibers obtained from plant stems reveal better mechanical properties and yield strength as they contain higher cellulose content [42]. Cellulose content characterizes the strength and firmness of fiber [43], owing to the number of hydrogen bonds and different linkages that exist in the cellulose [44,45]. Generally, fibers' mechanical properties are highly dependent on the production process, chemical processing, and final composite manufacturing techniques [46]. Pretty much all the fibers, barring cotton, are predominantly made out of cellulose, hemicelluloses, lignin, waxes, and a few water-solvent compounds [47–49]. Table 1 reports the most significant mechanical properties and composition of the most common natural fibers.

Coir fiber is an important class of natural fibers with attractive mechanical properties [22]. Coir fiber is cheap and widely utilized in several applications. Coir fibers are obtained from coconut trees, which are found in tropical regions. Moreover, the coir contains flexible lignocellulosic fibers with up to 42% cellulose content, 0.2% hemicellulose content, and 40–45% lignin content [50].

Jute fiber has a high perspective as it reveals high strength to weight proportion and excellent impact strength [51]. The largest producers of jute are India, China, and Bangladesh. Jute fiber reinforced polymer composites has many reported applications, e.g., for windows, furniture, I-shaped beam, skateboards, underground channel drains, water pipes, floor tiles, etc. [52].

However, bamboo fibers exist abundantly in Asia and South America but have not been investigated entirely to their potential, even though they are considered characteristic engineering material [53]. Generally, bamboo has been utilized in living spaces, offices, and instruments, owing to its high strength to its weight due to the longitudinal arrangement of fibers. The bamboo fibers generally have better mechanical properties yet are weak compared to other natural fibers because of the additional lignin content covering the bamboo strands. Furthermore, bamboo fiber has higher elasticity than most natural fibers, such as jute [54] and sisal [53].

Hemp has been cultivated annually in Central Asia for the last 12,000 years and reveals extraordinary tensile strength and modulus, making it useful for reinforcement in composite materials [55,56]. The applications of hemp fibers are in geotextiles, furniture, and manufacturing pipes [57].

Like other natural fibers, kenaf can replace wood, which is gathered once in 20–25 years, while the kenaf plant is collected two or three times a year. kenaf plants can grow 3–4 m high within four to five months and consists of three layers; bast, pith, and core [10,58]. The kenaf plant consists of 33% of the bast, and the remaining part accounts for pith and core. Kenaf bast fiber has been determined for to have predominant mechanical properties than other fibers [59,60].

Banana fiber, at present, is a byproduct of banana development [61]. Subsequently, banana fiber can be utilized for several applications [62]. Banana fiber is found to be a reasonable reinforcement to polyester tar. The properties of the composites are unequivocally impacted by the fiber length [63].

Table 1. Mechanical properties and composition of the most common natural fibers [50,57,64–70].

Properties	Natural Fibers								
	Cotton	Jute	Hemp	Coir	Date Palm	Flax	Ramie	Sisal	Pineapple
Elongation (%)	3–10	1.5–1.8	1.6	15–30	2–19	1.2–3.0	2.0–9.0	2–14	14
Density (g/cm ³)	1.5–1.6	1.3–1.4	1.4	1.2	0.9–12	1.4–1.5	1.5	1.3–1.5	1.4
Tensile Strength (MPa)	280–580	400–800	550–900	175–220	300–800	400–1500	220–938	400–700	400–1600
Cellulose (%)	82–91	60–70	71–75	32–42	46	71	68–76	67–78	70–82
Lignin (%)	–	12–13	3.7–5.7	40–45	20	2.5	0.5–0.7	8–11	5–12
Tensile Modulus (GPa)	6–13	10–30	70	4–6	7	28–80	44–128	9–38	34–82

Likewise, sisal is one of the natural fibers which is abundantly available, and its synthesis is mostly in a regularly developed wasteland, which helps in soil protection [71]. Tanzania and Brazil are the largest producers of sisal in the world [72]. The use of sisal fibers has been seen in many applications like in railway industries as the gear case, main doors, luggage racks, berths, interior panels and partitions, and modular toilets [73,74].

Figure 2 presents the comparison between the unit price of the most widely used natural fibers. The unit cost of natural fibers is significantly lower than synthetic fibers like

glass and carbon [75]. Henceforth, taking the mechanical properties, price, and environmental impact into account, flax [76,77], hemp [78], and jute [2] fibers can be considered as potential reinforcement to polymers [79].

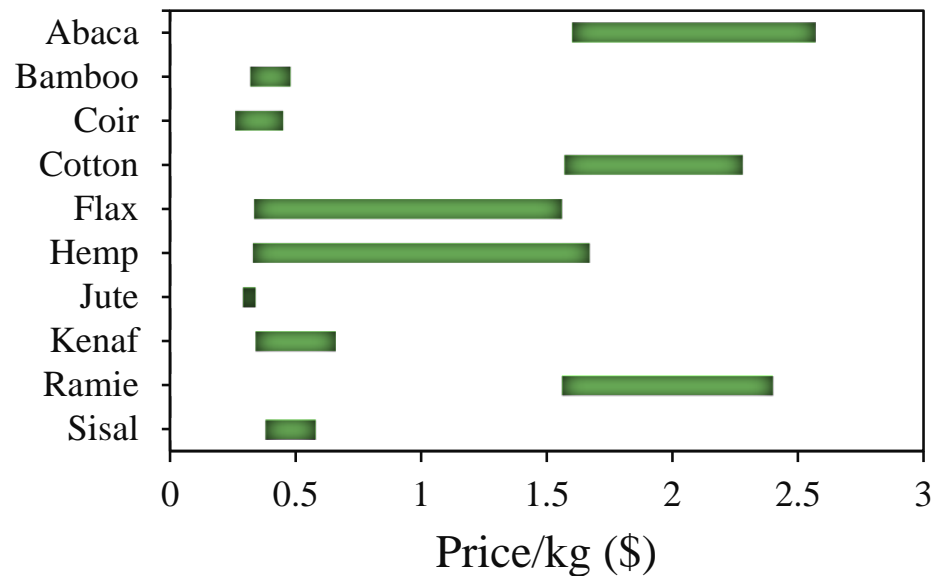


Figure 2. Comparison of cost/weight of different fibers.

3. Different Treatments for Natural Fibers

3.1. Physical Treatments

It is essential to understand the properties of the cell wall segments and their dependencies on fiber properties, to acknowledge how lignocellulosic fiber can be utilized in high-performance industrial applications [80–82]. Natural fibers mostly lag in the hydrophilic property, causing poor chemical resistance, inferior mechanical properties, and porous structure, which limit their engineering applications [83,84]. Hydrophilicity also reduces the applicability of textile products, especially in transport and packaging [85]. Another significant factor in NFRPCs production that virtually affects their properties and interfacial behavior is the different treatments. Many physical treatments [30] are performed on natural fibers, prior to chemical treatments [86]. These treatments [87] include Corona Discharge, Plasma Treatment, Ultraviolet (UV) Treatment, Fiber Beating, and Heat Treatment.

Corona treatment is possibly the most intriguing strategy for surface oxidation actuation. This treatment changes the cellulose strands' surface energy and is responsible for the improved compatibility between the hydrophilic matrix and fibers [88].

Plasma treatment has been effectively used to eliminate the pollutions/dust particles on the fibers, thus providing an improved fibers' surface. The gas type, pressing factor, and concentration need to be controlled precisely, for effective processing [87].

UV is a generally new approach, acknowledged for eliminating dust particles from the plant fiber surface. In UV treatment, some factors (e.g., stream, gas type, etc.) are uncontrolled [83,89]. During the treatment, the strands are set in a chamber for the surface oxidation of fibers. Besides, the UV treatment builds the polarity on the fiber surface, which prompts better wettability of the fibers, leading to the higher strength of the NFRPCs [87,88].

3.2. Chemical Treatments

Chemical treatments have a considerable effect on NFRPC's mechanical properties [90–92], owing to hydroxyl groups from cellulose and lignin [93]. Chemical-treatment strategies commonly rely on reagent functional groups/active groups capable of responding superiorly with natural-fiber structures, just as adequately removing non-cellulosic

materials from the fibers [94]. Besides, hydroxyl groups resulting from chemical treatments might be engaged with the hydrogen bonding inside the cellulose atoms, limiting the movement towards the matrix [6,90]. Thus, chemical modifications enact these groups or present new moieties that can viably interlock with the matrix, resulting in good bonding [95,96].

The poisonous and reactive synthetic chemicals are sometimes added to the composite to stop an organic attack [97], which is the basis for the wood-preservation industry [11]. Many surface treatments, for example, alkali, acetylation, silane, and peroxide treatments, have been conducted to improve fiber properties. Different chemical treatments and their particular significance on various natural fibers are reported in Table 2. Table 3 presents optimum concentrations of the solution in different chemical treatment procedures.

Table 2. Different chemical treatments and their effect on natural fibers.

Chemical Treatments Name	Coconut Fiber	Sisal Fiber	Jute Fiber	Banana Fiber	Hemp Fiber	Kenaf Fiber	Hemp Fiber	Flax Fiber	Oil Palm Fiber	Cotton Fiber	Significance or Improvement	References
Alkaline treatment	yes	yes	yes	yes	–	yes	–	–	yes	–	Adhesion	[88,98,99]
Silane treatment	–	yes	yes	yes	–	–	–	–	–	–	Control Fiber Swelling	[86,99,100]
Acetylation treatment	–	–	–	–	–	–	yes	yes	–	–	Moisture absorption	[20,101]
Benzoylation treatment	–	–	yes	–	–	–	–	yes	–	–	Thermal stability	[102,103]
Peroxide treatment	–	–	–	–	–	–	–	yes	–	–	Adhesion	[103,104]
Maleated coupling agents	–	yes	yes	–	yes	yes	–	yes	–	–	Bonding between fibers and matrix	[105]
Sodium chlorite treatment	–	yes	–	–	yes	yes	yes	yes	–	–	Moisture absorption	[105]
Acrylation and acrylonitrile grafting	–	yes	yes	–	–	–	–	yes	–	yes	coupling	[6,106]
Isocyanate treatment	–	yes	yes	–	–	yes	–	yes	–	–	Bonding	[94,106]
Oleoyl chloride treatment	–	yes	yes	–	–	–	–	–	–	–	Wettability	[85,93,106]
Stearic acid treatment	yes	–	yes	–	–	–	–	yes	–	yes	Water resistance	[99,105,107]
Permanganate treatment	–	yes	yes	–	–	–	–	yes	yes	–	Adhesion	[20]
Fungal treatment	–	–	–	–	yes	–	yes	yes	–	–	Remove lignin	[78,108]
Triazine treatment	–	–	–	–	–	–	–	–	–	yes	Adhesion	[109]

Table 3. Strength of chemicals and soaking time of different chemical treatments.

Treatment Name	Strength of Chemical (of Weight)	Soaking Time	Curing Temperature	References
Alkaline	5%	2 h	Room temperature	[76,110,111]
Bleaching	5%	1 h	60 °C	[7,112]
Benzoyl Chloride	30%	30 min	80 °C	[72]
Potassium Permanganate	0.125%	3 min	Room temperature	[7,103]
Maleated Coupling Agents	20%	5–10 min	Room temperature	[105]
Acetylation	2%	2 h	Room temperature	[113]
Isocyanates	5%	2 h	40–45 °C	[114]

3.2.1. Alkali Treatment

Among different methods/techniques, alkali treatment is considered to be cost-effective and most efficient strategy, resulting in changes in the fiber surface, just as removing amorphous hemicelluloses and lignin [94]. Alkali treatment is a typical method to clean and adjust the fiber surface to lower surface strain and improve the interfacial attachment between natural fiber and a polymer matrix [115].

To this end, a few endeavors have been made to create effective natural fibers for reinforcement. A past report showed that the cellulosic fibers removed from leaves of the Saharan aloe vera cactus plant utilizing an antacid treatment could potentially be used as strengthening material [83].

3.2.2. Silane Treatment

Silanes are productive coupling specialists widely used in fiber-reinforced composites and have an equivalent effect on synthetic-fiber-reinforced composite. Silanes also have the potential to act as an adhesion promoter in numerous glue formulations or utilized as substrate primers, providing strong adhesion. Various studies indicated that a layer was formulated on the fiber surface by silane adsorption. The surface morphology of sisal fibers changed by developing compound connections between the silane and the sisal fiber surface. Therefore, they are now extensively used in many studies [116]. Different steps involved in the silane treatment process are as follows [116]:

- Hydrolysis,
- Self-condensation,
- Adsorption,
- Chemical grafting.

3.2.3. Acetylation Treatment

The acetylation treatment reduces plant fibers' hydrophilicity and improves the fibers and matrix's interfacial bonding. It works on acetyl groups (CH_3CO), which removes the hydrophilic hydroxyl gatherings (OH) of the fiber. Accordingly, the fiber's hydrophilic nature diminishes and improves the composites' dimensional stability [36]. This treatment also results in a rough surface topology with fewer void substances, thus providing better mechanical interlocking with the matrix. Senthilraja et al. [113] reported that the mechanical properties of NFRPCs could be improved through acetylation treatment. These NFRPCs were utilized later for applications like entryway boards, vehicle parts, etc. Acetylation treatment reduces the dampness retention furthermore, it improves their life [117].

3.2.4. Benzoylation Treatment

Benzoylation produces a significant change in the natural blend [43]. Benzoyl chloride is regularly utilized in fiber treatment. Benzoyl chloride incorporates benzoyl ($\text{C}_6\text{H}_5\text{C}=\text{O}$), ascribed to the treated fiber's diminished hydrophilic nature and improved epoxy adhesion [20]. Kalia et al. [118] explained benzoylation treatment on the sisal fibers through a chemical reaction described in Figure 3. Results revealed that the outside surface of sisal strands got coarse, contrary to the sisal fibers' clear and smooth texture.

3.2.5. Maleated Coupling Agents

The maleated coupling technique is commonly used to strengthen the composites containing fillers and fiber. The setup function of this technique results from two principal factors, cost-effective production and the practical interaction of maleic anhydride with the fibers. Coupling specialists, for example, Polypropylene (PP) joined with maleic anhydride (PP-MAH) and PP united with acrylic corrosive (PP-AA), are generally utilized to improve interfacial properties [119]. Esterification response and H-bond collaborations may occur at the cellulosic filler interface, the PP-MAH, proposed in the current writing and portrayed in Figure 4.

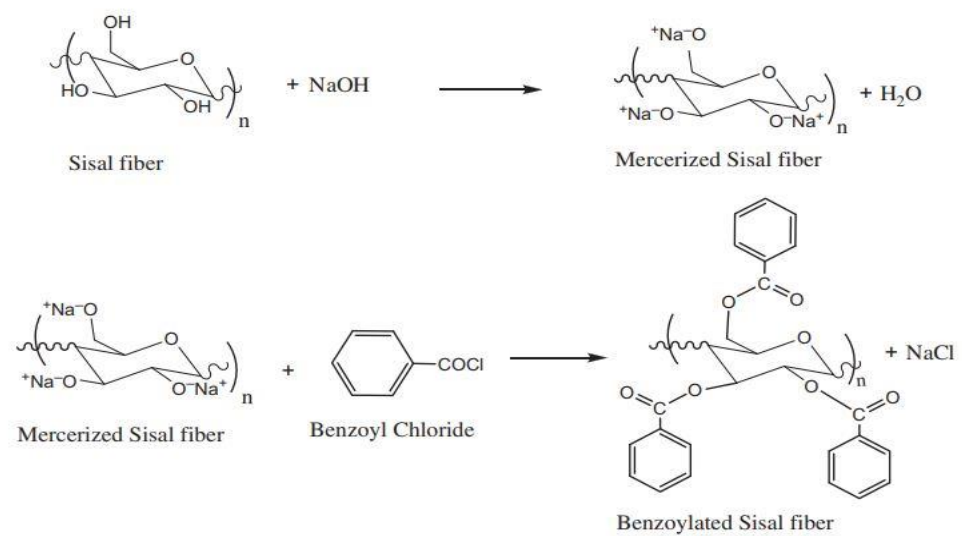


Figure 3. Reactions involved in benzoylation treatment with sisal fibers (Reprinted from permission from [72]. Copyright 2021 Copyright Taylor & Francis).

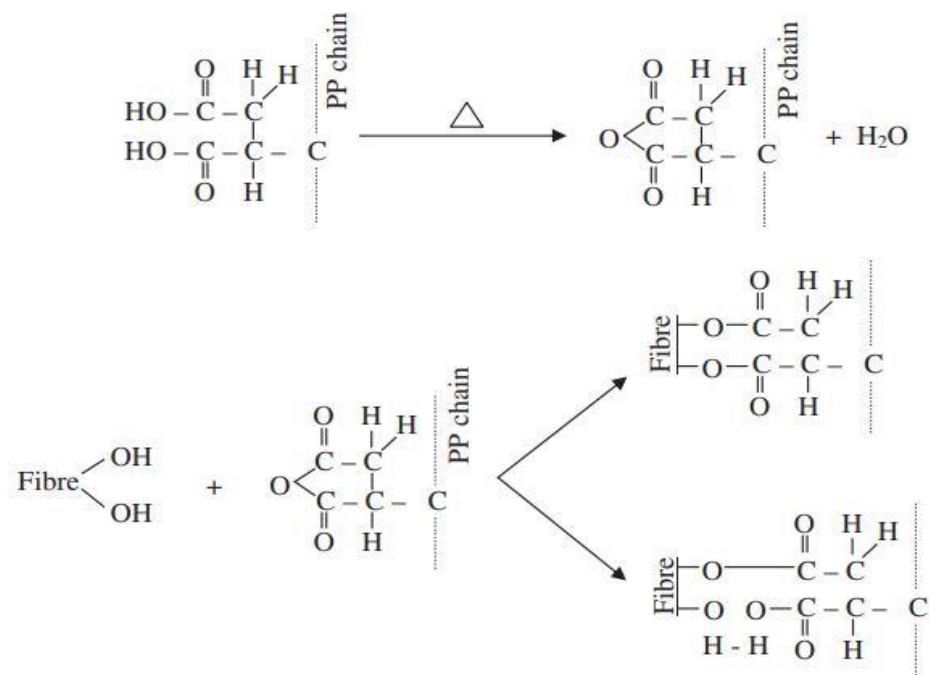
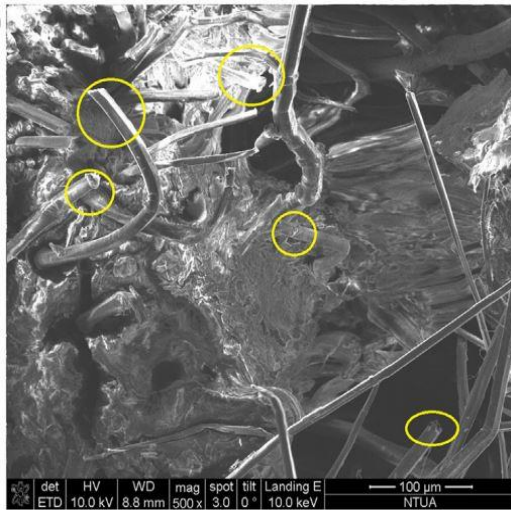
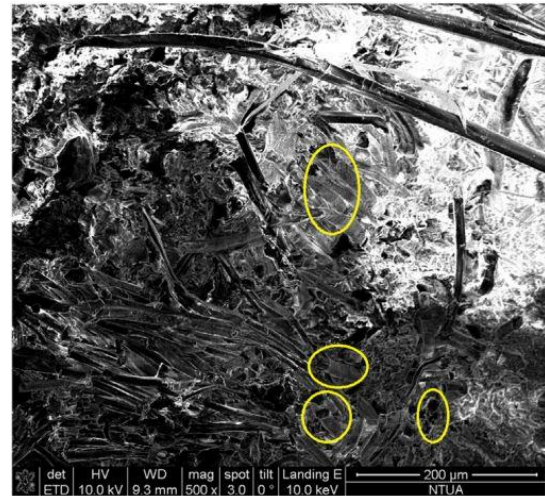


Figure 4. Reactions involved in maleated coupling agent technique (Reprinted from permission from [105]. Copyright 2021 Copyright Elsevier).

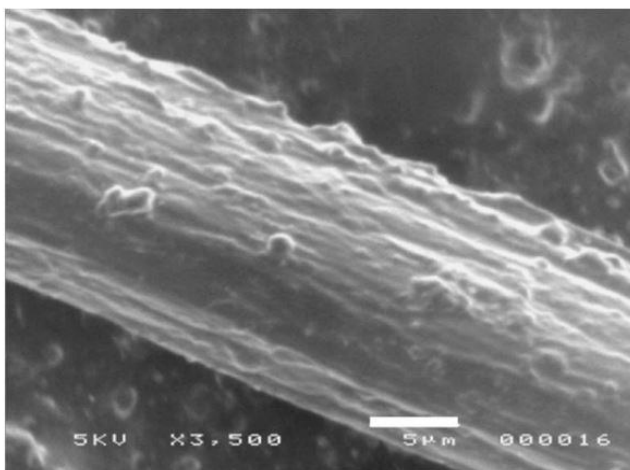
Other minor medications, for example, potassium permanganate [120,121], and acrylic acid can also be utilized. The effects of different treatments on a single flax fiber are presented in Figure 5. For example Figure 5a,b shows the comparison of silane treatment on the flax fiber surface. This treatment improves the good adhesion of flax fiber with matrix, resulting in less pull out of fibers from matrix surfaces [122]. Furthermore, it improves the flexibility of flax fiber. Figure 5c,d presents the effect of stearic acid treatment on the flax fiber surface. This technique removes the non-crystalline constituents of the fiber structure. Consequently, the strands are scattered better in the matrix by separating the fiber groups with more fibrillation [123].



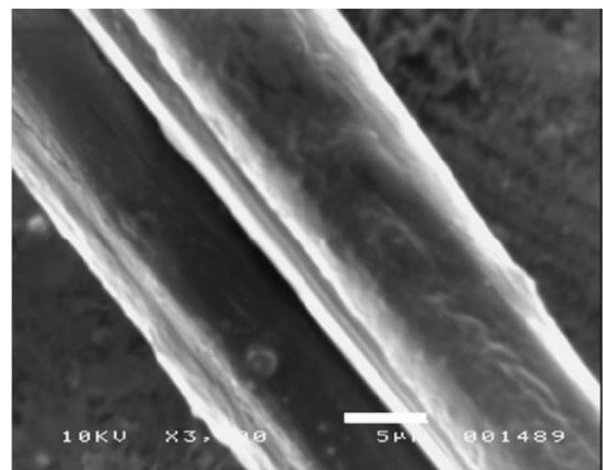
(a) Fractured surfaces of Untreated PLAflax



(b) Fractured surfaces of PLAflax Treated with Silane content 2wt. %



(c) Dew Retted (DR) Flax



(d) Stearic acid-treated Dew Retted (DR) Flax

Figure 5. SEM Images of different chemical treatments on flax fiber ((a,b) Reprinted from permission from [122]. Copyright 2021 Copyright Elsevier and (c,d) Reprinted from permission from [123]. Copyright 2021 Copyright Elsevier).

3.3. Effect of Treatments on Mechanical Properties of Composites

Table 4 reports the effect of different treatments on mechanical properties of natural fiber-reinforced (specifically sisal fiber) composites.

Table 4. Effect of different chemical treatments on sisal-fiber-reinforced composites [100,124,125].

Chemical Treatments	Concentration	Tensile Strength (MPa)	Elongation at Break (%)	Young's Modulus (GPa)
Alkali	5% and 10%	34	1	3.3
Benzoylation	Different weight %	45	7	1.01
Isocyanate	Different weight %	42	4	4.1
Permanganate	0.06%	33	5	1.1
Stearic	4%	32	5	1

4. Synthesis of Natural Fiber Reinforced Polymer Composites

NFRPCs composites are fabricated by different manufacturing techniques [87]. These manufacturing techniques include; automated fiber placement, extrusion, compression molding, Resin Transfer Molding (RTM), long fiber thermoplastic-direct (LFT-D) method, sheet molding compound (SMC), pultrusion, and Thermoset Compression Molding. These techniques have been evolved progressively and used by many researchers, revealing the potential of these techniques in composites manufacturing with good quality [74].

Innovative advancements and process solutions should focus on achieving high-quality NFRPCs identified with their new application zones [65]. However, sometimes the following factors affect the manufacturing process:

- Moisture;
- Constituents like cellulose and lignin in natural fiber;
- Final composite structure.

In any case, new downstream and supplementary equipment have been planned. Single or double venting frameworks, for example, are mostly used for heating for in-line drying, high-power splash cooling tanks [126]. An assortment of new feeding systems' arrangements through any gravimetric or vertical crammer, blends the expulsion infusion shaping expulsion pressure forming just as screw, bite the dust, and shape plan [88]. Most of the NFRPCs fabricated to date by these procedures are presented in Figure 6. The manufacturers aim to improve the possibility of utilizing these techniques [64,127].

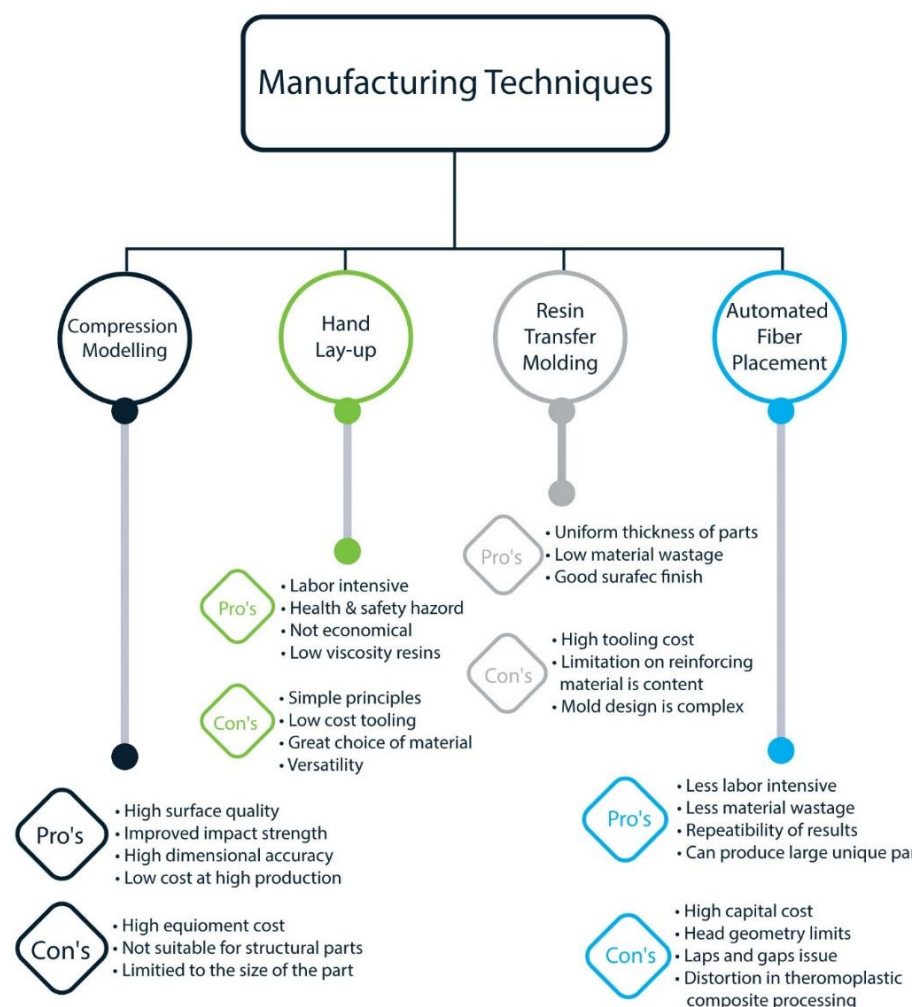


Figure 6. Different Manufacturing techniques for producing natural fiber composites (NFCs).

5. Potential Scope/Application of Natural of Fibers Reinforced Composites

The interest in the use of NFRPCs is developing rapidly in various engineering fields [128]. Figure 7 illustrates the applications of NFRPCs in different industrial areas. Natural fibers, like kenaf, hemp, flax, jute, and sisal, are providing several benefits, such as decreases in weight, cost, and CO₂ footprints; less dependence on oil resources; and recyclability [16,31,129]. Therefore, vehicle manufacturers have been keen on utilizing natural fiber composites both inside and outside of automobiles. For example, the various types of characteristic NFRPCs have gained incredible attention across multiple car applications and by numerous car manufacturers, for example, German auto organizations (BMW, Audi Group, Ford, Opel, Volkswagen, Daimler Chrysler, and Mercedes), Proton organization (Malaysian national carmaker), and Cambridge industry (a car industry in the USA) [48,68]. The use of NFRPCs serves multiple objectives to these organizations: to bring down the vehicle's overall load along these lines expanding eco-friendliness, and build the supportability of their assembling procedure [130].

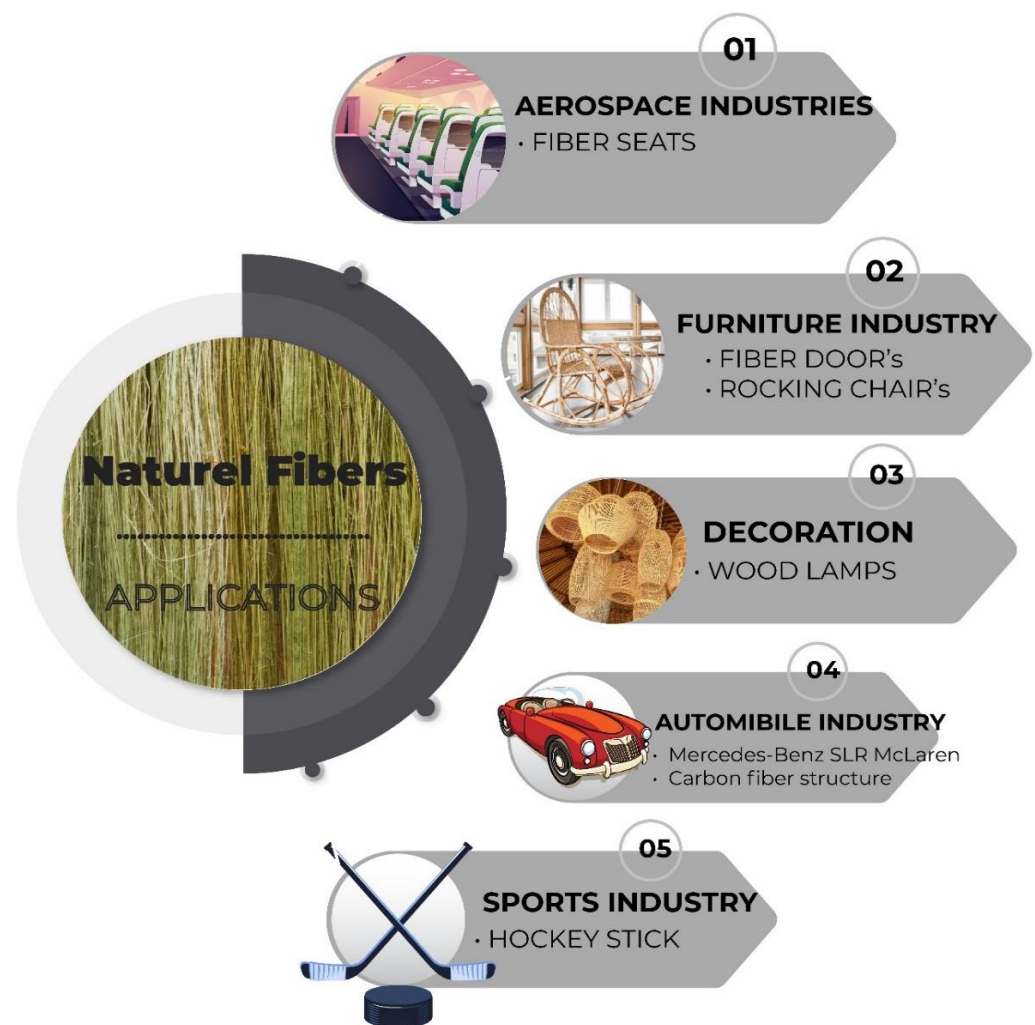


Figure 7. General applications of natural fibers.

Adjacent to the car business, the use of NFRPCs can be seen in the building and development industry, sports, aviation, and others, for instance, boards, window outline, decking, and bike outline frame [77,131]. The specific applications of different natural fibers in industrial products are discussed in Table 5.

Table 5. Applications of different natural fibres [38,48,132–136].

Natural Fibers	Applications
Jute Fiber	Skateboards, Tensil, Hockey, wind-turbines blades, door knobs, automobile interior and exterior parts
Sisal Fiber	In construction industry and also flax and sisal used in interior door-lining panels, MercedesBenz E-Class model
Oil Palm Fiber	Structural insulated panel, fencing and decking
Wood Fiber	In decks, doors, and back seat of automobile as well as molded panel components
Coconut Fiber	Soundproofing, cotton with PP/PET fibers used in trunk
Flax Fiber	Snowboarding laptop cases, tennis racket, automobile parts such as rearview mirror, and visor in two-wheeler; geopolymers panels and Chevrolet Impala automobile trim panels
Kenaf Fiber	Clothing-grade cloth passenger car bumper beam, animal bedding, material that absorbs oil and liquids, packing material and mobile cases, and bags
Coir Fiber	Storage tank, packing material, and engine transmission cover; Brazilian trucks' trim parts of seat cushions
Bagasse Fiber	Window frames and panels

6. Conclusions and Future Perspective

Alarming atmospheric conditions, environmental concerns, and the need for innovation have motivated many researchers to create novel materials. Researchers around the globe are effectively reacting to environmental concerns and now shifting towards biodegradable and sustainable materials. Subsequently, the natural-fiber-reinforced polymer composites (NFRPCs) are becoming a prime choice in several industrial applications. In view of growing interest in NFRPCs, this review aimed to present up-to-date knowledge about different natural fibers, the manufacturing and chemical treatments of natural fibers, and their applications in various fields. Chemical treatments were also highlighted in detail for getting better surface attributes, which permits us to lessen the hydrophilic capacity and improve the adhesion between the fibers and polymers [118]. Natural fibers' choice depends upon their availability, weight/cost, and mechanical properties [137]. The mechanical properties of NFRPCs are primarily affected by the adhesion property of the fibers. This property can be improved by pretreating the fibers. Alkali treatment can be utilized, as it is reported as the most effective technique for all NFRPCs. A combination of other treatments like (alkali + silane) can also be used. The higher concentration of chemicals and the longer soaking time of fibers result in significant mechanical properties improvement. It can be concluded that the development of NFRPCs is rapidly expanding and is visualized as potential future material for several applications [131].

Interfacial adhesion of natural fibers with matrix remains the critical issue in overall performance [99]. Among every chemical treatment studied, alkali treatment is a simple, traditional, and effective procedure for treating many fibers, which can be done on almost all-natural fibers to improve interfacial adhesion [138,139]. Biodegradation phenomena or potential ignition for NFRPCs is moderately new. Therefore, the research should also focus on evaluating the decomposition behavior of NFRPCs. It is necessary to get trustworthy information on the level of biodegradation and the total time for deterioration.

In the future, these NFRPCs will probably achieve complete biodegradability and comparable mechanical properties to those of synthetic-fibers-reinforced composites. Future improvement areas in NFRPCs composites are; mass production of NFRPCs, and thinking about their uses and popularity in the large-scale market are likely to be the primary goals of many researchers. Moreover, the consolidation of nano-cellulose (potentially nanoclay) into NFRPC, can enhance different useful properties, and finally, the examination of the

tribological properties of NFRPCs should be one of the prime areas of interest in future research-based studies.

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