Natural Fiber Reinforced PolymerComposites – An Review

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ABSTRACT:

Researchers and academics are focusing on using natural fibers in polymer composites because of their sustainability and commitment to the environment. The purpose of this review article is to give a thorough analysis of the most popular and relevant natural fiber reinforced polymer composites (NFPCs) and the applications for them. Additionally, it provides an overview of the various surface treatments performed to natural fibers and how these affect the characteristics of NFPCs. The characteristics of NFPCs depend on the fiber source, fiber type, and fiber structure. The impact of chemical treatments, on thermosetting and thermoplastic composites characteristics with natural fiber reinforcement investigated. Applications for NFPCs were constrained by a number of flaws, including increased water absorption, poorer fire resistance, and lesser mechanical qualities. NFPCs' water absorption, tribology, viscoelastic behavior, relaxation behavior, energy absorption, flame retardancy, and biodegradability qualities were also emphasized as effects of chemical treatment. It is shown how to use NFPCs in several applications, including the construction and automotive industries. The study came to the conclusion that chemically treating the natural fiber boosted adhesion between the fiber surface and the polymer matrix, improving the physicomechanical and thermochemical properties of the NFPCs.

1. Introduction

The usage of ecologically friendly materials has come into consideration as a result of rising environmental awareness and public interest, new environmental regulations, and the unsustainable consumption of petroleum. Natural fiber is regarded as one of the more eco-friendly materials with superior qualities to synthetic fiber [1].

According to recent industry data, the global market for natural fiber reinforced polymer composites reached U$2.1 billion in 2010. According to current indications, the global interest in NFPCs will continue to increase quickly. Over the past few years, the use of NFPCs in expanding industry sectors for consumer goods has increased significantly. According to estimates, the NFPCs business is predicted to increase 10% globally over the course of five years (2011–2016) [2]. Simple definition: Natural fibers are ones that aren't artificial or synthetic. They may come from both plants and animals [3]. The production of composite materials using natural fibers like jute, flax, sisal, and oil palm, both renewable and nonrenewable resources, has attracted a lot of attention in recent years. The plants, which produce cellulose fibers can be classified into bast fibers (jute, flax, ramie, hemp, and kenaf), seed fibers (cotton, coir, and kapok), leaf fibers (sisal, pineapple, and abaca), grass and reed fibers (rice, corn, and wheat), and core fibers (hemp, kenaf, and jute) as well as all other kinds (wood and roots) [4]. The most popular and widely produced natural fibers worldwide have been identified in Table 1.

Fiber source	World production (10^3 ton)
Bamboo	30.000
Sugar cane bagasse	75.000
Jute	2300
Kenaf	970
Flax	830
Grass	700
Sisal	375
Hemp	214
Coir	100
Ramie	100

Natural fibers have gained popularity in a variety of applications due to their superior qualities and advantages over synthetic fibers in terms of their relative light weight, low cost, less damage to processing equipment, good relative mechanical properties like tensile modulus and flexural modulus, improved surface finish of composite molded parts, renewable resources, abundance [5], flexibility during processing, and biodegradability. By incorporating the hardy and lightweight natural fiber into polymer (thermoplastic and thermoset), NFPCs with high specific stiffness and strength can be created [6]. On the other hand, natural fibers have glaring flaws in their qualities and are not without issues. The structure of natural fibres consists of (cellulose, hemicelluloses, lignin, pectin, and waxy components) and allows moisture absorption from the environment, resulting in weak bindings between the fibre and polymer. Furthermore, because the chemical structures of the fibres and matrix differ, couplings between natural fibre and polymer are regarded difficult. These are the causes of ineffective stress transfer at the contact of the manufactured composites. As a result, natural fibre alterations using particular treatments are unquestionably required. These alterations are typically focused on the use of reagent functional groups that have the ability to respond to fibre structures and change their composition. As a result, fibre modifications reduce natural fibre moisture absorption, resulting in a great improvement in fibre incompatibility.

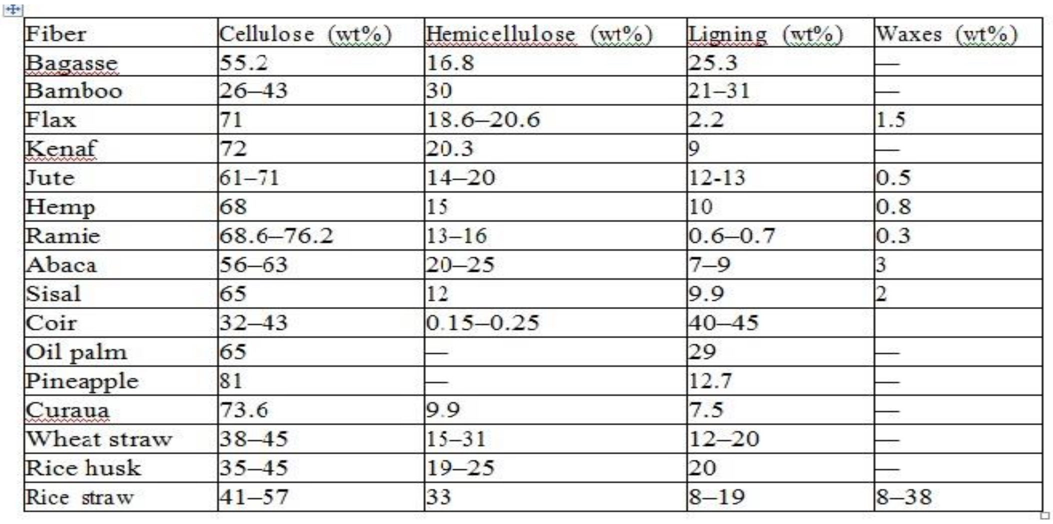
The variety of NFPC applications is expanding quickly across several engineering disciplines. Numerous automakers, including the national automakers of Malaysia and Germany (BMW, Audi Group, Ford, Opel, Volkswagen, Daimler Chrysler, and Mercedes), as well as the United States' Cambridge Industry, have given the various types of natural fibers reinforced polymer composite a significant amount of attention in a variety of automotive applications. Natural fiber composites have uses outside of the automotive business, too, including in the building and construction sector, sports, aerospace, and other products like panels, window frames, decking, and bicycle frames [8].

Kabir and colleagues [9] agreed that treatment is a crucial component that needs to be taken into account when processing natural fibers in their assessment of chemical treatments of natural fibers. They discovered that different chemical treatments cause fibers to lose their hydroxyl groups, which reduces the hydrophilic characteristic of the fibers and increases the mechanical strength and dimensional stability of natural fiber reinforced polymer composites. Their overall finding was that chemical treatment of natural fibers produces NFPCs that are noticeably improved.

1. Natural Fiber ReinforcedComposites (NFPCs)

High-strength natural fibers including jute, oil palm, sisal, kenaf, and flax are combined with a polymer matrix to create natural fiber polymer composites (NFPC) [10]. The two primary subcategories of polymers are thermosets and thermoplastics. Thermoplastic matrix materials have a tendency to become softer at higher temperatures and to restore their original properties as they cool because of the one- or two-dimensional molecular nature of their structure. Contrarily, thermosets are heavily cross-linked polymers that cure when exposed to heat, pressure, light, or any combination of these. The great strength and modulus of this structure, as well as its substantial flexibility for adjusting desired final characteristics, are advantageous to the thermoset polymer [3, 4]. Thermoplastics like polyethylene [11], polypropylene (PP) [12], and poly vinyl chloride (PVC) are widely utilized to create biofibers, whereas thermosetting matrices like phenolic, polyester, and epoxy resins are typically used [10]. A number of variables can affect the features and performance of NFPCs. The hydrophilicity of the natural fiber, as well as other parameters [5, fiber loading], affect the composite's properties [13]. To get good NFPC properties, substantial fiber loading is often needed [14]. Generally speaking, notice how composites' tensile properties are better as their fiber content does [8]. Another crucial element that significantly affects the composites' characteristics and surface features is the process settings that were employed. The necessary manufacturing processes and parameters should be carefully chosen in order to provide the optimum qualities for creating composite [10]. The chemical composition of natural fibers has a significant impact on the characteristics of the composite, which are indicated by the amounts of cellulose, hemicellulose, lignin, and waxes. In Table 2 [4], the chemical composition of a few well-known natural fibers is displayed.

Numerous researchers have investigated and analyzed the suitability, competitiveness, and capacity of natural fibers incorporated in polymeric matrix [8, 11, 15–17]. The importance of manufacturing processes and fiber surface modifications in improving fiber/polymer compatibility was the main focus of the researchers' [4, 18, 19] investigation. The stability of several natural fiber composites in diverse applications was examined and compared by other researchers, though [20]. The features of jute/plastic composites, such as crystallinity, fiber modification, thermal stability, weathering resistance, and durability, as well as their relevance to the automobile industry via ecodesign components, were researched by Al-Oqla and Sapuan [20]. Mohanty et al. Jute fiber was studied by Mohanty et al. [21] to see how it affected the mechanical qualities of pure biodegradable polymer (Biopol). The mechanical parameters of the composites that were produced, such as impact strength, tensile strength, and bending strength, increased when compared to pure Biopol.



Fiber	Cellulose (wt%)	Hemicellulose (wt%)	Ligning (wt%)	Waxes (wt%)
Bagasse	55.2	16.8	25.3	—
Bamboo	26–43	30	21–31	—
Flax	71	18.6–20.6	2.2	1.5
Kenaf	72	20.3	9	—
Jute	61–71	14–20	12-13	0.5
Hemp	68	15	10	0.8
Ramie	68.6–76.2	13–16	0.6–0.7	0.3
Abaca	56–63	20–25	7–9	3
Sisal	65	12	9.9	2
Coir	32–43	0.15–0.25	40–45	
Oil palm	65	—	29	—
Pineapple	81	—	12.7	—
Curaua	73.6	9.9	7.5	—
Wheat straw	38–45	15–31	12–20	—
Rice husk	35–45	19–25	20	—
Rice straw	41–57	33	8–19	8–38

2. General Characteristics of NFPCs

The properties of natural fiber composites are influenced differently by varied fiber kinds, sources, and moisture levels, according to past studies. Performance of NFPC is influenced by a variety of factors, including mechanical composition, microfibrillar angle, structure, defects, cell size, physical qualities, chemical properties, and a fiber's interaction with the matrix. Natural fiber reinforced polymer composites have disadvantages, just like any other product on the market. The couplings between natural fiber and polymer matrix are problematic since these two phases' chemical structures are different from one another. At the interface of the NFPCs, this leads to an ineffective stress transmission. As a result, natural fibers need chemical treatments to create the right interface properties. Reagent functional groups are used in chemical treatments to interact with fiber structures and alter their makeup [9]. The hydroxyl group, which serves as a functional element in natural fibers, makes them hydrophilic. Natural fibers' hydroxyl group makes it harder for hydrophilic natural fiber and hydrophobic polymer matrices to link together during the fabrication of NFPCs. As a result, NFPCs may have subpar mechanical and physical characteristics [8].

Mechanical Properties of the NFPCs. Natural fibers can benefit from significant improvements and recommendations that can be put into place to improve their mechanical characteristics, leading to high strength and structure. The polymers may readily be strengthened and enhanced if the fundamental structures are made robust [26]. There are several factors that have an impact on a composite's performance level or activities, but only a handful are as follows:

(a) orientation of fiber [5],

(b) strength of fibers [8],

(c) physical properties of fibers [27],

(d) interfacial adhesion property of fibers [28] and manymore.

Such composites are known as NFPCs, and their mechanical performance is influenced by the interface that the fiber-matrix provides as well as the stress transfer function that transfers stress from the matrix to the fiber. Numerous researchers have reported this in numerous studies [1, 23, 29]. Natural fiber characteristics such orientation [30], moisture absorption [31], impurities [32], physical qualities [33], and volume fraction [34] are examples of features that contribute to the mechanical properties of NFPCs. Numerous kinds of natural fibers can alter the mechanical properties of PLA, epoxy, PP, and polyester matrices; Figure 1 illustrates a few of these effects.

In this scenario, the tensile strength of PLA was increased by 75.8% when jute fibers were added; flax fibers, however, had a negative impact on this addition. NFPCs have mechanical properties that are even better than those of a pure matrix when jute fibers are added to PLA (polylactic acid). The introduction of flax fiber decreased the tensile strength of the composites by 16%. Conversely, PP composites were enhanced by the addition of hemp, kenaf, and cotton [5]. Maximum development is by far only noticeable in these composites that have jute or polyester included, where a total of 121% advancement is observed compared to pure polyester [5].

TABLe 3: Physicomechanical properties of natural fibers [38].

Fiber	Density (g/cm^3)	Tensile strength (MPa)	Young's modulus (GPa)	Elongation at break (%)
OPEFB	0.7–1.55	248	3.2	2.5
Flax	1.4	88–1500	60–80	1.2–1.6
Hemp	1.48	550–900	70	1.6
Jute	1.46	400–800	10–30	1.8
Ramie	1.5	500	44	2
Coir	1.25	220	6	15–25
Sisal	1.33	600–700	38	2-3
Abaca	1.5	980	—	—
Cotton	1.51	400	12	3–10
Kenaf (bast)	1.2	295	—	2.7–6.9
Kenaf (core)	0.21	—	—	—
Bagasse	1.2	20–290	19.7–27.1	1.1
Henequen	1.4	430–580	—	3–4.7
pineapple	1.5	170–1672	82	1–3
Banana	1.35	355	33.8	53

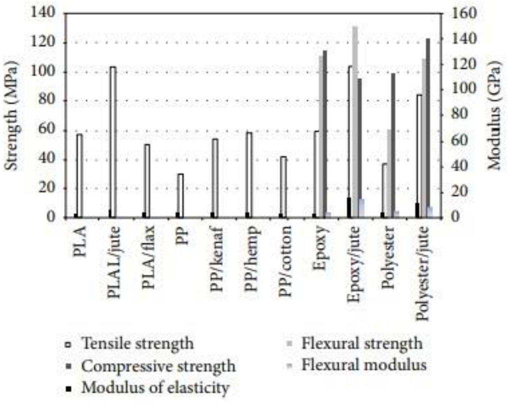


FIgURe 1: Some of mechanical properties of natural fiber reinforcedpolymer composite [5].

However, these materials have a wider range of flexibility because of the gum compound's rubber phase, which reduces stiffness and storage modulus.

Additionally, it is widely recognized that adding more or too much fiber makes composites stiffer and more capable of transmitting stress, which raises their loss and storage moduli. Additionally, it is thought that adding fiber can increase the loss modulus from 415 MPa of gum to 756 MPa after 50 hours [8].

A research team led by Ismail et al. [37] looked into the effect of fiber characteristics that heal a wound or any area of the body on size and filler content. Additionally, it was examined how Oil Palm Wood Flour (OPWF), which is reinforced with composites formed of epoxidized natural rubber (ENR), functions mechanically. The maximum torque was observed with the smallest OPWF particle size, and the torque of the fibers increased with an increase in fiber content. But when the OPWF factor was increased in ENR compounds, the tensile strength was reduced and there was obvious elongation at the break. Elongation, tear strength, tensile modulus, and hardness all clearly rise as a result of the OPWF being subjected to increasing loading. Even a small amount of OPWF loading improved the tensile strength, rip strength, and tensile modulus of the composites [10]. The fracture behavior of composites is similarly influenced by the nonlinear mechanical behavior of natural fibers under the influence of tensile-shear stresses [1]. Table 3, displays the mechanical characteristics of well-liked natural fiber variants from throughout the world.

It is crucial to evaluate the bonding strength between the fiber and polymer matrix in the composite in order to produce superior fiber reinforcement composite properties. The fiber absorbs a lot of moisture because of its dangling hydroxyl and polar groups, which results in poor interfacial contact between the fiber and the hydrophobic matrix polymers. To generate composite materials with superior mechanical properties, fibers are chemically altered to reduce their hydrophilic behavior and moisture absorption [15, 39].

The numerous surface treatments utilized in applications for advanced composites have been researched by several researchers [40–42]. Investigations were also done into how different chemical processes affected cellulosic fibers used as thermoplastic and thermoset reinforcements. For the treatments, the different kinds of chemical treatment include silane [43], alkali [44], acrylation [45], benzoylation [46], maleated coupling agents [47], permanganate [48], acrylonitrile and acetylation grafting [49], stearic acid [50], peroxide [51], isocyanate [52], triazine [53], fatty acid derivate (oleoyl chloride), sodium chloride, and fungal [9]. Enhancing the bond between the fiber and matrix and the ability of composites to transmit stresses are the main objectives of natural fiber surface treatments.

Cordeiroa et al. [54] conducted research on the effects of alkaline treatment on the surface properties of naturally grown natural fibers in Iran. The study found that partial lignin depolymerization-related nonpolar molecules, uranic acid (hemicellulose), aromatic moieties (extractives), and other chemical components on the surface of the fibers are removed by alkaline treatment. Chemical constituents of fibers other than wood are more strongly affected. There is just a slight increase in softwood fiber crystallinity as compared to nonwood fibers. As a result, alkaline treatment can significantly enhance both the wettability and the specific interaction of the fibers. The effects of several chemical treatments, including ethylenediaminetetraacetic acid (EDTA), NaOH, polyethylene imine (PEI), CaCl2, and Ca(OH)2, were disclosed by Le Troedec et al. [55]. By using differential thermal analysis and testing, the effects were on the mechanical characteristics of composite materials made from hemp fiber and lime mixes. Every treatment, it was discovered, directly affected the fiber surface. While the 6% NaOH treatment resulted in the separation of fibers and complex calcium ions associated to pectins, the EDTA treatment resulted in the separation of fibers and increased crystallinity index of fiber bundles.

Le Troedec et al. [55] investigated the effects of several chemical treatments such as ethylenediaminetetraacetic acid (EDTA), NaOH, polyethylene imine (PEI), CaCl2, and Ca(OH)2. The impact of differential thermal analysis and testing on the mechanical properties of composite materials manufactured from hemp fibre and lime mixtures were studied. It was revealed that every treatment had a direct effect on the fibre surface. While the 6% NaOH treatment separated fibres and complex calcium ions associated with pectins, the EDTA treatment separated fibres and enhanced the crystallinity index of fibre bundles.

The impact of alkali (NaOH) treatments at various concentrations (0.5%, 1%, 2%, 5%, 10%, 15%, and 20%) on the mechanical characteristics of banana/epoxy composite was investigated by Venkateshwaran et al. [35]. The findings showed that 1% NaOH treated fiber reinforced composites offer superior properties to other treated and untreated fiber composites. Better mechanical properties of the resulting composite are a result of the alkali concentration on the fiber surfaces. The higher alkali concentration might, however, harm the fiber's surface and lessen its mechanical properties. The effects of several chemical treatments on the mechanical properties of sisal-oil palm hybrid fiber reinforced natural rubber composites have been studied by John et al. [56]. After chemical treatment, the torque values rose, leading to greater crosslinking. The resulting composites' tensile strength was highest when the fibers were treated with 4% NaOH, much to how alkali treatment boosted the composites' tensile strength in comparison to untreated composites. In contrast, composites treated with 4% NaOH exhibit a robust interface as a result of improved rubber-to-fiber adhesion, which restricts solvent access and results in some swelling. Van van Weyenberg et al. [24] looked at the effects of flax processing variables and fiber treatment on the mechanical properties of flax fiber reinforced epoxy composites. It was discovered that employing long flax slivers couldn't always produce composite properties that were better. Chemical treatments can be utilized to increase the flexural properties of flax fiber reinforced epoxy composites to their maximum potential. Modulus and transverse strength both rose by up to 250% and 500%, respectively. The longitudinal properties of the UD composites (strength and modulus) also showed at least 40% improvements.

The lignocellulosic fibers' chemical and physical properties changed after the rubber wood fiber was treated with laccase enzymes. These chemical reactions alter the concentration of hemicellulose, which in turn modifies the crystallinity of natural materials [57]. Additionally, they make the lignin more amorphous. The morphology and single fiber tensile strength of the EFB fiber are treated by the fiber. The EFB fiber treated with boiling water, 2% sodium hydroxide (NaOH), and a combination of boiling water and NaOH were all examined by Norul Izani et al. [13]. It was found that the treatment changed the characteristics of the fiber surface topography. The two different types of treatments increased the thermal stability of treated EFB fibers over untreated EFB fiber. In contrast, when compared to untreated fibers, the treated fiber had a higher Young's modulus and tensile strength. Epoxy composites supplemented with sugar palm fiber now exhibit better tensile properties thanks to the alkaline treatment at higher alkaline concentrations and soaking durations. On the other hand, a rise in alkaline content can be detrimental to fibers [58].

It was examined BT how OPEFB fibers affected the coating of Acrylonitrile Butadiene Styrene (ABS). The coating method enhanced the mechanical, physical, and fiber properties. The fiber's ability to disintegrate when in contact with soil and the quantity of water it could absorb were both decreased by the ABS treatment. OPEFB fibers' tensile strength and elasticity moduli were increased compared to their initial state by the coating. Coating the fiber increased the surface area between it and the soil particles, improving the metrics for the shear strength of the fiber reinforced soils. [66].

Flame Retardant Properties of the NFPCs. Because they are more sustainable and kind to the environment than synthetic fiber-based composites, natural fiber composites are favoured. They are employed in a variety of industries, such as the aerospace industry [68], the automotive industry [69], and construction materials [9, 18, 20, 38, 67]. Natural fibers and polymers are particularly vulnerable to having their properties altered by flame since they are organic materials. Flame retardancy is a different element whose significance has increased dramatically in order to meet safety standards established while producing natural fiber composites.

When a flame is present, burning of composites happens in five phases, as seen below:

(a) Heating.
(b) Decomposition.
(c) Ignition.
(d) Combustion.
(e) Propagation [70]

If flame retardancy has been reached in the aforementioned phases, the process will cease before an actual fire is set up, whether the ignition stage has been completed or not. Two different sorts of products, one with a high cellulose content and the other with a high lignin content, are created when composites are burnt. While greater values of cellulose suggest a higher potential of flammability, higher values of lignin indicate a higher risk of char formation [71]. Thermal resistance is provided by flax fibers [72], while silica or ash is another important element that helps put out flames [73].

Different NFPCs had their fire resistance improved using various methods. Fire barriers can be utilized in addition to phenolics, ceramics, intumescents, glass mats, silicone, ablatives, and chemical additives. It has been demonstrated that the coatings and chemicals used in the intumescent system are very excellent fire barrier treatments. When heated, these barriers expand, giving the cell wall a uniformly burnt surface. However, with the help of this burnt surface, internal or below components are protected from flux and heat.

One of the well-known or efficient flame retardants for reinforced polymers (natural fibers) is employed with the addition of char-forming cellulose material [74]. Making the polymer more stable and char-forming is the only technique to reduce combustion in this situation. This will reduce flammability, reduce visible smoke, and restrict the number of products that can be released during combustions [72]. Fire retardant coating is another method for enhancing composites' fire resistance. During the impregnation or finishing stage, this coating is applied. The fibers and lingo-cellulosic particles go through alterations throughout the manufacturing process that have an impact on how fire resistant the products are [75].

The two most often utilized metal hydroxide flame retardants are aluminum hydroxide [Al(OH3)] and magnesium hydroxide [Mg(OH)2], and they are intentionally added to polymers. These two flame retardants undergo the aforementioned chemical degradation:

$$2Al\,(OH)3 \rightarrow Al2O3 + 3H2O \quad \Delta H = 20 \text{ cal/g} \quad (1)$$

$$Mg\,(OH)2 \rightarrow MgO + H2O \quad \Delta H = 328 \text{ cal/g} \quad (2)$$

Magnesium hydroxide exhibits better thermal stability than aluminum hydroxide among these two flame retardants because the temperature range produced by the decomposition of magnesium hydroxide is nearly 300-320 degrees centigrade (C), which is significantly higher than the temperature range provided by aluminum hydroxide, which is only 200-C. Aluminum hydroxide is thought to be more thermally stable, despite the fact that magnesium hydroxide may be used for polyamides, polypropylene, and other polymers. Additionally, research has shown that enhancing the fire resistance of PP composites constructed with flax fiber reinforcement by adding expandable graphite (EG) and ammonium polyphosphate (APP) to composite polymers as sources of FR. Additionally, it was shown that a composite addition of expandable graphite (25 wt%) and flax fiber (30 wt%) reduced the heat release rate (HRR) from 167 kW/m2 to 35 kW/m2 [76].

Spirocyclic pentaerythritol bisphosphorate disphosphoryl melamine (SPDPM), an intumescent flame retardant for PLA, was the subject of study by Zhan et al. [77]. With the addition of 25 weight percent of SPDPM (Spirocyclic Pentaerythritol Bisphosphorate Disphosphoryl Melamine), an active flame retardant, char develops, enhancing PLA's antidripping capabilities and flame retardancy. Incorporating flame retardancy is challenging, and it can only be done with a large high loading of inorganic filler. Hapuarachchi and Peijs conducted research on how to build a natural fiber composite with improved fire or flame retardancy [78].

In order to establish a synergy linked to flame retardancy, two distinct types of nanofillers were combined with PLA polymers derived from agricultural sources to generate this natural fiber composite.

Analysis will show that adding the hemp fiber mat to the PLA resin caused a decrease in PHRR (peak heat release).The biodegradability of NFPCs.

High strength composites are made possible by natural fiber reinforcing in polymers. These composites also have improved or added biodegradability, are inexpensive, lightweight, and have excellent mechanical properties [29].

Natural fibers degrade at 240 degrees Celsius, while other fiber constituents, including cellulose, lignin, and others, degrade at various temperatures. For example, lignin starts to decompose above 200°C, but temperatures above this will also cause other components to decompose [9].

Since lignin and hemicelluloses, two structural elements of fibers, control the fibers' thermal stability, it is possible to either raise or completely eliminate these elements' content. Chemical processes can help to accomplish this. Two important considerations for the degradation of natural fibers are the emergence of fibers and materials with functionalities [9]. Natural fibers are the least harmful to the environment and have a limited lifespan, but synthetic fibers cause pollution due to deterioration. The properties of lignocellulosic materials' thermal breakdown are influenced by the amounts or composition of cellulose, hemicelluloses, and lignin [13]. More than half of the weight of jute or Biopol composite is lost after exactly 1500 days of burial [21].

The NFPCs' Absorption of Energy. Composite materials, which are extensively employed in the automotive and racing industries, are known for their high strength, energy absorption, and stiffness. This is mostly because of their mass reduction feature [79].The greater volume fraction denotes improved energy absorption and is only possible at low speeds, such 2.5 m/s [80]. Jute showed brittleness and weak fibers, although flax, hemp, and hemp all performed equally at high speeds, such as 300 m/s [81]. The potential of NFPCs was examined by Meredith et al.; this is necessary for the application of supplying sustainable energy absorption. remembering motorsports [80]. Testing is done on conical specimens of hemp, jute, and flax utilizing the Vacuum Assisted Resin Transfer Molding (VARTM) procedure to determine their properties. In order to investigate specific energy absorption (SEA), different values produced by different kinds of materials were recorded.

Tribology Properties of NFPCs: Each material has some wear and friction properties that degrade with time, thus it is important to consider the tribological loadings for better mechanical part design [5]. Ninety percent of failures are achieved because of differences in tribological loading conditions, which alter their wear and friction characteristics [82]. Reinforcement has the ability to modify the tribological properties of fibers or polymers, either in a positive or negative way [83]. Studies on various forms of tribological investigation have been conducted on a variety of fibers, including kenaf/epoxy [84], betelnut fiber reinforced polyester [85], sisal/phenolic resin [86], sugarcane fiber reinforced polyester (SCRP) [87], and cotton/polyester [88].

For a particular kind of bearing application, Chin and Yousif [84] used kenaf fibers reinforced with epoxy composite, and they showed an 85% increase in wear performance and normal orientation in composites. El-Tayeb used a number of variables, such as speed, test duration, and load, to compare the wear and friction properties of glass fiber/polyester (GRP) and sugarcane fiber/polyester (SCRP) [87]. The results of the investigation showed that SCRP and GRP composite are competitors. Xin et al. [86] explored the same characteristics for sisal fiber reinforced resin brake composites and showed that sisal fiber may replace asbestos in brake pads [89, 90].

Laminate composites were produced using three different natural fibers, including grewia, nettle, optiva, and sisal. In their investigation of this connection of natural fibers, Bajpai et al. employed a hot compression procedure to combine three separate components into a PLA polymer [82]. The friction and wear properties of composites have been investigated in a number of contexts, including dry contact under various operating circumstances. Due to the potential of adjustable operating parameters, the applied force was varied between a range of 10 to 30 N, a speed between 1 and 3 m/s, and a sliding distance between 1000 and 3000 meters. The results of the investigation showed that adding natural fiber mats to a PLA matrix can enhance the wear and friction of neat polymers. Produced composites for a given wear rate exhibit an estimated decrease in the coefficient of friction of 10–44%, with a higher decrease of 70% [82].

Water Absorption Characteristics of the NFPCs. Natural fibers work well as reinforcement in plastics. However, the main disadvantage of natural fibers is their susceptibility to moisture [91]. The mechanical properties of polymeric composites are significantly influenced by the interface adhesion between the fiber and the polymer matrix [15]. Natural fibers have large amounts of cellulose, hemicelluloses, lignin, and pectins, all of which have hydroxyl 1 groups, making them generally hydrophilic sources and strong polar materials as opposed to polymers, which have a high degree of hydrophobicity. Due to serious problems with suitability between the matrix and fiber, the interface region between matrices and natural fibers is weakened [5]. Beginning with the composite materials' outer layers, water absorption gradually decreases into the matrix's main body. Due to its propensity to absorb a lot of water, composite materials tend to weigh more when wet, lose strength, deflect more, swell more, and put stress on nearby structures. These can impair composite materials' mechanical qualities by generating warping, buckling, a higher chance of microbial inhabitation, and damage from freeze and unfreeze [92].

Oil palm fiber natural rubber (OPF-NR) composites demonstrated a rise in the water absorption percentage that associated with an increase in fiber loading due to the hydrophilicity of the fibers. The absorption behavior of NR shifted from Fickian to non-Fickian with increasing OPF as a result of the microcracks and the viscoelastic characteristics of the polymer [8]. In trials using the two types of fabric, woven pandanus fabric composites improved the water absorption in comparison to woven banana fabric composites because of greater lignin and hemicellulose content and the presence of faults in the composite system [93]. The amount of water that composites absorb can also be influenced by temperature. Table 4 [4] shows the equilibrium moisture content of certain natural fibers at 65% humidity and 21°C. The OPF-NR composite was shown to have a lower water absorption rate than the OPF-sisal fiber-NR hybrid biocomposite. The inclusion of sisal fiber, which contains a greater proportion of the extremely hydrophilic holocellulose (23%), resulted in the usage of more water. In addition, OPF has 19% more lignin than sisal fiber (9%). Because lignin is hydrophobic, it absorbs less water [8].

Numerous research [8, 56] showed that the quantity of moisture that NFPCs absorb may be decreased by coupling agents such maleic anhydride polyethylene and chemical treatments including bleaching, acetylation, and alkali treatment. The fiber surface is cleaned during the chemical treatments, as given in the equation below [5, 9], to make sure there are no impurities that might increase the fiber surface roughness and prevent moisture absorption by eliminating the fiber's covering of OH groups.:

$$\text{Fiber-OH} + \text{NaOH} \rightarrow \text{Fiber-O}^{-}\text{Na}^{+} + H_2O \qquad (3)$$

The ability of the OPEFB fiber to absorb moisture at various temperatures was studied by Sreekala and Thomas [91]. They also looked at the effects of other treatments on the OPEFB fiber's ability to absorb moisture, including silane treatment, gamma irradiation, latex coating, mercerization, acetylation, peroxide treatment, and isocyanate treatment. They discovered that all treatments have moisture-absorbing qualities at all temperatures.

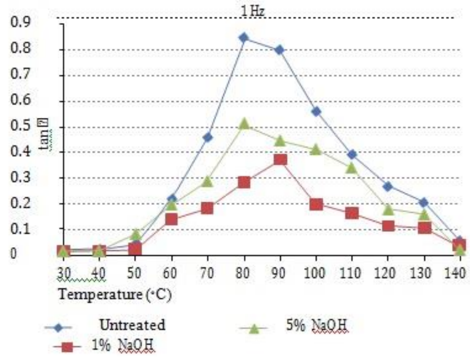


Figure 2: tan£ versus temperature curves of the alkali treated and untreated composites at 1 Hz frequency [35].

Mercerization of OPF-sisal fiber-NR hybrid composites resulted in a decrease in the composite's water adsorption by strengthening the adhesive capabilities of the fiber surface and producing a large surface area that promotes mechanical interlocking [94]. Shinoj et al. [8] investigated the effects of chemically modifying agave fibers to promote moisture absorption before combining with a polymer matrix. The chemical treatment is carried out using four distinct types of reagents: acetic anhydride (Ac), maleic anhydride (MA), styrene (S), and acrylic acid (AA). The study finds that water is more mobile in the fiber core than it is at the surface and that chemical treatment lowers water's total diffusivity.

Viscoelastic properties of the NFPCs. By using dynamic mechanical testing or the viscoelastic behavior across a wide temperature range, it is possible to better understand the structure, morphology, and determination of the interface properties of natural fiber composite materials [95]. The storage modulus offers details on how natural fiber composite materials behave in terms of stiffness and load bearing ability. The storage modulus is the maximum amount of energy that may be held inside a material during one oscillation cycle. The proportion of loss modulus to storage modulus is known as the mechanical damping coefficient, and it is related to the degree of molecular mobility in polymeric materials. However, the loss modulus varies directly proportional to the sample's rate of heat loss [96].

Reports on the viscoelastic properties of novel blended biocomposites manufactured from yarns including polypropylene and jute. The commingling procedure was used to produce composites made of jute yarn reinforced polypropylene. The viscoelastic behavior or dynamic mechanical properties of the resulting composites were examined in relation to the fiber content and various chemical treatments, such as potassium permanganate (KMnO4), maleic anhydride modified polypropylene (MAPP), toluene diisocyanate (TDI), and stearic acid (ST). The experiment found that increasing the amount of fiber enhances the storage and loss modulus of the composite. However, due to the chemical treatment with KMnO4 and MAPP, the storage modulus and loss modulus of the suitably treated composites are greater than those of the untreated ones at all temperatures.

Venkatesh-waran et al. [35] investigated the effects of alkali treatments on the viscoelastic behavior of natural fiber composite utilizing the dynamic mechanical analyzer. When the measurements were carried out in the tensile mode of the used apparatus, the related viscoelastic characteristics were established as a function of temperature and frequency. The trials produced the graphs plotted as storage modulus (E) versus temperature and tan versus temperature, as shown in Figures 2 and 3 [35], at frequencies of 0.1, 1, and 10 Hz, respectively.

Relaxation Behavior of the NFPCs. Natural fiber has an intrinsic relaxing tendency that plays a key role in helping NFPCs relax under stress. Therefore, a thorough study of the reinforcing fiber's tensile stress relaxation is required [38]. For instance, Sreekala et al. [29] conducted a study of this kind that focused on the characteristics of each individual OPEFB fiber and also looked at the impact of fiber surface modification, aging, and strain intensity on the fiber relaxation behavior. The capacity of the fibers to relax under stress was considerably diminished with surface modifications, such as latex modification, limiting the physical contact that would ordinarily occur between the latex particles and fiber surface. The rate of stress relaxation of the OPEFB fiber was optimized at 10% strain level, as shown in Figure 4, and the relaxation modulus values for the fiber reflect similar patterns as shown in Figure 5. Furthermore, water and thermal aging slow the rate of relaxation of the oil palm fiber. In contrast, OPF-sisal fiber-NR hybrid composites showed a decrease in stress relaxation rate as fiber% increased [97].

Thermal Properties of NFPCs. Untreated OPFs are more thermally stable than flax and hemp fibers, and OPF is expected to be more thermally stable than flax and hemp fibers. When temperatures climb from 20°C to 150°C, the heat capacity of OPFs rises, particularly from 1.083 J/g/C1 to 3.317 J/g/C1 [98]. The thermal diffusivity, thermal conductivity, and specific heat of flax/HDPE composites declined as fiber content increased. Thermal diffusivity and conductivity, on the other hand, did not alter much in the temperature range of 170 to 200 °C. The specific heat of the biocomposites rose with increasing temperature [4]. Pineapple leaf fiber was used as the base for practical polycarbonate composites. The silane-treated modified pineapple leaf fiber composite had the highest tensile strength and impact resistance. According to the thermogravimetric investigation, the composites exhibit poorer thermal stability than plain polycarbonate resin. Furthermore, when the fiber content of pineapple leaves grew, so did the heat stability [4]. Enzymatic treatment can enhance the surface and thermal characteristics of several natural fibers, including flax and hemp [56]. Hemicellulose and pectinase are two treatments that can improve the thermal properties of the aforementioned fibers. The use of enzymes to improve natural fiber surfaces for natural fiber composites is interesting [67]. Norul Izani et al. [13] studied the effect of chemical treatment on the morphology and tensile strength of the EFB fiber. As treatments, 2% sodium hydroxide (NaOH) and a mixture of NaOH and hot water were utilized. While the chemical treatment with NaOH and boiling water caused the EFB fibers to have higher thermal characteristics than untreated fibers, the chemical treatment with NaOH and boiling water improved the fiber surface topography, thermal stability, and tensile strength.

Thermal Properties of NFPCs. Untreated OPFs are thermally more stable than treated OPFs, and OPF is expected to be thermally more stable than flax and hemp fibers. OPFs' heat capacity rises with temperature, notably from 20°C to 150°C, from 1.083 J g C1 to 3.317 J g C1 [98]. Thermal diffusivity, thermal conductivity, and specific heat of flax/HDPE composites all reduced as fiber content rose. In the 170-200 C range, however, there were no discernible changes in thermal diffusivity or conductivity. As the temperature climbed, the specific heat of the biocomposites steadily increased [4]. Pineapple leaf fiber was employed as the foundation for workable polycarbonate composites.

3. Natural Fiber Polymer Composites Application

NFPC applications are expanding quickly in a variety of technical sectors. Natural fibres such as jute, hemp, kenaf, oil palm, and bamboo reinforced polymer composites have gained prominence in a variety of automotive applications, structural components, packing, and building [5, 99]. Electrical and electronic sectors, aircraft, sports and recreation equipment, boats, machines, office items, and so on all use NFPCs. NFPCs are widely used in polymer composites due to their low specific weight, relatively high strength, low production cost, resistance to corrosion and fatigue, total biodegradability, improving the surface finish of moulded part composites, relatively good mechanical properties, readily available and renewable sources [5, 98]. The NFPCs' physical drawbacks, such as moisture absorption, a limited range of processing temperatures, and fluctuating quality, have, on the other hand, limited their performance [73].

Natural Fiber Composites Applications in the Interior Car. The majority of automobile manufacturers worldwide have done extensive research to include NFPCs into their designs. Numerous studies have been conducted by European automakers to expand the use of NFPCs in the automobile sector, particularly in interior car components such seat backs, parcel shelves, boot liners, front and rear door liners, truck liners, and door-trim panels [89]. Natural fiber incorporated in polymers has been used for high demand applications for outside auto body components, in addition to being used for car interior parts[18].

As seen in Figure 6, German automakers (BMW, Audi Group, Ford, Opel, Volkswagen, Daimler Chrysler, and Mercedes) use cellulose fiber composites in a variety of car parts, including the Mercedes Benz A-class model's seats and the Mercedes Benz E-class model's fax-sisal fiber mat reinforced epoxy door panels [8]. Door trim panels are made by the Audi firm using a flax/sisal mat reinforced polyurethane composite [60]. Ford uses flax in the floor trays and kenaf reinforced PP composites in the door panels of their "Mondeo" model [61]. Kenaf fibers are imported from Bangladesh and used in the Mondeo's door panels. Opel Vectra package trays and door panel inserts now contain a kenaf and flax blend. In the Passat Variant, Golf, A4, and Bora models, Volkswagen employed cellulose fiber to make the seatback, door panel, boot-lid finish panel, and boot-liner. Many NFPCs are used in BMW Group vehicles. In 2004 [100], the BMW Group used around 10,000 tonnes of natural fiber. Each BMW 7 Series vehicle carries 24 kg of renewable raw materials, including sisal and flax for the door panels' internal lining. Use wool for the upholstery, cotton for soundproofing, and wood fiber for the seat backs as well. Sisal, jute, coconut, European hemp, and flax are among the natural fibers that Daimler-Benz in Germany is experimenting with to substitute glass fibers in high-quality polypropylene components. The dashboards, center armrest consoles, seat shells, and paneling on the seat backs were all developed by Daimler-

Benz. Additionally, it used natural fibers like abaca and flax to improve the consumption of NFPCs in some autos by about 98% over earlier models. On the other hand, the Cambridge company used a flax fiber/polypropylene composite to make the rear shelf trim panels for the Chevrolet Impala model from 2000 [8, 101]. Table 5 demonstrates how cellulose fiber was employed by Toyota, Proton, Volvo, and other auto manufacturers to create automotive components.

TABLE 6: Natural fiber composite applications in industry [3, 63–65].

Fiber	Application in building, construction, and others
Hemp fiber	Construction products, textiles, cordage, geotextiles, paper & packaging, furniture, electrical, manufacture bank notes, and manufacture of pipes
Oil palm fiber	Building materials such as windows, door frames, structural insulated panel building systems, siding, fencing, roofing, decking, and other building materials [14]
Wood fiber	Window frame, panels, door shutters, decking, railing systems, and fencing
Flax fiber	Window frame, panels, decking, railing systems, fencing, tennis racket, bicycle frame, fork, seat post, snowboarding, and laptop cases
Rice husk fiber	Building materials such as building panels, bricks, window frame, panels, decking, railing systems, and fencing
Bagasse fiber	Window frame, panels, decking, railing systems, and fencing
Sisal fiber	In construction industry such as panels, doors, shutting plate, and roofing sheets; also, manufacturing of paper and pulp
Stalk fiber	Building panel, furniture panels, bricks, and constructing drains and pipelines
Kenaf fiber	Packing material, mobile cases, bags, insulations, clothing-grade cloth, soilless potting mixes, animal bedding, and material that absorbs oil and liquids
Cotton fiber	Furniture industry, textile and yarn, goods, and cordage
Coir fibers	Building panels, flush door shutters, roofing sheets, storage tank, packing material, helmets and postboxes, mirror casing, paper weights, projector cover, voltage stabilizer cover, a filling material for the seat upholstery, brushes and brooms, ropes and yarns for nets, bags, and mats, as well as padding for mattresses, seat cushions
Ramie fiber	Use in products as industrial sewing thread, packing materials, fishing nets, and filter cloths. It is also made into fabrics for household furnishings (upholstery, canvas) and clothing, paper manufacture.
Jute fiber	Building panels, roofing sheets, door frames, door shutters, transport, packaging, geotextiles, and chip boards.

Natural Fiber - Applications in the Industry. Applications for NFPCs outside of the automotive industry include building and construction, aerospace, sports, and more. Examples include partition boards, ceilings, boats, office supplies, and machines. Due to their susceptibility to environmental damage, nonload bearing indoor components in civil engineering receive the majority of NFPC applications [72]. Green buildings are desired to be acceptable, healthy, and ecologically conscious places to live and work. At the moment, biocomposites are one of the main materials used to make green goods. Regarding their use in the construction industry, it may be divided into two types of biocomposites: first, structural biocomposites, which comprise bridge and roof structure, and second, nonstructural biocomposites, which include window and external construction [2].

Natural fiber reinforced composites have many benefits, including a high stiffness to weight ratio, being lightweight, and being biodegradable, which makes them suitable for a variety of applications in the building sectors [102]. Van de Weyenberg et al. [24] have demonstrated that sisal fiber reinforced composite thin walled elements with good properties, such as high strength in tension and compression, have a wide range of applications, including structural building members, long span roofing elements, tanks, facades, and pipes strengthening of existing structures. On the other hand, sisal fiber and coir fiber composites have been employed in roofing components to replace asbestos, while bamboo fiber can be used as reinforcement in structural concrete parts [15]. Natural fiber reinforced concrete sheets (both plain and corrugated), boards, and ceiling tiles are lightweight and perfect for use in roofing, ceilings, and walls when building affordable homes [103]. The numerous uses of cellulose fiber in manufacturing, construction, and other sectors are displayed in Table 6.

4. Conclusions

When compared to synthetic composite products, natural fiber reinforced polymer composites have advantageous properties like low density, lower cost, and reduced solidity, offering advantages for use in commercial applications (automotive industry, buildings, and constructions). The mechanical behavior of polymers is improved when natural fibers are used as reinforcement in polymeric composites. This research assesses the mechanical, thermal, energy absorption, moisture absorption, biodegradability, flame retardancy, and tribology properties of natural fiber reinforced polymer composites. Research is done on the relaxation and viscoelastic behavior of NFPCs. It is also reported that NFPCs are used in the automotive and industrial sectors. The impact of chemical treatment on the characteristics of natural fibers is also covered. The chemical treatment of these NFPCs can further improve their mechanical and physical characteristics, while coupling agents and alkalization of the fiber surfaces can prevent moisture absorption in the NFPCs.

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