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Natural Fiber Reinforced Polymer Composite – A Review

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Abstract: Researchers and professionals are enthusiastic with using natural fibres in polymer composites because of their environmental friendliness and long-term viability. The purpose of this review article is to give a thorough overview of the most appropriate and widely used fibres reinforced polymer composites (NFPCs) and their applications. It also includes a description of various surface treatments used on natural fibres and their impact on the qualities of NFPCs. Fiber structure, source and structure all influence the qualities of NFPCs. The impact of several chemical treatments on the mechanical and thermal characteristics of natural fibre reinforced thermosetting and thermoplastic composites were looked. NFPCs have a variety of limitations, including greater water absorption, poor fire resistance, and poor mechanical qualities, which limited their use. Chemical repercussions Water absorption, tribology, viscoelastic behaviour, relaxation behaviour, energy absorption, flame retardancy, and other treatments. The biodegradability of NFPCs was also noted. Chemical treatment of the natural fibre boosted adhesion between the fibres, according to the findings. The physicomechanical and thermochemical characteristics of the NFPCs were improved by combining the fibre surface with the polymer matrix.

Keywords: Natural fiber, polymer, properties, tests.

I. INTRODUCTION

The rise in environmental awareness and societal interest, as well as new environmental restrictions and unsustainable petroleum usage, have prompted consideration of ecologically friendly materials. Natural fibre is a type of fibre that comes from plants .regarded to be one of the most eco-friendly materials. When compared to synthetic fibres, which have good qualities [1]. According to a recent industry study, the global natural fibre reinforced polymer composites sector Approximately 2010, the industry brought in $2.1 billion. There are currently no pointers. that interest in the NFPCs business will continue to increase at a rapid pace all throughout the globe The use of NFPCs has grown in popularity. significantly in the shopper goods as developing Over the previous few years, there has been a shift in industry sectors. As already stated Over a five-year period (2011–2016), the NFPCs industry was evaluated. Globally, it is expected to rise by 10%. [2]. Natural fibres are those that aren't synthetic or man-made, to put it simply. They can come from either plants or animals [3]. The utilisation of natural fibre from both renewable and nonrenewable resources to make composite materials has gotten a lot of attention in recent decades. Bast fibres , seed fibres , leaf fibres , grass and reed fibres , and core fibres are among the plants that generate cellulose fibres [4]. Table 1 shows the world's most prevalent and economically viable natural fibres, as well as global production.Because of the good properties and superior advantages of natural fibre over synthetic fibres in terms of its relatively low weight, low cost, less damage to processing facilities, strong relative mechanical properties such as tensile modulus and flexural modulus, improved surface finish of moulded parts composite, renewable resources, and being abundant, fibre reinforced polymer matrix has received considerable attention in numerous applications [5].

Flexibility in processing, biodegradability, and low health risks are all advantages. By incorporating a strong and light-weight natural fibre with a polymer, NFPCs with high specific stiffness and strength may be created (thermoplastic and thermoset) [6]. Natural fibres, on the other hand, are not without flaws and have significant property deficiencies. The nature of natural fibres (cellulose, hemicelluloses, lignin, pectin, and waxy compounds) allows moisture absorption from the environment, resulting in weak fiber-polymer bond. Furthermore, because the chemical structures of both the fibres and the matrix are different, couplings between natural fibre and polymer are regarded a difficulty. These are the causes of ineffective stress transmission at the generated composites' interface. As a result, natural fibre changes utilising specialised treatments are unquestionably required. These changes are usually focused on the use of reagent functional groups that have the capacity to respond to fibre architectures and change their composition. As a result, fibre alterations cause natural fibre moisture absorption to be reduced, resulting in improved incompatibility between the fibre and the polymer matrix [7].

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Table 1: natural fibers in the world and their world population [4].

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
Abaca	70

The number of NFPC applications is quickly expanding in a variety of technical domains. Many automotive businesses, including BMW, Audi Group, Ford, Opel, Volkswagen, Daimler Chrysler, and Mercedes), Proton company (Malaysian national automaker), and Cambridge industry, have placed a high value on natural fibres reinforced polymer composites in various automotive applications (an auto industry in USA). Natural fibre composites have been used in a variety of industries, including the building and construction sector, sports, aerospace, and others, for example, panels, window frames, decking, and bicycle frames [8]. Kabir and co-workers agreed that treatment is an essential issue to consider when processing natural fibres in a study of chemical treatments for natural fibres. They discovered that different chemical treatments cause fibres to lose hydroxyl groups, lowering their hydrophilic nature and increasing the mechanical strength and dimensional stability of natural fibre reinforced polymer composites. Their overall finding was that chemical treatment of natural fibres improves the NFPCs significantly [9].

II. NATURAL FIBER POLYMER COMPOSITE

Natural fibre polymer composites (NFPC) are composite materials made out of high-strength natural fibres incorporated in a polymer matrix [10]. [3,4] Polymers are usually divided into two types: thermoplastics and thermosets. Because thermoplastic matrix materials structure is made up of 1D or 2D moleculars, these polymers tend to soften at higher temperatures and then roll back their characteristics as they cool. Thermosets polymers, on the other hand, are strongly cross-linked polymers that cure using simply heat, heat and pressure, and/or light irradiation. Thermoset polymers have good qualities because of this structure, such as tremendous flexibility for customising desired final properties, strong strength, and modulus. Polyethylene [11], polypropylene (PP) [12], and polyvinyl chloride (PVC) are common thermoplastics for biofibers, whereas phenolic, polyester, and epoxy resins are often used thermosetting matrices [10]. The features and performance of NFPCs can be influenced by a variety of variables. The natural fiber's hydrophilic character 5, as well as the fibre loading, have an influence on the composite qualities [13]. To get good NFPC characteristics [14], considerable fibre loading is usually required. In general, as the fibre content of the composites increases, the tensile characteristics of the composites improve [8]. The process parameters used are another important component that has a significant influence on the composites' properties and surface features. As a result, proper process techniques and parameters should be carefully determined in order to get the optimal composite features [10]. Natural fibre chemical composition has a significant impact on the qualities of the composite, which are indicated by the percentages of cellulose, hemicellulose, lignin, and waxes in the composite [4]. . [8,11,15-17] Natural fibres incorporated in polymeric matrix have been studied extensively for their appropriateness, competitiveness, and capacities. [4,18,19] The study focused on the impact of fibre surface changes and manufacturing techniques on fiber/polymer compatibility. On the other hand, other researchers investigated and compared the stability of various natural fibre composites in diverse applications [20]. Al-Oqla and Sapuan looked at the qualities of jute/plastic composites include crystallinity, fibre modification, thermal stability, weomponents. While Mohanty et al investigated the impacts of jute fibre on the mechanical characteristics of pure biodegradable polymer (Biopol), the mecathering resistance, and durability, as well as their usefulness for the automobile sector in terms of ecodesign chanical parameters of the composites, such as impact strength, tensile strength, and bending strength, were found to be higher when compared to pure Biopol. In compared to pure Biopol, the tensile strength of jute Biopol was increased by 50%, while the bending strength and impact strength of the composites were increased by 30% and 90%, respectively [21] .

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Table 2: chemical composition of some common natural fiber [4].

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

III. GENERAL CHARACTERISTICS OF NFPC'S

According to earlier studies, the characteristics of natural fibre composites change due to different types of fibres, sources, and moisture conditions. Mechanical composition, cell dimensions [23], defects [22], microfibrillar angle [20], chemical properties [24], structure [10], physical characteristics [4], and the interaction of a fibre with the matrix [25]are all elements that influence NFPC performance.

Natural fibre reinforced polymer composites, like any other product on the market, have disadvantages. As a result, the couplings between natural fibre and polymer matrix are taken into account as a challenge. as a result of the chemical structural differences between these two phases This results in inefficient stress transmission at the NFPC contact. To attain acceptable interface qualities, chemical treatments for natural fibres are required. Chemical treatments use reagent functional groups that can react with fibre structures and change fibre composition [9].functional group named as hydroxyl group which makes the fibers hydrophilic. During manufacturing of NFPCs, weaker interfacial bonding occurs between hydrophobic polymer matrices and hydrophilic natural fibre due to hydroxyl group in natural fibres. This could produce NFPCs with weak mechanical and physical properties [8].

Mechanical Properties of the NFPCs

There are several improvements and recommendations that may be made to natural fibres in order to improve their mechanical properties, resulting in increased strength and structure [26]. The polymers can be easily strengthened and enhanced if the base structures are made robust.

There are a variety of elements that affect composite performance or activities, including the following, to mention a few.

(a) orientation of fiber [5],
(b) strength of fibers [8],
(c) physical properties of fibers [27],
(d) interfacial adhesion property of fibers [28] etc.,

NFPCs are composites whose mechanical efficiency is determined by the fiber-matrix interface as well as the stress transfer function, which transfers stress from the matrix to the fibre. This has been documented by a number of researchers in a variety of studies. [1,23,29] Natural fibre characteristics like as orientation [30],volume fraction [34] , moisture absorption [31], physical properties [33], and impurities [32] are examples of factors that have a role in determining the mechanical properties of NFPCs. Many types of natural fibres can alter the mechanical characteristics of PLA, epoxy, PP, and polyester matrices, and Figure 1 shows some of them. [5] When jute fibres are added to PLA (polylactic acid), NFPCs exhibit even superior mechanical qualities than a pure matrix; in this example, 75.8% of PLA's tensile strength was increased; nevertheless, the introduction or incorporation of flax fibres had a detrimental influence on this addition. The inclusion of flax fibres lowered the composites' tensile strength by 16 percent. Incorporating hemp, kenaf, and cotton into PP composites, on the other hand, boosted their performance. By far, the greatest gain is shown in composites that include jute or polyester, with a total improvement of 121 percent when compared to pure polyester. However, because

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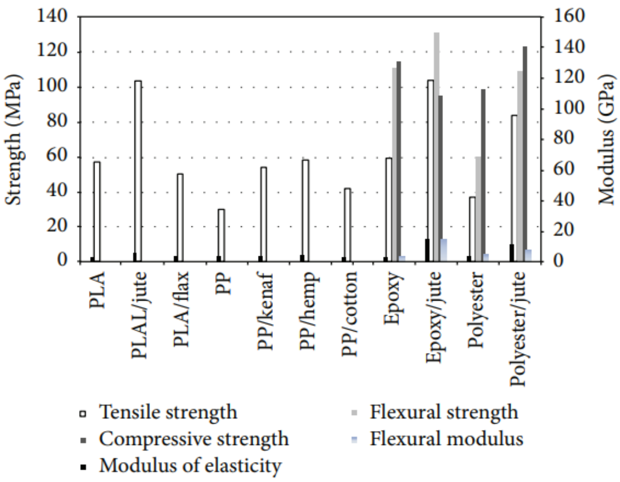
to the rubber phase contained in gum compound, such materials have a broader range of flexibility, resulting in lower stiffness and storage modulus.

Table 3: physicomechanical properties of natural fiber [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



It is also recognized that greater or excessive fibre insertion enhances stiffness and stress transmission in composites, resulting in a superior loss modulus and storage modulus. In comparison to the loss modulus of gum, which is 415 MPa, fibre addition is thought to raise the loss modulus up to 756 MPa at 50 phr fibre loading [8]. The influence of size and filler content on fibre qualities that treat a wound or any area of the body was researched by a group of researchers lead by Ismail et al 37. In addition, the mechanical characteristics of Oil Palm Wood Flour (OPWF) reinforced with (ENR) epoxidized natural rubber composites were investigated. The torque of the fibres increases as the fibre content increases, and the maximum torque was seen with the lowest feasible particle size of OPWF. Increasing the OPWF factor in ENR compounds, on the other hand, resulted in lower tensile strength and significant elongation at the break point. Due to greater OPWF loading, there was also a rise in elongation, tear strength, tensile modulus, and hardness. Composites packed with even the lowest fraction of OPWF have greater tear strength and tensile strength as tensile modulus [10]. The nonlinear mechanical behaviour of natural fibres under the influence of tensile shear stresses has an impact on composite fracture behaviour. [15,39] In order to get excellent fibre reinforcement composite qualities, the bonding strength between fibre and polymer matrix in the composite is considered a crucial component. Due to the presence of dangling hydroxyl and polar groups in the fibre, it absorbs a lot of moisture, resulting in poor interfacial interaction between the fibre and the hydrophobic matrix polymers. Chemical treatment of fibres was carried out to minimise the hydrophilic behaviour of fibres and moisture absorption in order to generate composites with high mechanical properties.

Several researchers looked at the various surface treatments used in advanced composites applications [40-42]. The effects of various chemical treatments on cellulosic fibres used as thermoplastic and thermoset reinforcements were also

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investigated. Silane [43], permanganate [48],alkali [44], acrylation [45], triazine [53], sodium chloride [9], benzoylation [46],stearic acid [50], maleated coupling agents [47], acrylonitrile and acetylation grafting [49], peroxide [51] ,fatty acid derivate [9], isocyanate, and fungal treatments [9] are among the chemical treatments available. The major goal of natural fibre surface treatments is to improve fiber/matrix interfacial bonding and stress transferability in composites.

Cordeiroa et al.[54] investigated the effects of alkaline treatment on the surface properties of Iranian farmed natural fibres.
Alkaline treatment removes several chemical components off the surface of the fibres, including uranic acid (hemicellulose), aromatic moieties (extractives), and nonpolar molecules from partial lignin depolymerization, according to the study. Nonwood fibres have a larger influence on chemical components. Improving the crystallinity of nonwood fibres results in just a slight rise in softwood fibres. As a result, alkaline treatment can significantly increase the particular interaction of the fibres as well as the wettability of the fibres.

55 Chemical treatments such as ethylene diaminetetra acetic acid (EDTA), NaOH, polyethylene imine (PEI), CaCl2, and Ca(OH)2 were studied by Le Troedec et al. Differential thermal assessment and testing were used to determine the impact on the mechanical characteristics of composite materials made from hemp fibre and lime mixes. Every treatment had a direct influence on the fibre surface, according to the findings. The 6% NaOH treatment resulted in fibre cleaning by eliminating amorphous compounds and a rise in the crystallinity index of fibre bundles, whereas the EDTA treatment resulted in fibre separation and complex calcium ions associated to pectins.In comparison to a calcium chloride treatment, which does not display calcium ions' fixation at the surface of fibres, PEI treatment indicates all analysed characteristics to have an intermediate character, and lime water treatment depicts calcium ions' fixation at the surface of fibres.

May-Pat et al.[1] investigated the effect of well-controlled surface treatment on the interphase characteristics of natural fibres. The qualities of components and the area of the fibre surface, or interphase, where stress transfer occurs, determine the fracture behaviour and mechanical properties of an NFPC. Furthermore, customising the interphase with various surface treatments and thoroughly defining it allows for a better understanding of the NFPCs' behaviour. Furthermore, under high loading rates, various fibre surface treatments alter the natural fibre microstructure.

Venkateshwaran et al. [35] investigated the effect of alkali (NaOH) treatments at various concentrations (0.5 percent, 1 percent, 2 percent, 5 percent, 10 percent, 15 percent, and 20 percent) on the mechanical characteristics of a banana/epoxy composite. The results showed that 1 percent NaOH treated fibre reinforced composites had better characteristics than other treated and untreated fibre composites. The higher the alkali content on the fibre surfaces, the better the composite's mechanical characteristics. The resulting composite has improved mechanical characteristics. However, an increase in alkali content may induce surface damage to fibres, resulting in a reduction in mechanical characteristics.

John et al. [56] investigated the effects of various chemical treatments on the mechanical properties and characteristics of sisal-oil palm hybrid fibre reinforced natural rubber composites. The torque values rose as a result of the chemical treatment, resulting in more crosslinking. Similarly, alkali treatment increased the composites' tensile strength when compared to untreated composites, and resulting composites with 4 percent NaOH treated fibres had the highest tensile strength. In contrast, when composites are treated with 4 percent NaOH, a strong interface is seen due to better adhesion between rubber and fibre, which prevents solvent penetration and causes some swelling.[24]The influence of flax processing factors and fibre treatment on the mechanical characteristics of flax fibre reinforced epoxy composites was investigated by Van van Weyenberg et al. It has been observed that using long flax slivers does not always result in better composite qualities. Chemical treatments provide the greatest improvement in the flexural characteristics of flax fibre reinforced epoxy composites. There was a 250 percent increase in transverse strength and a 500 percent increase in transverse modulus. Furthermore, the longitudinal characteristics of the UD composites (both strength and modulus) improved by at least 40%

After treating rubber wood fibre with laccase enzymes, several changes in the chemical and physical characteristics of lignocellulosic fibres can be noticed. These chemical treatments result in the formation of amorphous lignin, which alters the hemicellulose concentration and, in turn, the natural crystallinity [57]. The fibre has a treatment impact on EFB fibre morphology and single fibre tensile strength. Norul Izani et al. investigated EFB fibre treated with boiling water, 2 percent sodium hydroxide (NaOH), and a mixture of boiling water and NaOH [13].

After the treatment, it was discovered that the qualities of the fibre surface topography had altered. The treated EFB fibres with the two forms of treatment were more thermally stable than untreated EFB fibres. The treated fiber's tensile strength and Young's modulus, on the other hand, increased when compared to untreated fibres. The alkaline treatment improved the tensile characteristics of sugar palm fibre reinforced epoxy composites with longer soaking durations and higher alkaline concentrations. Increased alkaline content, on the other hand, may cause fibre damage[58].

The coating effect of OPEFB fibres on Acrylonitrile Butadiene Styrene (ABS) was examined BT. The coating procedure increased the fiber's mechanical and physical qualities as well as its performance. The ABS treatment reduced the fiber's water absorption as well as its biodegradation capacity when it came into contact with soil. The coating improved the tensile strength and elasticity moduli of the OPEFB fibres, which were previously poor. Coating fibre enhanced the surface area between fibre and soil particles, which improved the shear strength metrics of fibre reinforced soils [66].

Flame Retardant Properties of the NFPCs

Natural fibre composites are preferred over synthetic fibre composites because of their environmental friendliness and long-term viability.Natural fibres and polymers are organic materials that are very susceptible to changes in their properties when exposed to flame. Another feature that has become more important in order to meet safety requirements when producing natural fibre composites is flame retardancy.

Composites are burned in five separate phases in the presence of flame, as indicated below.
(a) Heating
(b) Decomposition.
(c) Ignition.
(d) Combustion.
(e) Propagation [70]

If flame retardancy has been accomplished in the preceding phases, the operation will be ended before a real ignition is set up, regardless of whether the ignition step has been completed or not. When composites are burned, two types of products are produced: those with high cellulose content and those with high lignin content. Higher cellulose levels indicate a higher risk of flammability, whereas higher lignin values indicate a higher risk of char formation [71]. Flax fibres give thermal resistance [72]. However, another crucial component that aids in fire extinguishment is silica or ash [73].

Different approaches are used to improve the fire resistance of various NFPCs. Fire barriers can be used on phenolics, ceramics, intumescents, glass mats, silicone, ablatives, and chemical additives, among other things. Coatings and chemicals employed in the intumescent system have been discovered to be extremely promising fire barrier treatments, since these barriers expand when heated, resulting in a scorched even cellular surface. Internal or underneath components, however, are shielded against flux and heat with the assistance of this burned surface. With the combination of char producing cellulose material, one of the well-known or deeper flame retardants for reinforced polymers (natural fibres) is employed [74]. In this case, the only way to reduce combustion is to increase the polymer's stability and char formation. As a consequence, flammability will be lowered, visible smoke will be minimized, and the volume of products created by combustions will be limited [72].

Another approach for improving the fire resistance of composites is to apply a fire retardant coating. This coating is applied at the conclusion of the impregnation or finishing stage. During the production process, fire resistance changes because to changes in fibres and lingocellulosic particles [75]. Aluminum hydroxide [$Al(OH_3)$] and magnesium hydroxide [$Mg(OH)_2$], which are purposely added to polymers, are the two most extensively used metal hydroxide flame retardants. The following is the chemical process that occurs when these two flame retardants decompose:

$$2Al(OH)_3 \rightarrow Al_2O_3 + 3H_2O \quad \Delta H = 20\ cal/g \qquad (1)$$
$$Mg(OH)_2 \rightarrow MgO + H_2O \quad \Delta H = 328\ cal/g \qquad (2)$$

Because the temperature range given off by the decomposition of $Mg(OH)_2$ is nearly 300–320 degrees centigrade (C), which is much higher than the temperature range offered by aluminium hydroxide, which is only 200 degrees centigrade (C), magnesium hydroxide has better thermal stability than aluminium hydroxide. As a result, aluminium hydroxide is not regarded thermally stable since it cannot be utilised with polyamides, polypropylene, or other materials, but magnesium hydroxide can. In another study, it was discovered that adding expandable graphite (EG) and ammonium polyphosphate (APP) to a composite polymer as a source of flame retardant (FR) improves the fire retardancy of flax fibre reinforced PP composites. It was also demonstrated that the heat release rate (HRR) in a composite additive containing 30 wt% flax fibre and 25 wt% EG (expandable graphite) was reduced from 167 kW/m2 to 35 kW/m2 [76]. Zhan et al. investigated Spirocyclic pentaerythritol bisphosphorate disphosphoryl melamine (SPDPM), an intumescent flame retardant for PLA.With a 25 wt percent addition of spirocyclic pentaerythritol bisphosphorate disphosphoryl melamine (SPDPM), an active component of flame retardancy, char formation improves antidripping performance of PLA as well as flame retardancy. Flame retardancy is a difficult property to achieve, and it can only be achieved by using a large amount of inorganic filler [77]. Hapuarachchi and Peijs investigated the creation of a wholly bio-based natural fibre composite with improved fire or flame retardant properties. This natural fibre composite was created using PLA polymers produced from crops, as well as two types of nanofillers that work together to provide a synergy that corresponds to flame retardancy. After integrating hemp fibre mat into PLA resin, there will be a drop in PHRR (peak heat release) in the calorimeter, according to study [78].

Biodegradability of the NFPCs

Natural fibre reinforcement in polymers produces high strength composites that also have additional or increased biodegradability, cheap cost, light weight, and superior mechanical structural features [29].
Natural fibres begin to degrade at temperatures as high as 240°C, whereas fibre constituents such as hemicelluloses,lignin,cellulose, and others begin to degrade at different temperatures; for example, lignin begins to decompose at 200°C, whereas other constituents begin to degrade at temperatures higher than this [9]. Because thermal stability of fibres is based on structural ingredients, such as lignin and hemicelluloses, it can be increased if concentration levels or structural constituents are totally eliminated. Chemical therapies can be used to accomplish this. While degrading natural fibres, two key factors to consider are the development of fibres and materials that give services [9]. Natural fibres have a short lifespan and do little environmental damage when they degrade, but synthetic fibres pollute the environment as they degrade. Thermal degradation characteristics of lingo-cellulosic materials are affected by lignin, hemicelluloses, and cellulose quantities or composition [13]. After exactly 1500 days of burialerials, more than half of the weight of jute or Biopol composite is lost [21].

Energy Absorption of the NFPCs

Composite materials, which are widely employed in the automotive and racing industries owing to their bulk reduction properties, provide energy absorption,high strength, and stiffness [79]. The higher volume fraction, which is only feasible when the speed is low, such as 2.5 m/s, indicates improved energy absorption [80] .flax, jute, and hemp, on the other hand, function similarly at high speeds, such as 300 m/s, although jute has brittleness and poor fibre strength [81]. Meredith et al. looked at the potential of NFPCs for enabling long-term energy absorption. Keeping the focus on motorsport [80]. The Vacuum Assisted Resin Transfer Molding (VARTM) technology is used to evaluate the qualities and characteristics of flax, jute, and hemp conical specimens. Various values displayed by different kinds of materials were documented to study specific energy absorption (SEA).

Tribology Properties of NFPCs

The tribological loadings are vital to consider for improved mechanical part design since every material has some wear and friction qualities that degrade with time [5]. tribological Differences in loading circumstances affect their wear and friction qualities, resulting in around 90% failure [82]. Reinforcement is a technique for changing the tribological characteristics of fibres or polymers (either positively or negatively) [83]. Fibers such as kenaf/epoxy [84],sisal/phenolic resin [86], betel nut fibre reinforced polyester [85], sugarcane fibre reinforced polyester (SCRP)[87], and cotton/polyester 88 have all been subjected to various types of tribological examination. The inclusion of natural fibres improved the wear performance of PLA, and the wear rate of composites was fairly low in contrast to wear rate at higher loads on neat PLA [82]. Chin and Yousif employed kenaf fibres reinforced with epoxy composite in a bearing application, demonstrating an 85 percent improvement in wear performance and normal composites orientation [84] .El-Tayeb investigated the wear and friction properties of glass fiber/polyester (GRP) and sugarcane fiber/polyester (SCRP) using a various of factors such as test time ,speed,and load [87]. SCRP was shown to be a rival to GRP composite based on the findings of the study. Xin et al. [86] investigated the same properties for sisal fibre reinforced resin brake composites, demonstrating that sisal fibre may be utilised in brake pads inplace of asbestos [89,90]. Three different natural fibres, such as grewia, nettle, optiva, and sisal, were used to create laminated composites. Bajpai et al. investigated this natural fibre connection using a hot compression process to insert three distinct components into a PLA polymer [82]. The friction and wear properties of composites were investigated in a variety of circumstances, including dry contact with varied operating settings. The applied force was altered between 10 and 30 N, with a speed ranging from 1 to 3 m/s and a sliding distance ranging from 1000-3000 m, thanks to the possibility of mutable operating parameters. The findings showed that infusing natural fibre mats into a PLA matrix can improve the wear and frictional behaviour of neat polymers. In compared to neat PLA, produced composites show a 10–44% reduction in coefficient of friction, for particular rate of wear. with a higher reduction of 70% found in developed composites [82].

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Water Absorption Characteristics of the NFPCs.

moisture content of certain natural fibres at 65 percent humidity and 21 degrees Celsius.Natural fibres function nicely as polymer reinforcement. The biggest disadvantage of using natural fibres is that they are susceptible to dampness [91]. The interface adhesion between the fibre and the polymer matrix has a substantial influence on the mechanical characteristics of polymeric composites [15]. Natural fibres are high in cellulose, hemicelluloses, lignin, and pectins, all of which contain hydroxy 1 groups, making them hydrophilic and strong polar sources, whereas polymers are hydrophobic. As a result, there are significant hurdles in terms of matrix and fibre appropriateness, which weakens the interface region between natural fibres matrices and natural fibres [5] . Water absorption occurs at the composite materials' outer layers and eventually declines within the matrix's bulk [92]. A significant water intake by composite materials leads to an increase in the weight of wet profiles, a potential loss of strength, and an increase in deflection, swelling, and pressure on neighbouring structures. These can result in bending, buckling, increased microbiological inhabitation, and mechanical features of composite materials being destroyed due to freeze and unfreeze. Because of the hydrophilicity of the fibres, water absorption percentages increased in oil palm fibre natural rubber (OPF-NR) composites as fibre loading increased [8]. Because of the microcracks and viscoelastic nature of the polymer, the absorption behaviour of NR changed from Fickian to non-Fickian with the addition of OPF.Because of greater lignin and hemicellulose content, as well as the existence of flaws in the composite system, woven pandanus fabric composites enhanced water absorption compared to woven banana fabric composites in the woven pandanus/banana fabric composites testing [93]. Furthermore, the degree of water absorption of the composites can be affected by temperature [4]. Table 4 shows the equilibrium.

Table 4: the equilibrium moisture content of different natural fiber at 65% relative humidity (RH) and 21 degree C [4].

Fiber	Equilibrium moisture content (%)
Sisal	11
Hemp	9.0
Jute	12
Flax	7
Abaca	15
Ramie	9
Pineapple	13
Coir	10
Bagasse	8.8
Bamboo	8.9

The water absorption of OPF-NR composite was found to be lower than that of OPF-sisal fiber-NR hybrid biocomposite. The addition of sisal fibre, which includes a higher percentage of holocellulose (23%) and is extremely hydrophilic, resulted in increased water intake. Furthermore, the lignin percentage of OPF (19%) was higher than that of sisal fibre (9 percent). Because lignin is hydrophobic, it absorbs less water [8]. Many studies have shown that chemical treatments like as bleaching, acetylation, and alkali treatment, as well as coupling agents such as maleic anhydride polyethylene, can reduce the moisture absorption of NFPCs [8, 56]. During chemical treatments, the surface of the fibres is cleaned to ensure that there are no impurities, which enhances the fibre surface roughness and prevents moisture absorption by removing the coat of OH groups on the fibre, as shown in the equation below [5, 9] .

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

Sreekala and Thomas [91] looked studied the moisture absorption capabilities of OPEFB fibre at various temperatures. They also looked at the effects of silane treatment, peroxide treatment, latex coating, mercerization, acetylation, gamma irradiation, and isocyanate treatment on the moisture absorption capabilities of OPEFB fibre. They came to the conclusion that all treatments lead to a reduction in moisture absorption characteristics at all temperatures. By increasing the adhesive qualities of the fibre surface and providing a broad surface area, the mercerization of OPF-sisal fiber-NR hybrid composites reduced water adsorption and improved mechanical interlocking [94]. Shinoj et al [8] investigated the effect of chemical treatment on moisture adsorption in agave fibres before mixing them into a polymer matrix. maleic anhydride (MA), Acetic anhydride (Ac), styrene (S), and acrylic acid are the reagents used in the chemical treatment (AA). The results of this study show that chemical treatment reduces water's global diffusivity and that water mobility in the fibre core is greater than at the surface.

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Viscoelastic Behavior of the NFPCs

The structure, morphology, and assessment of the interface properties of natural fibre composite materials can all be aided by dynamic mechanical tests or viscoelastic behaviour across a wide temperature range [95]. The storage modulus of natural fibre composite materials provides information on their load bearing capacity and stiffness characteristics. The greatest energy stored in a material during 1 cycle of oscillation is measured by the storage modulus. The mechanical damping coefficient is the ratio of the loss modulus to the storage modulus in a polymeric material, and it is related to the degree of molecular mobility. The loss modulus, on the other hand, is proportional to the quantity of energy wasted by the sample as heat [96]. The viscoelastic behaviour of new polyp-based commingled biocomposites is reported by [96]. Jute yarn reinforced polypropylene commingled composites were made utilising the commingling process. The viscoelastic behaviour and dynamic mechanical characteristics of the commingled composites were investigated in relation to fibre content and chemical treatments such as potassium permanganate (KMnO4),toluene diisocynate (TDI), maleic anhydride modified polypropylene (MAPP), and stearic acid (ST). According to the findings, increasing fibre content increases the composite's storage and loss modulus. Chemical treatment with KMnO4 and MAPP, on the other hand, increases the storage modulus and loss modulus of the treated composites over the untreated ones at all temperatures.

Venkateshwaran et al [35] investigated the effect of alkali treatments on the viscoelastic behaviour of natural fibre composites using a dynamic mechanical analyzer. When the tests were carried out in the tensile mode of the equipment, the associated viscoelastic characteristics were obtained as a function of temperature and frequency. Figures 2 and 3 show the graphs plotted as storage modulus (E) vs temperature and tan versus temperature, respectively, for temperatures ranging from 30 to 140°C with frequencies of 0.1, 1, and 10 Hz.

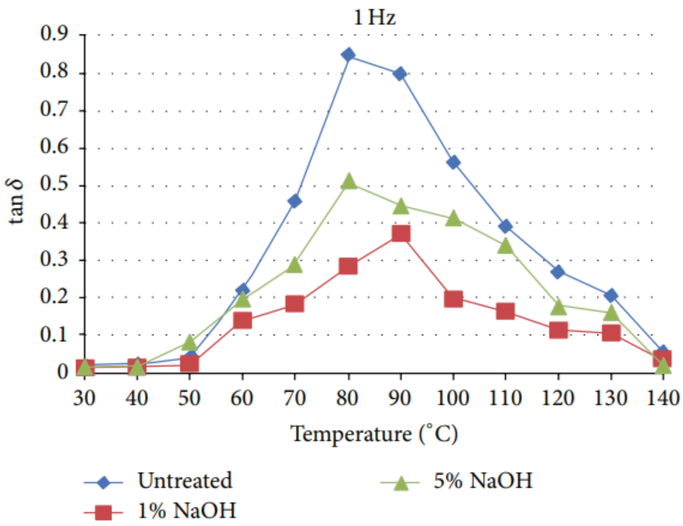

Figure 2: tan delta versus temperature curves of the alkali treated and untreated composite at 1 Hz frequency [35].

Relaxation Behavior of the NFPCs

Natural fibre has an innate relaxing tendency that plays an important role in NFPC stress reduction. As a result, the reinforcing fiber's tensile stress relaxation must be thoroughly investigated. Sreekala et al., for example, investigated the nature of individual OPEFB fibres as well as the impact of fibre surface modification, ageing, and strain intensity on fibre relaxation behaviour[29]. Surface treatments, such as latex modification, dramatically reduced fibre stress relaxation, resulting in less physical contact between latex particles and fibre surface. The rate of stress relaxation of the OPEFB fibre was tuned at 10% strain level, as shown in Figure 4, and the relaxation modulus values for the fibre show similar patterns as in the case of stress relaxation, as shown in Figure 5. The stress relaxation rate of OPF-sisal fiber-NR hybrid composites, on the other hand, decreased as the fibre proportion increased [97].

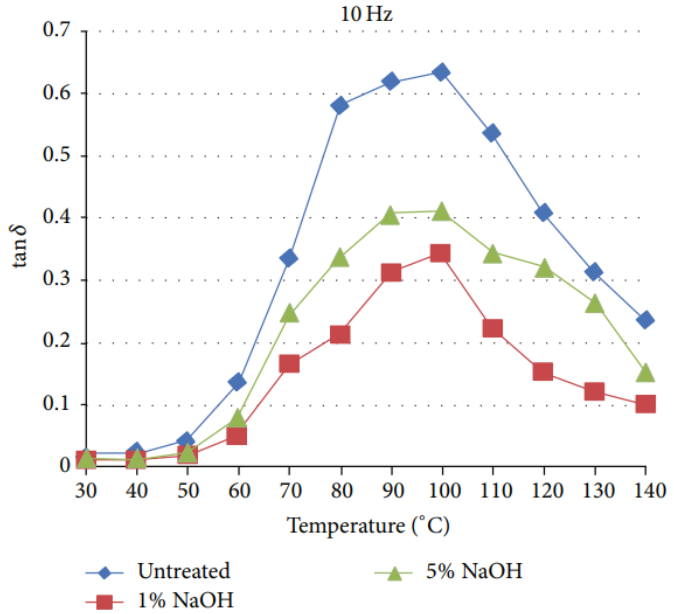

Figure 3: tan delta versus temperature curves of alkali treated and untreated composite [35].

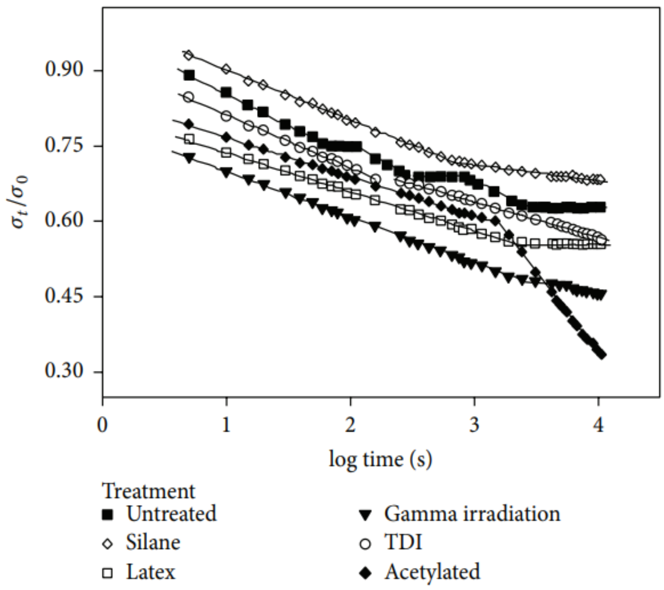

Figure 4: stress relaxation curves of untreated and treated OPEFB fiber at 10% strain [29].

Thermal Properties of NFPCs

When compared to treated OPFs, untreated OPFs are more thermally stable, and OPF is regarded more thermally stable than flax and hemp fibres. As the temperature rises from 20 to 150 degrees Celsius, the heat capacity of OPFs rises as well, from 1.083 J g1 C1 to 3.317 J g1 C1 [98]. With increasing fibre content, the thermal diffusivity, thermal conductivity, and specific heat of the flax/HDPE composites decreased. In the region of 170–200°C, however, the thermal conductivity and thermal diffusivity revealed no significant variations. The specific heat of the biocomposites increased with temperature [4]. Pineapple leaf fibre was used as a support in the creation of functional composites employing polycarbonate. The impact strengths and tensile strengths of the modified pineapple leaf fibres composite, treated with silane, were the greatest. According to thermogravimetric analysis, the composites' thermal stability is lower than that of plain polycarbonate resin. Furthermore, when the content of pineapple leaf fibres increased, the thermal stability decreased. Many natural fibres, such as flax and hemp, are treated using enzymes. Natural fibres can typically result in improved surface and thermal qualities [56].

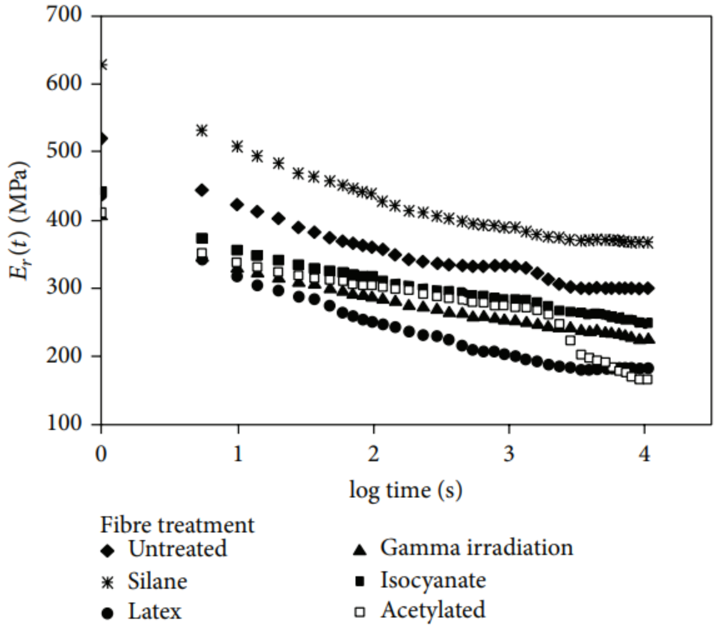

Figure 5: relaxation modulus curves of untreated and treated OPEFB fiber at 10 % strain [29]

Treatments such as hemicellulose and pectinase can help enhance the thermal characteristics of the fibres discussed. The enzymes have a desirable condition for improving the surfaces of natural fibres for use in natural fibre composites [67]. The impact of chemical treatment on the morphological and tensile strength of the EFB fibre was investigated by Norul Izani et al. [13]. The treatments included 2 percent sodium hydroxide (NaOH), as well as a mixture of both NaOH and hot water. Chemical treatment with NaOH improved the fibre surface topography, thermal stability, and tensile strength, but chemical treatment with NaOH and water boiling caused the EFB fibres to have greater thermal characteristics than untreated fibres.

IV. CONCLUSION

Natural fibre reinforced polymer composites have beneficial properties such as low density, less expensive, and reduced solidity when compared to synthetic composite products, thus providing advantages for utilisation in commercial applications (automotive industry, buildings, and constructions). The use of natural fibres as reinforcement for polymeric composites has a positive impact on polymer mechanical behavior. This paper evaluates the characteristics and properties of natural fibre reinforced polymer composites: mechanical, thermal, energy absorption, moisture absorption, biodegradability, flame retardancy, tribology properties. relaxation behaviour and Viscoelastic behaviour of NFPCs are researched.The use of NFPCs in automobiles and industry is also discussed. The effects of chemical treatment on the characteristics of natural fibres were also investigated. Chemical treatment can improve the physical and mechanical qualities of these NFPCs, while surface modification of fibres, such as alkalization and the inclusion of coupling agents, can reduce moisture absorption.

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