Characterization of Natural Fibres and Their Polymer-based Composites

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Abstract: Development of new alternative materials having the superior characteristics than traditional material has become a new buzz to the researchers. One of the achievements in this field is fibre reinforced polymer composites (FRPCs). The most fascinating aspect of FRPCs is light weight but higher strength and chemical resistance. Further to obtain a biodegradable one natural fibre are taking place of synthetic fibre in the processing of NFRPCs. Researchers have done extensive research works on NFRPCs to expand it application field. But sometimes only natural fibre reinforcement cannot fulfil the design requirement. Hybridization with synthetic fibre reinforcement can significantly improve the physical and mechanical properties despite of processing parameters. Again, nanoparticle fillers are also helpful to enhance the mechanical properties. The aim of this study is to clarify the use of different types of natural fibres as reinforcement to fabricate polymer composites and their corresponding mechanical properties for particular application which will be helpful to design NFRPCs for different application.

Keywords: Natural Fibre, Synthetic Fibre, Composites, Biodegradability, Mechanical Properties.

1. INTRODUCTION

A worldwide awareness has been emerged towards sustainability to quest and apply more environment friendly solutions in daily activities to reduce usage of products, harmful for the nature. Innovative strategies are required to generate products, which are not detrimental to the environment. Natural fibre is considered to be a substitution especially for synthetic composites and other traditional engineering materials. Natural fibres offer many advantages in terms of ecological performance such as renewability, recyclability along with cost efficiency, biodegradability and lightweight property. Natural fibres are considered to be renewable resource and have several advantages associated with them, for instance they impart the composite with high specific stiffness and strength, have a desirable fibre aspect ratio. Natural fibres are readily accessible from natural sources, are biodegradable and more prominently, they are cost efficient. Natural fibres have excellent properties like they can conduct heat, resist mildew, can be properly dyed, have natural antibacterial properties, block UV radiation and can be easily transformed into flame retardant. Genetic modification of natural fibrous raw materials improves their performance with respect to productivity. Natural fibres with their long history of serving mankind are significant in a wide range of applications, and they compete and co-exist in the twenty-first century with man-made fibres, especially in terms of quality, economy of production and sustainability [1]. In case of operation, there are two principle classifications of plants producing natural fibres: primary and secondary. The primary plants are those grown for their fibre contents and secondary plants are those where the fibres come as a by-product from some other primary operation. Jute, hemp, sisal, kenaf and cotton are examples of primary plants whereas pineapple, agave, oil palm, cereal, stalks and coir are examples of secondary plants [2]. Natural fibres resulting from plants mainly consist of cellulose, pectin, hemicellulose, lignin and other waxy substances. In several applications, natural fibres extracted from plants are utilized as reinforcements in both thermoset and thermoplastic composites. Cellulose is highly crystalline structure which encompasses as much as 80% of crystalline regions [3]. Cellulose is the utmost important structural component in plant natural fibres; nevertheless, thermal resistance of cellulose is poor. The other important aspects influencing the overall properties of plant fibres are their structure, cell dimensions, chemical composition, microfibrillar angle and fibre defects. The basic chemical structures of cellulose in all plant-based fibres are analogous, but they differ in degrees of polymerization however the cell geometry of each type of celluloses varies with the fibres. The usage of polymer composites based on synthetic fibres has substantially increased worldwide throughout the last couple of decades owing to the high energy costs, frequently associated with steel and aluminium products. In manufacturing applications, even though these composites facilitate an extensive variety of applications by enhancing the limits of mechanical

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properties, they are often vulnerable when exposed to high heated atmosphere, releasing heat that in some situations can contribute to the spread of fire. Additionally, significant quantities of smoke and toxic fumes may also be produced, posing health hazards and limiting visibility. For these reasons, stringent fire regulations govern the use of these composites in aircraft, buildings, land transport, ships, oil and gas facilities, home appliances, and other applications necessitating high fire resistance [4].

Researchers predicted that 1 ton of carbon dioxide is being emitted into the atmosphere while producing 1 ton of cement and this phenomenon enormously contributes to the already-existing issue of global warming. This is why natural fibre-reinforced polymer composites (NFRPCs) are a growing industry because of the fact they are environmentally friendly with adequate mechanical properties, in addition to the wide accessibility of their raw materials. The main difference between the two is that synthetic fibres are man-made textile fibres, nevertheless synthetic fibres do have their limitations and therefore natural fibre modifications are obligatory. These modifications are primarily focused on the use of reagent functional groups which transform the composition of NFRPCs by intensifying the incompatibility between the fibre and polymer matrix. Also, hybridization of NFRPCs with synthetic polymer were found to possess superior physical and mechanical properties than single crystal fibre. NFRPCs are environment friendly, cheap, biodegradable, lightweight, available in large amounts, and renewable [5]. Structure of fibre plays an imperative role in mechanical properties of composites. In FRP composite, matrix can either be thermosets or thermoplastic. One advantage is that thermosets are those which cannot be heat softened but thermoplastic can be melted, heat softened, and reshaped many times as desired. Matrix is being used to keep the fibres straight and transfer load to fibres. Matrix also provides shape, rigidity, and protects the fibres from corrosion and chemical effect. Thermoset polymers go on upgraded than thermoplastic in thermal stability, mechanical properties, chemical resistant and durability [6]. Epoxies, PP, HDPE, PVC, Polyester etc. are being generously used as polymer matrix. The major use of natural fibres reinforced polymer composite is in packaging industry because of their high specific strength and long durability. It is found that 42% of natural fibres is being used in packaging industry, 8% in automotive sector, 20% in building and construction, and 30% in other applications (household, wire etc) [7].

In this chapter we mostly focus on the utilization of natural fibres in the automobile industries. Several properties of the natural fibres, including their mechanical properties, are conversed in this chapter. Different procedures for fabrication of polymer matrix and their effect on mechanical properties have been reported. Finally, alteration of NFRPCs by hybridization has been revealed based on recent developments.

2. CLASSIFICATION OF NATURAL FIBRES

There are similarities in fibres with the pieces of thread and hair like class that are either continuous filaments or in the fragments of indiscrete elongated shape. They can not only be spun into filaments, thread, or rope but also can be used as components in the composite materials. Additionally, products can be made for instance paper or felt by matting them to produce sheets. There are two types of fibres. First type of fibre is natural fibre and the other type is man-made or synthetic fibre. Also, natural fibres can be classified into three sections which are plant fibre, animal fibre and mineral fibre [8].

2.1. Plant Fibres

Cellulose is the main fibre which is comprised in the plant fibre. Examples of cellulose fibres are flax, ramie, sisal, cotton, jute and hemp. Lately, manufacturing of paper and cloths is coming from the cellulose fibres. These plant fibres can be alienated into several fibres group as follows:

- Leaf fibre: This kind of fibres are produced from the leaves of the plant. Examples of the leaf fibres are sisal and agave.
- Seed fibre: From the seed or seed case of the plants, different seed fibres like cotton and kapok are collected.
- Stalk fibre: Stalk fibre that is one of the principle natural fibres that comes from the stalk of the plants such as straws of wheat, barley, bamboo, rice and grass. Tree wood also can be characterized into stalk fibre.
- Skin fibre: Skin fibre can be composed from banana skin, soybeans, hemp, jute, flax and others. All these fibres possess higher tensile strength compared to other fibres. Henceforth, these fibres can be utilized for preparing paper, durable yam, packaging and fabric. Method to collect the fibres are by receiving it from the skin

or bast surrounding the stem or their respective plant [8].

2.2. Animal Fibre

Generally, in animal fibre it encompasses of protein such as mohair, alpaca, wool, silk and angora. Examples of the animal fibres are animal hair and avian fibre and silk fibre which has been divided as below:

- Animal hair (wool or hair): From hairy mammal animals, this fibre can originate such as sheep wool, alpaca hair, goat hair or horse hair. Cashmere and mohair are different variations for the goat family.
- Silk fibre: From collected dried saliva of bugs or insects during cocoons preparation, this fibre is produced. Well-known example of the silk fibre is silk from the silk worms.
- Avian fibre: Another type of animal fibre is avian fibre such as feathers that comes from birds [8].

2.3. Mineral Fibres

The second largest source of natural fibre is mineral fibres. Even though it is naturally occurring fibre nevertheless it also can be a slightly modified as it is procured from minerals. They can be categorized into three categories as below:

- Asbestos: Asbestos is considered to be the only naturally occurring mineral fibre-like amphiboles, serpentine and anthophyllite.
- Ceramic fibres: Ceramic fibre is one of the biggest sources of mineral fibre. Examples for this kind of fibres are glass fibres, aluminium oxide, boron carbide and silicon carbide. Glass, quartz and wood can be categorized into the glass fibre group.
- Metal fibres: Aluminium fibre is one of the examples in the metal fibre family [8].

The performance of natural fibre-reinforced polymer composites can be contingent on several factors, including the chemical composition, micro-fibrillar angle, defects, structure, cell dimensions, physical and mechanical properties of the fibre and also the interaction of the fibre with the polymer. The main drawback in using these natural fibres is their hydrophilic characteristics which usually leads to problems of adhesion with hydrophobic polymer matrices [9-11].

3. CHEMICAL COMPOSITION OF PLANT BASED NATURAL FIBRES

In all plant-based fibres, the basic chemical structures of cellulose are similar. But they have different degrees of polymerization although the cell geometry of each type of celluloses differs with the fibres. Various fibres, with varying growth conditions and different testing methods used by different researchers concluded that it is difficult to present all the fibre properties in one table that lists all. In Table **1** common chemical compositions of some lignocellulose fibres are listed. It is important to analyse the individual properties and growing conditions of widely used plant-based fibres, with the purpose of using them effectively in composite applications. Unlike plant fibres, animal fibres are predominantly composed of proteins. The protein fibres attained from extensive natural sources, such as animals and insects, conduct a significant role as fundamental building blocks of life. They facilitate mobility, scaffolding, elasticity, stabilization and the protection of cells, organisms and tissue [12]. Overall properties of the fibres can be determined by the type and the sequence of amino acids forming polypeptide chains. Major divisions of protein fibres are fibroin fibres and α-keratin. These are appreciated for their high extensibility and usage in textiles development. The protein fibres generally consist of carbon, hydrogen, sulphur, nitrogen, and oxygen. The natural fibrous proteins are fabricated by multiple condensations of well-defined amino acids interrelated by peptide bonds [13].

4. PROPERTIES OF SELECTED NATURAL FIBRES

Natural fibres such as jute, sisal, silk and coir have excellent properties like inexpensive, high toughness, lightweight, with low density, abundant, renewable and biodegradable. As a replacement for traditional reinforcement materials in composites, natural fibres such as jute have the potential to be used for applications which require high strength-to-weight ratio and additional weight reduction. Nevertheless, natural fibres have low strength. The properties of different natural fibres are presented in Table **1**. From the table, it is found that the tensile strength of natural fibres is varying between 100-1500MPa which is much lower than most of the synthetic fibre. In contrast natural fibres are showing well hydrophilic properties than synthetic fibres. Even though natural fibres possess

Table 1: Properties of Selected Natural Fibres [4,16-17]

	76,77	Physical Properties			Mechanical Properties			Chemical Properties		
	Fibre Name	**Diameter (mm)**	**Density (g.cm^3)**	**Water Uptake %**	**Young's modulus (GPa)**	**Tensile Strength (MPa)**	**Elongation break %**	**Cellulose (wt%)**	**Hemicellulose (wt%)**	**Lignin (wt%)**
Natural Fibre	Jute	25-200	1.3-1.49	500	13-26.5	393-800	1.16-1.5	61-71	14-20	12-13
	Sisal	50-200	1.45	56	9.4-22	468-700	3.0-7.0	65	12	9.9
	Hemp	25-500	1.47	20	70	690	1.6	68	15	10
	Banana	100-250	.75-.95	60	8.5-23	180-430	2.0	63-64	10-19	5
	Date Palm	100-1000	.463-.92	60-65	70	125-200	3.6-10	46	18	20
	Coconut	50-300	.145-1.1	130-180	19-26	120-225	25-40	32-43	0.15-0.25	15-47
	Kenaf	-	1.45	-	53	930	1.6	31-72	20.3	8-19
	Flax	40-600	1.5	-	27.6	345-1500	2.7-3.2	71	18.6-20.6	2.2
Synthetic Fibre	E-Glass	7-20	2.55	N/A	73	3400	2.5	-	-	-
	Kevlar	10-12	1.44	Nil	60	3000	2.5-3.7	-	-	-
	Carbon	7-10	1.78	1.2-4.3	240-425	3400-4800	1.4-1.8	-	-	-

relatively lower strength properties compared to the synthetic fibres, the specific modulus and elongation at break signifies the potentiality of these fibres to substitute synthetic fibres in engineering polymer composites [14-15].

5. DRAWBACKS OF NATURAL FIBRES

Natural (plant) fibres in general contain large amount of the hydroxyl group, which makes them hydrophilic and polar in nature. On the other hand, most plastics are hydrophobic in nature. The accumulation of hydrophilic natural (plant) fibres to hydrophobic plastic will result in a composite with poor mechanical properties owing to non-uniform fibre dispersion in the matrix, and an inferior fibre matrix interphase [18]. This polar nature correspondingly results in higher moisture absorption in natural (plant) fibre-based composites, leading to fibre swelling as well as voids in the fibre matrix interphase. Moisture, if not distant from natural (plant) fibres prior to compounding by drying, will result in a porous product. High moisture absorption could also be a reason for loss of dimensional stability and deterioration in mechanical properties. These complications are usually solved by fibre surface treatment or matrix modifications [19-21]. Another major limitation, in exploiting the usage of natural (plant) fibres, is the inadequate thermal stability possessed by natural (plant) fibres. They endure degradation when processed beyond 200 ˚C; this further restricts the choice of plastic materials to be used as matrix [22].

6. MODIFICATION OF NATURAL FIBRES

The fibre–matrix interface is a critical diffusion or reaction zone, wherein two phases are either chemically or mechanically combined. Interfacial adhesion plays a major part to characterize the mechanical properties of the composites. If there is poor adhesion across the phase boundary, then relatively weak dispersion of force arises and results in poor mechanical properties [23]. A number of problems occur along the interface due to the presence of hydrophilic hydroxyl groups while reinforcement of natural fibre into the matrix is being ensued. This hydrophilic nature obstructs the effective reaction with the matrix. Along with this, pectin and waxy substances act as a barrier to interlock with the matrix and cover the reactive functional groups of the fibre. To enhance the efficiency of interfacial bonding, fibre surface needs to be modified with various chemical treatments, coupling agents and reactive additives. Chemical treatments expose supplementary reactive groups on the fibre surface and subsequently facilitates proficient coupling with the matrix. Consequently, better mechanical properties of the composites can be attained [24].

6.1. Physical Method

The reinforcement of fibres can be improved using physical methods, such as thermo treatment, stretching, calendaring and the production of hybrid yarns. Physical treatments modify the surface and structural properties of the fibre and by this means influence the mechanical bonding of polymers. Physical treatments do not extensively alter the chemical composition of the fibres. Consequently, the interface is generally enhanced by means of an increased mechanical bonding between the fibre and the matrix. Corona treatment is one of the most fascinating techniques for surface oxidation activation. This procedure changes the surface energy of the cellulose fibres. Plasma treatment is another alternative physical treatment method which is comparable to corona treatment. To induce changes on the surface of a material, the property of plasma is exploited by the method. A variety of surface modifications can be achieved depending on the nature and type of the gases used [25].

6.2. Chemical Method

From the hydrophilic nature of the fibre and hydrophobic nature of the matrix, the major problem of natural fibre composites originates. The intrinsic incompatibility between these two phases results weakening bonding at the interface. Chemical treatments on reinforcing fibre can decrease its hydrophilic tendency and therefore improve compatibility with the matrix [26-27]. Several research activities have been directed to enhance fibre adhesion properties with the matrix through chemical treatments. Among different chemical treatments alkali treatment is extensively used by the researchers on natural fibres by sodium hydroxide (NaOH) to modify the cellulosic molecular structure. It improves the orientation of highly packed crystalline cellulose order and establishing an amorphous region. This provides additional access to penetrate chemicals. In the amorphous region, cellulose micro-molecules are detached at large distances and the spaces are occupied by water molecules. Alkali sensitive hydroxyl groups present amid the molecules are fragmented, which then react with water molecules (H_2O) and move out from the fibre structure. Between the cellulose molecular chains, the residual reactive molecules form fibre–cell–O–Na groups [28]. Owing to this, hydrophilic hydroxyl groups are reduced and thus increase the fibres moisture resistance property. It similarly takes out a certain percentage of hemicelluloses, pectin, lignin, wax and oil covering materials [29-31]. Therefore, the fibre surface becomes clean. In other words, the fibre surface turns out to be more uniform due to the elimination of micro-voids and consequently the stress transfer capacity between the ultimate cells improve. Along with this, it reduces fibre diameter and, in that way, increases the aspect ratio (length/diameter). For good adhesion with the matrix, this increases effective fibre surface area [32]. Thermal and mechanical behaviours of the composite are enhanced significantly by this treatment. The excess delignification of the fibre can take place, when the alkali concentration is higher than the optimum condition which results in weakening or damaging the fibres [23,28]. Treated fibres have partial removal of wax and oil cover materials, lower lignin content and distension of crystalline cellulose order. Table **2** reviews the recent results on the effect of alkali treatments on the mechanical and thermal

Table 2: Effect of Alkali Treatment on Mechanical Properties of Polymer Composites [33-38]

	Fibre Reinforced composites	Chemical Treatment	Results of mechanical properties
1	Unsaturated polyester – short Alfa fibre	NaOH (1, 3, 5, 7%) for 24 hrs	Tensile and flexural strengths improvements were about 30% and 50%, respectively
2	Flax-epoxy	Alkali treatment	Tensile strength increased by 30% and modulus while removing of pectin
3	Sisal-polyester	0.5%, 1%, 2%, 4%, 10% NaOH treatment at room temperature	4% alkali treatment showed maximum tensile strength
4	Hemp non-woven mat with euphorbia resin	0.16% NaOH for 48 h	Tensile strength was increased by 30% and doubled the shear strength
5	Jute-vinylester	5% NaOH for 4, 6 and 8 h	4 h alkali treated composite accounted 20% and 19% increased in flexural strength
6	Sisal-polycaprolactone composite	10 NaOH for 1, 3, 24 and 48 h	Increment of elastic modulus with reaction time
7	Coir-polyester	5% NaOH treatment for 72 h	40% increment of Flexural and impact strength

properties of composites. In addition, sodium chloride treatment, benzoylation treatments, acetylation treatment, peroxide treatment, isocyanate treatments etc. are being carried out for specific purpose [32].

7. POLYMER MATRIX

A matrix is considered to be a binder material that is utilized to hold fibres in position and transfer external loads to internal reinforcements. Matrix provides structure and holds the reinforcing material of the composites together; they are likewise usually weaker compared to the reinforcing material. The matrix of plastic has low density, strength and stiffness. The fibrous reinforcement has higher strength and stiffness, but requires a medium to hold the fibres and transmit the loads between them. Owing to the plastic flow at the crack tip, the matrix also offers resistance to crack propagation and damage tolerance. On top of that, the matrix also functions to shield the fibre surfaces from adverse environmental effects and abrasion, particularly during composite processing [23]. It also keeps the reinforcement fibres in the appropriate orientation and location to enable them to carry the intentional loads, distribute the loads among the fibres and provide all of the interlaminar shear strength of the composite. The matrix is used to embed the fibres, essential for the production of a strong and stiff solid base for engineering purposes. The properties of the matrix are frequently chosen to stabilized the characteristics of the fibres. For instance, excellent toughness in the matrix balances the tensile strength of the fibres. The combination of the fibres and matrix would henceforth result in higher strength and stiffness. This is for the reason that the crack propagation depends onto the interaction between the two components. In natural fibre reinforced polymer composites, both thermoset and thermoplastic matrices such as unsaturated polyesters, polypropylenes, polyethylene, epoxies, phenolics and elastomers, respectively are extensively used for composites applications. These matrices have diverse chemical structures and undergo different reactivities with the surface molecules of fibres in composites [32,39].

8. PROCESSING METHOD

In principle, processing techniques of natural fibre composites are analogous to those utilized in processing synthetic fibres depending on the length, type of the fibre and orientation, unidirectional (raw and carded), randomly oriented (short) and woven fabrics. They are also used as reinforcements in thermoset and thermoplastic matrices. For thermoset composites, the basic fabrication technique is recognized as ‘‘hand layup’’. This is a manual mixing procedure between the matrix and fabrics. In this procedure, the uniformity of the composite in terms of fibre to matrix ratio, thickness and void content throughout the sample depends on the workmanship skill. On the contrary, in vacuum assisted resin transfer moulding (VARTM), resin is pulled inside under vacuum pressure while mixed with the fibres/fibre mats. Under this condition, the resin impregnation quality in a composite is much better in comparison with that fabricated by the hand layup technique while keeping the void content as minimal. Dimension of the composite and precise fibre spacing is provided in this method. For both thermoplastics and thermosets, another technique known as pultrusion is used. The composite profile is produced by pulling the reinforcement through a heated dye which is then mixed with matrix. For the thermoplastic matrix, injection moulding (fibre–resin is added as granulate to the machine and melted into fluid mass, then injected under high pressure) and compression moulding (reinforcement is mixed with matrix and pressed with a heated plate) are used for composite fabrication. These processes involve high temperature (over 200 ˚C) and pressure (5 MPa) for complete reaction between matrix and fibre. These methods have been well-developed, and are effective in producing composites with excellent quality. Processing methods have been established to meet specific designs of a product where method selection for a particular product rely on the material, design and application. Compression moulding, Pultrusion process, Resin transfer moulding, Vacuum assisted resin transfer moulding etc are widely used to fabricate fibre reinforced composites [40].

9. FACTORS AFFECTING COMPOSITES PROPERTIES

9.1. Plant Fibre Structure

The cellulose structure of the fibres is distinguished through amorphous and crystalline regions. In the crystallite region, large numbers of strong intra-molecular hydrogen bonds are developed. This generates cellulose block and makes it difficult for other chemical penetrations. Nevertheless, resins and dyes are absorbed easily by the amorphous region. From the atmosphere, the hydrophilic hydroxyl groups present in this region are combined with water molecules. Hemicellulose, pectin, lignin and waxy substances do generally hold these water molecules. This makes the fibre polar and hydrophilic in character that lowers the compatibility with the non-polar/hydrophobic matrix [41-43]. For the distension of the crystalline region, the removal of surface impurities (waxy substances) and the elimination of the hydrophilic hydroxyl groups, natural fibre requires to be chemically modified. Chemical treatments such as mercerization, acetylation, benzoylation, peroxide and coupling agents with or without heat are widely being applied to modify fibre surface and structure [32].

9.2. Fibre Length, Orientation and Loading Direction

The mechanical characteristics of the composites are dependent on quite a few factors such as fibre length, loading and orientation in the matrix. When a load is applied to the matrix some stress related phenomena occurs i, e. stress transfer by shear at the interface occurs along the fibre length and ends of the fibre. The extent of load transfer is a function of the critical fibre length (aspect ratio), the compatibility between fibre–matrix interfaces, the direction and orientation of fibre. Three types of composite are prepared, depending on the fibre orientation at the matrix. Firstly, longitudinally aligned fibre composites usually possess higher tensile strength but lower compressive strength (due to fibre buckling). Secondly, transversely directed fibres experience very low tensile strength, that is lower than the matrix strength. Finally, randomly orientated short fibre composites comprise different mechanical properties. This is because of the complexities of load distribution at different direction along the interfaces, consistent mechanical properties of these composites are far more difficult. By controlling factors such as the dispersion and orientation of fibres, the aspect ratio, considerable improvements in the properties can be accomplished [32,41].

9.3. Presence of Void

Throughout the insertion of fibre into the matrix, air or other volatile substances may be imprisoned inside the composites. Micro-voids are formed along the individual fibre tows and in the matrix rich regions, after the curing process. This shows poor mechanical properties and causes sudden failure of the composites. The curing and cooling rate of the composites are correspondingly responsible for the void formation. High void content (over 20% by volume) is responsible for greater affinity to water diffusion, lower fatigue resistance and increase variation (scatter) in mechanical properties. Composites at higher fibre content demonstrates more risk for void formation [44-46].

9.4. Thermal Stability of Fibres

Natural fibre usually starts degrading at temperature around 240 ˚C. Structural constituents of the fibre (cellulose, lignin, hemicelluloses etc) are sensitive with diverse range of temperatures. It was reported that, lignin starts degrading at temperature about 200 ˚C and hemicelluloses and cellulosic constituents degraded at higher temperatures [32]. Thermal stability of the fibre can be enhanced by eliminating certain proportion of hemicelluloses and lignin constituents by different chemical treatments. The degradation of natural fibres is an imperative issue in the development of composites in both manufacturing (curing, injection moulding or extrusion) and materials in service [47-48].

9.5. Moisture Absorption of the Fibres

The lignocellulosic fibres are hydrophilic in nature and absorb moisture. Between the macromolecules in the fibre cell wall, many hydrogen bonds (hydroxyl groups) are present. When moisture from the atmosphere comes in contact with the fibre, the hydrogen bond breaks and hydroxyl groups form new hydrogen bonds with water molecules. The cross section of the fibre turns out to be the main access of water penetration. The interaction between hydrophobic matrix and hydrophilic fibre causes fibre swelling within the matrix. This resulted in weakening of the bonding strength at the interface, which leads to dimensional instability, poor mechanical properties of the composites and matrix cracking. In view of that, the removal of moisture from fibres is an essential step for the preparation of composites [49].

10. CHARACTERIZATION OF POLYMER MATRIX

10.1. Tensile Properties

The tensile properties of a material provide the information about its characteristics during the application of axial loading. The tensile properties are among the most extensively tested properties of natural fibre-reinforced composites. An important factor regarding the selection of a specific natural fibre for a specific application is the strength of the fibre. A tensile test reflects the average property through the thickness. The main characteristics in determining the strength of the material, is the tensile property. Tensile properties are composed of the reaction of the materials to resist as soon as forces are applied in tension. Determination of the tensile properties is critical because it provides information about the modulus of elasticity, elastic limit, proportional limit, elongation, reduction in area, tensile strength, yield strength, yield point and other tensile properties. Tensile properties differ from material to material and are determined through tensile testing. Tensile testing produces a load versus elongation curve, which is formerly converted into a stress versus strain curve. Tensile properties are generally determined through tensile testing, normally described by an ASTM standard test, depending on the type of polymer composite, the appropriate standards for tensile testing are ASTM D638 and ASTM D3039. ASTM D638 is recommended for randomly oriented, mouldable, discontinuous or low reinforcement–volume composites. As an alternative, ASTM D3039 is applied for highly oriented and/or high tensile modulus fibre-reinforced polymer composites. Specimens for tensile testing are typically dumbbell or dog bone–shaped and rectangular bar-shaped [50].

10.2. Bending Properties

By placing a length of material across a span and pushing down along the span to bend the material until failure, bending tests are conducted. Bending tests reveal the information about the elastic modulus of bending, flexural strain, and flexural stress of a material. 3-Point bending involves inserting the material across a span supported on both ends of the material and bringing down a point source to the centre of the span and bending the material until failure occurs while recording applied force and crosshead displacement. The 3-point description comes from one point of deflection, brought down to the middle of the material and the two points of support at the ends of the material. 4-point bending tests are conducted corresponding to 3-point bending tests except that instead of one-point source being brought down to the centre of the span of material two points slightly separated from the centre of the material are brought down in contact with the material. This separation of the two-point sources spreads the region of bending out from the centre in such a way that a larger portion of the material is tested with only one point of deflection. Polymer composites can be tested by utilizing bending tests as a measure of the material in both tension (the bottom of the sample as it is tested) and compression (the top of the material as it is tested).

By using the tensile testing machine, three-point bending tests were performed to measure the bending strength σ. Bending strength was calculated according to the following equation,

$$\sigma = \frac{3F_{\max}L}{2W^2}$$

where $F_{\max}$ was the maximum load, *L* was the distance between the supporting points, and *w, h* were the width and thickness of the composite specimen, respectively. The properties of the specimen closest to the top and bottom surfaces, strongly influences a flexural test. For measuring deformability, the flexural stiffness is considered to a criterion. The flexural stiffness of a structure is a function, based upon two important properties: the elastic modulus (stress per unit strain) of the material that composes it, and next one is the moment of inertia, a function of the cross-sectional geometry [51].

10.3. Impact Resistance

Impact strength is known as the ability of a material to resist fracture under stress applied at high speed. Biofibre-reinforced plastic composites have properties that can eventually compete with the properties of glass fibre thermoplastic composites, especially when concerned with specific properties. Nevertheless, one property, known as the impact strength, is often listed among the major disadvantages of biofibre-reinforced composites. In recent years, the development of new fibre manufacturing techniques and improved composite processing methods along with enhancement of fibre/matrix adhesion has upgraded the current situation to some extent [52].

10.4. Water Uptake Properties

The water-swelling behaviour of the composites are determined by water uptake. The hydrophilic nature of natural fibres is a prominent difficulty since it hinders its effective use in outdoor application. This is a great problem as water absorption of natural fibre is time-dependent. Even though higher cellulose content provides an advantage of good mechanical properties in the fibre, but increased hydrophilicity results in more water absorption. More water-resistant bonds reduce the strong hydrophilic nature of fibre when polymer matrix is added onto fibre surface and this resulted in lower absorption of water. On the basis of hydroxyl (–OH) groups it can be explained. Hydroxyl(-OH) groups present in cellulose fibre, forms intermolecular hydrogen bonds with other cellulose molecules along with supplementary hydrogen groups of moist air. Nonetheless, the groupings of long-chain cellulose molecules in the cell contain crystalline and amorphous regions. It is believed that (–OH) groups of adjacent cellulose molecules are mutually bonded or cross-linked in the crystalline region. Consequently, there are no sites to hold water within crystalline groups which are accessible for the absorption of water. Normally at room temperature, in deionized water, water absorption ability of composite samples is carried out [18].

10.5. Degradation Properties

For the aim to determine thermal aging, a thermo stated oven is generally selected and the test is continued up to the time period of several weeks like for 30 days. Denver, AA-160 was the model of the instrument. Samples were taken out from the oven and reserved at 25ºC for 24 h after a certain time (5 days), for testing the tensile properties [52]. After 30 days of thermal aging, the raw and mercerized samples lost the tensile strength of 28%, 22% respectively. From thermal degradation test, it is observed that untreated composite lost a substantial amount of tensile properties while the treated one retained much of their properties. The degradation characteristics of fibre-reinforced composites is firstly associated with the breakage of glyosidic linkages of cellulose; the second relevant to the depolymerization of the α-cellulose, hemicellulose and pectin [53]. Reduction in tensile strength can be calculated using the following equation,

$$\text{Reduction in tensile properties} = \left\{ \frac{\text{Initial strength-Final strength}}{\text{Initial strength}} \right\} \times 100$$

The fibre composites are buried in soil up to a certain depth for instance 15 cm used by researchers and degradation test was carried out up to several month [48]. The strong attraction was found in damaged cellulosic fibres when they are kept under the soil medium. The water molecule enters into the cutting ends of the composites under the soil medium. As a result, the cellulose degraded significantly which reduced the tensile properties of the composites in a considerable manner [54].

10.6. Thermal Properties

A number of processes are involved in thermal degradation of plant fibres including the desorption of adsorbed water, formation of laevoglucose, cross-linking of cellulose chains with the evolution of water to form hydrocellulose, decomposition of the DE hydrocellulose to yield char and volatiles, and decomposition of the laevoglucose to yield flammable and non-flammable volatiles and gases, char and tar [55]. During degradation, lignin decomposes between 160°C and 450°C, cellulose between 250°C and 350°C and hemicelluloses between 200°C and 260°C. During thermal decomposition of lignin, the cleavage of stronger bonds in the aromatic rings takes place at a higher temperature, whereas relatively weak bonds break at a lower temperature. The fibres do not have the oxidation resistance given by the aromatic rings in the lignin, with a lower lignin content, the degradation begins at a higher temperature [56].

Many researches using different plant-based natural fibres have revealed comparative increase in degradation behaviour of the composites depending on the fibre content and type used. Glass transition temperature, pyrolysis temperature, melting temperature, combustion temperature are the significant parameters to select suitable fibres [57].

10.7. Interfacial Properties

The mechanical characteristics of the resultant composite are influenced by the strength of interfacial bond between polymer and reinforcing fibre. Interfacial bonding strength can be improved by using treatments like γ radiation generating active sites. By using scanning electron microscope (SEM), the types of failure and progression of damage on the nanocomposite laminates were analysed as it is the ideal tool to gain better understanding of crack propagation and fibre failures for the enhancement of impact strength [52].

10.8. Flammability

Several researchers have tried to enhance the strength properties of natural fibres in structural applications. Nevertheless, these composites have serious problems regarding flammability, which is not being focused adequately. Flame retardancy is a crucial property from safety point of view while developing natural fibre composites. Since the thermal stability of fibres is dependent on their structural constituents, it can be developed if the concentration levels or the structural constituents are entirely removed, such as hemicelluloses and lignin. This can be attained with the help of chemical treatments. Natural fibres have shorter lifetime, with minimum environmental damage when degradation occurs, whereas synthetic ones affect the environment due to pollution triggered by degradation. Throughout decomposition, a change in product mass takes place and this occurring effect can be accurately measured by using thermogravimetric analysis (TGA) as a function of temperature and/or time. The selection of a purge gas, the conditions present in the specimen chamber and the initial mass of the test sample are the crucial factors in determining accurate mass loss behaviour. Inert purge gases, such as helium, argon and nitrogen are suitable for determining purely thermal decomposition (pyrolysis). Oxygen and air serve as oxidizing purge gases for defining thermo-oxidative decomposition [58].

To determine the flammability ratings of plastic materials by visual observations, the Underwriters Laboratories (UL-94) test is a laboratory scale test is used. The test has two different types depending on sample's holding position: vertical and horizontal tests where each test follows a specific standard for testing procedure and setup condition. Again, to measure the fire reaction of test samples, the cone calorimeter (CC), which is a bench-scale testing device is being used. The instrument is fundamentally composed of an ignition source, an electric heater, and a gas collection system. The whole testing procedure and measurement of the modern device are described in detail in both the ASTM standards (ASTM E1354) and ISO standard (ISO DIS 5660) [59].

10.9. Functional Group Analysis

FTIR spectroscopy was used to detect functional groups in the composites such as hydroxyl groups, vinyl groups, carbonyl groups, ketone groups, and many more. In between the intensity of 3300–3450 cm^{-1}, the characteristics of the O–H group was visible. Peaks corresponding C–H stretching and C=O stretching at 2901-2950 cm-1 and 1701-1750 cm^{-1}, respectively. Wave number range 1300-1400 cm^{-1} indicates C-H bonding [52].

11. NATURAL RESIN

In most of the plant species, the process of resin secretion occurs in special cavities or passages. It is formed in the specialized structures known as "ducts". Resins come out from the bark of the trees and gets hardened once they are exposed to air. Natural resins possess great importance to the furniture coatings and they are rosin, copal, sandarac, damar, amber, and manila. In several studies of the medicinal plants, valuable resins with bioactive and photochemical properties provided scientific information about triterpenes that will be beneficial for additional research on the use of the various photochemical found in resins and plants to sustain human health [60]. Researchers proved in their study that the properties of the resins can be upgraded by treatment of the fibres with antimicrobial process and phenolic composition [61]. Researches showed that gram-positive bacteria were more susceptible to resin samples. Various combination of pure phenolic, cherry bud samples had high amounts of naringenin and showed strong activity against Listeria monocytogenes and Bacillus subtilis. Wood resins are valuable natural products with extensive utilizations of resin-containing woods. In the meantime, natural wood resins are typically complex mixtures consisting of various compounds. Fourier transform infrared (FTIR) spectroscopy can directly measure wood resin samples and principal component analysis can resolve the absorption bands of various compounds with respect to their positions in the resin containing woods [62].

Public concerns about the climate change and limited fossil fuel resources are imperative driving forces, which motivate researchers to discover alternatives to crude oil. By reducing the dependency on fossil fuels, biobased plastics may offer remarkable contributions while decreasing the related environmental impacts. A renaissance in recent years have been experienced by biopolymers. Many new polymers have been industrialized from renewable resources, such as starch, which is a naturally occurring polymer that was rediscovered as plastic material. Others are polyhydroxyalkanoate (PHA), which can be produced from vegetable oils next to other biobased feed stocks and polylactic acid (PLA) that can be produced via lactic acid from fermentable sugar [63].

12. COMPARATIVE STUDY OF NATURAL FIBRES WITH SYNTHETIC FIBRES

Natural fibres are generally hydrophilic and hold the capability to absorb moisture. A remarkable amount of hydrogen bonds (hydroxyl groups -OH) are present in the plant fibre cell wall. These hydroxyl groups fabricate new hydrogen bonds with water molecules when moisture is absorbed in the fibre. This is because of the weak bonding between the fibre and matrix, dimensional instability, matrix cracking, and poor mechanical properties of the composites [26]. Hence, the moisture needs to be removed from the fibres beforehand the preparation of the composites. Other than that, the moisture absorption of natural fibres can be reduced by chemical treatments such as applying silane, acetylation, alkali, benzoylation, and peroxide [48]. Synthetic fibres are more durable in comparison with most natural fibres, and will readily pick up different dyes. Additionally, many synthetic fibres offer consumer-friendly functions, such as waterproofing, stretching, and stain resistance. Moisture, sunlight and oils from human skin cause all fibres to break down and wear away. Natural fibres seem to be much more sensitive than synthetic blends. This is mainly for the reason that natural products are biodegradable. In general, synthetic fibres are formed by extruding fibre-forming materials through spinnerets into air and water, creating a thread. Before synthetic fibres were developed, artificially manufactured fibres were made from polymers found from petrochemicals [62].

13. RECENT DEVELOPMENT OF SOME NFRCs

In recent time, Okra fibre-based polymer composites are being developed. In a research, an attempt has been taken to manufacture okra fibre (OF) composites where the fibre content was varied within a range from 25-65% on total weight of the composites and polypropylene (PP) was preferred as matrix material. Maximum value of tensile strength (TS) and bending strength (BS) was examined 38.5 MPa and 72.5 MPa respectively, whereas the highest tensile modulus (TM) and bending modulus (BM) was detected 675 MPa and 5.4 GPa respectively. The optimum impact strength (IS) and hardness value was determined to be 22.87 KJ/m2 and 97 (Shore-A) for mercerized fibre composites containing 45% fibre [52]. In another study, the optimum value of TS, BS, TM, BM and IS for Jute fabric/PP composite were found to be 49.7 MPa, 92.5 MPa, 867 MPa, 5.6 GPa and 29.8 KJ/m^2[64]. Significant number of research work has already been done on jute fibre reinforced composites with the intention to observe the water uptake property and corresponding mechanical properties. Two blast fibres such as okra and jute were selected to manufacture composites. Here, polypropylene (PP) is taken as matrix material by means of compression moulding technique with maintaining 40% fibre content on the total weight of the composites. Water degradation tests showed that okra composite retained its original mechanical properties much higher than that of jute composite [65]. Various filler materials are being used to enhance the mechanical properties with lower water soaking, but could not achieve significant progress [66]. Varying percentage of Jute fibre reinforced Unsaturated Polyester Resin (UPR)-based composites were prepared by conventional hand lay-up technique. Result demonstrated that with fibre content up to 50% mechanical properties are increasing [67]. Pine apple leaf fibres are at the same time gaining popularity due to its superior properties [68-69]. Pineapple Leaf Fibber (PALF)-reinforced polypropylene (PP) based composites were fabricated successfully by conventional compression moulding technique with various weight percentages of fibre. For all percentages of fibre, the composites verified lower water uptake but increased in mechanical properties with the fibre loading up to 45% [70].

14. ADVANTAGES OF NFRCS OVER SFRCs

NFRPCs are environmentally friendly, lightweight, available in large amounts, cheap, biodegradable and renewable [71]. They are considered as a sustainable alternative to the metallic and synthetic fibres. Their high performance and cost efficiency complement the economic side of the business. NFPRCs have low density when compared to synthetic fibres or steel fibres like aramid, glass and carbon. The technical and recycling processes of composite materials are appropriate due to the abrasive nature of fibre. By NFPRCs in non-structural applications glass fibre-reinforced composites are now being replaced. The disposal of NFRPCs is much easy when compared with synthetic fibre reinforced polymer composites (SFRPCs). Natural fibre-reinforced polymers have good relative mechanical properties such as flexural modulus, tensile modulus and improved surface finish of moulded part composites. NFPRCs are correspondingly resistant to corrosion and fatigue. Natural fibres are also not free from problems as they have notable deficits in properties. Due to their structure, which consists of waxy substances and cellulose molecules, they permit water absorption from the surroundings, reducing the interfacial bonding between the polymer matrix and fibre. This creates detrimental consequences to the mechanical properties. Furthermore, the pairing between natural fibre and polymer is considered as a challenge as the chemical structures of both fibres and matrix are different. Sometimes there is an incompatibility with some polymeric matrices. Natural fibre reinforced composites also have some disadvantages like hydrophilic nature, high flammability, etc. Compatibilizers can be added to improve the compatibility because there is a poor internal contact between hydrophilic natural fibre and hydrophobic PP matrix between fibre and matrix which results in the enrichment of mechanical properties of the composites [59].

15. NATURAL/SYNTHETIC FIBRE REINFORCED HYBRID POLYMER COMPOSITES

Combining two or more different types of fibres within a common matrix, hybrid composites are materials that are fabricated. There are numerous definitions of hybrid composites given by various researchers. Thwe and Liao defined hybrid composites as a reinforcing material incorporated in a mixture of variety of matrices [72]. Then again, another researcher explained that these composites are a reinforcing material that is combined into two or more reinforcing and filling materials that are present in a single matrix [73]. Hybrid composites are more improved than other fibre-supported composites, and have an extensive range of potential applications. Previous studies on natural/synthetic fibre hybrid composites have generally focused on reducing the use of synthetic fibres [74-76]. Additionally, a previous study described the potential advantages associated with natural synthetic fibre hybridization [77]. The performance of hybrid composites is a sum of the individual constituents in which there is a favourable balance between the inherent advantages and disadvantages. The assistances of one type of fibre could complement properties that are lacking in other types of constituents in the hybrid composites. Therefore, a balance in cost and performance could be attained through proper material design [78]. A few examples of hybrid composites are kenaf aramid with Kevlar, woven jute/glass fabric, and sisal fibre-reinforced polyester composites with the addition of carbon [79-81]. Woven coir/Kevlar hybrid composites were examined and it was found that coconut coir could be used to replace some of the synthetic fibres within the composite, which would consequently enhance the resistance of the material to high speed impact and penetration [82].

16. MECHANICAL PROPERTIES OF NATURAL/ SYNTHETIC FIBRE HYBRID COMPOSITES

It is obtained that mechanical properties of natural fibre reinforced thermosets composites intensifies due to incorporation of synthetic fibre. In hybridization, the properties to be studied largely depend on the length of individual fibres, level of mixing, fibre loading, and orientation, fibre-to-matrix bonding, and the arrangement of individual fibres in the composites. Hybrid composites comprised of two different cellulosic fibres are less common when compared to cellulosic/synthetic fibres. Hybridization of rubber toughened polyester–kenaf nanocomposites demonstrated that all constituents of composites are fully cured and they also satisfy the thermal properties [83]. Natural rubber PP-based composites hybridized with carbon and kenaf fibres were investigated for their mechanical and thermal properties and it was shown that non-compatibilized composites were more consistent and performed better than those compatibilized with maleated PP [84]. Incorporation of glass fibres has improved the mechanical properties of single natural fibre reinforced thermosets composites [85]. The flexural, tensile and chemical resistance properties of sisal/carbon fibre reinforced polyester hybrid composites were also studied by different researchers. They reported that tensile modulus, tensile strength, flexural modulus and flexural strength are found to increases with increase in carbon fibre content in the hybrid composites [81]. Another study on mechanical properties (flexural, tensile and impact test) of glass fibre and hybrid banana reinforced polypropylene composite done by injection moulding

Table 3: Effect of Filler and Hybridization on Mechanical Properties of NFRPCs [87-92]

	Composites	Tensile Strength (MPa)	Tensile Modulus (GPa)	Elongation at Break %	Processing Method
Effect of Hybridization	Polyester [87]	34-105	2.1-3.5	8-30	-
	Jute-Polyester [88]	62.2	10.90	-	Pultrusion process
	E Glass-Polyester [89]	65	3.8	5.5	Hand lay up
	Jute/Glass-polyester [90]	266.22	27.5	-	Pultrusion process
	Jute/Palm leaf stalk [91]	83.3	3.78	-	Compression moulding
Effect of Filler	PP Sheet [92]	21	0.53	350	Compression moulding
	5% Sand/Jute (Fabrics)-PP [92]	40.68	1.25	12.25	
	15% Sand/Jute (Fabrics)-PP [92]	50.6	1.61	5.78	

process with various weight fraction of fibres the hybrid composite is prepared. They reported that the mechanical properties are upgraded due to incorporation of glass fibres into polypropylene matrix, which proves positive effect of hybridization [86]. The main summary of this study is that hybridization of natural fibre with synthetic one up to a certain percentage will upsurge the overall mechanical properties. Table **3** shows the effect of hybridization and effect of filler on improvement of mechanical properties of final composites.

17. APPLICATION OF NATURAL FIBRE REINFORCED POLYMER COMPOSITES

NFRPCs are used in different applications, such as insulation boards, construction materials, cosmetics, particle boards and medicine. They are also used in automobiles, specifically in head rests, parcel shelves, instrument panels, door panels, armrests, and seat shells. There is a variation in reasons why natural fibres are the one in the automotive industry. Firstly, it is because of their low density which can reduce the reduction of weight up to 10–30%. They have good acoustic properties that make the mechanical properties of the materials more satisfactory to be used. They also have properties that is suitable to process for instance low wear on tools. Additionally, they are favourable in most aspects like eco-balance for part production, due to weight savings during vehicle operation, and also for accident performance which give high stability with less splintering. In health aspect, they give some assistances compared to glass fibres during production and also, they can reduce the fogging behaviour.

The aerospace industry created the image of an ideal aeroplane: it would be extremely lightweight, run on renewable energy, have wings with variable geometry and would make no noise. Hence, natural/synthetic hybrid composites were significant owing to several factors which have shown their potential to be used in the aerospace industry, including their manufacturing, performance, functionality, and environmental superiority. One fundamental demand for composite materials used in the aircraft industry is the optimization of the design of complex composite structures. Other than that, composite structures demonstrate better and more reliable performance under humid conditions at high temperatures. Now-a-days, the aerospace industry has increased interest in reducing weight by substituting steel with natural_ synthetic hybrid composites. Moreover, hybrid composites have more elastic strain energy storage capacity, high strength-to-weight ratio and high strength ability compared to steel. Natural fibres are emerging as lightweight, low cost, and apparently environmentally superior alternatives to synthetic fibres in composites.

18. FUTURE TRENDS OF NFRPCs

The advanced biofibre-reinforced plastic composite subsidizes to enhance the development of bio-composites in regards to performance and sustainability. Bio-composites have shaped substantial commercial markets for value-added products specifically in the automotive sector. Bio-composites are currently the subject of extensive research, precisely in the construction and building industries owing to their many advantages such as lower weight and lower manufacturing costs. Green building is a movement that has attained global attention over the past few years. Green buildings are planned to be economically viable, environmentally responsible, and healthy places to live and work. One of the main materials currently used in green buildings is bio-composite. Bio-composites may be classified, with respect to their applications in the building industry, into two main groups: non-structural biocomposites (exterior construction, window, door frame, and composite panels) and structural (roof structure and bridge).

By the time that bio-composite materials and associated design methods are satisfactorily mature to allow their widespread use, issues associated to construction materials are likely to have become paramount in material selection. The advance of systems, methods, and standards could see bio-composite materials at a distinct advantage over traditional materials. There is a substantial research effort underway to develop bio-composite materials and explore their use as construction materials, especially for load-bearing applications. Biobased structural composites for housing and infrastructure applications possess significant importance in the building materials of the next generation of construction in fencing, doors, windows, decking, siding, bridges, fibre cement and so on. This research needs to continue in conjunction with development of conventional composite materials with the aim to provide a solution in the future which will allow extensive use of bio-composite materials by civil engineering applications. In the future, these bio-composites can be used extensively in structural and various other applications depending on their further improvements. Several drawbacks of natural fibre composites which would be even more pronounced in their use in infrastructure include their inferior fibre resistance, higher moisture absorption, variation in quality and price, non-linearity in mechanical properties and durability, and difficulty using established manufacturing processes when compared to synthetic composites.

19. CONCLUSION

Natural fibres are gaining attention to be used as reinforcement in polymer composites owing to its potential mechanical properties, processing advantages and environmental benefits. It is safe to conclude that NFRPCs are replacing synthetic fibres at a fast pace and this is due to their characteristics including being eco-friendly, light in weight, low-cost, biodegradable, and having resistance to corrosion, among others. In spite of the fact that chemical modification has to be used to nullify NFRPCs' limitations, which include restricted processing temperature, variable quality and moisture absorption, its advantages far overshadow its disadvantages. Potential areas of application include underbodies of heavy trucks, bicycle frames, cars, trains, and many more. In the building/construction sector, there is foremost potential for NFCs in the years ahead. As they have good acoustic and thermal insulating properties, they can be used in the interiors along with in exterior applications, where aesthetics has more importance. Nevertheless, further studies on newer and existing natural fibres have to be encouraged to discern the hidden potential of novel natural fibre composites. However, hydrophilic nature of the fibres reduces the compatibility with the matrix, resulting poor mechanical properties of the composites. To improve adhesion with the matrix, chemical treatment is an essential processing parameter to reduce hydrophilic nature of the fibres. Pre-treatments of fibre can modify its structure and surface morphology. For significant improvement in the mechanical properties of composites nano particle fillers can be used. Additional incorporation of synthetic fibre is found to be effective to obtain the desired properties to overcome the limitation of natural fibre reinforced polymer composites in diverse field of their application.

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