Chapter 9
Green Composites from Renewable Sources

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1 Introduction

Green composites can be considered as the sustainable materials envisaged for the next generation gaining rapid interest among various industries and also academic institutions. This detailed chapter is just an overview of the snapshot to provide a complete insight into the recent progress in fabrication of green composites, testing, characterization and at last few applications. Two or more materials are gathered through physical/chemical means with an interface available betwixt such materials to develop a new substance known as composite. The distinct materials can be represented as matrix form and dispersed form of phase substance which may be referred to reinforcement [1].

Such substance may act as load bearing component, whereas the adjacent matrix form completely bonds the attached reinforcement together and divides the load evenly among them. In spite of different properties possessed by matrix as well reinforcement, but on combining together yields a superior material with excellent properties when compared to their parent materials. Composites are graded as various types. (i) Metal matrix type, (ii) ceramics type and (iii) polymer-based type of matrix. Out of these, polymer matrix is of growing concern nowadays owing to its maximum stiffness, less weight, fabrication easiness and excessive strength. In case of polymer composites, the matrix occluded in composite is a polymeric material and usually it is based on aliphatic/aromatic hydrocarbons. The material of reinforcement can be synthetic type fibres generally carbon or else glass fibres. Thus, the polymers

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S. Thomas and P. Balakrishnan (eds.), *Green Composites*,
Materials Horizons: From Nature to Nanomaterials,
https://doi.org/10.1007/978-981-15-9643-8_9

are substituting the metal matrix materials in various engineering fields such as automobile, sports, aerospace equipment and so on [2].

Synthetic composites are primarily based on petroleum products. Owing to growing trend of petroleum resources as well as its minimum reserves and also to deduce the carbon footmark, research scientists are carefully identifying the alternatives to substitute the petroleum-derived composites [3]. Few major issues accounted with synthetic polymeric units are

1. Surplus quantity of plastic waste generation and disposal problems owing to its biodegradable nature.
2. Underdeveloped recycling techniques for degrading polymer composites.
3. More heat/pressure requirement involved during the synthesis of composites along with synthetic fibres.
4. Deficit for petroleum resources.
5. Rising demand for petroleum-based products [4].

Due to represented factors above, nowadays, research people aim at polymers derived from sustainable and eco-friendly base materials being more surplus in availability. This keeps a concern on natural fibres and fibre matrices allocated for synthesis of polymeric composite units. Many research studies forecasted that the involved energy in natural fibre development technique is definitely greater than fifty per cent of consumed energy that could be attributed to generation of synthetic fibres. In spite of higher energy consumption, natural fibres possess certain merits which include lighter weight, non-irritating, non-toxic, non-abrasive and extremely biodegradable [5].

The definite selection of natural fibres for the purpose of reinforcement material can be probably recalled back to nearly 12,000 years. Plant fibres were involved as reinforcement material that can be viewed in brick construction materials during the Egyptian era. Henry Ford designed an automobile body completely out of natural fibre–hemp. Such natural fibres possess good thermal insulation and better acoustic properties. Perhaps, these materials were used for structural panel construction units and also as sandwich vertical beams recommended in housing project units. The verdict of such naturally available fibre materials in construction technology is quite large owing to its maximum performance that can be expressed in terms of reliability, durability, stability, low cost maintenance as well as cost-effectiveness [6].

2 An Insight to Green Composites

The polymeric composite units were composed of both natural fibre units and biopolymers said to be known as green composites. Few natural fibres were coir pith, sisal, hemp, flax units, etc. The biopolymer material includes lactic acid, poly-lactic acid (PLA), starch, furan, etc.

2.1 Classification of Fibres

The coir, cotton kapok unit, jute, hemp, flax and manila type sisal belongs to the category of cellulosic vegetable fibres (Fig. 1). Wild silk material, crossbred unit and horse, rabbit, camel and alpaca can be obtained using aforementioned origin. Fibres generated from such cellulosic background can be comprised based on its origin as seed, leaf, bast, stalk and green grass. The resulted fibres from leaf, stem and bast are developed in to bundles and hence said to be known as fibre bundles, whereas fibre resulted from the seed were known as fibres. The three essential components occluded within the natural fibre units are lignin, cellulose and hemicellulose [7].

Out of this, cellulose is recommended as the primary component responsible for providing inherent strength and excellent stability to such fibre, whereas hemicellulose is associated with fibre structure. In general, natural fibre units are exclusively meant for certain non-structural application purpose which encompasses bag, rope, broom and even furniture in the rural areas. Moreover, apart from having coarse texture and available from white to deep brown colour, these can also be utilized effectively in roofing and insulation purpose.

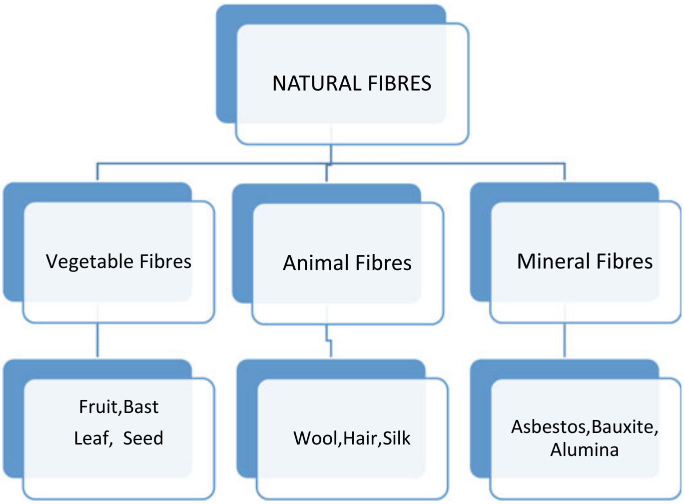

Fig. 1 Classification of natural fibre units *Source* Author

2.2 Extensive Role of Fibre Units

1. Coir

Coir fibre is considered to be extracted from rice husk, coconut shell exterior cover, and hence as a consequence, it may be utilized as a seed-driven fibre unit (Fig. 2-1). Coir is extremely water resistant and even resistant towards salt water damages. During harvest of fibre unit, the presence of coconut at premature stage generates a soft and fine pliable fibre (white in colour), whereas a strong brown fibre is obtained during fully mature stages which is even less flexible than the former one [8].

2. Bamboo

The fast growing plant belonging to grass variety is available in monsoon climate regions. Possess maximum inherent strength and stability to maintain temperature level, especially during the coupling of additive agents. Such bamboo fibres (Fig. 2-2) were involved in furniture making, surf board development and interiors to automobile components [9].

3. Hemp

It is obtained as a plant extract from cannabis family of species. These hemp units are explicitly utilized in textile manufacturing processes and also in paper industry (Fig. 2-3). During earlier centuries, they have found applications in manufacturing the sails of canvas ships, nets, rigging weirs and stable caulk owing to its excellent strength inbuilt with salt water resistance [10].

Fig. 2 Natural fibres. *Source* Google

4. Bagasse

Such fibre is developed from the squeezing remains of sugarcane and it has also been used as material for undergoing combustion operations in sugarcane industry itself also in pulp production industries to manufacture paper cloth (Fig. 2-4).

5. Jute

One of the cost-effective fibres generated in surplus quantities in India as well as China and Bangladesh is the jute fibre (Fig. 2-5). The associated specific modulus parameter of such jute fibre nearly approaches to that of glass fibre material and can even remain stable up to a temperature level of 20 °C without incurring any kind of damage to the inbuilt properties [11].

6. Flax

It is one of the very ancient fibres in the universe, such fibres can be definitely woven into various types of fabric units easily which are further utilized to manufacture excellent composites containing different properties (Fig. 2-6). Moreover, such flax material is eco-friendly in nature, economical to involve in process operations and also can be rivalled to modern synthetic fibres as per previous research studies.

Apart from above wood derivatives, various other natural fillers of organic basis have also been prompted to identify application in certain sectors. Few examples include cellulose, sisal, cotton, jute, kenaf, hemp and starch. Perhaps, environment friendliness can be established using post-consuming recyclable plastic materials instead of modern polymer matrices [12, 13].

Such wood flour matrix and fibre materials are much interesting due to its salient features of low cost, elastic modulus factor, dimensional stability but with less improvement in their tensile properties (Table 1). The main drawbacks are its lower toughness, poor adhesive nature associated betwixt filler materials and that of polymer matrix and thermal dissociation developed at operating temperatures beyond 200 °C [14].

Anyhow, hemp, sisal, kenaf and flax are geometrically similar to each other and essentially fibres of maximum length derived from bast of various plant species. These can be absolutely used as filler materials that can be made by means of proper segmenting into short or lengthier fibres. Starch is an organic polysaccharide that may exist in various plant species which aids as a source of energy. It is composed of monomers of glucose derivatives bonded with alpha linkages [15].

The proper addition of granular starch material to a polymer matrix results in a reduced property of large elongation at breakpoint and simultaneously enhanced elastic modulus factor due to high proportion of starch content [16]. A notable shortcoming of such filler material is the ability to absorb large amount of water due to its maximum surface distribution and hygroscopic nature. Few other natural fillers of organic form utilized in less extent are nutshells, rice husk, its ash, fibres of empty palm fruit, corn plants, coconut shells, etc. [16].

Table 1 Physical characteristics of few plant-derived fibres

S. No.	Fibre type	Fibre	Elongation %	Tensile strength (MPa)	Density (kg/m^3)	Young's modulus (GPa)
1	Stem	Jute	1.25–1.52	400–800	1400	15–55
		Hemp	1.5	575–900	1480	25–80
		Flax	1.4–3.2	350–2000	1500	20–80
		Bamboo	1.35	200–600	600–910	20–45
		Kenaf	1.58	160–940	1450	22–62
2	Fruit	Oil palm	5–19	50–410	700–1500	1–9
3	Wood	Softwood	–	–	1100	25
		Hardwood	–	–	1200	39
4	Leaf	Sisal	3.2–7.1	470–710	1500	9.5–22.2
		Banana	2–3.5	162–790	720–880	7.6–9.5
5	Synthetic	Glass	2.9	4500	2500	80
		Aramid	3.5	3125	1500	65

2.3 Polymer Matrices

The primary polymer matrix materials involved in the branch of green composites could be narrated in the following section.

2.3.1 Polypropylene

Several literatures reported the combination of polypropylene with natural filler materials extracted from flax, wood, sisal, kenaf, hemp and starch. The attention towards alternative cellulosic sources trace a fact of justification that these compounds are much more renewable compared to wood. Certain adhesive promoters are also well applied [16]. Few mentioned examples in previous literatures involve polypropylene grafted with maleic anhydride (PPgMA), styrene-styrene rubber embedded with ethylene/butadiene supported with maleic anhydride (SSEBgMA), silane-based components, copolymer formed out of propylene, ethylene and diene grafted with matrix of maleic anhydride (PEDgMA) which definitely allowed a significant enhancement in its morphological and mechanical characteristics.

Quite interesting phenomenon have been traced out of wood fibres impact on morphological behaviour and crystallization trends of polypropylene based organic composites. It is proven that wood fibres do not account to kinetics of crystal growth effectively, whereas it can render an elevated phenomenon of nucleation, still it is not evident whether the experimental improvement in mechanical characteristics could be primarily attributed to enhanced polymer-wood adhesion or even better wood supported dispersion or otherwise both. It is henceforth marked that the existence of amorphous portions within the polymer geometry can play a prominent factor to reduce the mechanical behaviour [17].

2.3.2 Polyethylene

The published literatures highlight polyethylene-derived composites involving various fillers such as corn starch [18], rice starch [19], kenaf/sisal fibres [13, 20], wood chips [19] and other fibres. Moreover, papers were being subjected to existence regardless post-consumed recyclable polyethylene, HDPE available from sealed milk bottles [21], wood fibres through food packing containers, polyethylene arising out of greenhouse filmy materials, sago starch and olive stones [22].

Wood fibres are generally blended with 50–70% by molar weight of polymer supported matrix. Thereby, a marked enhancement in stiffness, flexural strength and ductility reduction was also observed [23]. This drawback can be overcome by adapting polar adhesive promoters that is listed as maleic anhydride supported polypropylene/polyethylene (MASPP/MASPE) or even a copolymer constituting ethylene and acrylic acid [24].

Others:

Many classes of polymers when combined with wood such as sisal fibres/polystyrene, starch or wood flour, phenolic resins, polycaprolactone, natural fibres, palm flour, isora fibres, rubber and polyester resins were listed along with natural rubber [25].

2.4 Fibre Extraction Procedure

Retting technique and decortication procedure are generally applicable to disseminate the fibre bundles from agglomerated bast and leaf part of plants. Retting can be a process of subjecting the crop or deseeded part of straw to either chemical/biological treatment in order to assure the fibre bundles to be separated easily from the woody stem so as to ascertain the complete dissemination of fibre bundles. Dew entails of retting leaves the stem part in the agricultural field to undergo rot. Hence, such a process is to be carefully monitored to confirm the separation of bast fibres from the entire core of attached plants without loss in its inbuilt quality. Such dew technique is much famous in European countries in spite of its explicit dependency on geographical distribution and this develops coarser fibres of low quality than being obtained using water retting procedures. Water retting issues entails the discrete soaking of plant stem parts in any water source [26].

A decorticator is an equipment used to firmly strip aggregated bundles of fibre from leaf or stem. Leaves are certainly crushed and hardly beaten by a reciprocating wheel embedded through blunt knives such that the fibres alone remain. The left out leaf parts were washed using water. Such decorticated parts are slowly washed before subjecting them to drying via solar energy or hot air. The resulted dry fibres are then properly combed and arranged into various grade forms.

2.5 *Pre-treatment of Fibres*

Pre-treatment procedures conducted on fibres using both physical/chemical steps drastically improve the procured adhesion that occurs at the interface of fibre-matrix and thereby deduces moisture adsorption of organic fibres. Further, the chemical step involved in fibres also tend to aid in enhancing mechanical characteristics under the impact of controlled environmental ageing factors.

2.5.1 Physical Modification

Such modification has been always done with the aid of certain instruments to modify the surface and structural fibre properties with the possibility of enhancing the mechanical strength of involved fibres. The hydrophobic nature of fibres, thereby strongly impacts the mechanical bonding embedded onto matrix material. The treatments followed during decades are thermal method, stretching and calendaring process [27].

The thermal treatment is a traditional procedure to modify the organic fibres. When such fibres are exposed to heating temperature above transition range prevailing for lignin content, it is emphasized that softening along with migration of the same occurs on the fibre surface. The transition point of kraft lignin is 145 °C and starts to degrade in its content at 215 °C. Therefore, the prolonged heating beyond 200 °C would make it to soften. Surface disruptions through discharge treatment techniques such as plasma heating at low temperatures, sputtering step and corona decomposition are of much interest with a relative aim to improve the functional properties involved in organic fibres to a successful manner. The sputtering etch provides surface roughness and thereby enhances adhesion. This etch may also be possible by lengthier treatment operations which may also leads to better dye ability and surface wettability. Plasma heating may reduce the fibre strength which may also be affirmed due to elevated operating times involved in such treatment [28].

2.5.2 Chemical Modification

Chemical method involves the addition of chemical agents to disrupt the fibre surface or the entire fibre throughout. Modification comprises oxidation, mercerization, grafting, crosslink and coupling treatment as five main methods.

The above-mentioned research is definitely emphasized on filler surface modification in order to acquire enhancement of interstitial adhesion between the polymeric macromolecular matrix (hydrophobic) and filler materials (hydrophilic) and their essential dispersion in the polymer matrix. This is considered as a serious issue such that the gradual addition of organic filler materials may prone to undesirable mechanical behaviours which can be ultimately true when low strength/diameter ratio of fillers are used. Trendy changes in mechanical properties using mild addition of 25% by weight ratio of natural fillers to recyclable polyethylene are listed below [28].

Oxidation can take place under the influence of mild chemical condition with the introduction of aldehyde, carboxyl and ketone group along the cellulose chains by appropriate oxidation of both primary/secondary hydroxyl radicals. Mercerization is an alkaline addition for fibres using sodium hydroxide. Such treatment renders the fibre to swell which leads to nearly 30% breakage of hydrogen bonds during post-treatment procedures. Such bonds will reunite and produce various effects (i) decrease in spiral angle with increase of molecular detection, (ii) axial split of elementary fibres which thereby elevates fibre density and further structural collapse of cellular matrices and (iii) modification of primary cellulose to secondary cellulose.

As a whole, the overall advantage of green composites lies upon its extra-ordinary stiffness and excellent thermos-mechanical resistance in spite of its deduced ductility parameter and tensile strength. Hence, it is oblique that the modification of chemicals or adhesive promoter's usage can be effective means to excel the occluded mechanical properties. In general, modification process completely relies on physical/chemical steps primarily focused on successful grafting of chemical units that are viable to enhance the interstitial interactions. Few steps can be recalled as follows [29–38].

1. Acetylation

The selected fibres are completely dipped in a bath of glacial acetic acid for about an hour along with addition of acetic anhydride with careful blending of conc. sulphuric acid to few minutes, further filtrated, then washed and dried in an oven. This step is an esterification reaction which abruptly stabilizes the cell walls which could be pronounced in facts of humidity acquisition as well as simultaneous geometric variation.

2. Mercerization

Also known as alkali treatment, it is tested on short fibres by slow heating at nearly 60 °C in 12% NaOH solution for 4–5 h. Further, it is washed and dried via ventilated oven used to generate better fibre quality with an improvement in fibre wetting.

3. Benzylation

After alkali addition, the opted fibres are treated with benzoyl chloride for an hour and followed by filtration, slow washing and drying. Further, it is blended with ethanol for 2 h followed by gradual rinsing and oven drying such a process reduces the hydrophilic character of fibres.

4. Stearic acid addition

Mixture of ethanol and stearic acid was added dropwise to fibres based on its total weight and further dried through hot oven.

5. Peroxide addition

Fibres are saturated with benzoyl peroxide in acetone solution for thirty minutes, further decanted and then dried. Such addition has shown elevated improvement in mechanical properties as proven by recent research studies.

6. TDI treatment

Immersion of fibres in chloroform bath followed by little addition of a catalyst based on di-butylin di-laurate derivative followed by 2 h continuous stirring along with addition of toluene di-isocyanate, and at last dipped in acetone and then only oven dried.

7. Permanganate treatment

Fibres are strictly immersed in acetone-permanganate mixture (conc may vary from 0.005 to 0.25%) not less than a minute followed by decantation and drying. Hydrophilic behaviour is decreased by such treatment.

8. Anhydride treatment

Maleic anhydride mixed with toluene solution is utilized in such treatment, in which the fibres are entirely dipped for impregnation combined with hydroxyl reactions on the fibre surface. This step consequently reduces water absorption capacity.

9. Isocyanate treatment

Such isocyanate compound reacts with hydroxyl units onto fibre surface, thereby impacting better association of interstitial adhesion towards the polymer matrix molecule. Mostly, it performed at moderate temperatures to about 50 °C for an hour.

10. Silane treatment

Fibres are cohesively mixed with 2:3 water alcohol mixture comprising a silane type adhesive promoter for 2 h at a pH of 4 and then subjected to drying. Such silanes undergo reaction with hydroxyl units thereby results in surface quality improvement.

11. Plasma treatment

It enhances significant modification onto fibre surface. Anyhow, chemical as well as morphological modification may be quite heterogeneous which in turn depends on process conditions. Hence, such a step is difficult to materialize resulting in critical attention towards process control and also the final surface dissemination step.

2.6 Biopolymers

Polymers resulted from non-conventional resources can be typically segregated to three broad groups (i) natural organic polymers—starch/cellulose, (ii) artificial polymers resulting from natural organic monomers—poly-lactic acid (PLA), (iii) polymers produced out of microbial fermentation—poly-hydroxyl butyrate (PHB). Poly-lactic acid, one among the distinguished biodegradable polymers can be synthesized from natural source of feedstock including corn starch and also produced from rice, sugar beet, potatoes and other wastes obtained from agricultural activities. PLA production comprises feedstock raw material conversion into dextrose, therein undergoes further conversion into lactide/lactic acid through fermentation reaction in presence of catalyst. The formed lactide is ready for further processing so that the monomer can be purified and aftermath polymerization, PLA can be obtained through polymerization reaction which takes place in presence of a suitable catalyst.

2.6.1 Poly-L-Lactic Acid

PLLA has gained much attention and available on a wider basis which possesses high ordered melting point, wherein the process parameters are relatively similar to polypropylene. It possesses high grade of mechanical properties and also exhibit strong anisotropic effect such that the fibre will orient itself in four principal directions (0–135 °C).

2.6.2 Polyesters

This broad group includes poly-hydroxyl alkanoates and poly-dicarboxylates of alkylene form. They are synthetically leaded by condensation reactions leaded owing to chemical reaction betwixt dicarboxylic acids along with diols. PLA is a structural material due to its tendency to polymerize with high molecular weight. Also, hydrophobic and vapour permeable such permeability renders sufficient lifetime to achieve mechanical competence without drastic hydrolysis. This provided the composting capacity such that all other techniques are also employed [35].

2.6.3 Starch

It is a complex substance comprising amylo-pectin and amylose polysaccharides. The properties do not vary with amylo-pectin/amylose ratio and also according to plant source. A major propaganda of starch is corn but also extracted using rice, potato and wheat. Polymer behaves crystalline nature due to amylo-pectin presence. Poor mechanical properties and water solubility were two major demerits such organic polymer requires short form of durability where rapid degradation is conceivably advantageous. It is processed to a substance as foam which may be an alternate to polystyrene and involved in loose packing filter, moulded parts and food trays.

2.6.4 Cellulose Acetate

Cellulose acetate is an organic polysaccharide which is obtained through a chemical reaction betwixt anhydrous acid and cellulosic products extracted from wood pulp, cotton linters, sugarcane or recycled paper. The techniques involved in cellulose acetate manufacture were first recognized during the last periods of nineteenth century and this was used in films, filaments and organic lacquers, which also expose maximum toughness and moreover high transparency [37].

2.7 Bio-based Thermosetting Materials

Most of these were obtained through vegetable oils due to graft reaction of acrylate, hydroxyl group and that of maleate compounds or else the combined form of these substances onto triglycerides of fatty acids. Few were derived from cashew nut liquid from its shell obtained from cashew nut shells as an aggregated by-product from nut processing industry. This liquid contains large content of anarcardic acid, and during heat extraction operation, it may be converted to cardanol. This is being polymerized using free radical type of polymerization.

2.7.1 Liquid of Cashew Nut Shell

This liquid was a waste product of cashew extraction process. A viscous and dark liquid resulted from honey comb structure available in cashew shell which has been a topmost option for obtaining cost-effective and environmental-friendly resins. It comprises of anacardic acid with a few amount of cardol and cardanol in raw form, but when heated as well distilled, it possibly remains in technical grade [39].

2.7.2 Poly Butylene Succinate (PBS)

It obtained from succinic acid, 1,4-butane diol and PBS, which is a biodegradable polymeric material that is having greater attention in the area of bio-composites. Owing to its wider temperature aspect for polymeric processing, it is applicable for injection/extrusion moulding, film blowing and thermos forming.

2.7.3 Cellulose

The structural component exists in plant structures and it may be available in basic or esterified using cotton, trees, sugarcane or else recycled paper material. Examples of such esters are cellulose acetate (CA) and CA butyrate. It is mostly plasticized using citrate material to render it as a polymer matrix such that it can be effectively used as a polymer resin.

2.7.4 Merits of Biopolymer Techniques

1. Relative decrease of fossil fuel importing dependency.
2. Reducing petrol consumption.
3. Possible reduction in emission of greenhouse gases.
4. Simultaneous reduction of solid waste contamination.
5. Reducing the polymer waste.
6. Tremendous enhancement in agricultural sectors employment [40].

2.8 Parameters Impacting Composite Strength

The associated properties rely on characteristics of constituent components such as resins and fibres. The mechanical strength along with stiffness carries the entire load and its volume proportion. The resin component facilitates its relative position within the biocomposite and also used to transfer the adsorbed load from bottom of fibres to its intact portion. The three essential factors of resin/fibre properties along with its interfacial behaviours are more critical to design the strengthened composites. Certainly, modification also improves moisture resistance and also composite characteristics [8]. In addition to that, processing techniques also have specific impact on the mechanical behaviours of such composites. These associated properties may vary with respect to harvest quality, body and age of the plant from which it is derived, extraction operations and the ambient conditions of environmental site [10].

2.9 Rheology and Processing Techniques

With a focus to processing of polymer–organic filler composites, when correlated with neat polymer, it may be proposed as a common rule that viscosity enhancement is observed as a consequence of reduction in processing techniques which may also occur due to higher filler content. Anyhow such processability does not compromise owing to moderate increase in viscosity and torque along with higher shear expressions [41].

There are only few backups which deals with rheological studies of polymer ingredients that are filled with organic materials. Early discoveries prompted viscosity increase in both polyethylene and polypropylene-derived composites embedded with wood waste. In few cases, viscosity undergoes a gradual enhancement by adding more filler content [42]. It is also demonstrated the varying nature of HDPE composites by changing the filler addition employing a capillary tube rheometer. Moreover, wall slipping phenomena is present and extremely dependent on weight % and nature of fillers. Flow analysis by elongation depicted that viscosity relies on filler content rather than nature of filler. A selective analysis of Trouton's factor ratio confirmed it to be effectively reluctant upon type of fibre along with the observation of consistent interaction that occurs through the fibres [43].

It is being noted that rheological characteristics of PP embedded onto wood flour bio-composites with/without adding PP grafted maleic anhydride adhesion promoter. Such promoter aids in mild processing and anyway by keeping an increase in filler quantum, rheology tends to modify significantly owing to the development of bonds between filler-polymers, assisted by the promoter material [44].

2.10 Merits

Composites possess excellent mechanical properties per unit volume and its durability allows successful manufacture of large and complex shapes. They may be formed into complicated shapes and can be cut to desired length easily. These comprise jute, wood fibres, sisal, bamboo, banana leaves and coconut shells. These fibres can be blended either alone or in combined form as in hybrid varieties and sometimes partial addition to industrial fibres. These are non-conventional, non-abrasive to process instruments and may be subjected to possible incineration during the end of its lifecycle to recover energy owing to its maximum calorific value. Plant fibres possess less density, high stiffness, low production cost and highly renewable which adds to its extreme advantage when compared to fossil source derived fibres (47).

Plant fibres are carbon neutral and thus eco-friendly. Low specific density of cellulose-derived fibres prone to weight compensation in the manufacture of composite inclusive of direct merits on transportation. Higher amount of fibre volume proportions of various plants as compared to fossil-based reinforcements will lead to discrete cost savings of material due to less amount of investment rendered on plant fibres than binding matrices.

2.11 Demerits

The application of natural fibre polymer composites is being strictly prohibited owing to the natural fibre inbuilt properties inclusive of moisture absorbing ability, poor adhesion, reduced wettability along with synthetic counterparts and lesser thermal stability encountered during productive operation. Mechanical properties occluded with these natural composites slowly deteriorate on ageing as the fibre interface matrix portion is extensively influenced by moisture. The extent of deterioration and reversible nature of fibre characteristics is extraneously dependent on the degree of moisture absorption. Less amount of thermal influence, in other words, the chance of moderate temperature degradation from 240 to 250 °C [45].

2.12 Applications

In spite of lack in adequate strength accustomed by synthetic composites in most of the cases, various green composites are still then employed in bearing materials without load condition as in case of sports equipment, furniture, internal/external panels for vehicles and proper housing built for electronic goods. Flax is recorded widely to be strongest in its mechanical behaviours that can be legibly manipulated and showcases the properties as compared to glass fibres when rightly woven to conditions at an optimum level. Even though hard, its lightweight tendency makes the flax-based bio-composites to be useful for wider ranges of different products [46].

Of the above-mentioned bio-composites, cashew shell-based ones are mostly utilized in varying conditions. Sisal fibre derived composites with reinforcement have been analysed with a mechanical strength of around 25 MPa and its Young's modulus to be 9 GPa. The bending tests proved their roofing applications owing to its adequate mechanical strength. Plant fibre manufacturing technology formed from bio-composites centre has developed a variety of construction products based on natural feedstock materials. One of those is the Isonat@R fibre of insulation, obtained from hemp developed on UK farming companies and also available from waste fibres of cotton. This contains nearly 15% polyester so as to provide stability and loftiness. It can also be decomposed using incineration or composting without creating harmful effects. It is able to absorb and release the humidity effectively and such a characteristic feature is utilized in moisture control of buildings with no loss in its thermal performance, and also with no impact on insulation durability [47].

With a focus to industry-oriented applications, various modes have been proposed and it can be postulated that wood can be mostly used organic filler, in specific a cheap filler material for poly-olefins. Wood flour can be gathered from sawmill aftermath a simple sieve analysis. Wood fibres were derived from wastes accumulated in a sawmill by means of thermomechanical process under wet condition. The industrial utilizations comprise door/window frames, railroad sleepers, furniture, automotive panels, gardening tools, packaging materials, shelves and in other applications in which it does not involve high resistance in case of mechanical equipment, but inculcate low maintenance and purchasing expenditures [48]. Further, it is much convenient to employ recycled polymeric composites than the virgin ones, thereby enabling enhanced cost efficiency as well as eco-sustainability. Some more include indoor panels, platforms, footboards, upholstery, insulation panels for noise control were absolutely imported by American, Japanese, Italian, British and German firms [40].

In specific, automotive industry plays a prominent role in market. The earlier carmaker using polymer fillers with fibres was Benz in 1990s by adopting door panels constituting jute fibres [49]. This has been a popular set-task for other carmakers who engaged such polymeric composites containing natural fillers as ingredients for parcel shelves, headrests, roof upholstery, door panels, etc., such that they can confirm proven advantages such as less environmental impact, improved weight, high elastic modulus parameter, and less costs. Sometimes, it was necessary to enhance the mechanical characteristics through certain pre-treatment techniques rendered onto fibres (physical/chemical method) based on application specific, for example, such treated fibres may be used in mats, non-woven structural parts, etc. [30].

Few literatures assured that such pre-treatments subjected onto natural fibres could pave the way of developing better quality composites with enhanced mechanical features as compared to glass fibre intruded organic composites [50]. A consequence which would be no way possible to establish otherwise, however, the hydrophilic mechanism of organic filler encourages agglomeration, moisture absorption and also improper adhesive action with that of polymer matrix, and in fact, large measures were adopted to avoid the issue of interfacial adhesion [49]. Among these, experimental observations on silane mediated adhesion promoters or alkaline/resin addition to fibres prone to the chance of semi-conductor applications if the fibres are having longer lengths.

2.13 Moving Towards Environmental Sustainability

Some recent studies envisaged that, unfortunately, such green composite materials are not completely eco-compatible owing to certain limitations concerned with its recyclability (if processing temperature for recycling goes beyond 200 °C, the main characteristics will worsen due to degradation process) and even their biodegradability depends on filler and not based on conventional polymer matrices [51].

For such reasons, research studies mainly emphasized on the development of 100% eco-friendly green composites by alternating non biodegradable ingredients with biodegradable materials during the last decade. Many biodegradable polymers derived from nature exist as proteins (albumin, casein, elastin, silk, etc.), polysaccharides (cellulose, starch, collagen, chitin, etc.), poly-lactic acid, polyesters, lipids, lignin, natural rubber, few polyamides, poly vinyl acetates/alcohols, and poly lactones. Most of the cases involve degradation of above polymers through enzyme controlled chemical reactions under suitable humid environments [52].

In general, biodegradable polymers are classified on the basis of origin as microbial-assisted polymer (PHA), agro-polymers (starch), agro-monomers synthesized via chemical method (PLA) or traditional monomers (man-made polyesters). Many examples were reported in literature. For instance, Japanese scientists have demonstrated green composites developed from bamboo and starch fibres. In certain cases, they undergo alkaline pre-treatments and also chemical grafting technique. The interesting fact on Monsanto Biopol (a poly-hydroxy butyrate copolymer) synthesized from bananas and jute fibres [53].

Soya protein-based works were also made to produce polymer matrices. For example, Netravalli with his group mates involved soya proteins along with natural fibres yielding superior quality green composites which tend to show universal characteristics proximately better than large wood types. Soya and corn oil procured as feedstock materials for polymer production was an interesting note to few automotive applications inbuilt with excellent resistance, lightness, extreme flexibility and evergreen durability [52]. Few examples for these are seats, panels, furnishing, packaging, etc. Few concerns were working on artificial silk manufacture through the principle of genetic engineering that could also be applied to biodegradable composite materials as well [54].

Takagi have experimented polymeric composites with regards to dispersion class biodegradable cellulose and resin nanofibres, employing a stirring mechanism revolving at low speed along extended times and also upon varying the resin mould pressure. This process significantly enhanced flexural modulus and mechanical strength due to elevated mould pressure that can be compared to control composites, wherein there was no stirring process [47].

2.14 Considerations on Environmental Impact

It has been proposed that usage of organic fillers derived from nature executes certain advantages when compared to mineral-based inorganic constituents. Ultimately, such an environmental impact can be absolutely reduced by moving to renewable sources rather than fossil derived sources. Moreover, biodegradable polymers usage fully establishes biodegradable systems, thereby reducing the issues of solid material production every-day and handling of surplus quantity of polymeric waste [55].

The benevolent aspects were further analysed by invoking the concluded data by which total life cycle analysis (LCA) may provide a complete evidence. For instance, Joshi et al. collected and discussed LCA studies on composited supported with natural fillers as well as glass fibres. It is well known that LCA analysis permits the determination of total environmental impacts associated with products/processes via “cradle to grave” mechanism, thereby evaluating overall mass/energy flows obtained from product manufacturing stage to the effective use in its life cycle [56]. All such steps are associated with direct/indirect environmental implications which have to be evaluated quantitatively. The complete LCA process is governed by ISO 14043 and ISO 14040 regulatory standards [57].

The life cycle process of glass fibre reinforcement comprises both monomer and glass production and then to polymerization whilst glass is to be treated with a view to yield fibres. The feedstock materials are to be processed to get the final product. Then, the product will be used for some time period till its cycle gets over which can follow waste disposal technique, incineration or else recycling. Hence, it is understood that every step comprises of both mass flow and energy calculations that are not easy to quantify, with prevalent ecological impacts and obviously represented using suitable environmental indicators occluded with overall energy pattern for CO_2, SO_2, CH_4, CO, NO_x emissions, phosphates, nitrates, sulphates, BOD/COD emissions in water, etc.

The aforementioned information clearly examines the various outcomes of salient LCA studies demonstrated in the previous literature. The earlier one agrees the selection of polypropylene blend filled with glass/hemp fibres for automotive insulations, predicting that organic composites pave the way to definite deduction of conventional energy demand and also air pollutant emissions [58]. The next one compared the design of car panels using epoxy/ABS resins with hemp organic fibres. Notable decrease in energy utilization along with carbon emissions was also evaluated. Anyhow, NO_x, phosphates were not fully reduced owing to inclusion of man-made fertilizers employed for hemp growth [59].

At last, another one compared the pellets out of polypropylene along with bamboo/glass fibres. The outcomes envisaged a gradual enhancement of the primary environmental indicators: air pollutant emission, BOD/COD emissions and other carcinogenic/toxic impact [60]. The most worsened indicators of nitrate/phosphate emissions owing to artificial fertilizers usage in agricultural fields. Another author revealed four type of interesting indicators amidst NRF and GRF composites mentioning, (1) natural fibre wins due to energy consumption strategy along with lower emission rates excluding nitrate, (2) substitution of higher % of polymers leading to excellent gain in mechanical properties, thereby higher fractions of NF volumes used resulting in minimal usage of oil derived polymeric units, (3) minimum specific weights of NF exposes to reduced emissions along with decreased energy consumption directly than GFR composites, (4) combined credits of carbon as well energy owing to profitable incineration process of NF at the end of its life offers a double merit of maximum energy recovery since theoretical output of CO_2 emission just equals to the amount that is utilized by plants during photosynthesis [57].

Recently, few authors have examined LCA studies on green composites too, without considering certain aspects. Such gap factors may compromise certain stages in life cycle studies itself such as filler production, use or manufacture or disposal, energy input from fertilizers or other environmental parameters [60].

Specifically, the front part of bonnett was taken as the utilitarian unit and the related effects were: cancer-causing agents, respiratory organics, respiratory inorganics, environmental change, radiation, ozone layer, eco-poisonousness, fermentation/eutrophication, land use, minerals and petroleum products. Reusing, burning and landfill situations were considered [61]. They found that the jute fibre composites permit improving the natural execution. Specifically, fuel utilization ends up being lower because of the weight decrease of the vehicle, albeit some obscure effects in the creation and removal stages were discovered and identified with the co-ordinations of jute strands transportation and reusing situation. Besides, the authors featured that stages, for example, development, gathering, mercerizing, drying and fibre refining were credited without any effects, revealing that jute creation for a few little rancher networks along the Amazon River was thought of, with the stream giving additionally the humus and the entirety of the supplements required [62].

Three situations were considered, in particular, (1) mulling over a reuse for the half of materials in any case burned, (2) one portion of the composite material is viewed as arranged municipally, (3) breaking down the commitment of a theoretical powder filled composite having a similar explicit load as sugarcane bagasse composite. Effect classifications were abiotic consumption, fermentation potential, eutrophication potential, an earth-wide temperature boost potential (100 years' premise), ozone layer exhaustion potential and photochemical ozone creation potential. The examination was precise, since it considered helper procedures, for example, diesel, phosphate, nitrogen, potassium, phosphorus and lime creation/sources; nonetheless, still no land use impacts were unequivocally included [63]. The general examination recommended that the green composites are better that the powder filled composites in car applications, particularly, when weight decrease is especially significant. It is additionally proposed that sugarcane bagasse fibre creation prompts lower natural effects contrasted with powder creation, the composites are lighter, sugarcane has a positive commitment as far as carbon credits and the reuse of the finish of-life material is the ideal method to limit the ecological effects.

Similar authors assessed the specialized presentation and natural effects of similar composites in contrast with flawless polypropylene. Diverse finish of life alternatives included cremation, reusing and landfill. The composites indicated better natural execution during the whole life cycle, particularly, in the development stage [64]. Additionally, for this situation, reusing with monetary benefit of the composites was the best choice to limit the natural effects. For additional inside and out examination, an intriguing survey by Jorge on ecological effect and LCA of language cellulosic-determined items can be considered.

3 Conclusion

It was notable that various deformations such as compression, bending, tension, shear, torsion, abrasion, flexing and wear were accounted in common on fibres. Moreover, the usage of polymeric-based composites blended with organic fillers in place of mineral-based inorganic fillers is of greater attention in view of simultaneous reduction in the usage of petroleum-based conventional resources and in more common a diverse consumption of both financial and environmental resources. Instead such green composite materials find several applications in industrial sectors mentioning process ability, ductility, as well dimensional stability. Along universe, researchers aim at bringing suitable solutions which involve chemical alteration of filler along with usage of adhesive promoters/additives. Anyhow, a complete biodegradability with less environmental impact can only be suitable by using biodegradable natural ones for traditional polymeric materials. In such cases, several limitations arise, and right now, the research investigation has been analysing the effective selection of most prominent biodegradable matrix along with simultaneous optimization involved in the synthesis and processing of suitable material. Still, the market is an open phase, and effort can be put-forth in exploring novel applications, improvement in salient properties, the physical appearance, durability and marketing ability of these natural composite materials. All these pertinent issues require, also continues to avail prompt and benevolent research efforts in a view to explore new formulations (virgin type of recycled varieties, still-more biodegradable substances, type, attracting appearance, quality and composition of fillers), structurally characterizes them, utilize them for most specific applications, and in normal, to refine operating techniques for process. If the prevailing competition for such green composites arises, the governing market demand will also enhance leading to simultaneous reduction in cost and also greater improvement in quality can also be achieved.

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