Green Composites: Versatile Material for Future

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Abstract The growing concern towards environmental problems and the urgent need for more versatile environmental friendly materials has led to increasing attention about polymer composites, i.e. fillers/reinforcing materials coming from renewable sources and biodegradable, especially from forest. The composites usually referred to as "green", can find several industrial applications as discussed in this chapter. Biodegradable polymers coming from natural resources are also one important constituent of green composites. This chapter provides tactic for readers regarding the materials used for the fabrication and specific application of green composites in various fields. Furthermore, a discussion of the major material attributes of green composites is provided. From these focuses, a series of balancing application properties are explained. The chapter concludes that green composites have potential for use in a number of applications, but as with all design, one must carefully match the material to the application.

Keywords Reinforcing materials · Green composites · Biodegradable polymers · Plant fibers

1 Introduction

Man has been using materials since the beginning of the recorded history. Initially only natural materials like stone, clay, wood etc. were used. Materials have an important role in the life of modern man and have been making significant

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M. Jawaid et al. (eds.), *Green Biocomposites*,
Green Energy and Technology, DOI 10.1007/978-3-319-49382-4_2

contribution to the techno-economic development of the modern world. Materials have been divided into three broad categories: (i) metals, (ii) ceramics, and (iii) polymers (Buschow et al. 2001). Composites based on metal, ceramic and polymer matrices have also been developed. Polymers (synthetic and biopolymers) and polymer composites have emerged as important materials. The two main constituents of a polymeric composite are: (i) a polymeric matrix, and (ii) a reinforcing material. A composite offers better properties than those of its constituent materials, due to synergistic properties of its constituent materials. In a composite, one of the constituent materials is in continuous phase, and is termed as the matrix, and the other is discontinuous or dispersed phase and is termed as the reinforcement or the reinforcing material. Polymeric composite include, mica or any other particle reinforced polymer composites; short aramid fibers or any other short fiber reinforced polymer composites; continuous carbon fiber reinforced epoxy or any other thermoset or thermoplastic polymer composites; nanoparticles or nanofibers reinforced polymer composites. Properties of a polymeric composite are governed by properties and amount of the polymeric matrix; properties (for example; aspect ratio, chemical nature, purity, distribution, orientation and geometry) and amount of the reinforcement; and the interfacial adhesion between the two. Thus, the properties of a composite are strongly influenced by the properties of their constituent materials, their amounts and distribution, and the fiber/matrix interfacial adhesion (Herrera-Franco and Valadez-Gonzalez 2004).

There are several advantages of such polymeric composite; however, the main limitation is the problem of suitable removal or recycling after the end of life and reuse of both the components quite difficult. Furthermore, the synthetic polymers (like polypropylene, polyethylene etc.) production requires a remarkable consumption of oil-based resources, which are notoriously non-renewable and as a result of declining oil reserves and increase in cost of production of fossil fuels; scientists and researchers are now exploring alternative sources that are renewable, environment friendly and are sustainable. Energy Information Administration (EIA) reported that the oil production is expected to decline at the rate of 4% per annum after year 2010 and therefore great effort has been made in the policy and promotion in search of engineering sustainable solutions in energy and the environment (Nirma et al. 2015; Holbery and Houston 2006).

In view of this, the concept of "green composites" is gaining more and more importance these days because of increasing environmental awareness, decreasing oil reserves and demands of legislative authorities. This green composite consists of biodegradable polymers as matrix materials and natural fibers as reinforcement materials. Recent advances in polymer composites offer significant opportunities for improved materials from renewable resources with enhanced support for global sustainability. The green composites from natural fibers and biodegradable polymers will render a major contribution in the 21st century due to environmental problem as this composite gives a possible solution to waste disposal problems associated with traditional petroleum derived polymers. Green composites are emerging as new eco-friendly polymeric composite material and are offering commercial and engineering applications along with techno-economic advantages

(Mohanty et al. 2002). Green composites deriving from renewable resources bring very promising potential to provide benefits to companies, natural environment and end-customers due to dwindling petroleum resources. Nevertheless these materials have very high pressure from the global market. In present day it is a challenge for scientists and researcher to find out the properties and suitability of various polymers available in current market to make sure whether they are right to be used as a matrix material for green composite or not (Paul et al. 2003).

2 Constituents of Green Composite

One of the main components of the green composite is the use of natural/bio-fiber as reinforcement materials. Reinforcing material or reinforcement are embedded in the matrix of the composite, and form the discontinuous or the dispersed phase of the composite material. It carries the applied load and stress, and imparts improved mechanical properties, including stiffness and strength, to the composite. Another important constituent of green composites are biodegradable polymers which act as a matrix or continuous phase and plays an important role in determining the demanding properties of the green composite. It provides protection to the composite against environmental and chemical attack, and holds and binds the reinforcing materials together and transfers load and stress to the reinforcement (Thakur et al. 2014; Karim and Afrin 2015; Karim et al. 2016a).

2.1 Reinforcing Bio-Fibers

Bio-fibers are renewable fibers that can be obtained from plant, animal and mineral resources and can be used as reinforcements in manufacturing of green composite in the same way as the synthetic fibers. The classification of bio-fibers based on their origin is shown in Table 1.

Table 1 Classification of bio-fibers

Bio-fibers	Examples
Animal fiber	(a) Wool/hair—sheep, camel, rabbit hair, goat hair, yak, horse hair
	(b) Silk—mulberry silk, coarse silk
Mineral	Asbestos, wollastonite
Plant fiber	(a) Wood fiber—hardwood, softwood
	(b) Non-wood Stalk fiber—bamboo, wheat, rice, grass, barley, corn, maize, oat
	Fruit fiber—coconut, betelnut
	Seed fiber—cotton, oil palm, kapok, alfalfa
	Leaf fiber—sisal, banana, palm, date palm, pineapple, henequen, agave
	Bast fiber—hemp, jute, banana, flax, kenaf sugarecane, ramie, roselle

Adopted from Refs. Mohanty et al. (2002), Holbery and Houston (2006), Thakur et al. (2014)

In recent years, natural plant based fibers, for example—jute, coconut, hemp, sisal, coir, banana etc., have been used as reinforcing materials in place of conventional fibers like glass, carbon, aramid, etc. The main advantages of using these natural fibers over conventional synthetic fibers are their easy availability, low cost, bio-degradability, renewability, recyclability, low density, acceptable specific strength and stiffness, reduced tool wear, non-abrasiveness, easy to manufacture, light weight and non-toxic nature. Dittenber and Gangarao (2012) and Ahmad et al. (2015) discussed the comparison between natural fiber and synthetic fiber on the basis of cost per weight, and cost per volume versus tensile modulus and tensile strength for natural fibers, synthetic fibers, natural fiber composites, and synthetic fiber composites and it was found that as compared to synthetic fibers, the natural fibers are generally cheaper in cost (Oksman et al. 2003; Ramamoorthya et al. 2015).

2.1.1 Plant Fibers

Plants from which natural fibers obtained are classified as primary and secondary depending on their utilization. Primary plants are those grown for their fiber content for example; jute, hemp, kenaf, and sisal and/or secondary plants, for example; pineapple, oil palm and coir (Corbiere et al. 2001). Plant fibers have also been classified according to their origin and the part of the plant from which the fiber is extracted. The classification of natural fibers based on their origin is shown in Table 2.

Wood Fibers

Wood fibers have been categorized into hardwood and softwood fiber. Hardwood fibers for example; fibers from aspen and birch and softwood fibers for example;

Table 2 Comparison between natural fibers and synthetic fibers cost

Properties	Natural fibers	Synthetic fibers
Resource	Infinite	Limited
Renewability	Renewable	Non-renewable
Recyclability	Good	Moderate
Bio-degradability	Bio-degradable	Non-biodegradable
CO_2 neutral	Yes	No
Density	Low	High
Mechanical properties	Moderate	High
Moisture sensitivity	High	Low
Thermal sensitivity	High	Low
Abrasiveness	Low	High
Toxicity	Non-toxic	Toxic
Cost	Low	Higher than natural fiber
Energy consumption	Low	High

Adopted from Refs. Oksman et al. (2003), Dittenber et al. (2012)

Table 3 Estimated average global production of different natural fibers

Fiber type	Origin	Production per year (Million Tonnes)	Largest producer country
Cotton	Seed	25	China, USA, India, Pakistan
Jute	Bast	2.3–2.5	India, Bangladesh
Flax[a]	Bast	0.5–1.5	China, France, Belgium, Belarus, Ukraine
Coir	Seed	0.45	India, Sri Lanka
Kenaf	Bast	0.45–0.97	China, India, Thailand
Sisal	Leaf	0.39	Brazil, China, Tanzania, Kenya
Ramie	Bast	0.15	China, Brazil, Philippines, India
Abaca	Leaf	0.10–0.07	Philippines, Costa Rice
Hemp[b]	Bast	0.10–0.2	China, France
Pineapple	Leaf	0.74	Philippines, Thailand, Indonesia
Henequen	Leaf	0.03	Mexico

[a]The real production of flax was underestimated because the production of flax in Canada is not considered for calculation

[b]China has announced plan to substantially increase the hemp production for textiles in the coming years to 1.5 million tonnes of fiber per year

Adopted from Refs. Bledzki et al. (2002), Niska and Sain (2008)

fibers from pines, spruces, larches; are obtained from conifer. Hardwoods except balsa wood are generally denser than softwoods but the growth rate of softwood is faster than that of hardwood. The anatomy of softwood is simple in most cases, as 90% or more of softwood volume is composed of longitudinal tracheid which transports water and gives mechanical strength to the wood. Softwood fiber reinforced polymeric composites have better stiffness than hardwood fiber reinforced polymeric composites and this is due to higher lignin content in softwood fiber compared to that in hardwood fiber. However, hardwood fiber reinforced polymeric composites showed better tensile strength, impact strength, and elongation which could be attributed to higher cellulose content (Joshi et al. 2004; Oma et al. 2012). Softwood fibers are preferred for composite applications as it has higher aspect ratio than hardwood fibers.

Non-wood Fibers

Non-wood fibers have been further categorized into bast fibers, leaf fibers, seed fibers, fruit fibers and stalk fibers. Table 3 indicates the average global production per year of some commonly used non-wood fibers.

Compositions of Plant Fibers

The structure, microfibrillar angle, cell dimensions, defects, and the chemical composition of plant fibers are the most important properties that determine the

overall properties of the fibers (Saravana and Kumar 2010). The size and length of plant fibers obtained from various different plants of a particular type also varies depending upon the climatic conditions, location and age of the plants and the fiber extraction process. The overall structure of a plant fiber is very complex consisting of several layers and walls. The cell wall of a natural fiber is not homogeneous as it has a thin primary wall, which is the first layer formed during cell growth. Primary wall encircles secondary wall, which is made up of three different layers, known as outer layer, middle layer and inner layer. The transverse section of the unit cell in a fiber has a central hollow cavity (lumen). Each layer in the cell wall has been found to be composed of cellulose that embedded in a matrix of hemicellulose and lignin. The physical and mechanical properties of plant fibers differ among cited works, because different fibers were used, different moisture conditions were present, and different testing methods were performed. Mechanical properties of plant fibers can be affected by many factors for example; either single fiber or bundle of fibers is being tested. Table 4 represents the important mechanical properties of commonly used plant fibers. The physical properties of each natural fiber are critical, and include the fiber dimensions, defects, strength and structure. There are several physical properties for example; fiber dimensions, defects, strength, variability, crystallinity, and structure; that are important to know about for each plant fiber before that fiber can be used to reach its highest potential.

The chemical compositions of some of the commonly used plant fibers used as reinforcement are summarized in Table 5, and it is observed that plant fibers mainly consist of varying proportions of cellulose, hemicellulose, lignin and pectin (Nirma et al. 2015; Ahmad et al. 2015). In addition to these there are a number of non-structural components including waxes, inorganic salts and nitrogenous substances. Climatic conditions, age and the degradation process not only influence the structure of fibers, but also the chemical composition. The chemical compositions of the plant fibers are also influenced by the fiber growth time (days after planting), the botanical classification of the fiber and the stalk height (Dittenber and Gangarao 2012).

2.2 Biodegradable Polymer Matrix

The yearly disposal of synthetic polymers derived from petroleum products in both the US and EC country has raised the demands for managing this non-biodegradable waste. The commodity plastics for example; polyethylene, polypropylene, polystyrene and polyvinyl chloride etc. displaced metals, glasses, ceramics and wood products especially in the area of packaging and these polymers are available in variety of forms as films, bags, containers etc. They persist in environment, do not degraded after their disposal and thus giving rise to multitude of ecological and environmental concerns. Biodegradable polymers offered scientists and researchers a possible solution not only to the waste disposal problem associated with traditional petroleum based polymers but also to the rising oil prices

Table 4 Different physical and mechanical properties of natural fibers

Name of plant fibers	Density (g/cm^3)	Elongation (%)	Tensile strength (MPa)	Specific strength (MPa)	Young's modulus (GPa)	Specific modulus (GPa)	Specific gravity
Alfa	0.89	5.8	35	–	22	25	–
Bagasse	1.1–1.6	6.3–7.9	170–350	–	5.1–6.2	3.6–4.1	1.4–1.5
Bamboo	1.1	1.9–3.2	500–575	454	27–40	50–67.9	0.4–0.8
Banana	1.35	2.4–3.5	711–789	444	4.0–32.7	3.6–27.3	1.1–1.2
Betel nut	0.2–0.4	22–24	120–166	–	1.3–2.6	1.0–1.9	1.3–1.4
Coir	1.2–1.6	14–30	170–230	146	3.0–7.0	2.5–5.0	1.2–1.4
Cotton	1.5–1.6	2.1–12	200–600	179–373	5.0–15.1	3.3–10.1	1.5
Curaua	1.4	1.3–4.9	87–1150	113–521	11.8–96	39	–
Flax	1.3–1.5	1.1–3.3	340–1600	535–1000	25–81	16.7–54	1.5
Hemp	1.1–1.6	0.8–3	550–900	372–608	70	47.3	1.5
Henequen	1.2	3.7–5.9	430–570	–	10.1–16.3	11	–
Jute	1.3–1.5	1.4–2.1	385–850	269–548	9–31	6.9–20.7	1.3–1.5
Kenaf	0.6–1.5	1.6–4.3	223–1191	641	11–60	10–42.9	1.1–1.4
Oil palm	0.7–1.6	4–18	50–400	–	0.6–9.0	0.5–7.5	1.1–1.2
Pineapple	1.56	2.4	150–1627	–	11–82	7.8–57	1.4–1.6
Ramie	1.4–1.5	1.5–4	200–1000	147–625	41–130	27–81	1.5–1.6
Sisal	1.3–1.6	1.9–15	400–700	366–441	8.5–40	6.5–30.8	1.3

Adopted from Refs. Manita and Morreale (2011), Ahmad et al. (2015)

Table 5 Chemical compositions of different natural fibers

Name of plant fiber	Cellulose (%)	Hemicellulose (%)	Lignin (%)	Pectin (%)	Wax (%)	Ash (%)	Moisture (%)
Bagasse	28.3–55	20–36.3	21.2–24	NA	0.9	1–4	NA
Bamboo	48.2–73.8	12.5–73.3	10.2–21.4	0.37	NA	2.3	11.7
Banana	48–60	10.2–15.9	14.4–21.6	2.1–4.1	3–5	2.1	2–3
Betelnut	35–64.8	29–33.1	13–26	9.2–15.4	0.5–0.7	1.1–2.1	NA
Coir	19.9–36.7	11.9–15.4	32.7–53.3	4.7–7.0	NA	NA	0.2–0.5
Cotton	82.7	5.7	28.2	5.7	0.6	NA	10
Curaua	73.6	9.9	7.5	NA	NA	NA	NA
Flax	64.1	16.7	2	1.8	1.5	13.1	10
Hemp	55–80.2	12–22.4	2.6–13	0.9–3.0	0.2	0.5–0.8	6.5
Henequen	77.6	4–8	13.1	NA	NA	NA	NA
Jute	64.4	12	0.2	11.8	0.5	0.5–2.1	10
Kenaf	37–49	18–24	15–21	8.9	0.5	2.4–5.1	NA
Oil Palm	42.7–65	17.1–33.5	13.2–25.3	NA	0.6	1.3–6.0	NA
Pineapple	57.5–74.3	80.7	4.4–10.1	1.1	3.3	0.9–4.7	NA
Ramie	68.6	13.1	0.6	1.9	0.3	NA	10
Rice husk	38–45	12–20	–	–	–	20	–
Sea grass	57	38	5	10	–	–	–
Sisal	65.8	12.0	9.9	0.8	0.3	4.2	10.0

From kind Refs. Nirma et al. (2015), Ahmad et al. (2015)

(Satyanarayana et al. 1986; Ya et al. 2014; Mathew et al. 2014; Karim et al. 2014a, 2016b). The developments in emerging biodegradable polymers are impressive from a technological point of view and mirror their rapid growth in the market place (Mohanty et al. 2000; Azwa et al. 2013; Faruk et al. 2014; Karim et al. 2014b, 2016c, d).

2.2.1 Classification

Biodegradable polymers on the basis of their origin can be natural as well as synthetic. Almost all natural biodegradable polymers which can be obtained from the renewable resources degrade within a reasonable time scale. However, the

synthetic biodegradable polymers also degrade if they contain chemical bonds which occur in natural compound (Mohanty et al. 2000; Karim et al. 2014b). International organizations for example: American Society for Testing Materials (ASTM) in connection with Institute for Standard Research (ISR), the European Standardisation Committee (CEN), the International Standardization Organization (ISO), the German Institute for Standardization (DIN) are all actively involved in developing definitions and tests for biodegradability of polymers in different environments. Some of the commonly used biodegradable polymers used as matrix in green composites are polylactic acid, polyhydroxybutyrate, starch etc. Of all the biodegradable polymers polylactic acid (PLA) is the most commonly used and studied matrix material for green composites.

3 PLA Based Green Composites

Several works has been reported on the kenaf fiber with PLA. Various reports have been discussed relating to chemical modifications, biodegradability, and the mechanical and dynamic mechanical properties of fabricated composites (Ochi 2008; Huda et al. 2008; Lee et al. 2009; Karim 2014). Significant improvement in mechanical properties has been reported by silane-treated kenaf fiber reinforced PLA composite. The heat deflection temperature (HDT) was higher compare to neat PLA. The biodegradability (weight loss with time) of kenaf/PLA decreased approximately 38% after four weeks of decomposition. Young's modulus (6.3 GPa) and the tensile strength (62 MPa) of the kenaf (70%)-PLA composites were in the line compare to conventional composites.

Flax fiber reinforced PLA composite was processed and the interfacial characterization was performed using the microbond testing method (Le Duigou et al. 2010). The interfacial mechanisms was explained and discussed; depends on thermal treatment (Le Duigou et al. 2010).

Abaca fiber and cellulose fiber reinforced PLA composites was processed using two-step extrusion coating process followed by injection molding and compared with each other. It was reported that with man-made cellulose of 30 wt%, the tensile strength and modulus increased by factors of 1.45 and 1.75 times in comparison to neat PLA. Reinforcing with abaca fibers (30 wt%) enhanced both the E-modulus and the tensile strength by factors of 2.40 and 1.20, respectively (Bledzki et al. 2009).

3.1 Processing

PLA based green composites are manufactured using the same processing technique as used for the conventional synthetic fiber reinforced polymer matrix composites. These processing techniques are broadly classified as open mold process and closed mold process. Open mold process includes hand layup, spray

Table 6 Processing and tensile properties of PLA based green composite

Composite	Process	Tensile strength (MPa)	Tensile modulus (GPa)	Reference
PLLA/kenaf (70%)	Wet impregnation	62	6.3	Nishino et al. (2003)
PLA/kenaf (70%)	Hot pressing	223	32	Nishino et al. (2003)
PLA/ramie	Hot pressing	52	–	Tao et al. (2009)
PLA/cotton	Compression molding	41.2	4.24	Graupner et al. (2009)
PLA/jute (40%)	Film stacking	100.5	9.4	Placketta et al. (2003)
PLLA/flax (30%)	Film stacking	99	9.52	Bodros et al. (2007)
PLA/flax (30%)	Extrusion, compression molding	53	8.3	Manita and Morreale (2011)
PLLA/flax (30%)	Injection molding	53.1	7.32	Duigou et al. (2008)
PLA/wood flour	Injection molding	58.28	6.22	Petinakis et al. (2009)
PLA/flax (30%)	Solution casting, hot pressing	21	0.137	Kumar et al. (2010)
PLA/bamboo flour	Injection molding	50	–	Kim et al. (2011)
PLA/wood flour	Hot pressing	41.33	3.00	Febrianto et al. (2006)
PLA/sugar beet pulp	Extrusion, injection molding	29.55	2.59	Finkenstadt et al. (2007)
PLA/coconut (0.5%)	Extrusion, compression molding	67.99	2.37	Tayommai et al. (2010)

up, tape layup, filament winding and autoclave method. The compression molding, injection molding and transfer molding are closed mold processes. However the most commonly used processing techniques are extrusion followed by injection molding or compression molding. Some examples are given in Table 6.

3.1.1 Factors Influencing Processing of Green Composite

Some typical problems related to the processing of green composites are the hydrophilic and hygroscopic nature of natural fibers which is used as reinforcement, their poor thermal resistance and also the type as well as its content in the green composite. Natural fibers must be processed at lower temperatures to avoid the possibility of its burning and degradation (Nishino et al. 2003). This limits the use

of only those polymers as matrix resins for natural fiber composites that can be processed at lower temperatures, consequently, high performance and high glass transition temperature and high melting temperature polymers may not be used as matrix resins for green composites. Hydrophilic and hygroscopic reinforcing natural fibers have poor compatibility with hydrophobic polymer matrix, as a result of which, natural fiber reinforced polymer composites have weak fiber/matrix interfacial adhesion that limits load transfer from the fiber to the matrix and results in poor mechanical properties of the composites (Tao et al. 2009). The fiber/matrix interfacial adhesion needs improvement for use of natural fiber/polymer composites. Another drawback is the high moisture absorption by natural fibers in the green composites (Tao et al. 2009). Moisture swells the natural fibers in composites and adversely affects the dimensional stability and the mechanical properties of the natural fiber/polymer composites. The presence of humidity or moisture during the processing of green composite leads to the formation of water vapor which can, in turn, give rise to several problems, especially in the in the case of injection molding, if a venting or drying system is not present as it causes the formation of voids in the material and thus poor mechanical properties. Furthermore, it is a widely accepted step prior to the processing of green composite, to dry the natural fibers and this can be done by different ways such as hot air jets, rotating driers, ventilated ovens, in order to reduce the humidity level to approximately 2–3% (Graupner et al. 2009). Fiber treatment either chemically or physically can also reduce both the moisture content level and the rate of absorption very significantly. Bio-based polymers for example polylactic acid can be more sensitive to moisture than natural fibers. Moisture or water content in the sample also affects the mechanical properties (such as, compression, flexural and tensile) of the composites. Nowadays new extruder screw design (higher L/D ratio) allows better degassing and, consequently, lower moisture content. In addition, the machine's barrel must be redesigned. Type of natural fiber and its content is another important parameter that influences the processing of the green composite. The length of natural fibers (short or long), aspect ratio (length/diameter), and chemical compositions have great influence on the processing and therefore processing parameters are different for different fiber types (Placketta et al. 2003). In general, increase in fiber content in the composites increases the stiffness and strength of the composite.

3.1.2 Performance of Green Composite

The properties of a green composite cannot be achieved by any of the components acting alone. Overall, the properties of composite are determined by properties of the matrix, properties and aspect ratio of the reinforcing fiber, amount of fiber in the composite (fiber volume fraction), geometry and orientation of the fibers in the composite, and several others, including fiber/matrix interfacial adhesion, because the adhesion between the reinforcing fiber and the matrix polymer plays an important role in the transmission of stress from the matrix to the fiber and thus contributes towards the performance of the composite (Placketta et al. 2003; Bodros

et al. 2007). The principal purpose of a matrix is not to be load carrying constituent but essentially to bind the fibers together, transfer load to the fibers, and to protect the composite. Each fiber must be separated from the other and uniformly coated by the matrix. Properties of the polymeric matrix govern the resultant properties of the polymeric composites. Thermal stability and temperature dependent properties and high temperature applications of a polymeric composite depend on its polymeric matrix. The fundamental role of fibers is to perform as the reinforcing materials and to carry or support the load, limit deformation, and enhance the mechanical properties of the polymeric composite such that the polymeric matrix experiences negligible stresses (Duigou et al. 2008). Reinforcing fibers provide stiffness, strength, and other mechanical properties. The fiber aspect ratio (length/diameter ratio) is a critical parameter in a composite material. Mechanical properties improve with increasing fiber aspect ratio. The greatest stiffness and strength occurs, when the fibers are very long compared to their diameter; however, although, short fiber reinforced polymer composites are limited by the short length of the reinforcing fiber; but they offer good properties. One of the significant factors determining the mechanical properties of a composite is the content of reinforcing fiber (fiber volume fraction) (Petinakis et al. 2009; Kumar et al. 2010). Stiffness and strength increases with increasing fiber contents, however, beyond a particular volume fraction of fibers, there is increase in stiffness, but no proportional increase in strength. The geometry of the fibers in a composite is also important, since fibers have their highest mechanical properties along their lengths, rather than across their widths (Kumar et al. 2010). Orientation of the fibers in the composite plays an important role in imparting isotropic or anisotropic properties to a composite. Composite properties depend on the fiber/matrix interfacial adhesion also. The ultimate mechanical properties of fiber reinforced polymeric composites depend not only on the properties of the fibers and the matrix, but also on the extent of interfacial adhesion between the fiber and the polymer matrix. Poor fiber-matrix interfacial adhesion limits the load transfer from matrix to fibers. In polymer matrix composites, the interface between the reinforcing fiber and the polymeric matrix is important for the overall performance of the composite as a structural material.

It is important to know the certain mechanical properties of each green composite in order to understand its highest potential. Mechanical properties of a composite material are important because these properties decide the applications and performance of a composite material. Among all the mechanical properties the most commonly studied are the tensile, flexural and impact properties. However, maximum work has been reported on tensile properties of green composite than any other mechanical property. Table 6 summarizes the processing techniques and tensile properties reported for PLA based green composites. Tensile test has been performed to measure the ability of a material to withstand the force that tends to pull it apart and the extent of its deformation before breaking. Tensile testing gives result for tensile modulus, tensile strength and elongation at break of a material (Tayommai et al. 2010). Tensile modulus indicates the stiffness of a material and can be determined from the stress-strain curve. Stress is the force applied to produce deformation in a unit area of a test specimen and is ratio of applied load to the

original cross-sectional area. Strain is the change in the length per unit of the original length (Δl/l). Tensile strength is the maximum stress that a specimen can withstand during a tension test, and is measured in MPa. Tensile Modulus, also known as the Young's modulus, is a measure of the stiffness of the material and is the ratio of stress to corresponding strain below the proportional limit of a material; and is measured in GPa. Elongation at break of a material is the percentage increases in its length due to the applied tensile load up to its breaking point.

4 Green Composites in Future

The use of biodegradable polymers as matrix and natural fibers as reinforcement in composite materials contributes to enhancing the development of green composites in regards of performance as well as sustainability. Green composites have created substantial commercial markets for value-added products especially in packaging sector. Although PLA/kenaf fiber composites have been used for spare tire cover, circuit boards (Nakamura et al. 2009) and so on Bax and Mussing (2008) proposed the application in automotive and electronic industry. Graupner et al. (2009) suggested their applications for furniture, suitcase, car parts, grinding discs, safety helmets. However, to cover other fields, scientists and researchers still need to think about the up scaling of products. To launch various lab scale ideas into market a concise effort is required from scientific community.

In the future, these green composites will see increased use in structural applications. Various other applications depend on their further improvements and research. But there are still a number of problems that have to be solved before green composites become fully competitive with synthetic fiber composites.

In recent years, the major advancement lies within the establishment of nanocomposites (i.e., the use of nano cellulose in the form of crystal or fibers produced from natural fibers). Natural fibers consist of approximately 30–40% cellulose and about half of that is crystalline cellulose. It was reported that this nano cellulose could compete with components made from conventional materials. Nanotechnology shows numerous opportunities for improving the properties of green composite products. The use of cellulose nanocrystal and cellulose nanofibers is being explored for a variety of uses since it is stronger than steel and stiffer than aluminum. Cellulose nanocrystal reinforced composites could soon provide advanced performance, durability, value, service-life, and utility while at the same time being a fully sustainable technology.

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