Sustainable Biocomposites: Challenges, Potential and Barriers for Development

Faris M. AL-Oqla and Mohammad A. Omari

Abstract Since natural fibers have many advantages, modern societies start switching for new green materials including natural fibers to contribute meeting the demand of weight reduction, environmental issues as well as customer satisfaction attributes. However, fully replacement of green bio-composites has many challenges. Inadequate availability of data regarding the performance of bio-composites due to the large variety of their constituents is the most challenging barrier in this field. A gap in the way of assessing bio-composites relative to comprehensive desired criteria for various industrial applications have been revealed. Therefore, processing consideration and proper selection of the composite constituents and their characteristics should be extensively investigated in order to achieve good part design with bio-composites. Moreover, high coefficients of safety factors are still required in such green products. Inconsistency of natural fibers properties as a major drawback as well as others that limit their applications in bio-composites are comprehensively discussed here.

Keywords Bio-composites · Composites drawbacks · Bio-composites limitations · Green products

1 Introduction

Recently, green composites became one of the most significant research themes worldwide. Its significance revealed due to several reasons such as: the high performance in mechanical properties, many processing advantages, low cost and light weight, availability and renewable, cheap, environmentally friendly, recyclability and degradability features (AL-Oqla et al. 2014a; Faruk et al. 2012a). Enhancing the natural fiber polymers will form a new class of materials that have a good

F.M. AL-Oqla (✉) · M.A. Omari
Department of Mechanical Engineering, Faculty of Engineering,
The Hashemite University, Zarqa 13133, Jordan
e-mail: fmaloqla@hu.edu.jo

M. Jawaid et al. (eds.), *Green Biocomposites*, Green Energy and Technology,
DOI 10.1007/978-3-319-46610-1_2

potential in future as a substitute for rare wood based materials in many structural applications (Sapuan et al. 2013; AL-Oqla and Sapuan 2014b; AL-Oqla et al. 2015c). Different cells of hard plant fibers are bonded together by natural substance called lignin, acting as cementing materials. The composites- mainly consist of cellulose fibrils embedded in lignin matrix- exhibits high electrical resistance. Combining this composite into low modulus polymer matrix, will produce materials with better properties appropriate for various applications (AL-Oqla et al. 2016; Bendahou et al. 2008; AL-Oqla and Sapuan 2014c; Dittenber and GangaRao 2011). Moreover, electrical properties for the natural fibers polymers such as volume resistivity, dielectric strength are hot areas of research since the significance of these properties in use (Bora et al. 1993; George et al. 2013; AL-Oqla et al. 2015c).

1.1 Green Bio-Composites

Keywords such as “biodegradable”, “biocomposite”, “sustainable”, “biocompatible”, “green”, “bio-based”, “renewable”, “environmentally friendly”, “eco-friendly”, and “biopolymers” are common sight in the packaging-related literature. This explicitly demonstrated the growing awareness and concern of people regarding environmental issues driven by non-biodegradable and non-renewable plastics as well as the rapid depleting fossil fuel reserves. Generally, the term bio-composites covers composite materials made from the combination of;

1. natural fiber reinforced petroleum derived polymers which are non-biodegradable,
2. biopolymers reinforced by natural fibers, or
3. biopolymers reinforced synthetic fibers (i.e. glass, carbon etc.)

Bio-composite materials on the other hand, defined as: composite materials in which at least one of the constituents is derived from natural resources (AL-Oqla et al. 2014b). This includes composite materials made from the combination of: natural fiber reinforced petroleum derived polymers which are non-biodegradable, and biopolymers reinforced synthetic fibers such as glass and carbon, these two categories are not fully environmentally friendly (Mohanty et al. 2002). The third category which is, biopolymers reinforced by natural fibers which commonly termed as “green bio-composites” are more environmentally friendly (John and Thomas 2008). The term biodegradable bio-composites are those in which the polymeric matrix is biodegradable. It includes two different families: bio-based and petroleum-based. Biodegradable polymers are different than biopolymers in raw material. Biodegradable polymers can be created from bio-based or petroleum-based and can be classified as green polymeric matrices. In addition, bio-based bio-composites or sometimes called fully biodegradable green composite are terms used when both the fiber and matrix are from renewable resources. These bio-composites have less environmental impact.

1.2 Driving Factors for Bio-Composites

With the growth of environmentally conscious society, materials producers start concentrate on products which are "environmentally friendly". Such products (environmentally friendly and sustainability) can only be realized by considering the entire life cycle of the product; from the raw material extraction to the disposal, those materials generally poses no harmful impacts on the environment during their life cycle. Moreover, modern industries have been challenged with continuous pressure from the government, consumers and media; fascinating the industry to develop more sustainable products. The plastic industry usually responds to these new stringent environmental protection laws and has launch innovating sustainable packaging as bioplastics products. It was reported that the bioplastic market was estimated to reach a value of $3.94 billion soon (Ibrahim et al. 2014). The growing growth in the commercialization of biodegradable starch-based packaging materials is mainly affected by several factors. Some of those factors are (1) greater environmental awareness, (2) petrochemical resources shrinkage (3) government laws and company policies, and (4) suitable technology.

2 Bio-Composites in Macroscale

In these materials, natural fibers (such as sisal, hemp, kenaf, coir, jute, flax, date palm etc.) are used as reinforcing material (fillers) for polymer-based matrices. In light of the governmental emphasis on the new environmental regulations as well as sustainability concepts, ecological, social, and economical awareness, (Kalia 2011b; Faruk et al. 2012b); the optimal utilization of natural resources was highlighted. Utilizing natural fibers in particular, would decrease waste disposal problems, and reduce environmental pollution. Natural fiber composites (NFCs) as environmentally attractive materials have been proven and emerged as an alternative to the glass-reinforced or carbon reinforced polymer composites. The properties and performance of engineering products made from NFCs depend upon the properties of their individual components as well as their compatibility and interfacial (polymer/filler) features. Natural fibers have been utilized in such composites in various sizes ranged from micrometer to several centimeters. Various bio-fiber characteristics are illustrated in Table 1 (Khalid Rehman Hakeem et al. 2014).

Many examines have addressed the capabilities of bio-fibers as reinforced fillers in polymeric matrices. Most of the studies have focused on the mechanical properties, modifications to improve compatibility, manufacturing processes as well as other technical issues. The studded aspects of such composites included fibers treatments, crystallinity, fiber modification, weathering resistance, durability, and thermal stability (Alves et al. 2010; Mir et al. 2010; Sarikanat 2010). In addition, a gap in the way of assessing NFCs relative to comprehensive desired criteria for

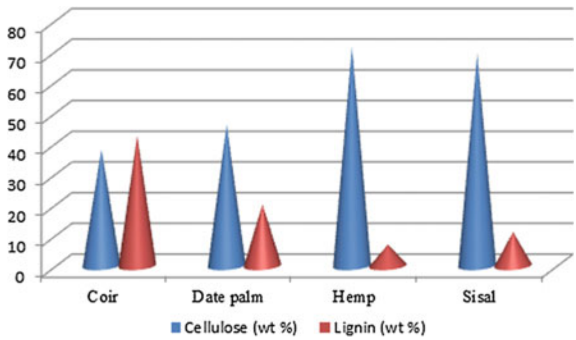
Table 1 Physical characteristics of bio-fibers

Agricultural biomass	Fibre length (mm)	Fibre diameter (mm)	Thickness of single cell wall (microm)	Width of lumen (microm)
Oil palm	0.6–1.4	8.0–25.0	–	6.9–9.8
Coconut coir	0.3–1.0	12.0–14.0	0.06–8.0	–
Banana	0.1–4.2	12.0–30.0	1.2–1.5	13.4–22.4
Pineapple leaves	3.0–9.0	5.9–80.0	1.8–8.3	2.4–3
Jute	0.8–6.0	5.0–30.0	5.2–11.3	3.4–7.6
Sisal	0.8–8.0	7.0–47.0	8.0–25.0	8.0–12.0
Flax	10.0–65.0	5.0–38.0	10.0–20.0	–
Cotton	15.0–56.0	10.0–45.0	3.6–3.8	15.7–16.4
Ramie	30.0–60.4	7.0–80.0	2.8–3	12.8–13.0
Kenaf (bast)	1.4–11.0	4.0–36.0	1.6–12.6	5.4–11.1
Kenaf (core)	0.4–1.1	0.27–37.0	0.5–11.5	14.8–22.7
Bagasse	0.7–2.8	10.0–40.0	1.4–9.4	1.0–19.1
Bamboo	2.0–3.0	14.0–17.8	3.0–9.0	3.8–8.6
Rice	0.4–1.2	8.0–15.5	2.0–5.6	1.1–8.7
Corn	0.4–1.4	12.1–26.7	2.4–6.5	2.4–20.1

Fig. 1 Levels of factors affect green composites

various industrial applications have been developed (AL-Oqla and Sapuan 2014c). In such assessment framework, criteria that affect the NFCs and their products were categorized and classified into levels, where principal criteria were suggested, collected and arranged according to each level. Moreover, several comparisons between bio-fibers were successfully conducted to demonstrate their own beneficial characteristics. Figure. 1 demonstrates the proposed levels (AL-Oqla and Sapuan 2014c),

Fig. 2 Comparison regarding cellulose and lignin contents of bio-fibers



whereas Fig. 2 illustrates one of such comparisons regarding cellulose and lignin contents of some bio-fibers (AL-Oqla and Sapuan 2014c).

3 Nanocomposites

Nanocomposites are mainly innovative materials in which at least one filler length is in the nano-meter scale. In regard to the filler geometry, nanocomposites can be sorted into three principal categories 1—Fumed silica dioxide and nano metallic powder are identified by having: length, width and thickness, all in the nano-scale. 2—Carbon nanotube got two dimensions in the nano-meter. 3—Expanded layered graphite platelets and clay have only single dimension in the nano-meter range (Cheng et al. 2010). Physical and thermal properties of composites reinforced with nanoparticles filler are superior to those filled with micron-sized particle of the same filler (Alamri and Low 2012). Moreover, some exclusive properties, which traditional micro-particles cannot attain, make nanocomposites be prominent and draw attention. Greater stiffness, strength and glass transition temperature are resulted from the considerable surface area developed when nano-particles are randomly distributed in the matrix (Benhamou et al. 2014). Carbon nanotubes, though, still cannot be formed in mass production context due to the complex manufacturing process. Thus, work is intended to bridge the gap in price and property by offering substitute nano materials like nano clay and exfoliated graphite platelets reinforced composites. These materials are plentiful in nature and have excellent mechanical and physical properties. Nanocomposites become attractive due to the tremendous interaction between nano-metric particles and the polymeric matrix within the structure, for example, an interphase of 1 nm thickness occupies about 30 % of the entire volume in case of nanocomposites where as it gets to 0.3 % of the total volume of polymer in case of micro-filled composites. The great surface area (interfaces) within the nanocomposites promotes adhesion energy, increasing molecular bonding, and this increase in chemical bonding enhances the polymer crosslinking resulting in improvements in mechanical properties (Ye et al. 2007).

3.1 Nanofibers from Natural Fibers

Nanofibers are fibers that have diameter equal to or less than 100 nm. One chief characteristic of nanofibers is the massive availability of surface area per unit mass. The high surface area of nanofibers offers a remarkable capacity for the attachment or release of absorbed molecules, functional groups, catalytic moieties, ions and nanometer scale particles of many kinds. On the contrary, a small participation made by the interphase provides diverse potential of performance tailoring and is capable of influence the properties of the matrices to a much higher extent under rather low particle content (Ye et al. 2007).

3.2 Nanoclay

Due to the tiny size and depth of the platelets, only one gram of clay layer includes over a million units of platelet (Majeed et al. 2013). There is a considerable progress in mechanical and physical properties of clay reinforced composites at a very low silicate loading (4 wt%). The field of polymer/ nanoclay composites has gained attention due to the fact that it is feasible to melt-mix resin with silica layers, and no need to use organic solvents. Polymer- silicate nanocomposites could have three types of morphological structures (Alexandre and Dubois 2000). A phase divided composite is obtained when matrix is incapable of intercalate between the silicate layers as shown in Fig. 3a. In intercalated formation, more than one matrix

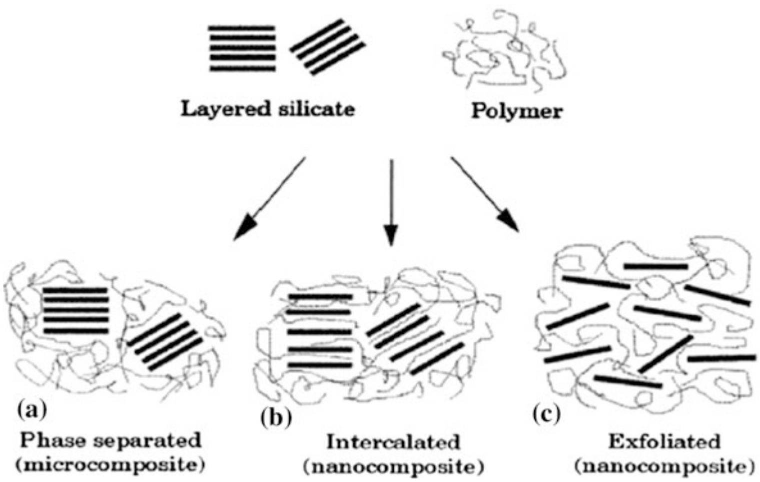


Fig. 3 SEM images of **a** intercalated, **b** expanded, and **c** sonicated (exfoliated) silicate nanocomposites (Alexandre and Dubois 2000)

molecules are intercalated between clay layers as shown in Fig. 3b but the layers remain parallel. In fully exfoliated structures, the silica platelets are no longer close to each other and the nano-metric layers are fully distributed in the matrix Fig. 3c.

Natural graphite is a black carbon stone, hardest material exists in nature. Its elastic stiffness is about 1000 MPa. The basic element of graphite is the graphene, in which a huge number of benzene rings are reduced to form a firm planar layer. The interlayer spacing is around 3.35 Angstrom and the force between the layers is Van der Waals type (Matsumoto et al. 2012).

3.3 Polymeric Based Nanocomposites/Applications

Polymeric based composites have been employed particularly in blast/ impact loading. Applications involve marine structures; mostly, lightweight glass/carbon polymeric-based composites, and modern concepts for the mitigation of blast/shock/impact effects (Cheng et al. 2010). Sandwich composites utilizing balsa wood and foam cores are currently being attributed in several navy applications such as in surface ship deck structures, and radar pole. Numerous new and promising cores have been explored in sandwich structures. Different types of cores have been used including Tycor; is an engineered three-dimensional fiber reinforced damage soft core for sandwich structures and has the potential to improve ballistic impact resistance.

Mechanical properties of polymer-based nanocomposites have been widely investigated where improved properties such as stiffness, strength, impact-toughness, gas permeability, vibration damping, and flame retardancy have been all reported. Key factors like filler loading, degree of filler dispersion (exfoliation), and type of interfacial linking can strongly modify the properties of bulk polymers (Hassan et al. 2011). To prepare a nanocomposite, small filler content is normally preferred due to their infinitesimal volume and huge interfacial area produced. Polymer-filled nanocomposites can be manufactured through melt processing or in situ polymerization. For the melt processing, pre-melt polymer is used for making the nanocomposite, whereas in the in situ polymerization the nanoparticles are diffused in monomers and then polymerization process of monomers continues to nanocomposite creation.

Ideal dispersion of filler inside the matrix is aimed to improve the bulk-material mechanical properties, while clustering can have improvements in electrical properties and decline in mechanical performance on the other side (Hassan et al. 2011). Synthesizing a totally agglomerated-free nanocomposite is hard, filler/ matrix interaction taking place at the interface needs to be controlled. Numerous studies have shown impressive advance in stiffness of nanocomposites with addition of nano-particles (Kalia et al. 2011). Again, total dispersion (exfoliation) and optimal filler orientation are difficult to reach. For example, the polymer chain ideally expands in between nanoparticles, increasing the inter-particle spacing which causes spatial adequacy toward complete exfoliation.

4 Barriers for the Development of Green Bio-Composites

Inconsistency of natural fibers properties is the main drawback that limits their applications in the composite industry (AL-Oqla et al. 2015a). Their properties mostly vary from one harvesting season to another or even from one plant to another (AL-Oqla et al. 2015b). Variations in physical properties affect in variation in mechanical properties as well when compare with synthetic fibers. Mixing batches of fibers from various harvest or parts of a single plant leads to resolve this problem (Koronis et al. 2013; AL-Oqla et al. 2014c). In fact, the properties of natural fibers may vary according to (1) rain and soil environments of the plant (2) maturity of the plant (3) part of the plant where the fibers are extracted from, and (4) harvest and treating method of the fiber (AL-Oqla et al. 2015e; AL-Oqla and Sapuan 2014a; Arbelaiz et al. 2005; Mohanty et al. 2002). A comparison between various specific strengths for different natural fiber types are illustrated in Fig. 4 (AL-Oqla et al. 2015b), and different natural fiber types are illustrated regarding their specific moduli in Fig. 5 (AL-Oqla et al. 2015b).

Another drawback of natural fibers is high moisture sensitivity which places a big challenge to use them for packaging applications and during shipment and long-term storage (AL-Oqla et al. 2014c). The hydrophilic nature of natural fibers leads to their low microbial resistance and susceptibility to rotting (Mohanty et al. 2002). Natural fibers absorb water from the surrounding environment. This causes

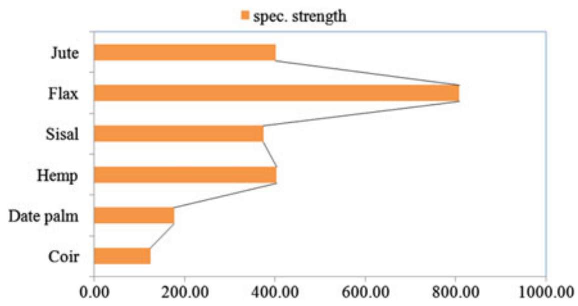


Fig. 4 Comparison of different natural fiber types regarding specific strength

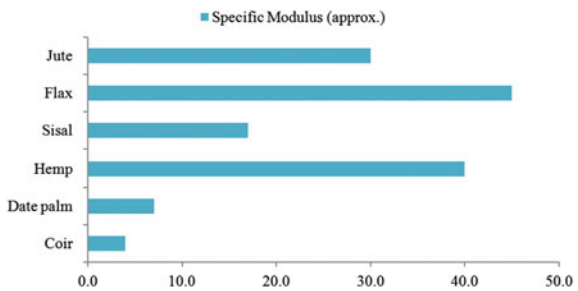


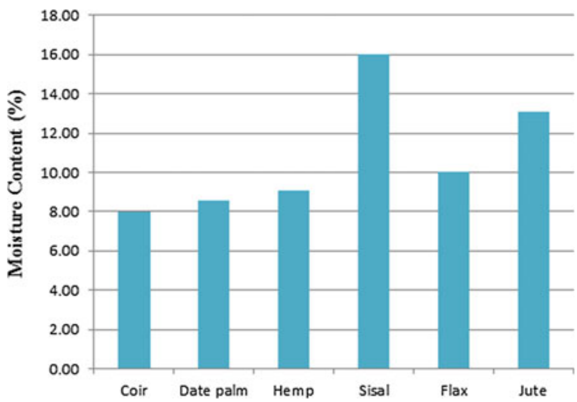
Fig. 5 Comparison of different natural fiber types regarding specific modulus

fibers to swell and have unstable dimensions, and changes the mechanical and physical properties of the composite. However, surface treatment can be useful in decreasing water sensitivity of natural fibers (Satyanarayana et al. 2009; Jawaid and Abdul Khalil 2011). Average values of moisture contents for various natural fibers are illustrated in Fig. 6 (AL-Oqla et al. 2014c).

Poor compatibility between polymeric matrices (since they are (non-polar) in nature and natural fibers (polar) causes poor fiber-matrix adhesion) is another drawback of the green composites (AL-Oqla et al. 2015a, d; AL-Oqla and Sapuan 2015; Azwa et al. 2013). Poor bonding will significantly affect the mechanical properties of the natural fiber reinforced polymer composites. In order to increase the adhesion between the fibers and thermoplastic matrix, chemical "coupling" agents can be used (AL-Oqla et al. 2015e; AL-Oqla and Sapuan 2014a; Aridi et al. 2016). Another technology been used is surface modifications on natural fibers to improve their adhesion with different matrices (Faruk et al. 2012a).

Moreover, low thermal stability of natural fibers is another disadvantage as they can only withstand temperatures up to 200 °C. More temperature will cause to degrade and shrink the fibers (Mohanty et al. 2002). This leads to change natural fiber physical and/or chemical structures due to depolymerization, hydrolysis, oxidation, dehydration, decarboxylation and recrystallization (Thakur et al. 2012; Yao et al. 2008). This in turn increases processing time to improve fibers properties. Thermal characteristics of raw, ripe, and matured betel nut husk (BNH) fiber are demonstrated in Figs. 7 and 8. They show the Thermogravimetric analysis (TGA) results of the weight loss and the temperature at 5 % weight loss for the fibers obtained at a heating rate of 10 °C/min and the initial degradation temperature was measured by the temperature at 5 % degradation (Yusriah et al. 2014).

Fig. 6 Average values of moisture contents for various natural fibers



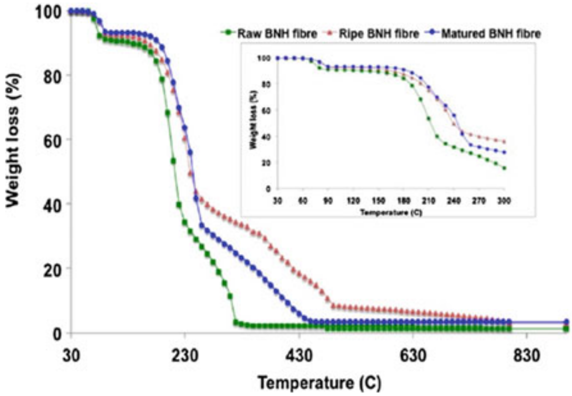


Fig. 7 Thermogravimetric analysis of raw, ripe and matured BNH fiber

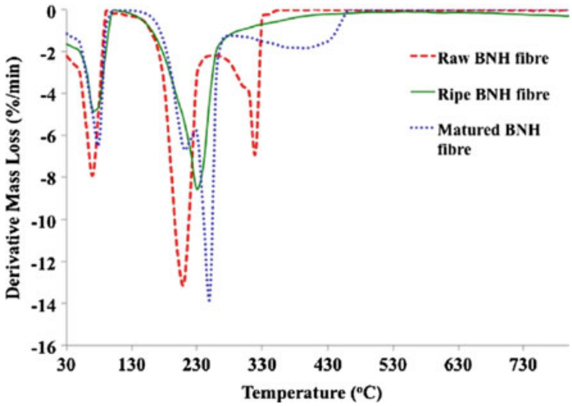


Fig. 8 DTG curves of BNH fibers

5 Material Selection for Bio-Composites and Its Importance

Material selection is the procedure of selecting specific material properties from a cluster of defined nominees after the physical design structures has been determined (Dweiri and Al-Oqla 2006). Or the identification of materials after appropriate manufacturing processes, which will hold the dimensions, shapes, and properties desired for the product to perform its required function at the lowest cost.

Material selection for a specific purpose is an important task since materials play significant role during the whole product design process (Dalalah et al. 2010; Dweiri and Al-Oqla 2006). It requires interdisciplinary efforts with experts from diverse backgrounds, depending on the product field of application (Jahan et al. 2010; AL-Oqla and Hayajneh 2007; Al-Oqla and Omar 2012; Al-Oqla and Omar 2015; AL-Oqla et al. 2015d). Materials selection process is considered as the main step of engineering design (Ashby and Johnson 2013). Materials are responsible for function, shape and interaction with other components of the product, also they effect on customer selection decision (Rashedi et al. 2012; AL-Oqla et al. 2015c; AL-Oqla et al. 2016).

6 Consequences of Improper Material Selection Decision

Wrong materials selection for engineering applications has many consequences; waste of money and time on the redesigning or fabrication of the designed parts (Jahan et al. 2010). Also leads to failure or undesired outcomes of products. Incorrect selection of materials leads to pre-mature failure of the product in the field of application. This will directly affect the productivity, performance of products and reputation of the company (Jabbour et al. 2013; Al-Widyan and Al-Oqla 2011, 2014; Al-Oqla and Omar 2012). Many factors affect material selection for a particular application (AL-Oqla and Sapuan 2014c; Ashby and Johnson 2013). In past years, material and design engineers typically select materials using trial and error method or based on previous experiences. Huge number of industrial materials and too many parameters will increase the complexity of the material selection task. Moreover, rapid growth of 'new materials' (i.e. natural fibers and bio-based polymers) which are alternatives to traditional materials, makes selection combination is really difficult process (Al-Oqla and Sapuan 2015; AL-Oqla et al. 2015e). Hence, systematic material selection procedure should be adopted to assist in evaluating and selecting the best materials for a precise product component (AL-Oqla et al. 2016).

7 Bio-Based Materials Usage

Over the last couple of decades, a growing number of new car models encouraged by government regulations, in both Europe and North America, have featured green materials in their components. Bio-materials have been playing a major role in many industries:

1. Parts (replacing glass fibers with plant fibers) which is started in the early 1990s in different components (Ashori and Nourbakhsh 2010).
2. Food industry (bottles, containers, cups, disposable tableware, and packaging) (Majeed et al. 2013).
3. Medical applications (disposable equipment and tools designed for easy breakdown) (AL-Oqla et al. 2015c).
4. Automobiles components (door panels, package trays, seat backs, trunk liners… etc.) (AL-Oqla and Sapuan 2014c; Friedrich and Almajid 2013).

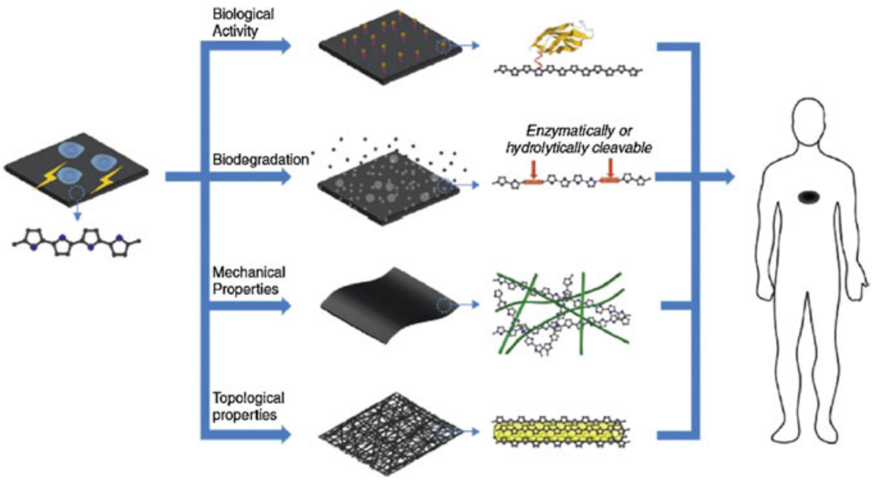


Fig. 9 Some aspects considered for biomimetic conductive polymeric materials

Moreover, bio-materials have been utilized in applications as a replacement for synthetic fiber composites as diverse as toys, marine railings, cases for electronic devices such as laptops and mobile phones, packaging, and funeral articles (Ho et al. 2012). In sports, surfboards incorporating bio-composites are presented. Recently, the production of natural fiber surfboard provides possibilities for better mechanical performance plus economic viability. Several researches on the other hand, have studied the suitability of the natural fibers as fillers for conductive polymers. The effects of several factors like fiber content, fiber length, temperature, fiber type, humidity and water absorption, and their chemical treatments have been investigated to enhance their favorite electrical characteristics. Such characteristics include DC conductivity, relaxation phenomenon, dielectric constant, electric charging phenomenon, surface current curves, capacitance, electrical resistivity, dielectric loss, volume and surface conductivities, dissipation and loss factors and so on. It was appeared that these bio-composites exhibit better electrical and thermal characteristics and may have potential applications as novel functional materials in textile and biological areas. On the other hand, various textile fibers and fabrics such as polyester, cotton, viscose rayon and wool, are now developed with conducting polymers for modern applications like electro-magnetic interference, conductive fabrics, super-capacitor, heating devices, shielding and antimicro-bial fabrics (Babu et al. 2013; Najar et al. 2007; Hardy et al. 2013). A schematic diagram of the reflected aspects for designing biomimetic conducting polymer-based materials is shown in Fig. 9 (AL-Oqla et al. 2015c).

Moreover, in the past fifteen years, bio-composites have been adopted by the European automotive industry. Nowadays, biomaterials have been gaining power in the United States. These materials are classified according to their physical and mechanical properties and each group occupied specific area in automotive components; Flax, sisal, and hemp are good in floor panel's seatback linings and door interiors. Coconut fiber and bio-based foams are used in seat bases, back pillows, and head restraints. Cotton and other natural fibers use in interior components. Abaca fiber used to create under-floor body panels. Natural latex uses to improve the safety of interior components by making the surfaces softer (Holbery and Houston 2006). Many automobile manufacturers as Audi, Honda, BMW, Chrysler, Fiat, General Motors, Mazda, Opel, Renault, Ford, Mercedes Benz, Peugeot, Toyota, Volkswagen, and Volvo start using bio-based materials from local sources (Ashori and Nourbakhsh 2010). Recently, Several attempts to use natural fiber composites in structural applications: an area which has earlier been the reserve of synthetic fibers like glass and aramid (Prajer and Ansell 2014). Combination of natural fibers with nano-materials to develop structural components that could possibly be used in automotive components is also an area of research.

- **Announced Usage**

Toyota manufacturer is the only company which stated that it plans to replace 20 % of the plastics used in its vehicles with bio-based plastics in their current productions. Ford on the other hand, has modified its specifications requirements to include a minimum amount of bio-based content in seat foams without specify numeric value. Generally, main sources of biomaterials are soybean, castor bean, corn, and sugar cane. Table 2 below shows a good comparison significantly- not only in the type of material used and its application, but also in terms of the renewably-sourced content in the material.

Table 2 The portion of renewably-sourced content in some automotive component

Bio-based content of some automotive components	Feedstock	Material	Application	Bio-based content (%)
BMW 7-series	Sisal	Acrylic polymer	Interior door panel	70
Chrysler sebring	Kenaf, hemp	Polypropylene	Interior door panel	50
Ford fiesta and focus	Kenaf	Polypropylene	Interior door panel	50
Ford fusion and lincoln MKZ	Soy	Polyurethane	Seating headrests	13–16
Multiple fiat vehicles	Castor	Zytel	Fuel lines	60
Nissan leaf	Corn	Sorona	Floor mats	20–37
Toyota camry	Castor	Zytel	Radiator end tank	40

8 Future Developments

Developments and new trends for bi-composites have occurred as a result of the enhancement of fiber selection as well as polymer-fiber evaluation methodologies. This in fact encourages all of treatment and interfacial engineering in addition to composite processing. Hence, it is necessary to found practical motivations relative to environmental performance considering bio-materials. This in order would allow designers to make informed judgments without conducting exhaustive experimental work as well as waste time and efforts. Such proposed methods may include elaborating more desired characteristics of bio-composites' constituents that designers have to take into consideration for sustainable designs to enhance achieving better performance for the future.

9 Conclusions

Bio-composite materials have been adopted in various applications. However, their implementations as alternatives for conventional materials are relatively slow. This is due to the fact that bio-composites have several limitations and barriers for development comparable to traditional materials. The inherent characteristics of their constituents are one of these limitations. In additions, the improper compatibilities between the fillers and matrices make the performance uncontrollable and difficult to be predicted. Therefore, keen selections for the constituents have to be properly studied and established. Moreover, proper theories and methodologies have to be examined in order to expand the usage of bio-composites into wider industrial applications. Recent methodologies for enhancing better performance in green composites have also to be supported to expand the development of such type of materials.

References

Alamri H, Low IM (2012) Effect of water absorption on the mechanical properties of nano-filler reinforced epoxy nanocomposites. Mater Des 42:214–222

Alexandre M, Dubois P (2000) Polymer-layered silicate nanocomposites: preparation, properties and uses of a new class of materials. Mater Sci Eng R Rep 28(1):1–63

AL-Oqla FM, Hayajneh MT (2007) A design decision-making support model for selecting suitable product color to increase probability. In: Design challenge conference: managing creativity, innovation, and entrepreneurship, Amman, Jordan

Al-Oqla FM, Omar AA (2012) A decision-making model for selecting the GSM mobile phone antenna in the design phase to increase over all performance. Prog Electromagnet Res C 25:249–269. doi:10.2528/PIERC11102702

AL-Oqla FM, Sapuan SM (2014a) Date palm fibers and natural composites. In: Postgraduate symposium on composites science and technology 2014 & 4th postgraduate seminar on natural fibre composites 2014, 28/01/2014, Putrajaya, Selangor, Malaysia
AL-Oqla FM, Sapuan SM (2014b) Enhancement selecting proper natural fiber composites for industrial applications. In: Postgraduate symposium on composites science and technology 2014 & 4th postgraduate seminar on natural fibre composites 2014, 28/01/2014, Putrajaya, Selangor, Malaysia
AL-Oqla FM, Sapuan SM (2014c) Natural fiber reinforced polymer composites in industrial applications: feasibility of date palm fibers for sustainable automotive industry. J Clean Prod 66:347–354. doi:10.1016/j.jclepro.2013.10.050
Al-Oqla FM, Omar AA (2015) An expert-based model for selecting the most suitable substrate material type for antenna circuits. Int J Electron 102(6):1044–1055
Al-Oqla FM, Sapuan SM (2015) Polymer selection approach for commonly and uncommonly used natural fibers under uncertainty environments. JOM 67(10):2450–2463
AL-Oqla FM, Alothman OY, Jawaid M, Sapuan SM, Es-Saheb M (2014a) Processing and properties of date palm fibers and its composites. In: Biomass and bioenergy. Springer, pp 1–25
AL-Oqla FM, Sapuan SM, Ishak MR, Aziz NA (2014b) Combined multi-criteria evaluation stage technique as an agro waste evaluation indicator for polymeric composites: date palm fibers as a case study. BioResources 9(3):4608–4621. doi:10.15376/biores.9.3.4608-4621
AL-Oqla FM, Sapuan SM, Ishak MR, Nuraini AA (2014c) A novel evaluation tool for enhancing the selection of natural fibers for polymeric composites based on fiber moisture content criterion. BioResources 10(1):299–312
AL-Oqla FM, Sapuan SM, Ishak MR, Nuraini AA (2015a) Decision making model for optimal reinforcement condition of natural fiber composites. Fibers Polym 16(1):153–163
AL-Oqla FM, Sapuan SM, Ishak MR, Nuraini AA (2015b) Selecting natural fibers for bio-based materials with conflicting criteria. Am J Appl Sci 12(1):64–71
AL-Oqla FM, Sapuan SM, Anwer T, Jawaid M, Hoque M (2015c) Natural fiber reinforced conductive polymer composites as functional materials: a review. Synth Met 206:42–54
AL-Oqla FM, Sapuan SM, Ishak M, Nuraini A (2015d) A model for evaluating and determining the most appropriate polymer matrix type for natural fiber composites. Int J Polym Anal Charact 20(just-accepted):191–205
AL-Oqla FM, Sapuan SM, Ishak M, Nuraini A (2015e) Predicting the potential of agro waste fibers for sustainable automotive industry using a decision making model. Comput Electron Agric 113:116–127
AL-Oqla FM, Sapuan SM, Ishak M, Nuraini A (2016) A decision-making model for selecting the most appropriate natural fiber–polypropylene-based composites for automotive applications. J Compos Mater 50(4):543–556
Alves C, Ferrão PMC, Silva AJ, Reis LG, Freitas M, Rodrigues LB, Alves DE (2010) Ecodesign of automotive components making use of natural jute fiber composites. J Clean Prod 18 (4):313–327. doi:10.1016/j.jclepro.2009.10.022
Al-Widyan MI, Al-Oqla FM (2011) Utilization of supplementary energy sources for cooling in hot arid regions via decision-making model. Int J Eng Res Appl 1(4):1610–1622
Al-Widyan MI, Al-Oqla FM (2014) Selecting the most appropriate corrective actions for energy saving in existing buildings A/C in hot arid regions. Build Simul 7(5):537–545. doi:10.1007/s12273-013-0170-3
Arbelaiz A, Fernandez B, Ramos J, Retegi A, Llano-Ponte R, Mondragon I (2005) Mechanical properties of short flax fibre bundle/polypropylene composites: Influence of matrix/fibre modification, fibre content, water uptake and recycling. Compos Sci Technol 65(10):1582–1592
Aridi N, Sapuan SM, Zainudin E, AL-Oqla FM (2016) Mechanical and morphological properties of injection-molded rice husk polypropylene composites. Int J Polym Anal Charact 21(4): 305–313
Ashby MF, Johnson K (2013) Materials and design: the art and science of material selection in product design. Butterworth-Heinemann

Ashori A, Nourbakhsh A (2010) Bio-based composites from waste agricultural residues. Waste Manag 30(4):680–684

Azwa Z, Yousif B, Manalo A, Karunasena W (2013) A review on the degradability of polymeric composites based on natural fibres. Mater Des 47:424–442

Babu KF, Subramanian SS, Kulandainathan MA (2013) Functionalisation of fabrics with conducting polymer for tuning capacitance and fabrication of supercapacitor. Carbohydr Polym 94(1):487–495

Bendahou A, Kaddami H, Sautereau H, Raihane M, Erchiqui F, Dufresne A (2008) Short palm tree fibers polyolefin composites: effect of filler content and coupling agent on physical properties. Macromol Mater Eng 293(2):140–148

Benhamou K, Dufresne A, Magnin A, Mortha G, Kaddami H (2014) Control of size and viscoelastic properties of nanofibrillated cellulose from palm tree by varying the TEMPO-mediated oxidation time. Carbohydr Polym 99:74–83

Bora M, Baruah G, Talukdar C (1993) Studies on the dielectric properties of some natural (plant) and synthetic fibres in audio frequency range and their DC conductivity at elevated temperature. Thermochim Acta 218:435–443

Cheng Q, Wang J, Wen J, Liu C, Jiang K, Li Q, Fan S (2010) Carbon nanotube/epoxy composites fabricated by resin transfer molding. Carbon 48(1):260–266

Dalalah D, Al-Oqla FM, Hayajneh M (2010) Application of the analytic hierarchy process (AHP) in multi-criteria analysis of the selection of cranes. Jordan J Mech Ind Eng JJMIE 4 (5):567–578

Dittenber DB, GangaRao HV (2011) Critical review of recent publications on use of natural composites in infrastructure. Compos A Appl Sci Manuf 43(8):1419–1429

Dweiri F, Al-Oqla FM (2006) Material selection using analytical hierarchy process. Int J Comput Appl Technol 26(4):182–189. doi:10.1504/IJCAT.2006.010763

Faruk O, Bledzki AK, Fink H-P, Sain M (2012a) Biocomposites reinforced with natural fibers: 2000–2010. Prog Polym Sci 37:1552–1596

Faruk O, Bledzki AK, Fink H-P, Sain M (2012b) Biocomposites reinforced with natural fibers: 2000–2010. Prog Polym Sci 37(11):1552–1596. doi:10.1016/j.progpolymsci.2012.04.003

Friedrich K, Almajid AA (2013) Manufacturing aspects of advanced polymer composites for automotive applications. Appl Compos Mater 20(2):107–128

George G, Joseph K, Nagarajan E, Tomlal Jose E, George K (2013) Dielectric behaviour of PP/jute yarn commingled composites: Effect of fibre content, chemical treatments, temperature and moisture. Compos Part A Appl Sci Manuf 47:12–21

Hardy JG, Lee JY, Schmidt CE (2013) Biomimetic conducting polymer-based tissue scaffolds. Curr Opin Biotechnol 24(5):847–854

Hassan ML, Hassan EA, Oksman KN (2011) Effect of pretreatment of bagasse fibers on the properties of chitosan/microfibrillated cellulose nanocomposites. J Mater Sci 46(6):1732–1740

Ho M-P, Wang H, Lee J-H, Ho C-K, Lau K-T, Leng J, Hui D (2012) Critical factors on manufacturing processes of natural fibre composites. Compos B Eng 43(8):3549–3562

Holbery J, Houston D (2006) Natural-fiber-reinforced polymer composites in automotive applications. J Miner Met Mater Soc 58(11):80–86

Ibrahim H, Farag M, Megahed H, Mehanny S (2014) Characteristics of starch-based biodegradable composites reinforced with date palm and flax fibers. Carbohydr Polym 101:11–19

Jabbour CJC, Jabbour ABLDS, Govindan K, Teixeira AA, Freitas WRDS (2013) Environmental management and operational performance in automotive companies in Brazil: the role of human resource management and lean manufacturing. J Clean Prod 47:129–140

Jahan A, Ismail MY, Sapuan S, Mustapha F (2010) Material screening and choosing methods–a review. Mater Des 31(2):696–705

Jawaid M (2011) Abdul Khalil, H.: Cellulosic/synthetic fibre reinforced polymer hybrid composites: a review. Carbohydr Polym 86(1):1–18

John MJ, Thomas S (2008) Biofibres and biocomposites. Carbohydr Polym 71(3):343–364

Kalia S, Dufresne A, Cherian BM, Kaith B, Avérous L, Njuguna J, Nassiopoulos E (2011a) Cellulose-based bio- and nanocomposites: a review. Int J Polym Sci 2011:1–35

Kalia S, Avérous L, James Njuguna J, Alain Dufresne A, Cherian BM (2011b) Natural fibers, bio- and nanocomposites. Int J Polym Sci 2011(Article ID 735932). 10.1155/2011/735932
Khalid Rehman H, Mohammad J, Rashid U (2014) Biomass and bioenergy: processing and properties, vol 1. Springer International Publishing, Cham
Koronis G, Silva A, Fontul M (2013) Green composites: a review of adequate materials for automotive applications. Compos Part B Eng 44(1):120–127
Majeed K, Jawaid M, Hassan A, Abu Bakar A, Abdul Khalil H, Salema A, Inuwa I (2013) Potential materials for food packaging from nanoclay/natural fibres filled hybrid composites. Mater Des 46:391–410. doi:10.1016/j.matdes.2012.10.044
Matsumoto R, Arakawa M, Yoshida H, Akuzawa N (2012) Alkali-metal-graphite intercalation compounds prepared from flexible graphite sheets exhibiting high air stability and electrical conductivity. Synth Met 162(23):2149–2154
Mir A, Zitoune R, Collombet F, Bezzazi B (2010) Study of mechanical and thermomechanical properties of jute/epoxy composite laminate. J Reinf Plast Compos 29(11):1669–1680
Mohanty A, Misra M, Drzal L (2002) Sustainable bio-composites from renewable resources: opportunities and challenges in the green materials world. J Polym Environ 10(1–2):19–26
Najar SS, Kaynak A, Foitzik RC (2007) Conductive wool yarns by continuous vapour phase polymerization of pyrrole. Synth Met 157(1):1–4
Prajer M, Ansell MP (2014) Bio-composites for structural applications: poly-l-lactide reinforced with long sisal fiber bundles. J Appl Polym Sci
Rashedi A, Sridhar I, Tseng KJ (2012) Multi-objective material selection for wind turbine blade and tower: Ashby's approach. Mater Des 37:521–532
Sapuan SM, Pua F-l, El-Shekeil Y, AL-Oqla FM (2013) Mechanical properties of soil buried kenaf fibre reinforced thermoplastic polyurethane composites. Mater Des 50:467–470
Sarikanat M (2010) The influence of oligomeric siloxane concentration on the mechanical behaviors of alkalized jute/modified epoxy composites. J Reinf Plast Compos 29(6):807–817
Satyanarayana KG, Arizaga GG, Wypych F (2009) Biodegradable composites based on lignocellulosic fibers—an overview. Prog Polym Sci 34(9):982–1021
Thakur V, Singha A, Thakur M (2012) Biopolymers based green composites: Mechanical, thermal and physico-chemical characterization. J Polym Environ 20(2):412–421
Yao F, Wu Q, Lei Y, Guo W, Xu Y (2008) Thermal decomposition kinetics of natural fibers: activation energy with dynamic thermogravimetric analysis. Polym Degrad Stab 93(1):90–98
Ye Y, Chen H, Wu J, Ye L (2007) High impact strength epoxy nanocomposites with natural nanotubes. Polymer 48(21):6426–6433
Yusriah L, Sapuan S, Zainudin ES, Mariatti M (2014) Characterization of physical, mechanical, thermal and morphological properties of agro-waste betel nut (Areca catechu) husk fibre. J Clean Prod 72:174–180

Springer

http://www.springer.com/978-3-319-46609-5

Green Biocomposites
Manufacturing and Properties
Jawaid, M.; Sapuan, S.M.; Alothman, O.Y. (Eds.)
2017, XII, 409 p. 150 illus., Hardcover
ISBN: 978-3-319-46609-5