Design and Fabrication of Green Biocomposites

Faris M. AL-Oqla, Ahmad Almagableh and Mohammad A. Omari

Abstract Many traditional materials that have been used in various engineering applications for long periods of time are being switched by new green materials to contribute meeting the demand of weight reduction, environmental issues as well as customer satisfaction attributes. Since natural fibers have many advantages, such as low cost, lightweight and environmentally friendly, researchers start put more effort in this area to utilize its benefits in producing bio-composite materials. However, design in green bio-composites has many challenges. One of the most important challenges is the limited availability of design data due to the large variety of fibers, matrices, and manufacturing processes. In consequence, several factors must be considered in the design process of green bio-composites, namely: processing consideration, selection of additives, selection of polymers, as well as good part design. Moreover, high coefficients of safety are still being used because of the difficulty to precisely model the material behavior, which in turn leads to oversize the structures. This is mainly due to the fact that the variation of material's properties is not linear; however, it depends on how far the material is from failure. Therefore, proper testing, evaluation and manufacturing processes have to be considered by designers to be capable of producing functional produces regarding both macro and nano-scale bio-composite.

Keywords Composites performance · Design of composites · Biocomposites · Green products

1 Introduction

The growing awareness regarding global environmental issues as well as concepts of sustainability, have together prompted the search for both new products and processes that are compatible with the environment. Designers and engineers are

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always looking for new materials and improved processes to be utilized in developing better products to maintain competitive and enhance their profit margins. Various materials that have been used in various engineering applications for long periods of time are being switched by new green materials to contribute meeting the demand of weight reduction, environmental issues as well as customer satisfaction attributes (AL-Oqla and Sapuan 2014c). As the accessible set of materials is increasing both in type and number, complex relationships between the various selections parameters appear and made the selection of a material for a particular application is a difficult task (Dweiri and Al-Oqla 2006; Al-Oqla and Omar 2015; Al-Oqla and Omar 2012; Jahan et al. 2010). It is estimated that more than 80,000 material types including metallic alloys and nonmetallic engineering materials are available in the world. Such materials include ceramics, glasses, plastics, composite materials, and semiconductors.

Designers and engineers have to consider several factors and materials related features during material selection process to achieve low-cost successful design. These factors include physical properties, mechanical properties, magnetic characteristics, electrical properties manufacturing abilities, material cost, durability, material impact on the environment, recyclability, availability as well as others. Moreover, metaphysical properties as well as the user-interaction aspects like perceptions, appearance and emotions are also considered during selecting materials (AL-Oqla et al. 2015c; AL-Oqla and Hayajneh 2007; Al-Oqla and Omar 2012; AL-Oqla and Sapuan 2014b, c). The user-interaction features usually affect the usability and nature of a product and formulated as intrinsic material properties. Therefore, the process of material selection is an interdisciplinary work and it often needs various fields of study including industrial engineering, material science and engineering, as well as other experts regarding the field of application.

On the other hand, design of an engineering element usually requires three interrelated tasks, which are 1—Choosing the material. 2—Identifying the geometry, and 3—Selecting a manufacturing process. To perform this properly right the first time via determining the optimal combination as proper design has huge benefits to any business. Such proper selection usually guarantees lower product costs, reduces the number of failures during service, fasters time-to-market, and, sometimes, significant advantages relative to business competition (AL-Oqla et al. 2015a; Alves et al. 2010).

Composite materials are on the other hand, one of the most functional types of materials for various applications. They are materials that contain at least two distinguished separated components one from another and uniformly filling its volume. They are usually produced in order to create particular desired characteristics (Bajpai et al. 2012; AL-Oqla and Sapuan 2014b; Aridi et al. 2016). Fiber reinforced polymeric composites have also been implemented in various structural applications due to their desired specific strength as well as modulus compared to metals. Such composites were initially developed for the aerospace and automotive industries, advanced composites are recently found in applications from circuit boards, to building materials as well as specialty sporting goods, energy saving and medical applications (AL-Oqla et al. 2015d; Al-Widyan and Al-Oqla 2011, 2014).

Most of these composites are designed for long-term durability and are prepared from non-degradable resins, such as polyurethane, polyethylene and epoxies in addition to high-strength fibers, like graphite, glass and aramids. As composites are formed from various dissimilar materials, it is not easy to recycle or reuse them. Moreover, most composites culminate in landfills, whereas some are burned after use, despite of some efforts for recycling and reusing.

On the other hand, the recent environmental awareness, high rate of petroleum reduction, in addition to the new environmental regulations have together prompted finding new generation of green materials. Thus, most main producers have policies to make their products green and pay efforts to enhance their recyclability to be consistence with sustainability themes. Undoubtedly, fully biodegradable plastics or green composites will have a major role in the future greening.

2 Greener Alternative Materials

Since natural fibers have many advantages, such as low cost, lightweight and environmentally friendly, researchers start put more effort in this area to utilize its benefits in using the natural fibers as reinforcement in polymers (AL-Oqla and Sapuan 2014a; Bledzki et al. 2006; Al-Oqla et al. 2016). Natural fibers play a major role in producing a wide range of composites for many applications. Comparison between glass fiber and natural fiber on environmental performance shows the superior advantages of fibers over glass in many aspects such as environmental effects during production processes, environmental pollution after use the product, and the light weight of the natural fiber composites makes it suitable in the automobile applications, so the fuel efficiency is increased, thus, emissions to the environment is decreased (AL-Oqla and Sapuan 2014c). Fiber reinforced polymeric composites have also high specific strength and modulus compared to metals. For all those reasons, fiber reinforced composites are used in wide variety of applications such as; aerospace industry, automotive parts, building materials, sporting goods, circuit boards, etc.

Currently, most of composites are made using either non-degradable polymeric resins, such as epoxies and polyurethane, or high-strength fibers, such as graphite, aramids, and glass. Many of these polymers and fibers are derived from petroleum which is a non-renewable product. For this reason using composites in place of common plastics will improve performance and reduce weight and cost of products. Since composites are made from two or more materials, it is difficult to get rid or recycle it. Most composites end up in landfills, while some are burned after use, although; some of them are recycled in expensive and complicated processes. In many applications products have been overdesigned. That is; increasing the mechanical properties for no specific reasons. A proper strength will be enough to stand the application. For instance, secondary structures, packaging, prototyping products… etc., using green composites would be strong enough to stand such applications. On other hand, get benefits from their overwhelming pros (AL-Oqla et al. 2015b).

3 Design of Green Bio-Composites

3.1 Design in Engineering

Design in engineering is a systematic way or steps used for creating functional products and/or processes. Many factors should be considered in designing a new product, some of those factors can be summarize into the following (Ashby and Johnson 2013; Dweiri and Al-Oqla 2006):

- Fitness for Purpose.
- Choice of Materials.
- Use of the product.
- Ease to manufacture.
- Quantity to be manufactured.
- Cost of the product.
- Finishing quality.
- Durability.
- Ease of Maintenance.
- Efficiency.
- Running Costs.
- Safety.
- Environmental and Social Considerations.

A design process model called Total Design in Product Development (TDPD) was established by Pugh (Pugh and Clausing 1996) to enhance engineering design process. TDPD includes several stages consist of market investigation, conceptual design, product design specification, detail design, manufacture, and sale. On other hand, many authors included embodiment design as an intermediate stage between conceptual and detail design (AL-Oqla and Sapuan 2014c; Ashby and Johnson 2013; Bledzki et al. 2006). Ashby have provided useful guidelines for product development include; geometrical design of natural fiber composites and materials selection process as shown in Fig. 1.

Generally, for design purpose one of the following well-known failure theories can be followed:

(1) Maximum shear stress theory.
(2) Maximum normal stress theory.
(3) Maximum strain energy theory.
(4) Maximum distortion energy theory.

However, the maximum normal stress theory is only applicable for brittle materials, whereas others are applicable for ductile ones (Kaw 2005). Since the natural fiber reinforced polymer 8 composites are neither isotropic nor exhibit gross yielding, other methods will be discussed in the below sections.

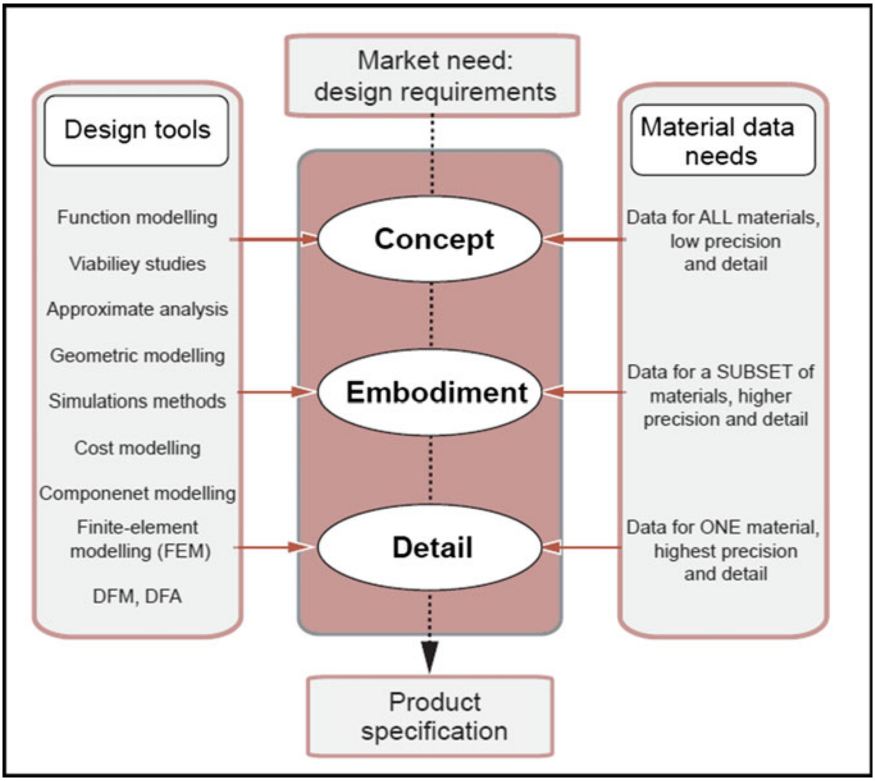

Fig. 1 Product development activities (Ashby and Johnson 2013)

3.2 Design in Composites

Design in composites has many challenges: one of the most important challenges is the limited availability of design data since the large variety of fibers, matrices, and manufacturing processes (AL-Oqla and Sapuan 2015; AL-Oqla et al. 2014a). Those changes appear because of different reinforcements materials, different fiber geometry, orientation and fiber arrangement been use. Therefore, composites have several design variables. They include the choice of material for the matrix and the reinforcement in addition to its shape, scale and configuration. The design variables in composites are demonstrated in Fig. 2.

Moreover, another serious challenge is the design against fatigue one. Since fatigue is the most common cause of structural failures in composite materials; high coefficients of safety are generally used because of the difficulty to precisely model the material behavior, which in turn leads to oversize the structures. The problem here in composites is that the variation of material's properties is not linear; however, it depends on how far the material is from failure. Therefore, safety

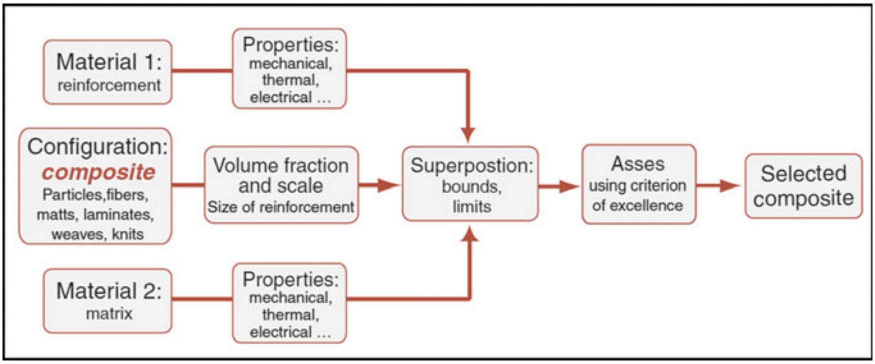

Fig. 2 The design variables in composites (Ashby and Johnson 2013)

Table 1 Safety factors for composite materials according to the loading type (Gay 2014)

High volume composites	Static loading	2
	Intermitted loading over long term	4
	Cyclic loading	5
	Impact loading	10
High performance composites		1.3–1.8

factors have to be seriously considered in the design of such composites. Safety factors for composite materials depending to the loading type are demonstrated in Table 1 (Gay 2014).

The reinforcement's variation could be in many aspects: it can be in; raw fibers; intermediate materials; or in finished items. Other ways of variation in reinforcement are fiber length, fiber arrangements (random chopped, woven roving, and nonwoven fabrics), as well as fiber types (glass, carbon, and Kevlar) fibers (Mayer 2012). In this chapter the design of green composites are considered since they have some especial treatment and behavior.

3.3 Design for Green Composites

If there were no needs for change, things would stay the same. However, in fact things are changing faster now than ever before due to several needs as shown in Fig. 3. The developing circumstances of the modern world change the boundary conditions for design. Among these circumstances are those for selecting materials and processes. These changes are driven by a number of needs. First, there is the market pull: the demand for materials that are lighter, cheaper, tougher, stiffer, stronger, and more tolerant of extremes of environment, and that offer greater functionality. Second, there is the science-push: where the curiosity-driven investigates of materials experts in

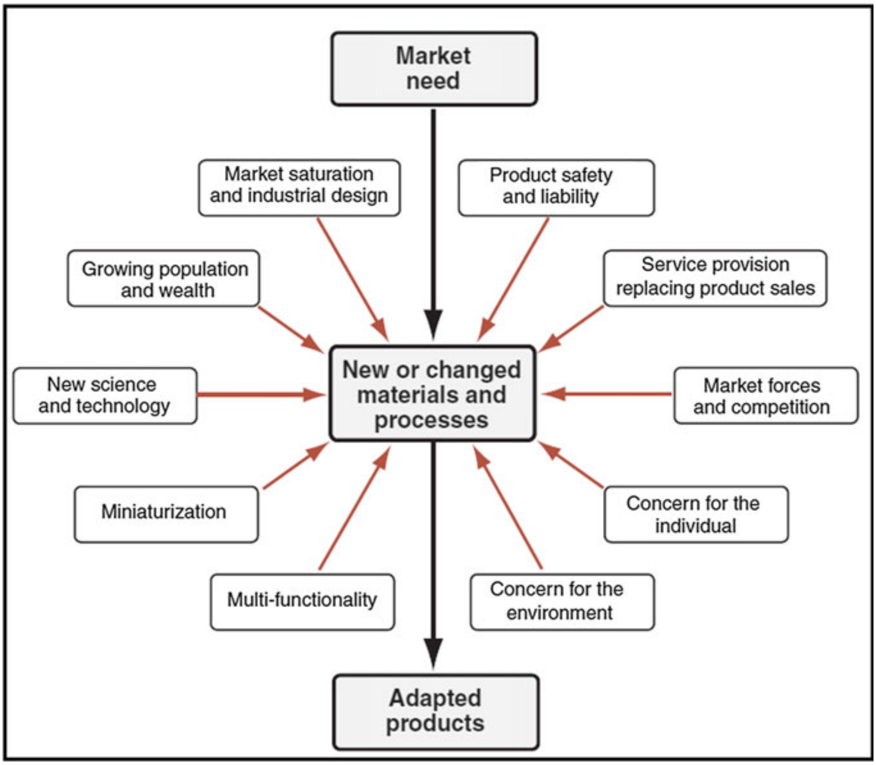

Fig. 3 Forces for change for developing new materials for product design (Ashby and Johnson 2013)

industries, universities and governments. In fact, there is a driving force of what might be called mega-projects such those of developing of nuclear powers, various defense programs as well as the space-race ones. But, today, one might think of alternative energy technologies, maintaining an ageing infrastructure of roads, drainage, bridges, and aircraft, and the threat of terrorism. In addition, the trend to miniaturization while enhancing the functionality of products is notably considered. Moreover, there is legislation regulating product safety and the liability conventional by recent legal precedent (Ashby and Johnson 2013).

In consequence, several factors must be considered in the design process of green fiber composites, namely: processing consideration, selection of additives, selection of polymers, as well as good part design (Al-Oqla et al. 2014a, b, 2015d; Al-Oqla and Sapuan 2014b). For design purposes, failure stresses of materials need to be evaluated. This can be done experimentally and/or by Finite Elements Analysis (FEA) techniques. Since the NFCs are neither isotropic nor exhibit gross yielding, the previous failure theories are not appropriate for them as these theories were developed for metals or other isotropic materials (Ihueze et al. 2013). As an alternative, various new failure theories were suggested for the NFCs, some of which will be discussed here.

3.4 Failure Prediction in a Unidirectional Lamina

Failure in composite could be caused by various deformation modes. The operative failure mode mainly be influenced by the microstructure and the loading conditions of a particular composite system. The microstructure means here fiber diameter, fiber distribution, fiber volume fraction as well as damage causing from thermal stresses, which may grow during fabrication and/or in service. Therefore, a multiplicity of failure modes may be observed in a given composite system due such many factors that do contribute to the fracture process in composites.

Plane stress condition of a general orthotropic lamina containing unidirectional fibers at a fiber orientation angle of θ with respect to the x axis (Fig. 4) will be discussed here as it is strongly suitable for the natural fiber reinforced polymer composite materials and their designs.

For such failure prediction, first, one needs to calculate the four independent elastic constants, namely, E11, E22, G12, and ν12 which are the moduli of

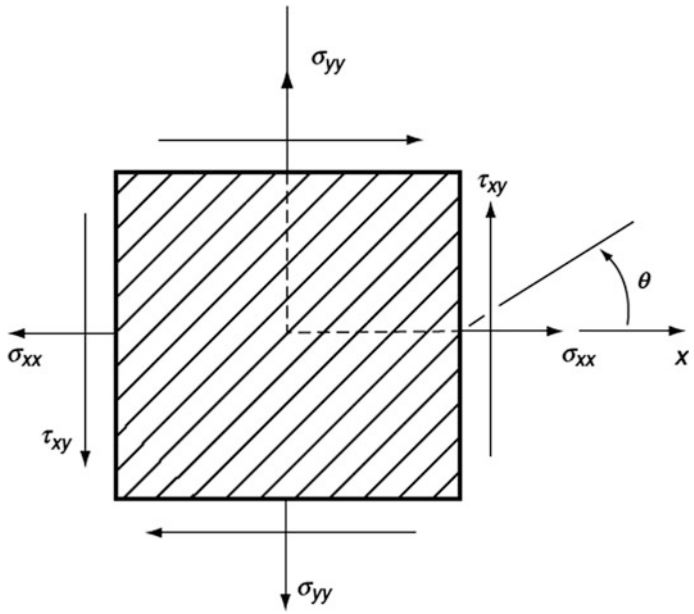

Fig. 4 Two-dimensional stress state in a thin orthotropic lamina

elasticities, modulus of rigidity and Poisson's ratio with respect to directions 1 and 2, in order to define elastic characteristics and properties namely:

S_{Lt} = longitudinal tensile strength
S_{Tt} = transverse tensile strength
S_{Lc} = longitudinal compressive strength
S_{Tc} = transverse compressive strength
S_{LTs} = in-plane shear strength

Then, based on of the following theories one can predict the failure in a unidirectional lamina under plane stress conditions.

3.4.1 Maximum Stress Theory

In this theory, failure is proposed to occur when any stress in the principal material directions equals or exceeds the corresponding ultimate strength. That is;

Normal stress (σ11 and 22) as well as the shear stress (τ12) must be within the following limits as:

- $S_{Lc} < \sigma 11 < S_{Lt}$,
- $S_{Tc} < \sigma 22 < S_{Tt}$,
- $S_{LTs} < \tau 12 < S_{LTs}$.

3.4.2 Maximum Strain Theory

According to the maxi mum strain theory, failure occurs when any strain (ε) in the principal material directions is equal to or greater than the corresponding ultimate strain.

- $\varepsilon_{Lc} < \varepsilon_{11} < \varepsilon_{Lt}$
- $\varepsilon_{Tc} < \varepsilon_{22} < \varepsilon_{Tt}$,
- $\gamma_{LTs} < \gamma_{12} < \gamma_{LTs}$.

3.4.3 Azzi-Tasi-Hill Theory

Here, failure will occur in an orthotropic lamina if the following equality is satisfied:

$$\frac{\sigma_{11}^2}{S_{Lt}^2} - \frac{\sigma_{11}\sigma_{22}}{S_{L1}^2} + \frac{\sigma_{22}^2}{S_{Tt}^2} + \frac{\tau_{12}^2}{S_{LTs}^2} = 1$$

Where σ_{11} and σ_{22} are tensile stresses.

3.4.4 Tasi-Wu Failure Theory

According to this theory, a failure may occur in an orthotropic lamina if the following equality is satisfied

$$F_1\sigma_{11} + F_2\sigma_{22} + F_6\tau_{12} + F_{11}\sigma_{11}^2 + F_{22}\sigma_{22}^2 + F_{66}\tau_{12}^2 + 2F_{12}\sigma_{11}\sigma_{22} = 1$$

where F1, F2,…etc. are the strength coefficients, and are expressed as:

$$F1 = \frac{1}{S_{Lt}} - \frac{1}{S_{Lc}}$$
$$F2 = \frac{1}{S_{Tt}} - \frac{1}{S_{Tc}}$$
$$\mathrm{F6} = 0$$
$$F11 = \frac{1}{S_{Lt}S_{Lc}}$$
$$F22 = \frac{1}{S_{Tt}S_{Tc}}$$
$$F66 = \frac{1}{S_{LTs}^2}$$

and $F12$ is a strength interaction term between σ_{11} and σ_{22}. $F1$, $F2$, $F11$, $F22$, and $F66$ can be found using the strength properties (tensile property, compressive, and shear ones) in the principal material directions in MPa (Tsai 2008) (Fig. 5).

3.5 *Failure Prediction for Unnotched Laminates*

For un-notched laminates, ultimate failure prediction theory will be used. In this theory the following steps can be tracked:

1. Compute stresses and strains using the lamination theory for each lamina.
2. Utilize the suitable failure theory for predicting the first failed lamina.
3. Give reduced stiffness and strength to the failed lamina.
4. Recalculate stresses and strains in each of the remaining laminas using the lamination theory.
5. Complete steps 2 and 3 to predict the next lamina failure.
6. Repeat steps 2–4 until ultimate failure of the laminate occurs.

Stress and strain are calculated in each lamina utilizing the lamination theory by following steps:

1. Finding the laminate stiffness matrices.

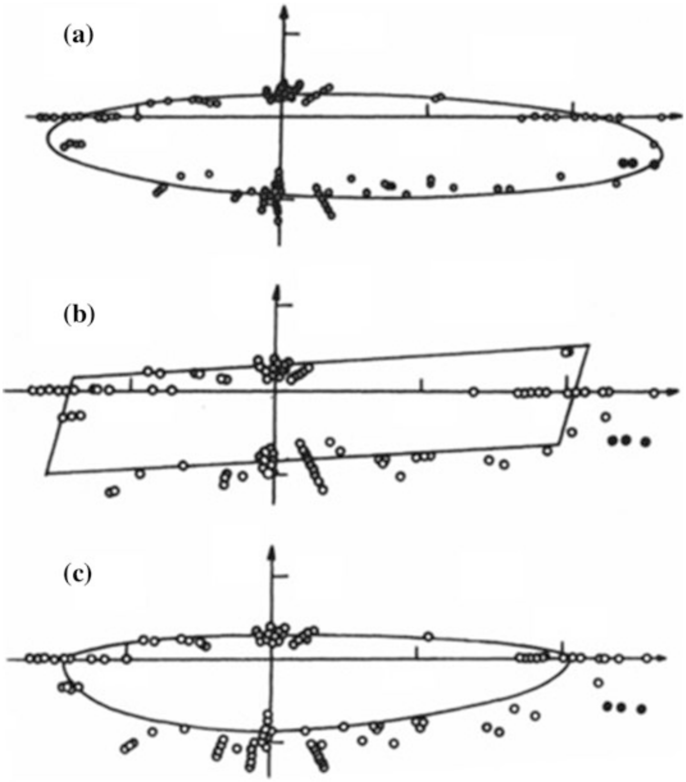

Fig. 5 Comparison of **a** Tsai–Wu, **b** maximum strain, and **c** Azzi–Tsai–Hill. Failure theories with biaxial strength data of a carbon fiber-reinforced epoxy composite where stresses are in MPa (Tsai 2008)

2. Computing the laminate mid-plane strains and curvatures corresponding to a given applied loading (forces and moments).
3. Calculating the in-plane strains ε_{xx}, ε_{yy}, and γ_{xy} for each lamina.
4. Calculating the in-plane stresses σ_{xx}, σ_{yy} and τ_{xy} in each lamina.

3.6 Failure Prediction in Random Fiber Laminates

The most common methods in predicting laminates failure in randomly oriented discontinuous fibers-based composites is the Hahn's method. Here, failure can be predicted if the laminate's maximum tensile stress equals a certain strength averaged over all possible fiber orientation angles (Mallick 2007) as:

$$S_r = \frac{4}{\pi}\sqrt{S_{Lt}S_{Tt}}$$

where,

Sr = the random fiber laminate strength
S_{Lt} = longitudinal strength of a 0° laminate
S_{Tt} = transverse strength of a 0° laminate.

3.7 Material Modelling

In the analysis of green composites many challenging concerns have to be considered including the complexity of the mechanical interactions between the composite ingredients, principally when the applied loads can generate local damage and successive failure. The failure mechanisms in natural composite components are totally unlike from that of conventional metal components. Moreover, the static/dynamic failure includes matrix cracking, fiber break, and layer delamination. The mechanical response complexity in natural fiber composites shows several problems in predicting reliable performance of such composites; however, finite element method (FEM) became a very common tool for simulating such engineering material problems. It is believed that material characterization needs to be performed looking towards the overall size and behavior of the structure. Finite element models are in substantial agreement with the small scale tests while larger differences may be found with the large scale ones. Besides to the manufacturing defects, which is more obvious to be higher in larger structures, the interaction of failure modes may lead to lower material strength. An example of a FE model with the consistent experimental test is shown in Fig. 6.

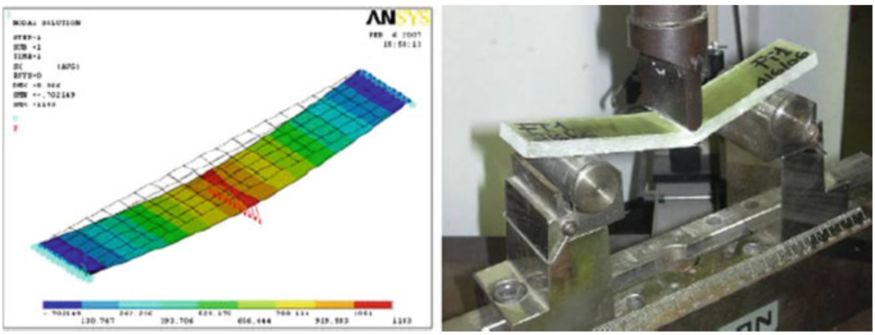

Fig. 6 Consistency between FE model and experimental test

4 Nano-Composites for Engineering Design

Conventional composites are no longer able to satisfy outstanding demands for materials with improved properties (particularly mechanical and thermal), nor can they be designed to be with controlled properties at the microscopic scale. Such controlled properties are highly needed as the macroscopic properties are highly influenced by their molecular structure particularly under external loading like that of impact and thermal energy. Fortunately, nanocomposite materials are now engineered at the atomic level to create large structures with primarily new molecular network.

4.1 Nanofibers from Natural Fibers

Nanofibers are fibers that have diameter equal to or less than 100 nm. One major feature of nanofibers is the huge availability of surface area per unit mass. Such area of nanofibers offers a notable capacity for attaching or releasing functional groups, catalytic moieties, absorbed molecules, ions and nanometer scale particles of many kinds. 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 for nano-composites but 0.3% of the total volume of polymer for micro-filled composites. Such large interfaces within the nanocomposites promotes adhesion energy, increasing molecular bonding, leading to an increase in the chemical bonding that enhances the crosslinking in polymers. This in order resulting in improvements in mechanical properties (Ye et al. 2007). On the contrary, a small participation due to the interphase offers diverse potential of performance tailoring and is capable of influencing the characteristics of the polymers to a much higher extent under rather low particle content. Moreover, to show excellent mechanical properties that are visible gains for nanocomposites, nanotubes, for instance, are predicted to have an fascinating mode of plastic performance, showing a step-wise diameter reduction (local necking) and lattice orientation change. Such highly flexible elastic mobility is extremely functional and could play a significant role in increasing the toughness of nanotube reinforced composites by increasing the energy absorption under deformation (Ye et al. 2007).

4.2 Nanoclay

For more sustainable design possibilities there is a considerable progress in the mechanical and physical properties of clay reinforced composites at a very low silicate loading (4 wt%). The field of polymer/nanoclay composites has gained

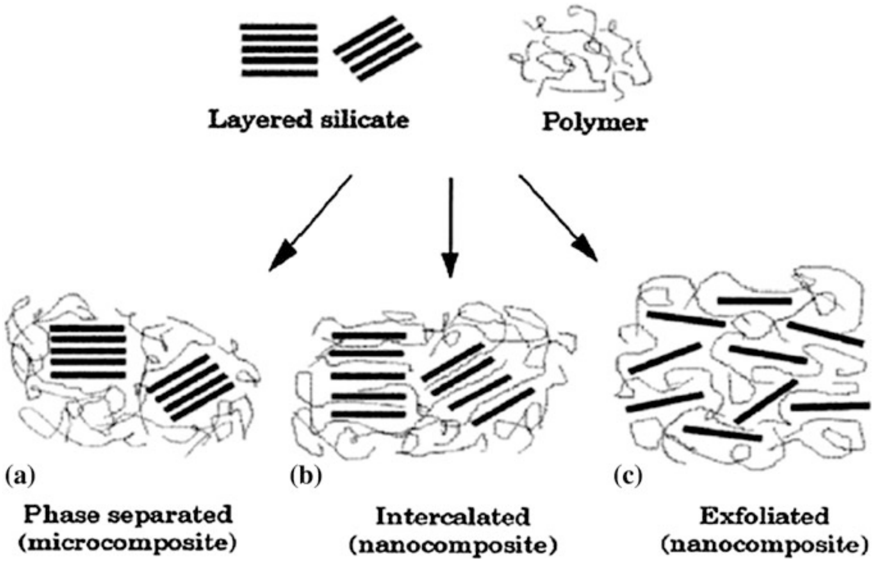

Fig. 7 SEM images of **a** intercalated, **b** expanded, and **c** sonicated (exfoliated) silicate nanocomposites (Alexandre and Dubois 2000)

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 to intercalate between the silicate layers as shown in Fig. 7a. In intercalated formation, more than one matrix molecules is intercalated between clay layers as shown in Fig. 7b 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. 7c.

4.3 *Exfoliated Graphite Nanoplatelet (XGnP)*

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).

Graphite allows to link with various atoms, ions, and molecules in the space provided between its hexagonal sheets of carbon atoms through physical and chemical treatment process. This process is called intercalation. Exfoliated graphite exhibits high aspect ratios, which can reach 1000, once intercalated and exfoliated by chemical processes. Graphite platelets reinforced nanocomposites show excellent electrical and thermal conductivity in addition to enhancements in strength, stiffness, heat distortion temperature (Matsumoto et al. 2012).

5 Natural Fiber Composites Tests

As in metals, mechanical features of natural fiber need to be tested and improved. The most important properties here are the tensile strength, flexural, impacts, fatigue and creep. Natural fibers generally are appropriate to reinforce polymers due to their relative high strength, stiffness and low density (AL-Oqla et al. 2015a, b).

5.1 Tensile Testing of Bio-Composites

The tensile test is the most important test in bio-composites as in metals. The properties taken from tensile test are vital factors for the selection of an exact cellulosic fiber for a precise application. Moreover, tensile properties can be improved, for example, to increase the tensile strength of HDPE/hemp fiber composites, silane as well as the matrix-resin pre-impregnation of the fiber should be done. Experiments presented that the longitudinal tensile strength dramatically increased for the silane-treated fibers. On the other hand, transverse tensile strength was not significant in natural composites. It is obvious that the performance of natural composites is fiber controlled, due to the fact that the longitudinal fiber direction is much greater comparable to the transverse direction.

General experimental conclusions in the area of natural fiber composites can be generally dedicated for the purpose of design as:

- The tensile modulus depends upon the amount of fiber loading as mentioned by the modified rule-of-mixture equation.
- The tensile strength for particular natural fiber/polymer composites tends to decrease with fiber loading, due to the poor adhesion between the matrix and the fibers.
- Tensile strength might be increased when natural fibers chemically treated.
- The following factors should be also considered to study the tensile properties for the thermoplastic matrices: moisture absorption, the effect of surface treatment (using NaOH), the performance of hybrid natural fiber reinforced polymer composites, the fiber size, and the fiber orientations in the composites.
- For natural fiber reinforced thermosets the following factors should be considered via the siloxane treatment of polyester-based and epoxy-based composites to determine the tensile properties; the temperature as well as the effects of a

differing geometry in the composites, the effect of moisture absorption, the effect of fibers volume fraction, and the impact of the fiber orientation, The hybridization and chemical mode-fictions of fiber-natural rubber composites, the impact of high temperature on biodegradability of resin composites, the result of biodegradable matrix sort like that of PLA, PHBV, and PBS on renewed cellulosic/biopolymer composites, as well as others (Faruk et al. 2014; Favaro et al. 2010; George et al. 2013; Sapuan et al. 2013; Satyanarayana et al. 2009).

5.2 Impact Test of Bio-Composites

Major challenge of bio-fiber reinforced composites is the impact strength. Continuous improvement of new fiber manufacturing techniques along with enhancement of filler/matrix adhesion is required to pass out this challenge. Charpy impact test showed increases in impact strength, in some cases the strength be doubled comparable to values in the literature. Compared four types of boards made from composites consisting of HDPE and types of rice straw components (rice husk, straw leaf, straw stem, and whole rice straw) formed by melting and compression molding (Shah and Lakkad 1981); the results revealed that panels with rice husk demonstrated the best impact strength. However, no significant changes occurred regarding the impact properties for boards made from leaf, stem, and whole straw fibers. On other hand, the recycled HDPE composites had better impact strength than the virgin ones (Shah and Lakkad 1981). Moreover, they have demonstrated that the toughness of natural composites can be subjective to various number of factors including the matrix intrinsic properties, the fiber volume fraction, and the filler-matrix bond strength (Anyakora 2013).

6 Manufacturing Processes of Bio-Composites

The public feature in all polymeric-based composite methods is the joining of a resin, a curing agent, some type of fillers, and sometimes a solvent. Usually, both heat and pressure are utilized to shape as well as curing the mixture into a final product. In natural fiber reinforced composites materials the resin holds the fillers together in addition to their protection as well as transferring the load to the fibers in the composite. The curing agent (or hardener) on the other hand, usually acts as a catalyst to help the curing process of the resin to a hard plastic. Several manufacturing process for green composites are usually utilized such as:

6.1 Hand Lay-Up

Fibers are trimmed here and spread over a mold after being designed to the wanted shape. Some layers may be necessary. After making, a vacuum bag is wrapped all over the place of the lay-up, where vacuum is utilized in this process to eliminate air, compressed the part and make a barrier for the assembly when it is located in an autoclave for curing under both heat and pressure.

6.2 Resin Transfer Molding

Resin transfer molding is utilized for making smooth surface parts with low pressure. Fibers are usually laid by hand into a mold then resin mixture is poured into its cavity. The part is then cured under heat and pressure. Pictorial view for the resin transfer molding is shown in Fig. 8.

Resin transfer molding has several advantages (Kim and Pal 2010) such as:

1. Large and complex shapes can be prepared efficiently and inexpensively.
2. Faster than the layup process.
3. Low clamping pressures is required.
4. Better surface definition than layup.
5. Inserts and special fillers can be easily added.
6. Operators may be unskilled.
7. Part consistency is good.
8. Worker exposure to toxic chemicals is minimized.

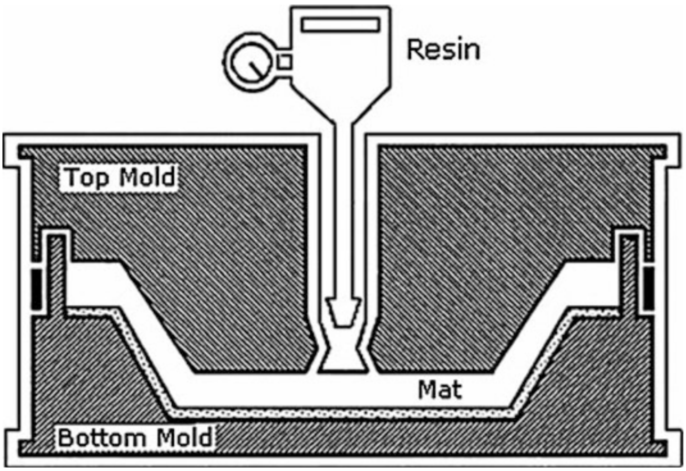

Fig. 8 Resin transfer molding

However the disadvantages including that the mold design is complex, produced material properties are good, but not optimal, resin to fiber ratio is hard to be controlled, and will vary in areas such as corners in addition to that reinforcement may move during injection causing problems in the produced parts.

6.3 Pultrusion

Pultrusion is a process where continuous roving strands are pulled from a creel through a strand-tensioning device into a resin bath. The coated strands are then passed through a heated die where curing occurs (Kim and Pal 2010). The continuous cured part is then cut into desired lengths. A schematic diagram of the pultrusion process is demonstrated in Fig. 9. It has some advantages (Kim and Pal 2010) such as:

1. Good material usage.
2. High throughput can be achieved.
3. Good resin contents.

The disadvantages are:

1. Needs uniform cross Section.
2. Fiber and resin might accumulate at the die opening resulting in increasing friction causing jamming and breakage.
3. If excess resin is used, part strength will decrease.
4. Voids can result if die is not conforming well to the fibers being pulled.
5. The strength of the produced part may be decreased due to the quick curing system.

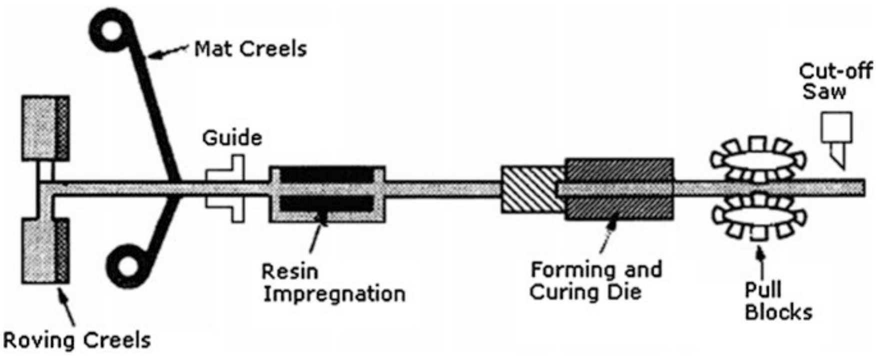

Fig. 9 Schematic view of pultrusion (Kim and Pal 2010)

6.4 Extrusion Processes

It is forcing a thick, viscous liquid through small holes of a device called a spinneret to form continuous strings (filaments) of semi-solid polymer. This process usually achieved by heat and pressure in case the polymers are thermoplastic synthetic, this kind of thermoplastics can be processed by heat, or by dissolving in a suitable solvent in case they are non-thermoplastic. Recently, new technologies have been developed for some specialty fibers made of polymers that do not melt, dissolve, or form appropriate derivatives by reacting with small fluid molecules. The most important part of this process is the spinneret. The spinneret looks like the bathroom shower head, i.e. it is a plate made from a corrosion-resistant metals has a bunch of small holes. Since those holes are small, they need a special kind of treatment; such that filtering the liquid that will feed them, maintenance, and schedule for disassemble and clean them regularly.

There are four methods of spinning filaments (solidification of the liquid polymer when exit from spinneret) of manufactured fibers: wet, dry, melt, and gel spinning.

6.4.1 Wet Spinning

It is used for fiber-forming substances that have been dissolved in a solvent. The spinnerets are submerged in a chemical bath and as the filaments emerge they precipitate from solution and solidify. Because the solution is extruded directly into the precipitating liquid, this process for making fibers is called wet spinning. Acrylic, rayon, aramid, modacrylic and spandex can be produced by this process.

6.4.2 Dry Spinning

The same as wet spinning but instead of the use of chemical reaction solidification is achieved by evaporating the solvent in a stream of air or inert gas.

6.4.3 Melt Spinning

In melt spinning, the fiber-forming substance is melted for extrusion through the spinneret and then directly solidified by cooling. Different cross-sectional shapes can be produced in this method such as; round, trilobal, pentagonal, octagonal, and others. For instance, to decrease soil and dirt in carpet make, it is recommended to use pentagonal-shaped and hollow fibers.

6.4.4 Gel Spinning

Gel spinning Uses to produce special fiber properties such as, high strength. The tensile strength can be increased by keeping the polymer in thick liquid state during extrusion process. The polymer chains will bound together at numerous points in liquid crystal form.

6.5 Natural Fiber Injection Process

The most widely used molding method in the industry to produce polymer composites due to its simplicity and fast processing cycle. Injection molding machine mixes and injects a pre-calculated amount of matrix and fiber mixture into the mold resulting in the desired product. It consists of three major sections: the injection unit, mold, and ejection & clamping unit.

The injection unit: contains a heated screw barrel having a compression screw. The function of each part is clear from its name. i.e., heated barrel provides heat to the polymer matrix to melt before injection, the screw carries and compress the pellets from the hopper into the heated barrel, mix the polymer matrix and fiber, and inject the mixture into the closed mold having the product final shape. The molds are as any other mold that uses in regular injection process. Molds are made by Computer Numerical Control (CNC) machining processes, they have cooling/heating coils to regulate the temperature of the mold itself and ejectors to eject the final product outside the mold when the processes complete.

7 Future Perspective

Bio-composites have been stressed to be implemented in wide range of industrial applications and have been slowly switching conventional materials. The upward interest in long-term sustainability as well as the awareness of the environmental issues, have made a need for design with green bio composite materials as they have greater specific strength and stiffness, greater fatigue strength and impact absorption capacity better resistance to corrosion, recyclability, natural hazardous environments, lower life-cycle costs, and non-toxicity. As green composites are developed to be involved to more structurally demanding components they have to be designed considering various conflicting factors. The mechanisms of failure in green bio-composite components are entirely different from that of conventional metal components. Static and dynamic failure includes matrix cracking, fiber break, and layer delamination. The complexity of the mechanical response of natural fiber composites presents great difficulties in predicting reliable performance of such composites. This in order makes the proper selection of the bio-composites constituents is mandatory issue utilizing new combined evaluation criteria for both macro and nano-scale of green products.

8 Conclusions

The interfacial bonding between bio-composites constituents is crucial in governing their mechanical performance. It is essential to attain the most constructive reinforcement conditions to minimize failure inside the composites. The fabrication process would dramatically affect the final behaviour of the green composites as they may destroy the desired properties of the reinforcement. Therefore, for design purposes, failure stresses of materials need to be evaluated. This can be performed experimentally and/or by Finite Elements Analysis (FEA) techniques. Since green composites are neither isotropic nor show gross yielding, failure theories established for metals or other isotropic materials are not applicable to those kinds of materials. Instead, many new failure theories have been proposed for such bio-composites.

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