Chapter 1
Introduction

This chapter provides several information about polymer composites with emphasis on vegetable fiber-reinforced polymer composite materials, as well the motivation to study the water absorption process in these materials. Herein, we present and discuss different topics such as definition, classification, constituents, technological characteristics, manufacturing techniques, performance and applications of polymer composites.

1.1 Motivation

Both academy and industry have given special attention to understand and predict the properties of composite materials as these materials have a wide range of applications in different sectors such as: boats, ships, automotive and aircraft components, submersibles, offshore structures and prostheses. Fiber reinforced polymer composite materials have been preferred to designing structural materials when compared to conventional materials (metals and ceramics), especialy that originated from vegetable fiber as reinforcement. The reasons for replacing syntetic fibers in polymer composites are the good set of mechanical properties (strength and stiffness) displayed by vegetable fibers, their availability, low cost, low density as well as other characteristics.

The mechanical properties of composite materials strongly depend on good adhesion between fiber and polymer matrix, which in turn, strongly depend on the manufacturing techniques employed to make them and on the operational and environmental conditions during use. One of these conditions is moisture absorption, especially at high temperatures.

Despite of its importance, few books offer detailed information about the water absorption process in vegetable-fiber reinforced polymer composites including experiments, mathematical models and their analytical and numerical solutions.

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Mathematical modeling and numerical computation are processes to obtain solutions for physical problems of academic and/or industrial interest and these include differential equations of mass and energy conservations. In these areas, books dedicated to this theme are rather scarce and limited to providing an understanding on this issue only under rectilinear infiltration using Fick´s second law of diffusion. However, is some situations, polymer composites display an anomalous behavior during the water absorprion process. In these cases, Fickian diffusion fails, particularly in the final stages of the process. Information addressed to the physical problems associated with the water uptake in polymer composite materials involve partial to non-Fickian moisture absorption. This information is almost null when dealing with polymer composites reinforced by vegetable fibers in 3D-geometry.

This comprehensive book aims to respond to the large growing interest associated with Fickian and non-Fickian moisture absorption processes in polymer composites, especially that involving advanced mathematical treatment of the governing equations, experiments and numerical computation. It is the first book entirely dedicated to this important subject.

The key challenge of this book is to document different information related to fiber-reinforced polymer composites ranging from basic material and manufacturing to advanced mathematical modeling of water migration in fibrous media, their effect, and applications, in a unique volume. This book contains information about Fickian and non-Fickian diffusion of water inside vegetable-fiber reinforced polymer composites, a subject not yet treated and discussed together.

The goal is to provide an in-depth analysis of the key issues including rigorous and coupled engineering models, theoretical and experimental results, and general fundamentals about water absorption in polymer composites reinforced by vegetable fiber. Thus, this book will assist professionals, curious readers, undergraduate and graduate students, as well as applied mathematicians, engineers and scientists to better understand advanced topics associated with fiber-reinforced polymer composites especially those related to the moisture absorption process.

Further, the authors sincerely believe that this book becomes an excellent reference source for professionals already cited and a start point for encouraging different people to study both polymer composite materials and the effect of water absorption in these materials.

1.2 Composite Materials: Fundamentals

Composites are multiphase materials consisting of one or more discontinuous phases (reinforcing filler), embedded in a continuous phase (matrix) [1–7]. Based in this definition, it is a new material obtained by combination of two or more materials insoluble in each other, with specific properties not found in either material alone.

Composites can be classified according to the type of matrix, the type, geometry and shape of the reinforcement used. In general, inorganic materials are used as reinforcement in organic matrices. Thus, composite materials can be classified as fiber-reinforced composites (fibrous composites) and particle-reinforced composites (particulate composites). Sometimes metallic wires and ribbons are used as reinforcement in composites.

Composite materials can also be classified according to the chemical and physical nature of the matrix which can be: ceramic, metallic or polymeric. Ceramic materials are inorganic in nature, have high resistance to heat and are fragile. Metallic materials, in general, present high ductility and excellent thermal and electrical conductivities. The great limitation in the use of metallic materials as reinforcement in composites is their high density and manufacturing costs. On the other hand, polymeric materials stand out for their low density, easy conformation and high electrical resistivity [8, 9].

Composites properties are strongly dependent on the properties of their constituents (matrix and reinforcement). In general, reinforcing materials are harder and stronger than the matrix. Thus, these materials are added to the matrix in order to increase some of its properties so as to achieve the best properties for a given application.

The shape, size, distribution, content and filler (reinforcement) orientation as well as the matrix/filler interfacial bonding strongly affect the initial and long term properties (hydro, thermal, electrical and mechanical) of the composites whose performance can also be affected by environmental exposure resulting in volumetric variations (swelling). Thus, it is very important to know these materials (matrix and reinforcement) in detail.

Depending on the nature and geometry of the reinforcement, the following classification applies:

(a) Nature: These materials must be hard to promote increase in hardness and abrasion resistance; rupture resistant to provide high tensile, flexural and shear strength; rigid to increase elastic modulus; flexible to increase impact resistance, and heat resistant to increase thermal stability of the composite.
(b) Geometric characteristics: These materials can be particulate, fibrous, and laminates.

Further, fiber reirforcements (long or short), globular particles and platelets can be incorporated into ductile or brittle matrices at random or in oriented laminates, generating composites with different structures and properties [8–14].

The reinforcing material can be a synthetic fiber (glass, carbon, aramid, etc.) or a natural fiber (sisal, ramie, jute, cotton, kenaf, pineapple, etc.) or particles (clay, mica, tungsten carbide, titanium carbide, etc.). Mineral fillers as reinforcements, often can be incorporated into matrix in order to reduce costs, especially when associated to ultra high strength fibers. Figure 1.1 illustrates a scheme for the classification and types of composite materials.

The matrix is responsible for the external appearance of the composite and the protection of the reinforcement against chemical and physical attacks. The fillers may be well dispersed of agglomerated in the composite matrix. However, when subjected to stresses, the matrix must deform sufficiently in order to adequately distribute and transfer stresses to the reinforcing material. The proper choice of matrix and reinforcement to be used in a structural application is defined based on the strain that

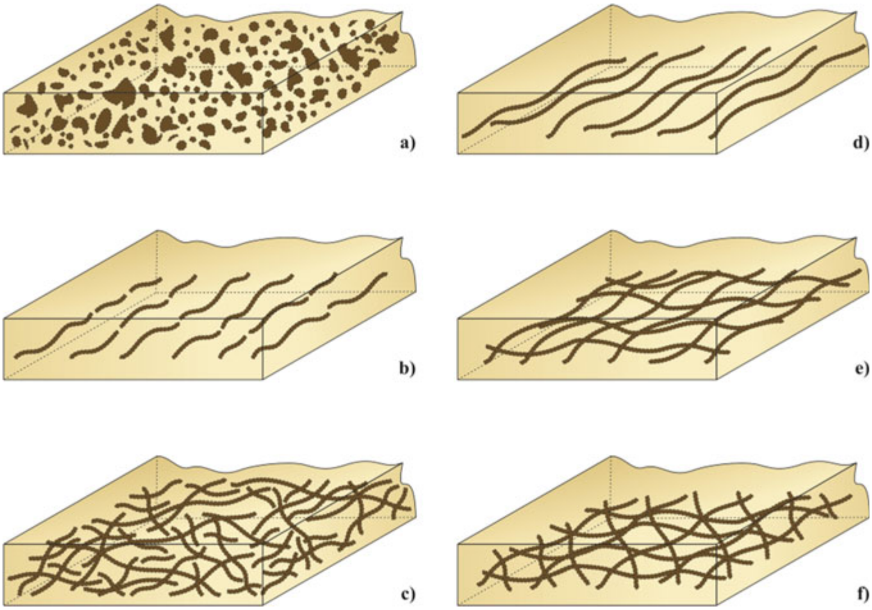

Fig. 1.1 Classification and types of composite materials. **a** Dispersed particle-reinforced, **b** Discontinuous fiber-reinforced (aligned), **c** Discontinuous fiber-reinforced (randomly oriented), **d** Continuous fiber-reinforced (aligned), **e** Continuous fiber-reinforced (aligned 0°–90° fiber orientation angle), and **f** Continuous fiber-reinforced (multidirectional fiber orientation angle)

the composite will receive during use. Mechanically speaking, matrix deformation must be compatible with the maximum deformation of the reinforcement [15–17].

Polymer composites can be defined as multi-phase materials formed by reinforcing fillers embedded in a polymer matrix.

Polymer matrices are classified as thermosets (epoxy, polyester, phenolic, silicone, polyimide, etc.) or thermoplastics (polyethylene, polystyrene, nylons, polycarbonate, polyether-ether ketone, polyphenylene sulfide, etc.). These matrices are most widely used due to their moderate cost, easy processing, good chemical resistance, and low density [1].

The use of conventional and engineering thermoplastics, as polymer matrices has been restricted to medium performance composites. The limited thermal stability of thermoplastics at high temperatures restricts their use for specific applications. However, the incorporation of reinforcements with specific characteristics in thermoplastic matrices has allowed applications of the polymer composite in temperatures up to 150 °C [15].

Epoxy resins, despite having excellent mechanical properties, are penalized by high costs and low resistance to weathering. Curing of these resins is much more complex than that of polyester resins. In the case of phenolic resins, their main disadvantage to the polyester and epoxy resins is that during their curing, water is formed as a by-product. Therefore, its application in composites is more complex, since the removal of produced moisture becomes an important factor during manufacturing [16].

Polyester resins are used in composites due to their low cost and satisfactory mechanical properties. After cured, these materials present good electrical properties, corrosion resistance and chemical attacks. Curing of the polyester resin is an exothermic process and requires an organic peroxide based curing system as the catalyst [16, 17]. Furthermore, polyester resins have ester groups as fundamental elements in their molecular chains, resulting from the condensation reaction of a diol with a diacid. Thus, depending on the type of acid used in the process, the polyester can be either saturated (thermoplastic) or unsaturated (thermoset) [17].

In general, fiber-reiforced polymer composite manufacturing techniques are classified as open mold and closed mold processes. The first allows for multi-directional orientation of the fibers relative to the mold or mandrel, except for pultrusion, where fibers are oriented in the direction parallel to the laminated surface. These processes include hand lay-up, spray up [18–22], filament winding [20, 21, 23], and pultrusion [20, 23, 24]. Closed mold process, in turn, produce fiber orientation in the direction parallel to the mold surface, includes compression molding and transfer molding [23, 25, 26].

Hand lay-up is the oldest and simplest manual production process; however, it also is the slowest. It can be adapted for the production of large structures, although it is more interesting for small productions [18].

Hand lay-up continues to be one of the most important manufacturing processes for small batch production of fiber reinforced composites, although increasing stringency of emission regulations has forced many manufacturers to explore the use of closed mold alternatives. Hand lay-up is carried out at room temperature using catalyzed liquid resins. The resin is poured in the mold containing the reinforcement. The matrix starts to cure in the mold, through an exothermic chemical reaction between the catalyst and the resin, solidifies and a fiber reinforced composite is obtained without the need of external heating. The method begins with the preparation of the mold where the reinforcing fiber layers will be stacked; usually a release agent is used on the mold, in order to facilitate demolding after curing. The impregnation process is performed manually with the help of rollers or brushes by pressing the resing and fiber layers to eliminate air bubbles and excess resin. Layers of fabric, mats, oriented or random fibers are stacked and impregnated with resin one by one in an open mold. After stacking all layers, an upper molding plate may be applied to allow for a better finish on both outer surfaces of the composite. Despite the steady progress to replace the manual layout with an automated process, it still persists as the method by which at least half of the entire advanced composite aerospace structures are made [19, 20, 27].

Hand lay-up continues to be used because it is extremely flexible to allow a wide variety of shapes of the desired composite [21]. Although it presents some disadvantages such as the quality of the final product depends on the ability of the worker, has low productivity and releases volatiles during manufacturing. Furthermore, as production volumes increase and economic factors become very important for decision making, manual placement gradually must be replaced or modified by the use of new automated technologies.

Nowadays, synthetic fiber-reinforced polymer composite materials are used in different sectors such as: aerospace, maritime, automotive, biomedical and transportation in specific applications as well as in high-tech sporting equipment [1–8, 12]. Already, vegetable fiber-reinforced polymer composites are used in the several construction sectors such as: automotive, building, transportation, consumer goods, sports equipment, design equipment, etc. [28–36].

Despite of the attractiveness, depending on the type of polymer composites, these materials are strongly affected when exposed to the adverse operating conditions such as electromagnetic and thermal radiation, galvanic corrosion (metals as reinforcement), oxygen at high temperatures (thermo-actived oxidative reactions), and water in the liquid and vapor (including moist air) phases. Therefore, innovative researches related to polymer composite degradation are strongly recommended, and with it, new challenges should arise.

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