ISSN : 2350-0743

www.ijramr.com

International Journal of Recent Advances in Multidisciplinary Research

Vol. 06, Issue 04, pp.4790-4797, April, 2019

REVIEW ARTICLE

A LITERATURE REVIEW ON NATURAL FIBERS, ITS PROPERTIES AND INFLUENCE OF WATER ABSORPTION ON MECHANICAL PROPERTIES OF COMPOSITES

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ARTICLE INFO

Article History:

Received 19th January, 2019
Received in revised form
16th February, 2019
Accepted 13th March, 2019
Published online 30th April, 2019

Keywords:

Natural Fibers, Composites, Chemical Property, Water Absorption, Hydrophilic Behavior, Mechanical Properties.

ABSTRACT

Natural fibers composites are low-cost fibers with high specific properties, low density and eco-friendly. The development of advanced bio composite materials made is increasing in the world. It will be an alternative way to develop the bio-composites which can be particularly used for daily needs of common people whether it is house hold furniture, house and light weight car components and other equipment. This effort to develop bio-composite materials with improved performance for global applications is an ongoing process. Therefore, it is important to study the water absorption behavior in order to estimate, not only the consequences that the water absorbed may have, but also the durability of natural fibers composites aged under water, to plan a possible surface treatment in order to improve its mechanical properties.

INTRODUCTION

In the context of challenging environmental issues and a global energy crisis, bio-based materials are attracting increasing levels of research interest, from both academia and industry because of their numerous advantages. We will have to face simultaneously with a rarefaction of the fossil resources and with the ecological risks, in particular the effect of greenhouse. The use of the biomass for chemistry, energy and the materials are one of the answers. This paper gives an overview of the various studies conducted in the recent past on natural fibers. A lot of researchers have studied the variation of properties of the natural fibers by varying many parameters. Natural fibers such as hemp, flax, abaca, sisal, jute, henequen (Herrera-Franco, 2004). kenaf, ramie, sugar palm, oil palm, pineapple leaf, banana pseudo-stem, sugarcane bagasse, coir, rice husk, wood, bamboo, chicken feather (Taylor, 1959). Silk and cotton have been reported as being used as fibers in polymer composites. Recent advances in the use of natural fibers in composites have been reviewed by several authors (Fabien Betene Ebanda, 2012; Richard Ntenga, 2007). Natural fiber composites find their application in many industries like building construction, furniture, aerospace, automotive and packaging due to some advantages that they offer. However, those promising fibers possess some negative characteristics: they are highly hydrophilic and they can vary a lot in properties because of the influence of their growing conditions, fiber processing technique, the fineness of the fiber and sample test-length, which makes accurate predictions of the respective composite properties difficult. All polymer composites absorb moisture in humid atmosphere and when immersed in water.

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The effect of absorption of moisture leads to the degradation of fiber-matrix interface region creating poor stress transfer efficiencies resulting in a reduction of mechanical and dimensional properties (Yang, 1996), of the main concerns for the use of the natural fiber reinforced composite materials is their susceptibility to moisture absorption and the effect on physical, mechanical and thermal properties (Thwe, 2002). It is and important therefore that this problem is addressed in order that the natural fiber may be considered as a viable reinforcement in composite materials. Several studies in the use of natural fiber reinforced polymeric composite have shown that the sensitivity of certain mechanical and thermal properties to moisture uptake can be reduced by the use of coupling agents and fiber surface treatments (Joseph, 1996; Mwaikambo, 2003).

Plant fibers and their applications: In nature, there is a wide range of natural fibers which can be distinguished by their origin. Precisely, natural plant fibers could also be classified according to their location in the plant. For example, bast fibers as flax, hemp or jute (Summerscales, 2010) are extracted from the stem of the plant whereas other fibers could be extracted from seeds (cotton) (Chand, 1988), fruit (coconut, pineapple) (Arib, 2004) or even the leaves of the plant (sisal) (Li, 2000). Table 1 presents the world production of the natural fibers. The idea of using cellulose fibers as reinforcement in composite materials is not a new or recent one. Man had used this idea for a long time, since the beginning of our civilization when grass and straw were used to reinforce mud bricks. In the past, composites, such as coconut fiber/natural rubber latex was extensively used by the automotive industry. However, during the seventies and eighties, cellulose fibers were gradually substituted by newly developed synthetic fibers because of better performance.

Table 1. Natural fibers in the world and their world production (Faruk, 2012).

Fiber source	World production (10^3ton)
Bamboo	30.000
Sugar cane bagasse	75.000
Jute	2.300
Kenaf	970
Flax	830
Grass	700
Sisal	375
Hemp	214
Coir	100
Ramie	100
Abaca	20

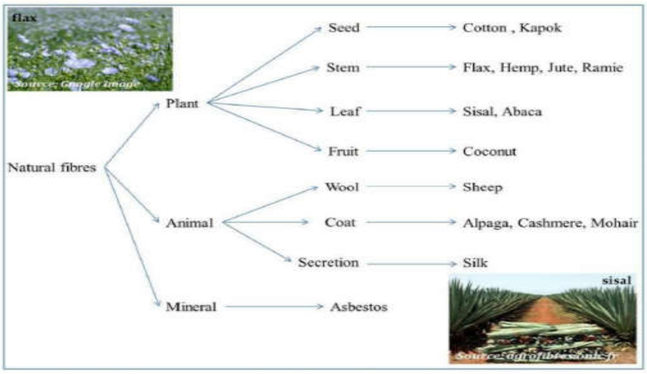

Figure1. Classification of natural fibers [14]

Since then, the use of cellulose fibers has been limited to the production of rope, string, clothing, carpets and other decorative products. Over the past few years, there has been a renewed interest in using these fibers as reinforcement materials to some extent in the plastics industry. This resurgence of interest is due to the increasing cost of plastics and also because of the environmental aspects of using renewable and biodegradable materials. During last years, the prices of natural fibers were not stable and particularly for flax fibers generally produced in Europe countries (France, Belgium…). Tanzania and Brazil are the largest producers of sisal. The henequen is produced in Mexico, the Manila hemp to the produced in Mexico, the Manila hemp to the Philippines. Larger jute producers are India, China and Bangladesh (Richard Ntenga, 2007). Natural fibers are divided into three categories including animal fibers, mineral fibers and plant fibers (Figure 1).

Plant fibers are composed of cellulose while animal fibers consist of proteins (hair, silk, and wool). Plant fibers are derived from renewable resources and are classified according to their origin as bast or soft fiber, leaf or hard fibers, seed, fruit, wood, cereal straw, and other grass fibers. In the present paper we will focus on this last group. Traditionally, especially in rural developing countries, natural fibers have been cultivated and used extensively for nonstructural applications such as multipurpose rope, bag, broom, fish net and filters. The fibers have also been used for applications in housing as roof material and wall insulation. Figure 2 shows natural fibers produced by plants. More interest is now shown in the investigation of the suitability ofnatural fiber composites in structural and infrastructure applications where moderate strength, lower cost and environmental friendly features are required. The application of natural fiber composites has started in automotive industries and productions of non-structural elements.

In 1986, Satyanarayana *et al*. (1986) reported that coir/polyester composites have been used to produce helmet and roof, mirror casing, voltage stabilizer cover, paper weights, projector cover, mail-box. Natural fiber composites have also been used to develop load-bearing elements such as beam, roof, multipurpose panel, water tanks and pedestrian bridge in structural applications and infrastructure applications. Figure 3 and 4 show some different applications of natural fibers

Chemical Compositions and Properties of Natural Fibers: The chemical composition of natural fibers greatly depends on the type and nature of fiber. The overall properties of each fiber are influenced by the properties of each constituent (Saheb, 1999). The variation in chemical composition from plant to plant, and within different parts of the same plant is quite obvious (Faruk, 2012). The main and prime constituent of all cell walls are sugar based polymers as cellulose and hemicellulose chiefly on dry basis (Faruk, 2012). The cell structure and chemical composition of natural fibers are quite complicated. Chemical composition of some important natural fibers is illustrated in Table 3. Natural fibers themselves regarded as the naturally occurring composites comprising mainly of helically wound cellulose micro fibrils, embedded in amorphous lignin matrix. Cellulose (a-cellulose), lignin, pectins, hemicellulose and waxes are the major components of natural fibers. The component hemicellulose present in the natural fibers is regarded to be a compatibilizerbetween lignin Hemi cellulose is responsible for thermal degradation, moisture absorption, and biodegradation of the fiber as it shows least resistance but lignin is thermally stable and is greatly accountable for the UV degradation (Saheb, 1999). Phenylpropane derivative constitutes the lignin and it is an amorphous natural polymeric material that regulates the transference of fluid in the plant (Majeed *et al*., 2013). Bismark *et al*. (2005) studied the chemical content of various natural fibers. The study shows that the strength of the composite is mainly influenced by the cellulose content of the fiber.

Mechanical properties of natural fiber composites: The mechanical properties of a natural fiber composite materials depend on the fiber orientation, fiber volume fraction, fiber geometry, the nature of the matrix and mainly on the adhesion between fiber and the polymer matrix. Natural fibers generally have poor mechanical properties compared to their synthetic counterparts. Table 4 shows the mechanical properties of some natural fibers. The fiber volume fraction plays a significant role in deciding the mechanical properties of natural fiber composite materials. The augmented percentage of fiber content in the composite improves the mechanical properties of the material. In addition, the maximum volume fraction is governed by the fiber orientation and packaging arrangement of fibers (Laranjeira, 2006). The second main factor affecting the performance of natural fiber composite material is fiber matrix interface strength (Betiana *et al*., 2007). The interface serves transfer of applied loads to the fibers via shearstresses over the interface between the fiber and matrix. In general, strong interfacial adhesion delivers high strength. Interfacial strength is essential if stresses are to be transferred properly to the fibers and to provide the necessary function. Weaker interfacial adhesion causes fiber pullout and energy absorption through particular mechanism of failure. Interfacial bond between the matrix and the fiber determines the effectiveness of stress transfer mechanism from the matrix to fiber when the matrix tends to crack under load (Christopher *et al*., 1994).

Figure 2. Variety of natural fibers which are produced by plants [15].

Figure 3. Some applications of natural fibers in the automotive field [17]

Figure 4. Some applications of natural fibers in construction field [17]

Table 2. Summarize of advantages and drawbacks of natural fibers

Advantages	Disadvantages
Low cost	Hydrophilic behavior
recyclable	Dimensional instability
Zero fingerprint CO2	Low thermal resistance
Biodegradability	Biodegradability
Renewable resources	Variability
Low density	Anisotropic behavior
High specific mechanical properties	Discontinuous
Good thermal and acoustics isolation	
Non abrasive	

Table 3. The chemical composition of some selected plant fibers [4, 20, 21]

Fiber	**Cellulose (%)**	**Hemicellulose (%)**	**Lignine (%)**	**Ash (%)**	**Pectin (%)**	**Silica (%)**
Jute	45-71,5	13,6-21	12-26	0,5-2	0,2	0,5-2
Ramie	68,6-91	5-16,7	0,6-0,7	-	1,9	-
Kenaf	31-57	21,5-23	15-19	2-5	-	2,2
Abaca	56-63	15-17	7-9	3	-	1,1
Hemp	57-77	14-22,4	3,7-13	0.8	0,9	-
henequen	77,8	4-8	13	-	-	-
Sisal	47-78	10-24	7-11	0.5-1	10	0,5
Pineapple	73,4	7,1	10,5	2	-	-
Banana	44,2	12,1	32,8	2,2	-	-
RC	68,2	10 -24	15,6	-	2	-

Table 4. Some mechanical properties of commonly used fibers [3, 4, 27]

Fibre	Density (g/cm^3)	Tensile strength (MPa)	Yong's modulus (GPa)	Elongation at break %)
OPEFB	0,7-1,55	248	3.2	2,5
Flax	1,4	88-1500	60-80	1,2-1,6
Hemp	1,48	550-900	70	1,6
Jute	1,46	400-800	10-30	1,8
Ramie	1,5	500	44	2
Coir	1,25	220	6	15-25
Sisal	1,33	600-700	38	2-3
Abaca	1,5	980	-	-
Cotton	1,51	400	12	3-10
Kenaf (bast)	1,2	295	-	2,7-6,9
Kenaf (core)	0,21	-	-	-
Bagasse	1,2	20-290	19,7-27,1	1,1
Henequen	1,4	430-580	-	3-4,7
Pineapple	1,5	170-1672	82	1-3
Banana	1,35	355	33,8	53
RC	0,947	377	7	24,2

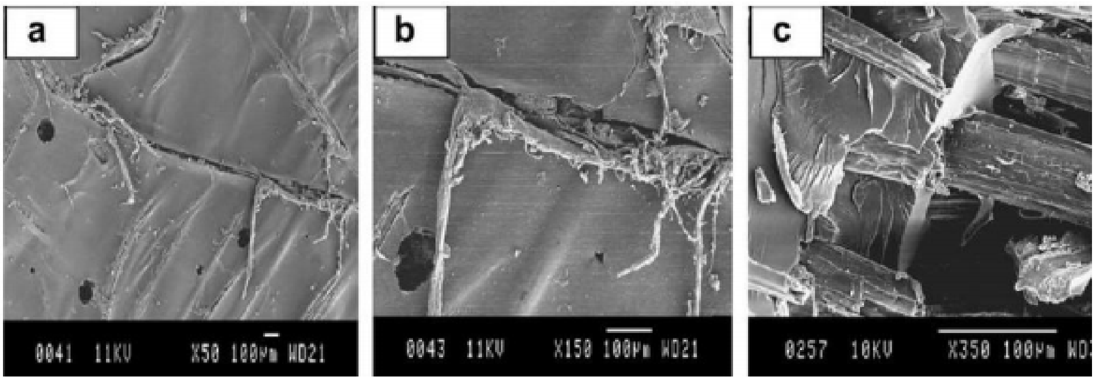

Figure 5. a) Matrix cracking, b) Fracture running along the interface, c) Fiber/matrix debondingdue to attack by water molecules [31].

Hydrophilic behaviors of plant fibers: For their use as reinforcement, the hydrophilic nature of plant fibers has to be considered with carefulness for several reasons. First, during the life cycle of the material, water absorption could induce a volume change of the fibers inside the composite, leading to the development of internal stresses. On the other hand, during the polymerization process of the matrix above 100°C, a vaporization of water trapped inside fibers could occur, leading to their shrinkage. These swelling and shrinkage of the fibers surrounded by the matrix generate internal stresses at the fiber/matrix interface and can eventually lead to the damage of the latter and to a significant degradation of the initial properties of the composite. Assarar *et al*. (2011) deal with water sorption of composites reinforced by bio-based fibers. For example, in their work on the water uptake of a flax fiber composite material they showed an increase of the water

Table 5. The equilibrium moisture content of different natural fiber at 65% relative humidity (RH) and 21°C [3, 13]

Fibers	Equilibrium moisture content (%)
Sisal	11
Hemp	9
Jute	12
RC	7.5
Abaca	15
Ramie	9
Pineapple	13
Coir	10
Bagasse	9.8
Bamboo	9.9
Flax	7

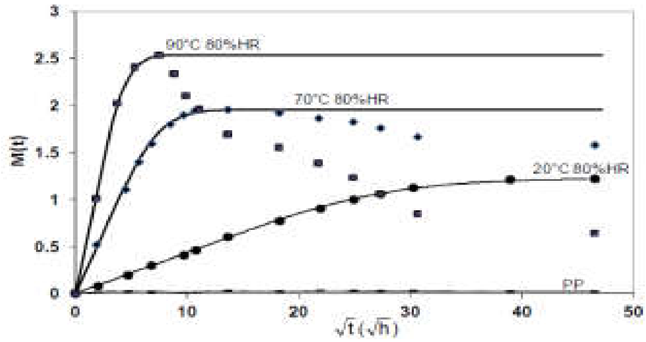

Figure 6. Water uptake variation as a function of the square rout of time of the neat matriceand hemp PP composites exposed to humid atmosphere (80%RH) at various temperatures. Solid lines fits based on Fick's law [40].

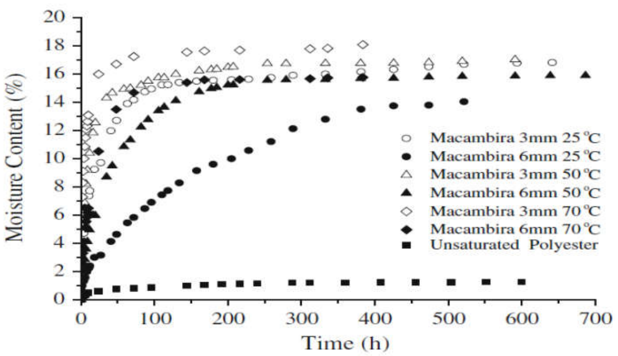

Figure 7. Effect of sample dimension and temperature in the water sorption of Macambira fiber reinforced unsaturated polyester composites [44].

content absorbed, compared to a material consisting of the same matrix reinforced with glass fibers. Betene *et al*., (2018) study the diffusion behavior of water vapor sorption in natural fiber: Rhecktophyllumcamerunenseon the relative humidities of 23%, 54% and 75% at 23°C.The results show that the kinetic adsorption is rapid at the first moments no matter the relative humidity and begin saturation at the seventh hour. The maximum moisture content increases with the relative humidity. The curve of all moistures obeys to the Fick model and the diffusion coefficients have been deduced. They observed that the diffusion coefficient was an increasing linear function of the relative humidity. For the same relative humidities, Noutegomo *et al*., (2019) study the diffusion behavior of water vapor sorption in natural fiber composite: Plaster/Rhecktophyllumcamerunense and the results show that the kinetic adsorption is also rapid at the first hours no matter the relative humidity and begin saturation after 28 hours. The maximum moisture content increases with the relative humidity. The curves of all humidities don't obey to the Fick's model and the diffusion coefficients have been deduced. We observed that the diffusion coefficient increase with the relative humidity. Dhakal *et al*. (2007) showed an increase in moisture absorption with the volume fraction of fiber, for composite polyester/hemp immersed in water at 25 °C. Table 5 presents the equilibrium moisture content of different natural fibers. The loss of mechanical properties in bending with the amount of water absorbed. According to them, the moisture absorption leads to swelling of the fiber, resulting in the occurrence of micro cracks in the matrix. Then, as the composite cracks and gets damaged, capillarity and transport viamicro cracks become active. The capillaritymechanism could involve the flow of water molecules along fiber/matrix interfaces as well as a process of diffusion through the bulk matrix. This could result in a debonding of the fiber and the matrix as shown on figure 5. Noutegomo *et al*[b]., (2017) studied the modelling moisture sorption isotherms of Rhecktophyllumcamerunense vegetable fiber.The maximum moisture content was calculated. Their isotherms were modelled by interpolating the experimental data of the maximum water content as a function of the relative humidity with the BET, GAB and DLP equations. The isotherms presented the sigmoid shape of typeII. The parameters of those mathematical models were also deduced and the goodness of fit have been evaluated. The DLP model gave an excellent adjustment.

Influence of water absorption on mechanical properties: Concerning the influence of water on the mechanical properties, several authors showed a relationship between moisture and mechanical properties of plant fibers. Although this influence has been clearly demonstrated, the different results of the literature are not consistent altogether as presented in table 3. Despite their attractiveness, natural fiber reinforced polymer matrix composites are very sensitiveto influences from external environmental agents such as water in the liquid or vapor phases, relative humidity. Moisture in any form is deleterious to polymer composites, especially to those reinforced by natural fibers.

Plant fibers are hydrophilic and fiber moisture not only acts a plasticizer but makes polymer impregnation more difficult, causing weak adhesion on the polymer matrix-fiber interface, which leads to internal tensions, porosity and premature failure of the system Davies et Bruce (Noutegomo, 2019) also observed experimentally a tendency to a decrease of the Young's modulus with increasing relative humidity for flax and nettle fibers (decrease of the Young modulus of flax fibers about 23 % when relative humidity varies from 30 to 80 %). This trend is also highlighted by Symington *et al*. (1998) for flax. Generally, bio-composites display lower mechanical properties than synthetic fiber-reinforced composites as water sorption adversely affects the performance, physical and mechanical integrity of the composites. Thus, knowing the effect of moisture on the composite properties is fundamental for outdoor applications. The incompatibilities between natural fiber reinforced composites and water may be diminished by surface modification (chemical treatment) of the fiber or the matrix. The mechanical properties of vegetable fiber reinforced composites significantly improve at high fiber content. However, when fibrous polymer composites absorb moisture they suffer swelling, plasticizing, dissolving, leaching and/or hydrolyzing, resulting in discoloration, embrittlement, lower resistance to heat and weathering and lower mechanical properties.

Table 3. Literature review of the moisture absorption influence on the mechanical properties of plant fibers

Fibres	Hygroscopic condition	Yong's modulos evolution	Failurestrength evolution	Elongation at break	Références
Flax and nettle	30, 40, 50, 60, 70%	decreases	Not significative effect	increases	[33]
Flax and sisal	30, 40, 50, 60, 70%	decreases	Maximum for HR=70%	increases	[46]
Flax	30, 40, 50, 60, 70%	decreases	Increases and stabilizes at RH=66%	increases	[47]
Hemp	30, 66, 93%	increases	Maximum for 50<HR<70%	increases	[48]
Jute flax sisai		Increases until a	Not significative effect	increases	[34]
Hemp, agave	10, 25, 50, 80%	threshold, then decreases depend			
Flax	33% et 60%	decreases	decreases	increases	[49]

The amount of water absorbed by a sample varies as a function of its composition, dimensions, void fraction (available free volume), temperature, surface area, surface protection, and exposure time. The effects of moisture and temperature of composites on several performance parameters, such as tensile and shear strengths, elastic moduli, fatigue behavior, creep, rupture stress, response to dynamic impact, and electrical resistance, has been investigated (Symington *et al*., 2009). UmitHuner (2006) studied the effect of water absorption on the mechanical properties of flax fiber reinforced epoxy composites. Flax fiber reinforced epoxy composites were subjected to water immersion tests in order to study the effects of water absorption on the mechanical properties. Epoxy composites specimens containing 0, 1, 5 and 10% fiber weight were prepared. Water absorption tests were conducted by immersing specimens in a deionized water bath at 25 °C and 90°C for different time durations. The tensile and flexural properties of water immersed specimens subjected to both aging conditions were evaluated and compared alongside dry composite specimens. The percentage of moisture uptake increased as the fiber volume fraction increased due to the high cellulose content. The tensile and flexural properties of reinforced epoxy specimens were found to decrease with increase in percentage moisture uptake. Moisture induced degradation of composite sampleswas significant at elevated temperature.

Faik*et al*. (2015) have reported the effect of water absorption on hardness properties for Epoxy reinforced with glass fibers in their research article. They used the Epoxy resin as matrix reinforced by 0–90° Woven Roving and Random with volume fraction 25%. The shore hardness of all samples investigated before and after immersion in water at room temperature. Results of the work show that the value of hardness done at room temperature decreases with increasing the time of immersion in water. Chandramohan *et al*. (Faik, 2011) studied the effect of dry and wet conditions on tensile and hardness properties of bio-epoxy composites. In their research, natural fibers like Sisal (Agavesisalana), Banana (Musa sepientum) & Roselle (Hibiscus sabdariffa), Sisal and banana (hybrid), Roselle and banana (hybrid) and Roselle and sisal (hybrid) are fabricated with bio epoxy resin using molding method. They studied flexural rigidity and hardness ofSisal and banana (hybrid), Roselle and banana (hybrid and Roselle and sisal (hybrid) composite at dry and wet conditions. Girisha *et al*.(38) studied the water absorption and mechanical properties of sisal/coconut Coir Natural Fibers–Epoxy Composites. Natural fibers (Sisal and Coconut coir) reinforced Epoxy composites were subjected to water immersion tests in order to study the effects of water absorption on the mechanical properties. Natural fibers like coconut coir (short fibers) and sisal fibers (long fibers) were used in hybrid combination and the fiber weight fraction of 20%, 30% and 40% were used for the fabrication of the composite. Water absorption tests were conducted by immersing specimens in a water bath at 250 C and 1000 C for different time durations. The tensile and flexural properties of water immersed specimens subjected to both aging conditions were evaluated and compared with dry composite specimens. The percentage of moisture uptake increased as the fiber volume fraction increased because of the high cellulose content of the fiber. The tensile and flexural properties of Natural fiber reinforced. Epoxy composite specimens were found to decrease with increase in percentage moisture uptake. Moisture induced degradation of composite samples was observed at elevated temperature. The water absorption pattern of these composites at room temperature was found to follow Fickian behavior, whereas the water absorption properties at higher temperature did not follow Fick's law. Bouzouita *et al*., (2011) studied the influence of hygrothermal aging on mechanical behavior of Hemp/ isotactic polypropylene composites using flexural tests associated to acoustic emission. They reported on figure 6 below that the (M(t)) moisture absorption variations according to the square root of time (t½) of the neat matrix (PP) and the hemp/PP composites exposed to 80% relative humidity at 23, 70 and 90°C. The neat PP matrix is almost inert to moisture. Indeed, it showed very little moisture uptake after moisture aging after three months whatever the temperature (about 0.02%) while moisture absorption levels for composites are in the range 1-2,5 %, depending on temperatures.

Dhakal *et al*., (2002) studied the effect of water absorption on mechanical properties of hemp fiber reinforced of unsaturated polyester matrix composites. The composites specimens containing 0, 0.10, 0.15, 0.21 and 0.26 fiber volume fraction were prepared. Water absorption tests were conducted by immersing specimens in a de-ionized water bath at 25 °C and 100 °C for different time durations. The percentage of moisture uptake increased as the fiber volume fraction increased due to the high cellulose content. They found that the tensile and flexural properties of composite specimens decrease with increase in percentage moisture uptake. Nóbrega (2006) and Nóbrega *et al*., (2007) conducted several experiments on the water absorption of caroá fiber reinforced unsaturated polyester composites, whileCruz *et al*. (2010) conducted similar experiments with macambira fiber reinforced unsaturated polyester composites as show on the figure below 7. The unsaturated polyester was cured with 1% MEK (methyl ethyl ketone).

Conclusion

Composites reinforced with natural fibers have developed significantly since many years because of their biodegradability, low cost, low relative density, high specific mechanical properties and renewable nature. These composites are welcome to find more and more applications in the near future since a lot of studies are led to understand and improve their properties. The understanding of the hygroscopic behavior of these materials is a key issue in order to use it in different weathering conditions.

Many studies are examined, reviewed and highlighted in this paper regarding the link between the microstructure and the hydrophilic behavior of plant fibers, the influence of moisture on their properties as well as the final properties of the composites they reinforce. Water sorption in fibers and their composites has been found to significantly affect their dimensional and structural properties.

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