

Water Ageing Studies of Sisal Fiber Polymer Composites - A Review

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ABSTRACT : The main objective of this work was to review the water uptake behavior of sisal fibre composites. One of the main disadvantages of lingo cellulosic fibers is their hydrophilic nature, which resulted in low compatibility with hydrophobic polymeric matrices during composite processing. Due to fiber hydrophilic character, swelling by water uptake could lead to micro cracking of the composite and degradation of mechanical properties. Therefore, water uptake is one of the most serious problems that prevents a wider use of lingo cellulosic fiber in composites. Currently, there is a lack of information on the water absorption behaviour of composites reinforced by natural fibers in comparison to bio composites with polymer matrix. The study of the hygroscopic behaviour of plant fibers as well as composites reinforced with cellulosic fibers is a key issue in order to use it in different weathering conditions and in order to improve their long-term performance. Therefore, it is important to study in detail the hygroscopic behaviour in order to estimate, not only the consequences that the water absorbed may have, but also the durability of natural fiber composites aged under water, sea water and different environments. However research is being done on reducing moisture absorption tendency of natural fiber based composite by using advanced manufacturing techniques and also by new techniques of surface modification.

KEYWORDS: Sisal fibre, polymer composites, hydrophilic behaviour, ageing effects, mechanical properties, durability

I. INTRODUCTION

Due to their wide availability, low cost, low density, high specific mechanical properties, and eco-friendly image, they are increasingly being employed as reinforcements in polymer matrix composites. In literature the term bio composite is often used to define a polymeric matrix reinforced by natural fibers. The increasing number of publications during last 13 years including reviews, reflect the growing importance of these new bio composites [1-3].

One of the major disadvantages of lingo cellulosic fibers is their hydrophilic nature, which resulted in low compatibility with hydrophobic polymeric matrices during composite preparation. Due to fiber hydrophilic character, swelling by water uptake could lead to microcracking of the composite and degradation of mechanical properties. Therefore, water sorption is one of the most serious problems that prevents a wider use of lingo cellulosic fiber in composites [4].

Water sorption in fibers and bio composites has been found to significantly influence their dimensional and structural properties. Increase in percentage moisture uptake in sisal fiber reinforced unsaturated polyester composites resulted in decrease of the tensile and flexural properties [5].

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Currently, there is a lack of information on the water absorption behaviour of composites reinforced by natural fibers in comparison to bio composites with polymer matrix. The understanding of the hygroscopic behaviour of plant fibers as well as composites reinforced with cellulosic fibers is a key issue in order to use it in different weathering conditions and in order to improve their long-term performance. Hence, it is important to study in detail, the water absorption behaviour 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[6].

More research has to be carried out to understand absorption mechanisms in such fibers. The following section is a literature review about their hydrophilic behavior as well as the influence of water on their properties [7].

II. LITERATURE REVIEW

Idowu David Ibrahim et al.[8] from their experimentations presented the influence of sisal fiber (SF) treatment and incorporation of MAPP (maleic anhydride-grafted PP) and nanoclay on water absorption of SF/rPP(recycled poly propylene) composites. Very little water was absorbed by neat rPP during the immersion time due to the hydrophobic character of rPP. Higher water absorption was observed with SF/rPP composites due to the hydrophilic nature of natural fibers. The surface changes of sisal fiber and incorporation of MAPP and nanoclay showed reduced water absorption for the SF/rPP composites as seen in Fig.1. The presence of lignin, hemicellulose, and wax in the fiber was responsible for the high level of water absorption of SF/rPP composites; these were controlled by alkalization; similar result was reported by Kaewkuk et al.[9]. The strong adhesion between the fiber and the polymer matrix caused by the fiber modification and MAPP and nanoclay inclusion reduced the water absorption capacity of the composites. The nanoclay functions as a water barrier medium in the composite, reducing down the rate of water absorption. Mohan et al.[10] reported similar phenomenon. The composite with treated fiber showed the least water absorption among all the composites after 3 hours' immersion time.

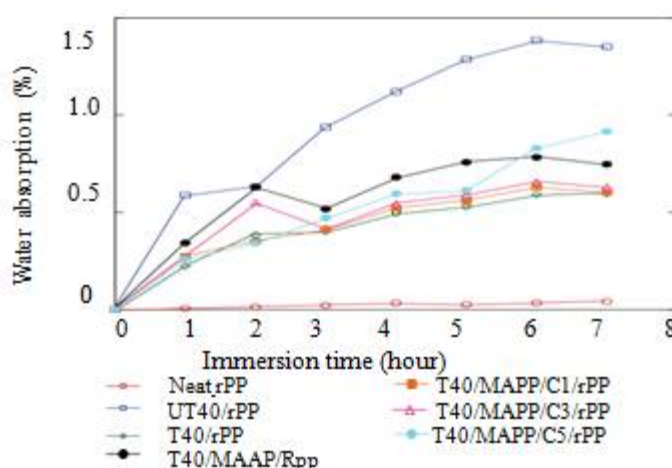


Fig.1. Effect of fiber treatment and nanoclay on sisal fiber/polypropylene composites.

Chow et al.[11] reported, the effects of the immersion treatment on the tensile and impact fracture characteristics of sisal fiber reinforced polypropylene (SF/PP) composites from their experimentation. Polypropylene homo polymer and maleic anhydride grafted polypropylene wax were used as the matrix and compatibilizer respectively. The specimens were dried and weighed, then the specimens were immersed into a hot water bath at 90°C for different durations before removal from the water bath. The water absorption characteristics of the composites were evaluated by two parameters: the percentage of apparent weight gain (WG), and the percentage of weight loss (WL). It is observed that the rate and the maximum value of moisture absorption increases with increasing sisal fiber content. WL increased sharply with

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increasing immersion time. The higher the SF content, the higher the WL value was found at any given immersion time. The weight loss was mainly related to the dissolution of the lignaceous material and waxy substances on the sisal fiber surface. Due to the weight loss characteristics of the SF/PP composites, the moisture absorption is non-Fickian. While the tensile modulus and tensile strength decreased continuously with increasing immersion time, the impact strength was improved initially with increasing immersion time, until reaching the maximum.

M.K.Gupta et al. [12] have investigated the mechanical and water absorption properties of hybrid Sisal/Glass fibre reinforced epoxy composite and observed that water absorption is found to be increased with increasing fibre content. The increasing water absorption is due to the hydrophilic nature of sisal fibre and greater interfacial area between fibre and matrix. The moisture absorption by epoxy is almost negligible due to its hydrophobic nature.

Laxmana Naik et al. [13] have studied the physical and water absorption behaviour of sisal – glass fiber reinforced polymer based composites and observed that with increase in weight fraction of glass fiber, the water absorption gradually increases, irrespective of laminating sequences. This behaviour was expected because the water absorption of these composites is mainly due to the presence of sisal fibers. There are three main reasons in the composite because of which water can reside in composite. Those are the lumen, the cell wall and the gaps between fiber and resin in the case of weak interface adhesion is found.

Rajesh et al. [14] investigated the mechanical and degradation properties of alkali treated completely biodegradable sisal fiber reinforced poly lactic acid composites and observed that the water absorption percentage decreased in composites with successive alkali treated sisal fiber. They reported that after alkali treatment sisal fibres became more hydrophobic.

Gnanasekar et al. [15] studied the water absorption characteristics of sisal with glass additives hybrid fibre reinforced polyester composite by immersion in distilled water at room temperature for 3, 6, 9 and 12 hours. The test specimens (25 mmx25 mm) were cut from composite and tested for water absorption as per ASTM D- 570. Edges of the sample were sealed with polyester resin. Samples were dried for 24 hours at 50°C. After 24 hours samples were weighed accurately. Conditioned samples were then immersed in distilled water at room temperature for 3, 6, 9 and 12 hours. Samples were taken out of water after appropriate time period and wiped with a tissue paper to remove surface water. They were then weighed and percentage of water absorption calculated for each case as shown in Fig.2.

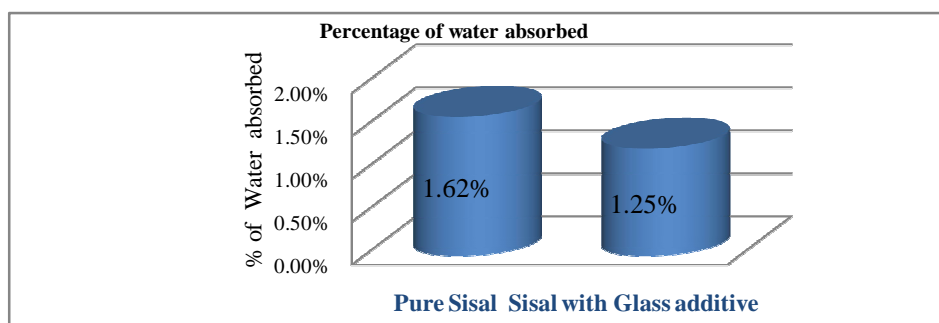


Fig.2. Percentage of Water Absorbed (%)

III. WATER ABSORPTION TESTS

After immersion for given time, the specimens were taken out from the water and water from all surfaces of specimens was removed by a clean dry cloth. All specimens were weighed again after their storage. Content of absorbed water in composites after immersion time t (M_t) was calculated by the weight difference between the samples immersed in water

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and dry composite samples. The water absorption, kinetic model was used to describe the sorption curves for composites based on natural fiber [5] using the following equation :

$$M_t / M_s = kt^n \quad (1)$$

where M_t , M_s are water content at time t and at equilibrium; k and n are constants giving some information about mechanism of diffusion taking place inside composites. Coefficients n and k were calculated from experimental data using classical method of the mathematical statistics, as regression analysis, correlation analysis and testing of hypotheses. First, the coefficient n was determined as a slope of sample regression line created by log of experimental set of data and verified by its coefficient of correlation. Using method of testing of hypotheses was proved that this corresponding coefficient of correlation between both sets, experimental and computed data are statistically significant. Second, the coefficient k was determined using the assumptions about the existence of a saturation point during process of absorption in time. This fact enables then to find the asymptotic line of the corresponding process of absorption also using the above-mentioned method of regression analysis.

The diffusion properties of composites represent the ability of the water molecules moving inside the specimens were evaluated by the coefficient of diffusion D according to the following formula :

$$M_t / M_s = (4/h) (D/\pi)^{1/2} t^{1/2} \quad (2)$$

where k is the slope of the linear part of water absorption curve and h is the initial thickness of the composites.

(A). Water absorption mechanisms

In their work, Dhakal et al.[16] showed a loss of mechanical properties in bending with the amount of water absorbed. According to them, the moisture absorption leads to swelling of the fibre resulting in the occurrence of micro cracks in the matrix. Then, as the composite cracks and gets damaged, capillarity and transport via micro cracks become active. The capillarity mechanism could involve the flow of water molecules along fibre/matrix interfaces as well as a process of diffusion through the bulk matrix. This could result in a debonding of the fibre and the matrix as shown on Fig.3. Eventually, those micro cracks create swelling stresses leading to the composite failure.

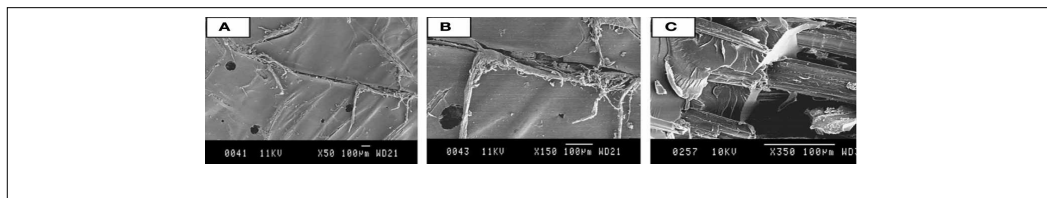


Fig. 3. Failure showing (a) matrix cracking, (b) fracture running along the interface and (c) fibre–matrix debonding due to attack by water molecules.

(B). Link between microstructure and hydrophilic behaviour

The hydrophilic behaviour of plant fibers, is mainly due to two factors: their composition and their specific structure. Generally, one of the most important factors controlling the water diffusion phenomenon in polymeric materials is the molecular interaction occurring between the diffusing compound and the substrate. The diffusion phenomenon is subjected to the ability of the polymer molecular sites to establish hydrogen bonds with the water molecules. In plant fibers, components which have polar groups and thus are responsible for absorbing moisture are cellulose, hemicellulose, pectin and lignin [17].

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According to Davies and Bruce [18], hemicelluloses which constitute the major part of the amorphous phase in plant fibres play an important role in the storage of moisture. The water was more or less linked to the network of the material, highlighting the presence of bound and free water within such structures. The amount of bound water depends on the chemical structure of the material. This water is bound to the network by hydrogen bonds, breaking the existing bonds between the hydroxyl groups of the polymer chain [7].

Techniques for quantification and examination of bound and free water are: DSC, Nuclear Magnetic Resonance (NMR), Raman spectroscopy and infrared spectroscopy [19]. In NMR, it is possible to characterize different types of water, the molecular motion of the bound water and the water interactions with specific polymeric chain of the material in which they are inserted [20].

Nakamura et al.[21] with DSC visualized and quantified these two types of water in cellulose samples. According to their works, there are actually three types of water called as follows: "freezing water," "freezing bound water," and "non-freezing water," The first term refers to free water while the two others are respectively, water weakly and strongly linked to the network. The amount of "non-freezing water" is directly related to the molecular structure of the material. Fourier Transform Infra-Red spectroscopy (FTIR) has also been proved to be well adapted to study water sorption phenomenon, since it allows characterizing molecular interactions involving potential sorption sites for water.

IV. EFFECT OF WATER ON NATURAL FIBERS PROPERTIES

The moisture absorption in these hydrophilic fibres leads to a modification of their physical and chemical properties. Indeed, the interaction of water with hydrophilic materials may cause multiple phenomena as dimensional changes, modification of the mechanical, and chemical properties, and so on.

(A). *Dimensional changes*

Experimental information about the hydro-expansion coefficient of natural fibers is an important factor for the development of new models adapted to these biomaterials. Some works have been published on the swelling of biocomposites. For instance, a study based on the deformation measurement of composites reinforced by hemp fibers, showed that the hydro-expansion coefficient increased with the fiber content in the material[22]. Hygroscopic strains may be reversible in this case they are predicted by the hydro-expansion coefficient or irreversible due to structural defects [7].

(B). *Influence on mechanical properties*

Several authors demonstrated 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. Experimentally, it was observed there is 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%) [18].

However, other studies show an increase of the Young's modulus of fibers with relative humidity up to a specific threshold of water absorbed [23,24]. It was reported that the young modulus of hemp fibers increases about 20% in the 25–80% relative humidity range. This increase in stiffness could be explained by a rearrangement of the microfibrils and the surrounding molecules acting as a matrix. This rearrangement could be activated by the swelling of the fibers. Beyond a certain moisture content threshold, the decrease of the Young's modulus could be explained by the plasticization of the fiber. In fact, the formation of hydrogen bonds replacing bonds in hemi cellulose macromolecular network could make the material more flexible and compliant [24].

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(C). Structural modifications

Nakamura et al.[21] reported that the amorphous phase of the crystalline cellulose might become crystalline in the presence of bound water. In connection with this increase of crystallinity, the authors showed an increase in tensile strength of hydrated cellulose I. The evolution of the crystalline structure of the fibres during drying was also investigated by Céline et.al [7] by calculating the total crystallinity index.

With the removal of water from the composite, hydrogen bonds created between the water and the hydrophilic sites of the fibers are broken, leading to a relaxation of the macromolecular network and a decrease of the crystallinity degree[7]. Recently, this hypothesis was confirmed by a XRD study on wood fibers submitted to hygroscopic cycles [25].

V. CONCLUSIONS

Water absorption in fibres and bio composites has been found to significantly influence their dimensional and structural properties. Increase in percentage moisture uptake in sisal fibre reinforced unsaturated polyester composites resulted in decrease of the tensile and flexural properties. The increasing number of publications during last 13 years including reviews, reflect the growing importance of these new bio composites. Currently, there is a lack of information on the water absorption behaviour of composites reinforced by natural fibres in comparison to bio composites with polymer matrix. The understanding of the hygroscopic behaviour of plant fibres as well as composites reinforced with cellulosic fibres is a key issue in order to use it in different weathering conditions and in order to improve their long-term performance. Hence, it is important to study in detail, the water absorption behaviour in order to estimate, not only the consequences that the water absorbed may have, but also the durability of natural fibres composites aged under water. It is concluded that there has to be continuous research on mathematical models, quantification and visualization techniques and protective coatings for water sorption studies of sisal fibre composites.

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