Evaluation of Water Absorption Effects on the Mechanical Properties and Sound Propagation Behavior of Polyester Matrix-Sponge Gourd Reinforced Composite

A. R. Feiferis and J. R. M. d'Almeida*

Department of Chemical Engineering and Materials – Pontifícia Universidade Católica do Rio de Janeiro, Rua Marquês de São Vicente 225 – 22451-900, Rio de Janeiro, RJ, Brazil

Abstract: This study aimed to evaluate the variation of the mechanical properties of a polyester matrix composite reinforced by sponge gourd fibers as a function of immersion time in water. The characterization of the composite was performed using bending mechanical test and a sonic test. The Young's modulus and the sound propagation characteristics of the composite were evaluated as a function of immersion time. The water diffusion coefficient was also determined. The results indicate that the percentage of water absorbed increases rapidly, but stabilizes at around 2 weeks after the start of the absorption process. The variation of elastic modulus and damping factor showed a direct correlation with water content in the composite, and both properties remained constant when the absorbed water content stabilized. These results were interpreted as an indication that the composites suffered only physical aging due to water absorption, at the immersion times used in this work. The mechanical properties evaluated by the bending test decreased after absorption of water, but the obtained variations were small. The results obtained indicate that the absorbed water acts as a plasticizer in this composite, but does not cause chemical aging.

Keywords: Composite, lignocellulosic fibers, mechanical behavior, sonic test, water absorption.

1. INTRODUCTION

The use of polymer matrix composites has increased steadily in recent years in respect to traditional engineering materials, such as metallic alloys. This has been due mainly to the fact that these composites ally high mechanical strength and low density, as well as do not present corrosion problems [1]. This feature is particularly important when the material should work buried, as is the case of many pipes, where carbon steel pipes require a series of corrective measures (e.g., cathodic protection), but polymer matrix composite pipes do not require great care.

The most widely used polymer composites are those using glass fibers as reinforcement, due to the combination of low price and excellent properties that these fibers possess. For example, mechanical strength values as high as 3500 MPa can be obtained for the most common type E glass fiber [1]. However, glass fibers are abrasive and, depending on the manufacturing process employed or the type of final assembly of the part produced, there is high wear of process equipment [2]. Furthermore, there is a big problem for recycling a composite part made of glass fiber at the end of its life, because the composite is difficult to post-use handling, either due to glass fiber abrasion, or due to the chemical stability of the thermosetting matrix and of the glass fiber [2, 3].

In this context, replacement of glass fibers by lignocellulosic fibers has been the target of several industries, such as the automotive. Several companies of this productive sector have been using non-structural parts manufactured in composites reinforced by natural fibers [4]. Numerous lignocellulosic fibers can be used for reinforcing polymer matrices. Among those most widely studied, both because of their volume of production or their growth in several countries, one can cite sisal fibers (*Agave sisalana*), jute (*Corchorus capsularis*) and coconut (*Cocos nucifera*) [5-8]. However, several other lignocellulosic fibers can be used as reinforcement and have been studied by several research groups. Among these other fibers, one can highlight peach palm (*Bactris gasipaes*), obtained from the wastes generated after collection of heart of palm [9], piassava fibers (*Attalea funifera*) [10] and also sponge gourd fibers (*Luffa cylindrica*) [11-13]. Sponge gourd fibers, also known as loofah, have as great feature the fact of forming a natural three-dimensional blanket. This naturally occurring 3D fiber structure provides greater toughness for sponge gourd reinforced composites when compared to composites manufactured using other lignocellulosic fibers [11]. This aspect is interesting when one thinks of using composites in automobiles, because absorption of impact energy by the materials that makes up the car interior is a goal of automakers.

*Address correspondence to this author at the Department of Chemical Engineering and Materials – Pontifícia Universidade Católica do Rio de Janeiro, Rua Marquês de São Vicente 225 – 22451-900, Rio de Janeiro, RJ, Brazil; Tel: 55(21) 3527-1789; Fax: 55(21) 3527-1236;
E-mail: dalmeida@puc-rio.br

E-ISSN: 2311-8717/16

However, it is well known that polymer matrix composites can have their properties affected when the composite is exposed to humid environments and/or due to exposure to UV radiation [14, 15]. Exposure of parts in car interiors, e.g., door panels, to moisture and temperature is expected during the life of these parts. Thus, this study aimed to evaluate the effect of exposure of a polyester matrix composite reinforced by sponge gourd fibers to moisture. To achieve this goal, accelerated aging of the composites was performed by immersing the composite in water and evaluating the variation of mechanical properties as a function of the immersion time.

2. EXPERIMENTAL METHODS AND MATERIALS

Composite plates with fiber volume fraction of 30% were manufactured by compression molding, placing the fibers inside the mold cavity and pouring over them the pre-formulated resin. In a previous work, it was observed that sponge gourd/polyester composites showed a controlled fracture, without a sudden load drop, with this volume fraction of fibers [11]. A commercial ortophtalic polyester resin mixed with 2 percent by weight of catalyst - methyl ethyl ketone - was used as matrix. After placing the appropriate amounts of fiber and matrix, the mold was subjected to a pressure of 1.5 MPa for 24 hours to assist in removing trapped air bubbles and to ensure the production of composites with uniform thickness. The manufactured composite plates had 200mm in length, 150mm width and, on the average, 7mm in thickness. The composites were kept at ambient temperature (23 ± 3 °C) for 7 days to ensure complete curing of the resin matrix prior to machining of the specimens for the flexural, absorption and sound tests.

From the obtained plates rectangular test pieces were machined with nominal dimensions of 100mm long, 25.4mm wide and 7mm thick. Figure **1** shows a machined test piece. Ten specimens were used at this work. Five were tested in the as manufactured condition and the other five after being aged by immersion in water. The sound and the absorption tests are non-destructive tests. Therefore, the experimental data of these two analyses were obtained at several immersion times using the same specimens. Only at the final specified time for the duration of this work the aged specimens were subjected to the three-point bending destructive mechanical test.

For aging by immersion in water, the specimens were placed in a glass container filled with distilled water and kept in a room maintained at constant temperature (23 ± 2 °C). The container was sealed to prevent contamination from the external environment and had opaque walls to protect the samples from light. This procedure was adopted because polymers are sensitive to UV radiation [14], and one wanted to avoid any effect than that caused by water. The aging of the samples took a total time of 63 days, and the samples were taken at regular intervals to be weighed and characterized by the non-destructive acoustic test. Initially, the interval between these tests (weighing + acoustic test) was of 1 week, but due to low water absorption presented by the specimens after the first two weeks, the interval between the tests has been increased to 2 weeks.

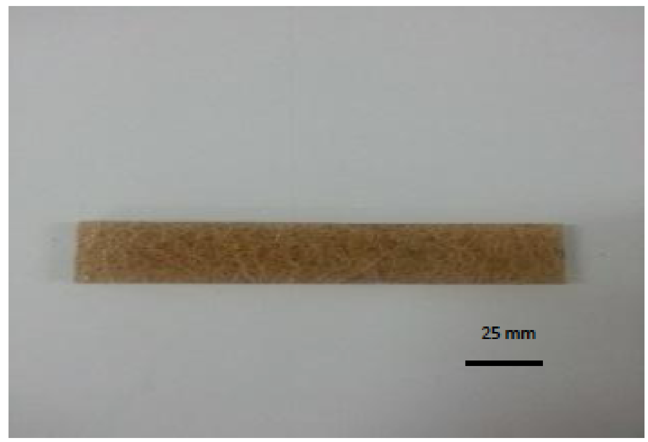

Figure 1: Test specimen used for the mechanical, absorption and acoustic characterization.

Weighing was performed within ± 0.001g and drying of the specimens to remove excess water on the specimen’s surface was performed according to the procedure recommended by ASTM D570-98 (2010).

The acoustic test was performed using an electret microphone with a detection range varying from 0.5 to 20 kHz and an acquisition time of 0.6s. In this test a low-mass dart strikes the sample surface at each 60 s, and the generated signal is processed by a dedicated software (*Sonelastic*®). The test procedures and analysis were based on ASTM standard E 1876 and both the Young's modulus and the damping factor of sound waves are calculated automatically. The results shown are the average of 20 measurements per test piece and test time. The test configuration is show in Figure **2**. The relative position between the dart and the microphone matches the boundary condition of bending-twisting, as described in the ASTM standard cited above.

Figure 2: Experimental setup for the acoustic test, showing the relative position of the dart (A) and the microphone, (B) in respect to the sample.

Three-point bending tests were performed on a mechanical driven equipment. The tests were performed using a loading speed of 5mm/min, and using a span (L) to depth (d) ratio equal to 10 (L/d = 10). These tests were performed according to ASTM D790-07. All tests were performed at room temperature (23 ± 2 °C).

3. EXPERIMENTAL RESULTS AND DISCUSSION

Absorption tests - An example of the data of the absorption tests is show in Figure **3**. It can be seen that after a quick absorption of water, characterized by an initial increase of approximately 5% of the mass, there is a reduction of the absorption rate. From the data shown in the graph of Figure **3** it is possible to calculate the percentage of mass gain as a function of square root of time, and model the experimental behavior obtained using the Fick's diffusion model, as described by equation 1[16]:

$$\frac{M_t}{M_\infty} = \frac{4}{b}\sqrt{\frac{D_x t}{\pi}} \quad (1)$$

where M_t is the percentage of mass absorbed at time t, M_∞ represents the amount of water absorbed at saturation and b is the thickness of the specimen. The diffusion coefficient, D_x, can be determined from the slope of the initial part of the M_t *vs.* $t^{1/2}$ curve. For the composite analyzed in this work, the amount of water at saturation, M_∞, was determined experimentally from the M_t *vs.* $t^{1/2}$ curves for each specimen evaluated. The mean value obtained for the diffusion coefficient was $9.7 \times 10^{-6} \pm 2.6 \times 10^{-6}$ mm^2/s. This value agrees very well with the data obtained for other polyester matrix/sponge gourd fiber composite manufactured with similar fiber volume fractions [17].

Bending tests - Figure **4** shows a typical stress *vs.* strain curve obtained both for as-manufactured composites and for the aged ones. One can observe an essentially linear behavior until the maximum stress followed by a sharp stress drop. However, after this sharp drop, the fracture process is controlled, with a continued decrease in the strength. This behavior is associated with the deflection of cracks in fiber/matrix interfaces [11, 18].

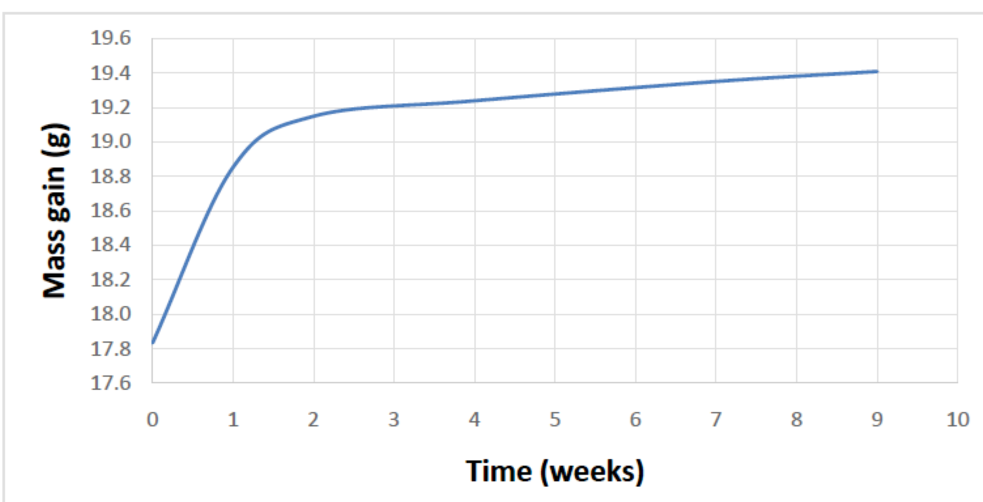

Figure 3: Example of the experimental absorption curves showing the evolution of the mass gain as a function of immersion time.

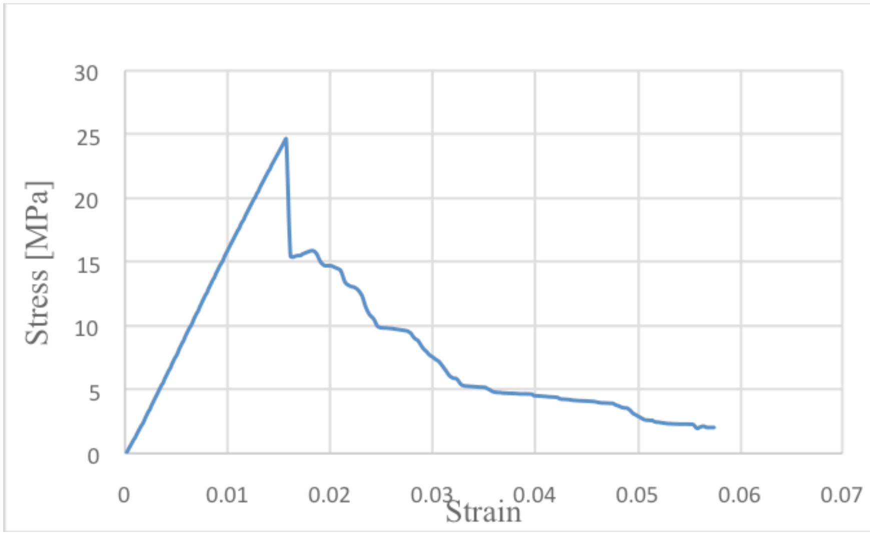

Figure 4: Typical stress-strain curve presented by the composites.

Table 1: Mean Values of the Properties before and after Aging

Composite	Maximum Stress [MPa]	Strain at Maximum Stress (mm/mm)	Energy at Maximum Stress [kJ/m^3]	Total Energy [kJ/m^3]
As-manufactured	21.2 ± 3.9	0.0146 ± 0.003	3.03 ± 0.55	5.77 ± 0.90
Aged	20.7 ± 4.7	0.0136 ± 0.002	2.96 ± 0.67	5.31 ± 1.31

The values of properties determined from the three-point bending tests are shown in Table **1**. It can be seen that the mean values of the properties of aged samples are nominally smaller than that of the samples without aging. However, with the exception of deformation at maximum stress, the mean values are statistically equal between each other to a degree of reliability of 95%, using the t-Student distribution. This result is a first indication that although there is high water absorption in the composite, no chemical aging occurred on the time scale used in this work. Therefore, the absorbed water caused no change in the mechanical properties.

Sonic tests - The modulus of elasticity (E) and the damping factor (ζ) were measured from the acoustic test. Figure **5** shows the modulus variation as a function of the immersion time. It can be seen that at the beginning of the immersion process, the modulus decreases, but the values are stabilized when the immersion time increases. This behavior is directly associated with the process of water absorption. In fact, water absorption causes plasticization on the polymeric matrix, with a consequent reduction in Young's modulus [19]. However, when the absorption approaches the saturation value (Figure **3**), the effect of plasticization becomes less relevant to the overall behavior of the composite and the values of the modulus instead of module are stabilized. Indeed, there is a good correlation between the plateau seen in Figures **3** and **5**, showing that when the mass of the water absorbed stabilizes, the values of the modulus also stabilize.

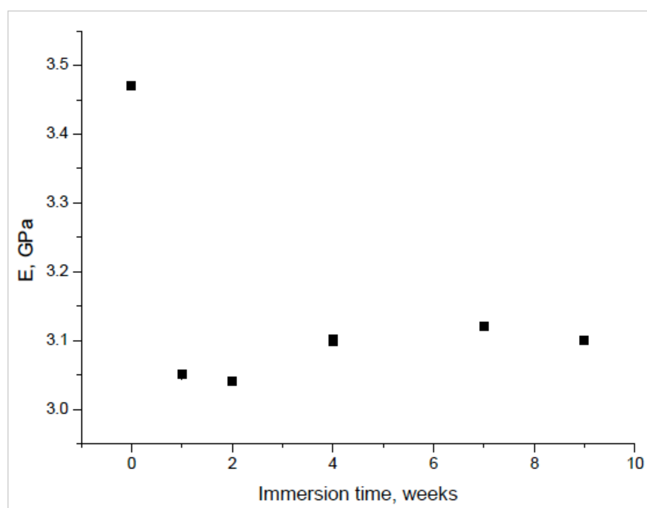

Figure 5: Evolution of the elastic modulus with the time of water absorption. Error bars were placed on the chart but are often too small to be visualized.

The damping factor (ζ) corresponds to the attenuation of an oscillation imposed on a material and, at the scope of this work, ζ can be correlated to the internal friction due to the microstructure of the composite, notably the fiber/matrix interfaces and also with the viscoelastic behavior of the polymeric matrix [20]. Figure **6** shows the effect of aging time on ζ. The results are consistent with the data shown in Figure **3**, indicating that there was an increase on the damping values during water absorption and that after the saturation value was reached, the damping factor remains constant. That is, variation of the properties of this polyester/sponge gourd composite is directly related to the amount of water absorbed and, once saturation was reached, the properties measured remain almost constant. This behavior seems to be related to physical aging and not to chemical aging, where the action of water absorption could cause irreversible changes in the composite structure due, for example, to hydrolysis, which could generate sufficiently active reactive groups to cause rupture of the fiber/matrix interfaces due osmotic pressure [21, 22]. The results indicate, however, that there was a homogeneous behavior of the composite, more consistent with the absorption of water evenly distributed throughout the composite volume.

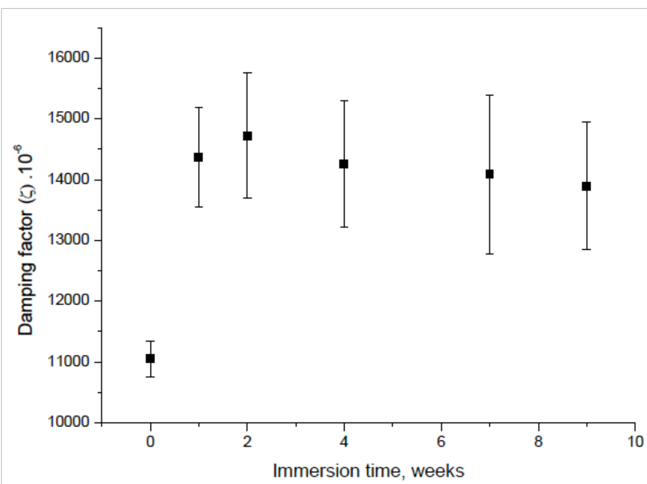

Figure 6: Variation of the damping factor (ζ) as a function of immersion time.

CONCLUSIONS

The following remarks were obtained from the experimental results obtained in this work:

(i) The water content absorbed in the polyester/sponge gourd composite was stabilized after only 2 weeks of immersion;

(ii) The mechanical and elastic properties varied while absorbed water had not reached its saturation value.

From these observations it can be inferred that the composite was submitted only to physical aging without any evidence of deterioration of properties due to chemical aging, during the immersion time evaluated in this work. That is, the water absorption occurred uniformly in the composite, predominantly by sponge gourd fibers (hygroscopic lignocellulosic fibers) or in the free volume of the polymeric matrix.

The correlation between stabilization of the properties with saturation of water absorption indicates that the plasticizing effect of water upon the polyester matrix was the major responsible for the variation of the evaluated properties.

ACKNOWLEDGEMENTS

The authors acknowledge the support from CNPq and FAPERJ to the development of this work.

REFERENCES

[1] GIBSON RF. Principles of composite material mechanics, Singapore, McGraw-Hill, 1994.

[2] PICKERING SJ. Recycling technologies for thermoset composite materials—current status. Composites: Part A 2006; 37: 1206-1215. http://dx.doi.org/10.1016/j.compositesa.2005.05.030

[3] JOB S. Recycling glass fibre reinforced composites – history and progress. Reinforced Plastics 2013; 57(5): 19-23. http://dx.doi.org/10.1016/S0034-3617(13)70151-6

[4] MARSH G. Next step for automotive materials. Materials Today 2003; 6(4): 36-43. http://dx.doi.org/10.1016/S1369-7021(03)00429-2

[5] LI Y, MAI YW and YE L. Sisal fibre and its composites: a review of recent developments. Composites Science and Technology 2000; 60: 2037-2055. http://dx.doi.org/10.1016/S0266-3538(00)00101-9

[6] NANGIA S and BISWAS S. Jute Composite: Technology and Business Opportunities. http://www.tifac.org.in/news/adcomp.htm. Accessed March 2016.

[7] Monteiro SN, Terrones LAH and d'Almeida JRM. Mechanical performance of coir fiber/polyester composites. Polymer Testing 2008; 27: 591-595. http://dx.doi.org/10.1016/j.polymertesting.2008.03.003

[8] Monteiro SN, Terrones LAH, De Carvalho EA and d'Almeida JRM. Efeito da Interface Fibra/Matriz Sobre a Resistência de Compósitos Poliméricos Reforçados com Fibras de Coco. Revista Matéria 2006; 11(4): 395-402. http://dx.doi.org/10.1590/S1517-70762006000400005

[9] TEMER BC and D'ALMEIDA JRM. Characterization of the Tensile Behavior of Pejibaye (Bactris gasipaes) Fibers. Polymers from Renewable Resources 2012; 3(2): 33-42.

[10] d'Almeida JRM, Aquino RCMP and Monteiro SN. Tensile mechanical properties, morphological aspects and chemical characterization of piassava (Attalea funifera) fibers, Composites: Part A 2006; 37: 1473-1479. http://dx.doi.org/10.1016/j.compositesa.2005.03.035

[11] BOYNARD CA and D'ALMEIDA JRM. Morphological characterization and mechanical behavior of sponge gourd (Luffa cylindrica)-polyester composite materials. Polymer-Plastics Technology and Engineering 2000; 39(3): 489-499. http://dx.doi.org/10.1081/PPT-100100042

[12] d'Almeida ALFS, Barreto DW, Calado V and D'almeida JRM. Effects of derivatization on sponge gourd (Luffa cylindrica) fibers. Polymers and Polymer Composites 2006; 14: 73-80.

[13] Demir H, Atikler U, Balköse D and Tihminlioglu F. The effect of fiber surface treatments on the tensile and water sorption properties of polypropylene–luffa fiber composites. Composites: Part A 2006; 37: 447-456. http://dx.doi.org/10.1016/j.compositesa.2005.05.036

[14] Chacón YG, Paciornik S and D'almeida JRM. Microstructural evaluation and flexural mechanical behavior of pultruded glass fiber composites. Materials Science and Engineering A 2010; 528(1): 172-179. http://dx.doi.org/10.1016/j.msea.2010.09.010

[15] Signor AW, Van Landingham MR and Chin JW. Effects of ultraviolet radiation exposure on vinyl ester resins: characterization of chemical, physical and mechanical damage. Polymer Degradation and Stability 2003; 79(2): 359-368. http://dx.doi.org/10.1016/S0141-3910(02)00300-2

[16] SHEN CH and SPRINGER GS. Moisture Absorption and Desorption of Composite Materials. Journal of Composite Materials 1976; 10: 2-20. http://dx.doi.org/10.1177/002199837601000101

[17] BOYNARD CA and D'ALMEIDA JRM. Water absorption by sponge gourd (Luffa cylindrica)-polyester composite materials. Journal of Materials Science Letters 1999; 18: 1789-1791. http://dx.doi.org/10.1023/A:1006643630959

[18] Costa FHMM and d'Almeida JRM. Effect of water absorption on the mechanical properties of sisal and jute fiber composites. Polymer-Plastics Technology and Engineering 1999; 38: 1081-1094. http://dx.doi.org/10.1080/03602559909351632

[19] Valentin D, Paray F and Guetta B. The hygrothermal behaviour of glass fibre reinforced PA66 composites: a study of the effect of water absorption on their mechanical properties. Journal of Materials Science 1987; 22: 46-56. http://dx.doi.org/10.1007/BF01160550

[20] Chandra R, Singh SP and Gupta K. Damping studies in fiber-reinforced composites: a review. Composite Structures 1999; 46: 41-45. http://dx.doi.org/10.1016/S0263-8223(99)00041-0

[21] Gautier L, Mortaigne B and Bellenger V. Interface damage study of hydrothermally aged glass-fibre-reinforced polyester composites. Composites Science and Technology 1999; 59: 2329-2337. http://dx.doi.org/10.1016/S0266-3538(99)00085-8

[22] Tsenoglou CJ, Pavlidou S and Papaspyrides CD. Evaluation of interfacial relaxation due to water absorption in fiber–polymer composites. Composites Science and Technology 2006; 66: 2855-2864. http://dx.doi.org/10.1016/j.compscitech.2006.02.022

Received on 05-05-2016 Accepted on 28-05-2016 Published on 30-06-2016

DOI: http://dx.doi.org/10.12974/2311-8717.2016.04.01.4