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INFLUENCE OF HORNIFICATION OF *LUFFA CYLLINDRICA* FIBRES IN THE REINFORCEMENT OF CEMENTITIOUS COMPOSITES

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Summary: *Vegetable fibres have good performance when used in reinforcement of cementitious composites. The present study investigates the influence of fibres hornification of Luffa cyllindrica in the interaction with the cementitious matrix. Fibres characterization was realized from moisture absorption and direct tensile tests. For analysis of fibres hornification performance in cementitious matrix were prepared moldings of fibre cement in Hatsckek process simulation and composites were subjected to bending in the ages of 28 and 90 days. There was no significant variation of moisture absorption and modulus of elasticity of hornified fibres when compared with natural fibres. However, there was a reduction in tensile strength for hornified fibres. The toughness of fibre cement reinforced with hornified Luffa cyllindrica increased when compared to natural fibres composites in the first ages. Furthermore in the composites with natural fibres there was toughness reduction of 83% at 90 days of age, which not observed for composites with treated fibres, that indicates possible improvement of the durability in the hornified fibres in the cementitious matrix.*

1 INTRODUCTION

Currently is notorious the search for new materials and methods by construction professionals. The cement industry has the concern to develop new materials that have economic, environmental and geological advantages. Engineers have looking for a compound that has good technological, physical and mechanical performance. In this context are the searches that have as subject the use of vegetable fibres as reinforcement in cementitious matrix.

The construction industry is responsible for the depletion of large amount of non-renewable resources and by releasing about 30% carbon dioxide emitted on the planet [1], and consequently aggravates the current context of climate changes from CO_2 emissions around the world. Therefore, it becomes necessary to use alternative and sustainable materials in construction, since it must reduce the consumption of raw materials and reduce waste generation.

Currently, researches prove the efficiency of modified vegetable fibres on strengthening of cementitious matrix, such as: *Luffa cyllindrica* fibre, *coir fibre* and sisal (*Agave sisalana*). The use of vegetable fibres in fibre cement contributes as an interesting option for the construction industry, primarily in developing countries [2]. This is because they are low-cost materials and are obtained from renewable sources, in addition to being biodegradable.

Vegetable fibres do not present health risks as other fibres such as asbestos, material still used by developing countries [3]. However, the vegetable fibres have some disadvantages, including the variations in its volume with the change of moisture content of composite, which results in loss of physical contact with the matrix that has capacity for absorption and strain different of the fibres [4].

Studies show that vegetable fibres subjected to successors cycles of wetting and drying (hornification) have decreased of water absorption, as well as the reduction of dimensional variations of the cross-section resulting from humidity variation [4]. Thus, there is the formation of a compound that has better physical and mechanical performance as well as economic, environmental and ecological benefits. Therefore, the present study has the main objective to evaluate the influence of hornification of Luffa cyllindrica fibres in the reinforcement of cementitious composites.

2 EXPERIMENTAL

2.1 TREATMENT AND FIBRE CHARARACTERIZATION

2.1.1 TREATMENT

The modification of *Luffa cyllindrica* fibres was performed from the hornification method, which consists in a process of wetting and drying of fibres [4]. This method comprised 10 cycles; for such natural mat of *Luffa cyllindrica* were submerged in water at room temperature for 3 h to occur saturation fibres, soon after, were dried in an oven for 16 h at 80 ºC. After the natural mat were cooled until room temperature in order to avoid a possible thermal shock.

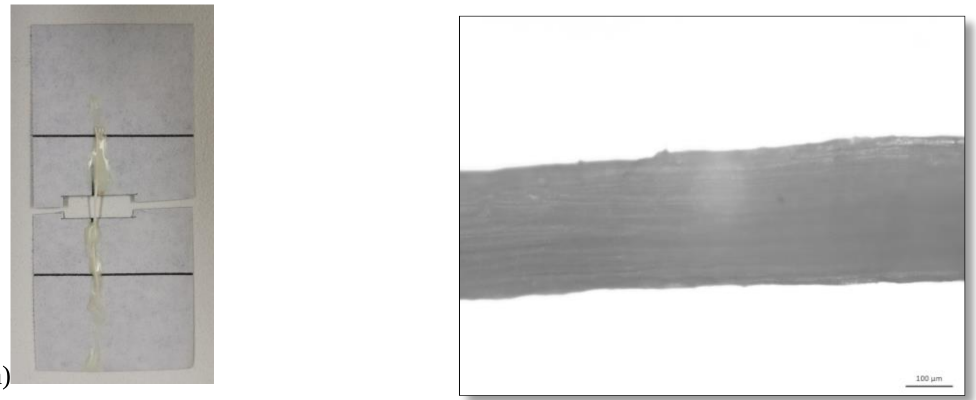
2.1.2 MOISTURE ABSORPTION TEST

The natural and modified fibres of *Luffa cyllindrica* were subjected to moisture absorption test to check the hornification effect. It was used a desiccator to create an atmosphere with humidity of 95%, with a saturated solution of potassium nitrate (KNO_3). All the fibres were dried in an oven for 24 h at a temperature of 100 ºC. The fibres were placed in the desiccator and analyzed by 120 h, performing mass measures at the following intervals: 1, 2, 24, 48, 72 and 120 hours.

2.1.3 TENSILE TEST

The fibres were characterized by direct tensile. For determining the tensile strength, strain and modulus of elasticity, the fibres were selected and removed from the *Luffa cyllindrica in natura*, so that they were not damaged. These were glued on template from 3 mm length (Figure 1a) and for determining the fibres diameters were made micrographs in optical microscope, OLYMPUS CX40 model. The images were obtained with camera ZEYSS AxioCam model ICc5. The dimensions of the fibres were determined by image analysis, using the ZEN lite application, version 2012. Figure 1b shows a micrograph of

Luffa cyllindrica fibre. From the average of the diameter measures were determined the cross sections of each specimen for tensile test.

a)


b)

Figure 1: Specimen for tensile test a) template with fibre; b) micrograph to obtain the fibre diameter.

Tensile test was performed in a universal machine INSTRON, model 5982 and load cell of 5 kN, with speed of 2 mm/min. They were assayed 20 natural *Luffa cyllindrica* specimens and 20 hornified fibres.

2.2 COMPOSITES PREPARATION

2.2.1 PREPARATION OF NATURAL MAT

The *Luffa cyllindrica in natura* were cut into natural mat with width and length of 210 mm. Upon cut and removing the inner part together with seeds, the natural mat were washed in warm water (approximately 45 ºC) to remove impurities (Figure 2).

Figure 2: Saturation of natural mat of sponge gourd fibre.

The natural mat of *Luffa cyllindrica* in the saturated state was compressed in a hydraulic press with a load of 800 kN for a period of 24 h (Figure 3). Once compressed, the natural mat was dried in an oven at the temperature of 60 ºC. Finally, the natural mat of *Luffa cyllindrica* was cut in a square of 200 mm x 200 mm wide.

Figure 3: Pressed mat.

2.2.2 MIXING AND MOULDING

The process of mixing and preparing the specimens was a simulation of the Hatschek process for moulding fibre cement. The fibres were mixed with cement and water with subsequent removal of water excess by vacuum. For the mixture all the water has added initially in the mixer, followed by cellulose fibre, dispersing this for 5 min. Cement is then added and mixed for over 5 min. The assembly of composite consisted basically on an overlay layer blending under the mat of *Luffa cyllindrica* and another layer over the mat. Finally, the composite was compressing with a pressure of approximately 3.2 MPa [5]. Figure 4 provides a schematic illustrating the sequence of composites preparation.

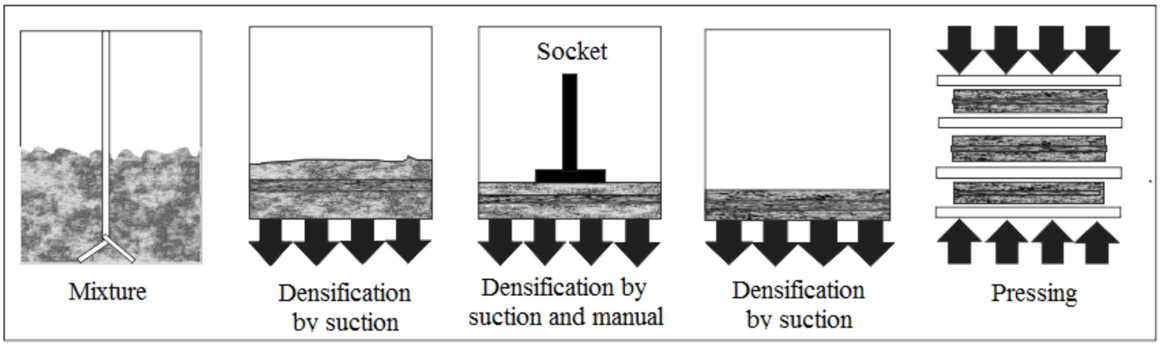


Figure 4: Schematic showing the mixing and molding of the specimens.

For each formulation were conducted four moldings. These moldings were carried out in random order and specimens distributed in order to eliminate the influence of molding sequence in average results. The plates were square shaped with 200 mm x 200 mm wide and average thickness of 4 mm (Figure 5). With these dimensions the *Luffa cyllindrica* fibre content resulted in approximately 3% and the content of cellulosic fibre, which is needed for the molding process, was 2%.

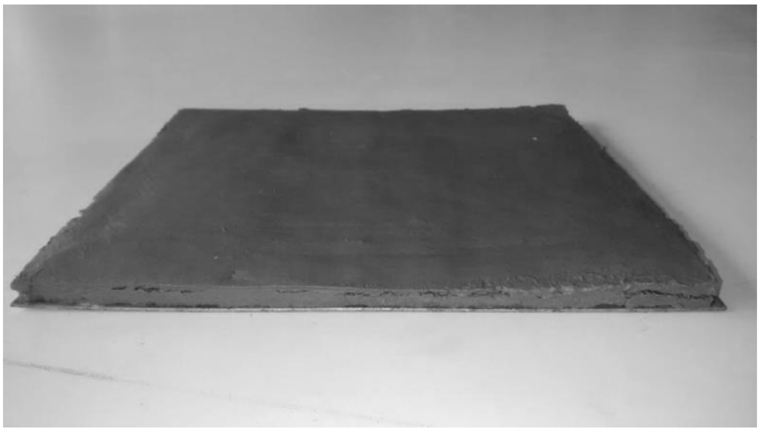


Figure 5: Fibre cement composite.

2.2.3 CURE AND CUT OF THE SPECIMENS

The cure of molded plates was in the chamber with relative humidity above 95% and temperature of 23 ± 2 ºC during the first 28 days of age. The specimens for the bending test were obtained of the plates. After the first 21 days of age, still during the cure period, the specimens were cut in the approximate dimensions of 200 mm length x 40 mm wide.

2.3 TESTS

2.3.1 COMPOSITES BENDING TEST

The specimens obtained from the plates were subjected to bending tests at 28 and 90 days. Through the bending test were determined: flexural strength, modulus of elasticity and toughness of composites. Were tested 4 specimens for each formulation, in each age (Figure 6). The parameters used for the carrying out the bending tests were based on the recommendations of [6], using a universal machine Instron, model 5982, with load cell with a capacity of 5 kN. The applied method was 4 points and automatic speed equal to 2 mm/min. The deflection in the center of span was measured with an LVDT Instron, with 5 mm course.

a)

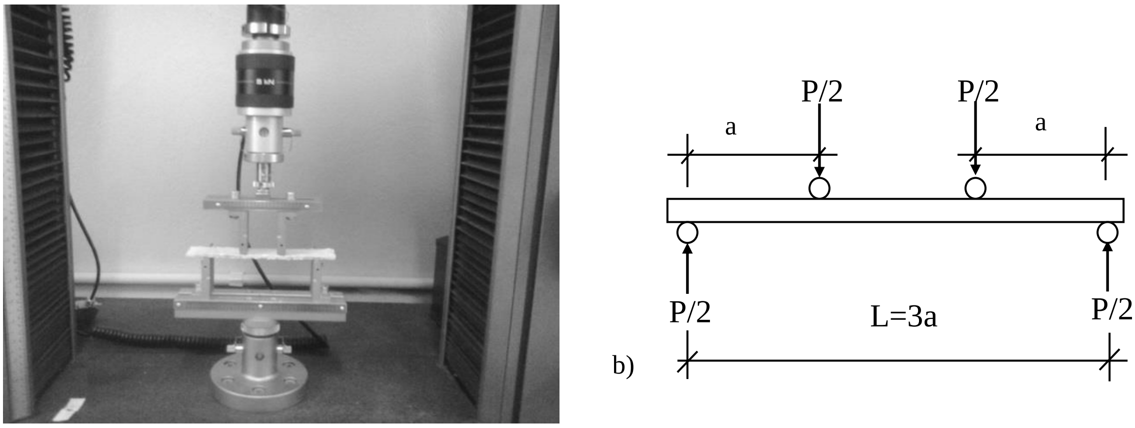


Figure 6: Bending tests of composites: a) Test in progress; b) method schema used.

The flexural strength was determined with the expression of Eq.1 and the elastic modulus in bending calculated by Eq. 2.

$$Flexural\,strength = \frac{P_{max}L}{be^2} \quad (1)$$

$$E = \frac{23L^3}{1296I}\left(\frac{P}{\delta}\right) \quad (2)$$

Where:
P_{max} = maximum flexural load (N);
L = support span (mm);
b = width of specimen tested (mm);
e = depth of specimen tested (mm);
E = modulus of elasticity in bending (MPa);
I = moment of inertia of cross section → $\frac{be^3}{12}$ (mm^4);
P/δ = slope of the tangent to the initial straight-line portion of the load-deflection curve, N/mm.

The toughness of the composite was determined by fracture energy in kJ/m². The specific energy was calculated from area under the load-deflection curve, divided by the cross-sectional area of the specimen.

3 RESULTS AND DISCUSSION

3.1 MOISTURE ABSORPTION TEST

Moisture absorption test is possible to notice that there was no significant variation of moisture absorption of hornified fibres when compared with natural fibres. This can be seen in Figure 7.

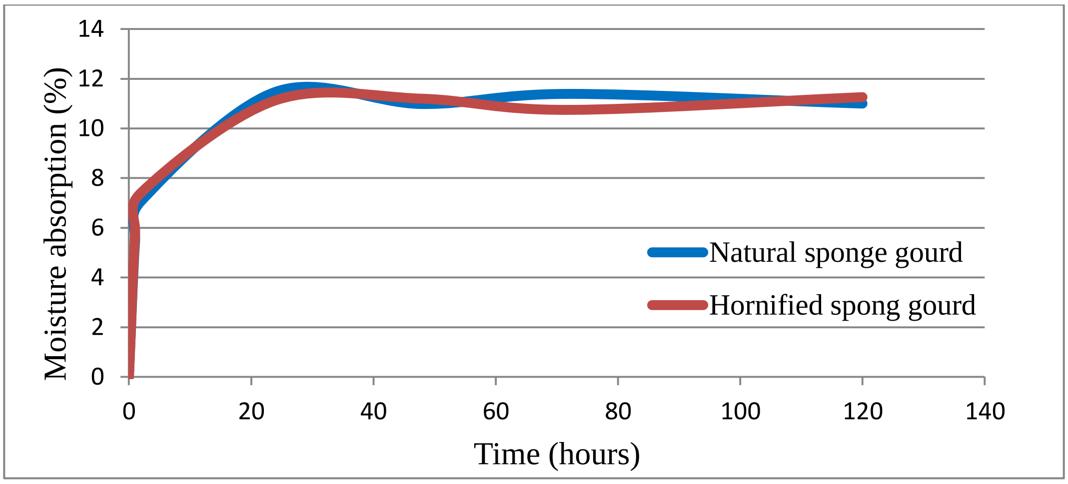


Figure 7: Absorption isotherms of *Luffa cyllindrica* fibres.

3.2 TENSILE TEST

From the tensile test of *Luffa cyllindrica* fibres *in natura* and modified, it should be noted that there was a 34% reduction in the tensile strength of hornified fibres when compared with natural fibres. The maximum strain of hornified fibres decreased 47% in relation to fibre natural. However, it is possible to observe that the elastic modulus of fibres did not change. Table 1 presents the data obtained in the direct tensile test of the fibres.

Fibres	Tensile strength (MPa)	Maximum strain (mm/mm)	Modulus of elasticity (MPa)
Natural	113.44	0.19	873.78
Hornified	74.58	0.10	871.17

Table 1: Tensile test results.

3.3 COMPOSITES BENDING TEST

The bending test of the composites aged 28 days indicates that there was a small decrease in the flexural strength and in the modulus of elasticity of composites with the hornified *Luffa cyllindrica* fibre regarding natural fibre. On the other hand, the toughness increased slightly.

However, the toughness of composites reinforced with natural fibres reduced 83% at 90 days of age, while the composites with treated fibres had a reduction of 52%. These results can be indicative of natural fibre/matrix interface suffered further deterioration then the hornified fibres.

It also noted that with the aging of composites, there was increased flexural strength and modulus of elasticity in composites with hornified fibres, while these properties suffered decrease of approximately 43% in natural composites. These results are indicative of both the durability as fibre/matrix interaction has been improved with the treatment of hornification of *Luffa cyllindrica* fibres. The results obtained are shown in Table 2.

Fibres	Age (days)	Flexural strength (Mpa)	Modulus of elasticity in bending (MPa)	Toughness (kJ/m²)
Natural	28	5.56	11534.43	0.63
	90	3.12	6169.34	0.11
Hornified	28	4.68	8819.47	0.66
	90	5.93	9476.51	0.32

Table 2: Results of bending test.

4 CONCLUSIONS

The use of vegetable fibres in fibre cement becomes an interesting option for the construction industry because they are low cost and materials obtained from renewable sources, in addition to being biodegradable. However, present degradation due to the alkalinity of the cementitious matrix.

The hornification of the *Luffa cillyndrica* fibres did not altered significantly the moisture absorption, or the modulus of elasticity of these fibres. However, the tensile strength of the fibre suffered slight reduction with the treatment. When tested in the composites, the fibre modification not has impacted the properties in the early ages, but with aging of composites could realize that the hornification fibre resulted in improvement of mechanical properties with age and less reduction in toughness compared with natural fibre composites.

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