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ELABORATION AND CHARACTERIZATION OF THE MECHANICAL PROPERTIES AND MOISTURE BUFFER VALUE OF A COMPOSITE BASED ON LIME AND DATE PALM PETIOLE FIBRE

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Abstract

This study concerns a new ecological material, bio-sourced and with reduced environmental impact. The material in question is a composite made from date palm fibers and lime. For the development of this material, we were inspired by the techniques used for the manufacture of hemp concrete. The latter is widely used especially in France for the thermal insulation of buildings. The idea is to design an insulation material from the natural resources of the southern Algerian region. The material made is a lightweight concrete that could provide both thermal and acoustic insulation. By its porous morphology, it also has the ability to absorb water vapor when it is in an environment with high relative humidity and to release the vapor if the environment is dry. It could therefore play the role of a water regulator. Experimental investigations revealed interesting mechanical and hydrous properties. Measurements of the moisture buffer value (MBV) reveal that according to the current standard, the material is classified between good and excellent. As regards the mechanical strength, the material produced has an acceptable compressive strength.

1. Introduction

The hygrothermal behavior of building envelopes must make it possible to limit energy needs, ensuring a satisfactory level of comfort. This behavior is linked to the water and thermal characteristics of the materials used. An experimental study of a composite material based on date palm fibers [1] shows that this material could play the role of a water regulator. So, it can provide heat and sound insulation. A work on the hydric performance of hemp concrete [2] deals with the dynamic characterization of the hydric behavior of molded hemp concrete. Two

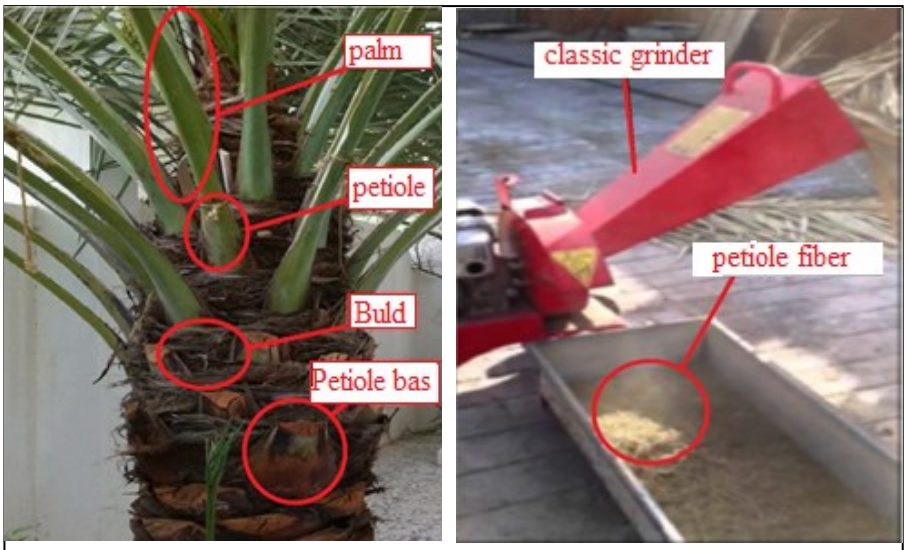
types of rendering are considered: sand-lime and hemp-lime. The results of this work show that molded hemp concrete is a very good water regulator with an open coating. Among the bio-resourced materials in the construction sector, hemp concretes occupy an important place for their interesting properties: water regulation, thermal and acoustic insulation [3], experimental measurements are carried out on a hemp-starch concrete in order to determine the water vapor permeability, the sorption isotherm and the moisture buffer capacity of the material. The use of vegetable fiber walls is a solution to reduce energy consumption while using ecological products with low embodied energy (A vegetable material based on hemp fibers and a binder based on wheat starch) [4]. The hydric behavior of a sample of hemp concrete subjected to static jumps in relative humidity has been studied experimentally and numerically [5], compared to plaster and brick, hemp concrete has a great capacity to absorb humidity. A numerical modeling has shown the importance of taking into account the phenomenon of hysteresis on the behavior of the material [6]. The use of composite materials based on date palm leaf stalks can play an important role in this area. The mixture of these petioles with lime gives a material with good mechanical properties and moisture buffering capacity. However, the value of the moisture buffer is sensitive to the composition of the material (fibre/lime ratio). Among the objectives of this work, it is the valuation of the petiole of the date palm. For this, we used palm petiole fibers resulting from the grinding of dry palms. It's denier, usually they are burned or in the best cases, they are used in traditional windbreaks.

First, we experimentally study the resistance of the sample of the composite material (date palm petiole/lime) to compression; then we discuss the moisture -buffer behavior of this material subjected to static jumps in relative humidity.

2. Experimental procedure

2.1. Material development

Sustainable waste management consists of the recovery, recycling and reuse of waste, in particular palm leaves (petiole fiber). We obtain the date palm fiber by grinding the lower part of the palm called the "petiole", using a conventional grinder (Figure 1).



a) Palm components. b) Classic grinder.

Figure 1. Petiole fiber production

We filled the mixture on molds and manufactured according to the shape and dimensions of the test piece. A pressure is applied to keep the same value of the density for all the specimens (figure 2).

According to standard C39/C39M–03 [7]; the chosen dimensions are: cylindrical specimens of dimensions (Φ80mmx160mm) and prismatic specimens of dimensions (100mm×100mm×30mm), are made (Figure 3). The fiber produced by crushing the petioles is mixed with slaked lime and water according to the chosen mass fractions **FPED.C80** (20% fiber /80% lime) - **FPED.C65** (35% fiber /65% lime) - **FPED.C50** 50% fiber /50% lime) and **FPED.C30** (70% fiber /30% lime).

After the specimens have been produced, a drying cycle under natural conditions (ambient temperature and humidity) is necessary before all the trials and tests on the specimens carried out (determination of the apparent density, mechanical tests, and measurement of moisture inertia), by a scale of 0.01mm precision, we made daily weighing's according to the C39/C39M-03 standard. The drying results are shown in Figure 6.

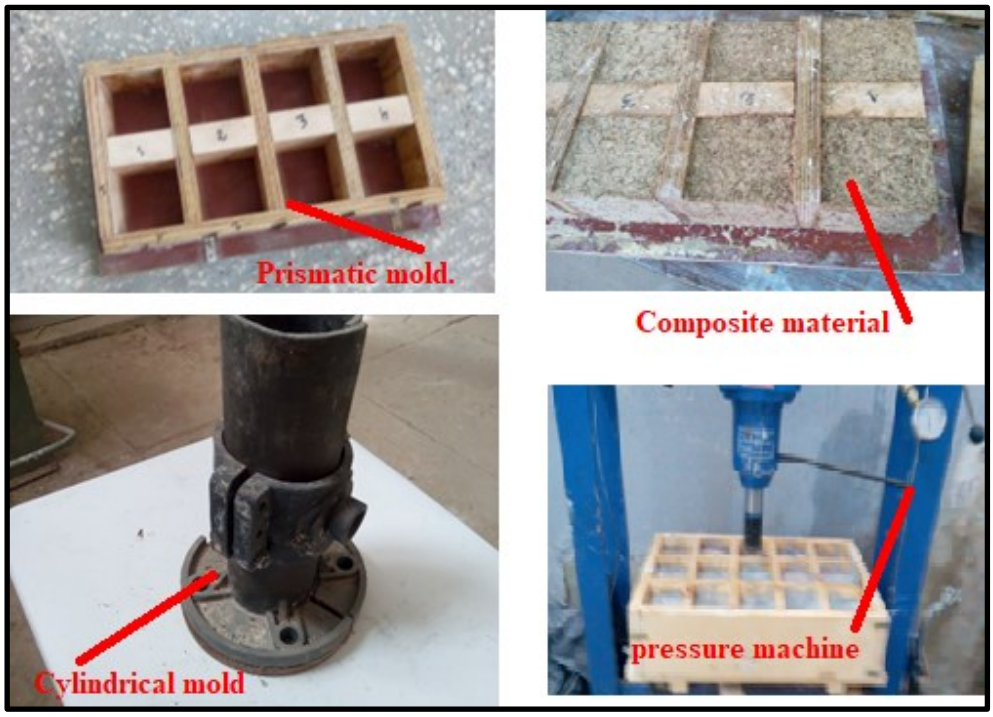


Figure 2. Filling of the moulds



Figure 3. Date palm/lime petiole specimen

2.2. Apparent volumetric mass

Specimens of different mass fraction (FPED.C80, FPED.C65, FPED.C50, FPED.C30) of rectangular shapes of dimension 100mmx100mmx30mm for each (figure 3) were used. The apparent density is determined indirectly from the masses for the different states (dry or wet) and the apparent volume of the samples (equation.1). the different atmospheres are ensured by the use of a climate chamber, where the types of comfort chosen (relative humidity and temperature) are: 15% RH/23°C, 50% RH/23°C and 75% RH/23 °C [8].

The determination of the apparent volume is ensured by a digital caliper which allows a direct reading with an accuracy of ± 0.01mm (measurement of height, width, and thickness).

Each dimension is calculated from an average of three measurements. The masses of the specimens are ensured by weighing using a 0.01g precision balance. Each test is repeated five times for each composition (5 samples for each composition).

$$\rho = \frac{m}{V} \quad (1)$$

2.3. Mechanical tests

On a uniaxial compression machine (Figures 4), we carried out compression tests on 5 samples of different mass fraction (FPED.C80, FPED.C65, FPED.C50, FPED.C30) of cylindrical shape of dimension Φ80mmx160mm for each (Figure 3). This recording makes it possible to determine the different mechanical characteristics according to the need (the uniaxial compressive strength RC, the elastic limit Re, the Young's modulus E and the Poisson's ratio ν). Cylindrical samples of section (S) were previously dried. The tests are generally carried out in batches of 5 samples to obtain a good average; the sample should preferably have an expansion (height to diameter ratio) of 2 to 2.5 (the usual size of our specimens is 160 mm in height by 80 mm in diameter). The stress/strain curves of our material are represented in figure 8.



Figure 4. Compression test

The average values of compressive stress σ and Young's modulus E obtained for each mixture during the simple compression tests carried out are given in table 2.

Let us briefly recall the main formulas used to calculate the mechanical properties in compression [9]. First, the compressive stress in MPa.

$$\sigma = F/A \tag{2}$$

We find F and A which represent the force (N) and the section of the sample. Second, the compressive stress and Young's modulus E calculated by the ratio of stress and strain from Hooke's law.

$$E = \sigma/\varepsilon \tag{3}$$

Where Ɛ is calculated by dividing the elongation by the original length.

$$\varepsilon = \Delta L/L \tag{4}$$

2. 4. Measurement of moisture inertia

The water inertia is evaluated according to the MBV (moisture buffering value) of the material. The moisture buffering value makes it possible to characterize the ability of a material or a multilayer component to moderate variations in the relative humidity of the surrounding air. This value indicates the quantity of water adsorbed or rejected when the material is subjected to a variation of 1% of relative humidity.

We carried out measurements of the moisture buffer value on 4 samples of different mass fraction (FPED.C80, FPED.C65, FPED.C50, FPED.C30) of parallelepiped shape of dimensions (100m×100m×30m) for each (figure 3). Each experiment is repeated five times (five specimens for each composition).

To measure the moisture buffering value, the surfaces of the samples are insulated with aluminum foil except the sorption/desorption surface (the upper surface) (figure 5), these samples were placed in an atmosphere at 23°C and 50% relative humidity until their mass stabilized, then they were subjected to periodic daily variation of relative humidity (8h at 75% and 16h at 33%) according to the ISO 8302 standard [10]. This atmosphere is ensured by a climatic chamber (figure 5). The mass of the samples was measured 5 times during the adsorption phase and 2 times during the desorption phase. The test is stopped when the variation in adsorption mass over 8 consecutive days is less than 5%.

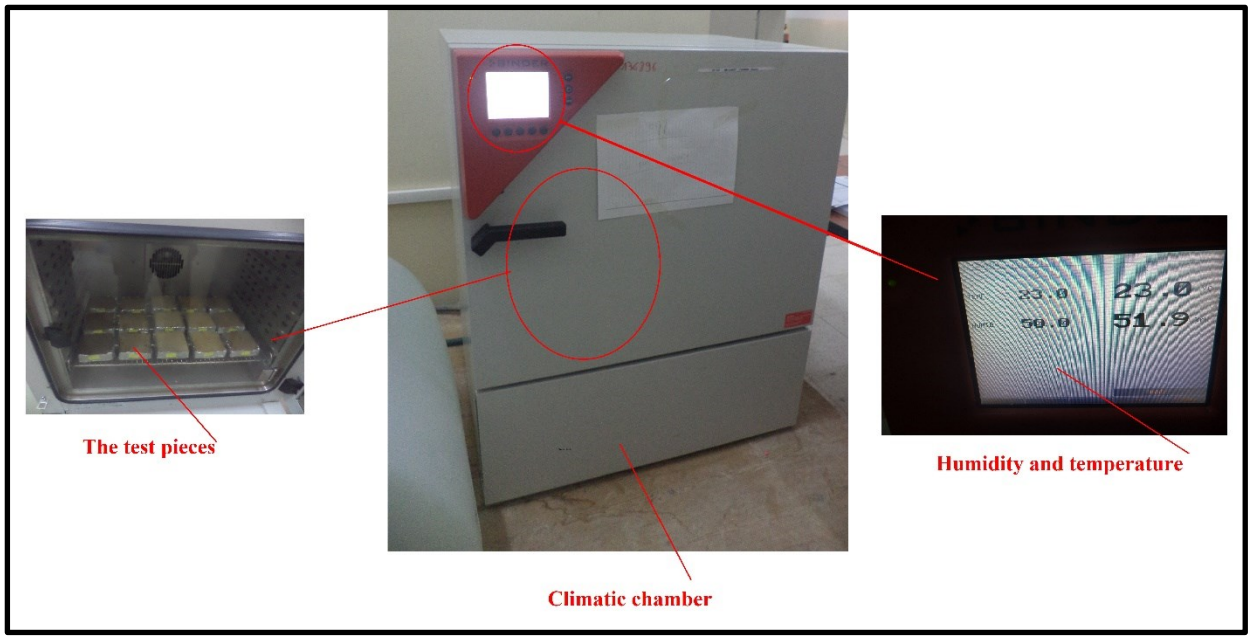


Figure 5. Climatic chamber

The moisture buffering value is calculated according to the following equation [10].

$$MBV = \frac{\Delta m}{A.(HR_{Haute} - HR_{Basse})} \quad (5)$$

Δm: mass change during the absorption/desorption phase (g)

A : Exchange area (m²)

$HRhaute / HRbasse$: high and low relative humidity during the cycle (%)

The results are shown in figures (9 and 10).

3. Discussions and results

3.1. Kinetics of drying

The figure 6 represents an example of drying kinetics for the material FPED.C65. We noted that the weight variation does not exceed 0.1 gram after the 1st week of drying, this value is acceptable according to the C39/C39M–03 standard, and we can say that the 21 days of drying are largely sufficient for our material.

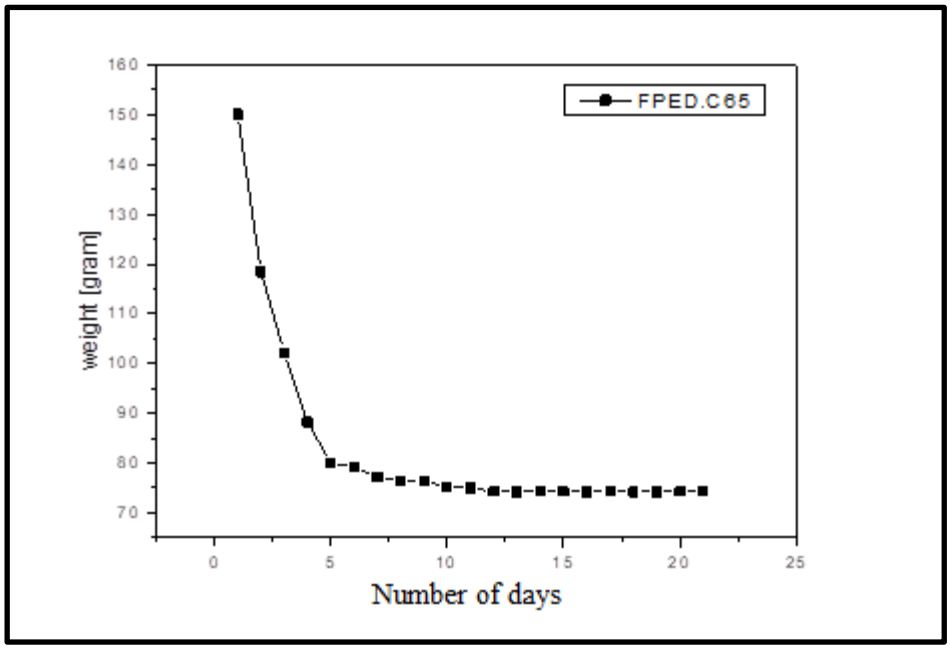


Figure 6. Example of drying kinetics for the material FPED.C65

3.2. Apparent volumetric mass

It is clear to notice in figure 7, that the density increases progressively with the rate of the binder (lime) for all the materials (FPED.C80, FPED.C65, FPED.C50 and FPED.C30) in all the states of comfort (15% HD, 50% HD, 75% HD), this result is logical since the density of the lime is greater than that of the petiole. It should also be noted that the difference in density between two successive comforts decreases with the increase in the binder: Δρ(15% HR, 50% HR) decreases from 40.16 Kg/m^3 (for 30% lime) to 12.83 Kg/ m^3 (for 80% lime) and Δρ(50% HR, 75% HR) decreases by 22.01 Kg/ m^3 (for 30% lime) at 4.86 Kg/ m^3 (for 80% lime). These observations show that the material stores water droplets on the pores when saturated with humidity (high porosity). These results are consistent with the results of other authors who work on material based on plant particles [12]. All results are summarized in Table 1.

Table 1. Densities of specimens for different comforts.

	FPED.C80	**FPED.C65**	**FPED.C50**	**FPED.C30**
15%HD	837.41 Kg/m^3	772.65 Kg/m^3	625.85 Kg/m^3	508.68 Kg/m^3
50%HD	850.24 Kg/m^3	796.71 Kg/m^3	651.23 Kg/m^3	548.87 Kg/m^3
75%HD	855.10 Kg/m^3	806.42 Kg/m^3	663.01 Kg/m^3	570.88 Kg/m^3

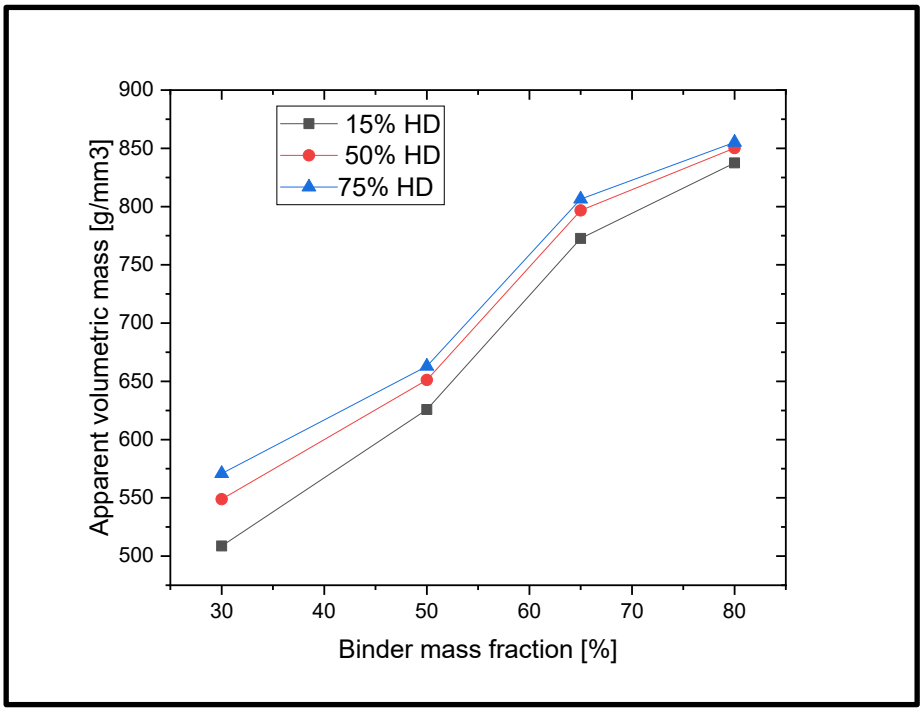


Figure 7. Apparent density

3.3. Mechanical properties

On some samples, we can observe the moment when the first cracks appear. This is reflected in the stress-strain curve σ-ΔL (Figure 8). It is also observed that the maximum breaking stress is often well marked on the σ-ΔL curve, in particular for the FPED.C80 material (80% of the binder). This material exhibits elastoplastic behavior from the smallest deformations with high rigidity depending on the binder dosage, the rigidities and compressive stresses of the manufactured parts increase when the binder content increases (the fiber content decreases), this means the high hardness of the lime compared to the hardness of the fibers, (this is the main reason for the realization of composite materials). It is also possible to relate these results to the previous results (the apparent density), because the latter can be directly proportional to the hardness, whatever the humidity level. These results are consistent with the results of other authors working on hemp/lime [8, 13]. Note that all the results are summarized in table 2.

Table2. Mechanical test results

Material	E [MPa]	Standard deviation	σ [MPa]	Standard deviation
FPED.C80	308	0.122	3.061	0.0001
FPED.C65	120	0.022	1.934	8.74E-05
FPED.C50	45	0.014	1.479	5.49E-05
FPED.C30	31	0.011	1.017	4.32E-04

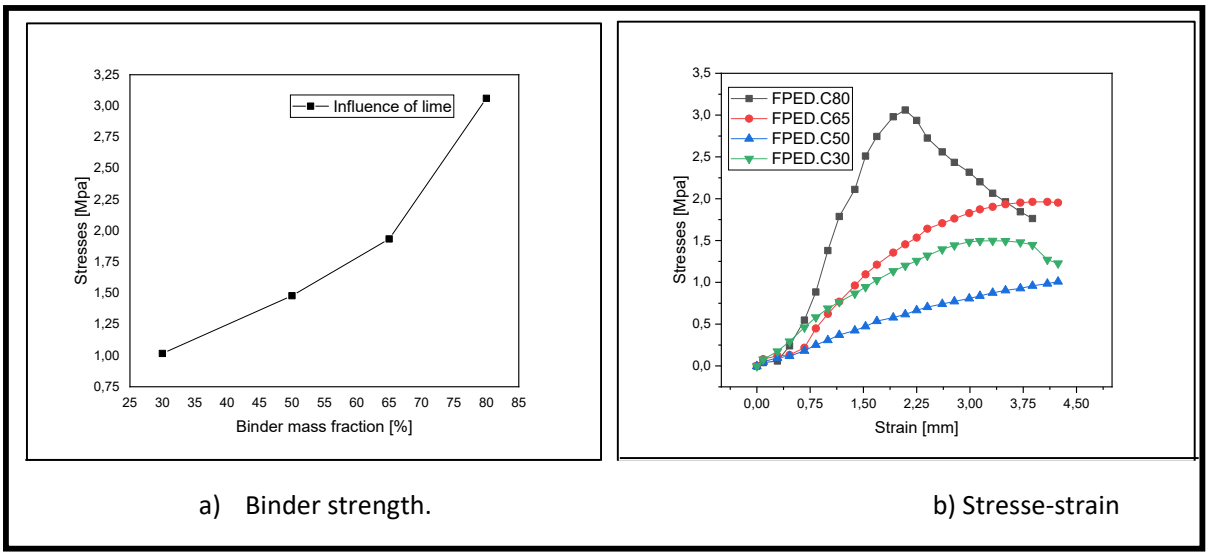


Figure 8. Mechanical properties

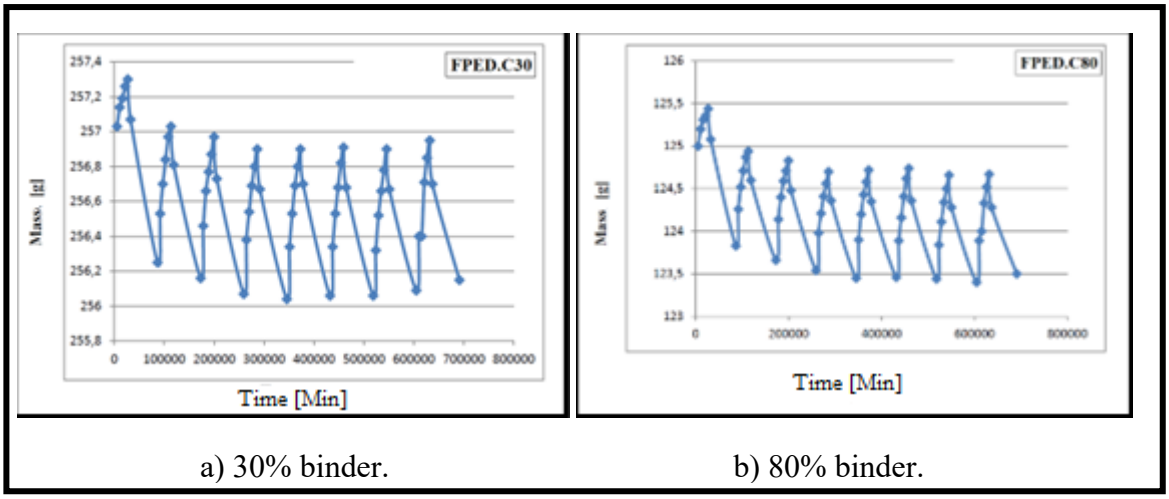
3.4. Moisture inertia

During the test, the average relative humidity value is slightly lower than 75% during the absorption phases and slightly higher than 33% during the desorption phases. This is due to the regular opening of the door during weighing. On the other hand, when changing setpoints, the change from 33 to 75% takes about 10 minutes, whereas it takes almost half an hour to go from 75 to 33%.

According to the Nordtest-project method [14], the setpoint change should ideally take place in less than thirty minutes, however it has been demonstrated that the duration of the rise/fall in relative humidity has a limited effect on the water buffer capacity value (less than 5%) even when this duration reached an hour and a half.

According to figure 9 and figure 10, the moisture buffer value (MBV) are (2.67 g/m^2.% RH, 2.95 g/ m^2.% RH, 3.01 g m^2.% RH and 3.38 g/ m^2.% RH respectively) for the materials (FPED.C80, FPED.C65, FPED.C50 and FPED.C30 respectively) and therefore, according to the classification of C. Rode and al [15] (figure 10), the elaborated materials are classified as being :

- FPED.C80 and FPED.C65 are classified as “good humidity regulator”.
- FPED.C50 and FPED.C30 are classified as “excellent humidity regulator”.



a) 30% binder. b) 80% binder.

Figure 9. Kinetics of mass gain/loss

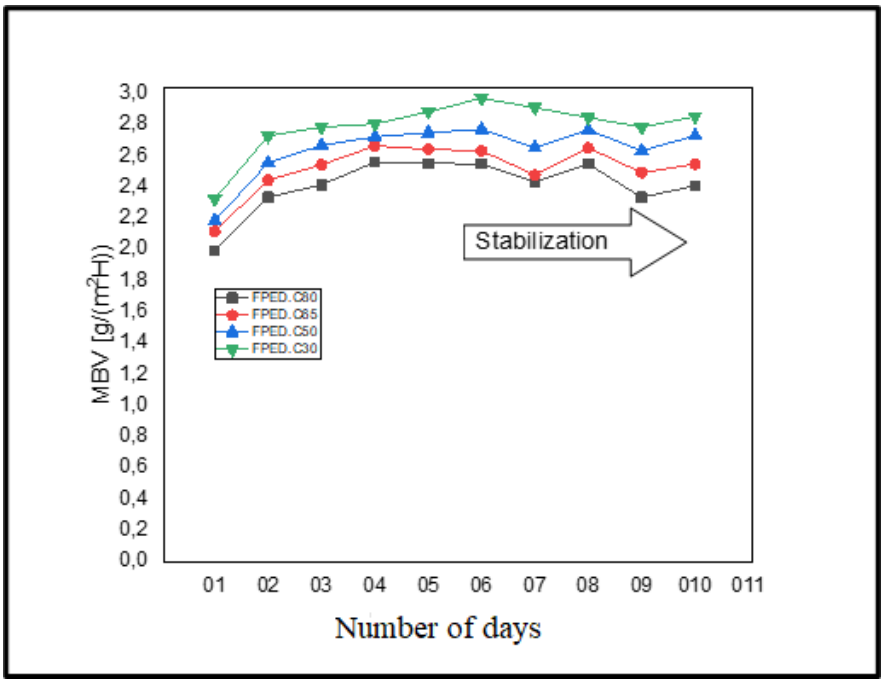


Figure 10. Variation of Moisture Buffer Value

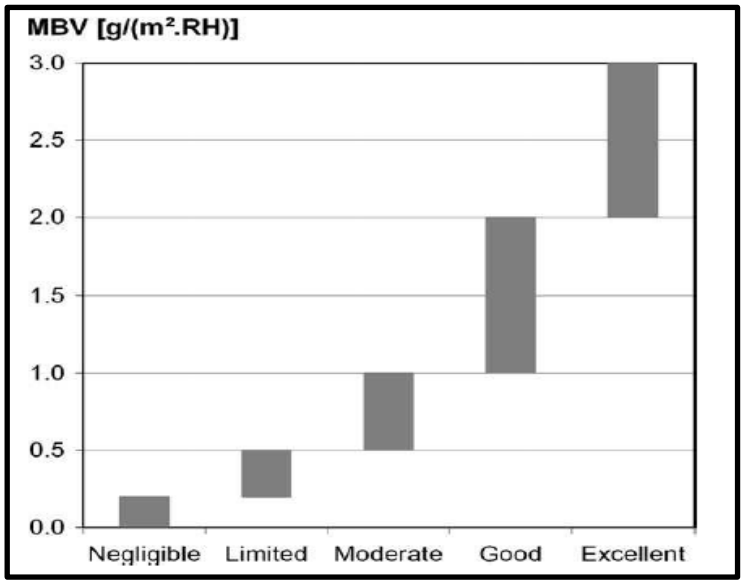


Figure 11. Ranges for practical Moisture buffer value classes [13]

4. Conclusion

Composites based on plant fibers and lime are materials essentially characterized by their thermo-hydric behavior. In this work, a material based on date palm petiole fibers and lime was successfully made. By appropriate experimental techniques, it was possible to estimate the apparent dry and wet densities, the compressive strength of the material in question as well as the water buffer capacity.

According to the analysis undertaken, the material produced has values of apparent density varied with the evolution of humidity, between (508.68 Kg/m3 and 837.41 Kg/m3) in the dry state (15%HD) and between (570.88 Kg/m3 and 855.10 Kg/m3) in the wet state (75%HD), in addition to an acceptable compressive strength, between (1.017 Mpa and 3.061 Mpa) according to the evolution of the fiber content (from 20% to 70% fiber). The composite reveals great capacities in terms of water regulation between (2.67 g/m^2. % RH, and 3.38 g/m^2.% RH). It was also observed the sensitivity of water properties to the percentage of petiole fiber used in the mixture. According to the values of the moisture buffer value measured the material is classified as excellent.

Acknowledgement

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Champagne-Ardenne, France.

References

[1] R. BELAKROUM et al., "*Etudes des propriétés d'absorption hydrique et acoustique d'un nouveau matériau d'isolation bio-sourcé*", 1er Colloque International sur les Hydrocarbures, Energies et Environnement 2019.

[2] F. Collet, S. Pretot, and C. Lanos, *"Performance hydrique de bétons de chanvre: effet de l'enduit sur leur capacité de régulateurs hydriques,"* 31ème Rencontres AUGC ENS Cachan 2013*,* pp. 1-10, 2013.

[3] B. S. Umurigirwa, C. Maalouf, H. Ali, and T. H. Mai, *"Etude numérique et expérimentale du comportement hygrothermique d'un agro-composite à base de fibres de chanvre et d'amidon de blé,"* in Conférence IBPSA France-Arras, 2014, pp. 1-10.

[4] U. B. Sandrine, A. Gacoin, M. Chadi, T. H. Mai, and M. Rebay, *"Etude expérimentale du béton de chanvre à base d'amidon"* in XXXèmes Rencontres AUGC/IBPSA, 2012.

[5] C. Maalouf, M. Lachi, T. Mai, and E. Wurtz, *"Numerical and experimental study of the hygric inertia of a hemp-lime concrete"* , International journal of mathematical models and methods in applied sciences, vol. 7, no. 2, p. 8, 2013.

[6] M. Benhaled, S.-E. Ouldboukhitine, and S. Amziane, *"Modélisation théorique et expérimentale du comportement énergétique et environnemental des matériaux de construction biosourcés"*, Academic Journal of Civil Engineering*,* vol. 36, no. 1, pp. 611-614, 2018.

[7] S. Braike, *Conception d'éléments préfabriqués de ponts avec des bétons fibrés à haute et ultra haute performance*, École Polytechnique de Montréal, 2007.

[8] D. Samri, *"Analyse physique et caractérisation hygrothermique des matériaux de construction: approche expérimentale et modélisation numérique*", Ecole Nationale des Travaux Publics de l'Etat, 2008.

[9] C. Massonet and S. Cescotto, *Mécanique des matériaux.* De Boeck Supérieur, 1994.

[10] E. ISO, *"8302 (1991) Thermal insulation-Determination of steady-state thermal resistance and related properties-Guarded hot plate apparatus",* International Organization for Standardization, Geneva, Switzerland, 1991.

[11] F. Collet and S. Prétot, *"Variation de la capacité hydrique tampon de bétons de chanvre en fonction de la formulation",* Ecobat Sciences et techniques 1ère édition, vol. 7, 2012.

[12] V. Cérézo, *"Propriétés mécaniques, thermiques et acoustiques d'un matériau à base de*

particules végétales: approche expérimentale et modélisation théorique", Institut National des Sciences Appliquées, Lyon*,* 2005.

[13] M. Chikhi, *"Young's modulus and thermophysical performances of bio-sourced materials based on date palm fibers",* Energy and Buildings, vol. 129, pp. 589-597, 2016.

[14] Department of Civil Engineering - Technical University of Denmark. (2005). Moisture Buffering of Building Materials.

[15] C. Rode *et al.*, *Moisture buffering of building materials*. Technical University of Denmark, Department of Civil Engineering, 2005.