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Hygric behaviour of a clay-Typha bio-based material for building

Ibrahim Niang[1], *Chadi* Maalouf[1,*], *Tala* Moussa[1], *Etienne* Samin[2], *Ton Hoang* Mai[1], and *Salif* Gaye[3]

[1]GRESPI, SFR Condorcet FR CNRS 3417, University of Reims Champagne Ardenne, 51687 Reims, Cedex 2, France
[2]Centre international de la construction en terre, Grenoble, France
[3]University of Thiès/LME, Thiès, Senegal

Abstract. This study deals with the impact of the amount and granulates type of Typha Australis on the hygric performance of building material based on clay. Three compositions are tested: Two of them have the same proportion of granulate but differ by their morphology (transversal or longitudinal cut of the plant). The third composition contains less Typha granulates resulting from the transversal cut. Hygric properties are experimentally, such as permeability, sorption isotherms, and moisture buffering value. Results show an influence of the Typha granulate and its volume content on the hygrothermal properties of the material due to the porosity.

1 Introduction

Bio-based composites are becoming more and more used as thermal insulating material for reducing building energy consumption due to their interesting technical performances [1-4]. Many investigations have been conducted to study their hygric behaviour , as for instance, the moisture buffering value (MBV) of a new agromaterial based on hemp and starch [3]. Results show that such materials are considered as excellent humidity regulator (MBV of 3.39 g m^{-2} $\%RH^{-1}$). In another study the hygric properties (isotherm, water vapor permeability, capillary water absorption, and moisture buffer capacity) of ‘‘rape straw lime concrete” were presented [1].

Results unveil an excellent moisture buffering capacity (between 2.02 and 2.59 $g.m^{-2}$ $\%RH^{-1}$), and interesting hygric properties.

This paper deals with the study of hygric properties of a Typha-clay based building material.

Typha Australis is a plant which grows in Senegal. However, it threatens the local ecosystem and constitutes a socio-economic danger for the invaded area [5]. One of the solution to get rid of the plant is to be valorised as a bio-based building material in association with clay. The choice of the clay binder was based both on environmental and availability criteria in Senegal, resulting in 100% natural and local resource building material, which use requires very little processing and for which techniques are very well mastered [6–8].

In literature, many studies concerns clay properties. Results revealed that unfired clay masonry MBV (Moisture Buffering Value) vary between 1.13 and 3.73 $g.m^{-2}$. $\%RH^{-1}$ [9]. McGregor et al. also show that the nature of the particles that composed the soil have an important influence on the moisture capacity, sorption isotherms, and water vapour permeability. The review on hygric properties of building materials derived from *Typha Australis* [10-12] shows a good hygrothermal performances.

The aim of this contribution is to elaborate and study the hygric properties of Typha and clay mixtures as a function of the ratio and morphology of two different types of Typha fibres: one obtained from a transversal cut (T) and the other from a longitudinal cut (L). The raw materials physical characteristics are detailed such as bulk and absolute densities. Then, the used experimental methods to determine the following properties are presented: permeability, sorption isotherm, and moisture buffering value. Experimental results are presented and the impact of the type of Typha chips as well as the ratio on the material’s behaviour are discussed.

2 Materials

2.1 Typha Australis

Typha *Australis* is a 3.50 meters herbaceous, monocotyledonous plant. It is composed of a cob-fed blade containing between 20,000 and 700,000 seeds (explaining its high reproductive capacity), a stem surrounded by leaves, and rhizomes [13]. In this work, Typha plants were harvested and transported from Senegal [14].

Samples are prepared using two types of Typha granulates: one from longitudinal and the second from transversal cut of the plant as shown in Fig.1.

Transversal cutting mode maintains the internal structure of the plant characterized by a high porosity. The outer surface of this kind of fibers is rough. The bulk density is about 51 ± 1.5 $kg.m^{-3}$. The fractions resulting from longitudinal cutting have a very low intra-particle porous structure and a very smooth external wall. The bulk density being 60 ± 1.2 $kg.m^{-3}$.

* Corresponding author: chadi.maalouf@univ-reims.fr

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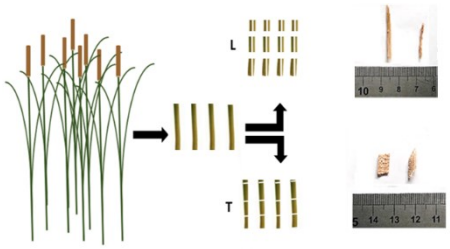


Fig. 1. Methods for cutting Typha plant into longitudinal (L) and Transversal (T) chips.

Fig.2 shows that the longitudinal fraction is smaller than the transversal fraction. In addition, the longitudinal fraction is formed of thinner chips that do not contain macrospores.

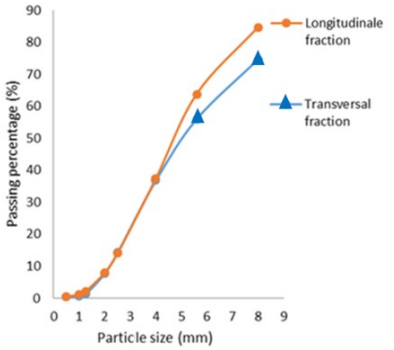


Fig. 2. Grain size distribution curve of Typha chips.

2.2 Clay

Clay soil from "Thicky town" (Thiès region in Senegal) is used for the samples preparation. Granularity and plasticity tests were carried out to examine if it is suitable to be used as a building material. Fig. 3 shows that this clay is composed of 62% fine particles.

Atterberg limits are determined to define indicators qualifying the plasticity and predict the behavior of the soil according to the water content variations [15]. Three geotechnical parameters are determined. First, liquidity limit [WL] (the water content of a soil at the point of transition between the liquid and plastic states). Then, plasticity limit [WP] (the water content of a soil at the point of transition between the plastic and solid states).

Finally, the plasticity index [Ip] which is the difference between the limits of liquidity and plasticity. This parameter allows the evaluation of the water content range in which the soil is in the plastic state. The results shown in Table 1 [16] show that the Thicky clay has to be considered as a plastic soil (Table 2).

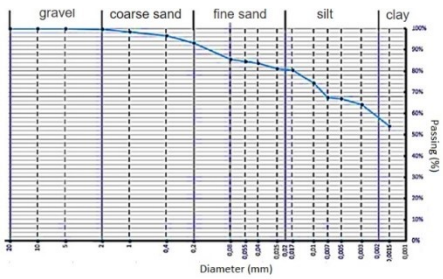


Fig. 3. Thicky soil granulometric analysis [16].

Table 1. Atterberg limits of *Thicky* soil [16].

Liquidity limit (WL)	50.2%
Plasticity limit (WP)	19.2%
Plasticity index (Ip)	31.0%

Table 2. Classification of the plasticity degree as a function of the plasticity index [6].

Plasticity index	Plasticity degree
0 < IP < 5	Non-plastic
5 < IP < 15	Moderately plastic
15 < IP < 40	Plastic
IP > 40	Very plastic

2.3 Materials formulation

Different mixtures are prepared (Table 3) [17] in order to estimate the influence of Typha granulates mass and fraction type on the behavior of this eco-material. Both formulations (L-80/20 and T- 80/20) produced by both L and T fraction. The measured bulk density varied between 300 and 330 kg.m^{-3}. The third formulation (T-66/33) was made from T granulates. The measured bulk density is between 500 and 600 kg.m^{-3}.

Table 3. Material characteristics.

Formulation	L-80/20	T-80/20	T-66/33
Raw materials	Typha: longitudinal cutting Clay Water	Typha: cross cutting Clay Water	Typha: cross cutting Clay Water
Weight proportion (%)	33	28	15.5
	66	70.5	81
	1	1.5	3.5
Density (kg.m^{-3})	323.0	304.3	585.5
Standard deviation (kg.m^{-3})	9.7	1.3	3.9

It can be seen that aggregates produced by longitudinal cut (L-80/20) present the highest standard deviation value. Indeed, it should be noticed that they broke up quickly after the drying phase. This is due to the

morphology of these particles. In fact, because of their low roughness, they adhere less to the binder.

3 Methods

3.1 Permeability

Water vapour permeability δv ($kg.m^{-1}.s^{-1}Pa^{-1}$) defines the ability to allow water vapour to pass throughout a material under a gradient of vapour pressure. The sample is put in a chamber where a solution of saturated (potassium nitrate KNO_3) salt is placed in a cup right underneath for the wet cup protocol, or anhydrous salt (calcium chloride anhydrous $CaCl_2$) for the dry cup protocol [18]. The overall system is conserved into a climatic chamber set to 50% RH at 23°C as shown in Fig.4.

First, the flow of water vapor through the test sample G is calculated. It corresponds to the slope of the curve representing the evolution of the overall mass of the "cup and sample assembly" as a function of time. The vapor flux density of the vapor g is deduced by the formula (1) where A represents the exchange surface between the sample and the water vapor. The water vapor permeance W ($kg.\ m^{-2}.sec^{-1}.Pa^{-1}$) is calculated using the formula (2).

$$g = \frac{G}{A} \tag{1}$$

$$W = \frac{G}{A.\Delta_{\rho v}} \tag{2}$$

$$\delta = W \times d \tag{3}$$

$$\mu = \frac{\delta_a}{\delta} \tag{4}$$

The water vapor permeability δ of the material is calculated by the formula (3). The resistance factor to water vapor μ is given by equation (4).



Fig. 4. Typha clay samples for permeability measurements.

3.2 Sorption isotherm

Sorption tests were carried out according to the standard [19]. Five samples of size 10x10x10 cm per mixture were prepared. They were dried for 7 days at 50 °C and 5% RH until they reach the dry state.

They were then placed in a climatic chamber at 23 °C and at various RH levels: 20, 40, 60, 80, and 97% as presented in Fig.5. At each humidity level, measurements were carried out until mass variation for three successive weighs less than 0.1% of the total mass. An additional measurement was performed in a hygrostat at 97% RH using a potassium sulfate saturated solution.

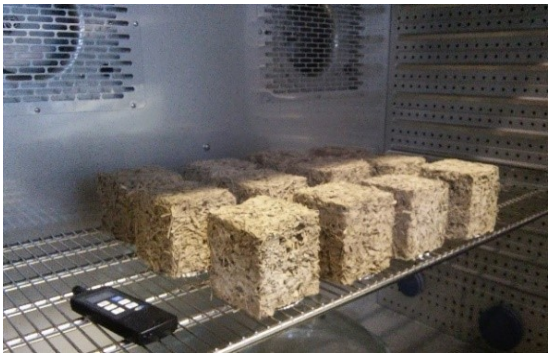


Fig. 5. Typha clay samples for sorption isotherm.

3.3 Moisture buffering value

Moisture buffering value characterizes the ability of a material to dampen relative humidity variations. Based on a specific protocol [20], it is defined as :

$$MBV = \frac{\Delta m}{A.(HR_{high} - HR_{low})} \tag{5}$$

where Δm is the mass variation during the absorption or desorption phase (g), A is the exchange surface (m^2), HR_{high} and HR_{low} are the high and low relative humidity during the cycle. It is expressed in $g.m^{-2}.\ \%RH^{-1}$. Samples of dimensions (100 x 100 x 50 mm^3) are subjected to several dynamic sorption and desorption cycles during which the relative humidity is successively set at 75% for 8 hours then at 33% for 16 hours (Fig.6). Test is stopped when the mass variation during adsorption phase is less than 5%, in 3 consecutive days.

A preliminary phase of mass stabilization is necessary where the samples are placed in a climatic chamber maintained at 23 ° C and 50% relative humidity.



Fig. 6. Typha clay samples for MBV measurements.

4 Results

4.1 Permeability

Water vapor permeability results are recapitulated in Table 4. Clay amount has an important effect on the moisture transfer throughout the material. Results show that while the binder amount is greater (T-66/33), the water vapour resistance increases.

The difference in permeability level between these two mixtures is due to the fact that the T-80/20 composition contains a larger amount of macrospores than in the L-80/20 composition.

Table 4. Permeability and resistance to water vapour as a function of the mixture.

Formulation	δ (wet cup)	δ (dry cup)	μ (wet)	μ (dry)
L-80/20	1.54E-10	6.16E-11	1.29	3.75
T-80/20	1.56E-10	5.34E-11	1.28	3.25
T-66/33	8.0E-11	2.83E-11	2.5	7.06

4.2 Sorption isotherm

Fig. 7 shows the average adsorption curves of different samples from the three tested formulations. The shape of the curves obtained can be assimilated to a type 2 sigmoid according to the theory of Brunauer, Emmett, and Teller (BET). According to the IUPA classification [21], this is a typical behaviour of cellulosic materials [22], [23]. Results show that the ratio between water content and RH is a non-linear function. For example, the water content reaches 4% while RH is less than 60% for the T-80/20 formulation. For greater RH, the water content reaches 12.9%.

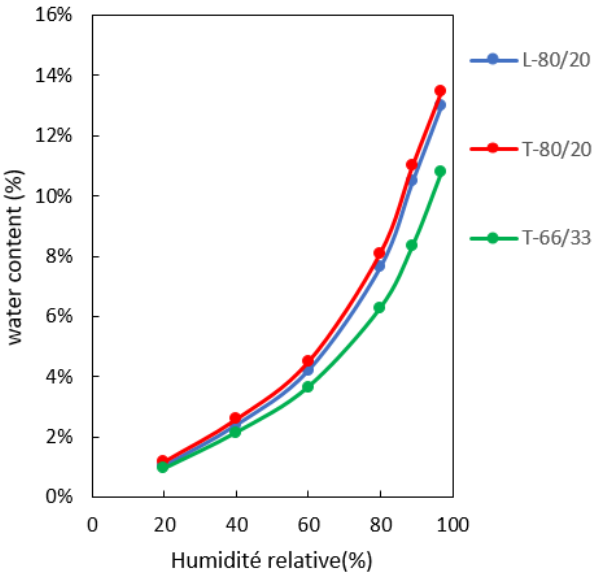


Fig. 7. Adsorption isotherms of Typha clay material.

The Typha amount has an effect on water adsorption of the composite. The Typha chips from a transverse cut of the plant increases the material water content. This can be explained by the porosity level (large quantity of mesopores) which enhances the adsorption and capillary condensation in the material [24].

However, a greater clay amount (T-66/33 formulation) slows down the adsorption phenomenon.

4.3 Moisture buffering value

Fig. 8 shows the water content evolution in the composite during three cycles of variation of RH at isothermal conditions. The L-80/20 composition have the greater amplitude of uptaking and rejecting water content. That is to say that its sensitivity to ambient humidity is the most important of the three mixtures.

Table shows the moisture buffering values, which varies between 3.23 to 4.3 $g.m^{-2}$ $\%.RH^{-1}$. According to Rode classification [20], Typha-clay agromaterial can be classified as an excellent moisture regulator (MBV > 2 $g.m^{-2}.\%RH^{-1}$). Measurements show that, at equivalent binder dosage, samples having chips from transverse cut present a lower moisture buffering value (3.71 $g.m^{-2}.\%RH^{-1}$) compared to those made by Typha fibers from longitudinal cut (4.3 $g.m^{-2}.\%RH^{-1}$). This could be explained by the porous structure of the longitudinal Typha fibers mainly composed of mesopores which are able to adsorb and desorb water more than macrospores presented in transversal fraction.

It should also be noted that for the same type of aggregate, an amount of additional binder leads to a decrease in the capacity of the moisture regulator material from 3.71 to 3. 23 g $m^{-2}\%$ RH^{-1}.

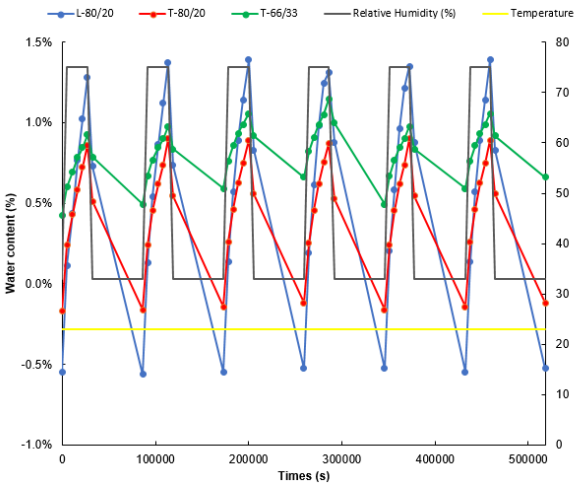


Fig. 8. Mass monitoring during MBV test.

Table 5: MBV values of the formulations.

Formulation	MBV ($g.m^{-2}.\%RH^{-1}$)	Standard deviation ($g.m^{-2}.\%RH^{-1}$)
L-80/20	4.3	0.14
T-80/20	3.71	0.11
T-66/33	3.23	0.36

5 Conclusion

In this work, results concerning hygric behaviour of Typha-clay based materials are presented. Three mixtures were presented, two having the same percentage by volume (80%) of Typha fiber but whose cutting type differed (L-80/20: longitudinal cut, T-80/20: transverse cut). The third mixture is composed of 66% of Typha fibers by volume from a transverse cut (T-66/33).

Results show the transverse fraction of Typha enhances the water vapour transfer and increased the moisture storage in the material. By contrast, a 14% increase in clay binder volume slowed moisture transfer by up to and reduced storage capacity. Finally, this paper shows that these materials are excellent moisture regulators due to their moisture capacity values which are higher than 2 $g.m^{-2}$. $\%RH^{-1}$.

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