Hygro-thermal properties of raw earth building material

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Abstract: Raw earth is the oldest building technique used for over 11 centuries thanks to its various benefits. The most known earth construction's technics are compressed earth blocks, rammed earth, raw earth concrete and daub and it can be stabilized with bio-sourced or hydraulic binders, mixed by fibers or hyper-compacted in order to improve its mechanical behavior. Besides, as many researches have been shown, the raw earth material is able to contribute to moisture and heat control in buildings. The aim of this study is to evaluate the hygrothermal behavior of stabilized raw earth material which called "Cematerre", using experimental tests such as the water vapor permeability and thermal conductivity and numerical simulations of thermal and hygroscopic transfers.

Key words: Raw earth, thermal conductivity, hygroscopic, relative humidity, hygrothermal.

I. INTRODUCTION

Raw earth, by its mechanical and hygrothermal performances, is one of the most known building materials used for different construction's techniques (Hibouche, 2013). This material is able to ensure the hygro-thermal comfort in buildings, and this is due to its capacity to absorb the water vapour. This allows it to stock up water vapor until reaching a hygroscopic equilibrium between the material and the surrounding air. In addition, its thermal properties allow it to contribute significantly to the thermal comfort in the building. In this study, we will evaluate the hygrothermal behavior of raw earth materials called "Cématerre", a new concrete based on raw earth material. This earthen material is stabilized with flax fibers, 3% of lime and 8% of cement which ameliorate the mechanical behavior.

II. MATERIAL AND EXPERIMENTAL METHODS

A. *Stabilized raw earth material*

The studied material is an earthen concrete called "Cématerre", composed of 88% of natural silt taken during earthworks on the construction site, and stabilized with hydraulic binders. Its formulation is given by the following table (TABLE 1). It is a basic formulation initially prepared by the company "Cématerre" in accordance with a precise specification for building materials designed for structural elements in buildings. The earth concrete samples were cast directly into cylindrical and parallelepipedal molds and were kept to be cured for 90 days under normal laboratory conditions (T=20°C±3°C and RH≈50%) before testing (Figures 1 and 2).

TABLE 1. Cématerre formulation in mass (kg) for each component, per (m^3) of Cématerre concrete

Silt GO (kg/m^3)	**Lime** (kg/m^3)	**Cement** (kg/m^3)	**Flax fibers** (kg/m^3)	**Water** (kg/m^3)
1405	45	130	7	200

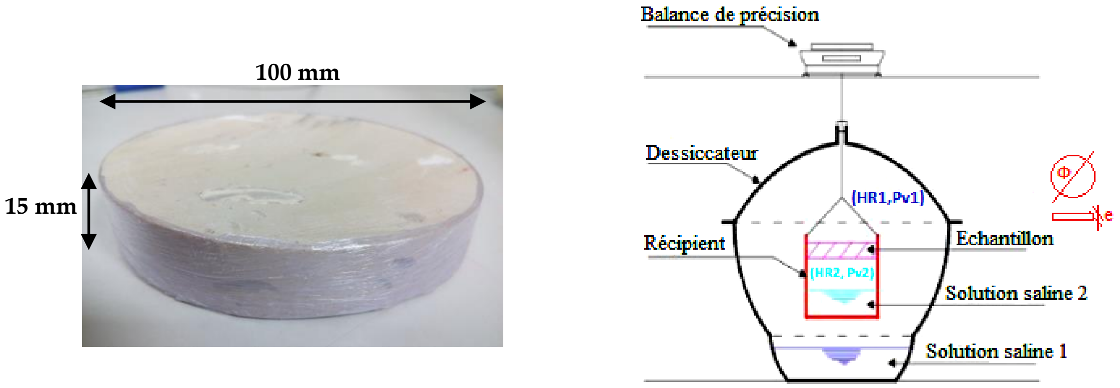
B. Experimental methods

1. Measurement of water vapor permeability

It is a gravimetric method called "cup method" (Hibouche, 2013; Galbraith et al. 1998; Bennai et al., 2016), This method consists in placing a cylindrical sample of "Cématerre" (Thickness e = 15 mm and diameter ϕ = 100 mm) under a constant and unidirectional vapor gradient in isothermal conditions. Knowing the flow of vapor through the material, determined by weighing, we can calculate the water vapor permeability δ_v [kg.$m^{-1}.s^{-1}.Pa^{-1}$] using Fick's law:

$$\delta_v = e\,\frac{j_v}{\Delta p_v}$$

e: sample 's thickness [m]; j_v : vapor flux density [kg.$m^{-2}.s^{-1}$]; p_v : vapor pressure [Pa].



(b)

(a)

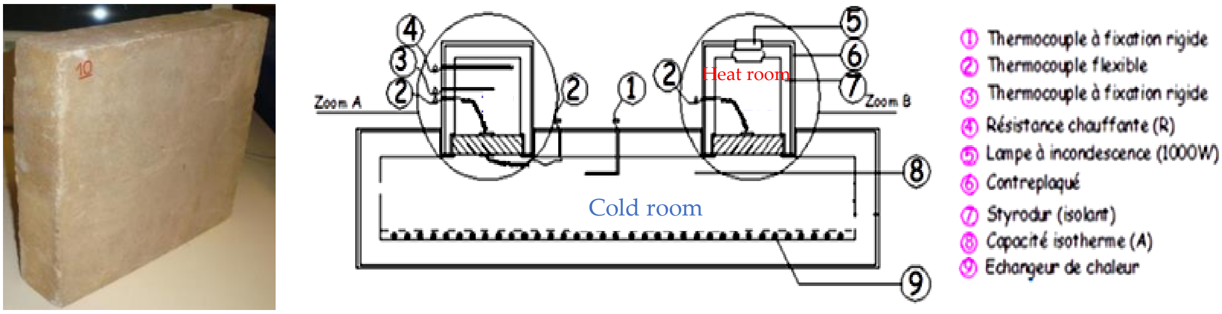
FIGURE 1: (a) Cylindrical sample of Cématerre, (b) Cup method for measuring water vapor permeability (Hibouche, 2013)

2. Measurement of thermal conductivity

Using the box method [Hibouche, 2013; Saidi et al., 2018), the variation of the thermal conductivity of Cématerre as a function of water content was measured. The samples are 270*270*60 mm^3 in dimensions. This method consists in putting the sample of Cématerre between two different temperatures conditions (heat and cold room) in order to apply a heat gradient across this sample. Based on Fourier law, the thermal conductivity in steady state is given by the following equation:

$$\lambda = \frac{q\,e}{S\,\Delta T} = \frac{e}{S\,\Delta T}\left(\frac{V^2}{R} - C.\Delta T'\right)$$

q: heat flow through the sample [W]; e: sample's thickness [m]; S: useful surface of the sample [m²]; ΔT: temperature difference between the hot surface and the cold surface [K]; V: voltage applied to the heating resistor [V] (measured); R: value of the heating resistance (R = 264.5 Ω); ΔT': temperature difference between the outside and the inside of the hot part [K].



(a) **(b)**

FIGURE 2: (a) Sample of Cématerre with 270*270*60 mm³ in dimensions, (b) Box method for measuring thermal conductivity (Hibouche, 2013)

C. Results

1. Water vapor permeability

The FIGURE 3 shows the evolution of mass of vapor passing through the sample as function of time. We can notice that at the start of the transfer (between 0 and 1 day), the flow regime is unsteady because the internal water balances have not yet been reached. This results in a nonlinear relationship. Once equilibrium is reached, the vapor transfer regime becomes permanent and a linear relationship is established. The value of water vapor permeability is calculated in the permanent regime using Fick's law.

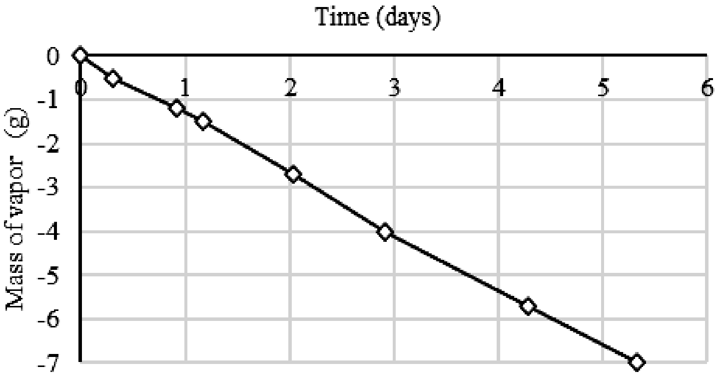


FIGURE 3: Mass of vapor passing through the sample evolution curve

The water vapor permeability of "Cématerre" is about 1,07.10^{-11} kg/m. s. Pa. Comparing this value to the vapor permeability of other building materials, Cématerre is 10 times more vapor permeable than cement concrete (Hibouche, 2013).

2. Thermal conductivity

The thermal conductivity of Cématerre was measured for different water content. The results are shows in the table (TABLE 2) below:

TABLE 2: Thermal conductivity of Cématerre as a function of water content

Sample's number	Water content [%]	Thermal conductivity [W/m. °C]
1	0 (dry)	0.558
2	2	0.605
3	3	0.712
4	4	0.707
5	5	0.763
6	9.5	0.751
7	19.2	0.968
8	25	1.24
9	28.2 (saturated)	1.32

Note that in the table above (TABLE 2), the thermal conductivity of the Cématerre increases with the water content. In comparison with cement concrete, the earthen concrete is three times more insulating (Zhang et al., 2015).

D. Conclusion

The results highlight the remarkable hygrothermal properties of stabilized raw earth material "Cématerre". This material is 10 times more breathable to water vapor and three times more insulating to heat than conventional cement concrete (Hibouche, 2013; Zhang et al., 2015). At present, a coupled hygro-thermal study which is in progress, will allow us to specify the effect of the humidity of the material on its performance, in order to simulate the climatic conditions around the earthen structure.

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