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# Investigation of the Mass Difusivity of two Local Construction Materials In Benin

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**Abstract**— The main objective of building construction is to put the occupants out of the harsh climate (hot, cold), creating a microclimate within satisfactory for carrying out various activities. This work is part of the comfort improvement in the building and focuses in particular on the hygrothermal characterization of local materials used in construction of housing in Benin. It aims at determining the mass diffusivity of wood composite materials and cement-stabilized laterite cement according to the water content. A sorption experimental measurement based on a magnetic suspension balance was designed, built and tested at the Laboratory for Studies and Research on Wood Material (LERMAB). This precision balance can weigh without contacting a sample placed in a measuring chamber controlled for temperature and relative humidity. So thanks to weighing, the mass diffusivity of the samples is determined by the transient slope method. From the analysis of the results, It follows that the earth stabilized with cement has a mass diffusivity lower than the wood-cement. Also, the materials studied can allow the realization of an acceptable hygrothermic housing with low cost.

**Index Terms**— heat and humidity, composite wood-cement, stabilized laterite, slope method, mass diffusivity.

## 1 INTRODUCTION

THE use of stabilized laterite cement or cement-sawdust composite in construction, allows the building envelope, in addition to its role as an insulator, to regulate the temperature and the indoor humidity. This helps to minimize the energy consumption of the building. These materials are hygroscopic; they function as a natural regulator of moisture in the housing. Transfer mechanisms paired up with heat and mass in hygroscopic materials must be controlled and taken into account when designing the building to achieve adequate and sustainable erections [1]. This paper focuses on the determination of the mass diffusivity of stabilized laterite with cement and composite cement-sawdust as a function of water content. Finally an explanation was proposed for non-fickian phenomena [2] observed for high relative humidity.

## 2 PRESENTATION OF THE EXPERIMENTAL SETUP

For the measurement of the kinetics in order to determine the mass diffusivity of porous materials, we used the experimental setup (Picture 1) which was designed at LERMAB. The principle is based on regular weighing of the sample introduced into a chamber with climate conditions (temperature, relative humidity) controlled using an electronic scale with magnetic suspension from "Rubotherm" [3]. This scale is used to perform regular calibrations being measured to cancel the drift without affecting the experimental conditions. This advantage encourages many acquisitions without loss of precision ($10^{-5} g$), setting water conditions is through two mass flow controllers with electronic control that are connected to a humidity generator. One flow is composed of dry air while the other catfish in water at same temperature as that of the measuring chamber to provide the saturated air. The mixing of both fluids in selected proportions ensures the desired humidity. The flow offered by the system will be guided by an insulated tube to the measuring chamber while obeying the laminar regime to ensure the stability measures. The tempera ture of the system is controlled by a thermocryosthat, offering the possibility of regulating the circulating water (maximum pump flowrate = 18l/mn) between -25 ° C and 150° C. A thermal insulation of the measuring chamber and humid air generator with a foam layer of polymethyl methacrylate and a layer of polyurethane foam has been made to ensure thermal stability of ±0.02 °C. A sensor Honeywell « 3602 C » is used for measuring temperature and relative humidity inside the measuring chamber and a J type of thermocouple for monitoring environmental conditions. The unit is controlled by a PC for synchronization between the various elements and regular registration records.

## 3 Sample Preparation

Samples of stabilized laterite used for sorption measurements are rectangular specimens 5 mm thick with a cutting section 20 mm x 20 mm. These were cut using a micro chainsaw. Samples of wood-cement composite are also cut rectangular 5mm thick.

**Table 1: Characteristics of specimens instrumented**

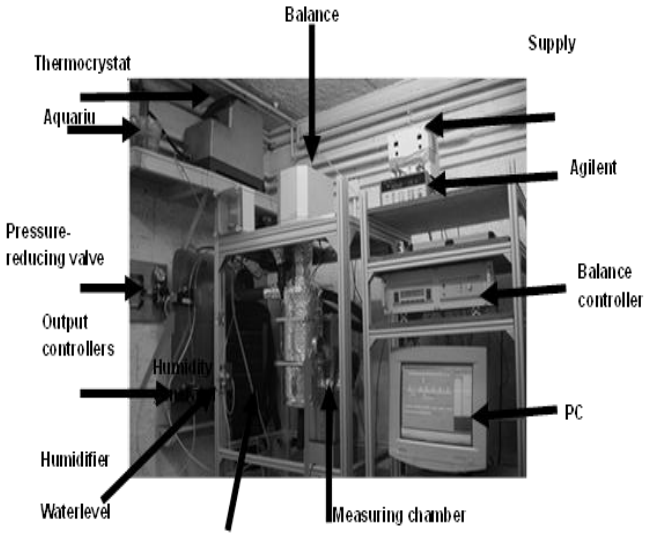
| Specimens | Wood-cement composite[4-5] | Stabilized Laterite |
|---|---|---|
| | Ratio C/S : 1.14<br>Ratio E/C: 1.5<br>Sawdust: 330 kg /m³<br>S : 8.8 kg | Stabilized earth : 1900kg/m³<br>Cement determination at 20% |
| **Measurement** | Cement CPJ 35 : 400 kg/m³<br>C: 10 kg ;<br>Water : 1000 kg/m³<br>E : 15 kg | Ratio E/C : 2.4<br>Laterite : 20kg<br>Cement : 5kg<br>Water : 12kg |
| **Dimensions (mm)** | 20x20x5 | 20x20x5 |
| **Temperature °C** | 30 | 30 |
| **Relative Humi (%)** | 0-90 | 0-90 |

# 4 RESULTS AND INTERPRETATIONS

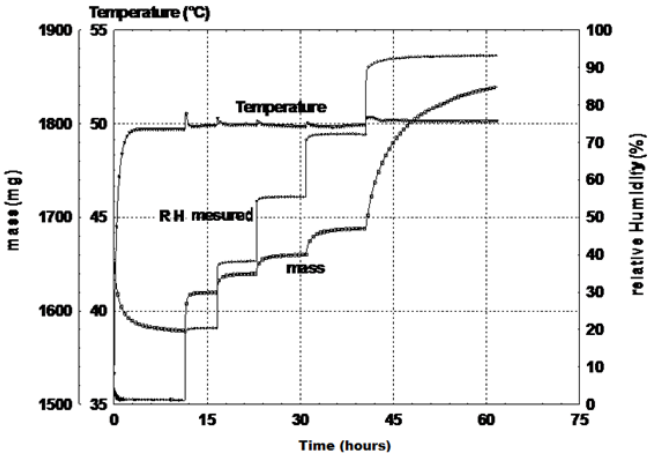
## 4.1 The Kinetics of Sorption

The experimental measurements in transient require monitoring, over time, the mass of the sample previously equilibrated in a controlled relative humidity environment and undergoes a sudden change of the latter. Thus, to determine the sorption kinetics, it is necessary to balance initially (Picture 2) and the wood-cement composite (Picture 3) at a given relative humidity (0 or 90%) in the measuring chamber and then to submit each sample at a higher relative humidity or lower according to whether they are in the adsorption process or desorption.

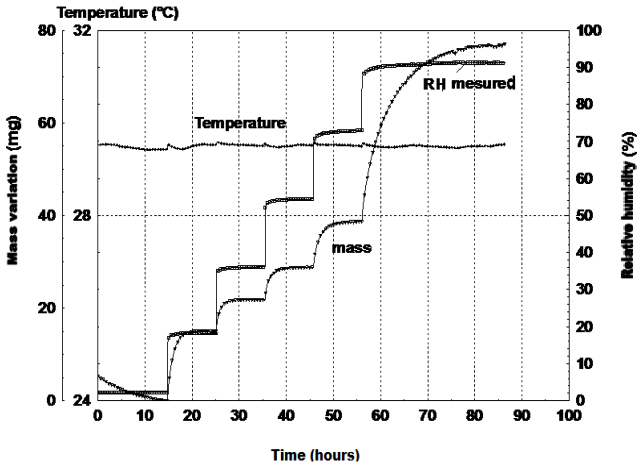
The pictures 2 and 3 show the adsorption kinetics of the composite cement-sawdust and the stabilized laterite at 30 ° C for various levels of relative humidities (0%, 18%, 36%, 54%, 72%, 90%). It is shown on this graph a complete agreement between the theoretical humidity imposed and that measured by the sensor Honeywell (HIH 3602-C). The temperature is very stable, this is a necessary factor for reliable kinetics of sorption. We also note that a minimum of 10 hours is sufficient to stabilize a sample of 5mm thick stabilized laterite with cement (Picture 3). It should be noted that as far as the relative humidity increases, the settling time becomes higher. This can be explained by non-Fickian phenomena [1] which are due to the behavior of macromolecules walls. For high water contents, a molecular reorganization is required to release the sorption sites. This phenomenon is also present on the kinetics of sorption of wood-cement composite (Picture. 2). Of these kinetics, it is possible to deduce the mass diffusivity of samples in a transient regime.




Picture 1. Photo of the experimental setup




Picture 2: Kinetics of sorption of wood-cement composite




Picture 3: sorption kinetics of stabilized laterite

## 4.2. DETERMINATION OF DIFFUSION COEFFICIENT THE SLOPES METHOD

### 4.2.1 Mathematical Formulation

According to Fick's second law, the diffusion equation in the samples of the materials tested can be written:

$$\frac{\partial X}{\partial t} = div(\overline{\overline{D}}\,\overrightarrow{grad X}) \quad (1)$$

With $X$ water content , $t$ the time and $\overline{\overline{D}}$ , the mass diffusivity tensor.

For a one-dimensional transfer depending on the thickness of the sample, and assuming that D is constant over this thickness and on each level or increment of relative humidity RH, the above equation becomes:

$$\frac{\partial X}{\partial t} = D\frac{\partial^2 X}{\partial x^2} \quad (2)$$

Assuming that on the exchange side, the water content is always very close to the equilibrium value, the initial conditions and limitations are:

-at $t = 0, \forall\, x, X = X_i$ Water content of hygroscopic material of the first humidity condition or initial water content;

-For all

$t > 0,\ \ X\ |x\ =\ 0$ et $x\ =\ e\ = X_f$ water content of the second humidity condition or the final water content of the sample.

By defining the dimensionless water content $X^*$ by:

$$X^* = \frac{X - X_i}{X_f - X_i} \quad (3)$$

Equation (2) can be rewritten:

$$\frac{\partial X^*}{\partial t} = D\frac{\partial^2 X^*}{\partial x^2} \quad (4)$$

Assuming the resistance to transfer negligible external mass, initial conditions and boundaries become:

$$t = 0, \forall\, x,\ X^* = 0,$$

$$t > 0,\ \ X^*|_{x\ =\ 0 \text{ et } x\ =\ e\ = 1.} \quad (5)$$

Assuming that the medium is semi-infinite, the partial differential equation (4) associated with boundary conditions (5) can be described in terms of a single variable $\eta = x/\sqrt{4Dt}$ . This leads after some transformations to the solution of equation (4) in the form:

$$X^* = 1 - \mathrm{erf}(\eta) \quad \text{où} \quad \mathrm{erf}(\eta) = \frac{2}{\sqrt{\pi}}\int_0^{\eta} \mathrm{erf}(-\eta^2)d\eta \quad (6)$$

**erf** = error function.

The Flux density which passes through a face exchange is given by Fick's law :

$$q = -\rho D\frac{\partial X}{\partial x}|x = 0 \quad (7)$$

$\rho$ stands for the density of the dry environment.

The change in mass of a sample over time is simply the integration of the flow between 0 and t:

$$\Delta m(t) = \int_0^t s.qdt \quad (8)$$

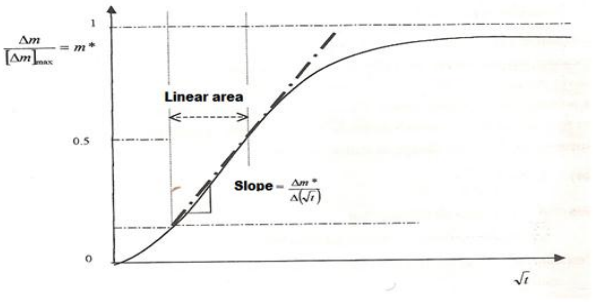
(S = section of the sample).

Considering the total thickness of the sample (both sides) and equations (6), (7) and (8), the analytical solution (9) shows that the gain in sample mass varies as the square root of time.

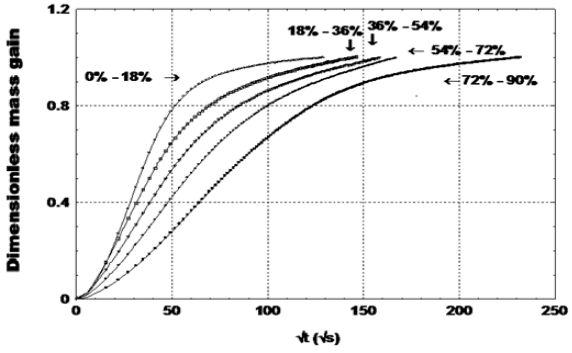
$$\frac{\Delta m(t)}{|\Delta m|_{max}} = \frac{4}{e}\sqrt{\frac{D}{\pi}}\sqrt{t} \quad (9)$$

Where $\Delta m(t)$ and $|\Delta m|_{max}$ represent the increase (or decrease) of the sample mass at time $t$ and at equilibrium. From equation (9), it is possible to determine D with the experimental measures. Of course, the assumption of semi-infinite medium is only valid for "short time".

After observation of the linear portion of the curve of the dimensionless mass plotted against the square root of time, we determined the slope by treating the portion between 0.1 and 0.5 of dimensionless mass (Picture 4).




Picture 4: Determination of the diffusion




Picture 5: Dimensionless mass gain of wood-cement composite coefficient by the slope of the curve linear part

Picture 5 shows the dimensionless mass gain of the cement-wood composite in terms of the square root of time for each range of water content.

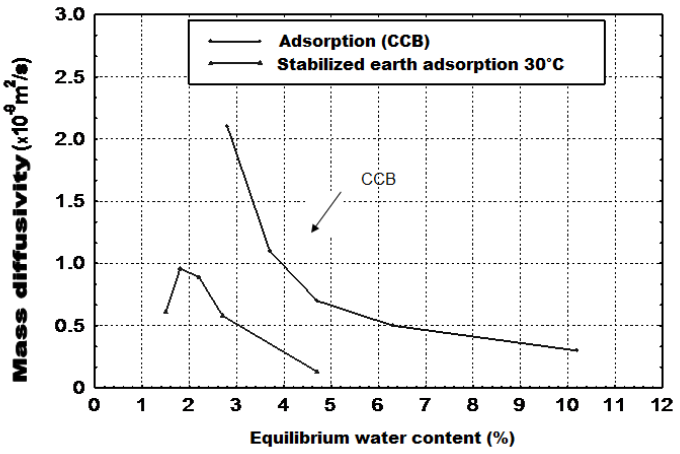
Tables 2 and 3 present the mass diffusivity values of the composites wood-cement and cement stabilized laterite calculated in adsorption. Picture 6 illustrates the variations of mass diffusivity got for these two materials with the water content to a temperature of 30 ° C.

**Table 2: Mass diffusivity in adsorption for Cement-Wood Composite**

| *Wood-Cement Composite thickness 5,07mm Adsorption* | | |
|---|---|---|
| Increment of RH at T = 30°C | Equilibrium water content (%) | Diffusivity $Dx10^{-10}$ m²/s |
| 0-18% | 2.8 | $21 \pm 0.9$ |
| 18-36% | 3.7 | $11 \pm 0.7$ |
| 36-54% | 4.7 | $7 \pm 0.4$ |
| 54-72% | 6.3 | $5 \pm 0.2$ |
| 72-90% | 10.2 | $3 \pm 0.1$ |

**Table 3: Mass diffusivity in adsorption for stabilized laterite**

| **Cement stabilized laterite material thickness 5,0mm Adsorption** | | |
|---|---|---|
| Increment of RH at T = 30°C | Equilibrium water content (%) | Diffusivity $Dx10^{-10}m^2/s$ |
| 0-18% | 1.5 | $6.1 \pm 0.5$ |
| 18-36% | 1.8 | $9.6 \pm 1.7$ |
| 36-54% | 2.2 | $8.9 \pm 1.5$ |
| 54-72% | 2.7 | $5.8 \pm 0.7$ |
| 72-90% | 4.7 | $1.3 \pm 0.1$ |




**Picture 6 : mass diffusivity of the composite CCB and that of the stabilized earth at 30 ° C**

### 4.3 INTERPRETATION OF THE RESULTS

The analysis of the Picture 6 lets say that the mass diffusivity of cement-wood composite decreases when the water content increases. As for the material stabilized earth, we find that the mass diffusivity in adsorption increases with the water content, reaching a maximum around 1.8% and then decreases with the water content. Mass diffusivities of the composite wood-cement for different water contents are higher than the stabilized laterite in adsorption at a temperature of 30 ° C (Picture 6). These differences may be related to the composition of the cement matrix of these materials. In fact, the cement-wood composite has a low density and higher porosity [6] than the cement stabilized laterite. The values of mass diffusivities obtained experimentally with these materials are between $10^{-10}$ and $2x10^{-9}$ m²/s, these values indicate that moisture transfers inthese materials, involve very slow process. Moreover the low variability of the diffusivity with water content for stabilized laterite highlights the complex interaction between vapor and liquid phases in the porous network of the material. Another reason for the low diffusivity of this material may be due to the absence of natural fibers in its matrix

## 5. CONCLUSION

In this paper, we have determined using the sorption kinetics, the mass diffusivity of materials according to the water content. The extraction of the diffusion coefficient of a sorption experimental curve in transient regimen is made using the slope of the curve in the area between 0.1 and 0.5 of a dimensionless water content plotted against the square root time. For wood-cement composite we find that the diffusivity decreases from $2.1x10^{-9}$ to $0.3x10^{-9}$ m²/s when the content varies from 2.8% to 10.2% in adsorption and at 30 ° C temperature. The cement stabilized earth has a diffusivity mass smaller than the wood-cement composite. Note that for this material, the absence of natural fibers in its composition makes that it is a bit diffusive. The use of these new materials could reduce the cost price of the masonry concrete since these aggregates exist in large quantities locally available in Benin..

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