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RESEARCH ARTICLE

THERMAL DIFFUSIVITY STUDY ONCLAY FROM BENIN BY "FLASH METHOD"

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ABSTRACT

Knowledge of thermo physical parameters of local materials of construction has been essential when one considered the fast development of the market of building and especially the need for saving energy while ensuring the thermal comfort in housing. This work aimed to measure one of these parameters, the diffusivity, with an instrumentation based on "Flash Method". It presented the results of measurement of the thermal diffusivity of dry clay and saturated clay, at different rates of cement, the clay has been taken in South of Benin. The results showed that the thermal diffusivity of dry samples was always lower than those of saturated samples. The first was about $0.468x10^{-6}m^2/s$ whereas the second was about $0.496x10^{-6}m^2/s$. In the two cases, the values confirmed that the clay is good to be used as building and construction material.

INTRODUCTION

The determination of the thermo physical parameters of local materials of construction proves to be essential in the scientific and industrialist fields. In the West African sub-region and in above all in Benin, the energizing efficiency notion, characterized by energy consumption level, is often ignored as well in the public building domain than in the one of single habitation. The consequences of this lack are the deterioration of the user's thermal comfort and a high cost of the energy consummation due to air-conditioned buildings. A good choice of local construction materials would permit to improve this efficiency at a lower cost. It is the reason why LEMA (Laboratoir ed' Energétique et de Mécanique Appliquée) in Benin, since its creation, purchases the theoretical and experimental works of research for a better knowledge of the thermo-physics properties of the construction materials in Benin (Carslawand Jaeger, 1959). The works of OBRGM (1999) go in the same direction. More and more, the authorities encourage the promotion of these materials.

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To build in clay nowadays, is between tradition and modernity; to construct in natural clay requires less expense; that is not possible with cement, concrete or steel. Today, the clay is consolidated more and more with cement to reinforce the resistance of the dwelling-places. In the literature, one hasn't the values of the thermal features of our local construction and building materials. To fill this lack, clay from south region of Benin has been studied to notably enrich the literature. This work presents the results of the measures of the thermal diffusivity of clay material. The effect of its stabilization at different contents of cement, from 0% to 12%, on the thermal diffusivity, will be enlightened. The buildings in clay being very often threatened by deterioration phenomena as water, a parallel survey has been lead about the influence of humidity on the thermal diffusivity of this material. The thermal diffusivity that determines the thermal characterization in permanent regime or in dynamic regime has been measured by a "bottle method" (Allognon, 2007).

MATERIALS AND METHODS

Determination of the thermal diffusivity has been done by a "bottle method". This method has been developed and tested in Laboratoir ed' Etudes Thermiques et Solaires of Claude Bernard University in Lyon, France.

An experimental device (EI 700) based on this method has been achieved also in the Laboratoir ed' Energétique Appliquée (LEA) of Dakar, Senegal. It's in this laboratory that campaign of measures has been done. The method uses prismatic specimens 27x27x5 cm^3 shown on Figure 1 (Photo) and Figure 2 (diagram) (Allognon, 2003). The sample E of the material to be tested, a parallelepipedic specimen of 27x27cm^2 with a thickness varying between 2 and 5 cm, is placed between the two ambiances. The sensors of temperature are placed on the two faces of the sample and in the ambiance of the boxes. The set of the wiring of link of the probes of temperature and the current supply of the heating thread converged on a box that can be bound to a measure center which has an important number of ways out giving instantaneous informations (Carslawand Jaeger, 1959).

To measure the diffusivity one uses the box (B2). The test-tube is placed between the hot box with internal reflecting faces B2 and the isotherm container (volume A). On the upper side of this box, an electric glow lamp (1000 W) permits to radiate during a short time t_0 (a few seconds) the upper face of the sample as shown in Figure 3. From apparition of the thermal impulse, one follows the evolution of the temperature on the non-exposed test-tube face to the radiance.

Theory and analysis of existing work

The analysis of the experimental thermometric diagram recorded on this non radiated face of the sample E permits to determine its apparent diffusivity (Allognon, 2003).

Fig. 1. Photo of the experimental device EI 700

A: Cell tests; $B_1$and B_2 : Bottles for measurement of λ; E: Sample; K: Cryostat

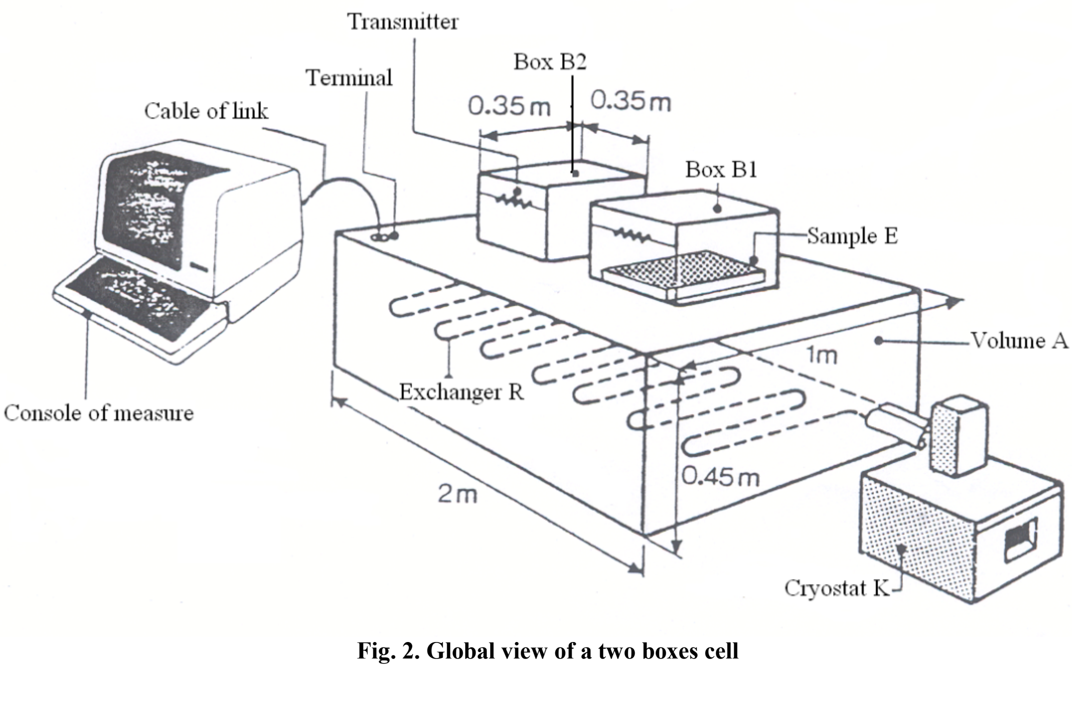

Fig. 2. Global view of a two boxes cell

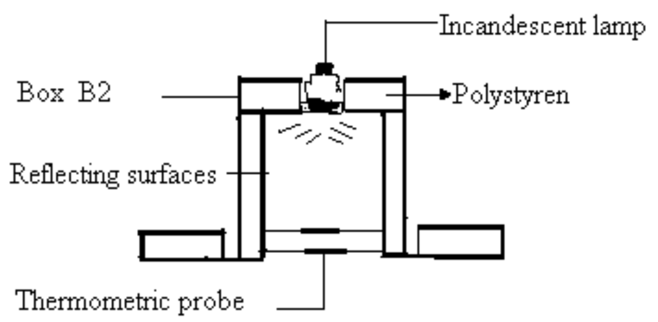

Fig. 3. Box of measurement of the diffusivity (realization of the flux impulse)

The most important assumptions formulated are the following:

- the materials are homogeneous;
- the mass transfer is supposed being unidirectional;
- duration of the discharge q is very brief (flash).

In these conditions, the evolution of the temperature on the non-exposed face to the radiance is given by the formula:

$$T(e,\ t) = \frac{q}{\rho ce}\left(1 + 2\sum_{n=1}(-1)^n \exp(-n^2 \frac{\pi^2}{e^2} at)\right) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots.. (1)$$

with:

a thermal diffusivity ($m^2.s^{-1}$)
c coefficient of thermal loss ($W.°C^{-1}$)
e thickness of the material (m)
q heat flux (W)
t time (s)
T temperature (°C)

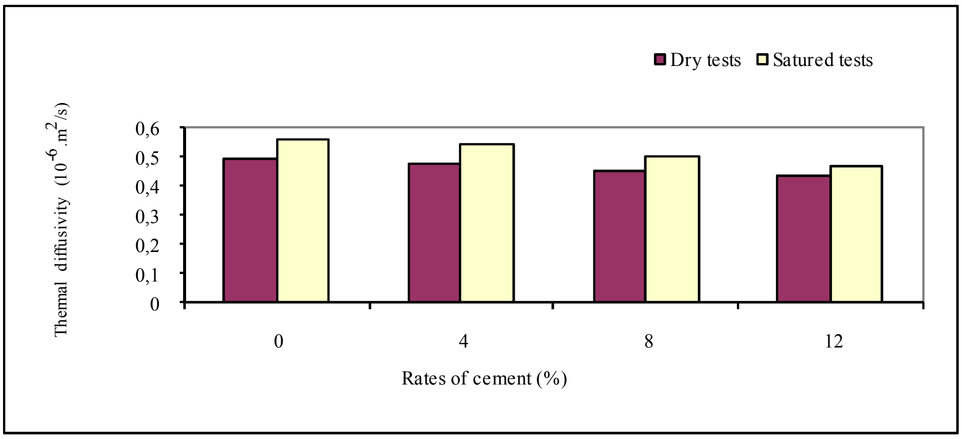

Fig. 4. Variation of thermal diffusivity of stabilized clay samples

Using this expression for high values of the time t, one gets the formula known as formula of Parker (Parker *et al.*, 1961)

$$a = \frac{\ln 4}{\pi^2}\frac{e^2}{t_{1/2}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.. (2)$$

where $t_{1/2}$ is the time corresponding to a temperature elevation being the half of the maximal temperature elevation recorded on the non-radiated face

$$T(l, t) = \frac{q}{2l\rho} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

q is the density of energy absorbed in the thickness l of the sample
l is the thickness of the sample
e is the thickness of the material

The model of Degiovani (1977) takes into account the thermal losses on all faces of the sample; this model includes the three coefficients of relative thermal exchanges on the face receiving the impulse, on the opposite face, and on the sides of the sample.

Then the thermal diffusivity is given by the following relations:

$$a = \frac{e^2}{t_{5/6}^2}\left(1.15t_{5/6} - 1.25t_{2/3}\right) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots... (4)$$

$$a = \frac{e^2}{t_{5/6}^2}\left(0.761t_{5/6} - 0.926t_{1/2}\right) \ldots\ldots\ldots\ldots\ldots\ldots\ldots...\ldots.. (5)$$

$$a = \frac{e^2}{t_{5/6}^2}\left(0.617t_{5/6} - 0.862t_{1/3}\right) \quad \ldots\ldots\ldots\ldots\ldots..\ldots\ldots\ldots (6)$$

where t_i represents the time after which the temperature of the face non-exposed to the radiation is i times the maximal temperature observed on this face. The author indicates that the result is acceptable if the possible gaps between the three values of "a" obtained by this way can be justified by the mistakes that one can normally make where measuring times. One gets therefore three values a_1, a_2 and a_3 normally equals to the measured thermal diffusivity. The value of the coefficient a retained is the arithmetic average of these three values.

RESULTS

The results of measures of the thermal diffusivity of dry clay and saturated clay at different rates of cement are below in Table 1. Remember that the clay commonly called "terre de barre" is a local construction material in Benin whose mechanical properties have been improved considerably when one consolidated it with cement; in this work tests have been limited to cement content between 0 and 12% (successively 0%, 4%, 8% and 12%).

Table 1. Values of the thermal diffusivity of stabilized clay samples

Material (Samples of 27cm x 27cm x 5cm)	Dried tests		Saturated tests	
	Specific gravity 10^3 kg/m^3	Thermal diffusivity (Mean value of 4 dried tests) 10^{-6}m^2/s	Specific gravity 10^3 kg/m^3	Thermal diffusivity (Mean value of 4 saturated tests) 10^{-6}m^2/s
Clay stabilized at 0% of cement	2,198	0,504	2,516	0,564
Clay stabilized at 4% of cement	2,554	0,466	2,816	0,476
Clay stabilized at 8% of cement	2,558	0,456	2,836	0,488
Clay stabilized at 12% of cement	2,562	0,448	2,846	0,457

DISCUSSION

Considering the important influence of humidity on the thermal diffusivity, the work has also examined dry clay and saturated clay in order to show the influence of water on the thermophysic properties of the material, as water is the main factor susceptible to damage the constructions made with clay. According to results obtained for clay stabilized at 0% of cement, 4%, 8% and 12%, one notices that these test-tubes present an increasing diffusivity when one goes from the dry state to the relatively saturated state. In contrast, the value of the thermal diffusivity of the stabilized clay decreases slightly when one increases the quantity of cement for stabilization.

Conclusions

While analyzing the experimental results obtained, one notices that:

- the thermal diffusivity is higher in the saturated materials than in the dry ones;
- the thermal diffusivity decreases when the rate of stabilization in cement increases;
- the thermal diffusivity decreases when the specific density for every type of test-tube increases; so the test-tubes in raw clay and those consolidated at lows rates of cement are more porous than the blocks in clay consolidated at relatively highs rates of cement.

Otherwise the value of the coefficient of thermal diffusivity of the test-tube in clay consolidated to 4% of cement is higher than the one of the bricks in clay consolidated to 8% and 12% of cement; such a result is not surprising because the thermal diffusivity coefficient is inversely proportional to the specific gravity. Finally, the clay material, considering its more and more crescent interest in buildings and constructions, merits to be studied as well on the thermal field that mechanical. A project of more general survey on its thermo - mechanics characterization is currently under future work.

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