

Research Article

Improvement of the Thermal Conductivity of a Composite Material has Clay Base

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Abstract: This study report to the improvement of thermo physical properties of cooked clay to obtain a porous and thermal conductor material. For this purpose we fabricates two series of samples having as base material a caolinitic clay of Thicky (Senegal) to which we added respectively cow dung and the copper filings. The tests of characterization that we have carried out showed us an increase of thermal conductivity from 0.308 to 0.476 W/m.K witch corresponding to an optimum percentage of 10% by volume in cow dung and 4% of copper. It would be interest to increase dosage in copper to obtain high value of conductivity.

Keywords: Clay, copper, cow dung, porosity, thermal characteristics

INTRODUCTION

Clay is a substance which is used for a very long time in many areas such as the construction, industrial ceramics and artisanal; including the one that is rich in Oxides of Silica (SiO_2) and Aluminum Oxide (Al_2O_3) (Traore, 2003). For example the tiles, the sanitary etc.

In most cases, the quality of the products in baked clay is often poor lack of rational investigation on the materials used and on the manufacturing processes. The composition of the initial mixtures is empirical, based only on the experience.

A large majority of the African population uses the argillaceous materials for the manufacture of tanks; either for the cooling of drinking water, either for food preservation. For this fact, the tank must be necessarily porous to allow the water to moisten the outer face. This tank must be isolated from sun radiations and placed in an air stream.

If we put ourselves only in the context of cold production, can we improve the quality of the products in baked clay? In particular, the products intended for cooling water or for food conservation? Because they take a relatively long time to give an acceptable result. In other words, can we improve the thermal and physical properties of materials in baked clay for that the time taken to produce cold either substantially to be reduced?

It is true that the clayey material, even cooked, has a thermal conductivity very low compared to metals. But, if we want to use it in an area where the

conductance is strongly desired, we must certainly mix it with other materials much more conductive to achieve the desirable characteristics. The search for porous and thermal conductor material, leads us to reflect on the study and development of a material composed by clay, copper and of cow dung (herbs). After cooking, the fingerprints of the herbs are pores and the copper allows improving the thermal conductivity of the clay. The final product remains essentially constituted by the baked clay, copper and pores. It is therefore a composite clay-based.

MATERIALS AND METHODS

To obtain a normal plasticity (Terzaghi and Peck, 1957), it has introduced 35% in volume of water in 6000 cm^3 of clay. It has retained the same percentage of water for all samples. Thus, we prepared a reference sample without additives and which will be brought to a cooking at 950°C. This sample will serve as a reference for assessing the influence of the presence of the cow dung (herbs) and copper in the clay. To prepare the other samples, we have carried out two series. The first series is composed of four samples in which it was introduced 5, 10, 15 and 20%, respectively by volume of cow dung (herbs). For the second series, we have retained the same dosage in cow dung (herbs) while introducing 2, 4, 6 and 8%, respectively by volume of copper. This allows assessing the influence of the conductivity of the copper on the overall conductivity of the material. For the execution of the experimental trials, we have rainwear prism specimens of

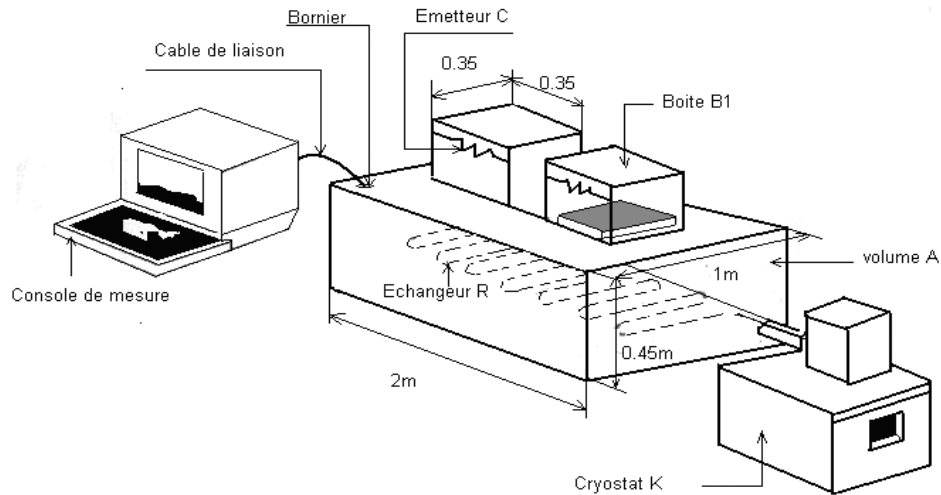


Fig. 1: General view of a measuring cell with two boxes

300×300×65 mm, the withdrawal is of approximately 10% and we found then, at the end of the drying process, dimensions close to 270×270×50 mm to determine the thermal conductivity and the thermal diffusivity. The specific heat and the thermal effusivity are deduced from simple correlations.

Description of the apparatus used: We have used the version to two boxes of the measuring cell EI700. Figure 1 this version allows performing measurements simultaneously on two samples; it has an advantage for tests on a series of samples (BT EI700 FR (Menguy *et al.*, 1986)). It is composed of the following components:

- An isothermal capacity A has external dimensions 200×100×50 cm. It is fitted at his base by a heat exchanger which is powered by a fluid (glycol water) whose temperature is regulated by a cryostat K with bath of movement to -5°C. This isothermal capacity is an enclosure in against plate; the internal faces are lined with polystyrene plates in order to ensure its thermal insulation from the external environment. It then plays the role of the cold atmosphere.
- Two identical boxes of measurement B in Styrodur allowing providing simultaneous measures; each equipped with a heating film C at its upper part including the issuance of the heat can be controlled using a rheostat and presenting an open face. The interior of each box plays the role of the warm atmosphere. The heating element is a resistance cut in a film of flexel, supplied with current by a variable autotransformer. The power charged is determined by measuring the potential difference at the terminals of the resistance.
- The sample E, of parallelepiped shape of 27×27×5 cm is placed between the two moods.

- The temperature sensors are placed on the two sides of the sample, in the atmosphere of the box and in the experimental hall.
- The whole connection wiring of the temperature sensors and the supply of the heated film leads to a terminal block which can be linked to a central measurement with a dozen tracks giving instant information.

CONDUCTIVE HEAT TRANSFER IN POROUS MEDIA

In considering the porous media as a homogeneous environment and continuous, when this environment is saturated by a stationary fluid phase, we can say that the thermal effects due to changes in phase (condensation or vaporization) or the effects of physical and chemical reactions (adsorption or hydration), do not affect the internal distribution of the thermal field. The heat transfer in this environment which is heterogeneous at the microscopic scale can be assimilated at the macroscopic scale to that of a continuous environment shadow without internal heat source. The equation of heat transfer is written (Menguy and Gaye, 2004; Jannot, 2005):

$$\text{div}(\lambda \times \text{grad} T) = (\rho \times C_p) \times \frac{\partial T}{\partial t} \quad (1)$$

with,

C_p : Specific heat at constant pressure (J/kg.K)

ρ : Mass Density (kg/m³)

λ : Thermal Conductivity (W/mK)

The medium is assumed being homogeneous and isotropic, the equation then becomes (Kreith, 1967):

$$\frac{\lambda}{\rho \times C_p} \times \Delta T = \frac{\partial T}{\partial t} \quad (2)$$

The ratio $\lambda/\rho \times C_p = \alpha$ is the thermal diffusivity of the material (m²/sec).

Thermal conductivity: The method of boxes used a technique of measurement based on permanent regime (Gaye, 2001).

The principle of this method is to place the test sample between a hot box fitted with a heating film and a cold isothermal capacity. In permanent regime, the thermal conductivity is given by the relationship:

$$\lambda = \frac{\dot{Q} \times e}{S \times \Delta T} \quad (3)$$

where,

\dot{Q} : Heat Flux through the sample

ΔT : Difference in temperature between the faces of the sample

e : Thickness of the sample

S : Area of the surface of sample

For temperatures T_c of the hot side and T_f in the cold side of the sample, in permanent regime, the heat flux through the sample can be written:

$$\dot{Q} = \frac{\lambda}{e} \times S(T_c - T_f) = \dot{Q}_1 - \dot{Q}_2 \quad (4)$$

With:

$$\dot{Q}_1 = \frac{V^2}{R} \text{ And } \dot{Q}_2 = C \times (T_B - T_A) \quad (5)$$

where,

\dot{Q}_1 : Power dissipated by joule effect in the heating resistor R

V : Voltage applied to the terminals of the heating resistor R

C : Overall coefficient of heat loss through the box, corresponding to a maximum deviation of 1°C between indoor and outdoor temperatures of the box B

\dot{Q}_2 : Power exchanged between the inside of the box B at temperature T_B and the external atmosphere at temperature T_A

The thermal conductivity is then given with an accuracy of 5% by the following relationship:

$$\lambda = \frac{e}{S(T_c - T_f)} \left(\frac{V^2}{R} - C(T_B - T_A) \right) \quad (6)$$

Thermal diffusivity: The experimental device is almost similar to the one used for the measurement of the thermal conductivity. The box B is replaced by a box B', whose internal walls are reflective and fitted at its basis by an opening through which the thermal pulse from a filament lamp of 500 Watts, is received by the

sample placed between the box B' and the isothermal capacity A. A dimmer and timer respectively allow varying the power and duration of the pulse, depending on the nature of the sample.

A thermo sensor in platinum is placed on the non-irradiated side of sample. The signal issued by this detector is amplified by an amplifier converter with low noise and gain varying from 100 to 600. After amplification, the signal is recorded on a potentiometric recorder. The curve obtained, corresponding to the variation of the temperature of the opposite side to the one receiving the pulse, will be used to determine the thermal diffusivity by using the theoretical model of DEGIOVANI (Ozisk, 1980; Carslaw and Jaeger, 1959).

In his model, DEGIOVANI characterized the reduced temperature $T^* = f(t^*)$ by the particular reduced time $t_{5/6}^*$ (Abcissa of the point of ordered 5/6 of the maximum evolution of temperature). He shows numerically that the theoretical curves giving $\frac{T^*}{T_M^*}$ according to $\frac{t^*}{t_{5/6}^*}$ are independent of the thermal

losses and the geometrical parameters of the system and that they are function of $t_{5/6}^*$. This property is checked for the following conditions:

$$0.1 < \frac{e}{R} < 10 \text{ And } 0.01 < \frac{r_c}{R} < 1$$

With reduced exchange coefficients below to one (which is often the case), he found:

$$t_{5/6}^* = 1.150 - 1.250 \frac{t_{2/3}}{t_{5/6}} \quad (7)$$

$$t_{5/6}^* = 0.761 - 0.926 \frac{t_{1/2}}{t_{5/6}} \quad (8)$$

$$t_{5/6}^* = 0.617 - 0.862 \frac{t_{1/3}}{t_{5/6}} \quad (9)$$

As well by using the definition of the reduced time, the thermal diffusivity can be deduced from the relationship:

$$t_{5/6}^* = \frac{at}{e^2} \frac{5/6}{2} \quad (10)$$

The latter is calculated with an accuracy of between 0.5 and 3% from the following relations:

$$a_1 = \frac{e^2}{t_{5/6}^*} \left(1.15 t_{5/6}^* - 1.25 t_{2/3} \right) \quad (11)$$

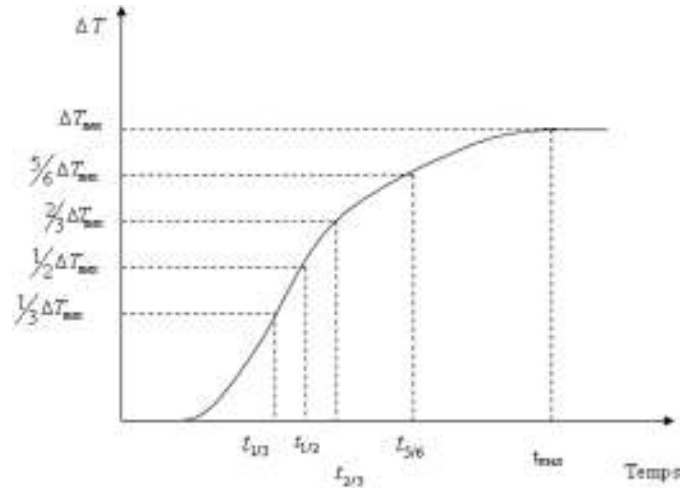


Fig. 2: Thermogram of the non-irradiated side for the measurement of diffusivity by the model of DEGIOVANI

Table 1: Thermo physical properties as a function of percentage of volume of cow dung

Cow dung (%)	0	5	10	15	20
Conductivity λ (W/m.K)	0.330	0.320	0.308	0.290	0.256
Diffusivity $\alpha \times E7$ (m ² /sec)	2.940	4.000	5.120	5.250	5.940
Density ρ (kg/m ³)	2255.850	2000	1920.430	1682.940	1634.860
Specific heat C (J/kg.K)	499.830	400	313.240	328.780	263.710

Table 2: Thermo physical properties as a function of percentage of volume of cow dung and copper

Cow dung (%)	0	5	10	15	20
Copper (%)	0	2	4	6	8
Conductivity λ (W/m.K)	0.3315	0.4303	0.476	0.4375	0.38
Diffusivity $\alpha \times E7$ (m ² /sec)	2.9400	5.7300	5.710	6.7000	6.87
Density ρ (kg/m ³)	2255.8000	2095.0200	2139.700	1998.3000	2221.10
Specific heat C (J/kg.K)	499.8000	358.4400	389.500	326.7700	248.60

$$a_2 = \frac{e^2}{t_{5/6}^2} \left(0.761 t_{5/6} - 0.926 t_{1/2} \right) \quad (12)$$

$$a_3 = \frac{e^2}{t_{5/6}^2} \left(0.617 t_{5/6} - 0.862 t_{1/3} \right) \quad (13)$$

$$a = \frac{a_1 + a_2 + a_3}{3} \quad (14)$$

In these relations, $t_{5/6}$, $t_{2/3}$, $t_{1/2}$ and $t_{1/3}$ designate the time at the end of which, the rise in temperature of the non-irradiated side is 5/6, 2/3, 1/2 and 1/3 times the maximum elevation of the temperature Fig. 2. The advantage of this method is to calculate the thermal diffusivity without prior evaluation of the superficial exchanges coefficients. Thermal losses are implicitly taken into account, that which extends the measurement of diffusivity in thick samples.

RESULTS AND DISCUSSION

We worked on two series of different samples. The first series has allowed us to vary the percentage of cow dung (herbs) from 0 to 20% with a step of 5% Fig. 3.



Fig. 3: Photography of a sample of mixture of clay of thiky and cow dung



Fig. 4: Photography of a sample of mixture of clay of thiky, cow dung and copper

The second series has allowed us to introduce copper while maintaining the percentage of cow dung (herbs). The copper has been introduced in the ascending order of the percentage of cow dung (herbs), from 2 to 8% with a step of 2% Fig. 4.

The results obtained on the first series of samples are summarized in Table 1 and those obtained on the second series of samples are summarized in the following Table 2.

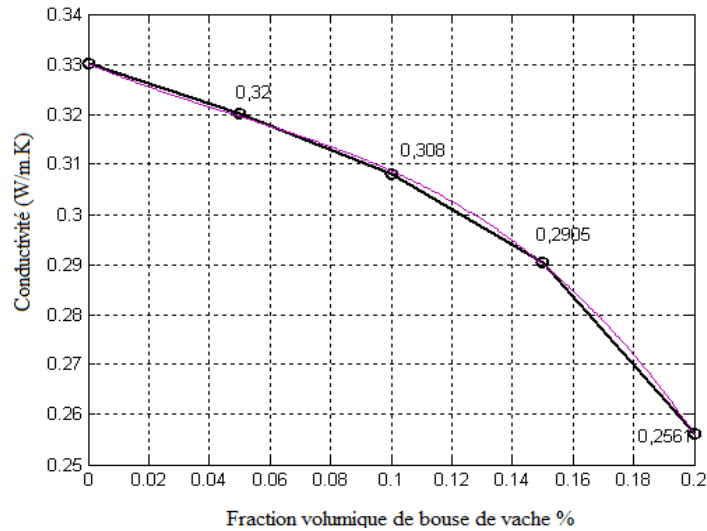


Fig. 5: Evolution of the thermal conductivity as a function of percentage of volume of cow dung

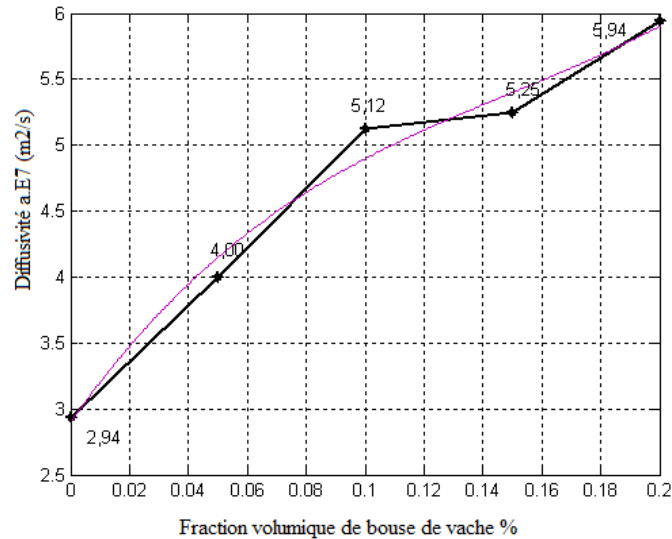


Fig. 6: Evolution of the thermal diffusivity as a function of percentage of volume of cow dung

Figure 5 and 6 above illustrate the variations of the conductivity and the diffusivity as a function of percentage of volume of cow dung.

We found that the thermal conductivity decreases when the percentage of volume of cow dung increases. The pores are air voids, which makes the material much more insulation; therefore thermally resistant.

By contrast, the thermal diffusivity increases when the percentage of volume of cow dung increases. This is explained by the fact that the density is changed significantly. The density decreases much more than does decrease thermal conductivity. Because these parameters are related by the following relationship:

$$a = \frac{\lambda}{\rho \times C} \quad (15)$$

Figure 7 illustrates the influence of copper on the conductivity. Each dosage by copper corresponds to a particular porosity that is why we cannot connect the dots.

We found that the conductivity increases with the dosage in copper, but this increase is relative because of the paradoxical effect due to the increase of porosity.

For 5% of cow dung, we obtain 0.32 W/m.K on the curve without copper; whereas if we put 2% of copper, we obtain 0.43 W/m.k. The increase of the porosity decreases the effect of copper. In effect, we find that with 20% of cow dung, we obtain 0.25 W/m.K on the curve without copper; then that by putting 8% of copper, we obtain 0.379 W/m.k.

Figure 8 below illustrates the influence of copper on the thermal diffusivity. For each dosage by copper

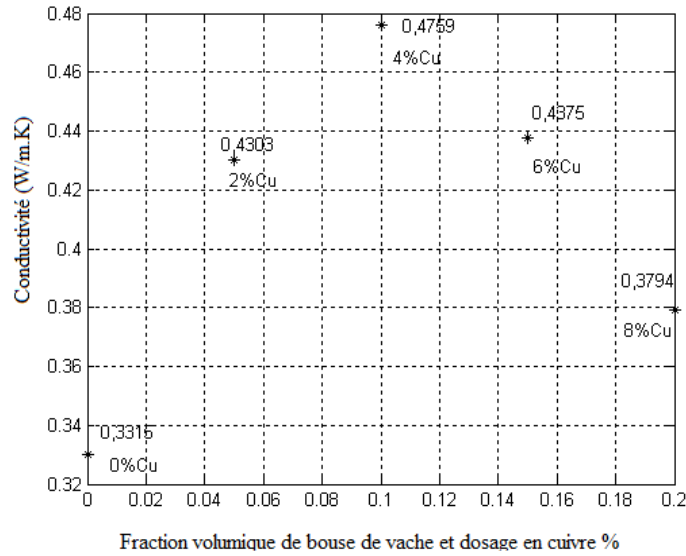


Fig. 7: Evolution of the thermal conductivity as a function of percentage of volume of cow dung and dosage in copper

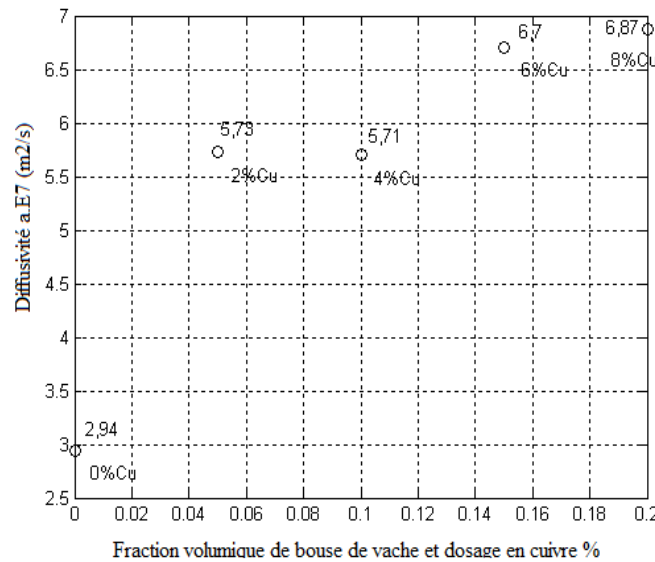


Fig. 8: Evolution of the thermal diffusivity as a function of percentage of volume of cow dung and dosage in copper

corresponds a particular porosity, it is for what here also we cannot join the points.

We find that the thermal diffusivity increases with the dosage in copper, but this increase is limited because of the porosity. The copper increases the conductivity and the mass density, whereas the porosity tends to decrease the density. For 5% of cow dung, we obtain a value of diffusivity of $4 \times 10^{-7} \text{ m}^2/\text{sec}$ on the curve without copper; then that by putting 2% of copper, we obtain a value of $5.73 \times 10^{-7} \text{ m}^2/\text{sec}$. The effect of copper is very limited with the increase of the porosity.

Despite the inadequacy of the number of samples, we find that for a given percentage of volume of cow dung, the thermal conductivity increases with the dosage in copper. Each percentage of volume of copper

corresponds to a particular porosity. This does not allow drawing a curve for each dosage in copper, but simply placing the corresponding points. Thus, we can compare point by point the values of the conductivity to the curve obtained without dosage in copper. The same observation is observed for the thermal diffusivity.

CONCLUSION AND RECOMMENDATIONS

The work that we have done implicitly contains two components: the research of the porosity and the improvement of the thermal conductivity of the baked clay.

The search for the porosity has allowed us to highlight a method of making a material much more insulation. Thus, the formulation of the first series of

samples, for which it has introduced the cow dung ranging from 0 to 20% by volume, with a step of 5%, has allowed us to obtain the values of the thermal conductivity: 0.3315, 0.320, 0.308, 0.2905 and 0.2561 W/m°C. This result has enabled to make a contribution to the results of previous work which have focused on the thermo physical characterization of construction materials, especially clay of Thick without additives, for which the conductivity obtained is 0.33 W/m°C (Khatri, 2007). This outcome is indeed very encouraging for a potential application in construction. But it will be interesting to complete the study with a mechanical characterization before to be able to decide on its possible application in buildings.

The search for the improvement of the thermal conductivity has led us to mix the clay with the copper while retaining the previous formulation; i.e., the same dosage with cow dung. Thus, in the order of the previous formulation, we introduced 2, 4, 6 and 8% of copper and we have obtained the following results: 0.4303, 0.4759, 0.4375 and 0.3794 W/m°C, respectively.

We note that the conductivity is significantly improved. Also, for a consistent comparison, it will be interesting to vary the dosage in copper while maintaining a rate of porosity constant which would enable to obtain a graphical representation in block, according to the dosage in copper and the rate of porosity.

The maximum conductivity obtained is 0.4759 W/m°C corresponding to 10% by volume of cow dung, with 4% by volume of copper.

To obtain a high value of conductivity, it will be interesting to increase the dosage in copper. But beyond certain limit value to determine, we risk weakening the clayey matrix.

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