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Valorization of sawdust as insulation in construction

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ABSTRACT: With the development of the wood industry for the needs of construction and furniture, the proliferation of waste thus produced poses serious environmental problems. An interesting avenue for mitigating or absorbing this nuisance would be to develop this substance in the form of a brick with an insulating effect in construction. The object of this study is to characterize the thermal properties of these bricks according to the water content and sawdust. Samples of different sawdust contents (from 0 to 0.33 $kg_{sb}kg_{ar}^{-1}$) with dimensions of 10x10x3 cm^3 were produced. An asymmetric hot plane type device was used to measure the volume thermal capacity and the thermal conductivity as a function of the water content from 0 to a maximum value of 0.069 $kg_{dm}kg_{w}^{-1}$. The profile of the experimental curves of the estimated parameters is in line with that of the theoretical models from the literature.

KEYWORDS: Environmental protection, thermal conductivity, volume thermal capacity, clay, sawdust, modeling.

1 INTRODUCTION

Adding a supposedly insulating material to a building material is the best way to improve the thermal performance of the latter. Light dense materials generally have a low thermal capacity: they absorb very little heat. This gives them a low thermal conductivity. Then sawdust, the appearance of which is shown in figure 1, is assumed to have low conductivity. Wood has always been used in construction and is the only completely renewable natural material. The dynamics of forest products shows its importance in the socio-economic fabric of this industry (Delisle, 2018). Despite the significant advantages they provide in terms of economy, speed of construction, carbon sequestration and remarkable energy performance, it has a negative side on the environmental impact especially at the level of the wooden joinery with the waste produced. Some studies relating to the determination of the thermal conductivity of earth-based materials have already been published. A study on the influence of different wood contents on an amount of cement has been made (Bouguerra and al, 2001). The variation of the thermal conductivity of porous media has also been made by several authors. From this perspective, a model based on that of (Kirsher, 1956) have been developed for a humid porous medium (Azizi and al, 1988) and (Tong and al, 2009). Later, another thermal conductivity model from samples composed of different millet waste and water contents was developed (Bal and al, 2013).

2 EXPERIMENTAL PRINCIPLES AND PRINCIPLE OF METHODS

2.1 SAMPLE PREPARATION

The clay powder is extracted directly from the Thicky quarry located into the Thies region in Senegal. The raw clay extracted is sieved so that it has the largest grain size in the range of 1 mm and stored in sealed jars. The clay powder was first mixed with a given amount of sawdust. The mixture thus obtained is pressed into a mold having the internal dimensions 10×10×3 cm^3 with manual pressure of the order of 1 bar (figure 2). After removal from mold, the samples (figure 3) are kept in plastic bags (figure 4) for several days in order to obtain uniform humidity over the entire sample. This operation is repeated after each measurement (of weight and thermal property) until the mass no longer varies by natural drying. Not having a vacuum device, we used an oven to extract the maximum humidity from the sample. The measurements respectively of the weight and the thermal properties must then be made immediately before the sample rehydrates.

Fig. 1. Physical appearance of sawdust

Fig. 2. Representation of the mold

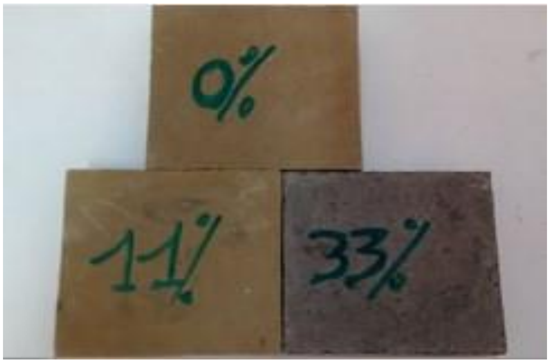

Fig. 3. Representation of the mold

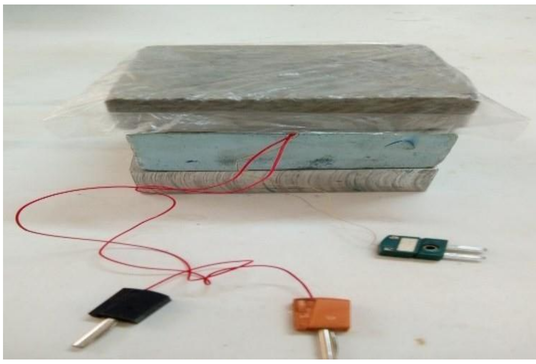

Fig. 4. Plastic sample packaging

2.2 METHOD OF MEASURING THERMAL PROPERTIES

The thermal conductivity was previously determined by several methods including the hot plate kept and the hot tape (figure 5). However, since it cannot strictly have identical samples, that is to say of the same water content, we opt to make an asymmetric type device. A heating element wrapped in a 10x10 cm² square membrane is placed below the sample. A type K thermocouple designed with 2 wires 0.005 mm in diameter is taped on the underside of the heating element. This set (probe + sample) is placed between 2 blocks of polystyrene 5 cm thick and all between 2 blocks of aluminum 4 mm thick. By sending a step of heat flow, through the heating resistor, the temperature is recorded in the center of the sample. The point of contact of the thermocouple with the polystyrene does not cause significant contact resistance because the latter is deformable especially since the polystyrene is an insulator (Bal et al, 2012).

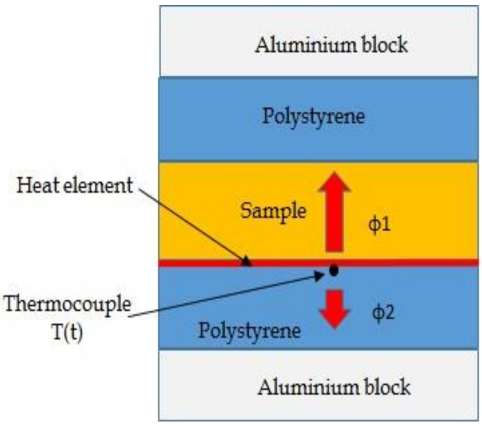

Fig. 5. Diagram of the asymmetric hot plan device

The system is modeled assuming that the heat transfer is unidirectional to the center of the sample throughout the experiment. This hypothesis will be verified by a 3D simulation carried out with COMSOL by applying the method of least squares of the Levenberg and Marquart type.

3 Method Of Measuring Thermal Properties

The samples of building materials on which we work are not identically reproducible in form and constitution. Therefore, the measurements made on the basis of the classical method will not be correct because the symmetry hypothesis is not fully verified at the start. In addition, these materials have surface roughnesses which could generate fairly high contact thermal resistances. Faced with these difficulties, we opted to use the asymmetric hot plane method in which we will use a non-rigid insulator to reduce the contact resistances.

3.1 Quadripole Method

As in the case of the asymmetric hot plane, one can apply the formalism of the quadrupoles (Maillet and al, 2000) on the model applied on the diagram of figure 5. Between the heating resistor and the rear face of the insulation (upper side), the temperature of the T0 (t) is obtained.

On the upper side (sample), we get:

$$\begin{bmatrix}\theta_0\\ \phi_1\end{bmatrix}=\begin{bmatrix}1 & 0\\ C_1 & 1\end{bmatrix}\begin{bmatrix}1 & R_{c1}\\ 0 & 1\end{bmatrix}\begin{bmatrix}A_e & B_e\\ C_e & D_e\end{bmatrix}\begin{bmatrix}A_i & B_i\\ C_i & D_i\end{bmatrix}\begin{bmatrix}0\\ \phi'_1\end{bmatrix}=\begin{bmatrix}A & B\\ C & D\end{bmatrix}\begin{bmatrix}0\\ \phi'_1\end{bmatrix} \qquad 1$$

With

$$\begin{bmatrix}A_e & B_e\\ C_e & D_e\end{bmatrix}=\begin{bmatrix}ch(qe) & \dfrac{sh(qe)}{\lambda qS}\\ \lambda qSsh(qe) & ch(qe)\end{bmatrix} avecq=\sqrt{\frac{p}{a}} \qquad 2$$

And

$$\begin{bmatrix}A_i & B_i\\ C_i & D_i\end{bmatrix}=\begin{bmatrix}ch(qie) & \dfrac{sh(qie)}{\lambda qS}\\ \lambda qSsh(qie) & ch(qie)\end{bmatrix} avecqi=\sqrt{\frac{p}{ai}} \qquad 3$$

By developing the previous matrix product, we obtain:

$$\phi_1=\theta_0\frac{D}{B} \qquad 4$$

On the lower side:

$$\begin{bmatrix}\theta_0\\ \phi_2\end{bmatrix}=\begin{bmatrix}A_i & B_i\\ C_i & D_i\end{bmatrix}\begin{bmatrix}0\\ \phi'_2\end{bmatrix} \qquad 5$$

By developing the previous matrix product, we obtain:

$$\phi_2=\theta_0\frac{D_i}{B_i} \qquad 5$$

However:

$$\phi_0=\phi_1+\phi_2=\frac{\varphi_0}{S} \qquad 7$$

So:

$$\phi_0=\theta_0\left(\frac{D}{B}+\frac{D_i}{B_i}\right) \qquad 8$$

And we deduct the value of θ_0 by the following relation:

$$\theta_0 = \frac{\phi_0}{p} \frac{1}{\left(\frac{D}{B} + \frac{D_i}{B_i}\right)} \qquad 9$$

3.2 SIMPLIFIED MODEL

In long time (p → 0), the expression of the temperature at the center of the probe in the Laplace space becomes:

$$\theta_0 = \frac{\phi_0}{p} \frac{1}{(C_p - E\sqrt{p})(1 - R_{c1}E\sqrt{p}) + (C_p + E_i\sqrt{p})(1 - R_{c2}E_i\sqrt{p})} \qquad 10$$

Either again:

$$\theta_0 = \frac{\phi_0}{p} \frac{1}{(E + E_i)\sqrt{p} + p(2C - R_{c1}E^2 - R_{c2}Ei^2)} \qquad 11$$

Then:

$$\theta_0 = \frac{\phi_0}{p} \frac{1}{(E + E_i)\sqrt{p} + p(2C - R_{c1}E^2 - R_{c2}Ei^2)} \qquad 12$$

And by inverse Laplace transform of the expression (12), we get:

$$T_0(t) = \phi_0 \left[\frac{R_{c1}E^2 + R_{c2}E^2}{(E + E_i)^2} - \frac{2(\varrho ce)_s}{(E + E_i)^2}\right] + \frac{\phi_0}{(E + E_i)\sqrt{\pi}}\sqrt{t} \qquad 14$$

The inertia of the probe and the contact resistance have no influence on the temperature value over_ a long period of time. The curve $T_0\,(t) = f\,(\sqrt{t})$ becomes comparable to a straight line at a certain time, the determination of the slope β of this straight line makes it possible to calculate the theoretical thermal effusivity by the relation $E + E_i = \frac{\phi_0}{\beta\sqrt{\pi}}$

The estimation of the parameters (E, λ, ρc and a) will be done using the complete model by an adequate minimization which allows to approximate the experimental curves as well as those of the model. The product ρc is obtained in the following way (Bal, 2011).

Consider the flux dissipated in the sample and the insulator during an infinitely small time interval dt and which causes a rise in temperature dT, the temperature profile can be represented by figure 6.

However, the thermal resistance that we measure corresponds to that between the probe and the rear face of the sample.

$$R_{th} = \frac{e}{\lambda} + R_c \Leftrightarrow \frac{e}{\lambda} - R_c \qquad 15$$

Since the contact resistance Rc is not well known, there will be an influence on the ratio e/λ and therefore on λ.

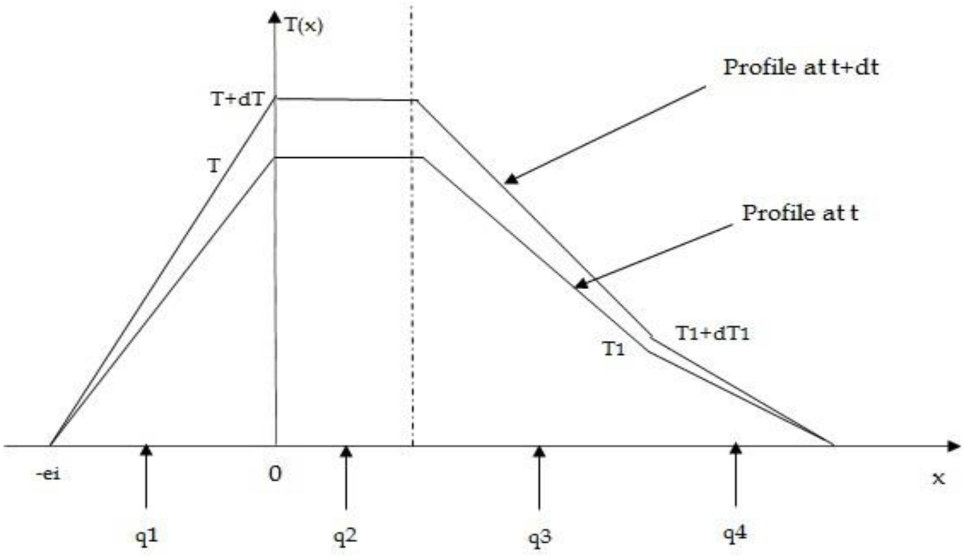

Fig. 6. Temperature profile in different materials

By using the linear part of the temperature curve of the front face, we can estimate the product ρc.

$$\phi dt = q_1 + q_2 + q_3 + q_4 \qquad 16$$

With

$$q_1 = \frac{m_i c_i}{2} dT;\ q_2 = m_{pr} m_{pr} dT;\ q_3 = \frac{m_{sp} c_{sp}}{2} dT_1 \ and\ q_4 = m_i m_i \frac{dT_1}{2} \qquad 17$$

If

$$R_i \gg R_{sp}, \qquad 18$$

Then

$$T \approx T_1 \qquad 19$$

$$\phi = [(\rho c)_e e_e + (\rho c)_i e_i + (\rho c)_s e_s] \frac{dT}{dt}$$

At long times when the curve seems to be linear, the slope is calculated by deducing the coefficient (ρc) e of the sample by the following relation:

$$(\varrho c)_e = \frac{\frac{\phi}{\beta} - (\rho c)_i e_i - (\rho c)_s e_s}{e_e} \qquad 20$$

4 Experimental Results

The objective of this study is to measure the thermal properties, in particular the thermal conductivity and the volume thermal capacity of earth bricks incorporated with sawdust inclusions as a function of the water content. The results obtained were presented and compared to those existing in the literature for a thermal insulation application. An asymmetric hot plane type assembly is used for the measurements of these thermal properties mentioned above by varying the water content from 0 to about 7%. A technique for packaging plastic test tubes prevents water migration at the edges during heat transfer. Tests for the estimation of the parameters ρc and λ are made using the complete model resulting from a MATLAB program on the asymmetric hot plane method on the samples having respectively 0%, 11% and 33% of sawdust content of wood. The results obtained are shown in the following table:

Table 1. Presentation of measurement of sawdust

Sawdust content - Y = 0%			Sawdust content - Y = 11%			Sawdust content - Y = 33%		
X - %	ρc	λ	X - %	ρc	λ	X - %	ρc	λ
7,76	3,15E+06	1,18	5,96	2,64E+06	1,01	8,78	2,47E+06	0,89
4,73	2,88E+06	1,07	3,33	2,41E+06	0,97	5,91	2,18E+06	0,73
2,84	2,80E+06	0,99	1,75	2,18E+06	0,91	4,10	1,81E+06	0,70
1,43	2,46E+06	0,94	1,15	1,92E+06	0,86	2,71	1,80E+06	0,66
0,56	2,09E+06	0,90	0,69	1,72E+06	0,84	1,59	1,73E+06	0,59
0,30	2,08E+06	0,88	0,37	1,67E+06	0,82	0,94	1,50E+06	0,56
0,14	2,00E+06	0,85	0,15	1,55E+06	0,74	0,40	1,31E+06	0,54
-00	1,78E+06	0,81	-00	1,51E+06	0,62	-00	1,29E+06	0,49

4.1 Study Of Reduced Sensitivities

The principle of the analysis of reduced sensitivities has been described by several authors (Maillet, 1991), Kurpiz and Novak; 1995). Reduced sensitivities thus have the advantage of allowing direct comparison of the relative influence of different parameters on temperature. Compared to the study which we plan to make, we propose to study the reduced sensitivity of the temperature compared to the parameters mc, Rc, ρc and λ for the sample of pure wet clay and that dry made up of maximum in sawdust content (33%). We stopped at this value because the samples became brittle.

- **Pure wet clay (0% sawdust)**

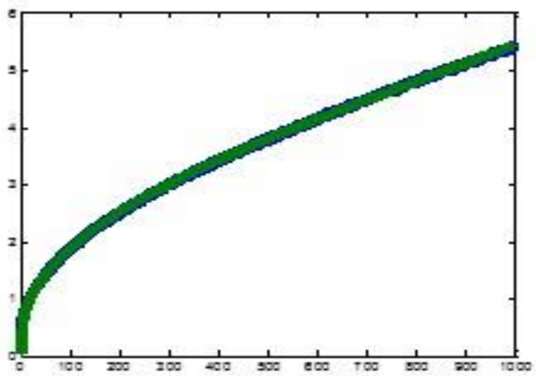

Fig. 7. Thermogram (pure wet clay)

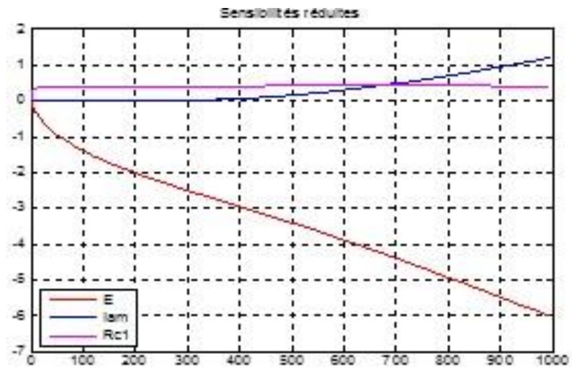

Fig. 8. Reduced sensitivities (pure wet clay)

- **Dry sample with 33% sawdust**

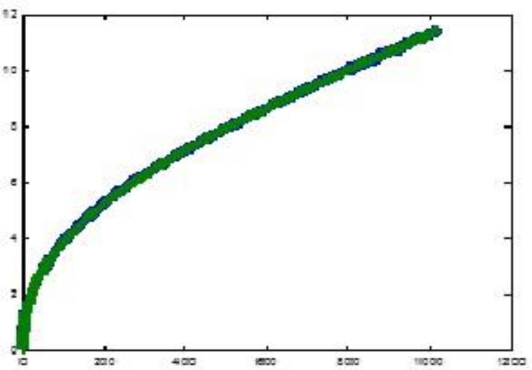

Fig. 9. Thermogram (dry 33% sawdast)

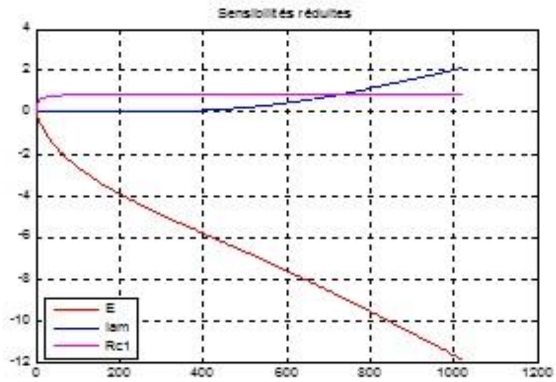

Fig. 10. Reduced sensitivities (dry 33% sawdust

On the thermogram of figure 7, the linear zone starts from 300s; the exploitation of the slope of this straight line makes it possible to estimate the volume thermal capacity. On the sensitivity curve of figure 8, we note the influence of the mass of the probe and the contact resistance at the very start of the measurement. From the sensitivity curve over the interval [0; 1000s], we can estimate the effusivity between 0 and 150s that of the conductivity from 700s.

On the thermogram of figure 9, the linear zone starts from 400s; the exploitation of the slope of this straight line makes it possible to estimate the volume thermal capacity. On the sensitivity curve of figure 10, one notes the influence of the mass of the probe and the contact resistance at the very beginning of the measurement. From the sensitivity curve over the interval [0; 1200s], we can estimate the effusivity between 0 and 200s that of the conductivity from 800s.

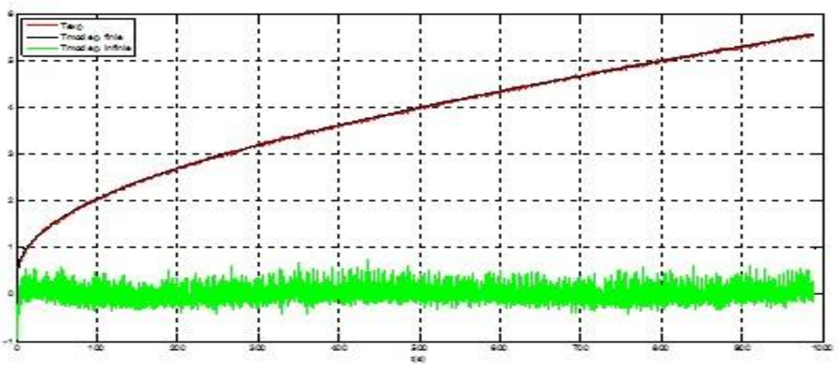

Fig. 11. Theoretical, experimental and residual curves

In Figure 11, the green residue curve shows that the experimental and theoretical curve is superimposed between 0 and 1000s. During this time, the residuals are practically centered on zero and the transfer remained unidirectional. We can observe the influence of the thermal capacitance of the heating element at the start of heating between 0 and 5s. The results obtained verify the criterion for minimizing the quadratic difference between the experimental curve and the theoretical curve. The sensitivity and residue curves show that the thermophysical properties ρc and λ can be estimated with precision by this method.

4.2 Presentation And Analysis Of Experimental Results

Using an asymmetric hot plane type device and the use of quadrupoles modeling, leads to the determination of the temperature in Laplace space first and by inversion in real space. A (Levenberg, 1944) type minimization method is used in a MATLAB type program operating with a complete model to determine the thermophysical parameters for which the experimental curve coincides with the curve of the model.

4.2.1 Thermal Conductivity

Using the data in the table1, the curve connecting the thermal conductivity as a function of the water content can be plotted for different sawdust contents.

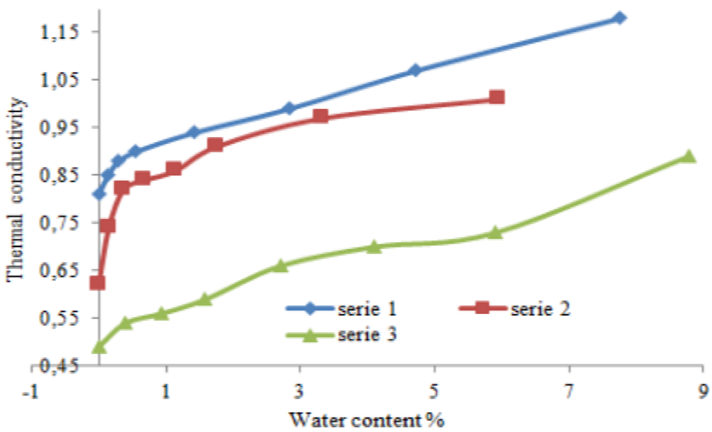

Fig. 12. Thermal conductivity as a function of the water content

The analysis of the curves obtained inform us of several aspects:

- The thermal conductivity decreases with the sawdust content.
- The thermal conductivity increases with the water content regardless of the sawdust content of the sample.
- This increase is quite rapid at the start of humidification but it stagnates thereafter.

4.2.2 Volume Thermal Capacity

As in the case of thermal conductivity, the data in figure 13 make it possible to follow the evolution of the volume thermal capacity as a function of the water content.

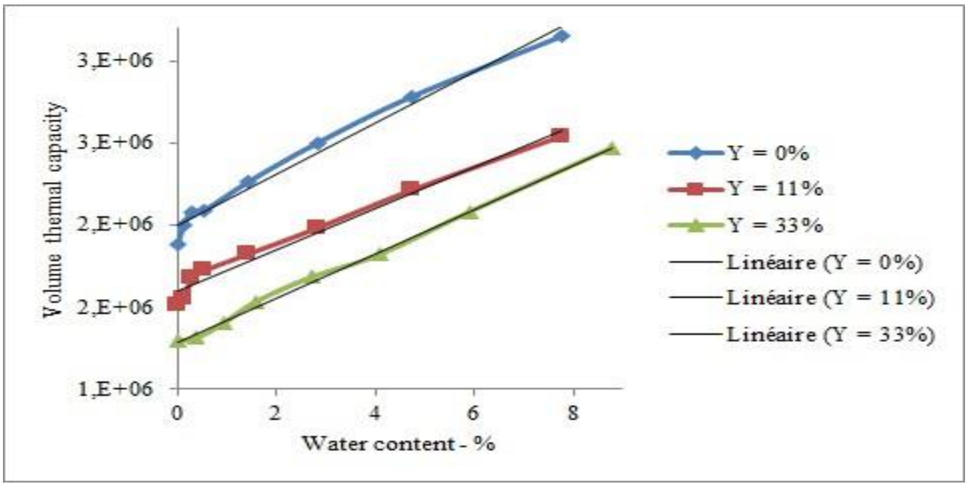

Fig. 13. Volume thermal capacity as a function of water content

These curves also tell us about several aspects:

- The volume thermal capacity decreases when the sawdust content increases;
- The volume thermal capacity increases almost linearly with the water content regardless of the sawdust content of the sample.

This study shows that the water content has an important influence on the thermal properties of materials. Thus, to predict thermal comfort in a given environment, it is essential to understand this dependence of properties on thermo-hygrometric conditions.

5 Conclusion

The study clearly shows that the gradual addition of sawdust with clay leads to a product with low thermal conductivity. Indeed, its recovery as a building material can resolve environmental pollution, among other things.

With regard to thermal conductivity, the results obtained are very interesting because it is shown that the addition of sawdust with clay makes it possible to note the following:

- The thermal conductivity decreases with the sawdust content.
- The thermal conductivity increases with the water content regardless of the sawdust content of the sample.
- This increase is quite rapid at the start of humidification but it stagnates thereafter.

With regard to the volume thermal capacity, the results are in perfect adequacy with the theoretical models:

- The volume thermal capacity varies inversely with the sawdust content.
- The volume thermal capacity increases almost linearly with the water content regardless of the sawdust content of the sample.

Clay is an abundant material used in ancient times in construction in rural areas. Public awareness of this aspect would allow it to be used more at the expense of concrete-based materials.

In addition to preserving the environment by reducing energy production, this would lead to significant savings for these generally low-income populations and strengthen their purchasing power.

As perspectives, it is envisaged to

- Carry out studies on porosity in order to compare our experimental curves with that of conventional models of thermal conductivity that we find in the literature.
- Carry out studies on the determination of the optimal percentage of sawdust to mix with clay as well as the mechanical characterization of this composite material.

NOMENCLATURE

Symbols		Greek letters	
a	Thermal diffusivity m^2s^{-1}	λ	Thermal conductivity, $Wm^{-1}K^{-1}$
c	Specific heat $Jkg^{-1}K^{-1}$	ρ	Density kgm^{-3}
e	Thickness (m)	ϕ	Heat flow density Wm^{-2}
D, B	Sample constants	Φ	Laplace transform of heat flux density
D_i, B_i	Insulation constants	θ	Laplace transform of the temperature
E	Effusivity $Jm^{-2}{}^{\circ}C^{-1}s^{-1/2}$	Subscripts	
Rc	Thermal contact resistance between Element and the the sample m^2KW^{-1}	cl	clay
		i	Insulating material
p	Laplace parameter	pr	probe
t	Time (s)	sd	Sawdust
T	Temperature (°C)	sp	Sample
X	Water content $kgkg^{-1}$	w	Water
Y	Sawdust content $kgkg^{-1}$		

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