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THERMOPHYSICAL CHARACTERIZATION OF AN ENVIRONMENTALLY CONSTRUCTION MATERIAL MADE BY CLAY AND WHEAT CLOVE

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ABSTRACT

In Africa, several techniques have been used depending on the region for the construction of habitats. Modern buildings with excessive energy consumption are very costly for developing countries and cause environmental degradation.

At Chad, pod of wheat and cow dung are the two main traditional materials mixed with clay for the construction of housing. However, the characteristics of these materials are still unknown. This is why we studied the thermal characteristics of clay-based brick and wheat pod.

Clay of the Site of Madagua (in N'Djamena) that we used was dug to a depth of 1.5 m and sieved at 80 microns diameter.

The results show that the studied materials are environmentally friendly and can improve the thermal efficiency of buildings.

KEYWORDS: Clay, pod corn, thermal properties, chemical analysis, ecology.

Nomenclature

Latin letters

a	*Thermal diffusivity* $(m^2.s^{-1})$
C_p	*Specific heat* $(J.kg^{-1}.K^{-1})$
c_h	*Thermal capacity of the heating element per area unit* $(J.m^{-2}.K^{-1})$
e	*Thickness (mm)*
E	*Thermal effusivity* $(J.m^{-2}.K^{-1}.s^{-1/2})$
h	*Convection heat transfer coefficient* $(W.m^{-2}.K^{-1})$
p	*Laplace parameter*
R	*Electrical resistance of the heating element* (Ω)
R_c	*Thermal contact resistance between the heating element and the sample* $(m^2.K.W^{-1})$
t	*Time (s)*
T	*Temperature (°C)*
U	*Voltage of the electric current (V)*

Greek symbols

λ	*Thermal conductivity* $(W.m^{-1}.K^{-1})$
ρ	*Density* $(kg.m^{-3})$
ρc	*Thermal capacity* $(J.m^{-3}.K^{-1})$
$\emptyset$	*Heat flux density* $(W.m^{-2})$
θ	*Laplace transform of the temperature*
Φ	*Laplace transform of the heat flux*
Ψ	*quadratic error between experimental and theoretical curves.*

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INTRODUCTION

The consumption of energy in the air conditioning or heating still needs to be better controlled in the building sector. Indeed, the increase of demand for energy in developing countries, weighs not only on the energy bill, but also contributes to the degradation of the environment.

Several thermophysical characterization studies were performed on samples with local African materials [1-2]. However, the thermal characteristics of clay-based materials, which are used in traditional construction in Chad, are not yet well known. This is why we are interested in this work to study these clay-based ecological materials from N'Djamena, Chad, mixed with wheat pods to see their impact on the thermal performance of buildings.

The materials used in this study were the subjects of a detailed study to determine their thermophysical properties. To this end, we opted for two experimental methods appropriate for this type of composites and porous materials: the method of hot plane based on steady and unsteady state for the determination of thermal conductivity and thermal effusivity and the transient flash method to determine the thermal diffusivity [3-4].

MATERIALS AND METHODS

To respect the dimensional constraints of the measuring equipment, we have prepared clay samples of dimensions 10 × 10 cm^2 and thickness ranging from 2 to 3 cm. The weight proportions of wheat pods added range from 2% to 13%. For each formulation, we have made three samples.

From the measurements, we then identified the thermal properties of our material, namely conductivity, diffusivity, effusivity and the specific heat.

CHEMICAL ANALYSIS OF N'DJAMENA CLAY

To complete the study of the thermophysical properties of the clay we did the chemical analysis. This analysis of the Ndjamena clay (table1) was made on the basis of Fluorescence Test X at the UATRS division of laboratory CNSRT (Morocco).This chemical analysis relates to only clay without additive (100% clay).

Table:

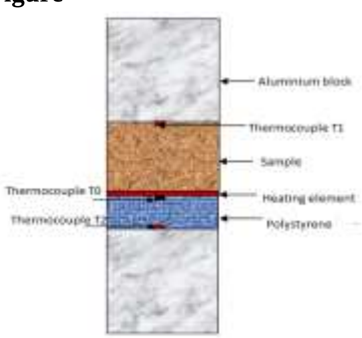
Table 1: Chemical composition of N'djamena's clay

constituents	SiO_2	*P.A.F*	*CaO*	Al_2O_3	MgO	Fe_2O_3	K_2O	Na_2O	TiO_2	Cl	SO_3	P_2O_5
Conc%	*39.6*	*19.9*	*14.5*	*14*	*4.33*	*3.56*	*1.99*	*0.833*	*0.455*	*0.32*	*0.213*	*0.192*
constituents	MnO_2	*SrO*	ZrO_2	*l*	*ZnO*	*Rb*	*Y2O3*	*Somme*				
Conc%	*0,0634*	*0,039*	*0,0146*	*0,01440*	*0,00834*	*0,00753*	*0,0036*	*100*				

DETERMINATION OF THE THERMAL CONDUCTIVITY

Experiment study

Figure



1. **Experimental device of the centered hot plate method in steady state regime.**

Figure

2. **Assembly of state regime (LEM/Sale/Morocco)**

Four elements are used to form the experimental model: two aluminums plates, polystyrene, three thermocouples (To, T1 and T2) and a heating film (Figure 1 and Figure 2):

- *To is the temperature at the connection of the heating film;*
- *T1 is the temperature at the internal face of the upper block;*

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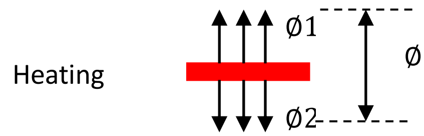
- *T2 is the temperature at the internal face of the lower block of aluminium.*

The heating element dissipates two flows $\emptyset_1$ and $\emptyset_2$ in opposite direction, respectively directed towards the insulator (polystyrene) and toward the sample such that (Figure 3):

Figure:



3. ***Dissipation of heat flow***

We have thus:

$$\emptyset 1 = \frac{\lambda_1}{e_1}(T_0 - T_1);\ \emptyset 2 = \frac{\lambda_2}{e_2}(T_1 - T_2) \quad (1)$$

$$\emptyset = \emptyset 1 + \emptyset 2 = \frac{\lambda_1}{e_1}(T_0 - T_1) + \frac{\lambda_2}{e_2}(T_0 - T_2) = \frac{U^2}{RS} \quad (2)$$

$$\lambda_1 = \frac{e_1}{T_0 - T_1}\left[\frac{U^2}{R\,S} - \frac{\lambda_2}{e_2}(T_0 - T_2)\right] \quad (3)$$

e_1 and e_2 are respectively the thickness of the sample and the insulator.

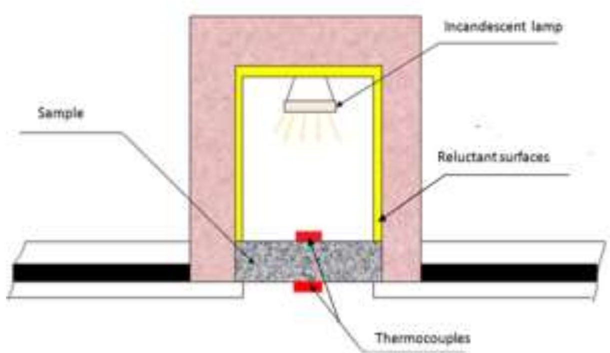
DETERMINATION OF THE THERMAL DIFFUSIVITY

Experiment Description

We used the boxes method to characterize our samples. The sample was mounted on the box, in such a way to avoid any possibility of light leakage emitted to the internal face of the sample. Sample face not subjected to radiation is connected to a thermocouple with a computer read where readings graph could be appreciated (Figure 4). An excel spreadsheet give the Parker and Degiovanni model. The same spreadsheet processed with Levemberg Marquard algorithm [1] gives the complete model.

We start the console, ensuring that the enclosure temperature is greater or equal to 5°C.

Figure:



4. ***Thermal diffusivity measurement apparatus***

Parker's Model

This model neglects the thermal losses on the sides. Diffusivity is calculated from the time $t_{1/2}$ required for the temperature measured at the non-expose face to radiation. It corresponds to half of the maximum temperature reached t_{max} [5].

Let T(x,t), an expression of the temperature in a medium thickness "e" and diffusivity "a", and T(x, 0), an initial temperature distribution, we have [6]:

$$T(x,t) = \frac{2}{e}\sum \exp[-(\frac{n\pi}{e})^2 at] \cos\frac{n\pi x}{e}\int_0^\infty T(x,0)\cos\frac{n\pi x}{e}dx + \int_0^\infty T(x,0)dx \quad (4)$$

On the erradiated face [7] :

$$T(e\,,t) = \frac{q}{\rho.C.e}[1 + 2\sum_{n=1}^{\infty}(-1)^n \exp(^{-n\pi}/_e)^2\ at] \quad (5)$$

For values of high time:

$$T(e\,,t) = \frac{q}{2(\rho.C.e)} \quad (6)$$

and

$$a = \frac{\ln(4)e^2}{\pi^2 t_{1/2}} \quad (7)$$

q = density of absorptive energy ($J.\ m^{-2}$)

The formula of PARKER [8]:

$$a = 0{,}139\ \frac{e^2}{t_{1/2}} \quad (8)$$

The Model of Degiovanni

Takes into account the heat losses; small flash duration. Degiovanni formula is given by the average of the three following formulas:

$$a_1 = \frac{e^2}{t_{5/6}{}^2}\left[1{,}15\ t_{5/6} - 1{,}25 t_{2/3}\right] \quad (9)$$

$$a_2 = \frac{e^2}{t_{5/6}{}^2}\left[0{,}761\ t_{5/6} - 0{,}926 t_{1/3}\right] \quad (10)$$

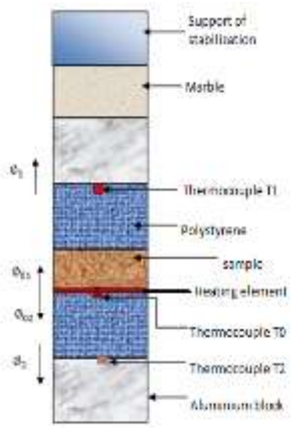
$$a_3 = \frac{e^2}{t_{5/6}{}^2}\left[0{,}617\ t_{5/6} - 0{,}862 t_{1/3}\right] \quad (11)$$

DETERMINATION OF THE THERMAL EFFUSIVITY

Experiment Description

The asymmetrical mounting of the hot plane (Figures 5 and 6) help to determine the effusivity E, the thermal capacity ρc, the contact resistance Rc and the thermal capacity of the heating element C_h to obtain an experimental program, with the Levemberg Marquard algorithm [1]. This method minimizes the error between the experimental and the theoretical curve [9].

Figure:



5. schema of the experimental transient hot plate device.

Figure:

6. view of the hot plate

$$\begin{bmatrix}\theta\\ \Phi_{01}\end{bmatrix} = \begin{bmatrix}1 & 0\\ C_h & 1\end{bmatrix}\begin{bmatrix}1 & R_c\\ 0 & 1\end{bmatrix}\begin{bmatrix}A & B\\ C & D\end{bmatrix}\begin{bmatrix}A_i & B_i\\ C_i & D_i\end{bmatrix}\begin{bmatrix}0\\ \Phi_1\end{bmatrix} = \begin{bmatrix}A_1 & B_1\\ C_1 & D_1\end{bmatrix}\begin{bmatrix}0\\ \Phi_1\end{bmatrix} \quad (12)$$

$$\begin{bmatrix}\theta\\ \Phi_{02}\end{bmatrix} = \begin{bmatrix}A_i & B_i\\ C_i & D_i\end{bmatrix}\begin{bmatrix}0\\ \Phi_2\end{bmatrix} \quad (13)$$

$$\Phi_2 = \frac{\emptyset}{p} = \Phi_{01} + \Phi_{02} \quad (14)$$

C_h is the thermal capacity of the heating element per unit area; $C_h = P_h\ c_h e_h$. p is Laplace parameter. Rc is contact resistance between the heating foil and the sample.

$$A = D = \cos\left(\frac{\rho c}{E} e\sqrt{p}\right)\ ;\ B = \frac{\sin h\left(\frac{\rho c}{E} e\sqrt{p}\right)}{E\sqrt{p}}\ ;$$

$$C = E\sqrt{p}\sin h\left(\frac{\rho c}{E} e\sqrt{p}\right) \quad (15)$$

$$A_i = D_i = \cos h\left(\sqrt{\frac{p}{a_i}} e_i\right)\ ;$$

$$B = \frac{\sin h(\sqrt{\frac{p}{a_i}}e_i)}{\lambda_i\sqrt{\frac{p}{a_i}}}\ ; C = \lambda_i\sqrt{\frac{p}{a_i}}\ \sin h(\sqrt{\frac{p}{a_i}}e_i) \qquad (16)$$

Where:

e is the thickness of the sample;
e_i , the thickness of the polystyrene;
λ_i , the polystyrene thermal conductivity;
a_i , the polystyrene thermal diffusivity.
Combining these equations, we obtain:

$$\theta(p) = \frac{\Phi_2(p)}{\frac{D_1}{B_1} - \frac{D_i}{B_i}} \qquad (17)$$

The method principle is to estimate the parameters E, (ρc), R_c et C_h. The inverse Laplace transformation is performed by De Hoog algorithm [10]
This allows to reduce at minimum the quadratic sum error Ψ between theoretical and experimental curves, calculated using the Levemberg-Marquard algorithm.

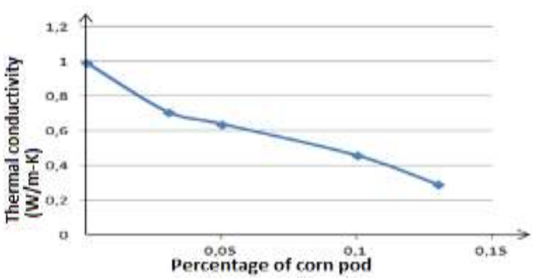
$$\Psi = \sum_{j=o}^{N} [T_{exp}(t_j) - T_{mod}(t_j)]^2 \qquad (18)$$

RESULTS

Thermal conductivity

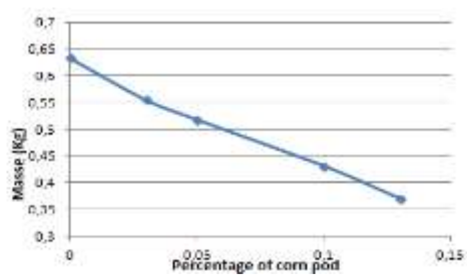
The thermal conductivity decreases with the percentage of pod corn and sample mass (Figures 7 and 8). The greater pod corn percentage is, the lighter becomes the sample. Therefore the sample is less compact and its heat resistance decreases.

Figure:



7. Thermal conductivity as a function of the corn pod percentage.

Figure:

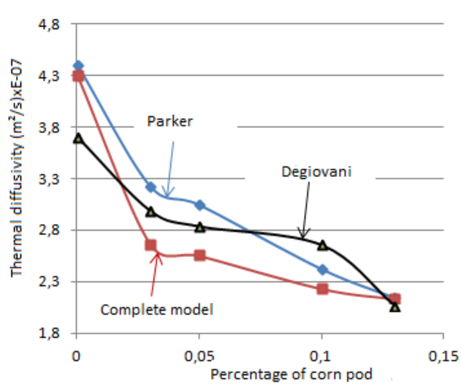


8. thermal conductivity as a Function of the mass

Thermal Diffusivity

From the above, we used the three models (Parker, Degiovanni and complete Model) [5] to build these curves (Figure 9):

Figure:



9. Thermal diffusivity as a function of con pod percentage.

These three curves show that thermal diffusivity a decrease function of pod corn percentage.

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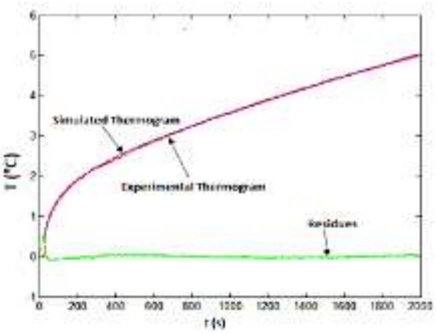
It is noted that heat propagation speed decreases inside the sample.

Thermal effusivity

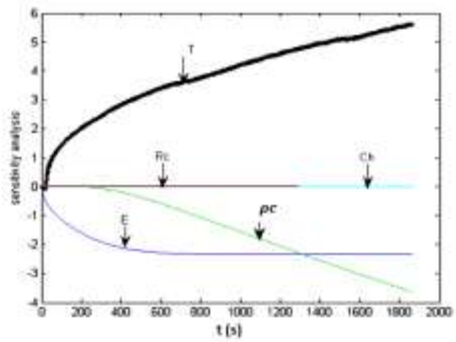
The Lavemberg Marquard algorithm is used to identify the following parameters: the effusivity E, the product ρc, the thermal contact resistance Rc, and thermal capacity C_h to obtain an experimental program. With this method there is an error between the experimental curve and the theoretical curve [3, 9]. Thermal effusivity is therefore deduced from the curve (Figure 10):

Figure :



10. experimental and theoretical curves of the temperature as a function of time.

Figure:



11. time-evolution of the experimental and the simulated hot plate temperature curves

In this figure we see the times elapsing of the two thermograms. The residues are defined as the difference between the two curves.

At the beginning of the experiment (short periods),

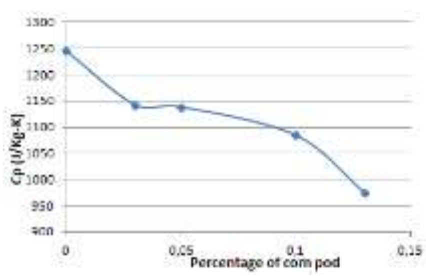
The thermograph is only sensitive to E parameter (Figure 11). After that, it becomes sensitive to ρc and its sensitivity E increases. While for Rc and C_h sensitivities is zero so these parameters have no influence on the thermograph. At t seconds E sensitivity curve reaches a certain value while ρc continues to increase; and other parameters remain constant. At a value of t between 1200s

and 1400s, the sensitivity of Rc stops at a point whose abscissa is the intersection of E and ρc. This means that the thermograph is quite sensitive to these two parameters [11].

SPECIFIC HEAT

From the formula of diffusivity $a = \frac{\lambda}{\rho Cp}$, we deduced the values of the specific heat C_p for different samples; this allowed us to see the decrease of heat stored in the samples function of the percentage of the wheat pod (figure 12).

Figure:



12. ***specific heat of the clay of Djamena***

CONCLUSION

The main objective of our study is the improvement of the thermal characteristics of a new ecological material used in Chad in traditional buildings with clay. We found that the pod wheat mixed with clay, has interesting thermal characteristics.

Building professionals to build a natural habitat, cheaper and environmentally friendly, could use our contribution.

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