

Original Research Article

New materials for insulation in rural construction

ABSTRACT

This work is part of development of local materials such as clay, laterite, lime, cement, and nere pod. These materials are abounding natural and renewable, they have thermal properties very interesting. Our objective is to study the nere pod, lime and cement on the thermal characteristics of clay and laterite based materials. For this reason we mix laterite, clay with different percentages of nere pod, lime and cement. Then we compare the properties thermo physical of this new material with those of clay only, or laterite only, to motivate the proposal to use this material as insulation in rural construction. This comparison of the energy performance of these materials will enable use to reduce that the new the new material is less effusif than clay or laterite only.

Keywords: Thermal insulation, asymmetric hot plan model, thermophysical properties, economy of energy, nere pod, decrement factor, time lag.

1. INTRODUCTION

The use of a composite material requires first of all knowledge of its thermo-physical ownership, especially if it is about a natural, lasting and environmental material. The objective of this job is to characterize ownership thermophysical by a new material based on laterite and clay mix with nere pod, lime and cement. In order to do that, we base principally on the method of the hot plan transitional (because this one allows to characterize the effusivity E), and also method of hot plan in regime permanent to determine thermal conductivity λ . Certain studies have already established and published on materials at the root of clay and alfa. Laaroussi and al [1] studied thermal properties of a sample prepared using mixtures of clay bricks. Also, Pierre Meukam [2] studied the mechanical and thermal characteristics of the bricks of earth stabilized with the aim of use in building. O. Bahloul and al [3] had as objective to determine the effect of fibers alfa on the mechanical and thermal resistance of mortar of cement. Imbga and al [4] had as objective to determine the thermal and mechanical performance of laterite blocks mixed with nere pod for the thermal insulation of buildings.

31 2. MATERIALS AND METHODS

32 2.1. Clay and laterite

33 In this study, we use clay from the region of karpala (Burkina Faso). The laterite we used
34 comes from a compagny located in the Gandigal region in sénégál. The diameter of its lower
35 than or equal 4mm. Atterberg limits and size of laterite studied were studied by Sekou Bodian
36 [5].

37 $W_p = 16.02\%$, $W_p = 16.02\%$ $W_p = 16.02\%$ and *The finess modulus is 2.476 .*

38 2.2. Nere pod

39 The nere pod are retained for reasons of availability and economy.

40 2.3. Preparation of samples

41 We preceded the preparation of samples on which will based our job. We prepared three
42 samples of the only clay or only laterite, have the same dimensions as the overs , to compare
43 the variation of thermophysical ownership some mixture, in function of the percentage of ,
44 nere pod, lime and cement with those of only clay or laterite. They are driedup to a constant
45 mass. Afterwards, we measure their dry masses, then we wrap them in plastic bags so that
46 they keep a content of uniform water almost zero. The measurements which we shall perform
47 will then be taken on these dry samples.

48 2.4. Theoretical approach of the measure of thermal effusivity and thermal 49 conductivity

50 2.4.1. Method of the hot plate centered in permanent permanent regime for 51 determination of thermal conductivity

52 The thermal conductivity was determined by method plate hot centerd in permanent regime
53 Y. Jannot and al [6]. This method is based on the measure of the temperature in the centre of
54 the heating element interposed between the sample and the foam of polyethylene , Fig.1
55 illustrates the fundamental schema of method, the sample of dimensions
56 $100\text{ mm} \times 100\text{ mm} \times 25\text{ mm}$ is put on a heating element of section $100 \pm 1\text{ mm} \times 100 \pm 1\text{ mm}$ and
57 a thickness $0.22 \pm 0.01\text{ mm}$ equal to that of the sample. The temperature evolution recorded
58 at every each 0.1s. The presence of the thermocouple does not increase the contact
59 resistance between the heating element and the polystyrene. Since polystyrene is an

insulating material, this thermal resistance will be marginal . The system is modeled with the unidirectional transfer hypothesis (1D). At the center of the heating element and the sample during the measurement . This hypothesis is checked with (3D) simulation using comsol and residues analysis : the difference between the temperature provided by the theoretical model $T_{\text{mod}}(t)$ and provided by the experience $T_{\text{exp}}(t)$. They put, under the heating element , an insulating foam of dimension $100\text{ mm} \times 100\text{ mm} \times 40\text{ mm}$. So that the majority of the flux of warmth, issued by the heating element , pass towards the sample to be characterized. The assembly sample, heating element and insulating foam is put between two dimensions $100\text{ mm} \times 100\text{ mm} \times 40\text{ mm}$. These last have as role, thanks to their big conductivity, to make attain the system towards thermal equilibrium as quickly as possible.

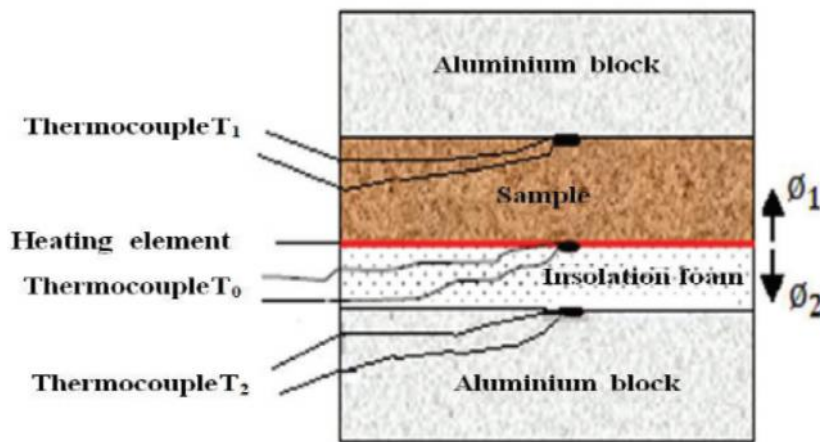


Fig.1. Experimental device of the Hot Plate method in steady state regime

One thermocouple is glued together on the centre of the lower face of heating up element to measure the temperature T_0 , other one to measure the temperature T_1 of the not heated face of the sample and the third to measure the temperature T_2 of the not heated face of the insulating foam. With this shape, we can write :

$$\Phi = \Phi_1 + \Phi_2 \quad , \quad \Phi_1 = \frac{\lambda_1}{e_1}(T_0 - T_1) ; \quad \Phi_2 = \frac{\lambda_2}{e_2}(T_0 - T_2)$$

(1)

Φ_1 the heat flux through the sample, Φ_2 the heat flux through the insulation foam. Φ the total flux emitted by the heating element. λ_1 the thermal conductivity of the sample as we

seek to determine, e_1 the thickness of the sample. λ_2 and e_2 are successively thermal conductivity and thickness of the insulating foam. But the heating element is an electrical resistance R dissipating heat flux by Joule effect when it is crossed by an electric current I under the effect of voltage U so :

$$\Phi = \frac{U^2}{R.S} \quad (2)$$

Combining equation 1 and 2 We have :

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

Equation 3 allows us to determine the thermal conductivity of the sample once the system reaches the steady state regime.

2.4.2. The method of Hot plate in transitional regime to measure the thermal effusivity

The thermal effusivity is measured by using the method of transitional hot plate [7]. We used here the recent asymmetrical experimental implement (represented on the fig. 2). An element of heating plan having the section of $100 \pm 1 \text{ mm} \times 100 \pm 1 \text{ mm}$ is put under the sample. One thermocouple of type K with two sons accomplished with a 0.005 mm diameter is glued together on the lower face of heating element. This arrangement is disposed two extruded polystyrene blocks having a thickness of 40 mm fixed between two aluminum blocks with a thickness of 40 mm.

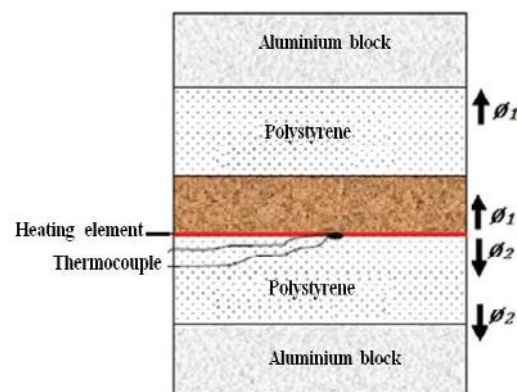


Fig. 2. Schema of the experimental Plate

The flux of warmth is sent to the heating element and the transitional temperature $T(t)$ are recorded. Since the thermocouple is in contact with polystyrene that is a deformable material, the presence of the thermocouple does not increase their thermal contact resistance between the heating element and the polystyrene. Furthermore, since polystyrene is an insulating material, this thermal resistance will be neglected. The system is modeled with the hypothesis that the heat transfer remains unidirectional (1D) at the center of the sample during the experiment. Considering the very low value of the heat flux reaching the aluminum blocks through the polystyrene and high thermal capacity, their temperatures are supposed equal and constant.

Within these hypotheses one can write :

Using the temperature of the side before the sample $T_1(t)$:

$$\begin{bmatrix} \theta_1 \\ \Phi_{01} \end{bmatrix} = \begin{bmatrix} 1 & 0 \\ C_s p & 1 \end{bmatrix} \begin{bmatrix} 1 & Rc_1 \\ 0 & 1 \end{bmatrix} \begin{bmatrix} A_e & B_e \\ C_e & D_e \end{bmatrix} \begin{bmatrix} A_i & B_i \\ C_i & D_i \end{bmatrix} \begin{bmatrix} 0 \\ \Phi_1' \end{bmatrix} = \begin{bmatrix} A & B \\ C & D \end{bmatrix} \begin{bmatrix} 0 \\ \Phi_1 \end{bmatrix} \quad (4)$$

$$C_s = \rho_s c_s e_s$$

$$\begin{bmatrix} A_e & B_e \\ C_e & D_e \end{bmatrix} = \begin{bmatrix} ch(qe) & \frac{sh(qe)}{\lambda q S} \\ \lambda q S sh(qe) & ch(qe) \end{bmatrix}$$

$$\begin{bmatrix} A_i & B_i \\ C_i & D_i \end{bmatrix} = \begin{bmatrix} ch(q_i e_i) & \frac{sh(q_i e_i)}{\lambda q_i S} \\ \lambda q_i S sh(q_i e_i) & ch(q_i e_i) \end{bmatrix}$$

$$q = \sqrt{\frac{p}{a}} \quad \text{et} \quad q_i = \sqrt{\frac{p}{a_i}}$$

$$\text{Concerning the (polystyrene) insulator, we have } \begin{bmatrix} \theta_1 \\ \Phi_{02} \end{bmatrix} = \begin{bmatrix} A_i & B_i \\ C_i & D_i \end{bmatrix} \begin{bmatrix} 0 \\ \Phi_2 \end{bmatrix} \quad (5)$$

$$\text{With} \quad \Phi_0 = \Phi_{01} + \Phi_{02} = \frac{\varphi_0}{p}$$

(6)

θ is the Laplace transform of the temperature $T(t)$, Φ_{01} the Laplace transform of the heat flux density living the the heating element (upstream), Φ_{02} the Laplace transform of the heat flux density living the heating element (downstream), Φ_0 the Laplace transform of the total heat flux density produced in the heating element. θ the heat flux density produced in the

heating element, C_s the thermal capacity of the heating element per area unit. R_c the thermal contact resistance between the heating element and the sample, Φ_1 , Laplace transform of heat flux density input on the upper aluminum block, Φ_2 is the Laplace transform of heat flux density input on the lower density aluminum block.

λ_i the polystyrene thermal conductivity, a_i and a are successively the thermal diffusivity of polystyrene and sample. e_i and e are successively the thickness of polystyrene and sample.

Combining equation 4 and 5, the system leads to :

$$\theta(p) = \frac{\Phi_0(p)}{\frac{D}{B} + \frac{D_i}{B_i}} \quad (6)$$

The principle of the method is to determine the value of the effusivity E , the thermal conductivity λ of the sample and the contact resistance R_c that minimize the Mean Squared

$$\text{Error of the sum } \psi = \sum_{j=0}^N \left[\Delta T_{\exp(t_j)} - T_{\text{mod}(t_j)} \right]^2 \quad (9) \text{ between the theoretical curve}$$

$T_{c\text{mod}(t)} = T_{c\text{mod}}(0, t)$ and the experimental curve $\Delta T_{c\text{exp}} = T_{c\text{exp}}(0, t) - T_{c\text{exp}}(e, t)$ in the Levenberg-Marquardt-like algorithm program [8].

3. RESULTS AND DISCUSSION

The application of this method in samples allowed to characterize their thermophysical properties in function of the percentage of nere pod, lime and cement.

Table 1: Thermophysical properties of laterite plus the different pod of Nere

material	$\lambda (W / m.K)$	$\frac{\Delta \lambda}{\lambda} \%$	$E (J / m.K.S^{1/2})$	$\frac{\Delta E}{E} (\%)$
LS	0.750	±0.121	1277.561	±0.027
LG4%	0.603	±0.226	1160.735	±0.017
LG8%	0.552	±0.175	1082.955	±0.053
LG12%	0.483	±0.240	1056.508	±0.013
LG14%	0.428	±0.113	1005.946	±0.016
LG16%	0.427	±0.118	975.141	±0.019

Table 1 shows that the thermal conductivity of laterite decreases as the néré pod level increases. It is reduced when Nere's pod is added to the laterite and if Nere's pod is added to

the laterite. It can be seen that the thermal effusivity also decreases as the néré pod rate increases in the laterite. It is reduced when we add 8% and 23.67 % of néré pod.

Table 2. Thermal properties of Karpala clay stabilized with cement and Nere's pod

Material	$E(J/m^2.K.s^{1/2})$	$\frac{\Delta E}{E}(\%)$	$\lambda(W/mK)$	$\frac{\Delta \lambda}{\lambda}(\%)$	$\rho c(KJ/m^3.K)$	$\frac{\Delta \rho c}{\rho c}(\%)$
Clay	1269.447	±0.183	0.814	±0.173	1985.900	±0.539
Clay96%C4%	1125.987	±0.018	0.572	±0.165	2225.730	±0.201
Clay92%G4%C4%	1069.651	±0.068	0.544	±0.129	2104.479	±0.265
Clay88%G8%C4%	985.146	±1.930	0.443	±0.434	2194.722	±4.294

Table 2 indicates that thermal effusivity and thermal conductivity decrease as the clump rate increases in the clay. Thermal effusivity decreases with the addition of cement and clay seed in the clay and when cement and clay seed are added to the clay. However, the volume heat capacity increases when the rate of néré pod increases in the clay.

Table 3. Thermophysical properties of laterite stabilized with cement, lime and néré pod

Material	$\lambda(W/mK)$	$\frac{\Delta \lambda}{\lambda}(\%)$	$\rho c(KJ/m^3.K)$	$\frac{\Delta (\rho c \%)}{\rho c}$
La92%lime4%G4%	0.458	± 0.367	2079.561	± 0.399
La92%lime4%C4%	0.509	± 0.367	1871.197	± 0.399
La96%C4%	0.611	± 0.183	2605.126	± 0.219
LaG4%	0.603	±0.226	2234.337	± 0.260

The results in Table 3 indicate that the addition of the cement in the laterite-chalk mix increases the thermal conductivity compared to the addition of the pearl pod.

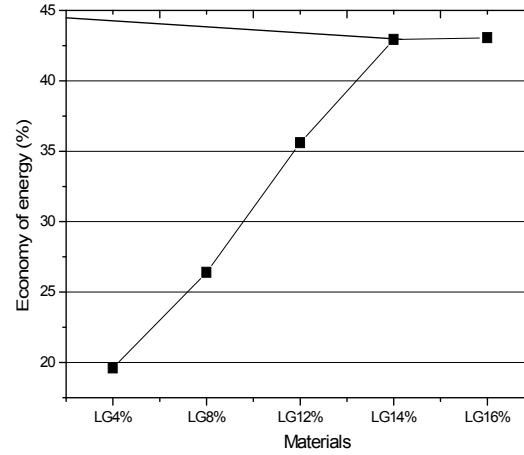
Consider two envelopes of the same habitat that are subjected to the same temperature gradient. We can write the following relation:

$$\frac{\Phi_{Laterite + x\% gn}}{\Phi_{Laterite}} = \frac{\lambda_{Laterite + x\% gn}}{\lambda_{Laterite}} \quad (7)$$

This relationship allows us to estimate energy saving by using composite materials by the relation the following relation

$$Es = 100 \left(1 - \frac{\lambda_{Laterite + x\% gn}}{\lambda_{Laterite}} \right) \quad (8)$$

161 $\lambda_{Laterite+x\%gn}$: Thermal conductivity of the laterite mix + a percentage of néré pod; Es :
 162 economy of energy.



163

164 **Fig. 3. Economy of energy depending on the nature of the building envelope**

165 A wall with a more insulating envelope saves more energy because the percentage of energy
 166 savings increases when the conductivity is low. The performance of the envelope is
 167 determined by the decrement factor f (equation 9) and the time lag φ_d (equation 10).

168
$$f = \frac{T_{mi}^{max} - T_{mi}^{min}}{T_{me}^{max} - T_{me}^{min}} \quad (9)$$

169
$$\varphi_d = t_{T_{mi}^{(max)}} - t_{T_{me}^{(max)}} \quad (10)$$

170 f : decrement factor ; T_{mi}^{max} : Maximum temperature of the interior wall (°C); T_{mi}^{min} : Minimum
 171 temperature of the interior wall (°C); T_{me}^{max} : Maximum temperature of the outside wall (°C);
 172 T_{me}^{min} : Minimum temperature of the outside wall (°C); φ_d : time lag (h); $t_{T_{mi}^{(max)}}$: Time when the
 173 temperature of the interior wall is maximum (h); $t_{T_{me}^{(max)}}$: Time when the temperature of the
 174 outside wall is maximum (h).

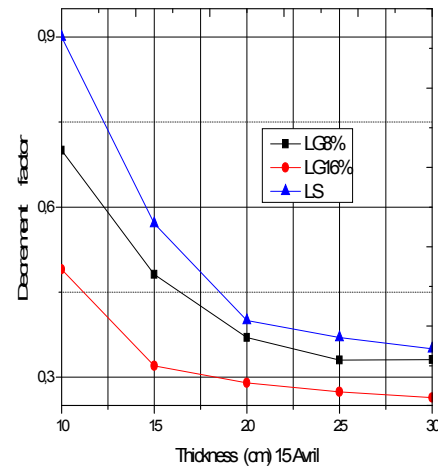
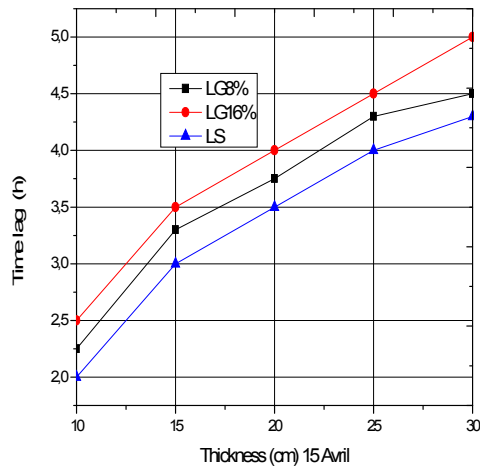


Fig. 5. Time lag according to the thickness

Fig. 4. Decrement factor according to the thickness

The decrement factors are calculated on the south wall (Fig. 5) because they have large variations on this part of the habitat. The decrement factor decreases with increasing thermal capacity and wall thickness, and increases with the thermal conductivity of the material. The time lag (Fig. 4) increases as the thermal capacity and wall thickness increase and the thermal conductivity decreases. B. Belhadj et al [8] carried out an experimental study also on the influence of cereal fibers on the thermal properties of concrete. The thermal results from this experimental study were used to simulate using the EnergyPlus software to determine the decrement factor and the time lag. Vincent SAMBOU [9] has shown that the thermophysical properties of the wall have important effects on the time lag and decrement factor of the thermal wave.

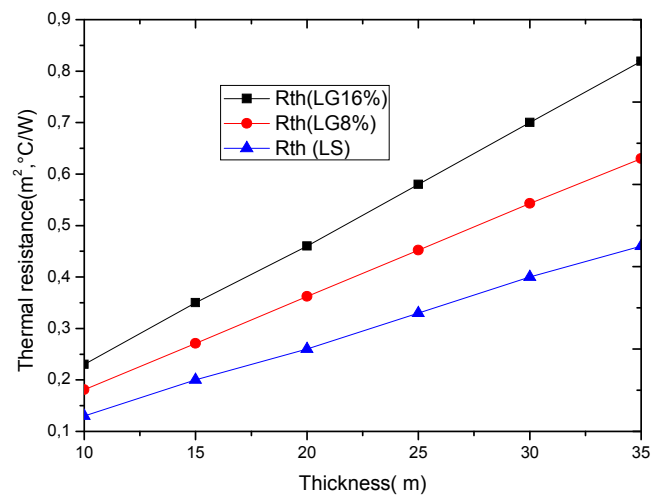


Fig. 6. Thermal resistance of stabilized materials with laterite and néré pod.

The performance of the insulation is also related to the thermal resistivity of the insulation. For a new building, the thickness of the insulation may vary depending on the type of material, the nature of the wall and the level of performance. The resistivity increases when the material is insulating, it also increases with the thickness of the wall. Reducing air infiltration in low-energy housing is an important lever for achieving energy performance.

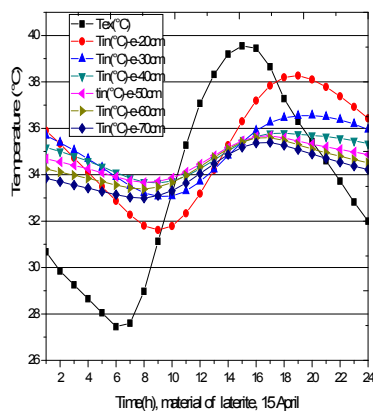


Fig. 7. Air temperature according to the thickness of the wall.

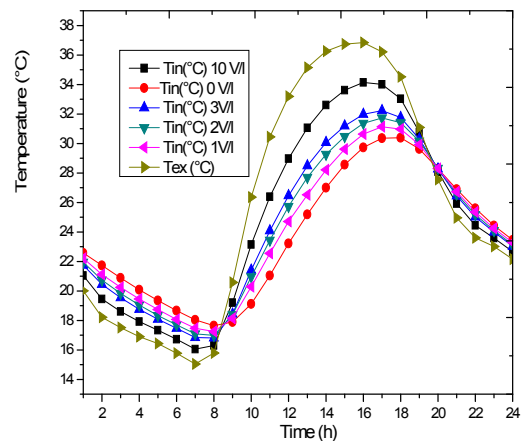


Fig. 8. Indoor air temperature according to the air infiltration rate

The same amount of heat uniformly distributed in the wall will cause in it a temperature that depends on its thickness and the thermophysical properties of the materials used for

construction (Fig. 7), plus a wall receiving a quantity of heat is thick minus its temperature internal rises, it rises all the less as the mass heat C is great. The flux density crossing the two media is proportional to the thermal effusivity. The rate of air infiltration increases the temperature of the air during the day and refreshes it at night (Fig. 8).

4. CONCLUSION

This paper presents the results of the thermophysical properties of local materials stabilized with lime, cement and néré pod by the asymmetric hot plane method. The results indicate that the thermal conductivity decreases when the néré pod level is high in the laterite. The thermal effusivity and the thermal conductivity of the mixture (clay plus cement) decrease when the rate of néré pod increases. The thermophysical results obtained were simulated under the EnergyPlus software, the results resulting from this simulation indicate that the thermal phase shift increases as the thermal conductivity decreases and the thickness of the wall increases. The decrement factor decreases when the thermal conductivity decreases and when the thickness of the wall is large. The indoor air temperature of a home is stable when the thermal time lag is high and the decrement factor is low.

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