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THE EFFECT OF NERE POD DECOCTION ON THE THERMOMECHANICAL PROPERTIES OF BALKUY CLAY

Tanga BAGA[1], Aboubacar ALI [1], B. Kossi IMBGA[1,2], Makinta BOUKAR [1]

[1] LAERT-LA2EI : Laboratoire d'Energétique, d'Electronique, d'Electrotechnique, d'Automatique et d'Informatique Industrielle, Université Abdou Moumouni BP:10896 , Niamey, Niger

[2] LAREME : Laboratoire de Recherche en Météorologie et l'Espace ; Université Norbert ZONGO, BP. 376 Koudougou –Burkina Faso

[3] LETRE : Laboratoire d'Energie Thermique Renouvelable, Unité de Formation en Sciences Exactes et Appliquées / U.F.R/ S.E.A./ UO/Ouagadougou /10 BP : 13495/ Ouaga10 Burkina Faso /Université de OUAGADOUGOU I, Joseph KI-ZERBO

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ABSTRACT

This article is devoted to the thermomechanical characterization of clay taken from the Balkuy area (Latitude: 12.30 North; Longitude: -1.47 West), a locality of south of Ouagadougou in Burkina Faso. Thermal characterizations were carried out on clay materials formulated from different concentrations (or decoction) of nere pod. The results obtained show an improvement in thermal conductivity of 31.25%, 36.87%, 46.87%, 65.93% and 73.12% respectively when the formulation is made with a concentration of 4g/l to 20g/l in 4g/l steps, respectively. The diffusivity increases by 35.25% for a clay formulated with a concentration of 16g/l corresponding to an optimum formulation. However, the density of the different formulations increases respectively by 2.64%, 16.05%, 17.34%, 18.25% and 18.85% when the clay is formulated with a concentration of 4g/l to 20g/l following an evolution step of 4g/l. Increasing the concentration of nere pods in clay improves compressive strength. The mechanical strength of clay mixed with water is 1.181 MPa. This strength is multiplied by 10.30 when the clay is mixed with a concentration of 8g/l, for a curing period of 28 days. This concentration of 8g/l of nere pod corresponds to an optimum level that improves compressive strength .

KEYWORDS: Hot plan; asymmetry; thermal conductivity, heat capacity, Nere pod, compressive strength, decoction/concentration.

1. INTRODUCTION

Earth is undoubtedly the world's oldest building material. Over 30% of the world's homes are made of earth. Whether raw, baked or reinforced with straw, or even stabilized in some other way, the variety of earthen architecture has abounded throughout the world since the dawn of man. [1]. Clay and sandy raw earth bricks are molded into a paste using water, then dried in the sun or in the open air. These blocks are assembled with a mud mortar made from the same clay. The compressive strength of materials is a property used in building design. The thermal resistance of a material gives it a certain insulating power depending on its thickness; in particular, this resistance is inversely proportional to the thermal conductivity coefficient. The main aim of this article is to improve the thermo-physical properties of clay by formulating it with different concentrations of a decoction of nere pods. The thermo-physical properties of clay will be studied as a function of the concentration of nere pods present in the solution used to make the materials. Nere pods are very rich in cellulose. In addition, clay and nere are abundant in rural areas.

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2. MATERIALS AND METHODS

2.1 Materials

1.6.1 Clay

Clay minerals are made up of silicon, aluminum and OH^- ions, organised in layers, two types depending on whether the oxygens or hydroxyls are associated in tetrahedral or octahedral. The layers of tetrahedrons are dominated by Si^{4+} *and* OH^-. Octahedral layers are dominated either by Al^{3+} (di-octahedral layers, two atoms are sufficient to occupy the six vertex sites of the octahedron) and OH^-, or by Mg^+ (trioctahedral layers, three magnesium atoms are needed to balance the charges of the octahedral) The layers of octahedral and tetrahedral are joined together along the plane, by pooling O and OH hence the sheet structure separated by inter-leaf space [2] [3]. The geotechnical properties were estimated by Imbga [4] et al , where W_P is 26.6% ; W_L is 52% and finally I_p is 26.4%

The clay was collected from a production site for banco bricks (Adobes) in the Balkuy locality situated south of the city of Ouagadougou. Nere pods come from Parkia Biglobosa (Nere) in the Ziou department, Nahouri province of Burkina Faso. The different masses of nere pods are: 0g; 4g; 8g; 12g; 16g and finally 20g. They were then placed in a 1-liter bottle of water, and the whole set left in the laboratory for 7 days before the solution was used to make the various bricks

a) Formulation of materials

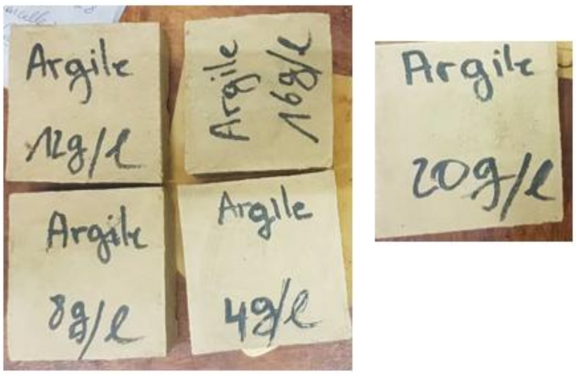

Figure1: formulation of materials

b) decoction of nere pods

Figure 2 : different decoctions of nere pods

1.6.2 Chemical composition of Clay and nere pods

The chemical composition of nere pods and clay was determined by laboratory analysis group from Dakar (GLA) at Cheik Anta Diop University.

Table1 : chemical composition of nere pods

Parameter	Loss at Fire	H2O	CaO	MgO	Al2O3	F2O3	P2O5	MnO	SiO2	SO3	Na2O	K2O
%	89.57	4.1	1.70	1.52	00	00	00	0.27	1.02	1.0	0.10	0.5

Tableau 2 : Chemical composition of clay 21 (in %).

Parameter	SiO2	Al2O3	Fe2O3	MnO	MgO	CaO	Na2O	K2O	TiO2	P2O5
%	60.2	22.3	7.12	< L.D.	1.69	0.19	0.16	1.5	1.06	0.20

Thermal-physical characterization method

Method of determination of thermal conductivity

Thermal conductivity was measured using the steady-state asymmetric hot-plane method. This method is based on measuring the temperature evolution at the center of the heating element placed between the sample and a polystyrene insulator. Figures 3 and 4 show the experimental models for steady-state measurement (conductivity measurement) and transient measurement (effusivity measurement), respectively. The sample measuring 100 mm*100 mm*25 mm is placed on the heating element measuring 100±1mm*100±1mm and 0.22 ±0.01mn of thickness. The heating element and sample have the same surface area.

The uncertainty in the heating device area is thus around 2% , add the uncertainty to the sample thickness estimated at 1% , and to the heat flux produced in the heating device estimated at 0.5%. The sum of these uncertainties leads to an overall uncertainty rate of 3.5% to which must be added the estimation error due to noise measurement on ΔT and the errors due to phenomena that have not been taken into account in the model.
Most of the heat dissipated into the heating device which electric resistance Re =40 Ω . The temperature evolution T(t) is recorded at every each 0.1s by a K-type thermocouple. The presence of the thermocouple does not increase the contact resistance between the heating element and the polystyrene as it is a deformable material. 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 the COMSOL and residues analysis: the difference between the temperature provided by the theoretical model $T_{\text{mod}}(t)$ and that provided by the experience $T_{\text{exp}}(t)$, to determine the time $t_{\max}$ at which the unidirectional hypothesis (1D) is checked. The polystyrene foam is placed on the lower surface of the heating element, allowing the majority of the flow to pass through the sample placed on the upper surface of the sample. The heating element, sample and polystyrene foam assembly is inserted between two (02) aluminum blocks of dimensions $100\,mm \times 100\,mm \times 40\,mm$.

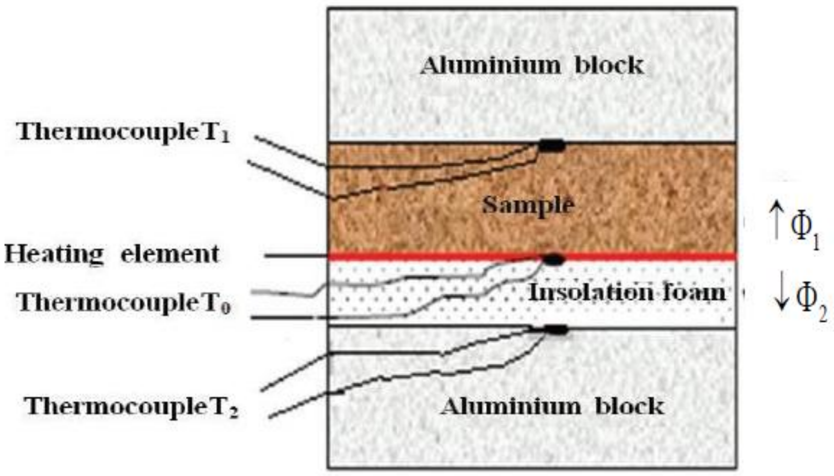

Figure 1: Asymmetrical hot-plane method steady-state experimental set-up

A first thermocouple is inserted on the underside in the center of the heating element, and measures the evolution of temperature T_0.

A second thermocouple T_1 is placed on the top of the sample. A third thermocouple T_2 is placed on the underside of the polystyrene located on the underside of the heating element. Taking all these assumptions into account, we can write

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$$\Phi = \Phi_1 + \Phi_2 \qquad (01)$$

$$\Phi_1 = \frac{\lambda_1}{e_1}(T_0 - T_1) \; ; \quad \Phi_2 = \frac{\lambda_2}{e_2}(T_0 - T_2) \qquad (02)$$

Φ_1 : is the flux through the sample placed on the top of the heating element

Φ_2 : is the heat flow through the polystyrene on the underside of the heating element.

Φ : is the total flux emitted by the heating element.

λ_1 : is the thermal conductivity of the sample as we seek to determine

e_1 : is the thickness of the sample

λ_2 and e_2 are successively thermal conductivity and thickness of the thermal insulation. The heating plate is an electrical resistance R dissipating heat flux by Joule effect when it is crossed by an electric current (I) under of voltage (U), so $\Phi = \frac{U^2}{R.S}$ (03).

Combining equations (01), (02) and (03)

We can write: $$\lambda_1 = \frac{e_1}{T_0 - T_1}\left[\frac{U^2}{R.S} - \frac{\lambda_2}{e_2}(T_0 - T_2)\right] \qquad (04)$$

Equation (4) allows determining the thermal conductivity when the system reaches the steady state regime.

Determination of thermal effusivity by the hot plane method in transient regime

Thermal effusivity is determined using the hot plane method in transient regime. We use the asymmetric experimental device (represented on the Figure 4). An element of a heating plan having the section of 100 ± 1mn* 100 ±1 mm is put under the sample. One thermocouple of type K made with two wires of a 0.005 mm diameter is glued together on the lower face of the heating element. This arrangement is placed between two thermal insulation in polystyrene having a thickness of 40 mm fixed between two aluminium plate with a thickness of 40 mm

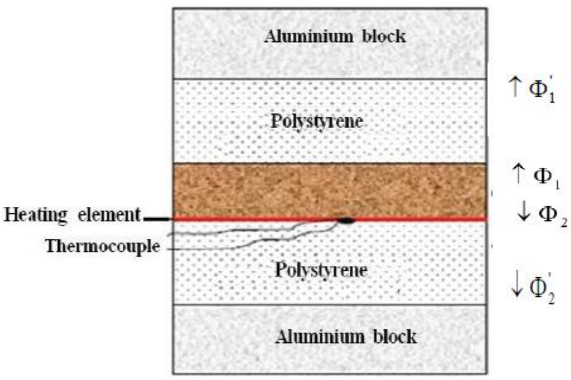

Figure 2 : Transient asymmetrical hot plane device

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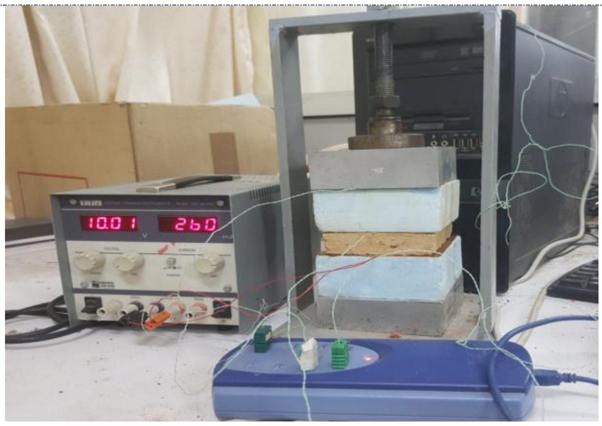

Figure 3 : Photo of experimental set-up

Figure 5 above shows the experimental set-up we used. The heat flux sent by the heating plate and the transitional temperature T (t) are recorded every 0,1s. It is assumed that the thermocouple in contact with the insulation does not increase the thermal contact resistance between plate and polystyrene, this thermal resistance is neglected. The system is modelled using the unidirectional heat transfer assumption (1D) at the centre of the sample Given the very low value of the heat flow reaching the aluminum blocks through the polystyrene and their high capacity, the temperature is assumed to be equal and constant. By applying the quadrupole formalism [5] , on the device shown in Figure 4, and by using the temperature of the side before the sample $T_1(t)$, taking these assumptions into account, we can write the following equations:

$$\begin{bmatrix}\theta_1\\ \Phi_1\end{bmatrix}=\begin{bmatrix}1 & 0\\ C_s p & 1\end{bmatrix}\begin{bmatrix}1 & Rc_1\\ 0 & 1\end{bmatrix}\begin{bmatrix}A_e & B_e\\ C_e & D_e\end{bmatrix}\begin{bmatrix}A_i & B_i\\ C_i & D_i\end{bmatrix}\begin{bmatrix}0\\ \Phi_1^{'}\end{bmatrix}=\begin{bmatrix}A & B\\ C & D\end{bmatrix}\begin{bmatrix}0\\ \Phi_1^{'}\end{bmatrix} \quad (05)$$

$$C_s = \rho_s c_s e_s$$

$$\begin{bmatrix}A_e & B_e\\ C_e & D_e\end{bmatrix}=\begin{bmatrix}ch(qe) & \dfrac{sh(qe)}{\lambda qS}\\ \lambda qS\, sh(qe) & ch(qe)\end{bmatrix},\begin{bmatrix}A_i & B_i\\ C_i & D_i\end{bmatrix}=\begin{bmatrix}ch(q_ie_i) & \dfrac{sh(q_ie_i)}{\lambda q_iS}\\ \lambda q_iS\, sh(q_ie_i) & ch(q_ie_i)\end{bmatrix} \quad \text{with} \quad q=\sqrt{\frac{p}{a}} \quad et \quad q_i=\sqrt{\frac{p}{a_i}}$$

Formula (5) leads to formula (06) by replacing the elements of the matrix by their expressions:

$$\begin{bmatrix}\theta_1\\ \Phi_1\end{bmatrix}=\begin{bmatrix}1 & 0\\ C_s p & 1\end{bmatrix}\begin{bmatrix}1 & Rc_1\\ 0 & 1\end{bmatrix}\begin{bmatrix}ch(qe) & \dfrac{sh(qe)}{\lambda qS}\\ \lambda qS\, sh(qe) & ch(qe)\end{bmatrix}\begin{bmatrix}ch(q_ie_i) & \dfrac{sh(q_ie_i)}{\lambda q_iS}\\ \lambda q_iS\, sh(q_ie_i) & ch(q_ie_i)\end{bmatrix}\begin{bmatrix}0\\ \Phi_1^{'}\end{bmatrix}=\begin{bmatrix}A & B\\ C & D\end{bmatrix}\begin{bmatrix}0\\ \Phi_1^{'}\end{bmatrix} \quad \textbf{(06)}$$

By developing the previous matrix product (01), then we get Φ_1 :

$$\Phi_1 = \theta_1 \frac{D}{B} \quad \textbf{(07).}$$

Concerning the (polystyrene) insulator, we have $\begin{bmatrix}\theta_1\\ \Phi_2\end{bmatrix}=\begin{bmatrix}A_i & B_i\\ C_i & D_i\end{bmatrix}\begin{bmatrix}0\\ \Phi_2^{'}\end{bmatrix}$ **(08)**

by developing the previous matrix product (08) , we have Φ_2:

$$\Phi_2 = \theta_1 \times \frac{D_i}{B_i} \quad (09)$$

The total flux emitted by the heating element is:

$$\Phi_0 = \Phi_1 + \Phi_2 = \frac{\varphi_0}{S} \quad .(10)$$

By replacing Φ_1 and Φ_2 with their expression. We get

$$\Phi_0 = \theta_1\left(\frac{D}{B}+\frac{D_i}{B_i}\right) \tag{11}$$

and then we draw the value of θ_1 using the relation:

$$\theta_1 = \frac{\phi_0}{p}\left(\frac{1}{\frac{D}{B}+\frac{D_i}{B_i}}\right) \tag{12}$$

With the inverse transformation of equation (11), we obtain the following relationship (12)

$$T_1(t) = L^{-1}\left(\frac{\phi_0}{p} * \frac{1}{\left(\frac{D}{B}+\frac{D_i}{B_i}\right)}\right) \tag{13}$$

During the entire time, when the hypothesis is assumed to be unidirectional (1D). The temperature at the center of the heating element becomes:

$$T_s(0,0,t) = \Phi\left[R_c - \frac{m_s c_s}{E^2 S^2}\right] + \frac{2\Phi\sqrt{t}}{ES\sqrt{\pi}} \tag{14}$$

the Laplace transform of formula (13) in long time gives formula (14)

$$\theta_s(0,0,p) = \frac{\Phi S}{2p}\frac{1+R_c ES\sqrt{P}}{m_s c_s p + [R_C m_s c_s p + 1]ES\sqrt{P}} \tag{15}$$

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 Error of the sum $\psi = \sum_{j=0}^{N}\left[\Delta T_{\exp(t_j)} - T_{\mathrm{mod}(t_j)}\right]^2$ (16) between the theoretical curve $T_{c\,\mathrm{mod}(t)} = T_{c\,\mathrm{mod}}(0,t)$ and the experimental curve $\Delta T_{c\exp} = T_{c\exp}(0,t) - T_{c\exp}(e,t)$ in the Levemberg-Marquardt-like algorithm program [6].

θ_1 : is the Laplace temperature transformed $T_1(t)$

Φ'_1 : is Laplace transformed of the heat flow from the probe toward the sample above.

Φ'_2 :is the Laplace transform of the flux density reaching the underside of the polystyrene in contact with the aluminum

Φ_0 is the sum of Laplace transformed of the total flux released by the probe to the sample (on top) and to the insulator (polystyrene) underneath.

C_s : is the heat capacity per unit area of the probe.

R_c : is the contact resistance between the sample and the probe

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λ_i : is the thermal conductivity of polystyrene

a_i et a : are respectively the thermal diffusivity of the polystyrene and the material

e_i et e are the thicknesses of the insulator and the sample respectively.

a_i is the thermal diffusivity of the polystyrene.

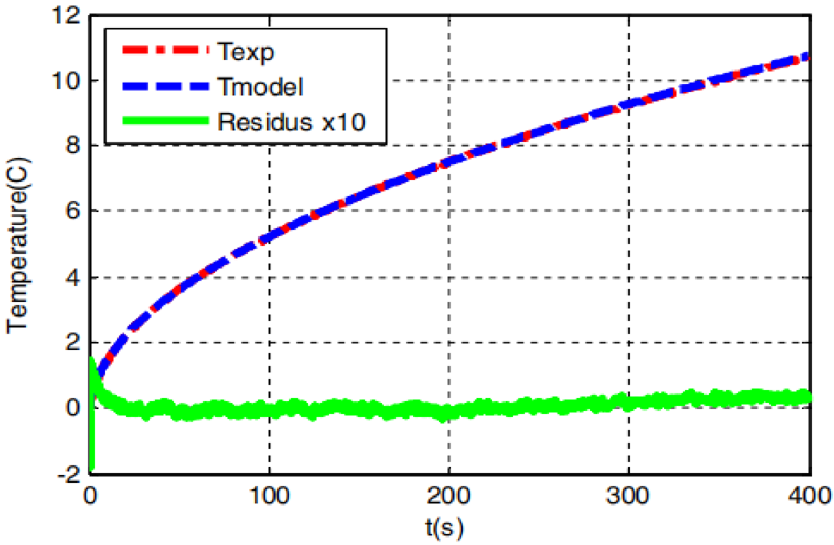

Figure 6: Theoretical, experimental and residual curves

Figure 6 shows that the residual is flat and centered on zero.
In other words, the “Tmodel (t)” curve in blue overlaps exactly with the “Texp (t)” curve in red. By this criterion, our measurement is correct.

Mechanical characterization of the different formulations

Compression and bending tests on specimens measuring 4x4x16 cm3 were carried out according to the EN 196 - 1 standard **[14]**

Figure 4 : Photo of specimens measuring 4*4*16 cm^3

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Figure 5: mechanical press for mechanical test

Figure 11 shows the 4*4*16 cm3 specimens we characterized, using the mechanical press shown in figure 12.

3. RESULTS AND DISCUSSION

The results and discussion may be combined into a common section or obtainable separately. They may also be broken into subsets with short, revealing captions.

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Thermal conductivity as a function of the concentration of nere pod in the mixture

Figure 7 shows the variation of thermal conductivity as a function of the concentration of the nere pod mixture

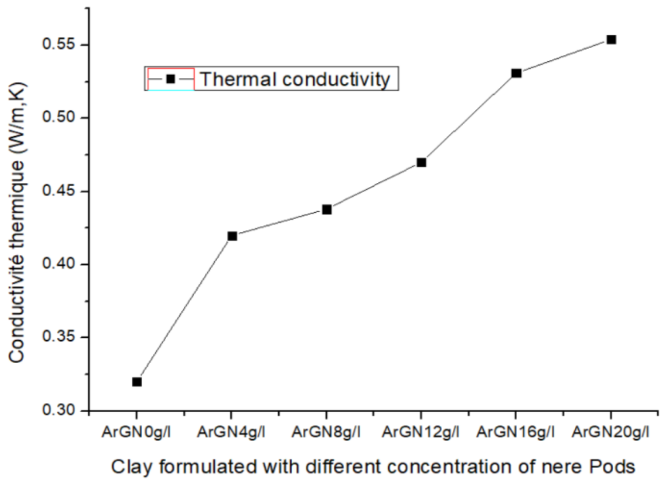

Figure 6 : Thermal conductivity of clay formulated with different concentrations of Nere pod

We find a thermal conductivity of 0.32 W/m.K for a clay brick made with simple water. This value is 8.12% less than the value found by **Laroussi [7]**, which is 0.35W/(m.K) . The thermal conductivity value increases respectively by 31.25%; 36.87%; 46.87%; 65.93% and finally 73.12% when the formulation is made with a respective concentration of 4 g/l; 8 g/l; 12 g/l; 16 g/l and then 20 g/l. Thus, the addition of nere pod decoction had the effect of increasing thermal conductivity.

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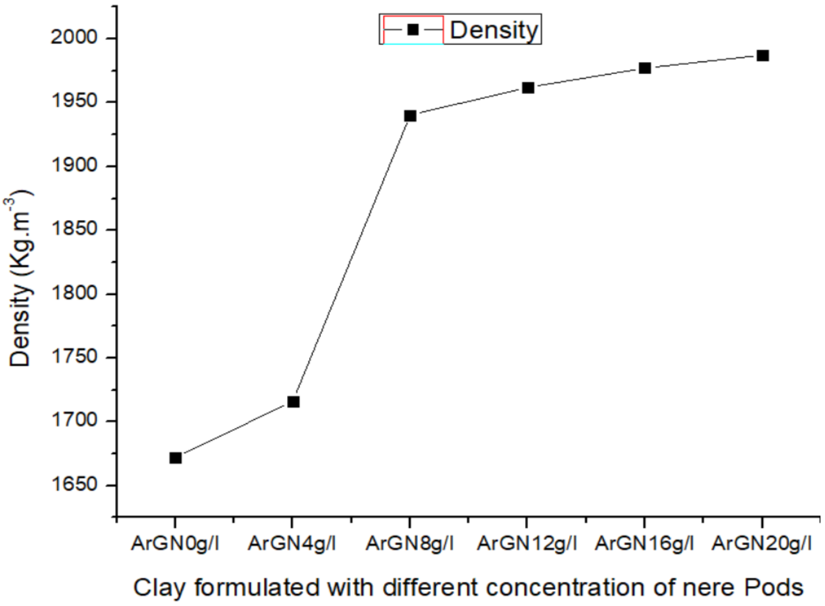

Figure 7: Evolution of the density as a function of the concentration of Nere pod in the clay

Figure 8 shows the increase in density of the material as a function of the concentration of nere pods. We find a density of 1671.981 kg.m-3 when the clay is formulated with water only. This value is 6.28% close to that found by **Lamrani [8]** which is 1565,308 kg.m-3. The density increases respectively by 2.64%; 16.05%; 17.34%; 18.25% and 18.85% when the clay is formulated with respective concentrations of 4 g/l; 8 g/l; 16 g/l and finally 20 g/l. We note that from the 12g/l formulation onwards, density evolves very rapidly, reaching a maximum at 16g/l and beginning to fall. According to **Sorgho et al [9]**, the increase in density is due to tannins, which help maintain a higher density of contacts between grains.

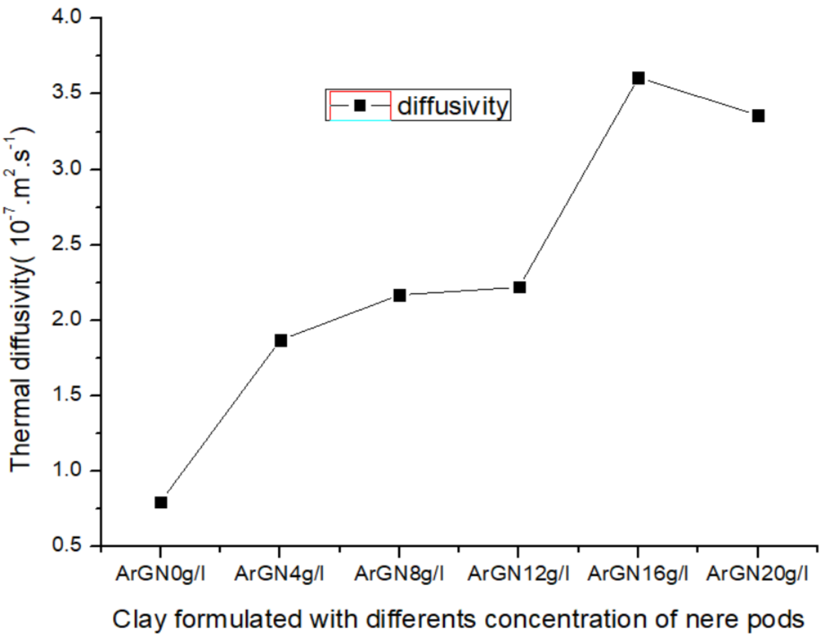

Figure 9: Variation in thermal diffusivity of different formulations.

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Thermal diffusivity indicates the rate at which heat diffuses through the material. The curve in figure 9 , shows that thermal diffusivity increases as a function of the concentration of nere pod decoction in the clay. Clay formulated with simple water has a thermal diffusivity of $8*10^{-8}$. m^2. s^{-1} . Clay formulated with a 16g/l concentration of nere pod decoction has a thermal diffusivity of 3.75 10-7.m^2. s^{-1} .This value, corresponding to the optimum value, it is 4.687 times higher than the initial value., The diffusivity decreases, above concentrations of 16g/l

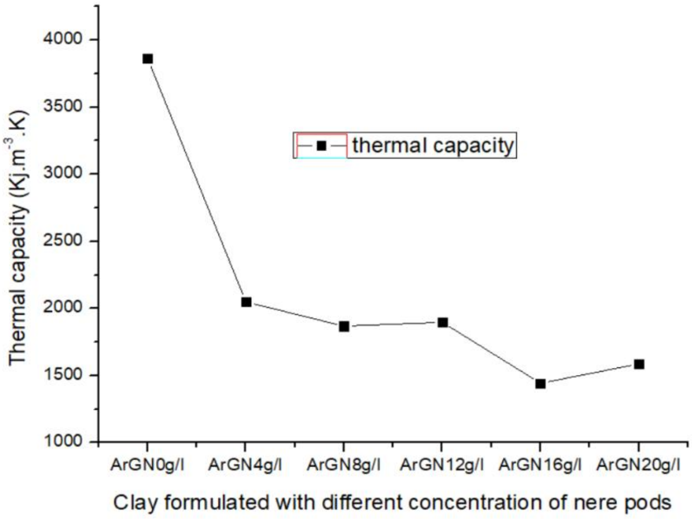

Figure 8 : Volumetric thermal capacity of different formulations

The volumetric thermal capacity is a very important parameter. It reflects the capacity of the material to store heat according to its volume. The volumetric thermal capacity of clay is 3863.5 KJ.m-3. K-1. This value drops by 47 % when the clay is formulated with a concentration of 4 g/l, and 58.93 % when it is formulated with a concentration of 20 g/l. This significant drop explains the reduction of thermal diffusivity of the clay formulated with a concentration of 20 g/l.

Interpretation of measurement results relative to thermal characteristics

We note that the thermal conductivity of simple clay is 0.32 W/m.K when the brick was made with simple water. It corresponds to that found by **IMBGA et al [10]** when the brick was made with water without any mixing. This thermal conductivity increases by 31.25%, 36.87%, 46.87%, 65.93% and 73.12% when the formulation is made with a decoction concentration of 4g/l, 8g/l, 12g/l, 16g/l and 20g/l respectively. The chemical elements of Nere pod and clay react to form chelations (pore clogging). This reaction reduces the porosity of the material, while increasing their conductivity and density. The material containing fewer pores has a very high conductivity, since the pores contain air. Air is a thermal insulator, since its conductivity is very low (0.026W/(m.K) at a temperature of 27°C).

Laaroussi et al [7] determined the thermal properties of clay taken from an industry called SLOUI in Morocco using the hot plane method. The thermal conductivity value found is 0.35 W/m.K. **Aurelie Michot et al [9-11]** determined the thermal conductivity and specific heat of Kaolin clay using the laser flash technique, the value of the thermal conductivity found is 0.3 W/m.K for a temperature below 1050 °C and this value increases as the temperature increases, it is worth 3.2 W/m.K when the temperature is 1400 °C. The thermal characteristics of a kaolinite clay stabilized with Nere pod for thermal insulation of building envelopes in the Sahelian zone were determined by **Imbga et al [12].** A rate of 4%, 8% and 12% by mass of Nere pod was added to the clay in order to observe its thermal behavior. The thermal properties of the Nere pod clay mixture were estimated using the hot plane method. The results show that the thermal properties of the clay evolve according to the rate of nere pod in the clay: effusivity is reduced by 11.3% if 4% of nere pod is added to the clay, and by 15.74% and 22.40% if 8% and 12% of nere pod is added to the clay respectively.

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The same applies to thermal conductivity, which is reduced by 29.73% when 4% of nere pod is added, and by 33.16% and 45.57% when 8% and 12% of nere pod is added to the clay, respectively. Laterite blocks combined at rates ranging from 0% to 16% following an evolution step of 4% of nere pod , indicate that the thermal conductivity of laterite without the addition of nere pod is 0.750 W / (m K). This value is reduced by 19.6% when 4% Nere pod is added and by 35.6% when 12% nere pod is added, but stabilizes at 14-16% with a corresponding value of 0.427 W /(m K) **Imbga et al [13]**.

Mechanical test results

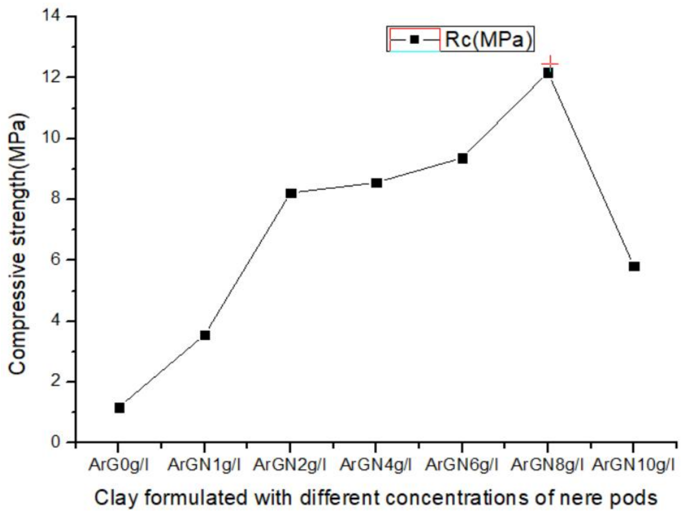

Figure 9 : Variation in mechanical strength as a function of the concentration of nere pods in clay.

Figure 13 shows the mechanical strengths of clay formulated with different concentrations of nere pods during 28 days of curing. We note that the mechanical strength increases as the concentration of nere pod in the clay increases. The mechanical strength of clay formulated with simple water is 1.181 MPa. This value was obtained by **Baga et al [15].** This value increases by a maximum of 10.30 times, when the clay is formulated with a concentration of 8g/l of nere pod in the clay for a 28-day curing period. However, the value is reduced by 52.26% for a concentration of 10g/l of nere pods in the clay. The maximum value is therefore that obtained with 8g/l of nere pods.

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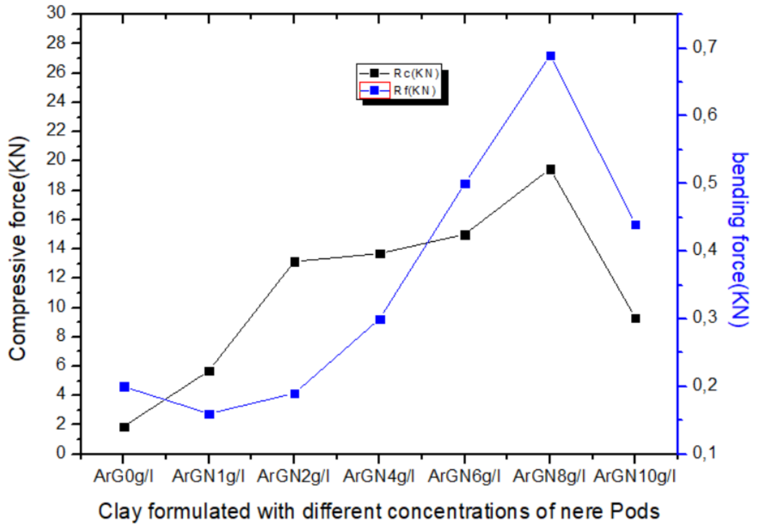

Figure 10 : Compressive and flexural strength of formulations as a function of the concentration of nere pods in clay.

Figure 14 shows the variations in compressive and flexural strength. Compressive and flexural strength increase as the nere pod decoction increases in the clay. The compressive strength that our clay specimens can withstand is 1.89 kN when the clay is formulated with water only. This value increases by 2.01; 6; 6.24; 6.93; 9.30 and finally 4 times the compressive strength when the clay is formulated with the following decoctions: 1g/l; 21g/l; 41g/l; 61g/l; 81g/l and 101g/l of nere pods in clay respectively. The optimum mechanical strength is obtained by a concentration of 8g/l. The mechanical strength obtained by **Sorgho et al [9]** on KORO clay materials, formulated with a 4g/l decoction of nere pods, indicates that Ce1 and Ce4 geo-materials formulated with water alone have a mechanical strength of 2.75 MPa and 1.44 MPa respectively. However, these values increase by 21.18% and 25% respectively when these geo-materials are formulated with a 4g/l decoction of nere pods.

4. CONCLUSION

In the context of sustainable development and environmental protection, we carried out a study on the effect of Nere pods decoction on the thermal properties of clay in order to improve thermal regulations in the building sector. The study focuses on the evolution of thermomechanical properties of clay formulated with different concentrations of nere pods decoction in clay. Thermomechanical characterization of different formulations was carried out using the hot plane method. The concentrations of 4g/l, 8g/l, 12g/l, 16g/l and 20g/l were used to increase thermal conductivities by 31.25%, 36.87%, 46.87%, 65.93% and 73.12% respectively. Thermal diffusivity increases progressively with the concentration of nere pods, reaching a maximum value of 1977.179 m2.s-1 corresponding to a concentration of 16g/l. Above this concentration, thermal diffusivity decreases. Thermal conductivity increases with the concentration of nere pods in the clay, so these formulations are not suitable for thermal insulation of the building envelope. As for mechanical strength, for a value of 1.181MPa found in the case of clay formulated with water without the addition of nere pod, this value increases 10.30 times when the clay is formulated with a concentration rate of 8 g/l of nere pod for a 28-day curing period. Nevertheless, we note that this value is reduced by 52.26% for a dosage rate of 10% nere pod in clay. The addition of nere pod to clay and laterite materials reduces thermal conductivity. However, formulating clay blocks with dwarf clove decoction improves the mechanical properties of clay matrices but degrades thermal properties (increased conductivity).

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