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RESEARCH ARTICLE

THERMAL AND MECHANICAL STUDY OF LATERITE STABILIZED WITH LIME FOR SUSTAINABLE BUILDING APPLICATIONS IN SAHEL COUNTRIES

[1]IMBGA B kossi, [2]SAMBOU Vincent, *,[3]KIENO P. Florent and [2]DIEYE Younouss

[1]Laboratoire d'Energies Thermiques, Renouvelables, Université de Ouagadougou. L.E.TRE/UO/ Ouagadougou /10 BP: 13495 Ouaga10, Burkina Faso
[2]Laboratoire d'Energétique Appliquée, Ecole Supérieure Polytechnique de DAKAR (ESP-UCAD) Sénégal. LEA/ESP/UCAD/Dakar Fann, BP 5085.
[3]Centre International de Formation et de Recherche en Energie Solaire / E S P/ UCAD/ BP 5085 Dakar Fann (Sénégal)

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ABSTRACT

In this work, we have determined the thermophysical parameters of various formulations with laterite and slaked lime. This shows that the thermal conductivity decreases when the lime rate is lower than 4% and increases when the rate is higher than 4%. The thermal conductivity was for a rate of 4%; it increases to 21.13% for 16% of lime used. We found that the compressive strength increases but very slowly. However, the increase in mechanical strength of the various formulations still remains lower than the strength of the laterite without lime. Lime has a significant impact on the thermal properties, but this impact on the mechanical properties is low, since the mechanical strength increases by 6.84% for rates of 12% and 16% of lime used.

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INTRODUCTION

Improving the comfort and reducing expenditures related to air conditioning and heating by low costs ecological sources of energy are now considered as a priority by both energy distributors and users. Lateritic soils largely exist in tropical and subtropical regions. They are used in road construction and buildings. The stabilization of clay and lateritic soils using lime remains a technique used worldwide to improve the performance of materials in buildings and road construction. When lime is added to clay soil, this produces the exchange of cations between the metal ions present on the surface areas of clay particles and lime calcium ions. This change in clay layers due to the exchange of ions leads to the change in the mixture of the electronic density (Bell, 1996). The work by Millogo *et al.,* 2012 shows that the same minerals react with lime in lateritic clay soils because both types of soil chemically have the same behavior when treated with lime. Research by Patrick *et al.,* 2011 indicate that the addition of quicklime in clay or lateritic soils reduces the quantity of clay, the plasticity index, the maximum dry density and increases the content in optimal humidity. The lateritic gravels, very rich in minerals, have good mechanical strength when they are stabilized with lime. Abu Sadique *et al.,* 2013 showed that soil compressive strengths treated with lime increase with the content of the lime and the long term maturing age. They showed that alluvial soil compressive strength stabilized at 15% and hardened during 16 weeks is 8.4 higher than the strength of a non-stabilized sample. The works by Attoh-okine *et al.,* 1995 show that the compressive strength of a stabilized soil is obtained by an optimal dosage and thereafter the compressive strength decreases with an additional 6% dosage rate. The compressive strengths obtained by Santasi in his samples in Florida, stabilized with lime are close to the values we found in our works. In this study, we propose to conduct a thermal and mechanical study of laterite blocks to which we have progressively added a gradual percentage rate of lime mass with the view to offer to the populations, appropriate construction

Corresponding author: **KIENO P. Florent,**
Centre International de Formation et de Recherche en Energie Solaire / E S P/ UCAD/ BP 5085 Dakar Fann (Sénégal)

materials which also ensure thermal insulation. Imbga *et al.,* 2014 showed that adding Cymbogogon Schoenantus Spreng fibers to adobe reduces the thermal conductivity in the building. The results show that the mechanical strength increases with fiber dosage rate in the solid matrix. Diatta Michel *et al.,* 2010 have stabilized Thiéki clay with lime. The results show that the maximum strength is 2.72 MPa and is obtained by adding 6% of lime mass in the clay. This value of the mechanical strength can provide safety to the building because it corresponds to the required value so that the material can be used in construction. The value obtained for the thermal conductivity is $0.42W(m.K)$. The results obtained enable to conclude that lime stabilizes the Thiéki clay and respects the mechanical and thermal requirements for a sustainable development framework. Raheem *et al.,* 2010 have stabilized laterite from Olomi, a Nigerian region, with a rate varies from 5% to 25%. They obtained a maximum value of 1.25MPa for 10% of lime used; this value is reduced by 8%, 15.2% and 24.8% for rates of 15%, 20% and 25% of lime mass used. These results show that lime does not change the mechanical strength of the laterite. They also observed the compressive strengths for 7 days of treatment. The maximum compressive strength is 0.60 MPa and is obtained for 10% lime rate. Recent works were carried out by Azakine *et al.,* 2014 on earth blocks stabilized with lime. The results of the thermal properties of the various formulations were measured using the hot wire method. They obtained $0.59W(m.K)$ for a 4% lime rate, $0.62W(m.K)$ for a rate of 8% and $0.68W(m.K)$ for a rate of 12% of lime used as stabilizer. The results of these researches are very close to those found with the method of asymmetric hot plan of the Applied Energy Laboratory of the Polytechnic School of Dakar (L.E.A) using the laterite stabilized with lime under various formulations.

MATERIALS AND METHODS

Geotechnical Study of the Laterite Studied

The laterite used was provided by a company located at Gandigal in Senegal (14.7°N ; 17° W). Its grains diameter is lower than or equal to 4mm. The Atterberg limits and the sieve size of this material were studied by Bodian (2011).

Wp=16.02% WL=33.07% Ip=17.05% The slimness module is 2.476

Here we here represent the result of the sieve size of the laterite studied.

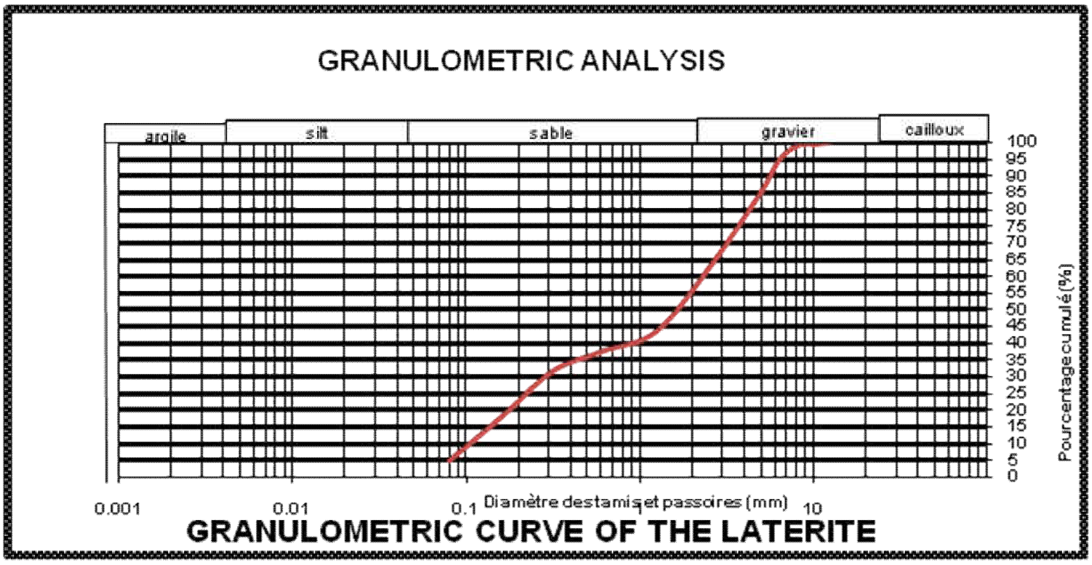

Figure 1. Sieve Size Analysis of the Laterite

Method and measuring the characteristics of thermal performances

Method

We used the asymmetric hot plan method available in the Applied Energy Laboratory of the Polytechnic School of Dakar, to study the thermal properties of laterite, to which we gradually added a rate of 4%, 8%, 12%, 14% and lastly 16% of the mass of lime clove in order to follow the evolution of the thermal properties of the composites. The different stabilizers were weighed using a precision acale of 0.1g. The dimensions of the bricks used for thermal tests are $10 \times 10 \times 2.5cm^3$. An experimental study of the effusivity and thermal conductivity was mainly conducted using the method of the asymmetric hot plan in a transitory regime. Figure 3 and 4 shows the asymmetric experimental device. The method is based on temperature measurement at the center of the heating device with a heated surface $100 \pm 1mm \times 100 \pm 1mm$ and a thickness $0.22 \pm 0.01mm$. The uncertainty in the heating device area is thus around 2%. We must 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.

Figure 2. Image of a laterite brick plus 14% of lime

Measurements of the Thermophysical Properties

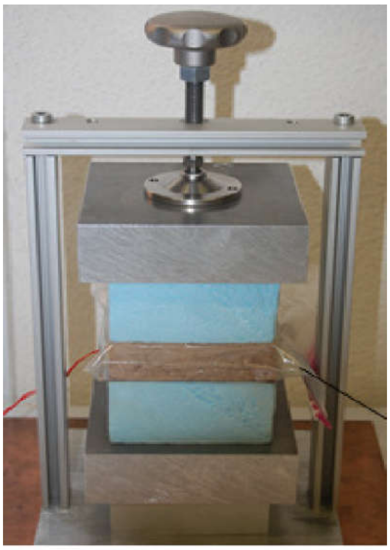

Figure 3. Asymmetric Hot Plan Model

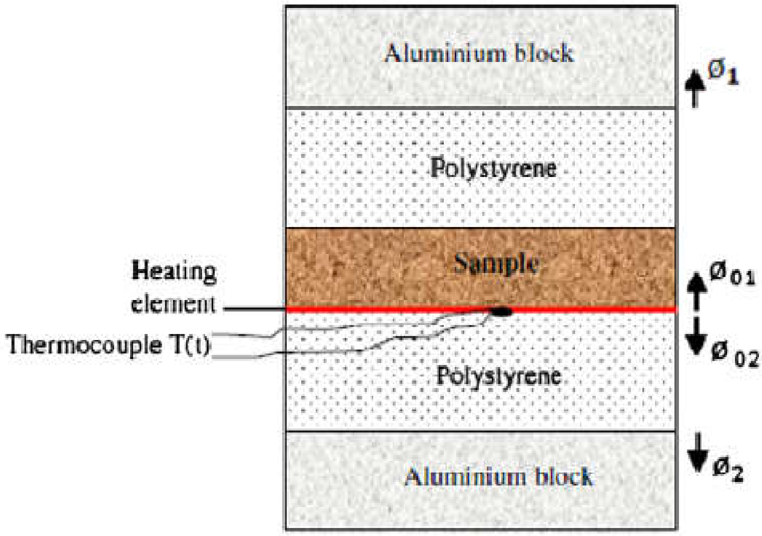

Figure 4. Simplified Hot Plan Model

Most of the heat dissipated into the heating device which electric resistance $R_e = 40\,\Omega$, passes through the upper part of the heating device. A plan heating device sharing the same section with the sample is placed under it. K-type thermocouple comprising two cords of $0.005\,mm$ diameter is placed at the underside of the heating device. The sample is placed between a $40mm$ thick two blocks of extruded polystyrene set between two $40mm$ thick aluminum blocks. A heat flow is sent from the heating device. The temperature evolution $T(t)$ is recorded at every each $0.1\ s$. The presence of the thermocouple does not increase the contact resistance between the heating device 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 device 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 $T_{mod}(t)$ and that provided by the experience $T_{exp}(t)$, to determine the time t_{max} at which the unidirectional hypothesis (1D) is checked. 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 in these hypotheses. By applying the quadrupole formalism (Bodian, 2011) on the device shown in Figure 1 and 2. We may write:

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

$$C_s = \rho_s c_s e_s$$

$$\begin{bmatrix}A_e & B_e\\ C_e & D_e\end{bmatrix}=\begin{bmatrix}ch(qe) & \dfrac{sh(qe)}{\lambda q S}\\ \lambda q S\, sh(qe) & ch(qe)\end{bmatrix} \quad \begin{bmatrix}A_i & B_i\\ C_i & D_i\end{bmatrix}=\begin{bmatrix}ch(q_i e_i) & \dfrac{sh(q_i e_i)}{\lambda q_i S}\\ \lambda q_i S\, sh(q_i e_i) & ch(q_i e_i)\end{bmatrix}$$

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

The formula (1) leads to the following formula (2):

$$\begin{bmatrix}\theta_1\\ \Phi_1\end{bmatrix}=\begin{bmatrix}1 & 0\\ C_s p & 1\end{bmatrix}\begin{bmatrix}1 & Rc_1\\ 0 & 1\end{bmatrix}\begin{bmatrix}ch(qe) & \frac{sh(qe)}{\lambda qS}\\ \lambda qS\,sh(qe) & ch(qe)\end{bmatrix}\begin{bmatrix}ch(q_ie_i) & \frac{sh(q_ie_i)}{\lambda q_iS}\\ \lambda q_iS\,sh(q_ie_i) & ch(q_ie_i)\end{bmatrix}\begin{bmatrix}0\\ \Phi_1^{'}\end{bmatrix}=\begin{bmatrix}A & B\\ C & D\end{bmatrix}\begin{bmatrix}0\\ \Phi_1^{'}\end{bmatrix} \quad \text{……………………………………… (2)}$$

By developing the previous matrix product (01), then we get $\Phi_1 : \Phi_1 = \theta_1 \frac{D}{B}$ ……………………………………………. (3)

Concerning the (polystyrene) insulator, we have $\begin{bmatrix}\theta_1\\ \Phi_2\end{bmatrix}=\begin{bmatrix}A_i & B_i\\ C_i & D_i\end{bmatrix}\begin{bmatrix}0\\ \Phi_2^{'}\end{bmatrix}$ ……………………………………………. (4)

by developing the previous matrix product, we have Φ_2 : $\Phi_2 = \theta_1 \frac{D_i}{B_i}$ but $\Phi_0 = \Phi_1 + \Phi_2 = \frac{\varphi_0}{S}$ So $\Phi_0 = \theta_1\left(\frac{D}{B}+\frac{D_i}{B_i}\right)$ and then

we draw the value of θ_1 using the relation $\theta_1 = \frac{\phi_0}{p}\left(\frac{1}{\frac{D}{B}+\frac{D_i}{B_i}}\right)$ ………………………………………………………. (5)

With the inverse transformed (De Hoog, 1982), the relation (5) enables to get.

$$T_1(t) = L^{-1}\left(\frac{\phi_0}{p}\times\frac{1}{\left(\frac{D}{B}+\frac{D_i}{B_i}\right)}\right) \quad \text{……………………………………………………… (6)}$$

Simplification of the model nothing that $\lambda q = \sqrt{p}E$ *and* $\lambda_i q = \sqrt{p}E_i$. The size is written when the time is long

$$\theta_0 \approx \frac{\Phi_0}{p}\frac{1}{\left(CP+E\sqrt{P}\right)\left(1-R_{C1}E\sqrt{P}\right)+\left(CP+E_i\sqrt{p}\right)\left(1-R_{C2}E_i\sqrt{P}\right)} \quad \text{………………………………………………… (7)}$$

This relationship becomes

$$\theta_0 \approx \frac{\Phi_0}{p}\frac{1}{\left(E+E_i\right)\sqrt{p}+p\left[C-R_{c1}E^2+C-R_{c2}E_i^2\right]} \quad \text{………………………………………………… (8)}$$

$$\theta_0 \approx \frac{\Phi_0}{p^{3/2}\left(E+E_i\right)}\frac{1}{1-\frac{\left(2C-R_{c1}E^2-R_{C2}E_i^2\right)\sqrt{p}}{E+E_i}} \quad \text{………………………………………………… (9)}$$

$$\theta_0 \approx \frac{\Phi_0}{p^{3/2}\left(E+E_i\right)}\left[1+\left(\frac{R_{c1}E^2+R_{c2}E_i^2}{E+E_i}-\frac{2C}{E+E_i}\right)\right]\sqrt{p} \quad \text{………………………………………………… (10)}$$

By performing the Laplace inverse transform, one obtains

$$T_0(t) = \Phi_0\left[\frac{R_{c1}E^2+R_{C2}E_i}{\left(E+E_i\right)^2}-\frac{2\left(\rho ce\right)_s}{\left(E+E_i\right)^2}\right]+\frac{\Phi_0}{\left(E+E_i\right)\sqrt{\pi}}\times\sqrt{t} \quad \text{……………………………………… (11)}$$

When P approaches zero (long time). The curve $T = f(\sqrt{t})$ tends towards a straight line. The inertia of the probe and the contact resistance has a negligible effect on this temperature. To determine the effusively, the slop β of the line is used. This will provide

$$E + E_i = \frac{\Phi_0}{\beta\sqrt{\pi}} \quad \text{.......} (12)$$

The principle of the method is to determine the value of the effusively E, the thermal conductivity λ of the sample and the contact resistance R_C that minimize the Mean Squared Error of the sum $\psi = \sum_{j=0}^{N} \left[\Delta T_{\exp(t_j)} - T_{\mathrm{mod}(t_j)} \right]^2$ 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 (Marquardt , 1963). 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 Laplace transformed of the heat flow from the probe to the insulator (polystyrene) located at the bottom. 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. $C_s = \rho_s e_s c_s$ is the heat capacity per unit area of the probe. R_c is the contact resistance between the sample and the probe. e_i et e are the thicknesses of the insulator and the sample respectively. a_i is the thermal diffusivity of the polystyrene.

Results and discussion of the characteristics of thermal performance of the various formulations of lime with laterite

Results of thermal performance

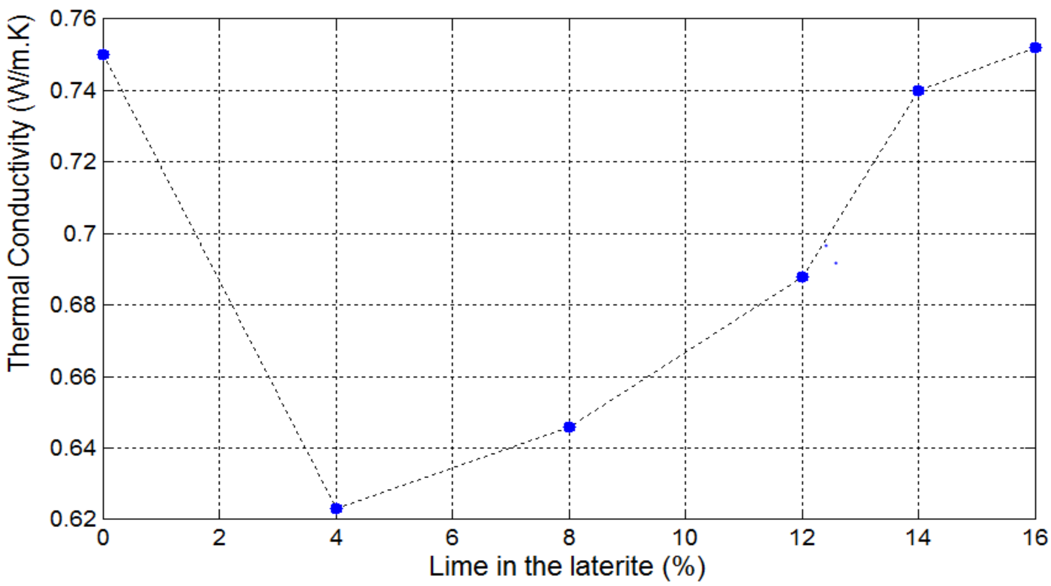

Figure 5. Variation curve of the thermal conductivity according to the lime dosage rate.

We notice that conductivity increases when lime dosage rate is higher than 4%; it increases by 15.92% when dosage rate is multiplied by 2 and reaches $0.688W/(m.K)$ when the rate is 12%. This value was obtained by Azakine *et al.,* 2014 with the hot wire method. However, the difference between the values on the thermal conductivities for the same dosage rates, measured by Azakine using the hot wire method and our values obtained using the asymmetric hot plan method is $0.688W/(m.K)$ for a lime rate of 4% and $0.026\ W/(m.K)$ for a rate of 8%. The rate of 12% corresponds to $0.68W/(m.K)$, this same value is found in our measurements.

Table 1. Thermophysical properties of the various formulations

Materials	$E(J/m.K.s^{1/2})$	$\frac{\Delta E\ (\%)}{E}$	$\lambda(W/mK)$	$\frac{\Delta\lambda\ (\%)}{\lambda}$
LS	1277.561	0.027	0.750	0.121
LCh4%	1096.283	0.022	0.623	0.135
LCh8%	1107.280	0.025	0.646	0.136
LCh12%	1120.770	0.025	0.688	0.087
LCh14%	1130.288	0.035	0.740	0.122
LCh16%	1143.296	0.026	0.752	0.121

Table 2. Thermophysical parameters calculated

Materials	$\rho c (KJ/m^3K)$	$\frac{\Delta \rho c}{\rho c}$ (%)	$\frac{\Delta \alpha}{\alpha}$ (%)	$\alpha (m^2/s) \times 10^{-7}$
LS	2176.261	0.175	0.175	0.296
LCh4%	1929.111	0.180	0.180	0.314
LCh8%	1897.939	0.185	0.185	0.322
LCh12%	1825.763	0.137	0.137	0.224
LCh14%	1726.420	0.192	0.192	0.314
LCh16%	1738.199	0.173	0.173	0.294

Figure 6. Test tubes for mechanic tests (laterite plus 16% of lime)

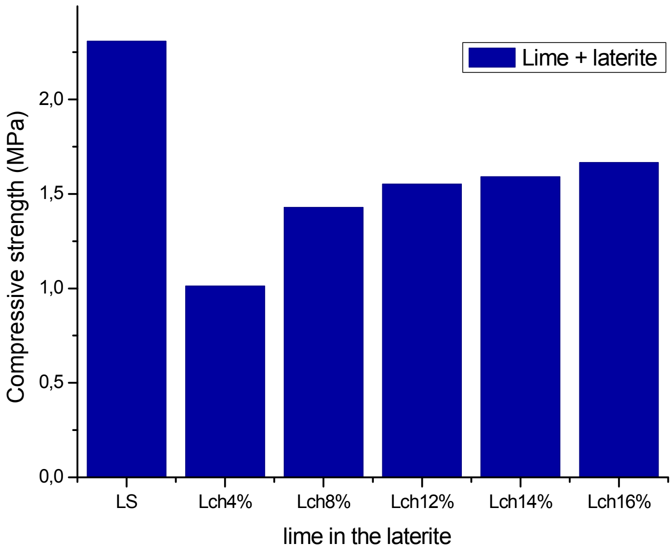

Figure 7. Variation of the resistance to Compressive Strength depending on LCH formulations

We notice that effusively increases the same rate as the thermal conductivity. Based on the results in Table 1, we develop other thermo physical parameters such as thermal volumetric capacity, and thermal diffusivity in Table 2. The deduction is made using the following formulas:

$$\rho c = \frac{E^2}{\lambda} \quad (01) \quad \text{and} \quad \alpha = \left(\frac{\lambda}{E}\right)^2 \quad (02)$$

4- Compressive strength of the laterite plus lime

The dimension of the test tubes is $4 \times 4 \times 16\ cm^3$. Compressive tests are determined after the 28^{th} day after the production of bricks. These properties are the average of the three specimens for each mix ratio.

$$Rc = \frac{F}{S}$$

R_C = Compressive Strength (MPa)
F = Maximum Compressive Strength (N)
S = Contact surface of the strength (mm^2)

We notice that the mechanical strength of laterite without lime is 2.3 MPa; this value is found in Hakimi's work and reported by Meukam 2004 this value decreases by 56.12% when we add 4% of lime. The value of the mechanical strength obtained for 4% of lime is close to that obtained by Solomon-Ayeh 1994. It decreases by 38.11%; 32.78% and 27.84% when 8%, 12% and 16% of lime is gradually added. The value of the compressive strength for a dosage of 8% is very close to that found by Attoh-Okine 1995 on Santasi's samples in Florida, for the same dosage and the same curing time of 4 weeks. Raheem *et al.,* 2010have obtained a maximum mechanical strength of when 10% of limeare used. This value is between the one we found for LCH4% and LCH8%. The values obtained for the rates of 15%, 20% and 25% are significantly lower than our values. This is probably due to the fact that our laterite contains more clay than that used by AA Raheem because according to Bell *et al.,* 1996, the stabilization of lime is more suitable in clay soils. The flexural strengths of these specimens are very low.

Conclusion

Thermophysical parameters of the various formulations with laterite and slaked lime were determined in this study. This shows that the conductivity decreases when lime rate is below 4% and increases when the rate higher than 4%. We found that the compressive strength increases but very slowly. However, the increase of the mechanical strengths of the various formulations still remains lower than the mechanical strength of the laterite without lime; which enables us to conclude that lime does not improve the mechanical properties of laterite. It rather modifies the mechanical properties of clay soils. The authors would like to thank PAFROID Project (Inter-University Partnership between Africa and the Indian Ocean-Development) for having financed this research in Senegal.

REFERENCES

AttOh-Okine, N. O. 1995. Lime treatment of laterite soils and gravel –revised, Department of Civil and Environnemenal Engineering, Florida International University.Miami FL 33199, USA. Construction and building Materials Volume 9, issue 5, October 1995.

Ayeh, S. and al., 1963. 'Studies of strengths of stabilized laterite blocks and rendering mortards'. Building Res Inf 1994, (22) (3)

Azakine Sindanne, S. and al ., 2014. 'Thermophysical characterisation of earth blocks stabilized by Cement Sawdust and lime' *J. Build Mater. Struct*, 1-58-64

Bell, F.G. 1996. Department of Geology and Applied Geology, University of Natal Private Bag XIO, Dalbridge, 4014, South Africa. *Engineering Geology,* 42, 223-237

Bodian, S. 2011. 'Comportement Thermomécanique d'une brique de Terre Crue et en Terre Cuite.' Master de Recherche. Mémoire de fin de stage à L'Ecole Supérieure Polytechnique (E S P) Dakar.

De Hoog, F.R. 1982. An Improved method for numerical inversion of Laplace Transforms*. Society of Industrial and Applied Mathematics*, 3(3); 357-366.

Diata, M. *et al*. 2010. 'Etude thermomécanique de l'argile stabilisée à la chaux. CIFEM210-ART-4-116

Imbga, B. K. and al., 2014. 'Thermal and Mechanical Study of Adobe Stabilized with Straws and / or Cement at the Different Dosage rate. *International Journal Of Engineering and Innovative Technology (IJEIT)*, vol4- issue4.

Jannot, Y. 2011. 'Théorie et pratique de la métrologie thermique' LEMTA. Octobre.

Lemougna, P. N. 2011. 'Laterite Based Stabilized Products for Sustainable Building Applications in Tropical countries : Review and Prospect for the case of Cameroom' Materials Promotion Authority MINRESI/MIPROM P.O BOX 2396, YAOUNDE . Sustainability, 3,293-305 /doi 103390su3010293

Marquardt D. An Algorithm for least Squares estimation of non-linear parameters. *Soc Ind Appl Math*., 11, 431-41

Meukam, P. and al., 2004. 'Thermophysical characteristics of economical building materials,' *Construction and building materials,* 18, 437-443.

Millogo Younoussa ' Microstructure , geotechnical and mechanical characteristics of quicklime- Lateritic gravels Mixtures Used in road construction' Université Polytechnique de Bobo Dioulasso 01 BP 1096 Bobo, Burkina Faso. Construction and Building Materials 26(2012)663-669

Raheem, A. A., Bello, O. A. and Makinde, O. A. 2010. 'A comparative study of Cement and lime stabilized lateritic interlocking Blocks' *Pacific Journal of science and technology,* 11(2):27-34

Siddique Abu and al, 2013. 'Effect of Lime Stabilization on Engineering Properties of Expansive Soil for use in Road Construction'. Department of Civil Engineering and Technology. Bangladesh University of Engineering and Technology (BUET) Dhaka, *Journal of Society for Transportation and Traffic Studies* (*JSTS*), vol2 no4.

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