

RESEARCH ARTICLE

THERMAL CHARACTERIZATION OF A GEOCONCRETE COMPOSITE: LATERITE WITH ADDITION OF PEANUT SHELL

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Abstract

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Key words:-

Geoconcrete, Laterite, Peanut Shell, Thermal Insulation, Thermal Conductivity, Thermal Effusivity, Thermal Diffusivity This paper presents a study on the thermal characterization of laterite used as a building material. In Senegal, laterite has been used in construction on a semi-industrial scale since the 1990s through projects aimed at promoting local materials that can contribute to the energy efficiency of buildings. The aim of the work is to determine the thermal characteristics of a composite (laterite + peanut shell). The results showed that the pure laterite specimens have a higher conductivity than the laterite + peanut shell composite specimens. The formulation BTS10-12,5–4 has a thermal conductivity of 0.48 W.m⁻¹.K⁻¹, the bricks of this formulation can then be classified as insulating earth bricks.The thermal performance of the material has been improved by the addition of peanut shells.

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Introduction:-

The thermal insulation character of a building envelope is directly based on the nature of the material or materials used in its construction.

In the current context of energy scarcity and high energy prices, energy efficiency in buildings, particularly housing, is an imperative. However, the materials used must be resistant to mechanical stresses and the effects of water on the walls to ensure the safety of the occupants but must also have certain insulating properties to contribute to the thermal performance of the building envelope. Hence the problem of the choice of materials on the basis of their thermal characteristics.

This work is part of a thermal characterization study of a geoconcrete composite with the addition of peanut shells. The objective is to determine, through laboratory experiments, the thermal characteristics of the material: thermal conductivity, thermal inertia, effusivity and thermal diffusivity of the brick-made material in order to decide whether or not to use it in the construction of the building envelope.

It should be noted that our previous work of mechanical performance testing on the material that is currently being studied showed satisfactory results.

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Material And Method:-

Geoconcrete bricks are bricks made with stabilized and compressed earth (laterite). Stabilization is the set of physical, chemical or physico-chemical treatment processes used to improve the mechanical characteristics of the earth.

For stabilization we used cement as a stabilizer with a mass content of 10% laterite. Indeed, a stabilizer is a material that can eliminate the shrinkage effects of bricks with geoconcrete but also the protection against the effects of water on walls

Material:-

Laterite

Laterite or lateritic soil is soil that forms in humid tropical regions and is the result of a particular process of alteration. Laterite is a bright red or brown red soil, very rich in iron oxide and alumina formed in a warm climate [1].

The laterite that we will use for the production of the test tubes is exploited in the Mont Rolland quarry on the road to Mont Rolland Thies, an area where the soil is very lateritic. The Mont-Rolland quarry is located north of the town of Thies (Fig.1). It developed on the soils of the Thies plateau after a chemical and mechanical alteration of sediments (clay and marl-limestone) eccenes [2]. Analysis of the particle size curve shows that the sample taken is essentially made up of aggregate with a grain size between 2 mm and 12.5 mm. Indeed, in this range, we have (93.5% - 21.8%) = 71.7% in mass of the sample analyzed.



Fig.1:- Location of the Mont-Rolland quarry.

Cement

Cement is a widely used construction material on the planet and is its main application in concrete. Cement is a hydraulic binder, a material that allows aggregates and other materials to be joined together.

Cement has several strength levels: 32,5 - 42,5 - 52,5 (expressed as MPa). The higher the index, the stronger the cement). Depending on its class of compressive strength, cement will be used in the manufacture of mortar or concrete for common purposes, structural work, or high-performance work.

In our work, class 32,5 cement was used as a binder or stabilizer for sample formulation.

Peanut shell

The peanut shell is a waste obtained during the shelling of the peanut pods for the recovery of the seeds. Knowing the total production, the amount of peanut shell produced per year can be calculated from the Residue-to-Product Ratios (RPR). The RPR calculation formula is as follows:

$$RPR = \frac{quantity of peanut shell}{quantity of seed}$$
(1)

For the peanut shell we have RPR = 0.58 [3].

An important fact to note and therefore to take into account is the share of the export of groundnut production to Senegal which is growing more and more in recent years. The exploitable potential of peanut shells will then be estimated by applying the RPR to the quantity of production processed at the local level.

Sieves

The sieves used comply with ISO 565, which prescribes the nominal dimensions of the openings of perforated metal sheet and electroformed sheets used as sieve bottoms in the test sieves.

Scales

The scales used are of electronic type and high precision. For the measurement of masses greater than 1 kg, a balance with a precision of 5 g was used.

Mould

For the preparation of the specimens, we have chosen a block mould of which the section at the base is $10x10cm^2$ and of thickness 1,7 cm.

Sampling and preparation of test specimens Sampling

After processing the material (crushing, drying and sieving), two different batches of test pieces are prepared. This will be a batch of test specimens prepared with different granularities and a second batch consisting of composite material, consisting of 12,5 mm of laterite mixed with different content with a sifted peanut shell with a sieve of 5 mm

Preparation of test specimens

The preparation and preservation of the test pieces is done according to the standard NF P 18-404.

For the series of specimens with different granularity:

To obtain different grain sizes, a treatment is carried out by sieving after natural drying of the laterite by spreading with a thin layer for more than 7 days in the open air and in the sun. It should be understood here that the consideration we have taken to speak of different particle size corresponds to the use of passers-by after sieving laterite with three different sieve sizes. Indeed, we used loops of mesh sieves 5 mm, 12.5 mm and 20 mm.

The amount of spoilage water was taken equal to 10.2% representing Wopt found per Proctor test. We therefore took a mass of water equal to 10.2% of the laterite mass.

Cement is used as a binder with a quantity equal to 10% by mass of laterite (10% of the mass of laterite is replaced with cement for the same quantity).

Table 1 below gives a summary of the composition of the samples of the material used in the preparation of the specimens.

Designation of test specimens	Latérite (kg)	Cement (kg)	Wateur (liter)				
BTS10P5	0,900	0,100	0,102				
BTS10P12,5	0,900	0,100	0,102				
BTS10P20	0,900	0,100	0,102				

Table 1:- Mass composition of samples.



Fig. 2:- Geoconcrete test tube for thermal test.

For composite material (laterite + peanut shell)

The peanut shell is dried in the open air and in the sun for more than 7 days. This ensures that its natural water content is almost negligible. Then it is crushed and sieved with a 5 mm sieve. In the series of specimens, laterite passing from sieve 12.5 mm is mixed with peanut shell at different percentages (4%, 6% and 8%). The amount of spoilage water was taken equal to 10.2% of the laterite mass. Cement is used as a binder with a quantity equal to 10% by mass of laterite (10% of the mass of laterite is replaced by cement for the same quantity).

Table 2 below gives a summary of the mass composition of the samples of the material used in the preparation of the specimens

	Latérite (kg)	peanut shell	Cement (kg)	Water (liter)				
BTS10 -12,5 – 4%	0,860	0,040	0,100	0,102				
BTS10-12,5 - 6%	0,840	0,060	0,100	0,102				
BTS10-12,5 - 8%	0,820	0,080	0,100	0,102				

Table 2:- Mass composition of composite samples with pass-through laterite 12.5 mm.



Fig. 3:- Test tube (laterite+ peanut shell) for thermal test.

Method:-

We use the asymmetric hot plane method. This method is chosen because it is very suitable for the thermal characterization of building materials used in buildings. These materials include earth-based materials, concrete and wood. The asymmetric hot plane generally gives satisfactory results. It is also a very rapid characterization method. The diagram below shows the experimental installation with the equipment of the Applied Energy Laboratory of the Ecole Supérieure Polytechnique (ESP) in Dakar.



Fig. 4-a:- Experimental set-up.



Fig 4-b:- Block diagram of the experimental set-up.

The principle consists of placing a 10 x 10 cm2 heating element between the sample and a polystyrene or polyurethane insulating block. The thin heating element has the same surface area as the polystyrene and the sample. A small diameter thermocouple, about 0.05 mm, is placed in contact with the heating element, between the latter and the polystyrene. On the other side of the sample, another insulating block of the same size is also placed. Two aluminum blocks of the same surface as the insulation and 4 cm thick finally sandwich all the elements mentioned. The back faces of the insulation, in contact with the aluminum blocks, are kept at a constant temperature. When a flow step is applied to the heater, the temperature T(t) is recorded from the thermocouple.

After data acquisition, a simulation program on Matlab makes it possible to determine directly the conductivity and thermal effusivity; the diffusivity can be deduced after calculation of the volumetric thermal capacity (ρ c). The hypothesis that the heat transfer remains at one dimension is made and allows us to obtain the following relationships in which θ is the Laplace transform of T(t).

$$\begin{bmatrix} \theta \\ \Phi_{0I} \end{bmatrix} = \begin{bmatrix} I & 0 \\ C_h p & I \end{bmatrix} \begin{bmatrix} I & R_c \\ 0 & I \end{bmatrix} \begin{bmatrix} A & B \\ C & D \end{bmatrix} \begin{bmatrix} A_i & B_i \\ C_i & D_i \end{bmatrix} \begin{bmatrix} 0 \\ \Phi_I \end{bmatrix} = \begin{bmatrix} A_I & B_I \\ C_I & D_I \end{bmatrix} \begin{bmatrix} 0 \\ \Phi_I \end{bmatrix}$$
(2)

$$\begin{bmatrix} \theta \\ \phi_{02} \end{bmatrix} = \begin{bmatrix} A_i & B_i \\ C_i & D_i \end{bmatrix} \begin{bmatrix} 0 \\ \phi_2 \end{bmatrix}$$
(3)

Note:

$$\Phi_0 = \frac{\phi_0}{p} = \Phi_{01} + \Phi_{02} \tag{4}$$

We then have:

$$A = D = \cosh\left(\sqrt{\frac{p}{a}}e\right) \tag{6}$$

 $C = \lambda \sqrt{\frac{p}{a}} \sinh\left(\sqrt{\frac{p}{a}} e\right)$

$$B = \frac{\sinh\left(\sqrt{\frac{p}{a}}e\right)}{\lambda\sqrt{\frac{p}{a}}}$$
(7)

(5)

$$A_i = D_i = \cosh\left(\sqrt{\frac{p}{a_i}}e_i\right) \tag{9}$$

 $C_h = \rho_h c_h e_h$

$$B_{i} = \frac{\sinh\left(\sqrt{\frac{p}{a_{i}}}e_{i}\right)}{\lambda_{i}\sqrt{\frac{p}{a_{i}}}}$$
(10)

(8)

$$C_i = \lambda \sqrt{\frac{p}{a_i}} \sinh\left(\sqrt{\frac{p}{a_i}} e_i\right)$$
(11)

Parameters a and λ refer respectively to the diffusivity and thermal conductivity of the sample. The index "i" is used to designate the thermal insulation used in the experimental assembly and p is the Laplace variable. This leads to the following relationship.

$$\theta_{s}\left(p\right) = \frac{\Phi_{0}\left(p\right)}{\frac{D_{I}}{B_{I}} + \frac{D_{i}}{B_{i}}} \tag{12}$$

The expression of $\theta_s(p)$ is finally given by

$$\theta_{s}(p) = \frac{\phi_{0}}{p} \frac{1}{\frac{(m_{th+r}c_{th+r})_{s}}{S_{r}}p + \left[1 + R_{c}\frac{(m_{th+r}c_{th+r})_{s}}{S_{r}}p\right]b_{ech}\sqrt{p}} + \frac{b_{i}\sqrt{p}}{1 + R_{ci}b_{i}\sqrt{p}}$$
(13)

With the reverse Laplace transform, we end up with the following relationship.

$$T_{s}(t) - T_{s}(0) = \frac{2\phi_{0}}{(b+b_{i})\sqrt{\pi}}\sqrt{t} + \phi_{0}\left[\frac{R_{c}b^{2} + R_{ci}b_{i}^{2}}{(b+b_{i})^{2}} - \frac{(mc)_{s}}{(b+b_{i})^{2}}S\right]$$
(14)

A simplifying hypothesis is made, we neglect the thermal resistance and the calorific capacity of the heating element. The graphic representation of $T_s(t) - T_s(0)$ as a function of \sqrt{t} gives a right part of the origin up to 150s [6], whose slope α , with:

$$\alpha = \frac{2\phi_0}{\left(b + b_i\right)\sqrt{\pi}} \tag{15}$$

Effusivity b is then calculated with the following formula (16)

$$b = \frac{2\phi_0}{\alpha\sqrt{\pi}} - b_i \tag{16}$$

For a semi-stationary diet, the following relationship can be written (17):

$$\phi = \left[\rho c e + \left(\rho c e\right)_{i} + \left(\rho c e\right)_{s}\right] \frac{dT}{dt}$$
(17)

For a long time, for example $t \ge 400s$ we obtain a quasi-linear part of the graphical representation of *T* as a function of *t* from the relation (17) [6].

This line has a slope β , with:

$$\beta = \frac{\phi}{\rho ce + (\rho ce)_i + (\rho ce)_s} \tag{18}$$

The volumetric thermal capacity of the sample can then be calculated by applying the following formula (19):

$$\rho ce = \frac{\phi}{\beta} - \left[\left(\rho ce \right)_i + \left(\rho ce \right)_s \right]$$
⁽¹⁹⁾

It should be noted that this relationship, which makes it possible to calculate the thermal capacity of the sample, gives precise results only for heavy materials with $\rho c > 10^6 J.m^{-3}.K^{-1}$ [6].

Finally if we have the Effusivity and the volumetric thermal capacity of the sample will allow to calculate the thermal conductivity of the sample to be characterized from the formula (20):

$$\lambda = \frac{b^2}{\rho c} \tag{20}$$

The advantage of the asymmetrical hot-plane method is that it allows the determination of most of the thermal characteristic of the material.

Effects of particle size on geoconcrete thermal properties

After data acquisition, a simulation program on Matlab makes it possible to determine directly the conductivity and thermal effusivity; the diffusivity can be deduced after calculation of the volumetric thermal capacity (ρ c).

The program written on Matlab allows to obtain the curves of figures 5 and 6

For each formulation, two specimens are made up in order to have two estimated values, the average of which is taken as the value of the measured quantity. The results of the measurements carried out are given in Table 3 below



Fig. 5:-Asymmetric Hot Plane Thermogram.

The analysis of the curve in Fig.5 shows that for a long time, for example $t \ge 400s$, a quasi-linear part of the graphic representation of as a function of from the relation is obtained.

The volumetric thermal capacity ρc of the sample can then be calculated after determining the slope of the linear part of the thermogram. The program written on Matlab will also allow to calculate Effusivity. Thermal conductivity and thermal diffusivity will also be calculated.



Figure 6 shows that the sensitivity to thermal conductivity is high for a long time, for example. The method used (asymmetric hot plane) is therefore well suited for measuring conductivity and thermal effusivity.

However, the sensitivity to contact resistance is very low and does not vary for the entire duration of the test. This shows that the influence of the contact resistance on the measurements made is negligible.

The results of the thermal characterization of the material are given in Table 3.

Designation of specimens		Dried specimens				Thermal effusivity (J.s ^{-1/2} .m ⁻² .K ⁻¹)			Thermal diffusivity
		(kg.m ⁻³) (mean)		uncertainty (%)	mean		uncertainty (%)	mean	$(.10^{+} m^{2}.s^{-1})$
BTS10 P5	Ech 1	2198	0,53	0,45	0.52	1051,20	0,17	1031,54	2,54
	Ech 2		0,52	0,47		1011,89	0,18	, í	,
BTS10 P12,5	Ech 1	2526	0,58	0,41	0,56	1223,93	0,15	1206,68	2,15
	Ech 2		0,55	0,35		1189,44	0,13		
BTS10 P20	Ech 1	2692	0,65	0,49	0,62	1272,88	0,19	1257,57	2,43
	Ech 2		0,60	0,49		1242,27	0,18		

Table 3:- Thermal characteristics of geoconcrete specimens.

The graphs in Fig.7 are plotted from the data in Table 3.



Fig. 7:- Effect of particle size on thermal conductivity and density.

Analysis of the graphs in Fig.7 shows that the density of laterite briquettes increases with grain size. We also find that the thermal conductivity of the material increases with density. Indeed, when the density increases, it means that there are fewer pores in the briquette, so less air trapped in the material. A decrease in the porosity of the material gives the latter a better heat conduction power. In the literature, insulating stabilized earth blocks have a thermal conductivity of 0.47 W.m⁻¹.K⁻¹ [5].

Recall that the 12.5 mm passers-by were retained because in our previous work, we found that they give a higher compressive strength. The thermal conductivity of samples passing 12.5 mm is equal to 0.56 W.m^{-1} .K⁻¹, therefore

much higher than that of insulating stabilized earth bricks. In the remainder of our experimental study, we will verify the change in thermal conductivity with the addition of peanut shells.

Effects of peanut shell content on geoconcrete thermal properties

In this part of the work, the objective is to show the influence of peanut shell content on the thermal properties of the material. We selected three formulations with 4%, 6% and 8% peanut shell. The composition of the samples is given in Table 2 above.

The test results are summarized in Table 4 below.

Designation of Dried		Thermal conductivity			Thermal effusivity			volumetric	Thermal	
specimens specimens		λ			b			heat	diffusivity	
		density (kg.m ⁻³) (mean)	(W.m ⁻¹ .K ⁻¹)			$(J.s^{-1/2}.m^{-2}.K^{-1})$			capacity	a
				Incerti-	moyen-		Incer-	Moyenne	ρc	$(.10^{-7})$
				tude	ne		titude	ıde	$(J.m^{-3}.K^{-1})$	$m^{-}.s^{-}$)
				(%)			(%)			
BTS10-	Ech	2198	0,46	0,36		984,56	0,13			
12,5_	1				0,48			1008,05	2117010	2,26
4%	Ech		0,51	0,58		1031,55	0,22			
	2									
BTS10-	Ech	2039	0,47	0,51		989,89	0,19			
12,5_	1				0,45			972,44	2101421,23	2,14
6%	Ech		0,43	0,75		955,00	0,26			
	2									
BTS10-	Ech	1875	0,37	0,85		880,46	0,26			
12,5_	1				0,36			870,30	2103950,25	1,71
8%	Ech		0,35	0,68		860,14	0,19			
	2									

Table 4:- Thermal Characteristics of geoconcrete specimens with Added Peanut Shell.

The graphs in Fig. 8 and 9 are thus plotted from the data in Table 4 above.



Fig. 8:-Effects of peanut shell content on thermal conductivity and thermal diffusivity.



Fig.9:- Effects of peanut shell content on density and volumetric heat capacity.

The combined analysis of the graphs in Fig. 8 and 9 shows that the conductivity, thermal diffusivity of the material and density decrease for an increase in the peanut shell content. This fact gives these formulations insulating characteristics.

The thermal inertia of the material also decreases with the peanut shell content from 4% to 6%. For a content greater than 6%, we see an increase in thermal inertia. This can be explained by the fact that the peanut shell is very hygroscopic and the mass thermal capacity of the material increases due to the presence of more and more water in the material when the peanut shell content is increased.

It should be noted that at the end of the mechanical tests, the peanut shell content retained is 4% because it gives a compressive strength higher than the minimum standard value. Thus, we will focus our analysis on the results of the sample _ BTS10-12.5_ 4% peanut shell content _. This material formulation gives a thermal conductivity of

 0.48 W.m^{-1} .K⁻¹, close to that of insulating earth blocks (0.47 W.m⁻¹.K⁻¹). To confirm the choice of this formulation, a comparative table of data from the literature and the results of this work is developed.

Autors	Material designation	compressive strength (MPa)	Thermal conductivity (W.m ⁻¹ .K ⁻¹)
Clément Ahouannou et al	BTC 10 – 2% sawdust of Tectona	2,12	0,85
P. Meukam et al	81 % laterite + 9 % sawdust + 10 % cement	2,59	0,55
P. Meukam et al	45 % laterite + 45 % pouzzolane + 10 % cement	1,01	0,68
Our current work	BTS10-12,5_4% peanut shell	2,05	0,48

Fig. 10:-Comparison of study Results Table.

Through this table, we can see that our formulation has given the best result as having the lowest thermal conductivity.

For the mechanical characteristics the results obtained are also acceptable because the compressive strength obtained is greater than the minimum value required by the standard which is 2 MPa.

Conclusion:-

The results obtained from the tests show that the addition of peanut shells significantly improves the thermal performance of geoconcrete. We have thus noted that conductivity and thermal diffusivity are inversely proportional to the peanut shell content.

In order to comply with the normative requirements in relation to the mechanical resistance in compression, the formulation _ BTS10-12,5-4%_ has been retained. The mechanical tests carried out on the series of composite specimens of this formulation give a compressive strength of 2.05 MPa, therefore higher than that required by ARS 674:1996 and ARS 675:1996. Therefore, the analysis of the thermal test results was more focused on this sample. The thermal conductivity found for BTS10-12.5-4%_ is 0.48 W.m⁻¹.K⁻¹, the bricks of this formulation can then be classified as insulating earth bricks. The results obtained from the thermal characterization work show that the laterite composite + peanut shell could contribute effectively to the thermal insulation of the housing envelope while respecting the normative requirements in terms of strength mechanical.

Also, by the results obtained, the use of the peanut shell is already found, from an environmental point of view, to manage a bio-sourced waste by using it as a building material. The second interest of the results of this work is the proven possibility of improving the thermal insulation of the building with this material.

References Bibliographiques:-

[1]:Zondjé Poanguy Bernadin Bohi, « Caractérisation des sols latéritiques utilisés en construction routière : cas de la région de l'Agneby (Côté d'Ivoire) », Mécanique des matériaux [physics.class-ph], Ecole des Ponts ParisTech, 2008. Français. NNT : 2008ENPC0834. pastel-00503010

[2]:Strasbourg : Institut de Géologie – Université Louis-Pasteur, «Genèse des phosphates alumineux du Sénégal occidental. Étapes et guides de l'altération », 1982. pp. 3-230. (Sciences Géologiques. Mémoire, 67); https://www.persee.fr/doc/sgeol_0302-2684_1982_mon_67_1

[3]: Ansoumane DIEDHIOU, « Étude hydrodynamique et valorisation énergétique par transformation thermochimique de déchets de biomasse pour l'alimentation d'une briqueterie», Thèse présentée en cotutelle pour l'obtention du grade de Docteur de l'UTC, 28 Avril 2017

[4]: P. Meukam et al, « Caractérisation thermophysique et mécanique de briques de terre stabilisées en vue de l'isolation thermique de bâtiment », Matériaux et Constructions, Vol. 36, aout-septembre 2003, pp 453-460

[5]: Kurt Marti, bureau d'ingénieurs pour l'énergie et l'environnement, « Catalogue d'éléments de construction avec calcul de la valeur U Construction neuve », Office fédéral de l'énergie, 2002.

[6]: Y Jannot, « Mesure des propriétés thermiques des matériaux », Agence Universitaire de la Francophonie, décembre 2017

[7]:Ahmed Berthome, Eric Silvestre, Claude Yao Kouame, « Matériaux locaux et éco architecture au Sénégal, état de lieux et perspectives dans le cadre d'une transition verte. Migration, environnement et développement local », OIT, 2013

[8]:Harouna Bal et al, «Water content dependence of the porosity, density and thermal capacity of laterite based bricks with millet waste additive», Construction and Building Materials 31 (2012) 144–150

[9]:P. Meukam- Y. Jannot - A. Noumowe - T.C. Kofane, « Thermo physical characteristics of economical building materials », Construction and Building Materials 18 (2004) 437–443

[10]:Clément AHOUANNOU et al, « Caractérisation thermomécanique des blocs de terre comprimée avec ajout de sciure de bois », CIFEM 2012 – ART – 14-101

[11]:M. El MARHOUNE et al, « Étude expérimentale des propriétés thermophysiques d'un composite à base de fibre naturelle » 13ème Congrès de Mécanique 11 - 14 Avril 2017 (Meknès, MAROC)

[12]: **Amadou WARORE, Biram DIENG,**« Determination of the Critical Thermal Mass Capacity of Building Materials of Building Envelope », Journal of Scientific and Engineering Research, 2018, 5(5):177-184;

[13]: **Sayouba KABRE et al,** « Évaluation des propriétés thermo-hydro-mécaniques des briques en terre compressée (BTC) issues de la carrière de Matourkou, au Burkina Faso », Afrique SCIENCE 15(3) (2019) 12 – 22.