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Thermomechanical Behavior of Ndouloumadjie and Tattaguine's Millet Involucre Improved Mud Bricks for Their Use in Ecobuilding

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Abstract

This work's aim is to participate in local materials (raw or fiber improved), which can be used in sustainable and accessible buildings to every Senegalese. To do this, studied materials are respectively collected from a laterite clay pit in Ndouloumadjie Dembe (Matam, Northern Senegal) and another from a termite mound in Tattaguine (Fatick, Central Senegal). These samples are first subjected to Geotechnical identification tests. Mud bricks are then made with raw or sifted millet involucre improved to 1%, 2%, and 3% at 5 mm sieve samples. These briquettes are subjected to compression tests and thermal evaluations. Lagrange and Newton methods of numeric modelling are used to test the whole mixture points between 1% and 3% millet involucre for a better correlation between mechanical and thermal parameters. The results show that in Matam, as well as in Tattaguine, these muds, raw or improved, are of good thermomechanical quality when they are used in bricks making. And the thermomechanical coupling quality reaches a maximum situated at 2.125% for Ndouloumadjie and 2.05% for Tattaguine. These briquettes' building quality depends on the mud content used in iron, aluminum, silica and clay. Thus, same natural materials can be used in the establishment of habitats according to their geotechnical, chemical, mechanical and thermal characteristics.

Keywords

Building, Soil Improvement, Millet Involucre, Polynomial Interpolation

1. Introduction

Today, the global warming phenomenon is at the center of scientific debates and some think it is related to wastes and released gas in the atmosphere by human activity. This warming is felt at human's habitat scale including intertropical countries, among which Senegal, where energy consumption is growing. Besides, energy sources, like electricity, have become very expensive and this impacts on building materials prices, like cement, aggregate and others. The prices of these materials today are unaffordable for the average income social class Senegalese. Therefore, it is necessary to look for a material that can enable to build decently and affordably in Senegal, with less energy consumption. Mud building has been known for years in Senegal, in the subregion and even in Africa but was not correlated to a modern scientific method. Buildings made of these materials collapsed prematurely and in the Groundnut Basin of Senegal, the habitat should be redone at the end of every rainy season. In this way, it is impossible to use that mud, which is improved at times for a sustainable building. However, we know that there are exceptionally, in Senegal, mud buildings that went through centuries. A good study then must report that if that material is used properly, it can serve for more modern buildings [1] [2]. In Senegal, in Africa and around the world, some works are done on that mud, sometimes mixed with various materials and even of plant origin [3]-[9]. They have shown they can satisfy the recommendations found in bibliography. The work will consist of improving materials in Senegal-basin [10] with millet involucre between 1% and 3%. A numeric modelling will enable to check the evolution of extreme points based on the points tested in laboratory, in order to project the evolution of admixtures [11]. Today, it's about to try to build sustainably with cheap materials while ensuring the thermal comfort it needs. That will also solve the building materials access problem for the low or average-income social class. The works shown in this paper are based on mud samples collected in two regions of Senegal: in Matam and Fatick, respectively in the localities of Ndouloumadjie Dembe and Tattaguine. Ndouloumadjie Dembé and Tattaguine improved from invoclure millet with a percentage range from 1% to 3%, their mechanical and thermic features have been indicated. From experimental results obtained, a modeling of the resistance to the compression thermal conductivity by the two methods of interpolation has been suggested: Lagrange method and Newton method [11] [12]. A correlation study is conducted between these two parameters.

2. Methodological Approach of the Study

2.1. Implementation to the Adobe Bricks

First, the expensiveness of the modern building materials makes people think more and more to the use of local materials in the fabrication of bricks for the housing. These types of construction have been known since the age-old times through the Nubian arch of the area of the Nil, the "sakh" and the "hut" of Sine, Senegal, the "banco boumg "of Casamance. These earthen constructions or in fiber ameliorated earth were spread in Senegal and through the world. The banco (in Africa) and adobe (in Europe) are a technology used since millennia all over the world. It is a raw earth brick molded and dried under the sun, sometimes added with binding fiber or aggregates. The raw material, of so clayey nature (up to 30% of thin portions), but very sandy, is added with water to obtain a semi firm paste (15% to 30% of water). The mixture is put into a mold so that to make the brick [1] [7]. The blocks are assembled by a mud mortar made from the same earth. It is largely used in the majority of the Senegal areas. The adobe bricks are cast in an open parallelepiped frame.

In the frame of this study two types of soils are used. Two samples will be submitted to that study. It's about the Ndouloumadjie Dembe quarry hammer (Figure 1(a)) and the Tatttaguine termite (Figure 1(b)) whose grain size distribution is shown in Figure 2. A sample of raw earth for the construction derived from the Ndouloumadjie quarry (Matam, Senegal), and another sample stemming from an exploited termite mount in Tattaguine, Fatick region (Figure 3). The described experimental procedure in Figure 4 will be continued.

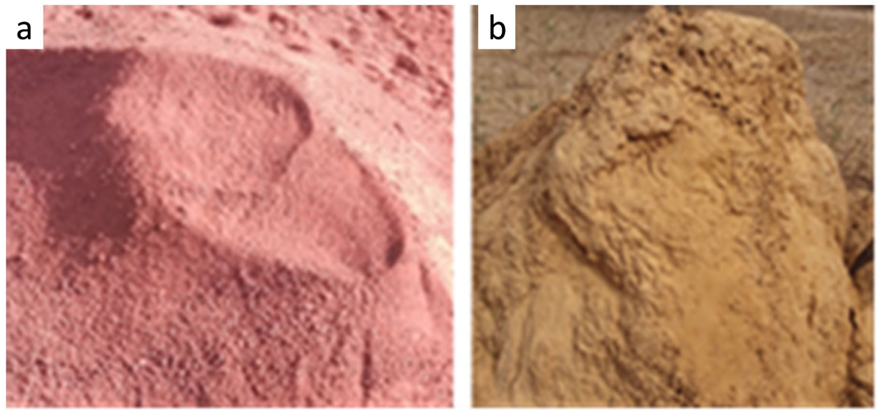

Figure 1. Soil visual appearance of Ndouloumadjie quarry (a) and Tataguine termite (b).

2.2. Identification of the Materials

These raw samples are used for experimental analysis in order to have a geotechnical characterization by determining their identification and classification parameters. This characterization is done in performing identification tests at geotechnical laboratory of Thies University. Among the geotechnical tests we have, the granulometric analysis, the VBS value, the Atterberg limits and Proctor test.

The granulometric analysis (Figure 2) shows the percentage of the loops to 0.075 micron is 38% for the Ndouloumadjie sample and 19% for the Tattaguine sample. These two percentages are inferior to 50%, we have a granny soil. The loops in the sieve 4.75 mm are 99% for the Ndouloumadjie sample and 100% for the Tattaguine sample. Since these percentages are superior to 50%, we have sands. The coefficient of uniformity of 4.5 (inferior to 6) and the coefficient of curvature of 0.42 is out of the range 1 - 3 hence, a graduated soil (SP). The loops to 0.075 micron are over 12% for the both samples. Thus, the Ndouloumadjie sample which the liquidity limit is 23 and the plasticity index is 13, is a soil of (SP-SM) type whereas for Tattaguine which has 32 as liquid limit and 15 as plasticity index, the soil is SP type (Table 1).

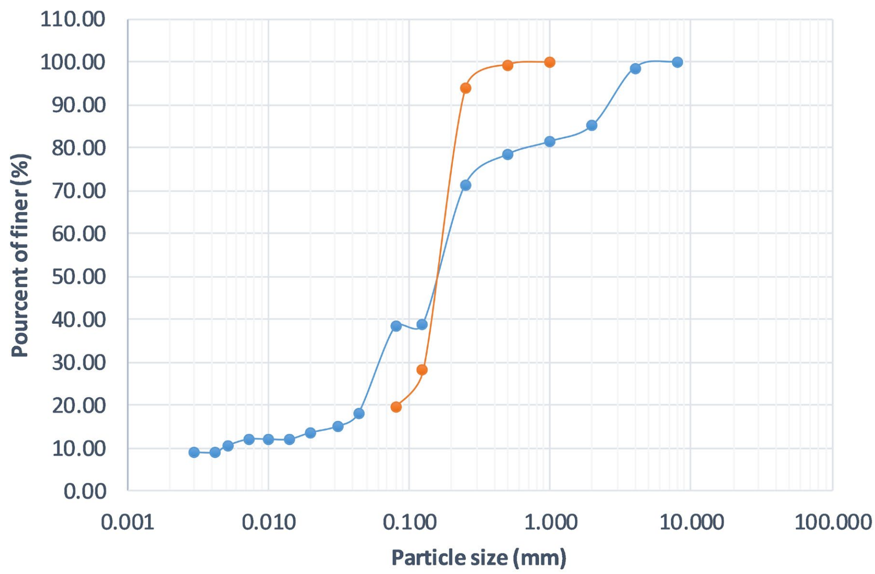

Figure 2. Grading curve of samples (in red Tattaguine, in blue Ndouloumadjie).

Table 1. Geotechnical characterization of soil samples.

Samples	Ndouloumadjie Dembé			Tattaguine		
VBS	0.65			0.8		
Atterberg Limits	WL	WP	IP	WL	WP	IP
	23	10	13	32	17	15
Modified Proctor	W (OPM) (%)	γdmax kN/m^3		W (OPM) (%)	γdmax kN/m^3	
	10	2.149		12.96	1.91	
Granulometry	Sands %	Limons %	Clays %	sands %	limons %	clays %
	23.6	67.3	9.1	80.1	19.9	

A chemical analysis through spectrometry technique by X fluorescence to wave length dispersion of these samples has been carried out (**Table 2**).

These components allowed determining two modules (**Table 3**): the silica module given through equation 1 that inform on the ratio between the quantity of silicate (stemming from SiO_2) and that of aluminates (stemming from Al_2O_3 and Fe_2O_3), and the alumina module given in Equation (2) and which is the ratio between the quantity of the alumina and iron oxide. For Ndouloumadjie we have an alumina module (AM) of 0.47 (inferior to 0.638) whereas for the Tattaguine termite it is 1.97 (superior to 0.638). The Ndouloumadjie quarry material is then rich in iron whereas the Tattaguine termite normal. The alumina content is higher for the Tattaguine termite. Physically that is shown through the brown colour of the Ndouloumadjie sample (rich in iron) and yellow for the Tattaguine termite (rich in alumina).

$$MS = SiO_2/(Al_2O_3 + Fe_2O_3) \quad (1)$$

$$MA = Al_2O_3/Fe_2O_3 \quad (2)$$

Table 2. Chemical components of soil samples (in %).

Sample	S_iO_2	Al_2O_3	Fe_2O_3	CaO	MgO	K_2O	Na_2O	P_2O_5	Pf
Tattaguine	92.6	3.47	1.76	2.01	0.07	0.09	0	0.02	1.82
Ndouloumadjie	68.1	9.27	19.6	2.33	0.15	0.17	0.01	0.36	3.73

Table 3. Silica modulus and alumina values.

Samples	MS	MA
Ndouloumadjie (Matam)	2.36	0.47
Tataguine (Fatick)	17.71	1.97

An improvement with a small percentage 1%, 2% and 3% of the involucre of the millet collected has been made also. The millet involucre has been sieved at 5 mm to eliminate coarse elements. **Figure 3** shows the tests execution procedure.

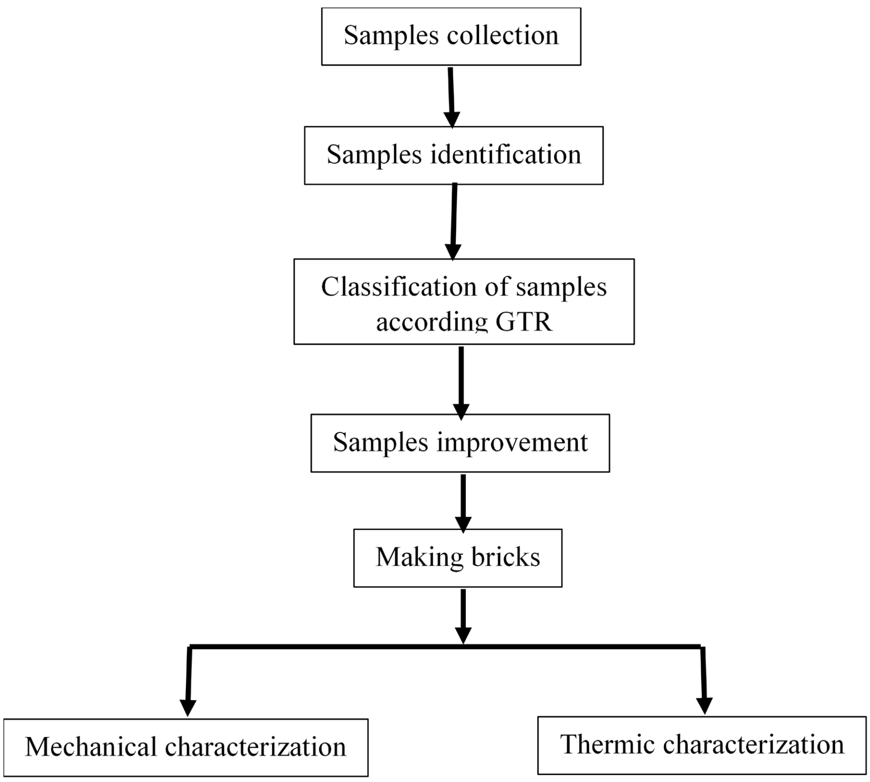

Figure 3. Experimental procedure.

In order to improve the thermomechanical properties raw earth samples from Ndouloumadjie and of Tattaguine, millet involucre (**Figure 4(a)** and **Figure 4(b)**) has been used.

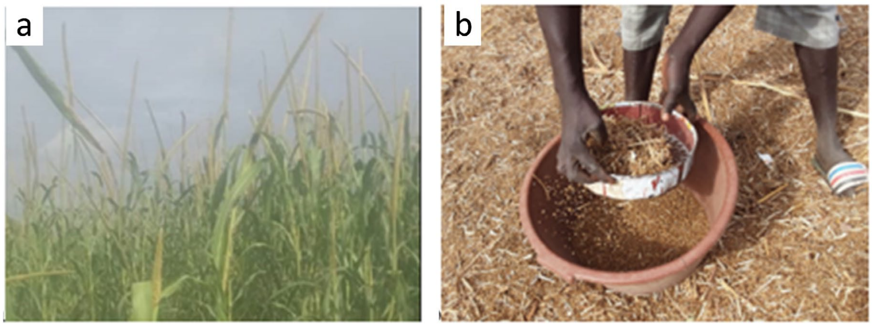

Figure 4. Millet components: (a) Millet plant; (b) Millet involucre.

2.3. Characterization

The compressive strength is determined on adobe bricks of size (15 cm × 15 cm × 40 cm) for raw and improved samples. The anchorage (**Figure 5(a)**) and resampling for making of adobes is done on the basis of the parameters of Proctor optimum (Apparent dry density and optimal water content). Mixing is done by shovels, hands or feet until obtaining a homogeneous and manageable paw (**Figure 6(a)**). The mold (15 cm × 15 cm × 40 cm) is then filled into three layers (**Figure 5(b)**. Each layer filled undergoes 3 consecutive falls of 40 cm height in order to expel voids and have good compaction. After filling of three layers, a surplus of earth is deposited on the surface of the mould. It's finally subjected to the blows of a dune metal plate of 72.5 g in size (15 cm, 30 cm, 4 cm). The number of strokes of the plate metal is between 10 and 15 up to cancellation of settlements. The samples are dried in the shade for 14 days (**Figure 5(c)**). These are briquettes will be crushed (**Figure 5(d)**) by the way.

Figure 5. Manufacturing steps of adobe bricks: (a) Mixing and compounding; (b) Adobe bricks confectioning; (c) Removal and drying; (d) Positioning for compression.

$$Rc = 10 * F/S \quad (3)$$

where Rc = corrosion resistance in MPa, F = strength in MN, S = mm^2.

For bricks made from raw sample and ameliorated of Tattaguine and that of Ndouloumadjie improved, the mold (10 × 10 × 5) was used (Figure 6). The filling of the mold is done in one go and suffers five consecutive blows until what is observed any settlement. Equation (3) is used to determine the compressive strength of those adobe bricks.

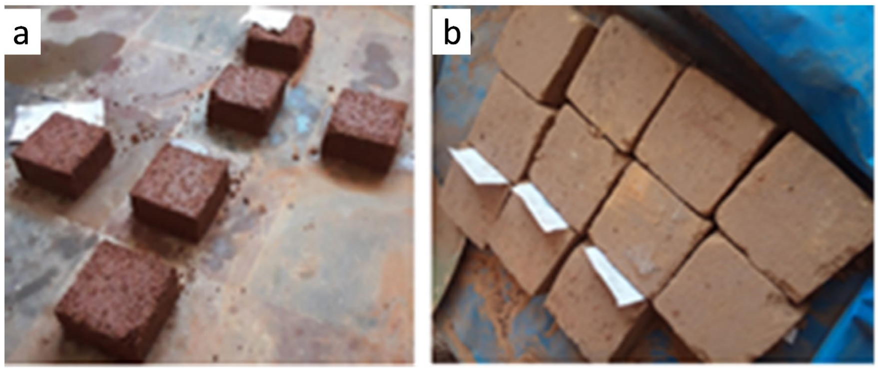

Figure 6. Adobe bricks and adobe bricks improved with millet involucre samples.

Thermic characterization consists to determine thermic parameters such as conductivity (λ) effusivity (E) and thermic Resistance (Rth) of raw and improved earth briquettes with involucre of millet. The thermic properties are determined using the plate method kept warm. This latest is a device which makes it possible to measure the thermic conductivity (λ) and thermal Resistance (Rh). A heat flow is generated by Joule effect at the center of a plate kept warm. The perimeter of the heating zone is surrounded by an electrical resistance, the guard. A regulation maintains a difference of null temperature between the guard and the heating zone. The flux which crosses a pair of test specimens, placed on either both sides of the hot plate, is then unidimensional. Two cold plates placed against the outer faces of the specimens allow them to set their temperature. Because of the two samples are identical the flow crosses at equal share each eprouvette. Measurement of two sides of each temperature on sample, once permanent regime reached then allows to calculate the thermic conductivity and deduct the thermal resistance.

$$\lambda = Q * L/\Delta T \quad \text{en W/m·K} \quad (4)$$

QL: steady state heat flow;

ΔT: $T_a - T_b$ = thermal gradient;

L: sample thickness.

2.4. Numerical Approximations

The tests carried out in the laboratory make it possible to have results on very challenging changes. Then, use the techniques of interpolation and approximation are used [11] [12]. These are two techniques which make it possible to represent by one simple function, but in an approached way, an unknown function which we acknowledge the value in a certain number of points. Hence, it comes to the thermo-mechanical properties on the whole extension interval of the mixture. Two approximation methods will be used in the frame of this work, namely the Lagrange method and the Newton method (divided differences). The two methods will allow to do an approximation of compressive strength by polynomial: First of all, through Equation (5) and Equation (6), then Newton polynomial (divided differences) through Equations (7)-(9).

$$P_n(x) = \sum_{i=0}^{n} y_i L_i(x) \tag{5}$$

L_i is Lagrange polynomial define by:

$$L_i(x) = \prod_{j\neq 1}^{n} \left[(x - x_j) / (x_i - x_j) \right] \quad i = 0, 1, \cdots, n \tag{6}$$

Newton polynomial (divided differences method) by function:

$$P_n(x) = f[x_0] + f[x_0, x_1](x - x_0) + \cdots + f[x_0, \cdots, x_n] \prod_{k=0}^{n-1} (x - x_k) \tag{7}$$

with

$$f[x_{i-1}, x_i] = (y_i - y_{i-1}) / (x_i - x_{i-1}) \tag{8}$$

$$f[x_{i-2}, x_{i-1}, x_i] = \left[f(x_{i-1}, x_i) - f(x_{i-2}, x_{i-1}) \right] / (x_i - x_{i-2}) \tag{9}$$

These approximation methods are going to be couples with some laboratory data in order to extend the field of the study results. It is then to extend the results in numeric integrant of the points. This worked is executed by using the laboratory data in **Table 4** for the compressive strength and data in **Table 5** for the thermal variables. The tests are taken 14 days after dredging under shade on the raw test tubes or improved with millet involucre.

Table 4. Compressive strength of adobe bricks and adobe bricks improved with millet involucre.

Quarry	Parameters	
	% millet involucre	Rc (Mpa)
Ndouloumadjie Dembé (Matam)	Raw	1.25
	1%	1.42
	2%	1.65
	3%	1.53
Tataguine (Fatick)	Raw	1.15
	1%	1.38
	2%	1.54
	3%	1.39

Table 5. Thermal and physical characteristic of adobe bricks (thickness equal to 1.5 cm) and adobe brick improved with millet involucre.

Quarry	% of involucre	λ (W/mK)	Rth (m^2K/W)	E ($J/K/m^2/s^{1/2}$)
Ndouloumadjie Dembé (Matam)	Raw	0.847	0.018	1200
	1%	0.787	0.019	1218.91
	2%	0.690	0.022	1007.09
	3%	0.847	0.018	1200
Tattaguine (Fatick)	Raw	0.891	0.017	1317
	1%	0.817	0.018	1147.8
	2%	0.751	0.020	1130.18
	3%	0.668	0.022	1087.13

3. Discussion of Results

The results of the tests allow to have a second-degree polynomial given through Equation (10) for the Lagrange method.

$$P_2(x) = y_0 L_0(x) + y_1 L_1(x) + y_2 L_2(x) \tag{10}$$

3.1. Uniaxial Compressive Strength

For the Ndouloumadjie earth bricks case, the uniaxial compressive strength is given through the following polynomial in relying on the recapitulated results in Table 4.

For Ndouloumadjie, we have:

Hence, we have for Lagrange:

$$P_2(x) = 1.42(x-2)(x-3)/2 - 1.65(x-1)(x-3) + 1.53(x-1)(x-2)/2$$

For Newton method, in accordance with Equation (7) mentioned above, we have Table 6.

Table 6. Newton coefficient calculation for Ndouloumadjie

i	x_i	y_i	$f[x_{i-1}, x_i]$	$f[x_{i-2}, x_{i-1}, x_i]$
0	1	1.42		
1	2	1.65	0.2300	
2	3	1.53	−0.1200	−0.1750

Hence, the following Newton polynomial:

$$P_n(x) = 1.42 + 0.23(x-1) - 0.1750(x-1)(x-2)$$

For Tattaguine, we have the same $L_i(x)$ $i = 0,1,2$, as for Ndouloumadjie, we have the following Lagrange polynomial:

$$P_2(x) = 1.38(x-2)(x-3)/2 - 1.54(x-1(x-3) + 1.39(x-1)(x-2)/2$$

Due to $n = 2$, the Newton polynomial writes:

$$P_n(x) = f[x_0] + f[x_0, x_1](x - x_0) + f[x_0, x_1, x_n](x - x_0)(x - x_1)$$

$$P_2(x) = 1.38 + 0.16(x - 1) - 0.155(x - 1)(x - 2)$$

according to the presented results in Table 7.

Table 7. Newton coefficient calculation for Tattaguine.

i	x_i	y_i	$f[x_{i-1}, x_i]$	$f[x_{i-2}, x_{i-1}, x_i]$
0	1	1.38		
1	2	1.54	0.1600	
2	3	1.39	−0.1500	−0.1550

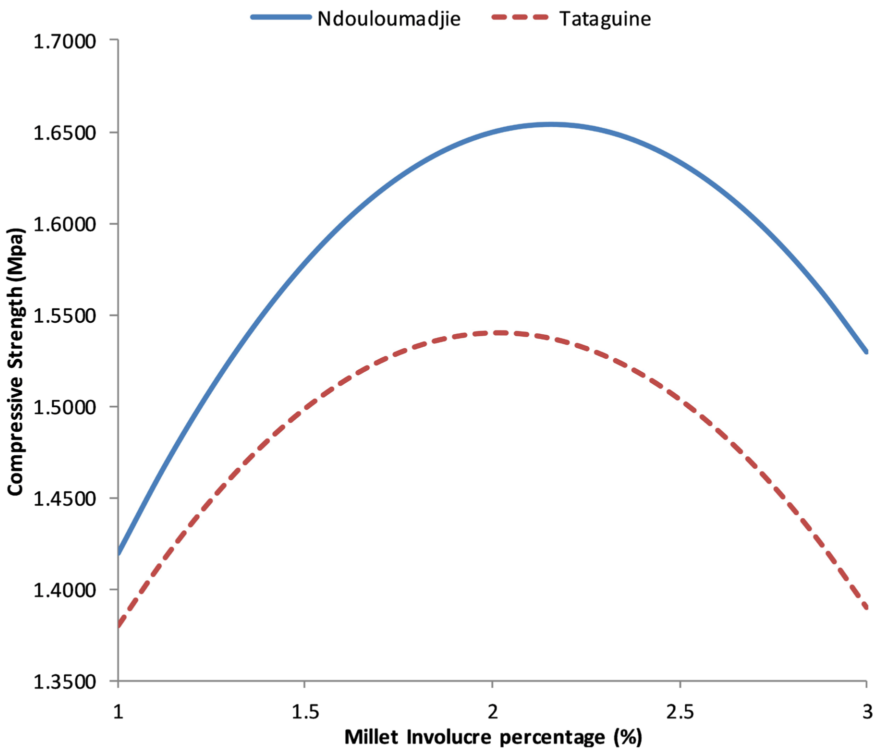

Figure 7. Compressive strength according to millet involucre percentage.

For these two materials, the shape of the resistance curves as a function of the percentage of millet involucre is identical even if the maximum values reached are different (Figure 7).

3.2. Thermal Capacity

By presenting the thermal capacity education in reference to the millet involucre percentage (Table 5 and Figure 6), its evolution is analyzed.

For Ndouloumadjie,

The Lagrange polynomial is the following:

$$P_2(x) = 0.787(x - 2)(x - 3)/2 - 0.690(x - 1)(x - 3) + 0.561(x - 1)(x - 2)/2$$

For the Tattaguine samples, we have:

$$P_2(x) = 0.817(x-2)(x-3)/2 - 0.751(x-1)(x-3) + 0.67(x-1)(x-2)/2$$

With Newton's method, we have Table 8 for Ndouloumadjie.

Table 8. Newton's coefficient calculation for Ndouloumadjie Tattaguine.

i	x_i	y_i	$f[x_{i-1}, x_i]$	$f[x_{i-2}, x_{i-1}, x_i]$
0	1	0.787		
1	2	0.690	−0.0970	
2	3	0.561	−0.1290	−0.0160

$$P_n(x) = 0.787 - 0.097(x-1) - 0.016(x-1)(x-2)$$

For Tattaguine,

$$P_n(x) = 0.817 - 0.066(x-1) - 0.0085(x-1)(x-2)$$

With Newton's method, we have Table 9 for Tattaguine.

Table 9. Newton's coefficient calculation for Tattaguine.

i	x_i	y_i	$f[x_{i-1}, x_i]$	$f[x_{i-2}, x_{i-1}, x_i]$
0	1	0.817		
1	2	0.751	−0.0660	
2	3	0.67	−0.0830	−0.0085

The obtained tends for the Newton method in the case of the uniaxial compressive strength, and the thermal capacity are the same as those obtained through Lagrange method (Figure 8).

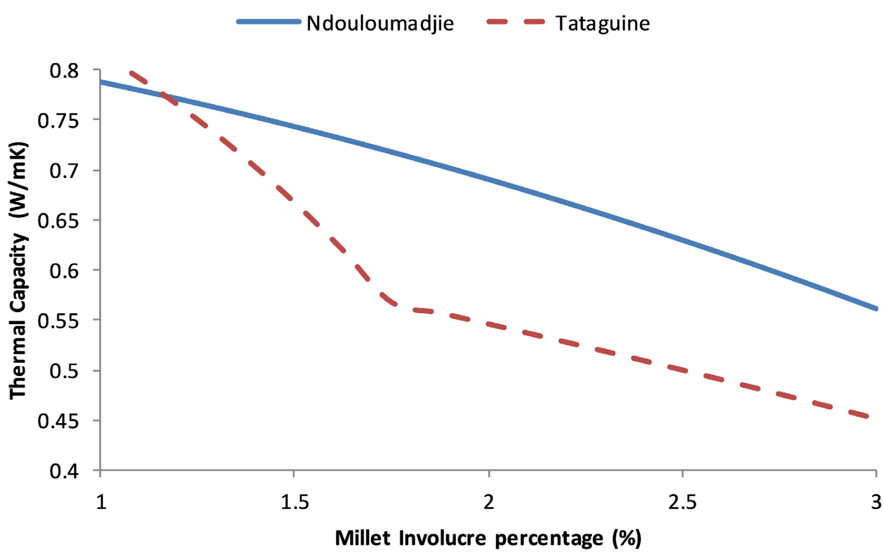

Figure 8. Thermal capacity according to millet involucre percentage.

3.3. Correlation between Thermal Capacity and the Uniaxial Compressive Strength

In this part, we study the correlation between the compressive strength and the thermal capacity. It has been noticed that between 1% and approximately 2.125% of involucre, the raison of the resistance to the compression leader to a decrease of the thermal capacity (**Figure 9**). In contrast, between 2.125% and 3% of millet involucre capacity (**Figure 10**).

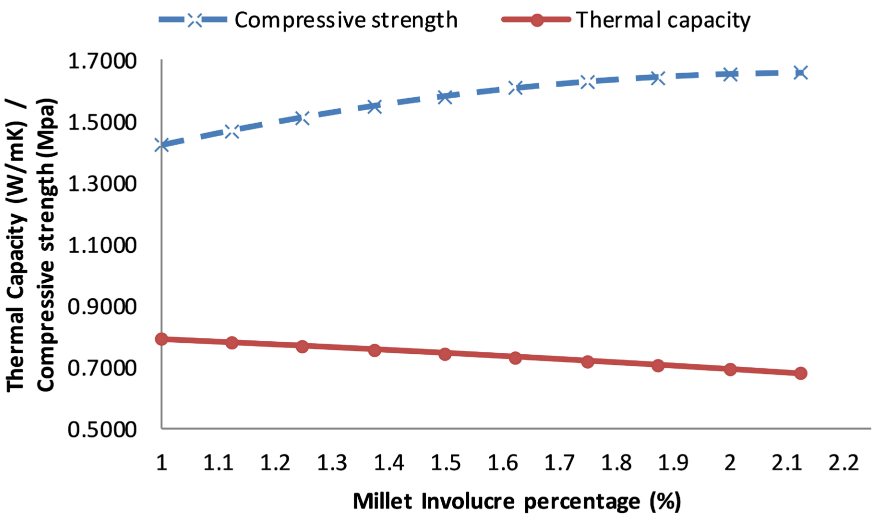

Figure 9. Compressive strength end thermal capacity correlation according to millet involucre percentage (1% to 2.125%) for Ndouloumadjie.

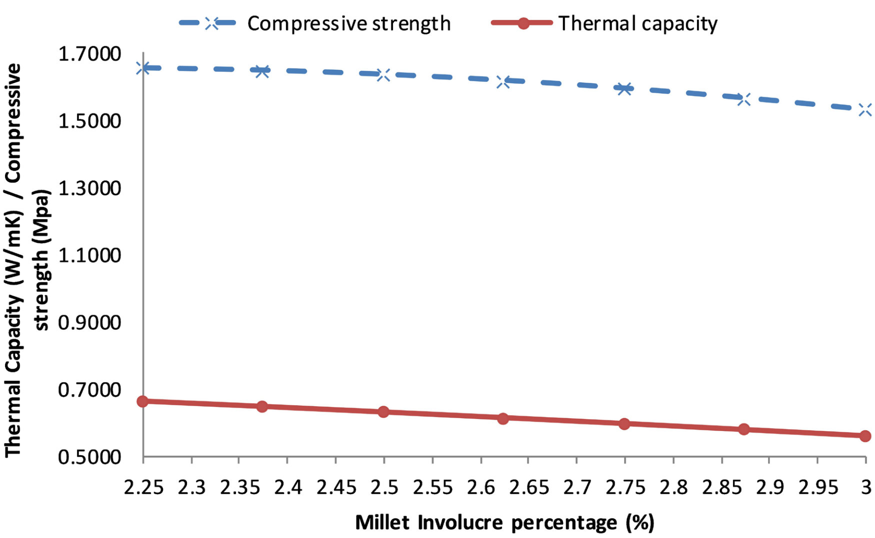

Figure 10. Correlation between the resistance to the compression and the thermal capacity in accordance with the involucre percentage (2.125% to 3%) for Ndouloumadjie.

We are going to calculate the linear correlation coefficient *r*, which given us a measurement of the intensity and of the meaning of the linear relation between two variables (**Table 10**), thermal capacity and the uniaxial compressive strength.

This coefficient is given through the following relation:

$$r = \left[\sum_{i=1}^{n}(x_i - \bar{x})(y_i - \bar{y})\right] \Big/ \left[\sum_{i=1}^{n}(x_i - \bar{x})^2 * \sum_{i=1}^{n}(y_i - \bar{y})^2\right]$$

where x_i corresponds to uniaxial compressive strength; y_i corresponds to the thermal capacity.

Table 10. Values for correlative coefficient calculation.

x_i	1.42	1.47	1.51	1.55	1.58	1.60	1.63	1.64	1.65	1.65
y_i	0.79	0.78	0.77	0.75	0.74	0.73	0.72	0.70	0.69	0.68

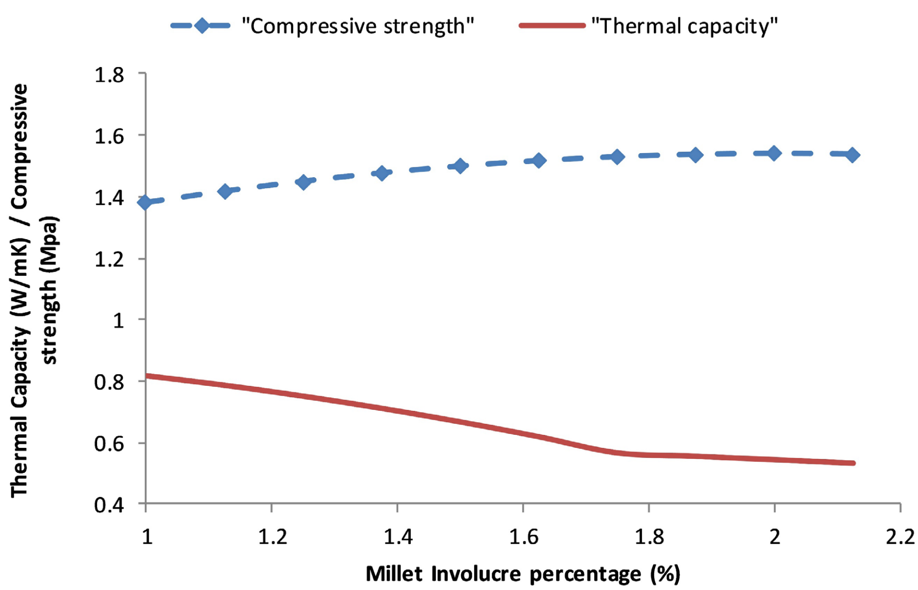

Figure 11. Compressive strength and thermal capacity correlation according to percent of millet involucre (1% to 2.05%) for Tattaguine.

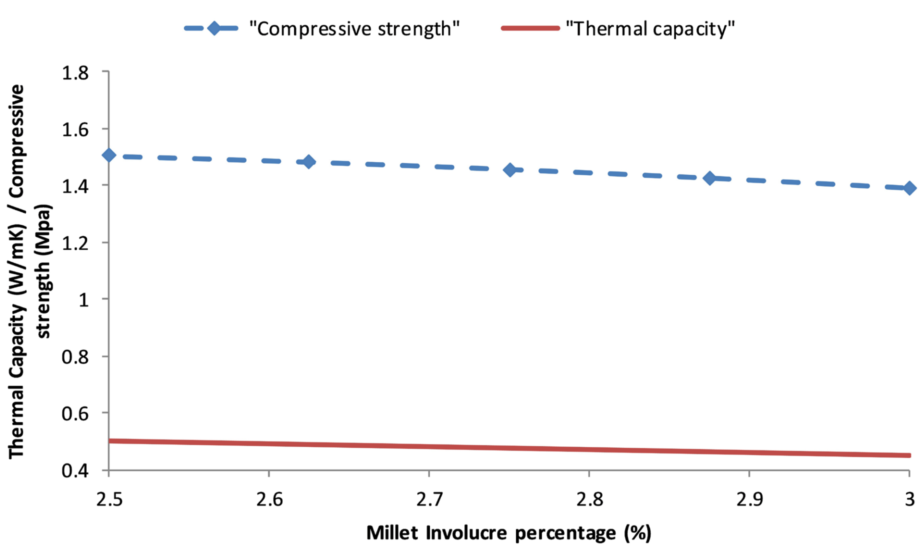

Figure 12. Variation of the thermal capacity in accordance with the resistance to the compression between 2.05% to 3% of millet involucre.

Let's be the averages $\overline{x} = 1.57$ and $\overline{y} = 0.73$.

Between 1% and 2.125% of millet involucre, we have for Ndouloumadjie a correlation coefficient $r = -0.997$ (**Figure 11**, **Table 7**) While for Tattaguine $r = -0.987$ between 1% and 2.05% and 3% that shows that the more the resistance to the compression raides on this interval, the conductivity increases meaning a bad thermal capacity (**Figure 12**).

3.4. Discussion

Test results for mud bricks (Ndouloumadjie and Tataguine samples) improved with millet involucre show that with the 1% and 2.125% improvement for Ndouloumadjie and 1% to 2.05% for Tattaguine, compressive strength gradually increases before gradually decreasing after these peaks to 1.67 MPa and 1.54 MPa respectively. These strength values obtained in are satisfactory for construction with local soil Materials (Rc > 0.6 MPa). The different silica ratios (higher for Tattaguine) are linked to their genesis, corresponding to simple transport for the termite mound and chemical alteration for the Matam sample. This genesis controls the values of iron and alumina moduli. At peak, the higher strengths for Ndouloumadjie than for Tattaguine are due to the phyllosilicate, iron and silica content of these materials. The ratios found in the Ndouloumadjie sample are more favorable to the manufacture of earthen eco-construction bricks and to the inactivity noted in the Matam sample, where Ca = 0.16 (≤0.75). Thermal test results show that the Ndouloumadjie Dembé sample has better thermal performance than the termite mound sample of the Tattaguine termite mound. Both samples have very good thermal performance. They are well suited to construction in intertropical countries like ours. These thermal qualities become even better with improvements using millet involucre. Millet involucre is an effective thermal regulator for ecological construction and saves energy. The materials with maximum particle size of 0.080 mm (**Figure 3**, **Table 1**) and with high plasticity are characterized by their aluminous phyllosilicate content. These minerals are able to regulate the temperature.

4. Conclusion

The samples collected at Ndouloumadjié and Tattaguine were first subjected to geotechnical and chemical identification tests. This material is then improved with millet involucre at 1%, 2% and 3%. Then, briquettes are made to assess the relationship between compressive strength and thermal parameters. Intermediate points at experimental percentages were modeled using Lagrange and Newton methods. The results showed that thermal capacity decreases continuously with involucre content, while compressive strength increases to a maximum value before decreasing progressively. These maxima correspond to the optimum resistance, while the thermal capacity is that of the corresponding mix. Although both materials have acceptable values, properties are better for Ndouloumadjie than for Tattaguine. The good correlation between these parameters is a function of fines content, iron, aluminum and silica content. Millet is a common cereal in Senegal, it is important to extend this work to more materials to impact more individuals.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

[1] Fall, M., Sarr, D., Cissé, E.M. and Konaté, D. (2021) Physico-Mechanical Characterization of Clay and Laterite Bricks Stabilized or Not with Cement. *Open Journal of Civil Engineering*, **11**, 60-69. https://doi.org/10.4236/ojce.2021.111004

[2] Kouakou, C.H. and Morel, J.C. (2009) Strength and Elasto-Plastic Properties of Non-Industrial Building Materials Manufactured with Clay as a Natural Binder. *Applied Clay Science*, **44**, 27-34. https://doi.org/10.1016/j.clay.2008.12.019

[3] Bruno, A.W., Gallipoli, D., Perlot-Bascoules, C., Mendes, J. and Salmon, N. (2015) Briques de terre crue: Procédure de compactage haute pression et influence sur les propriétés mécaniques. Rencontres Universitaires de Génie Civil.

[4] BACHIR (2014) Etude du comportement physico-Mécanique du bloc de terre comprimée avec fibre. Thèse de Doctorat de Génie Civil, Université Mohamed Khider, 183 p.

[5] Fall, M., Mbengue, A., Gueye, N.S. and Sall, O.A. (2021) Physico-Mechanical Characterization of Composite Bricks from Laterite, Typha and/or Rice Hull. *American Journal of Civil Engineering and Architecture*, **9**, 9-12.

[6] FAYCAL (2013) Conception, production et qualification des briques de terre cuite et en terre crue. Thèse de Doctorat de Génie Civil, Ecole Centrale de Lille, 123 p.

[7] Eurocode 6 (1996) Calcul des ouvrages en maçonnerie. AFNOR-CEN. Envi.

[8] Kabore, M. (2015) Enjeux de la simulation pour l'étude des performances énergétiques des bâtiments en Afrique sub-saharienne. Thèse de Doctorat de Génie Civil et Sciences de l'Habitat, Université de Grenoble, 195 p.

[9] Minke, G. (2006) Building with Earth Design and Technology of the Sustainable Architecture. Birkhäuser—Publisher for Architecture, 207 p.

[10] Roger, J., Noel, B.J., Barusseau, J.P., Serrano, O., Nehlig, P. and Duvail, C. (2009) Notice explicative de la carte géologique du Sénégal à 1/500000, feuilles nord-ouest, nord-est et sud-ouest. Ministère des Mines, de l'Industrie et des PME, Direction des Mines et de la Géologie, 61 p.

[11] Brezinski, C. and Redivo-Zaglia, M. (2013) Interpolation, approximation et extrapolation rationnelles. *Techniques de l'Ingénieur,* AF1390 V1. https://doi.org/10.51257/a-v1-af1390

[12] Brezinski, C. and Redivo-Zaglia, M. (2020) Extrapolation and Rational Approximation. Springer Nature. https://doi.org/10.1007/978-3-030-58418-4