Scientific Research Publishing

Open Journal of Civil Engineering, 2025, 15(2), 129-138
https://www.scirp.org/journal/ojce
ISSN Online: 2164-3172
ISSN Print: 2164-3164

Thermomechanical Characterization of Earth Bricks Made from Excavated Earth from Diamniadio in Senegal

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How to cite this paper: Sène, M.B., Bodian, S., Sène, N.A., Touré, A.O., Niang, I., Gaye, A., Thiam, G., Dieng, E., Diaw, I., Sakouvogui, A., Millimono, T.N., Faye, M. and Sambou, V. (2025) Thermomechanical Characterization of Earth Bricks Made from Excavated Earth from Diamniadio in Senegal. *Open Journal of Civil Engineering*, **15**, 129-138.
https://doi.org/10.4236/ojce.2025.152008

Received: March 26, 2025
Accepted: June 8, 2025
Published: June 11, 2025

Abstract

Earth, the raw material most used in the construction of buildings in Africa and particularly in Senegal, is a malleable material, easy to handle, from which hard bricks can be made. The objective of this work is to study the thermomechanical performances of raw earth bricks made from a mixture of excavated Diamniadio earth and cement. We carried out a series of experiments to measure the impact of adding cement on the mechanical and thermal properties of these earth materials. The results obtained show that earth bricks made from a mixture of excavated Diamniadio earth and cement can be used in the construction of buildings. However, the addition of cement improves the compressive strength of the material but increases the thermal conductivity of the material.

Keywords

Diamniadio Excavated Earth, Raw Earth Materials, Mechanical Properties, Thermal Properties

1. Introduction

The building is an object of concern in terms of health, energy consumption and environmental impacts. With more than 40% of global energy consumption and high CO_2 emissions, the building industry is among the most energy-intensive sectors. Indeed, from the beginning of the 1990s, the building sector was already positioned among the sectors that emit the most greenhouse gases, leading to major economic and environmental issues around the world [1]. Several solutions have been put in place to reduce the impact of buildings on energy consumption and, more generally, on the environment. They include the use of materials that have little impact on the environment and are more thermally efficient.

Long used as a natural building material alongside wood, earth is a material that appears to meet all of the above requirements due to its low environmental impact and interesting hygroscopic properties [2].

In advanced economies, earth construction was abandoned in favor of concrete for several decades after the Second World War [2]. Concrete, the most widely used material currently in Senegal, is unsuitable for the climatic conditions of Sahelian countries. In addition, cement production consumes a lot of energy and is a source of greenhouse gas emissions. This is why today the earth has become attractive again. The advantages of this material compared to the new requirements described above are clear: the resource is available in large quantities, the energy required to extract, transform and produce earth materials is low and it is a material offering workability easy allowing the manufacture of solid bricks. It is a completely recyclable material. Although there are numerous studies on the mechanical properties of earthen materials, there are few scientific studies on the thermomechanical properties of these materials.

Researchers have studied the thermal, mechanical and hygroscopic properties of earthen materials. Among them is the work of Meukam *et al.* [3] on the characterization of local materials used in the thermal insulation of buildings. They showed that laterite bricks incorporating natural pozzolan or sawdust have better thermal insulation than simple laterite bricks. Bal *et al.* [4] carried out a study on the valorization of local construction materials in Senegal with a view to improving their performance in terms of thermal insulation. They used the laterite plus millet pod mixture. The results showed that the gradual addition of the millet pod to the laterite significantly reduced the thermal conductivity of the final composite material. Sutcu [5] studied the influence of expanded vermiculite on the physical, mechanical and thermal properties of clay bricks. It was observed that the porosity rate improved with increasing vermiculite, while the compressive strength decreased. The thermal conductivity of the 10% porous vermiculite samples decreased from 0.96 W/m·K to 0.65 W/m·K. The author showed that samples of bricks produced by adding vermiculite can be used as an insulating material in construction. Demir [6] studied the effect of the addition of organic residues on the thermal properties of terracotta bricks. He mixed clay with sawdust, tobacco and grass residue. He reports that adding 5% organic residue improves thermal insulation properties in buildings.

Diatta *et al.* [7] studied three Senegalese clays from the regions of Ziguinchor and Tambacounda for use in the ceramic industry. The results reveal that these clays do not have all the satisfactory characteristics for the production of bricks and tiles. While the addition of certain organic materials could allow their use in the local traditional ceramic industry.

Kute *et al.* [8] studied clay bricks made from clay and fly ash. Laboratory tests were conducted to evaluate the compressive strength and water absorption of the bricks produced. The results showed that the use of fly ash increases the compressive strength and decreases the water absorption of the bricks. The highest compressive strength of 12.4 MPa (an average of eight samples) was obtained at 40% fly ash content and the corresponding water absorption being 13.8%. Abdessalam *et al.* [9] studied the mechanical and thermal properties of earth (clay) bricks. The materials are composed of a mixture of clay, dune sand and date palm fibers. He varied the percentage of sand from 0% to 40% and that of fibers from 0% to 3% by mass. The results showed that increasing the percentage of sand or fibers is beneficial for improving thermal properties with acceptable mechanical strengths. Walker *et al.* [10] determined the flexural and compressive strength of earth brick compressed and stabilized with cement. The results show that the flexural and compressive strengths are improved by increasing the cement content but this decreases with the increase in the clay content. Oti *et al.* [11] studied the physical and mechanical properties of lime-stabilized raw clay bricks. Laboratory results show that the compressive strength, moisture content, water absorption rate, void percentage, density and durability assessment meet acceptable technical standards for structural elements. clay masonry.

Millogo *et al.* [12] presented a study on clay blocks reinforced with Hibiscus cannabinus fibers. This study aims to establish the physical and mechanical properties of adobe blocks pressed and reinforced with Hibiscus cannabinus fibers. It has been established that the addition of 0.2% to 0.6% by weight of fibers of length 30 mm reduces the pore dimensions in pressed adobe blocks and improves their mechanical properties. However, the addition of 0.8% by weight of fibers of length 60 mm has negative effects on the compressive strength. Bodian *et al.* [13] determined the physical, mechanical and thermal properties of unfired and fired bricks made from a mixture of clay and laterite. Experiments were carried out with five clay brick compositions prepared by adding laterite (between 10% and 50% by weight). Test results showed that clay brick containing 30% laterite has the best compressive strength and thermal conductivity compared to other bricks. The works presented above show that some authors focused on laterite while others worked on clay. To our knowledge, there are no studies on the thermomechanical performance of earth bricks made from excavated earth from Diamniadio in Senegal. This is what motivates this research work.

The aim of this work is to study the thermomechanical performances of raw earth bricks made from a mixture of excavated Diamniadio excavated earth and cement. A series of experiments was carried out to measure the impact of the addition of cement on the mechanical and thermal properties of these earth materials.

2. Materials and Methods

In Africa, and particularly in Senegal, earth is the most widely used building material. The use of these materials therefore requires a good knowledge and mastery of their various physical, mechanical and hygrothermal properties. In this section, we present the materials used in the manufacture of our clay bricks. The procedures involved in preparing and making the bricks will also be explained. The recommended experimental methods will then be described, namely mechanical and thermal characterization methods.

2.1. Materials

The study was carried out on excavated clay soil from the Diamniadio Urban Pole (**Figure 1**). Diamniadio is located in the Dakar region of Senegal at 14˚43'13" north, 17˚10'57" west.

In this project, excavated soil from Diamniadio and CEM II 32.5 R cement from the company "CIMENT DU SAHEL" were used.

Figure 1. Clay soil of Diamniadio.

Earth Brick Production Process

Earth brick is a material mainly used to construct buildings. These bricks are made from clay which is transformed into a paste of regular consistency and fineness, which is moistened before shaping, then dried for a long time. Earth can be combined with other materials such as cement or hydraulic lime for greater hardness and resistance but we can also combine it with natural insulators for better insulating qualities. For our case, the samples were prepared by first mixing the clay and cement. The necessary quantity of water is then added until a paste of normal consistency and fineness is obtained. The cement content varies between 0 and 10% of the clay mass. At the end of mixing, the mixture is placed in prismatic molds measuring 4 cm × 4 cm × 16 cm for mechanical tests and 10 cm × 10 cm × 2 cm for thermal tests. The manufactured samples are dried at room temperature in the laboratory. Unmolding takes place 24 hours later.

2.2. Methods

2.2.1. Physical Characterization Method

1) Atterberg limits

The purpose of these tests is to determine the liquidity limit WL and the plasticity limit Wp of the raw materials. The difference between the liquidity and plasticity limits gives the plasticity index IP.

The liquidity limit (WL) was measured by the method of the dish of Casagrande and the plasticity limit (WP) by the method of the roller. These measures were realized according to the french standard [NF P94-051, 1993] [14].

2) Particle size analysis

Particle size analysis presents the percentage distribution of solid particles according to their dimensions.

For our raw materials, the particle size analysis was done according to two techniques: the coarser fraction (>80 µm) was analyzed by wet sieving, and the finer fraction (<80 µm) by sedimentometry according to the standard [NF P 94-057, 1992] [15].

2.2.2. Mechanical Characterization Method

1) Compressive strength

The compression test, used in this work, measures the compressive strength of a material an automated mechanical press in accordance with the standard (NF EN 196-1), type E0160 with a maximum pressure of 250 kPa (see **Figure 2**). The compressive strength is determined by applying a force to the axis of a test piece placed between the jaws of a press. This force is increased until the specimen breaks. The figure below shows a mechanical press.

Figure 2. Mechanical press.

2) Flexural strength

Flexural strength is measured by placing the cylindrical specimen transversely between the press plates. A rectangular parallelepiped strip of the material to be tested is placed on two supports and an increasing force is applied to the center of the strip until it breaks. The result is directly given by the device (see **Figure 3**).

Figure 3. Flexural testing device.

2.2.3. Thermal Characterization Method

The thermal characterization of a material makes it possible to obtain the thermo-physical properties of the material. In our study, we used the asymmetric hot plane method (Figure 4) which makes it possible to simultaneously measure the thermal conductivity and thermal effusivity of a material in a transient state in a short time.

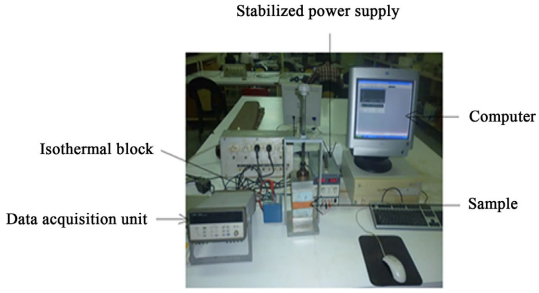

Figure 4. Experimental device of the asymmetric hot plane.

3. Results and Discussions

3.1. Physical Soil Characterization Results

3.1.1. Atterberg Limits

The results of the Atterberg limits of our material are shown in Table 1.

Table 1. Atterberg limits of the sample.

Atterberg limits	Liquid limit W_L (%)	Plastic limit W_P (%)	Plasticity index I_P (%)
Clay of Diamniadio	33	13	20

The results show that our material has a liquid limit $W_L = 33\%$, a plastic limit $W_P = 13\%$ and a plasticity index $I_P = 20\%$. This shows that Diamniadio clay is a moderately plastic material [16] [17].

3.1.2. Particle Size Analysis

The particle size distribution of our material is shown in Figure 5.

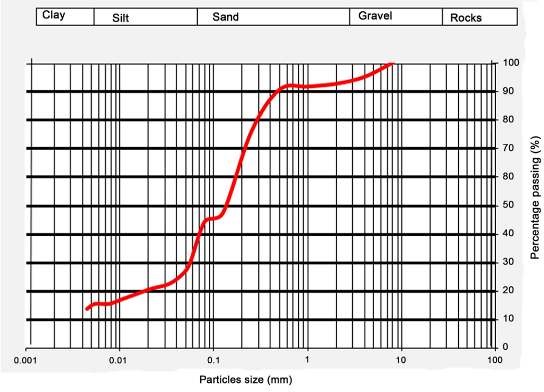

Figure 5. Particle size distribution curves of the material.

According to the distribution of granular fractions defined by NF EN ISO 14688-1 standard [17] [18], the results indicated that our sample is composed primarily of a fraction of 3% clay, 23% silt, 57% sand and 17% gravel.

3.1.3. Formulation of Manufactured Brick Samples

For the preparation of the samples, a mixture of a certain mass of clay with several doses of cement by weighing was carried out. The proportions of cement incorporated into the clay are shown in Table 2.

Table 2. Constitution of samples in%.

Designation Samples	E0	E2	E4	E6	E8	E10
Proportion of Cement (%)	0	2	4	6	8	10
Clay content (%)	100	98	96	94	92	90

3.2. Mechanical Results

3.2.1. Compressive Strength

Figure 6 shows the variation in the compressive strength of unfired bricks as a function of the percentage of cement. The results show that the addition of cement increases the compressive strength of unfired bricks. This is explained by the fact that cement is a binder which improves the resistance of the material. It is also noted that the compressive strength at 8% cement is substantially equal to that of 10% cement.

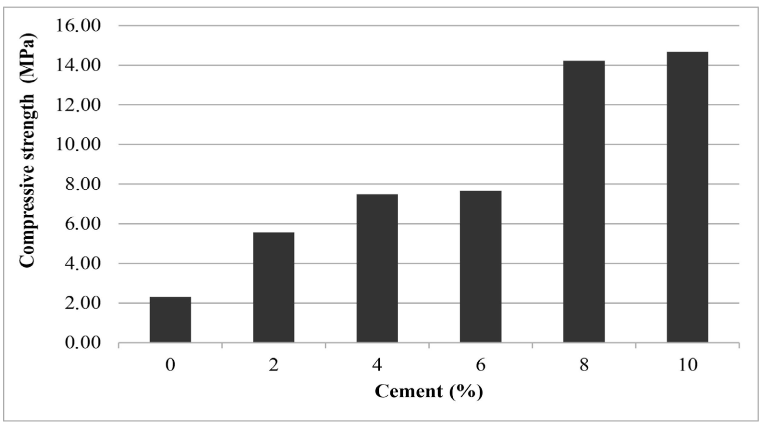

Figure 6. Variation in compressive strength of clay bricks as a function of cement addition.

3.2.2. Flexural Strength

Figure 7 shows the variation in the flexural strength of clay bricks as a function of the percentage of cement.

The results show that the addition of cement increases the flexural strength of clay bricks but only slightly. We note values greater than or equal to 1 MPa from an addition of cement of 8%. This value obtained at 8% is close to that obtained at 10% cement.

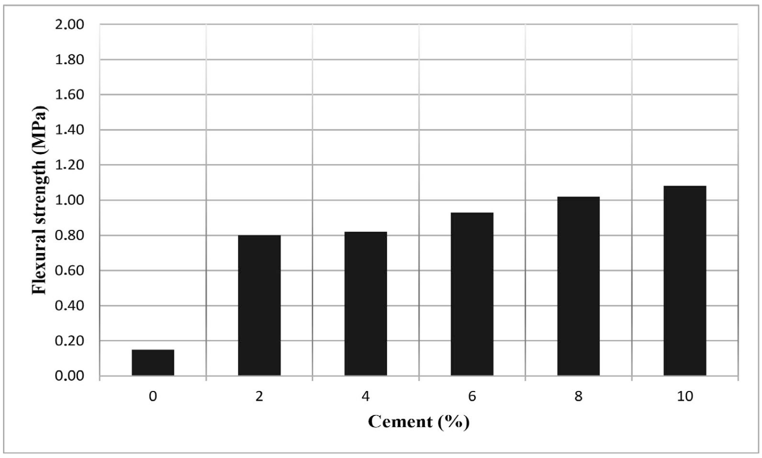

Figure 7. Variation in the flexural strength of raw earth bricks as a function of cement addition.

3.3. Thermal Results

Figure 8 shows the variation in the thermal conductivity of raw earth bricks as a function of the percentage of cement. The results show that the addition of cement increases the thermal conductivity of raw earth bricks. This increase in thermal conductivity is explained by the fact that cement is a conductive material.

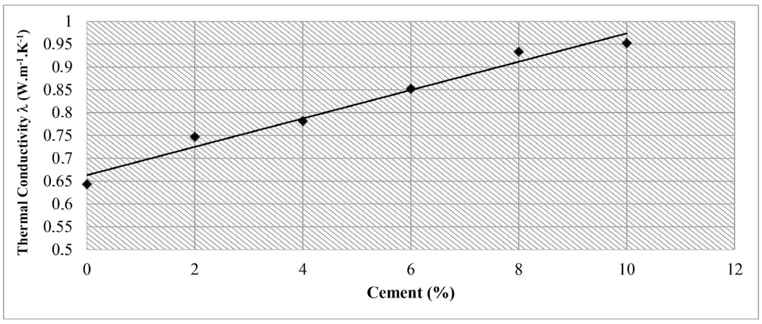

Figure 8. Variation in the thermal conductivity of raw earth bricks as a function of cement addition.

4. Conclusions

As a conclusion, it can be noted that the earth bricks excavated from Diamniadio can be used in the construction of housing. We can also remember that clay bricks are weak in flexural.

Due to the fact that at 8% cement, the compressive and flexural strengths of the samples are roughly equal to those of 10% cement. In addition, thermal conductivity is better at 8% cement than at 10%. Therefore, the 8% cement formulation can be chosen over the others. Further testing is required to select the best formulation.

Acknowledgements

We would like to thank the Higher Polytechnic School of Cheikh Anta Diop University for awarding us a grant under the Research Impulse Fund, 2021 edition, to carry out this work.

Conflicts of Interest

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

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