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Comparative study of the mechanical and thermal performance of two-clay-Based Compressed Earth Blocks (BTC) for housing building

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Abstract

This study is part of a sustainable construction approach by exploring the mechanical and thermal performance of compressed earth blocks (BTC) made from Dialakoro and Kita clays. BTC measuring 23 x 11 x 8 cm and cylindrical specimens measuring 5 cm in diameter by 10 cm in height were manufactured for the mechanical tests, and rectangular specimens measuring 27 x 27 x 3 cm were used for the measurement of thermal conductivity. The water absorption results by capillary action reveal a low resistance to humidity for the BTC from Kita (caused by rapid degradation in the presence of water) with a coefficient of -8 $g/cm^2{\cdot}s^1/^2$, compared to 2 $g/cm^2{\cdot}s^1/^2$ for those from Dialakoro, indicating better resistance to humidity. In terms of compressive strength, Dialakoro BTC averaged 6,85 MPa on the 28th day compared to 4,97 MPa for Kita. After 7 days, both types of BTC exceed the minimum permissible compressive strength for BTC, which is **2 MPa** according to the **NF EN 772-1** standard, with 3,86 MPa for Dialakoro and 2,29 MPa for Kita. Thermal conductivity measurements also show an advantage for Dialakoro's BTC with 0,86 W/m·K compared to 1,02 W/m·K for Kita's, suggesting better thermal insulation. These results confirm the superior potential of Dialakoro's BTC in terms of mechanical performance and thermal efficiency.

Keywords: Compressed Earth Blocks (BTC); Capillary Water Absorption; Compressive Strength; Thermal Conductivity; Sustainable Construction

1. Introduction

Clay has been the most widely used material on earth for several centuries. The various archaeological sites around the world bear witness to this.[1]

- Nowadays, earthen constructions are still visible on different continents.
- It is estimated that one-third of the world's population lives in earthen structures [2].

Despite the contribution of other resistant and durable materials (cement, lime, bitumen, steel, etc.) for construction through economic and technological development, the problems of global warming have forced man to use healthy materials that do not emit greenhouse gases. This has encouraged the return of earth in construction. The first reason is the availability of land and its proximity to the construction site. The implementation, which is relatively easy, does not require heavy materials and equipment, let alone advanced technology. The earth material does not require energy for its implementation and it has excellent thermal inertia due to its high density. This thermal inertia makes it possible to have a cool home in summer and warm in winter. On the other hand, the earth material also has disadvantages such as low mechanical strength and high sensitivity to water. Man has always thought about finding solutions to the inadequacies of the earth material using several means of stabilization, such as mechanical, chemical and physical,

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which allowed the invention of the different earth products, these are: adobe; cob; rammed earth; terracotta bricks, and compressed earth block (BTC). Among the various raw earth building material products, BTC is the recent version of adobe, which has the advantage of limited shrinkage, high strength, low water sensitivity and a well-erect shape with straight edges. , [1][2]

The building trade accounts for a significant share of global energy consumption and greenhouse gas (GHG) emissions. Faced with growing environmental and economic challenges, the optimization of building materials is becoming an essential lever to promote more sustainable and eco-responsible architecture. The use of local, minimally processed materials with a low environmental impact is therefore a priority in the search for alternative solutions to conventional materials such as concrete or fired bricks, which require highly energy-intensive manufacturing processes. In this context, compressed earth blocks (BTC) appear to be a promising solution. Used for centuries in traditional construction, these blocks are now being re-evaluated from a modern perspective thanks to technological advances and new building standards. They are distinguished by their low carbon footprint, their ability to naturally regulate indoor humidity and their thermal performance that contributes to the comfort of the occupants. Compressed earth blocks are building blocks obtained by mechanical compaction of a mixture of earth and water, with or without the addition of stabilizers such as lime or cement. [3]

The effectiveness of BTC depends largely on the properties of the clay used. The Dialakoro clays (located in the Sikasso region of Mali) and Kita (located in the region of the same name in Mali), two regions known for the richness and quality of their clay soils, have mineralogical and particle size compositions that can influence the mechanical and thermal characteristics of the blocks.

The comparative study of these two types of clays will therefore make it possible to assess their potential as sustainable building materials and to identify their advantages and limitations according to the requirements of the building sector.

The main objective of this study is to evaluate and compare the mechanical and thermal performance of BTC made from Dialakoro and Kita clays, in order to determine their suitability for use as sustainable building materials.

In this context, the central question of this research is the following:

How are the mechanical and thermal characteristics of BTCs that are made from the clays of Dialakoro and Kita different, and what implications might this have for their use in sustainable construction?

2. Methodology

The methodology adopted for this study is based on four (4) main parts:

- The presentation of the materials used,
- The presentation of the specimens produced,
- The geotechnical characterization of the basic materials (Dialakoro and Kita clays),
- The mechanical and thermal characterization of BTC.

2.1. Presentation of the materials used

The materials used for the production of our test tubes are: Dialakoro and Kita clays and drinking water provided by SOMAGEP-SA.

2.2. Presentation of the specimens produced

We have produced:

- Cylindrical specimens of diameter and height intended for capillary water absorption and compression tests;$\phi = 5cmH = 10\ cm$
- BTC dimensions for compression testing;$23\ x\ 11\ x\ 8\ cm$
- Rectangular specimens of dimensions intended for the measurement of thermal conductivity.$27\ x\ 27\ x\ 3\ cm$

Cylindrical test pieces BTC Bricks : Rectangular test tubes

Figure 1 Test tube and brick products

2.3. Geotechnical characterization of the base materials

2.3.1. Particle size analysis by sieving

Purpose of the Experiment

It determines the distribution of grains by weight of the elements of a material according to their size.

Principle of the Experiment

Sieving is carried out for elements of dimensions greater than or equal to 0.08mm on a series of sieves.[4]

Figure 2 Experimental set-up for particle size analysis by dry sieving

2.3.2. Atterberg Limits

Purpose of the Trial

The aim is to characterise the consistency of a soil as a function of water content.
Three conventional physical constants are defined:

- Liquidity limit **WL**: Transition from liquid to plastic.
- WP **plasticity limit**: transition from plastic to solid state.
- WS shrinkage limit : Transition from solid state without shrinkage to solid state with shrinkage.

Principle of the Experiment

The principle of the trial is as follows:

- Finding the liquidity limit using the CASAGRANDE device.
- Search for the plasticity limit by making rolls of 3mm in diameter.

Liquidity Limit

The WL liquidity limit is the water content (expressed in **%**) of a reworked soil characterizing the transition from a liquid state to a plastic state that corresponds to a 25-shock closure.

The Atterberg limit is applied to fine soils whose elements pass through the 0.4mm sieve .[5]

The test was carried out in accordance with the **NF P94-051 standard.**

Figure 3 Liquidity Limit Trial Set-up

Plasticity limit

The plasticity limit consists of determining the water content of a moist soil in the form of a roll, diameter (**Φ = 3 mm**) and length (**L = 10 to 15 cm**) when it passes from the plastic to the solid state.[5]

The test was carried out in accordance with the **NF P94-051 standard**.

Figure 4 Experimental device of the plasticity limit

Plasticity index

The plasticity index is the difference between the values of the liquidity limit and the plasticity limit.

$$\boldsymbol{I_p = W_L - W_P} \quad (1)$$

2.3.3. Absolute density

The density of solid soil particles in $\boldsymbol{\rho_s}$ ***(g/cm3)*** is the ratio of the mass of these solid particles (**Ws**) to their absolute volume (**Vs**).

The density of our sample is measured in accordance with the standard **NF P 94-054** with a water pycnometer. This method uses solid soil particles that are not larger than 2 mm in diameter.[6]

Figure 5 Pycnometer test experimental set-up

2.3.4. Normal Proctor

Purpose of the Experiment

The purpose of the Proctor test is to determine the optimum water content () and maximum dry density by means of a standard compaction (of known intensity) or for a given compaction energy $\omega_{opt}(\gamma_{d\,max})$.

Principle of the Experiment

Samples of the same soil with different water contents are compacted in a normal mould (or standard mould) in the same way. The dry densities obtained vary with the water content of the samples at the time of compaction. This density passes through a maximum which is obtained for an optimum water content.[7]

The test was carried out in accordance with the **NF P94-093 standard**.

Figure 6 Proctor Normal trial investigational device

2.4. Characterization of compressed earth blocks (BTC)

2.4.1. Physical characterization

Water absorption capacity by capillary action

The capillary water absorption test is essential to evaluate the porosity and the ability of a material to absorb moisture. It is particularly relevant for building materials such as BTC, as it allows you to appreciate their durability and their behaviour in the face of water.

Objective of the experiment

The objective of this test is to measure the speed and quantity of water absorbed by capillary action of a porous material when it is in contact with a water source. It is used to assess its sensitivity to moisture and its suitability for use in construction.

Principle of the experiment

The test is based on the phenomenon of capillarity, where water rises in the material through pores and micro-cracks as a result of adhesion and cohesion forces. The amount of water absorbed is measured as a function of time, allowing the coefficient of water absorption by capillary action to be calculated.

Procedure

- Specimens are selected and put in an oven at 105°C for 24 hours to ensure complete removal of water.
- After complete drying, each specimen is weighed (initial dry mass **Mi**).
- They are placed in a tank of water with an immersion limited to 5cm in height
  (50% of the total height of the individual specimens) and then the stopwatch is started immediately.
- After 5 minutes, each of them is gently removed from the water and the surface is quickly wiped with a paper towel or a dry cloth to remove the unabsorbed water and then immediately they are weighed (wet mass **Mf).**
- Calculation of the coefficient of water absorption by capillary action:

The coefficient of capillary absorption is calculated by the following formula:

$$C_{ab} = \frac{M_f - M_i}{S * \sqrt{t}} \qquad (2)$$

With: C_{ab} : Capillary absorption coefficient (**g/cm²·s¹/²**).

M_i**:** Initial dry mass of the specimen (**g**).

M_f**:** Wet mass of the specimen after immersion (**g**).

S**:** Immersion surface (**fifth grade**)

t**:** Immersion time (**Seconds**)

Figure 7 Experimental device of the water absorption test by capillary action

2.4.2. Mechanical characterization

In this study, we are interested in the determination of the compressive strength of cylindrical specimens and BTC.
For each test, three cylindrical specimens and three BTC were tested.

The tests were carried out at 7, 14 and 28 days, thus making it possible to monitor the evolution of mechanical strength over time.

Compressive strength of cylindrical specimens

This test is used to determine the nominal compressive strength of cylindrical specimens. This involves subjecting the specimens to simple compression until they break at 7, 14 and 28 days.

The manual 60KN CBR press from the Civil Engineering Laboratory of ENI-ABT was used for our test.

Procedure

- The specimen is placed by centering it on the bottom plate of the press, making sure it is properly aligned with the top plate (piston).
- The piston is lowered until it comes into contact with the specimen.
- The initial load is checked to be almost zero before starting the test.
- The manual press works with a cylinder activated by a lever, which allows the force to be gradually applied to the specimen. The lever is turned slowly and steadily to avoid a sudden shock (application of the load).
- The application of the load is continued until the specimen breaks (cracks or collapse). The value of the maximum breaking load is read directly in **KN** on the press' pressure gauge.
- The compressive strength is obtained by the following formula:

$$\boldsymbol{R_c = 10 * \frac{F_{max}}{S}} \qquad (3)$$

With: $\boldsymbol{R_c}$ The compressive strength of specimens in **Mpa**

$\boldsymbol{F_{max}}$**:** The breaking load in **KN**

$\boldsymbol{S}$**:** The compression surface of the specimen in **fifth grade**

Figure 8 Experimental device for the compression test on cylindrical specimens

Resistance to BTC compression

BTC bricks are selected and subjected to the 7, 14 and 28-day compression test. The hydraulic press of the Civil Engineering Laboratory of ENI-ABT was used for our test.

Procedure

- The BTC is placed in the center of the lower plate of the press to ensure proper axial loading. We make sure that it is well aligned with the upper plate in order to avoid off-center efforts that could distort the results.
- The trial involves applying an increasing load until the BTC breaks. The load is applied gradually and continuously at a constant speed. The recommended loading speed is usually **0.5 to 1 Mpa/s**
- At breakage, the value of the maximum load is directly read in **KN** on the pressure gauge of the press.
- The compressive strength is obtained by the following formula:

$$\boldsymbol{R_c = 10 * \frac{F_{max}}{S}} \qquad (4)$$

With: $\boldsymbol{R_c}$ The compressive strength of BTC in **Mpa**

$\boldsymbol{F_{max}}$**:** The breaking load in **KN**

$\boldsymbol{S}$**:** The cross-sectional area of BTC in **fifth grade**

Figure 9 Experimental setup of the BTC compression assay

2.4.3. Thermal characterization

In this study, we are interested in the measurement of thermal conductivity on rectangular specimens.

Measurement of thermal conductivity

It characterizes the ease with which heat enters the material. It is always positive and corresponds to the density of the heat flux passing through a homogeneous body subjected to a temperature gradient of 1 Kelvin (or 1°C) per metre in a steady state.

Thermal conductivity depends mainly on the nature of the material and the temperature.

The measurement of thermal conductivity was made using a device set up by the thermal laboratory of ENI-ABT.

Thermal Conductivity Measurement Protocol

Instrumentation

- Thermal conductivity measuring device
- Clamp meter (to measure the current of the electric heating resistor)
- Voltmeter (to measure the voltage of the electric heating element)
- Five (5) T-type thermocouples or any other type available for measuring different temperatures
- Conversion table of the thermocouple used (Type K for our test)
- Dewar vase containing melting ice (or a thermos)
- Autotransformer 0 – 240 V
- Air-conditioned room

Procedure

- **Thermocouple Positioning**
  - A thermocouple is fixed in the centre of each side of the specimen, using plaster, a very thin layer, to measure the temperature of the faces of the specimen. We wait for the plaster to dry;
  - A thermocouple is positioned between the hot plate and the bottom of the plate to measure the temperature of the air on the hot side;
  - The fourth thermocouple is suspended in the air of the room next to the apparatus, for the measurement of the temperature of the room;
  - The fifth thermocouple is placed in the melting ice contained in the Dewar mud (or in the thermos) for the measurement of the reference temperature.

Measurement process

- The room's air conditioner is turned on at a temperature of no more than 25°C (21°C for our test);
- The specimen is placed in the apparatus in the designated place;
- The edges of the specimen are insulated to prevent movement between the heating plate and the room;
- The autotransformer is adjusted to have an output voltage of less than 60 V to supply the heating element;

- Temperature, intensity and voltage measurements are made every 30 minutes to ensure that the temperature gradients are established correctly;
- We wait about 10 to 12 hours to resume the measurements mentioned above for 2 hours (the permanent regime should be obtained);
- The coefficient of losses is measured;
- After the steady state at which the measurements have been made, the voltage is reduced to 30 V;
- We hear that the temperatures of the two sides of the specimen are identical, this can take hours;
- The measurements are then carried out.

Experimental outcomes (Only steady-state values are used)

Heating power$P = U * I = C * (T_{air\ chaud} - T_{air\ local})$

Hence the loss coefficient: (in $C = \frac{U*I}{T_{air\ chaud} - T_{air\ local}}$**W/°C**) (5)

The net power passing through the specimen:

$P_{ep} = P - C * (T_{air\ chaud} - T_{air\ local}) = \frac{\lambda * S * \Delta t}{e}$

Hence the thermal conductivity coefficient:

$$\boldsymbol{\lambda = \frac{P_{ep} * e}{S * \Delta t}} \quad (6)$$

Where: = thickness of the specimen;e

S = surface area of the specimen;

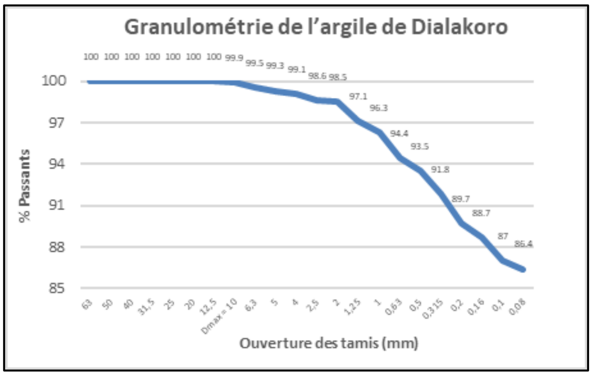
$\Delta t = T_{face\ chaude} - T_{face\ locale}$= temperature difference between the two sides of the specimen.

Figure 10 Experimental device for measuring thermal conductivity

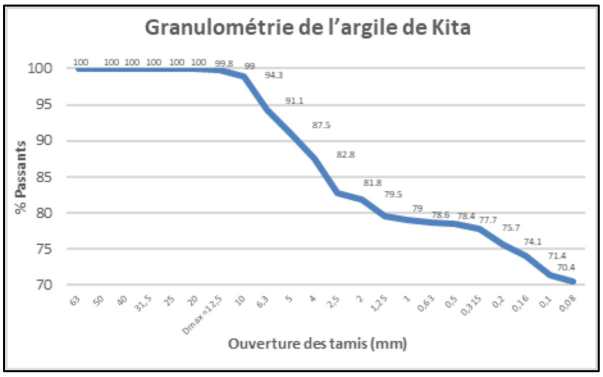
3. Results and discussions

3.1. Geotechnical characteristics of the base materials

3.1.1. Particle size analysis by sieving



Particle size curve of Dialakoro clay



Particle size curve of Kita clay

Figure 10 Particle size curves

Table 1 Results of the sieve particle size analysis

% of particles	Dialakoro Clay	Kita Clay
% Fines	86.4	70.4
% of sand	11.4	24.6
% Gravel	2.2	5

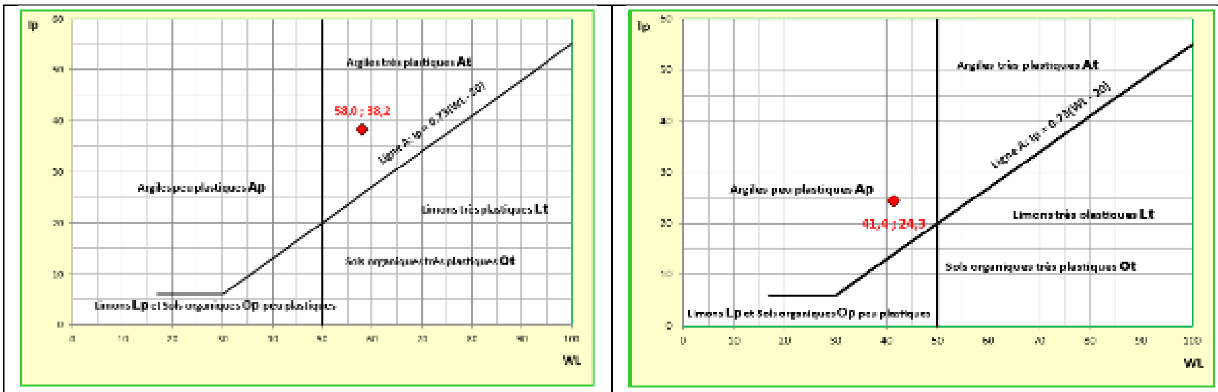
The particle size analysis revealed marked differences between the two clays studied:

- For the Dialakoro clay, the particle size distribution shows that about 86.4% of the particles are fine, 11.4% sand and 2.2% gravel. This abundance of fine particles can give the material excellent plasticity and cohesion when mixing. This can be essential for compaction.
- For Kita clay, the proportion of fines is lower, at about 70.4%, accompanied by a higher proportion of sand (24.6%) and a notable presence of gravel (about 5%). This particle size distribution results in a less plastic, but potentially more dimensionally stable material, which can limit shrinkage and cracking during drying.

3.1.2. Atterberg Limits

Table 2 Atterberg Limit Results

	Dialakoro Clay	Kita Clay
WL Liquidity Limit (%)	58	41.4
WP Plasticity Limit (%)	19.85	17.06
IP Plasticity Index (%)	38.15	24.34
Plasticity	Very plastic	Low plastic



Classification of the Dialakoro clay	Classification of Kita Clay

Figure 11 Classification of the Dialakoro clay on the Casagrande diagram

The analysis of the Atterberg limits has shown that the Dialakoro clay is more plastic than the Kita clay. This makes it easier to work with (ease of molding), but also more prone to shrinkage and cracking during drying. On the other hand, Kita clay, which is less plastic, is more stable after drying but more difficult to process (poses challenges during compaction).

These differences have a direct impact on BTC performance:

- Dialakoro's BTC is more homogeneous and resistant to compression, but it requires controlled drying to prevent cracking.
- Kita's BTC is more stable when dried, but it is likely to be more porous and less mechanically resistant.

3.1.3. Absolute density

Table 3 Absolute Density Results

	Dialakoro Clay	Kita Clay
Specific density ρ_s(g/cm3**)**	2.32	2.42

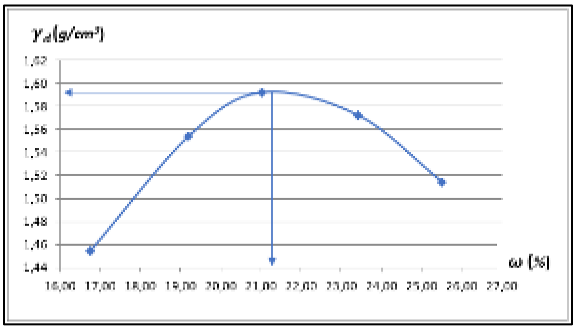
The results show that the Dialakoro clay has a lower absolute density than that of Kita with a value of 2.32 g/cm3 compared to 2.42 g/cm^3.

- A higher density (such as that of Kita clay) is often associated with greater thermal conductivity, as dense materials promote faster heat transmission. This means that Kita's BTC may perform worse in terms of thermal insulation.
- On the other hand, a lower density (such as that of the Dialakoro clay) is often linked to low thermal conductivity and higher thermal inertia, which would allow BTC to better store and release heat, thus improving the thermal comfort of buildings.

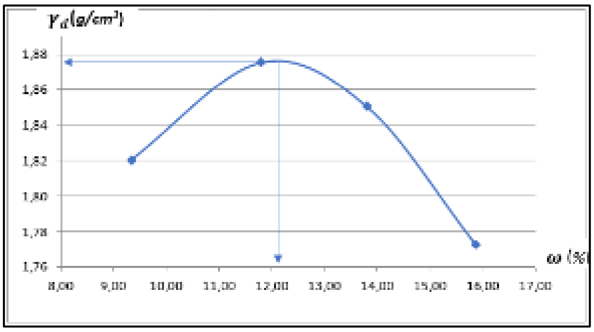
3.1.4. Normal Proctor

Table 4 Proctor Normal trial results

	Dialakoro Clay	Kita Clay
Optimal water content ω_{opt} (%)	21.25	12.15
Maximum Dry Density (g/cm$\gamma_{d\ max}{}^3$)	1.59	1.88



Natural Proctor of Dialakoro Clay



Proctor Normal for Kita Clay

Figure 12 Normal Proctor Curves

Tests show that the Dialakoro clay has a higher optimal water content than Kita but a lower maximum density than Kita.

These results from the Proctor trial show that:

- Dialakoro clay requires more water to achieve good compaction, but it offers better cohesion and water resistance.
- Kita clay with a higher density, requires less water to be compacted, but it can be more porous and less cohesive, which affects its mechanical strength and durability.

3.2. Physical, mechanical, and thermal characteristics of BTC

3.2.1. Water absorption by capillary action

Table 5 Results of water absorption by capillary action

	Dialakoro test tube	**Kita Specimen**
Capillary absorption coefficient C_{ab} (g/cm^2·s$^{1/2}$)	2	8

Tests show that Dialakoro specimens have a lower capillary water absorption capacity with stability after immersion *(see figure7)* due to a more homogeneous structure and good cohesion between fine particles, while Kita's specimens have a higher capillary water absorption capacity with signs of degradation after immersion *(see figure7)* due to higher porosity and rapid water infiltration. Indeed, after the test, the absorbed water was partly retained by the cylindrical Kita specimens. But there has been degradation of a significant quantity of materials. Thus, the sum of the lost particles and the retained water resulted in a final wet mass lower than the initial dry mass, resulting in a negative value of the capillary absorption coefficient. This prevented a reliable measurement of the capillary absorption capacity.

These results show that Dialakoro's BTC are more resistant to moisture than Kita's. This difference is due to the particle size, porosity and plasticity of the clays used.

These suggest that Dialakoro BTC can be used without stabilization in moderately humid environments and that Kita's BTC require stabilization (cement, lime or natural fibers) and surface treatment to reduce porosity, improve cohesion and ensure durability.

3.2.2. Compressive strength

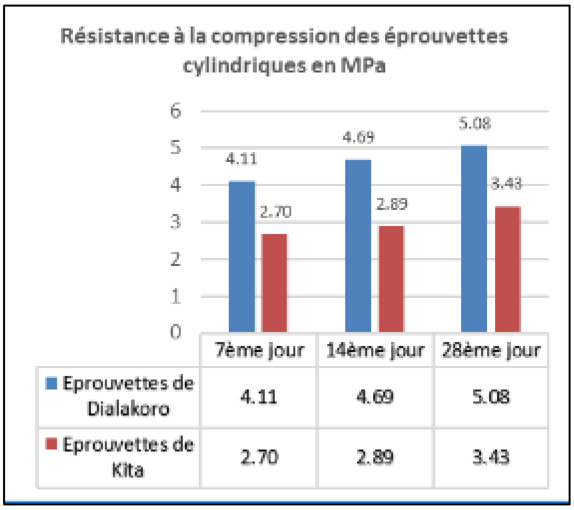


Figure 13 Results of the compression test on cylindrical specimens

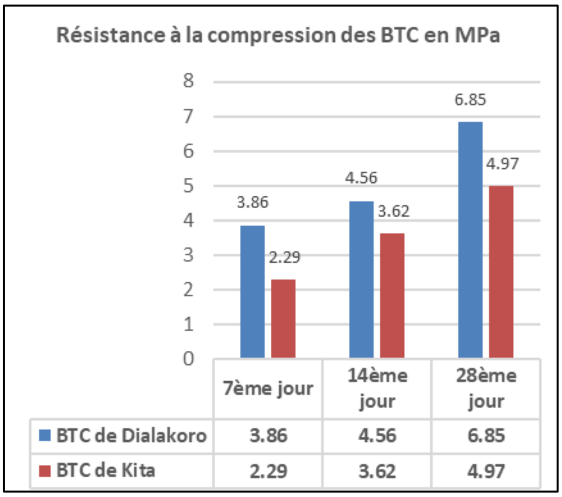


Figure 14 BTC Compression Test Results

4. Discussions

BTC and specimens made from Dialakoro clay have significantly higher compressive strength than Kita.

This difference is due to the finer and plastic nature of Dialakoro clay, which improves the cohesion of the mixture and reduces the porosity of BTC. On the other hand, Kita clay, which is richer in sand, results in a more porous and less homogeneous structure, thus reducing compressive strength.

The increase in strength over time is observed for both types of clay. However, this increase is more marked for Dialakoro clay test tubes and BTC. This suggests that this clay has a better hardening capacity after drying, probably due to better reorganization of fine particles and more efficient compaction.

At 28 days, there is a greater resistance gain, especially for Dialakoro BTC which reaches 6.85 MPa, compared to 4.97 MPa for Kita's.

According to the standard **NF EN 772-1 and other standards** BTC have a guaranteed minimum compressive strength of **2 MPa**[8], . Comparing this value with those obtained, we can see that the BTC studied can be used in the construction of only 7 days with an average of 3.86 MPa for Dialakoro BTC and 2.29 MPa for Kita BTC respectively. [9]

4.1. Thermal conductivity

Table 6 Results of the thermal conductivity measurement

	Dialakoro test tube	Kita Specimen
Thermal conductivity coefficient **λ** (W/m. K)	0.86	1.02

The analysis of the experimental results revealed significant differences between the thermal conductivities of the specimens made from the Dialakoro and Kita clays.

The measurements revealed that the thermal conductivity of the Kita specimens is higher (1.02 W/m.K) than that of the Dialakoro specimens (0.86 W/m.K). This difference can be attributed to several factors influencing heat transfer through these materials.

4.2. Influence of mineralogical composition

The nature of the minerals found in the clay plays a key role in the thermal conductivity of BTC. Kita clay contains a higher proportion of sand, a material known for its relatively high thermal conductivity. In contrast, Dialakoro clay has a higher content of fine particles, which reduce heat transmission due to their lamellar structure and ability to trap air.

4.3. Effect of density and porosity

A higher density tends to increase thermal conductivity by reducing the amount of air trapped in the material. The BTCs of Kita, having a higher density than those of Dialakoro, have a higher thermal conductivity. In addition, porosity plays a key role: a more porous structure with small, well-distributed pores can improve thermal insulation by trapping air, while too much porosity can facilitate heat conduction.

4.4. Influence of humidity

Since water has a higher thermal conductivity than air, a higher moisture content in Kita's BTC could also explain their higher thermal conductivity. Dialakoro's BTCs, which are less sensitive to water absorption, thus maintain better insulating performance in wet conditions.

It should be noted that the thermal conductivity of an insulating material is less than or equal to **0.065 W/m.K** and its thermal resistance greater than or equal to 5 m2. W^{-1}. K . BTC with a thermal conductivity of [10]**0.81 to 1.04 W/m.K**[11], are therefore not thermally insulating. Placed inside the insulating envelope, they provide thermal inertia to the building, which results in damping and phase shifting of indoor temperature variations from outside temperature variations and improves hygrometric comfort, in particular by smoothing the humidity level of the indoor air [9].

5. Conclusion

The use of compressed earth blocks as an alternative to conventional materials in sustainable construction is a promising solution, not least because of their low environmental impact and advantageous thermal properties. This study evaluated and compared the performance of BTC made from Dialakoro and Kita clays by determining their mechanical and thermal characteristics.

The results obtained show that BTC from Dialakoro clay has better mechanical strength, lower water sensitivity and better thermal performance compared to those made with Kita clay. Despite these differences, both types of BTC mechanically meet the minimum structural requirements for load-bearing applications according to the **NF EN 772-1 standard.**

The water sensitivity of BTC represents a major challenge to their sustainability. Kita's BTC, which have particularly shown a loss of cohesion under the effect of humidity, require stabilization or protective treatment before their use in a humid environment.

As BTC is not thermally insulating with its thermal conductivity of the order of 0.81 W/m.K, it requires a reduction in thermal conductivity by adjusting its porosity and integrating materials with low thermal conductivity (wood powder, rice husks, perlite, etc.).

So, while these BTCs offer interesting prospects for green and sustainable construction, several improvements are to strengthen their mechanical strength, thermal performance, and durability. Optimizing formulations, introducing stabilizers, and improving manufacturing techniques are key avenues for producing BTC that perform better and are better suited to local climatic conditions.

Finally, this study highlights the importance of further research on BTC in order to refine its design and maximize its effectiveness. The development of local resources such as Dialakoro and Kita clays remains a major challenge to promote the use of BTC in the construction sector in Mali and other regions facing similar challenges.

Compliance with ethical standards

Acknowledgments

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Disclosure of conflict of interest

No conflict of interest to be disclosed.

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