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Research Article

Thermomechanical Characterization of Massakory Clay Reinforced by Seyal Gum Arabic for Sustainable Building Applications

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Abstract

This study focuses on determining the thermomechanical properties of clay extracted from the Kangartoulo brickyard site in Massakory, reinforced with seyal gum arabic for sustainable development construction applications. Raw earth has been used and is used in the construction field for its abundance and low environmental impact. The experimental results of thermal tests show that a decrease in thermal conductivity and thermal effusivity is observed for a gum arabic content below 4%, followed by a slight increase beyond this threshold and also by varying the compaction pressure from 3 to 6 MPa. Regarding mechanical properties, the simple compressive strength almost tripled with the addition of gum arabic from 0 to 8%, it increased from 3.2 to 9.4 MPa for compaction pressures ranging from 3 to 6 MPa. The three-point bending strength has also been improved, increasing from 0.78 to 2.10 MPa for the same binder contents. The numerical simulation carried out with the RETScreen software made it possible to estimate an energy gain of 29% for the optimal formulation retained compared to cementitious materials.

Keywords

Clay, Seyal Gum Arabic, Thermomechanical Characterization, Compaction Pressure, Numerical Simulation

1. Introduction

The current trend is the return to the use of building materials that reduce environmental impact, are less energy-intensive and locally available in abundance. The significant share of energy consumed by the building sector, coupled with the ever-increasing price of energy, has led researchers to focus on the problems of building thermal energy [1]. Raw earth is used for construction and is widespread throughout the world due to its geological formation, which is the degradation of parent rocks. This makes it available almost everywhere and therefore accessible to low-income populations

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[2]. The local and natural nature of these local materials also plays an important role in sustainable construction and mitigating carbon emissions linked to transport. Building with these can reduce the amount of energy consumed during the construction phase by up to 215% and the environmental impact linked to transport by up to 453% [3]. The development of sustainable construction practices is therefore essential, not only to comply with current greenhouse gas emission reduction targets, but also to limit energy consumption in buildings on a global scale [4]. Its most important advantages are its low-energy implementation, its aesthetic qualities and its good thermal inertia. The latter allows for a cool home in summer and retains heat in winter, however its disadvantages are its lack of mechanical strength without additives, its systematic cracking due to shrinkage and its problem related to its sensitivity to water [5].

Our choice of the Kangartoulo brickyard site in Massakory is justified because the clay identification study was previously carried out by [6]. In this perspective, the mechanical and thermophysical parameters for the safety and thermal comfort of occupants are studied in this article.

2. Material and Methods

This section allows us to review the material used and the methods adopted for the mechanical and thermophysical tests.

Clay Soil

The choice of this basic material is not accidental, clay is a promising material due to its local availability, low environmental impact and ease of processing. However, it is crucial to consider maintenance requirements to ensure its durability. Clay is a loamy soil composed mainly of hydrated aluminum silicates that is used in the manufacture of bricks, tiles, pottery, etc. when the soil exceeds 30% of its proportion of clay particles, it is considered a clay [7]. Clay minerals are in fact phyllosilicates, and their tetrahedral and octahedral layered structure is fundamental to understanding their unique properties. They are differentiated by the arrangement of these two layers [8]. The main compositions of the latter are silica, alumina and other elements that assemble to form layered structures. This layered structure and the presence of water molecules between the layers give clays different characteristics.

3. Main Caracteristics of the Clay

The geotechnical study of this clay was previously carried out by [6] whose results are summarized in table 1 below.

Table 1. *Results of geotechnical study [6].*

Paramters	Symbols	Values
Liquid limit	L_L (%)	44
Plastic limit	L_P (%)	21
Plasticity index	I_P (%)	23
Water content	W (%)	19.4
Methylene blue value	VBS	2.65
Activity	A_{CB}	7.57
Specific gravity	γs (g/cm^3)	2.40

4. Admixture

In general, adding an adjuvant to raw earth works by coating the earth particles and reducing their mobility. Gum arabic, from the acacia seyal tree, is used as an adjuvant. However, the latter is the fourth Chadian product and has given Chad the world's leading exporting country for friable gum arabic known as talha. Gum arabic is very soluble in water, of low viscosity and used as an emulsifier, stabilizer, or binder, and as a source of soluble dietary fiber. Only the exudates of acacia senegal and acacia seyal are recognized as gum arabic by the Food Codex under the name E414. The gum from acacia seyal is more friable than the hard drops of the acacia senegal [9]. It is a unique natural carbohydrate that has properties similar to those of cement, a mineral material such as dissolution in water, adhesiveness and bonding, agglomeration and coating of aggregates. [10].

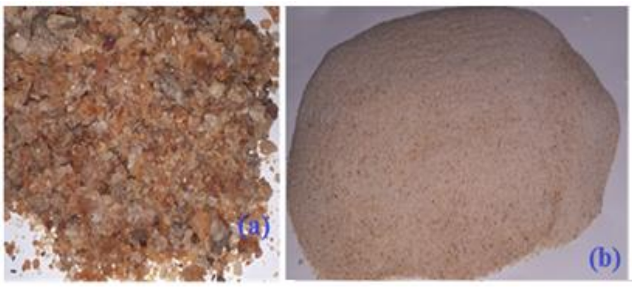

Figure 1. *Gum arabic in granulate (a) and powder (b)*

5. Mechanical Caracterization

Mechanical tests are essential for characterizing materials, they must possess specific mechanical properties to ensure structural strength and occupant safety. They are essential to ensure that the materials used in construction meet the required performance and safety standards. The samples used for these tests are compressed with a compaction pressure that varies from 3 to 6 MPa and stabilized with gum arabic depending on its content, which ranges from 0 to 8%. These tests allow the determination of important properties such as simple compressive strength and flexural/tensile strength.

The CBR press is used for crushing parallelepiped specimens of dimensions 4×4×16 cm^3 through its two simple compression and three-point bending cells, also the 10 kN ring is used for these tests. Figure 2 shows the CBR press.

Figure 2. *CBR press with different three-point bending and single compression cells.*

The following equations (1) and (2) are used to determine the simple compression and fthree-point bending strengths:

$$R_C = \frac{F}{S} \quad (1)$$

$$R_f = \frac{1.5 \times F \times l}{b \times a \times a} \quad (2)$$

5.1. Thermophysical Characterization

Thermal characterization of materials is an important step in many fields of engineering and research. It allows the determination of the thermal properties of materials, such as thermal conductivity, thermal effusivity, etc. These are essential for understanding the behavior of materials under different temperature conditions and for designing thermally comfortable systems. The methods aim to measure the amount of heat passing through a material in response to a temperature gradient. The thermal measuring device used is the FP2C conductivity meter equipped with two hot wire and hot plane probes that respectively measure the thermal conductivity and thermal effusivity of solid materials.

Figure 3. *FP2C conductivity meter with its accessories.*

Thermal conductivity is one of the most sought-after thermophysical properties for building materials. The heat flux density expressed in W. m^2 is given by equation 3.

$$\Phi = \frac{\lambda}{e}(T_i - T_e) \quad (3)$$

Thermal effusivity is an essential property for understanding heat exchange between a material and its environment. It depends on the thermal conductivity and thermal inertia of the material. It has important applications in many fields, including construction.

$$E = \sqrt{\lambda \times \rho \times C_P} \quad (4)$$

Thermal resistance (Rth) of a wall represents its ability to resist the passage of heat. The higher it is, the more insulating the wall is and the less heat it allows to pass through. It is expressed in m^2. K/W. Thermal resistance is defined by the following relationship:

$$R_{th} = \frac{e}{\lambda} \quad (5)$$

5.2. Numerical Simulation

It consists of performing thermal balances of the two buildings, one is built with a reference material with cement bricks (concrete block) and the other is built with the study clay-based bricks.

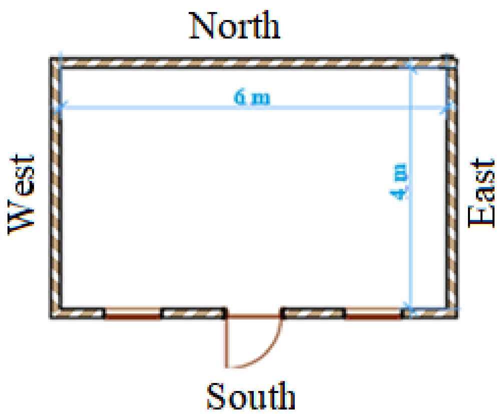

Figure 4. *Prototype or experimental cell.*

The software takes into account climate data by referring to a meteorological database from NASA soils and satellites.

6. Results and Discussion

The granulometric analysis and the physicochemical test carried out by [6] show that the soil is made up of 55% clay, 17% silt and 28% sand. Silica (SiO2) and iron (Fe2O3) are the major elements followed by magnesium (MnO). However, the sum of the three elements, namely silica, iron and alumina, is greater than 70%, which corresponds to the provisions of the ASTMC618 standard, and the Alumina/Silica ratio provides information on the material's permeability to moisture; the determined of the material content is to 8.64%.

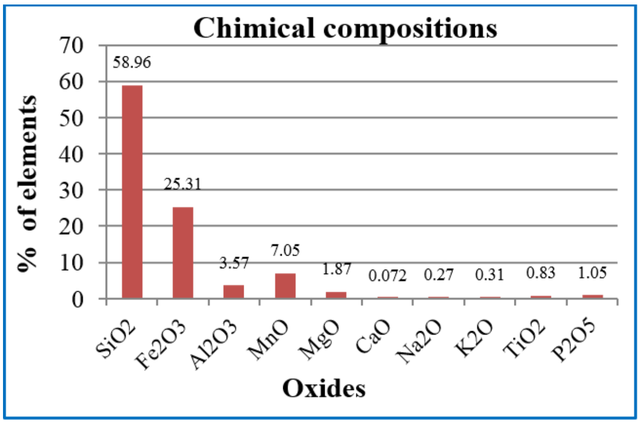

Figure 5. Physicochemical analysis of clay.

This clayey soil is low in calcium and potassium but is very suitable for BTC according to the granulometric results and the Atterberg limits.

The combination of L_L and L_P defines the soil's sensitivity to humidity variations, the plastic properties of a soil can be represented on a plasticity diagram delimiting the BTC domain [11]. According to the XP P 13-901 standard, the Kangartoulo brickyard soil is suitable for brick production. The plasticity index and liquid limit are the BTC range.

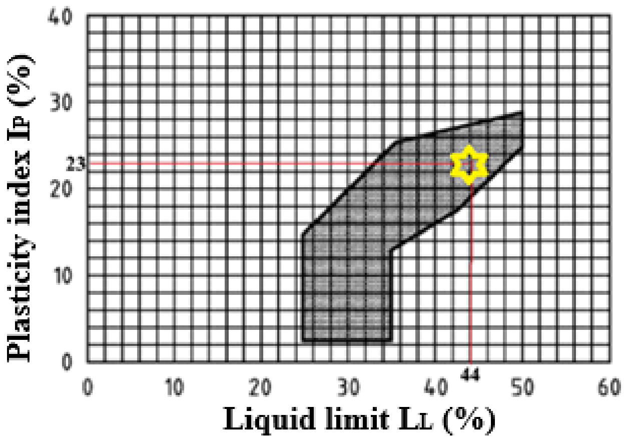

Figure 6. Diagram determining the domain of BTC (XP P 13-901 standard)

The curves of the three-point bending and simple compressive strengths are given as a function of compaction pressures ranging from 3 to 6 MPa and percentages of gum arabic ranging from 0 to 8%.

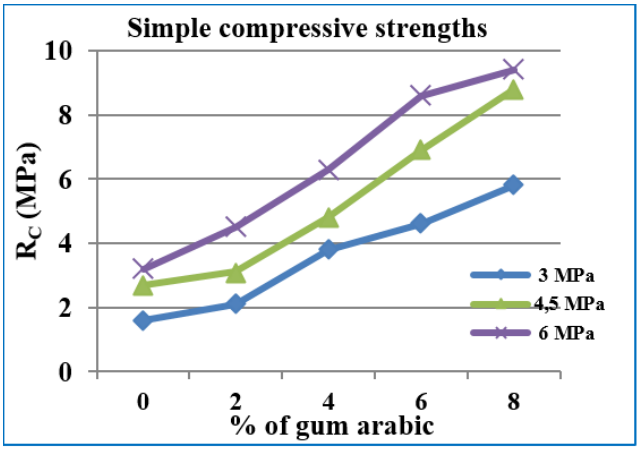

Figure 7. Simple compressive strengths as a function of percentage of gum arabic and compaction pressure.

For a given compaction pressure, when increasing from 0 to 8% of gum arabic, the compressive strength triples. For the average compaction pressure (4.5 MPa), The compaction pressure determines the compressive strength of the blocks. For higher pressures, the maximum stress reached is higher [12], in the same vein [5] observed that, for the same cement content, the increase in compaction stress leads to an increase in the compressive strength of BTC.

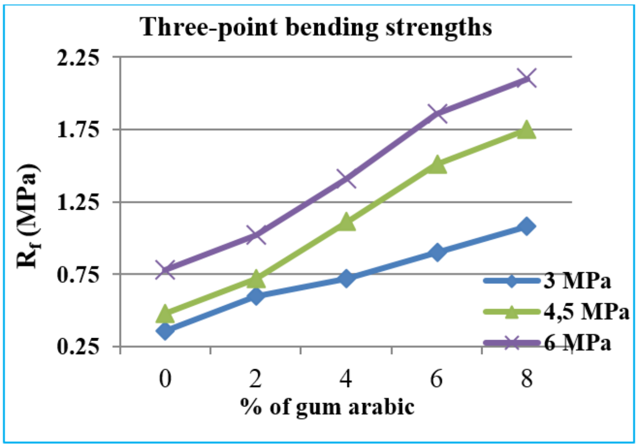

Figure 8. Flexural/tensile strength as a function of percentage of gum arabic and compaction pressure.

Generally speaking, an increase in compressive strength and flexural strength is observed with the addition of gum arabic, regardless of the counting pressure. This means that gum arabic has a strengthening effect on the materials studied. The greater the compaction pressure, the more the pores are reduced and the material becomes dense.

The thermal test parameters are also plotted as a function of compaction pressures and percentages of gum arabic, which range from 3 to 6 MPa and from 0 to 8% respectively. These thermal quantities are represented in the figures below:

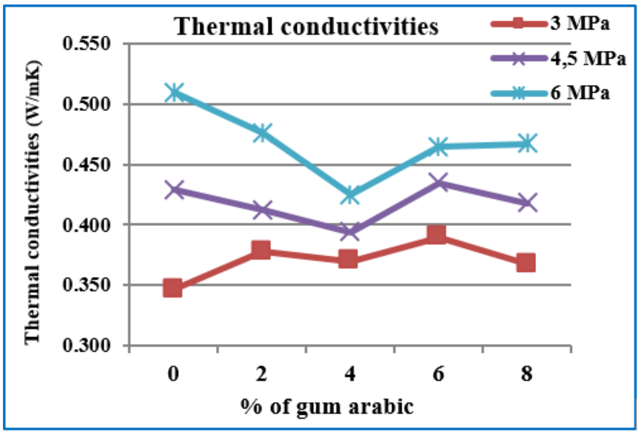

Figure 9. Thermal conductivity as a function of percentage of gum arabic and compaction pressure.

Thermal conductivity decreases with the percentage of gum arabic which ranges from 0 to 4% of the admixture for all compaction pressures and increases from this threshold and stagnates at 8%. This phenomenon is explained by the fact that conductivity is a function of the nature of the material, the optimal water content and the porosity. The curve obtained by [13] shows that thermal conductivity varies according to the cement content. Beyond 5%, an increase is observed with the percentage of cement.

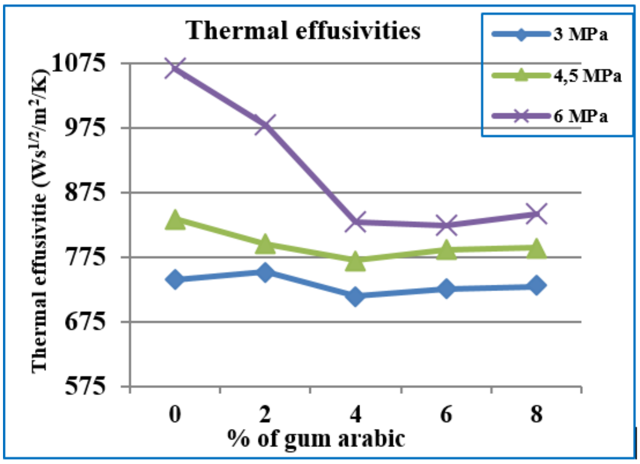

Figure 10. Thermal effusivity as a function of percentage of gum arabic and compaction pressure.

Thermal effusivity hardly changes after 4% of the admixture despite the compaction pressures varying from 3 to 6 MPa. It is observed that from 6% of the gum arabic it is almost constant.

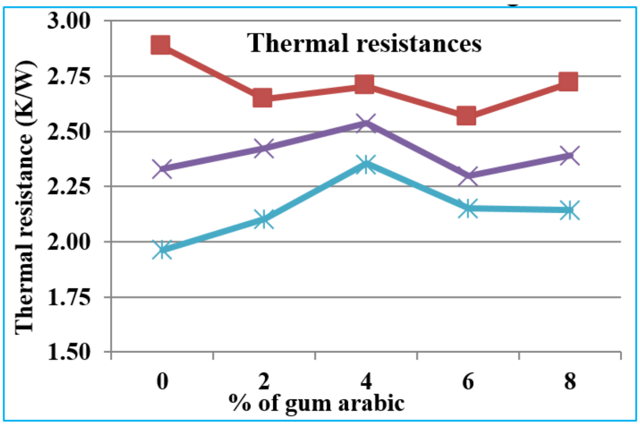

Figure 11. Thermal resistance as a function of percentage of gum arabic and compaction pressure.

Thermal resistance is important for the 92% clay and 8% gum arabic formulation and for low compaction pressures. The study conducted by [13] shows that thermal resistance varies according to the cement content. Indeed, in small quantities, cement causes an increase in this. The curves obtained by [14] show that a decrease in conductivity for percentages lower than 5% of stabilizer increases beyond this threshold.

The thermomechanical curves of clay reinforced by gum arabic and with the variation in compaction pressure are given by the figure below:

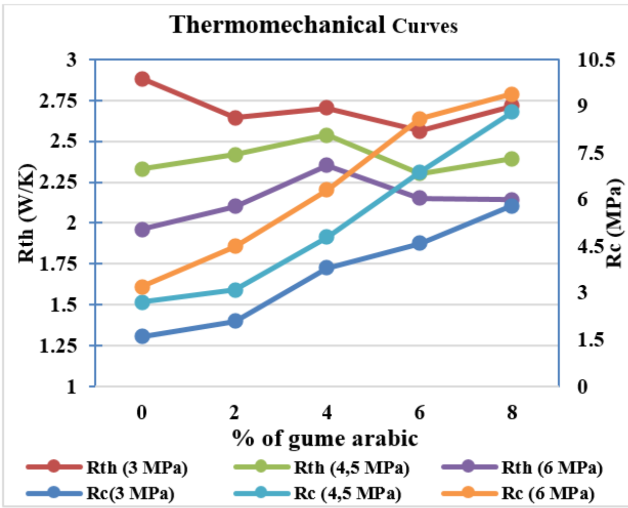

Figure 12. Thermomechanical resistances as a function of percentage of gum arabic and compaction pressure.

The graph shows that the addition of gum arabic improved the thermal and mechanical properties of the clay. However, the numerical simulation carried out by RETScreen software for the optimal formulation of 92% clay plus 8% gum arabic gave an energy gain of 29% compared to that of a building constructed of concrete blocks.

7. Conclusion

The thermomechanical characterization study on local construction materials is a major challenge for promoting the use of this ecological and economical material in the building sector. It has made it possible to discover the properties of compressed and stabilized raw earth in the field of sustainable construction.

The results obtained show that the thermomechanical characteristics of clay stabilized with gum arabic are improved. Compressive strength tripled with the addition of gum arabic and also with the compaction pressure. The role played by gum arabic in the mixture is not negligible and could replace in the future certain stabilizers that are harmful to the environment.

The numerical simulation carried out by the RETScreen software gave an energy gain of 29% for the optimal formulation, thus the study of the composite's durability is part of our perspective on these local construction materials.

Nomenclature

Symbol	Title	Unit
a	Thickness	mm
A_{CB}	Activity	-
b	Length	mm
E	Thermal effusivity	m^2/s
l	Distance	mm
I_P	Plasticity index	%
L_L	Liquid limit	%
L_P	Plastic limit	%
Rc	Compressive strength	MPa
Rf	Bending resistance	MPa
Rth	Thermal resistance	W/K
VBS	Methylene blue value	-
w	Water content	%
Φ	Thermal flow	W/m^2
λ	Thermal conductivity	W/mK
ρ	Volumic mass	kg/m^3

Abbreviations

BTC Compressed Earth Brick
CBR California Bearing Ratio
ENSTP National School of Public Works
GA Gum Arabic
INSTA National Institute of Sciences and Technics of Abeche
LBTP Public Works and Construction Laboratory
LREM Energy and Materials Research Laboratory
SSHN High-Level Scientific Stay

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Conflicts of Interest

The authors declare no conflicts of interest.

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