



(RESEARCH ARTICLE)



EFFECTS OF STABILIZERS ON THE MECHANICAL PROPERTIES OF A CLAY USED IN ECO-CONSTRUCTION

Insa BADIANE ¹, Amadou Tidia DIALLO ², Thierno Abdoulaye BARRY ^{1, 4, *}, Laurent MOLEZ ³,
Bérenger ARANDA ³ and Magatte CAMARA ¹

¹ Laboratory of Chemistry and Physics of Materials (LCPM), Faculty of Sciences, Technology and Engineering (STI), Assane Seck University of Ziguinchor (UASZ), P.O. Box 523, Ziguinchor, Senegal.

² Laboratory of Applied Research in Natural Sciences LARASCINA, Department of Chemistry, University of Kindia, P.O. Box 212, Conakry, Guinea.

³ Laboratory of Civil Engineering and Mechanical Engineering (LGCGM), National Institute of Applied Sciences of Rennes, 20 Avenue des Buttes de Coësmes, 35708, France.

⁴ Laboratory of Analytical Chemistry, Department of Chemistry, Gamal Abdel Nasser University of Conakry, P.O. Box 1147, Conakry, Guinea.

* Corresponding Author: Thierno Abdoulaye BARRY

ORCID Details

Thierno Abdoulaye BARRY: <https://orcid.org/0009-0003-2349-5210>

World Journal of Advanced Research and Reviews, 2026, 31(03), 1999–2011

Publication history: Received on 11 August 2026; revised on 28 September 2026; accepted on 30 September 2026

Article DOI: <https://doi.org/10.30574/wjarr.2026.31.3.2437>

Copyright © 2026 Author(s) retain the copyright of this article. This article is published under the terms of the Creative Commons Attribution License 4.0

ABSTRACT

Earthen building materials are attracting renewed interest due to the high cost of binder-based construction materials such as cement. Added to this is the environmental pollution caused by their production. To reverse this trend, current research efforts are focusing on developing and improving the mechanical properties of earth-based materials and stabilizers, commonly referred to as eco-materials. Against this backdrop, we manufactured Guinea clay bricks using the following formulations: clay + lime (5 % and 10 %), clay + fibers (0.25 %, 0.5 % and 0.75 %), and clay + lime + fibers (ratios 8/0.35 % and 12/0.35 %), and studied their physical and mechanical properties after 14 and 28 days. The results show an increase in the compressive and flexural strength of the bricks.

The formulation with the best performance was that with 12 % lime and 0.35 % fiber, with compressive and flexural strength values of 9.14 MPa and 2.10 MPa, respectively, after 28 days of drying. This formulation is comparable to mortar made with 9 % CEM I 42.5 R cement, mixed with soil containing 30 % clay and silt, 40 % sand, and 30 % gravel, with optimum moisture content and cured for 28 days, reaching 9.30 MPa. Our study shows that clay bricks with 5% lime at 28 days are lighter in bending, with an apparent density of 1.8 g/cm³, compared to bricks obtained with the other two formulations and those made of natural clay.

Keywords: Clays, Stabilizers, Formulation, Mechanical Properties, Eco-Construction

1 INTRODUCTION

The construction of affordable housing in developing countries has become an urgent concern. The cost of cement, an essential building material, remains high due to the considerable energy requirements associated with clinker production. In addition, concern for the environment is crucial[1].

Bricks have always been one of the world's most common building materials, used in various forms for construction[2]. According to previous studies, 1,391 billion units of brick are consumed worldwide every year[3]. The production process for traditional “fired” bricks releases large quantities of toxic gases into the air, in particular carbon dioxide, resulting in environmental pollution[4],[5],[6].

It is estimated that over two billion people currently live in earthen dwellings, and around 10% of World Heritage properties incorporate earthen structures[2].

Despite the technological developments of recent centuries, offering modern man a wide variety of building materials such as concrete and steel, there is now a growing return to earthen construction in both developing and industrialized countries[7].

With current global concerns about sustainable development, interest in natural building materials, such as unfired clay materials, has increased[8].

A comprehensive assessment of sustainable infrastructure development requires the consideration of various aspects, ranging from environmental to economic factors. In fact, Goal 9 of the United Nations' 2030 Agenda for Sustainable Development emphasizes the need for “quality, reliable and sustainable” infrastructure[9].

Worldwide, buildings account for around a third of energy consumption and greenhouse gas emissions[10].

The global greenhouse gas emission rate in the building sector was 4.1 Gt CO₂ (gigatons CO₂ equivalent) in 2016[10],[11]. Studies have shown that the production of one ton of cement consumes around 4.9 GJ (gigajoules) of energy and emits around one ton of carbon dioxide[12].

Consequently, the use of environmentally-friendly materials is a viable solution to the dual challenge of reducing construction costs and protecting the environment[1].

In situations where a soil does not intrinsically exhibit adequate mechanical behavior, improving its mechanical properties is one of the most important measures to take into account. Consequently, soil improvement through the use of various materials and methods has been widely discussed in the construction field. Soil improvement techniques can be classified into two broad categories: physical and chemical methods, to name but a few. In addition, several studies have investigated the simultaneous use of stabilization and reinforcement techniques[7],[13],[14],[15].

The use of clay materials is an alternative to costly imported materials and helps reduce the foreign exchange deficit. Their use also promotes youth employment, scientific innovation, and economic growth. As a result, they have been the subject of several studies aimed at improving their value in terms of cost, energy efficiency, mechanical strength, and even aesthetics[14],[16].

The ambition to reduce energy consumption and promote sustainability by developing low-cost, eco-friendly building materials with improved properties has become a major research concern. Clay bricks are among the most widely used building materials. Clay brick houses, especially in humid regions, still suffer from mechanical and thermal stability problems. To remedy this, scientists recommend the use of various stabilizers such as lime or cement, and the addition of fibers to reinforce structures, among other methods[17],[18].

The use of unfired clay materials offers several advantages: (1) local availability and abundance, (2) lower energy consumption, (3) good thermal properties, and (4) biodegradability[5],[8],[19].

2 MATERIALS AND METHODS

2.1 Study area

The Kankan area is located in the north-east of the Republic of Guinea, 635 km from the capital Conakry. Its surface area is approximately 72145 km² with a population of 472,505 inhabitants in 2019[20]. In geographical coordinates, it extends from 10°23' North latitude and 9°18' West longitude (Figure 1).

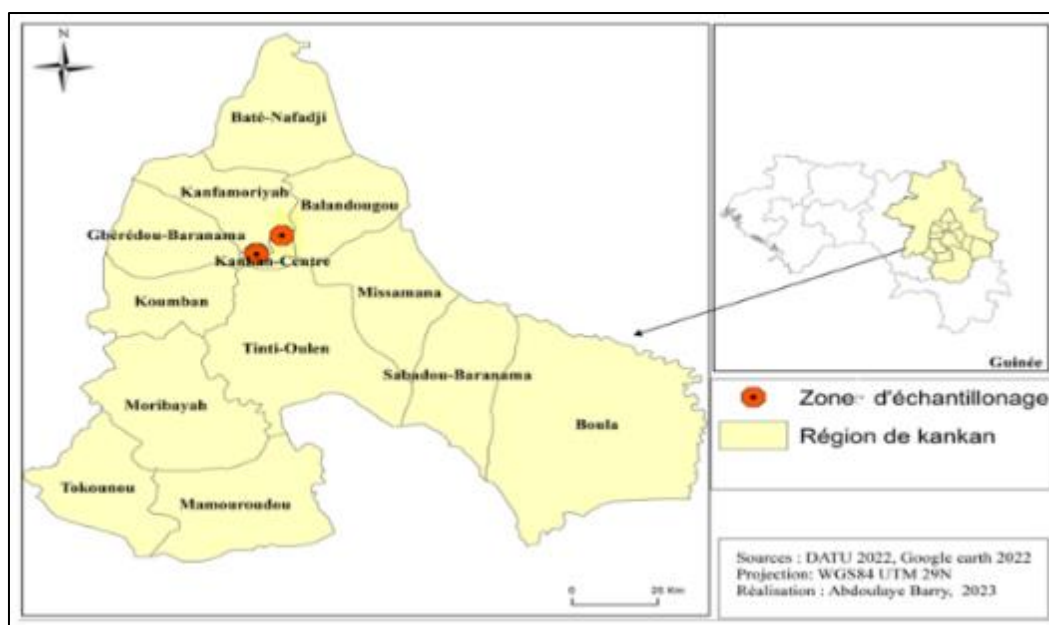


Figure 1: Map of the Kankan region showing sampling zones[21].

2.2 Sampling

The clay sample was taken in such a way as to faithfully reflect the local geological and mineralogical characteristics. The sample was taken at a depth of 3 m. A quantity of 5 kg was collected for in-depth analysis.

The Process used appropriate tools, including a geological map, shovel, spatula, hammer, bags, GPS, labels, and marker. The sample was labeled with precise information (date, location, and coordinates). The sample was packaged in an airtight plastic bag to preserve its physical and chemical properties.

For the present work, we took a clay sample from one of the places reputed to be the most exploited for fired bricks in Kankan.

Table 1: AKKO clay sampling in Kankan

Region	Sampling area	N	W
Kankan	Kankankoura neighbourhood	10°36'11.3"	_ 09°30'15.2"
		10°36'68.4"	_ 09°28'70.2"

2.3 Analytical methods

Clay moisture was determined using a "Despatch 2000" oven calibrated at 105 °C.

The following formula was used to calculate the natural moisture content (%W):

$$\%W = \frac{P_1 - P_2}{P_e} \times 100 \quad (1)$$

- P_1 : poids du bac plus échantillon avant séchage.
- P_2 : poids du bac plus échantillon après séchage.
- P_e : poids de l'échantillon.

Mineralogical phases were identified using a Panalytical X'Pert Pro diffractometer equipped with an X' Celerator detector. Experimental conditions were as follows: Cu $K\alpha$ radiation ($\lambda = 1.542 \text{ \AA}$), $I = 40 \text{ mA}$, $V = 45 \text{ kV}$. Peaks were identified using X'Pert HighScore software.

Chemical composition in terms of major oxides was determined by X-ray fluorescence spectrometry. This analysis was carried out using the "AXIOS FAST, PANalytical 206204" instrument.

FT-IR measurement was carried out on a Perkin Elmer Frontier spectrometer using the UATR (Universal Attenuated Total Reflectance) accessory. The spectrum was recorded between 650 and 4000 cm^{-1} , on the clay sample.

The Atterberg limit is determined by the falling cone method, which measures the penetration of the cone into the soil after release, with better resolution.

The Malvern Mastersizer 2000 manufactured by Malvern Instruments, was used as a laser particle analyzer for clay. This device works on the basis of Mie theory to obtain particle size distribution by converting light scattering data.

Specific surface area was measured by a Dewar “vacprep 061” gas vacuum spectrometer coupled to a TriStar II Plus Porosimeter.

Thermal analyses were carried out with a Perkin Elmer Pyris Diamond ATG/ATD analyzer between room temperature and 950 °C at a rate of 5 °C/minute in a platinum crucible under a nitrogen atmosphere. The compound was held for 1 hour at 950 °C in an air atmosphere to ensure complete combustion.

3 RESULTS AND INTERPRETATION

3.1 Structural analysis of clays

3.1.1 Phase identification

X-ray diffraction patterns for the AKKO clay are shown in Figure 2. The main lines observed on the diffractogram of the clay sample are attributed to kaolinite ($\text{Al}_2\text{Si}_2\text{O}_5(\text{OH})_4$), illite-montmorillonite $\text{K-Al}_4(\text{SiAl})_8\text{O}_{20}(\text{OH})_4\text{xH}_2\text{O}$, muscovite $[(\text{K}, \text{NH}_4, \text{Ca}) \text{Al}_2(\text{Si}, \text{Al})_4\text{O}_{10}(\text{OH})_2]$.

The crude sample also contains quartz (SiO_2), chlorite $[\text{Mg}_2\text{Al}_3(\text{Si}_3\text{Al})\text{O}_{10}(\text{OH})_8]$ and magnetite (Fe_3O_4) in small proportions.

Figure 2 shows the X-ray diffraction (XRD) diffractogram of AKKO clay taken from the Kankankoura, highlighting the different mineral phases identified in the sample.

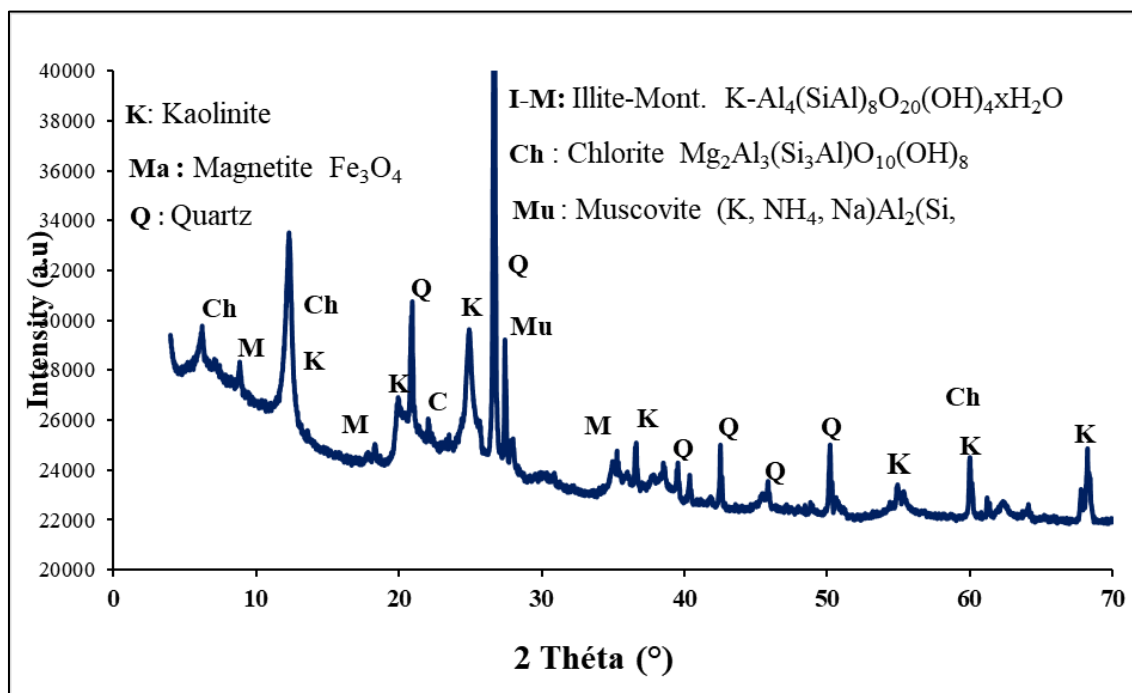


Figure 2: Diffractograms of AKKO clay from Kankankoura.

3.2 Determination of chemical composition

X-ray fluorescence spectrometry analysis of the AKKO sample has enabled us to quantify the major chemical elements, in the form of the oxides shown in Table 2. The sample is mainly composed of silicon oxide (SiO_2), aluminum oxide (Al_2O_3), iron oxide (Fe_2O_3) and potassium oxide (K_2O).

3.3 Infrared spectroscopy

The adsorption bands located in the high-frequency zones appearing at 3693, 3655, and 3620

cm^{-1} are related to the vibrations of OH hydroxyl groups in kaolinite. The first two bands are respectively attributed to the symmetrical stretching vibrations of the internal surface OH groups and the stretching vibrations of the out-of-plane OH groups. Whereas the band at 3620 cm^{-1} is linked to the stretching vibrations of kaolinite's internal OH groups[22]. The sharp absorption band at 1632 cm^{-1} , attributed to the deformation vibration of H-O-H, and the absence of the elongation vibration around 3400 cm^{-1} shows the low water content of our sample[22].

The absorption bands at 1113 and 1000 cm^{-1} represent asymmetrical and symmetrical stretching of Si-O groups, while the band around 900 cm^{-1} (910 cm^{-1}) corresponds to the deformation of the Al-OH bond in kaolinite[23].

The presence of kaolinite and muscovite can be confirmed by the stretched Si-O bands located at 1113 cm^{-1} and 1026 cm^{-1} , respectively (Vedder, 1964; Kristof et.al., 1993)[24].

Figure 3 presents the infrared spectrum (FTIR) of AKKO clay from Kankankoura, highlighting the main absorption bands characteristic of the functional groups and mineral phases present in the sample

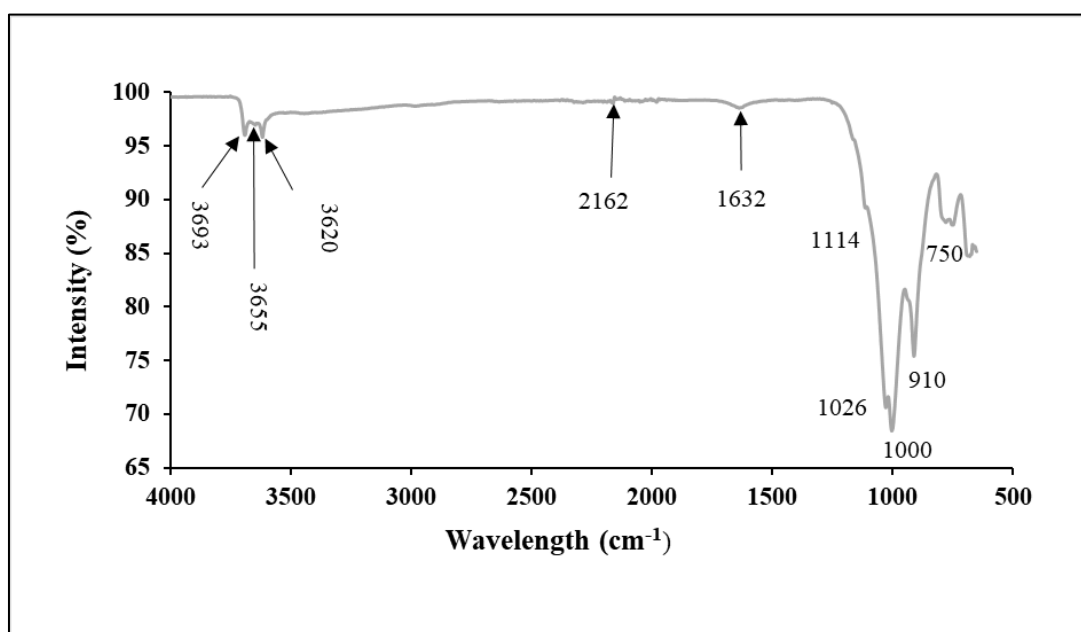


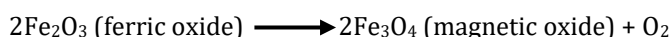
Figure 3: Infrared spectrum of AKKO clay from Kankankoura.

3.4 Differential thermal and gravimetric analysis

Figure 4 shows the ATG/ATD curves for AKKO clay. The ATG curve shows three levels of mass loss corresponding to three endothermic peaks.

AKKO clay shows 4 endothermic peaks and one exothermic peak. The first endothermic peak, at 48.7°C , corresponds to the departure of moisture water, accompanied by a mass loss of 2.6 %. The second peak at 251°C reflects the loss of interfoliar water and the transformation of iron oxide and/or organic matter, resulting in a mass loss of around 1.7 % [25].

An (OH) component is released from the mineral at temperatures between 260 and 400°C , where the conversion of Fe_2O_3 to Fe_3O_4 occurs after the hydroxylation process. This phenomenon is observed for the AKKO sample, which contains magnetite according to XRD [26].



The endothermic peak at 482°C , is characteristic of the elimination of the constitutive water resulting from the release of hydroxides belonging to the kaolinite lattice according to the following equation $\text{Al}_2\text{Si}_2\text{O}_5(\text{OH})_4 \longrightarrow \text{Al}_2\text{Si}_2\text{O}_7 + 2\text{H}_2\text{O}$ (Hajjaji et al., 2001; Bennadji et al., 2008 and Ozkan et al., 2010) [27].

This phase is accompanied by a mass loss of 5.1 %. This event can be attributed mainly to dehydroxylation of kaolinite, although dehydroxylation of illite may also make a minor contribution[28].

We note a peak at 583 °C that highlights the transformation of α -quartz into β -quartz[29]. Finally, an exothermic peak at 972 °C corresponds to the formation of mullite, pseudo-mullite, spinel, amorphous silica, and γ -Al₂O₃ (Földvári, 2011)[30].

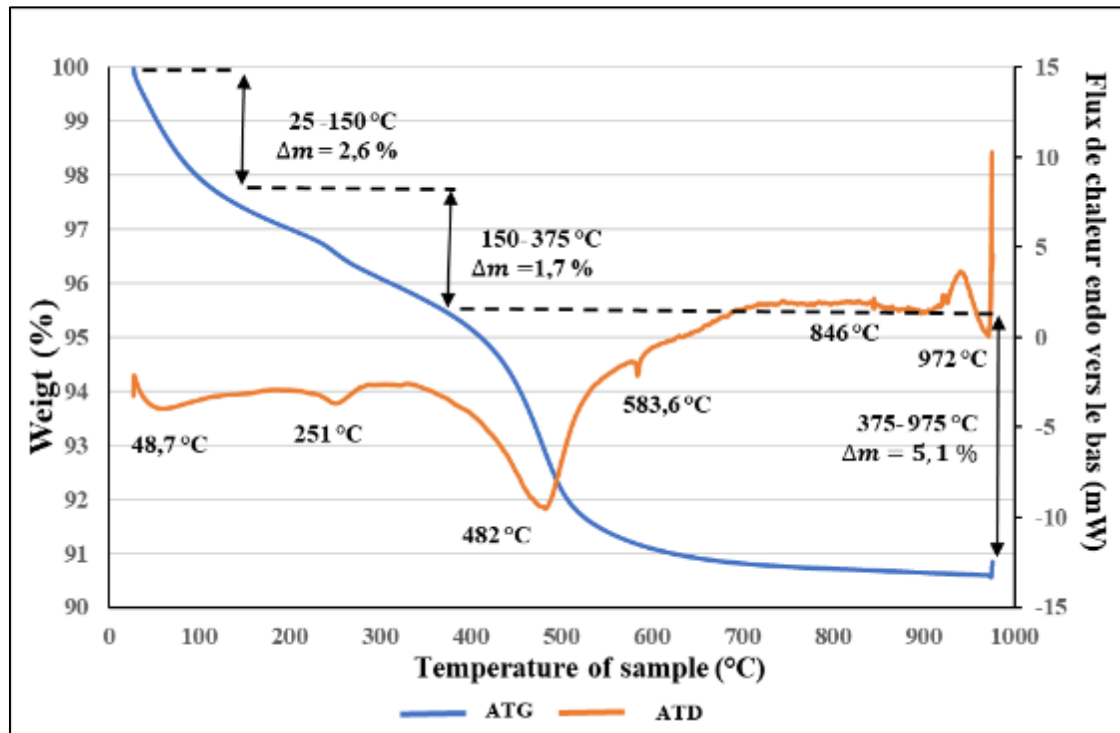


Figure 4: ATG/ATD curves for Kankankoura AKKO clay

3.5 Geotechnical analyses

3.5.1 Moisture content

The water content of Kankan AKKO clay is 12.10 %. This value, compared with the literature, is explained by the low natural permeability of the raw material and remains slightly lower than the water content of a pure kaolinitic clay (14 %)[31].

3.5.2 Granulometric analysis

Figure 5 shows the particle size distribution of the AKKO sample, characterized by a unimodal curve, reflecting the presence of a dominant particle size population within the material

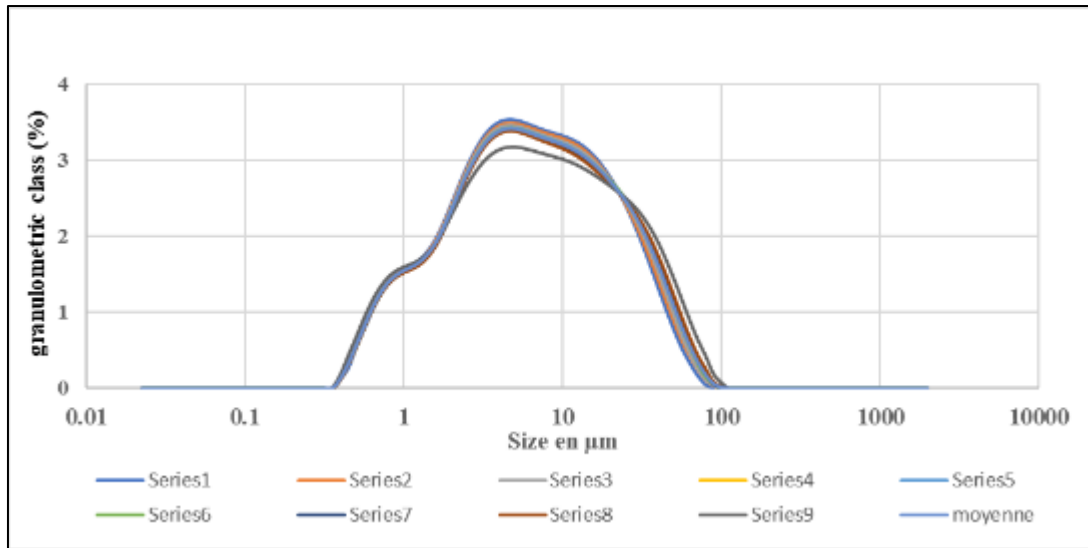


Figure 5: Grain size distribution of AKKO sample showing a Unimodal pattern

The clay and silt fractions account for more than 82.7 % of the grain size, while the sand fraction represents only a small proportion (17.3 %), which justifies the unimodal distribution of the grain size curves obtained for the AKKO sample.

The GL shows that the sample is less rich in clay fraction (20 %), but rich in silty fraction (62.7 %). This observation is consistent with the particle size classification of ceramic raw materials from Cameroon, Morocco, and Turkey[32].

3.6 Specific surface area

Figure 6 shows the discrete distribution of pore size of AKKO clay from Kankankoura area, highlighting the main classes of pore dimensions and their distribution within the material

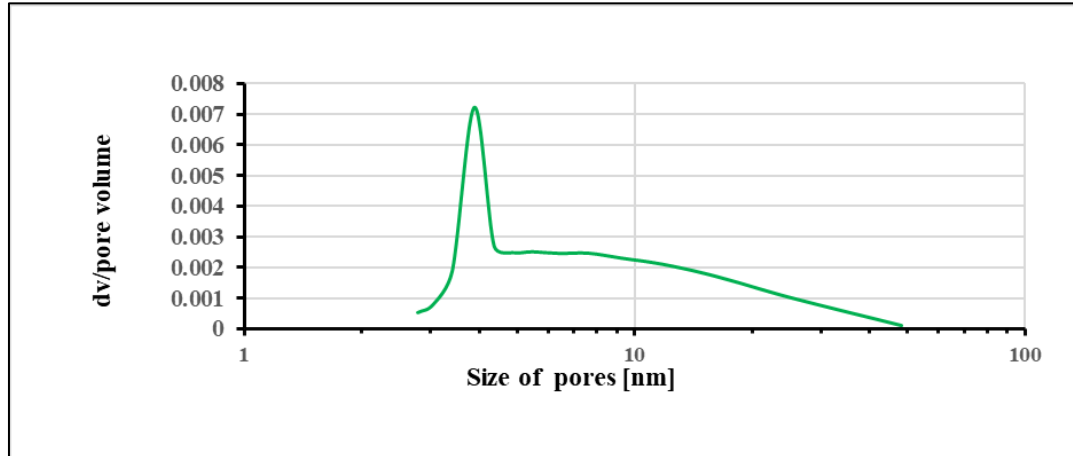


Figure 6: Discrete pore size distribution of Kankankoura AKKO clay

The specific surface area of AKKO clay is 23.22 m²/g. This value, comparable to that of kaolinite (10-30 m²/g), is significantly lower than that of illite (80-100 m²/g) and pure smectite (750-800 m²/g s). This indicates that the clay is predominantly kaolinite[33],[34].

The value of 3.8 nm, ranging from 2 to 50 nm, indicates that AKKO de Kankan clay belongs to the mesopore class according to the IUPAC classification (Figure 6).

3.7 Plasticity index

The plasticity index (PI) is equal to 12.07%, and the consistency index is 3.13 %.

The relatively low value of the plasticity index is in line with the clay content of our sample.

The plasticity index of the sample is lower than Turkish clay (31-33 %) (Celik, 2010), and higher compared to Brazilia clay (6.5-9.8 %) (Azzi et al., 2018).

Table 2: Physico-chemical and geotechnical parameters of a Kankankoura clay

Parameters	Sample		
	AKKO		
Geotechnical properties		Oxides	%
Humidity (%)	12.10	SiO ₂	66.42
Particle size		Al ₂ O ₃	19.23
Clay (%)	20.0	Fe ₂ O ₃	3.61
Sand (%)	17.3	K ₂ O	1.83
Silt (%)	62.7	TiO ₂	1.08
Specific surface (m ² /g)	23.22	CaO	0.42
Atterberg limits		LOI	6.89
Liquidity limit (%)	39.08	Total	99.48
Plasticity limit (%)	27.01	SiO ₂ /Al ₂ O ₃	3.45
Plasticity index (%)	12.07	Al ₂ O ₃ /SiO ₂	0.28
Consistency index (%)	3.13	Al ₂ O ₃ /Fe ₂ O ₃	5.32

3.8 Mechanical resistances (Flexural and compression)

The evolution of the mechanical resistance of the specimens as a function of the stabilizer content is presented in Figures 7 and 8.

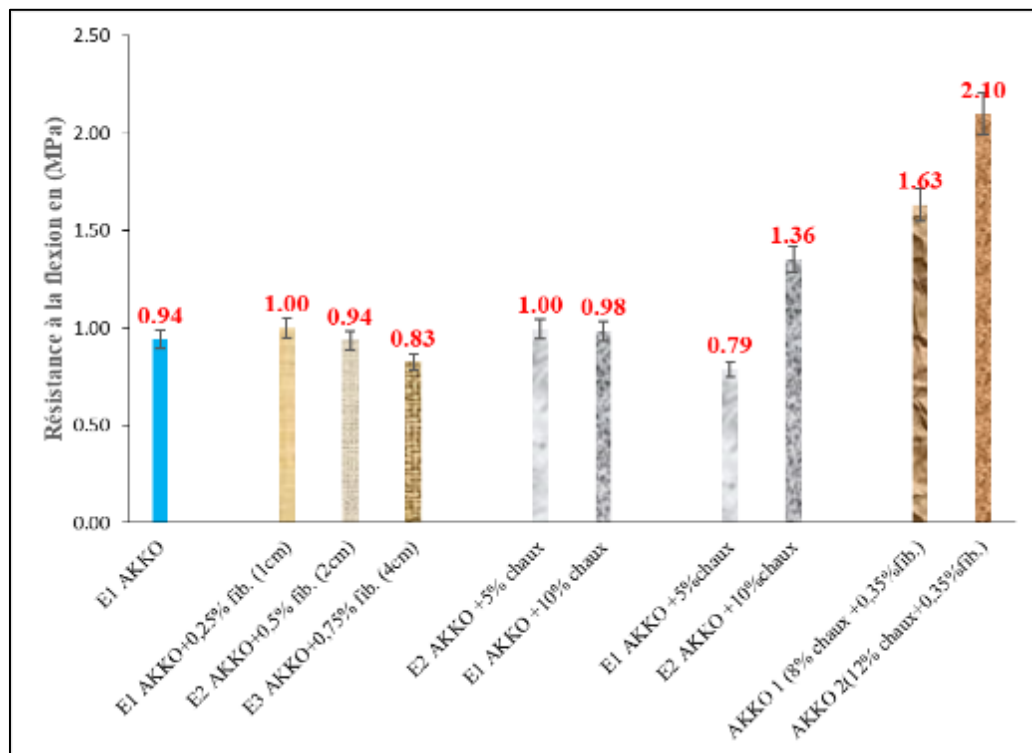


Figure 7: Flexural strength of specimens as a function of stabilizer content

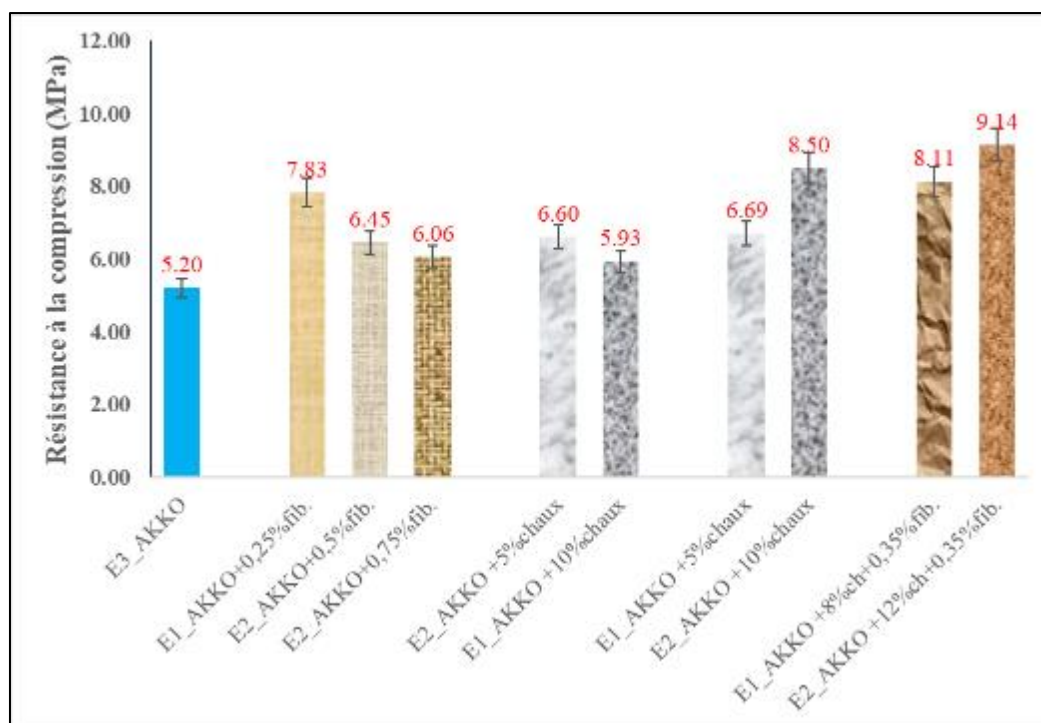


Figure 8: Compressive strength of specimens as a function of stabilizer content

Flexural strength, compressive strength, and other mechanical properties of experimental specimens are not easy to interpret, as they depend on several parameters such as test procedure, specimen size, type of stabilizer, chemical composition of clay and additives.... We will therefore attempt to identify general trends depending on the nature and composition of the soil, the nature of the additives, their quantity and size.

The figures above illustrate the variation in mechanical stress (flexural and compressive strength) of experimental briquettes, whether natural or stabilized with plant fibers and lime at different proportions.

There was a 20.5 % decrease in flexural strength, from 1 to 0.83 MPa, with increasing fiber weight and size.

For clay-lime mixes after 14 days of curing, flexural strength varies from 1 MPa at 5 % dosage to 0.98 MPa at 10 %. However, after 28 days, this resistance increases from 0.79 to 1.36 MPa for a dosage of 5 to 10 %.

The effect of lime addition on flexural strength depends mainly on the nature of the soil and the curing time observed.

Flexural strength decreases by 2 % after 14 days of curing when lime content is increased from 5 % to 10 %, from 1 to 0.98 MPa. However, after 28 days of curing, strength increases by 72 %, from 0.79 to 1.36 MPa.

In the case of the clay-fiber-lime mixture, after 28 days of curing, the flexural strength increases from 1.63 to 2.1 MPa when the lime dosage is increased from 8 % to 12 %, with the addition of 0.35 % of 2 cm-long fibers.

These results show that the flexural strength of samples containing fibers increases with sample age. This finding is in line with previous studies[35],[36] which confirm the increase in flexural strength of samples over time. The flexural strength values of samples containing fibers and lime at 28 days gradually increased, surpassing those of samples without fibers, which in turn surpassed those of samples containing lime alone[37].

It can be seen that the flexural strength of the samples is higher with shorter fibers than with longer ones. This result is contrary to the findings of some authors (Danso et al., 2015b; Mostafa and Uddin, 2015), who have claimed that an increase in fiber length increases the adhesion area, thereby improving flexural strength. This discrepancy could be explained by the fact that, for the same fiber content, a mixture containing short fibers has a greater number of particles than one with long fibers, leading to a better distribution of particles in the matrix. Another explanation could be linked to the existence of an optimum length limit as a function of sample size, beyond which the difficulty of fiber dispersion cancels out the positive effect of reinforcement[38].

Although most studies show an increase in flexural strength with the addition of plant aggregates [41],[42], some studies have observed a negative effect (a decrease in flexural strength). For example, Villamizar et al[39] found a decrease in strength with the addition of cassava peels, and Algin and Turgut[40] observed a similar effect with cotton waste. This decrease could be due to material heterogeneity or poor adhesion between aggregate particles and matrix[41].

On the other hand, adding 0.35% 2 cm-long fibers and 12% lime to the sample produced earth blocks that met standards higher than those mentioned, suitable for all types of earth construction [42].

The average compressive strength of AKKO decreased significantly, from 7.83 MPa to 6.06 MPa, a reduction of around 29 %, after the addition of 0.5 % and 0.75 % fiber.

Analysis of the figure above shows that the compressive strength of unstabilized specimens is 5.2 MPa. This value is comparable to that of lateritic clay composites, which lies between 5.36 and 6.88 MPa for firing temperatures ranging from 900 to 1100 °C[14].

The average compressive strength of samples using starch as a binder is 341% lower than that of samples stabilized with *Triumfetta cordifolia* fibers[43]. Furthermore, the compressive strength of our specimens exceeds the minimum strength required for clay bricks by 5 %, and by more than 840 % for unfired clay bricks, according to the Turkish standard (TS EN 771-1, 2005), which imposes respective strengths of 8 MPa and 1 MPa[44]. What's more, our samples exceed by more than 100 % the strength required for traditional clay bricks according to TS 2415, which lies between 0.5 and 1 N/mm²[45].

At a compaction pressure of 8 MPa, unfired, compressed clay bricks containing 5 % sisal or coir fibers achieve a compressive strength of 6.85 N/mm². This compressive strength value is lower than that of our specimens, whether they contain 0.25 % fibers, 10% lime at 28 days, or both, with between 8 and 12 % lime and 0.35 % 2 cm fibers[46].

The addition of 9 % CEM I 42.5 R cement to soil mixtures containing 30 % clay and silt, 40 % sand, and 30 % gravel, with optimum moisture content and dried for 28 days, gives a compressive strength of around 9.30 MPa. This strength is almost identical to that of the AKKO mixture containing 12 % lime and 0.35 % fiber (2 cm)[47].

In comparison, adobe bricks with a lime ratio of 15 % and 0.2 % palm fiber have a compressive strength of 1.23 MPa, 9 times lower than that of our specimens stabilized with 12 % lime and 0.35 % fiber (2 cm)[48].

4 CONCLUSIONS

We shall therefore attempt to identify general trends in order to determine, on the one hand, whether fibers, lime, and their combination contribute to enhancing the flexural and compressive strength of experimental specimens. On the other hand, if this is the case, we will seek to identify ideal fiber and lime contents within a more precise range.

An analysis of figures 7 and 8 concerning flexural and compressive strengths shows that stabilizing clays with *Triumfetta cordifolia* plant fibers and hydraulic lime from the INSA Rennes laboratory has a positive impact on these parameters.

According to French standard NF P13-300, we observe good flexural and compressive strength of specimens classified as follows:

- The incorporation of 12 % lime plus 0.35 % fiber (2 cm) gives a flexural strength of 2.10 MPa and a compressive strength of 9.14 MPa; these specimens belong to class A.
- Specimens made of 0.25 % fiber (1cm), 10 % lime, the 8 % lime and 0.35 % fiber mixture, after 28 days of curing, belong to class B.
- The other specimens natural clay, the 0.5% and 0.75 % fiber mix, the 5 % and 10 % lime composites after 14 days of curing, and the 5 % lime composite after 28 days of curing - belong to class C.

In short, despite the limited reaction time allowed for lime, both objectives were achieved in these tests. We note that the presence of fibers and lime, and their combination, contribute significantly to increasing the mechanical strength of clay-based composites. These results would probably be more interesting with a longer curing time.

STATEMENTS ON COMPLIANCE WITH ETHICAL STANDARDS

Acknowledgments

The authors express their profound gratitude to the Islamic Development Bank (IsDB) for its financial support, which made this research possible. They also extend their sincere thanks to the Laboratory of Chemistry and Physics of Materials (LCPM) of the Faculty of Sciences, Techniques and Engineering (STI) at Assane Seck University of Ziguinchor, as well as to the Laboratory of Biopolymers, Interactions and Assemblies, Plant Cell Wall and Cellular Polymers (PVPP) team in Nantes, and to the Laboratory of Civil Engineering and Mechanical Engineering (LGCGM) at the National Institute of Applied Sciences (INSA) in Rennes. Their contribution to the physicochemical analyses of clays and plant fibers, as well as to the mechanical testing of the briquettes, was particularly appreciated.

Funding Source

This research was supported by a scholarship from Islamic Development Bank (IsDB) awarded to the third author during his doctoral studies

Disclosure of conflict of interest

The authors declare that they have no conflicts of interest that could have influenced the conduct of this study, the analysis or interpretation of the results, or the writing of the manuscript. This research was conducted independently, without any commercial, financial, or personal relationships that could affect the objectivity of the work. All authors contributed to this study, approved the final version of the manuscript, and consent to its submission for publication.

REFERENCES

- [1] I. Sanou et al., "Raw Earth Bricks Amended with Cement and Kenaf Fibers: Microstructure and Physico-Mechanical Properties," 2023. doi: 10.2139/ssrn.4668518.
- [2] Khedidja Himouri 1, Abdelmadjid Hamouine 1 and Lamia Guettatfi 1, "Effects of Portland Cement and Quicklime on Physical and Mechanical Characteristics of Earth Concrete," vol. 15, no. N° 04, p. 597, 2021.
- [3] L. Zhang, "Production of bricks from waste materials – A review," Constr. Build. Mater., vol. 47, pp. 643–655, Oct. 2013, doi: 10.1016/j.conbuildmat.2013.05.043.
- [4] N. S. Huy, N. N. Tan, M. T. N. Hang, and L. N. Quang, "Environmentally friendly unburnt bricks using raw rice husk and bottom ash as fine aggregates: Physical and mechanical properties," J. Sci. Technol. Civ. Eng. STCE - NUCE, vol. 15, no. 1, pp. 110–120, Jan. 2021, doi: 10.31814/stce.nuce2021-15(1)-10.
- [5] A. Vincenzini, C. E. Augarde, and M. Giofrè, "Experimental characterization of natural fibre–soil interaction: lessons for earthen construction," Mater. Struct., vol. 54, no. 3, p. 110, Jun. 2021, doi: 10.1617/s11527-021-01703-z.
- [6] S. N. Malkanthi, N. Balthazaar, and A. A. D. A. J. Perera, "Lime stabilization for compressed stabilized earth blocks with reduced clay and silt," Case Stud. Constr. Mater., vol. 12, p. e00326, Jun. 2020, doi: 10.1016/j.cscm.2019.e00326.
- [7] S. D. Mvogo Neme, S. A. Zogo Tsala, P. M. Anicet Noah, H. L. E. Nkougou, and S. Nguiya, "Study of the Phyco-Mechanical Behavior of Raw Clay Bricks from Cameroon Stabilized with Lime Reinforced with Tropical Vegetable Fibers," Int. J. Eng. Trends Technol., vol. 72, no. 4, pp. 101–120, Apr. 2024, doi: 10.14445/22315381/IJETT-V72I4P111.
- [8] V. Voišnienė, O. Kizinievič, R. Albrektienė-Plačakė, D. Vasiliauskienė, J. Urbonavičius, and R. Vilkauskaitė, "The Effect of Organic Lake Sediments (Sapropel) on the Properties and Biological Resistance of Unfired Clay Bricks," Sustainability, vol. 16, no. 6, p. 2327, Mar. 2024, doi: 10.3390/su16062327.
- [9] M. Ramesh, M. Parente, M. Azenha, and P. B. Lourenço, "Influence of Lime on Strength of Structural Unreinforced Masonry: Toward Improved Sustainability in Masonry Mortars," Sustainability, vol. 15, no. 21, p. 15320, Oct. 2023, doi: 10.3390/su152115320.
- [10] Olivier, J.G.J., Schure, K. and Peters, J, "Trends in Global CO2 and Total Greenhouse Gas Emissions. Report December," 2017.
- [11] Madeleine Nitcheu et al, "Thermomechanical Characterisation of Compressed Clay Bricks Reinforced by Thatch Fibres for the Optimal Use in Building, Materials Sciences and Applications," Mater. Sci. Appl., vol. 09, pp. 913–935, 2018, doi: 10.4236/msa.2018.912066.

- [12] M. Ouedraogo et al., "Characterization of sugar cane bagasse ash from Burkina Faso for cleaner cement production: Influence of calcination temperature and duration," *Results Mater.*, vol. 14, p. 100275, Jun. 2022, doi: 10.1016/j.rinma.2022.100275.
- [13] A. A. Habibi, M. Fallah Tafti, S. Narani, and M. Abbaspour, "Effects of waste tire textile fibres on geotechnical properties of compacted lime-stabilized low plastic clays," *Int. J. Geotech. Eng.*, vol. 15, no. 9, pp. 1118–1134, Oct. 2021, doi: 10.1080/19386362.2021.1907069.
- [14] P. C. Mengue, M. Mbessa, R. C. Kaze, A. Adesina, and C. Pettang, "Characterization of Clay Materials and Performance Evaluation of Fired Clay Composites Made for Low-Cost Housing," *J. Miner. Mater. Charact. Eng.*, vol. 10, no. 04, pp. 338–359, 2022, doi: 10.4236/jmmce.2022.104024.
- [15] N. Suffri, M. Jeludin, and S. Rahim, "Behaviour of the Undrained Shear Strength of Soft Clay Reinforced with Natural Fibre," *IOP Conf. Ser. Mater. Sci. Eng.*, vol. 690, no. 1, p. 012005, Dec. 2019, doi: 10.1088/1757-899X/690/1/012005.
- [16] G. F. Ngon Ngon et al., "Geological study of sedimentary clayey materials of the Bomkoul area in the Douala region (Douala sub-basin, Cameroon) for the ceramic industry," *Comptes Rendus Geosci.*, vol. 344, no. 6–7, pp. 366–376, Jun. 2012, doi: 10.1016/j.crte.2012.05.004.
- [17] H. Limami, I. Manssouri, K. Cherkaoui, and A. Khaldoun, "Mechanical and physicochemical performances of reinforced unfired clay bricks with recycled Typha-fibers waste as a construction material additive," *Clean. Eng. Technol.*, vol. 2, p. 100037, Jun. 2021, doi: 10.1016/j.clet.2020.100037.
- [18] I. Bouchefra, F. Z. El Bichri, H. Chehouani, and B. Benhamou, "Mechanical and thermophysical properties of compressed earth brick reinforced by raw and treated doum fibers," *Constr. Build. Mater.*, vol. 318, p. 126031, Feb. 2022, doi: 10.1016/j.conbuildmat.2021.126031.
- [19] G. A. Abanto, M. Karkri, G. Lefebvre, M. Horn, J. L. Solis, and M. M. Gómez, "Thermal properties of adobe employed in Peruvian rural areas: Experimental results and numerical simulation of a traditional bio-composite material," *Case Stud. Constr. Mater.*, vol. 6, pp. 177–191, Jun. 2017, doi: 10.1016/j.cscm.2017.02.001.
- [20] ONU-HABITAT, "Diagnostic du développement urbain, de la mise en œuvre des politiques publiques et des défis de l'urbanisation durable en Guinée." Jun. 2020.
- [21] T. A. Barry, "DATU 2022, Google earth Projection WGS 84 UTM 29 N," Mar. 2023.
- [22] G. Jozanikohan and M. N. Abarghoee, "The Fourier transform infrared spectroscopy (FTIR) analysis for the clay mineralogy studies in a clastic reservoir," *J. Pet. Explor. Prod. Technol.*, vol. 12, no. 8, pp. 2093–2106, Aug. 2022, doi: 10.1007/s13202-021-01449-y.
- [23] S. Vahur et al., "Quantitative mineralogical analysis of clay-containing materials using ATR-FT-IR spectroscopy with PLS method," *Anal. Bioanal. Chem.*, vol. 413, no. 26, pp. 6535–6550, Nov. 2021, doi: 10.1007/s00216-021-03617-9.
- [24] A. El-Shater, "Crystallographic and Morphological Characteristics of Natural Kaolins, Aswan Region, Egypt," *Int. J. Earth Sci. Geol.*, vol. 4, no. 1, pp. 121–130, Nov. 2022, doi: 10.18689/ijeg-1000116.
- [25] R. Ravisankar, A. Naseerutheen, A. Rajalakshmi, G. Raja Annamalai, and A. Chandrasekaran, "Application of thermogravimetry–differential thermal analysis (TG–DTA) technique to study the ancient potteries from Vellore dist, Tamilnadu, India," *Spectrochim. Acta. A. Mol. Biomol. Spectrosc.*, vol. 129, pp. 201–208, Aug. 2014, doi: 10.1016/j.saa.2014.02.095.
- [26] M. Milošević, P. Dabić, J. Gulicovski, V. Dodevski, and M. Rosić, "Mineralogical Characterization of Raw Clay from Rujište (Serbia) Used in Traditional Pottery Manufacture," *Minerals*, vol. 14, no. 5, p. 469, Apr. 2024, doi: 10.3390/min14050469.
- [27] A. K. Chakraborty, *Phase Transformation of Kaolinite Clay*, 1st ed. 2014. New Delhi: Springer India : Imprint: Springer, 2014. doi: 10.1007/978-81-322-1154-9.
- [28] R. Snellings et al., "Paper of RILEM TC 282-CCL: mineralogical characterization methods for clay resources intended for use as supplementary cementitious material," *Mater. Struct.*, vol. 55, no. 5, p. 149, Jun. 2022, doi: 10.1617/s11527-022-01973-1.
- [29] J. Geng and Q. Sun, "Effects of high temperature treatment on physical-thermal properties of clay," *Thermochim. Acta*, vol. 666, pp. 148–155, Aug. 2018, doi: 10.1016/j.tca.2018.06.018.
- [30] M. Földvári, *Handbook of thermogravimetric system of minerals and its use in geological practice*. in Occasional papers of the Geological Institute of Hungary, no. 213. Budapest: Geological Inst. of Hungary, 2011.

- [31] R. Dewi, H. Agusnar, Z. Alfian, and Tamrin, "Characterization of technical kaolin using XRF, SEM, XRD, FTIR and its potentials as industrial raw materials," *J. Phys. Conf. Ser.*, vol. 1116, p. 042010, Dec. 2018, doi: 10.1088/1742-6596/1116/4/042010.
- [32] S. A. Salihu, I. Y. Suleiman, "Comparative analysis of the physical and chemical characteristics of selected clay deposits in Kebbi State, Nigeria," vol. 13(10), no. 10, pp. 163–173, Apr. 2018, doi: 10.5897/IJPS2018.4727.
- [33] S. Ferrari and A. Gualtieri, "The use of illitic clays in the production of stoneware tile ceramics," *Appl. Clay Sci.*, vol. 32, no. 1–2, pp. 73–81, Apr. 2006, doi: 10.1016/j.clay.2005.10.001.
- [34] Marou Gourouza and et al., "Characterization of a mixed clay from Niger," *Rev. CAMES*, vol. Vol. 1, pp. 36–37, Dec. 2013.
- [35] G. Araya-Letelier, J. Concha-Riedel, F. C. Antico, and C. Sandoval, "Experimental mechanical-damage assessment of earthen mixes reinforced with micro polypropylene fibers," *Constr. Build. Mater.*, vol. 198, pp. 762–776, Feb. 2019, doi: 10.1016/j.conbuildmat.2018.11.261.
- [36] R. G. Elenga, B. Mabilia, L. Ahouet, J. Goma-Maniongui, and G. F. Dirras, "Characterization of Clayey Soils from Congo and Physical Properties of Their Compressed Earth Blocks Reinforced with Post-Consumer Plastic Wastes," *Geomaterials*, vol. 01, no. 03, pp. 88–94, 2011, doi: 10.4236/gm.2011.13013.
- [37] A. Kabore and C. M. Ouellet-Plamondon, "The Impact of Vegetable Fibres on the Shrinkage and Mechanical Properties of Cob Materials," *Materials*, vol. 17, no. 3, p. 736, Feb. 2024, doi: 10.3390/ma17030736.
- [38] Aurélie L.-Preneron, "Formulation and characterization of unfired clay bricks with plant aggregates." Doctoral thesis, University of Toulouse, Sep. 2017.
- [39] M. C. N. Villamizar, V. S. Araque, C. A. R. Reyes, and R. S. Silva, "Effect of the addition of coal-ash and cassava peels on the engineering properties of compressed earth blocks," *Constr. Build. Mater.*, vol. 36, pp. 276–286, Nov. 2012, doi: 10.1016/j.conbuildmat.2012.04.056.
- [40] H. M. Algin and P. Turgut, "Cotton and limestone powder wastes as brick material," *Constr. Build. Mater.*, vol. 22, no. 6, pp. 1074–1080, Jun. 2008, doi: 10.1016/j.conbuildmat.2007.03.006.
- [41] Ş. Yetgin, Ö. Çavdar, and A. Çavdar, "The effects of the fiber contents on the mechanic properties of the adobes," *Constr. Build. Mater.*, vol. 22, no. 3, pp. 222–227, Mar. 2008, doi: 10.1016/j.conbuildmat.2006.08.022.
- [42] A. El-Yahyaoui, I. Manssouri, O. Noureddine, H. Sahbi, and A. Khaldoun, "Physical and mechanical properties of unfired clay bricks with saw palmetto fibers additive as a construction material," *Mater. Today Proc.*, vol. 72, pp. 3804–3814, 2023, doi: 10.1016/j.matpr.2022.09.487.
- [43] G. Balčiūnas, S. Vėjelis, S. Vaitkus, and A. Kairyte, "Physical Properties and Structure of Composite Made by Using Hemp Hurds and Different Binding Materials," *Procedia Eng.*, vol. 57, pp. 159–166, 2013, doi: 10.1016/j.proeng.2013.04.023.
- [44] I. Demir, "Effect of organic residues addition on the technological properties of clay bricks," *Waste Manag.*, vol. 28, no. 3, pp. 622–627, Jan. 2008, doi: 10.1016/j.wasman.2007.03.019.
- [45] H. Binici, O. Aksogan, and T. Shah, "Investigation of fibre-reinforced mud brick as a building material," *Constr. Build. Mater.*, vol. 19, no. 4, pp. 313–318, May 2005, doi: 10.1016/j.conbuildmat.2004.07.013.
- [46] Heavy Geoffrey Njau, Eugene Park, "Compressive Strength of Unfired Composite Bricks Made of Same Clay and Natural Fiber of Tanzania," *International Research Journal of Engineering and Technology*, vol. 02, no. 09, p. p 14, Dec. 2015.
- [47] P. Narloch, P. Woyciechowski, J. Kotowski, I. Gawriuczenkow, and E. Wójcik, "The Effect of Soil Mineral Composition on the Compressive Strength of Cement Stabilized Rammed Earth," *Materials*, vol. 13, no. 2, p. 324, Jan. 2020, doi: 10.3390/ma13020324.
- [48] B. Ahmed, F. Abdelkader, D. Adel, M. M. Nadjib, B. Imene, and A. Imene, "Evaluation of the mechanical properties of adobe bricks when adding palm fiber and lime," *Stud. Eng. EXACT Sci.*, vol. 5, no. 1, pp. 2799–2812, Jun. 2024, doi: 10.54021/seesv5n1-138.