

Ceramic Properties of Three Specimens of Alluvial Clays Used in Local Constructions from Mbouda Clay Deposit, West Cameroon

Philémon Zo'o Zame¹, Sylvain Kouayep Lawou², Philippe Samba Assomo^{2*}, Audrey Erman Moutsou², Yannick Lontchi Dzoti², Véronique Kamgang Kabeyene Beyala³

¹Faculty of Science, University of Yaoundé I, Yaoundé, Cameroon

²Higher Teacher Training College Bertoua, University of Bertoua, Bertoua, Cameroon

³Faculty of Science, University of Dschang, Dschang, Cameroon

Email: philippesamba850@gmail.com

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Abstract

The Mbouda alluvial deposit is located at the foot of the Bamboutos mountains (West Cameroon) where three types of clayey materials are widespread. The populations collect these clays in their natural state in view of constructions using fired bricks or compressed blocks. Unfortunately, these buildings are not strong. This study investigates the causes of the strengthlessness of buildings and suggests solutions to overcome the difficulty. The research content includes field and laboratory studies. The methodology consists of sampling black (AN), white (AB) and red (AR) clays specimens identified in the study area and analysing them simultaneously at MIPROMALO (Cameroon) and at ACME LAB in Vancouver (Canada). The results obtained show a high sand content in the samples AN (64%), AB (55.2%), AR (30.9%). The compressive strength of the built specimens is low at 900°C considered as the traditional firing temperature AN (0.94 MPa), AB (5.25 MPa), AR (2.18 MPa). The mineralogical series are identically made by kaolinite, chlorite, gibbsite, quartz, muscovite, biotite, goethite, magnetite and hematite. Silica (SiO₂) presents higher contents AN (52.87%), AB (48.02%), AR (47.68%) followed by alumina (Al₂O₃) AN (29.96%), AB (28.13%), AR (24.72%). The other elements are poorly represented.

Keywords

Sand, Bricks, Clays, Mechanical Properties, Local Constructions

1. Introduction

Interest in clay as a raw material for construction goes back to ancient times [1]. The Egyptian pyramids and other great historical monuments were built using clay [1]. Fired or compressed bricks are the technological element used in all earthen constructions [2] [3]. Today, a number of studies focus on the applications of ceramic clays in several areas around the world [4]-[11], as well as in Africa [12]-[23].

In Cameroon, the use of clays as construction materials is gaining momentum [24]-[31]. The work focuses either on the characterization of lateritic or alluvial clays for their use as building materials [27]-[29], or on the evolution of physico-chemical and mechanical properties during the firing process [25] [26] [30] [31].

However, local people continue to face difficulties linked to the fragility of earthen materials in their constructions. This is due to a lack of knowledge regarding the processes involved, as clays do not have the same origins, let alone the same mineralogical or chemical compositions. However, numerous researchers have already recommended methods for selecting and improving the mechanical quality of bricks [32] [33]. Selection involves separating healthy clay from impurities, notably organic matter or coarse fractions [32] [33]. Improving the mechanical quality of bricks involves compressing the materials, firing or other various amendments. The addition of 10%wt CaCO₃ or the mixture of clay with lateritic gave to improve the mechanical quality of fired bricks, are cited as examples [15] [34].

2. Materials and Methods

2.1. Geological Settings

The study area extends from parallels 5°36'50.09" to 5°53'02" north latitude and from meridians 10°15'36.19" to 10°22'20.43" east longitude (**Figure 1**). The substratum is marked by the presence of the Cameroon Volcanic Line (CVL). The CVL is a N30°E alignment of anorogenic plutonic complexes and oceanic and continental volcanic massifs from the Gulf of Guinea to Lake Chad [35]. The CVL comprises some sixty anorogenic complexes composed of various plutonic rocks (granite, syenite, diorite, gabbro) of mantle origin and alkaline to hyper alkaline affinity, sometimes associated volcanism [36]. They were emplaced in the Upper Cretaceous (73 Ma) to the Middle Eocene (40 Ma). The oceanic and continental volcanic massifs are also alkaline. The volcanism began around 44Ma and continues episodically until now [37]. The development of magmatism appears to be linked to the reactivation of ancient Pan-African structures [38]. The rejection of an NE-SW mega-crack triggered volcanic activity from the Tertiary to now and a succession of horsts and grabens defining the Cameroon Line [38]. The peneplain and the southern part of the western plateau have been rejuvenated by very recent volcanic eruptions. Most of them erupted, while three of them had vulcanic regimes accompanied by variable ash projections [39].

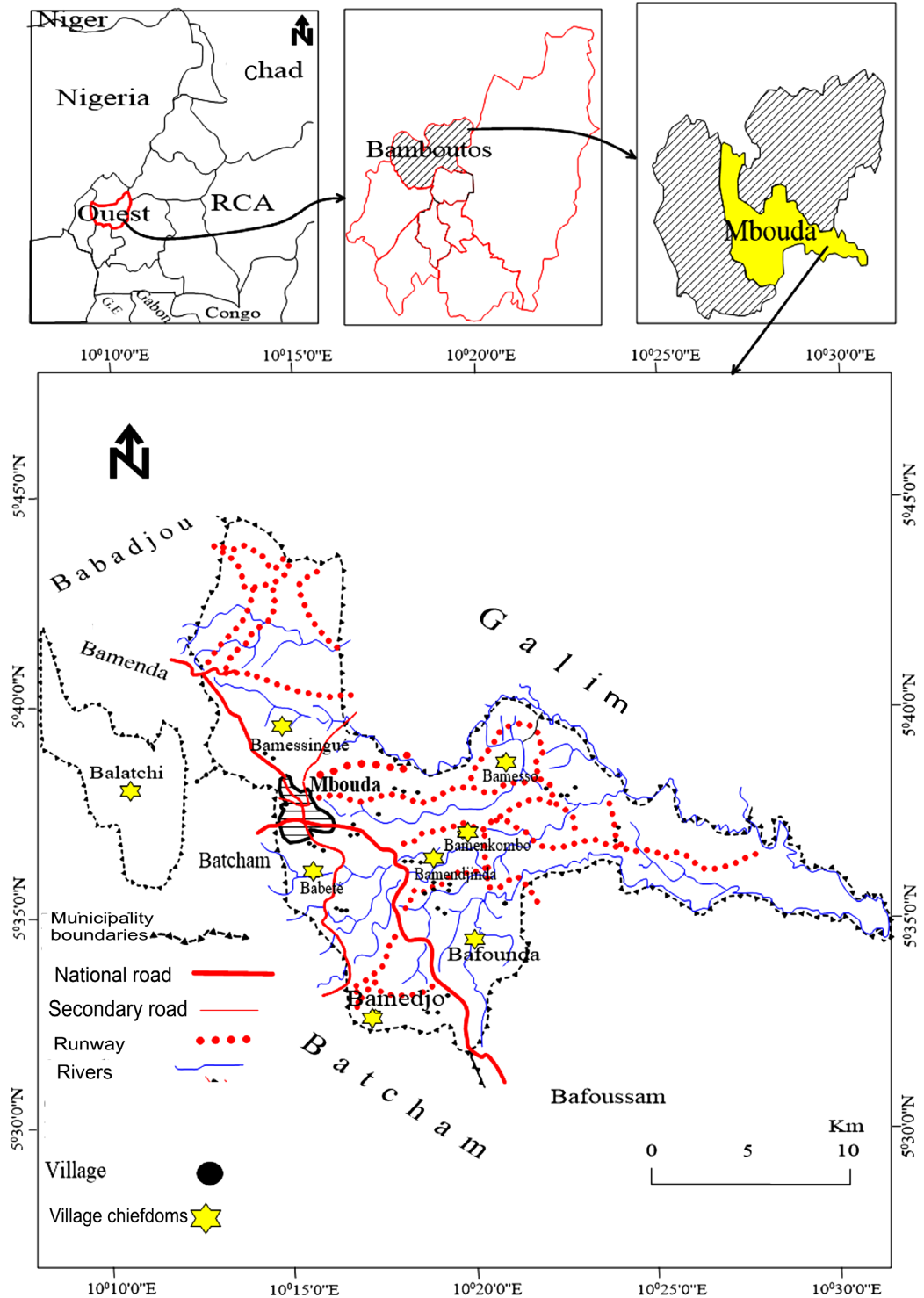


Figure 1. Study area location.

2.2. Field Work

Alluvial clays derived from the weathering of basalts and migmatites in the locality of Mbouda constitute the key material of the present study. Clay samples were collected from three wells (P1, P2 and P3) dug in the three representative clay

facies, namely white clay (AB), black clay (AN) and red clay (AR). For each well, two samples were collected and mixed from the clay stratum as follows: P1 (AB1 and AB2); P2 (AN1 and AN2) and P3 (AR1 and AR2). Samples AB, AN and AR are the result of mixtures AB1 + AB2, AN1 + AN2 and AR1 + AR2, respectively.

2.3. Laboratory Analysis

2.3.1. Physicomechanical and Ceramic Properties

These properties were evaluated at the MIPROMALO (Mission for the Promotion of Local Materials) laboratory in Yaoundé (Cameroon). Physical analyses (grain size distribution) and ceramic tests (color, cohesion, resonance, linear shrinkage, porosity, density, water absorption and compressive strength) were also carried out there.

2.3.2. Mineralogical and Chemical Evaluations

Samples were analyzed at the Mineralogical and Geochemical Analysis ACME LAB in Vancouver, Canada. Mineralogical analysis was carried out using the diffractometric (DRX) principle [40]. X-ray diffraction patterns were obtained with a Bruler D8 Advance Eco type diffractometer of 1kw power, gas flow with copper (CuK α) anode of wavelength 1.5418 Å. Electron acceleration conditions in the tube were 40.125 KV and 25 mA with an Xe-type energy-dispersive. Analyses were carried out on non-oriented powder with ground particles smaller than 50 μ m.

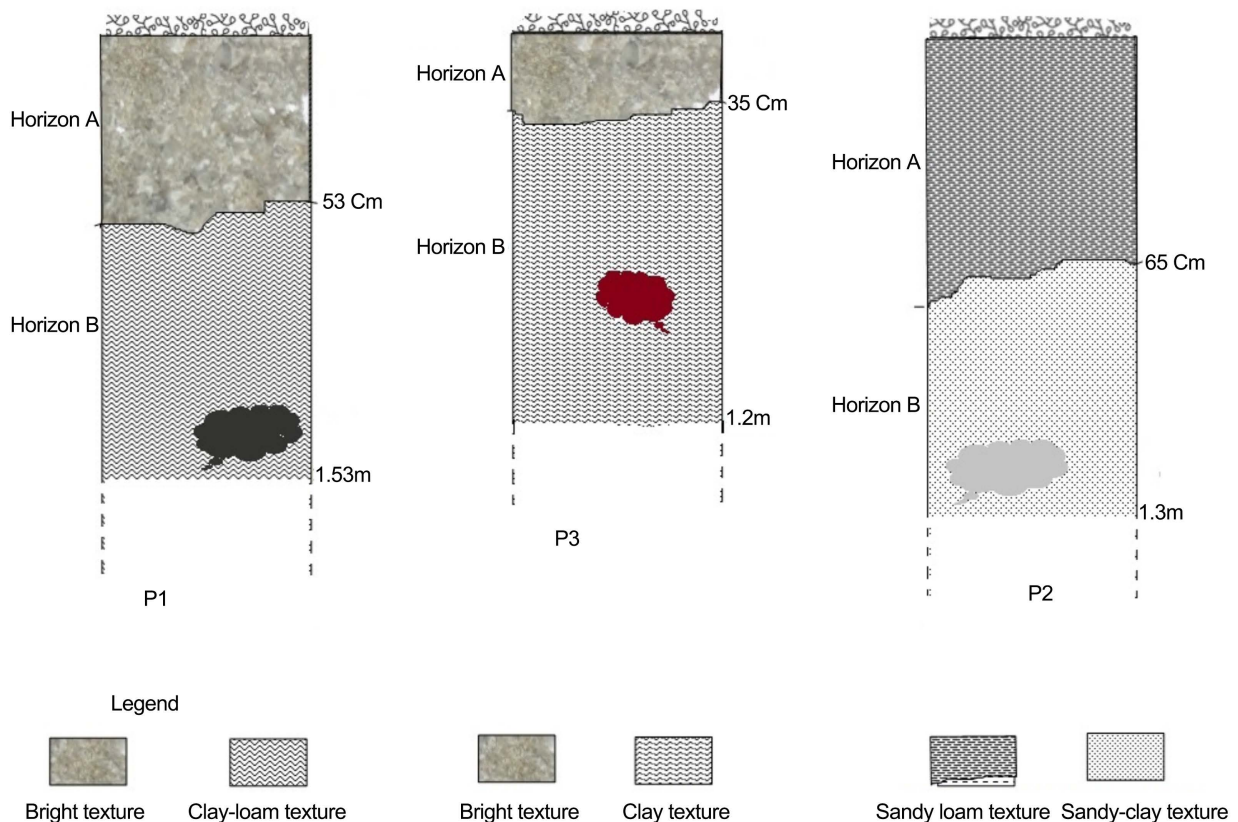


Figure 2. Sampling wells.

3. Results

3.1. Field Results

The soil profiles of the wells are characteristic of two horizons, A and B, with different textures (**Figure 2**). The colorations of the clays are different in the three wells, with black clays (AN) in well 1, white clays (AB) in well 2 and red clays (AR) in well 3. The color of the alluvial clays is closely linked to the nature of the material in which they are found. The black color results from the importance of organic matter [33]; the white color is linked to the presence of kaolinite, while the red color shows the influence of iron oxides [13] [29] [41] [42].

3.2. Laboratory Results

3.2.1. Grains Size Distribution

The distribution of the proportions of the different granular families is shown in **Table 1**. The AN material is characterized by a high proportion of sand (64%), while the AR sample is characterized by high levels of silt (33.6) and clay (33.6). The clay content of the analyzed materials ranges from 9.3% to 35.5%. The grading was very tight for samples AB and AR, and spread out for sample AN. These results show that sand content is significant in all the samples examined (64.4%, 55.2% and 30.9% for AN AB and AR respectively). These large quantities of sand in the samples are thought to be responsible for the brittleness of bricks made from these local materials. The consequence is that houses built with earth bricks cannot withstand the slightest environmental weathering.

Table 1. Grain size fractions of samples.

| Sample | % of gravel $\Phi > 2 \text{ mm}$ | % of sand $2 > \Phi > 0.02$ mm | % of silt $0.02 > \Phi > 0.002$ mm | % of clay $\Phi < 0.002$ mm |
|--------|--------------------------------------|--------------------------------------|--|-----------------------------------|
| AN | 1.3 | 64.4 | 25.0 | 9.3 |
| AB | 2.6 | 55.2 | 8.8 | 33.4 |
| AR | 0.3 | 30.9 | 33.6 | 35.2 |

3.2.2. Ceramic Properties of Bricks after Firing in a Kiln at Variable Temperature

Ceramic properties such as linear shrinkage (**Figure 3**), density (**Figure 4**), water absorption (**Figure 5**) and compressive strength (**Figure 6**) show that water absorption decreases while the other ceramic parameters increase with firing temperature. The departure of the water is due to the densification of the bricks, which is reflected in the increase in linear shrinkage, density and strength. In fact, this behaviour is common to all brick specimens subjected to firing [13] [29] [41] [42]. The compressive strength of the specimens is low because of the high sand content, except for AB, which is an alluvial clay rich in kaolinite. Alluvial clays appear more suitable for the manufacture of fired bricks than lateritic clays [25].

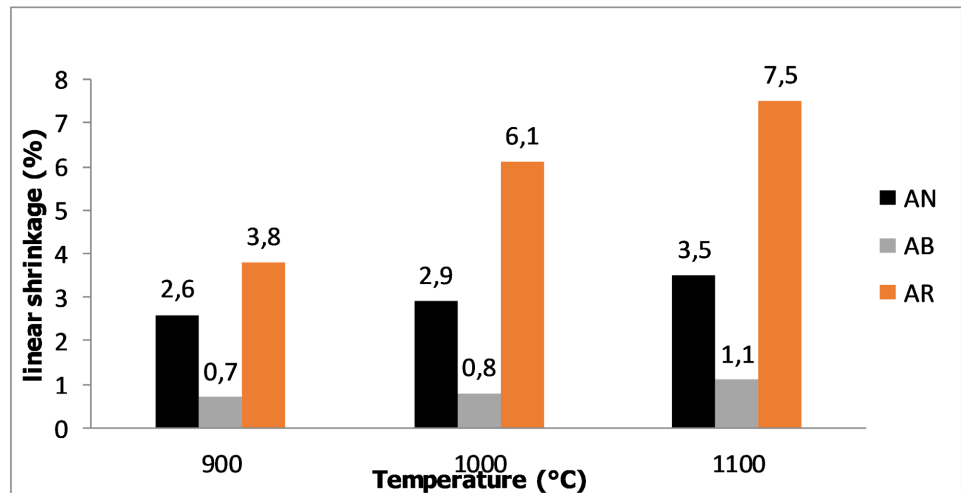


Figure 3. Diagram showing the variation of linear shrinkage during the firing process.

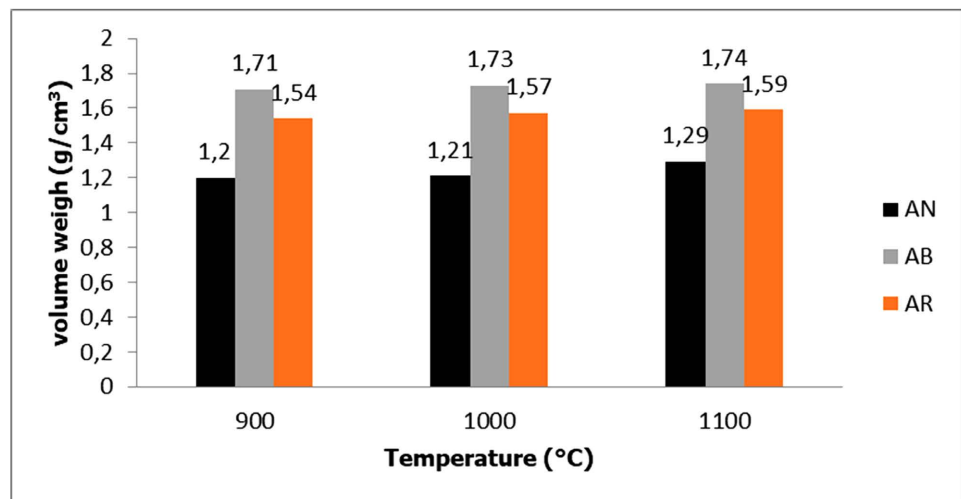


Figure 4. Diagram showing the variation of density during the firing process.

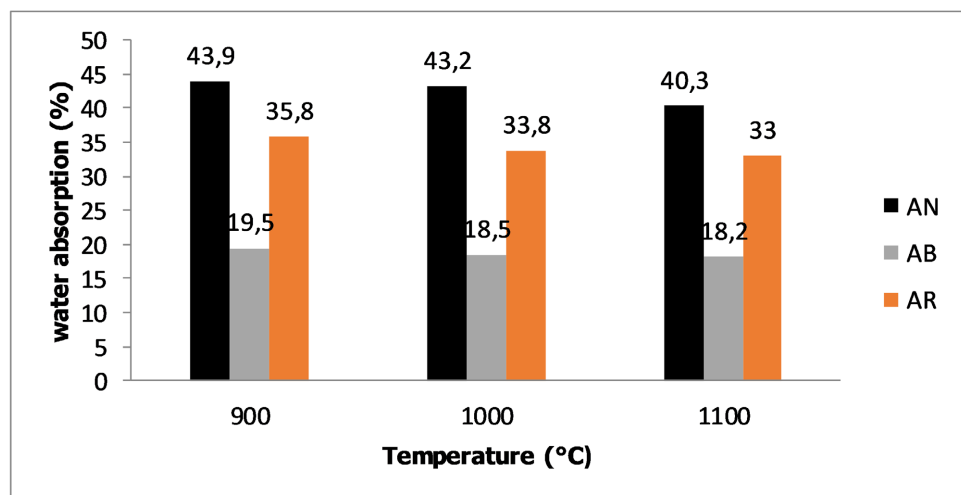


Figure 5. Diagram showing the variation of water absorption during the firing process.

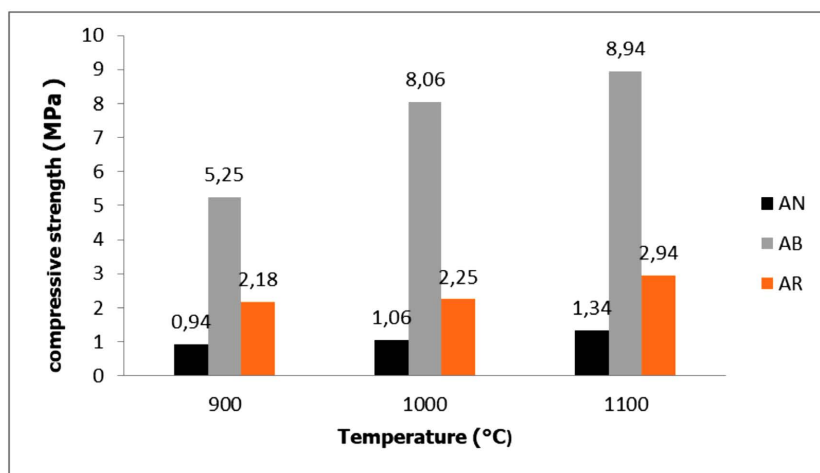


Figure 6. Diagram showing the variation of compressive strength during the firing process.

3.2.3. Mineralogical Analysis by X-Ray Diffraction

Qualitative analysis by X-ray diffractometry on disoriented powder was carried out on three samples. Recognition of the mineralogical composition led to the production of diffractograms and indexing of the hkl lines characteristic of the main minerals. **Figures 7-9** depict diffractograms. The AN(P1) sample contains minerals such as kaolinite, anatase, quartz, goethite, hematite, biotite and gibbsite. The mineralogical composition of sample AB(P2) consists of chlorite, kaolinite, anatase, quartz, biotite, hematite, muscovite, goethite and magnetite. Sample AR(P3) contains the following minerals: chlorite, kaolinite, anatase, quartz, biotite, hematite, muscovite, goethite and gibbsite.

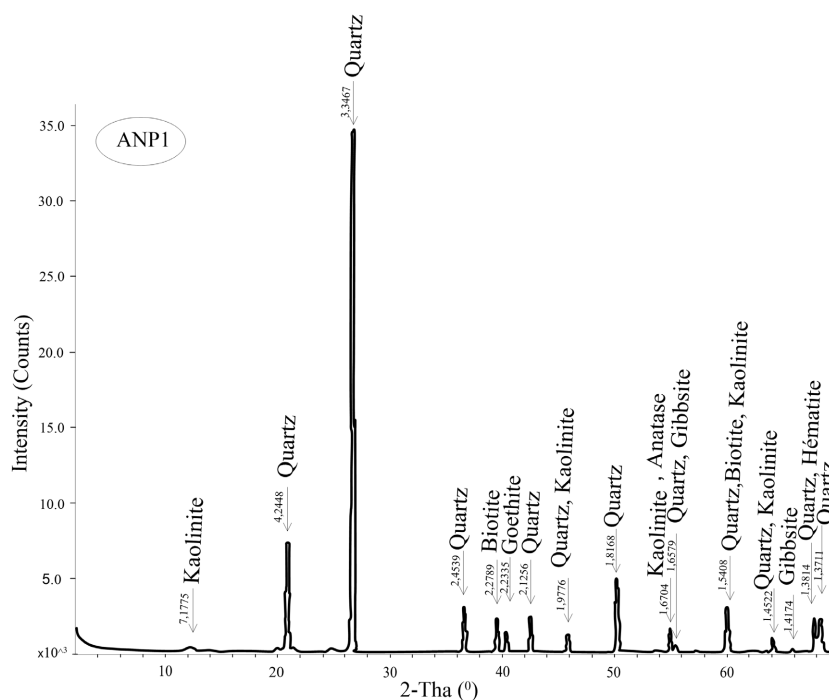


Figure 7. Diffractogram of the AN sample.

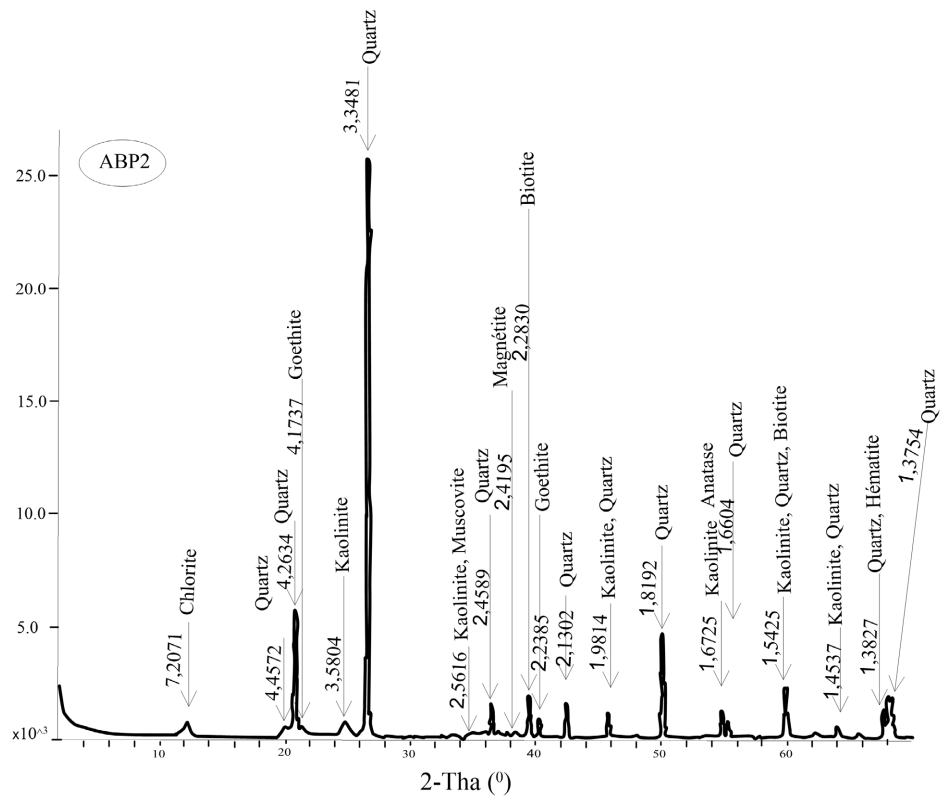


Figure 8. Diffractogram of the AB sample.

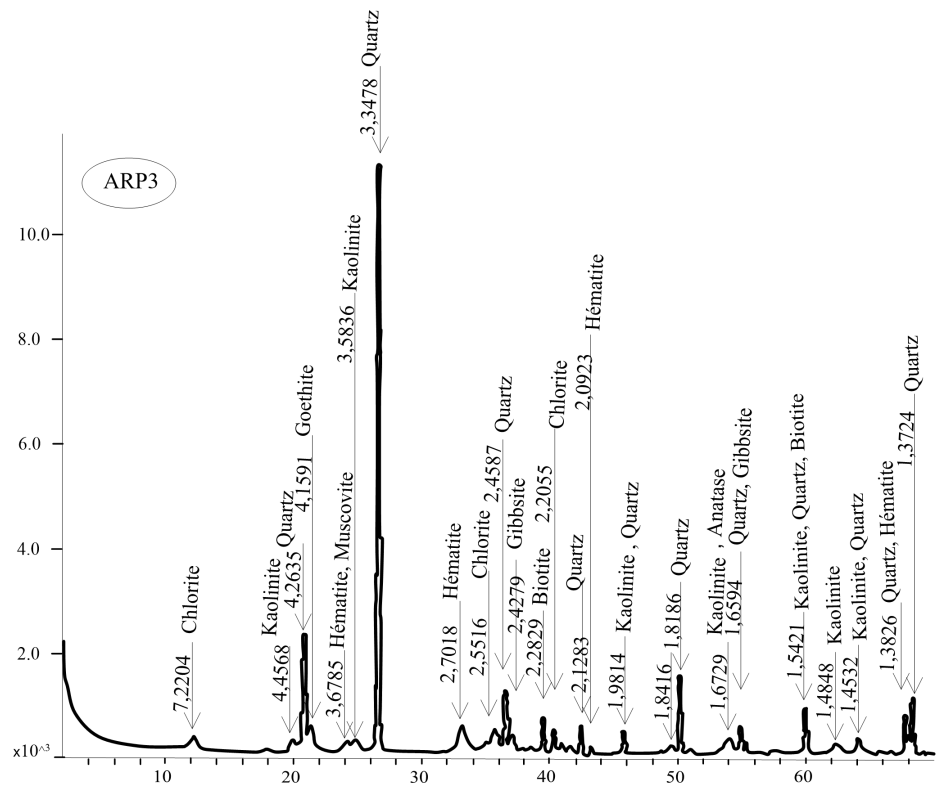


Figure 9. Diffractogram of the AR sample.

3.2.4. Geochemical Analysis

Geochemical analysis of the samples (AN, AB, AR) enabled the major elements to be expressed as a percentage (%) of oxides. The assessment (**Table 2**) reveals high SiO₂ content ranging from 47.68% to 52.87%, with an average of 49.52%. The Al₂O₃ content ranged from 24.77% to 28.13%, with an average of 26.62%. The Fe₂O₃ content varies from 1.45% to 5.13%, with an average of 3.16%. MgO content ranged from 0.32% to 0.40%, with an average of 0.37%. CaO concentrations ranged from 0.04% to 1.08%, with an average of 0.39%. Na₂O content varied from 0.10% to 0.13%, with an average of 0.11%. K₂O content ranged from 1.08% to 2.71%, with an average of 1.81%. The other sample contents of TiO₂ (1.69% - 2.29%), P₂O₅ (0.26% - 0.48%) and MnO (0.01% - 0.13%) have very poor content.

Table 2. Major element content (in % oxides) of samples.

| Oxide | DL | Sample | | | | | |
|--------------------------------|------|--------|---------|----------|---------|-------|--------|
| | | ANP1 | ABP2 | ARP3 | AVERAGE | PAAS | UCC |
| SiO ₂ | 0.01 | 52.87 | 48.02 | 47.68 | 49.52 | 62.8 | 66 |
| Al ₂ O ₃ | 0.01 | 26.97 | 28.13 | 24.77 | 26.62 | 18.9 | 15.2 |
| Fe ₂ O ₃ | 0.04 | 1.45 | 2.90 | 5.13 | 3.16 | 6.5 | 4.5 |
| MnO | 0.01 | 0.01 | 0.01 | 0.02 | 0.013 | 0.11 | 0.1 |
| MgO | 0.01 | 0.32 | 0.38 | 0.40 | 0.37 | 2.2 | 2.2 |
| CaO | 0.01 | 1.08 | 0.04 | 0.04 | 0.39 | 1.3 | 4.2 |
| Na ₂ O | 0.01 | 0.10 | 0.11 | 0.13 | 0.11 | 1.2 | 3.9 |
| K ₂ O | 0.01 | 1.08 | 1.81 | 2.71 | 1.87 | 3.7 | 3.4 |
| TiO ₂ | 0.01 | 1.69 | 2.29 | 2.12 | 2.03 | 1 | 0.5 |
| P ₂ O ₅ | 0.01 | 0.26 | 0.34 | 0.48 | 0.36 | 0.16 | 0.17 |
| LOI | -5.1 | 14.13 | 14.99 | 16.24 | 15.12 | 0 | 0 |
| Total | - | 99.96 | 99.02 | 99.72 | 99.57 | 97.87 | 100.17 |
| Total - LOI | - | 85.83 | 84.0311 | 83.48449 | 84.45 | - | - |

DL: Detection Limit.

4. Discussion of the Results

Earthen buildings in the Bouda area are made using compressed earth blocks. This method reduces environmental pollution caused by the use of kiln fuel in the fired brick production industries [43]-[46]. The results obtained in this research are in agreement with the work showing that unfired bricks are characterised by low strength and high permeability [3]. The main handicap of compressed blocks being their high sand and organic matter content [32] [33]. Prior treatment of the material is necessary by removing the coarse fraction and organic matter from the clay [32] [33]. Even, when healthy clay is used, the mechanical quality of compressed earth blocks remains mediocre [3] [8]. To improve the mechanical quality of earth blocks, several treatments are envisaged, mainly material mixtures and firing [13] [31] [33] [34] [47]-[49]. When the preliminary treatments are applied,

brick solidification mechanisms based on microstructural and molecular arrangements under the effect of pressure or temperature are likely to occur, in accordance with the results of numerous studies [6] [17] [27] [35] [50]-[57].

The results of the particle size analysis show a high sand content in all the samples with low clay fraction. These are responsible for the changes in the ceramic parameters. The high sand content explains the good evolution of density, which is accompanied by low compressive strength and low percentage of linear shrinkage, as well as water absorption, since these three parameters are closely linked to the clay fraction. The results obtained in this work are similar to those obtained by other authors who have proposed amendments to improve the mechanical quality of bricks [32]-[34] [57]. The mineralogical series as well as chemical analysis enabled a rapid classification of clays as alumino-silicate materials [25] [27]-[29] [35]. The chemical composition of the samples (AR, AB and AN) is favourable for the crystallisation of kaolinite and quartz, whereas quartz is unfavourable for the cohesion and consolidation of fired bricks [33]. Similarly, high levels of iron oxides also play the same unfavorable role as quartz [27]. *In contrario*, other minerals can play an important role in the mineralogical transformations that affect them during the firing process necessary to acquire the good mechanical properties of fired bricks. The main mineralogical transformations contributing to the acquisition of good mechanical properties in bricks have been listed [58]-[60].

5. Conclusions

When closing this work devoted to the ceramic properties of three specimens clays from Mbouda deposit, the following conclusions are deduced:

- The materials examined have high sand content with low clay fraction.
- The mineralogical and geochemical composition is similar, with silica predominating, followed by alumina. The main minerals are quartz, kaolinite, haematite and biotite.
- The ceramic properties of the fired bricks are mediocre due to the high percentage of sand and organic matter in the samples. This explains the fragility of buildings.
- To produce bricks with good mechanical properties, it is recommended the pretreatment by reducing sand fraction and organic matter from the raw material. Amendments can also be made by adding small quantities of laterite or sand (<10% wt) in healthy clay.

Conflicts of interest

The authors declare no competing interests.

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References

- [1] Delbecque, C. (2001) Approche contemporaine de la construction en terre. Histoire de la construction en terre, 22. http://www.cd2e.com/sites/default/files/eco-construction%20Ch.%20Delbecque_histoire_construction_terre_oct11.pdf,p22
- [2] Rigassi, V. (1995) BTC Production Manual. CRA Terre-EAG.
- [3] Muheise-Araalia, D. and Pavia, S. (2021) Properties of Unfired, Illitic-Clay Bricks for Sustainable Construction. *Construction and Building Materials*, **268**, Article 121118. <https://doi.org/10.1016/j.conbuildmat.2020.121118>
- [4] Celik, H. (2010) Technological Characterization and Industrial Application of Two Turkish Clays for the Ceramic Industry. *Applied Clay Science*, **50**, 245-254. <https://doi.org/10.1016/j.clay.2010.08.005>
- [5] Ngun, B.K., Mohamad, H., Sulaiman, S.K., Okada, K. and Ahmad, Z.A. (2011) Some Ceramic Properties of Clays from Central Cambodia. *Applied Clay Science*, **53**, 33-41. <https://doi.org/10.1016/j.clay.2011.04.017>
- [6] Zurita Ares, M.C., Pérez, M.R., Quesada Carballo, L. and Fernández, J.M. (2015) Assessment of Clays from Puertollano (Spain) for Their Use in Fine Ceramic by Diffuse Reflectance Spectroscopy. *Applied Clay Science*, **108**, 135-143. <https://doi.org/10.1016/j.clay.2015.02.010>
- [7] Semiz, B. (2017) Characteristics of Clay-Rich Raw Materials for Ceramic Applications in Denizli Region (Western Anatolia). *Applied Clay Science*, **137**, 83-93. <https://doi.org/10.1016/j.clay.2016.12.014>
- [8] Pardo, F., Jordan, M.M. and Montero, M.A. (2018) Ceramic Behaviour of Clays in Central Chile. *Applied Clay Science*, **157**, 158-164. <https://doi.org/10.1016/j.clay.2018.02.044>
- [9] González-López, J.R., Juárez-Alvarado, C.A., Ayub-Francis, B. and Mendoza-Rangel, J.M. (2018) Compaction Effect on the Compressive Strength and Durability of Stabilized Earth Blocks. *Construction and Building Materials*, **163**, 179-188. <https://doi.org/10.1016/j.conbuildmat.2017.12.074>
- [10] Dewaele, S., Ottenburgs, R., Van Oyen, P. and Viaene, W. (2003) Prospection and Evaluation of Clay Deposits in the Republic of Ireland. In: Degryse, P. and Elsen, J., Eds., *Industrial Minerals Resources, Characteristics and Applications*, Leuven University Press, 97-105.
- [11] Millogo, Y., Hajjaji, M. and Ouedraogo, R. (2008) Microstructure and Physical Properties of Lime-Clayey Adobe Bricks. *Construction and Building Materials*, **22**, 2386-2392. <https://doi.org/10.1016/j.conbuildmat.2007.09.002>
- [12] Nyakairu, G.W.A., Kurzweil, H. and Koeberl, C. (2002) Mineralogical, Geochemical, and Sedimentological Characteristics of Clay Deposits from Central Uganda and Their Applications. *Journal of African Earth Sciences*, **35**, 123-134. [https://doi.org/10.1016/s0899-5362\(01\)00077-x](https://doi.org/10.1016/s0899-5362(01)00077-x)
- [13] Baccour, H., Medhioub, M., Jamoussi, F., Mhiri, T. and Daoud, A. (2008) Mineralogical Evaluation and Industrial Applications of the Triassic Clay Deposits, Southern Tunisia. *Materials Characterization*, **59**, 1613-1622. <https://doi.org/10.1016/j.matchar.2008.02.008>
- [14] Ferrari, S. and Gualtieri, A. (2006) The Use of Illitic Clays in the Production of Stoneware Tile Ceramics. *Applied Clay Science*, **32**, 73-81. <https://doi.org/10.1016/j.clay.2005.10.001>

- [15] Andji, J.Y.Y., Toure, A.A., Kra, G., Jumas, J.C., Yvon, J. and Blanchart, P. (2009) Iron Role on Mechanical Properties of Ceramics with Clays from Ivory Coast. *Ceramics International*, **35**, 571-577. <https://doi.org/10.1016/j.ceramint.2008.01.007>
- [16] Mahmoudi, S., Srasra, E. and Zargouni, F. (2008) The Use of Tunisian Barremian Clay in the Traditional Ceramic Industry: Optimization of Ceramic Properties. *Applied Clay Science*, **42**, 125-129. <https://doi.org/10.1016/j.clay.2007.12.008>
- [17] El Ouahabi, M., Daoudi, L. and Fagel, N. (2014) Mineralogical and Geotechnical Characterization of Clays from Northern Morocco for Their Potential Use in the Ceramic Industry. *Clay Minerals*, **49**, 35-51. <https://doi.org/10.1180/claymin.2014.049.1.04>
- [18] Bennour, A., Mahmoudi, S., Srasra, E., Boussen, S. and Htira, N. (2015) Composition, Firing Behavior and Ceramic Properties of the Sejnène Clays (Northwest Tunisia). *Applied Clay Science*, **115**, 30-38. <https://doi.org/10.1016/j.clay.2015.07.025>
- [19] Boulingui, J.E., Nkoumbou, C., Njoya, D., Thomas, F. and Yvon, J. (2015) Characterization of Clays from Mezafe and Mengono (Ne-Libreville, Gabon) for Potential Uses in Fired Products. *Applied Clay Science*, **115**, 132-144. <https://doi.org/10.1016/j.clay.2015.07.029>
- [20] Hammami-Ben Zaied, F., Abidi, R., Slim-Shimi, N. and Somarin, A.K. (2015) Potentiality of Clay Raw Materials from Gram Area (Northern Tunisia) in the Ceramic Industry. *Applied Clay Science*, **112**, 1-9. <https://doi.org/10.1016/j.clay.2015.03.027>
- [21] Boussen, S., Sghaier, D., Chaabani, F., Jamoussi, B. and Bennour, A. (2016) Characteristics and Industrial Application of the Lower Cretaceous Clay Deposits (Bouhedma Formation), Southeast Tunisia: Potential Use for the Manufacturing of Ceramic Tiles and Bricks. *Applied Clay Science*, **123**, 210-221. <https://doi.org/10.1016/j.clay.2016.01.027>
- [22] Abdelmalek, B., Rehia, B., Youcef, B., Lakhdar, B. and Nathalie, F. (2017) Mineralogical Characterization of Neogene Clay Areas from the Jijel Basin for Ceramic Purposes (NE Algeria -Africa). *Applied Clay Science*, **136**, 176-183. <https://doi.org/10.1016/j.clay.2016.11.025>
- [23] Jordán, M.M., Boix, A., Sanfeliu, T. and de la Fuente, C. (1999) Firing Transformations of Cretaceous Clays Used in the Manufacturing of Ceramic Tiles. *Applied Clay Science*, **14**, 225-234. [https://doi.org/10.1016/s0169-1317\(98\)00052-0](https://doi.org/10.1016/s0169-1317(98)00052-0)
- [24] Zouaoui, H. and Bouaziz, J. (2017) Physical and Mechanical Properties Improvement of a Porous Clay Ceramic. *Applied Clay Science*, **150**, 131-137. <https://doi.org/10.1016/j.clay.2017.09.002>
- [25] Ngon Ngon, G.F., Yongue Fouateu, R., Lecomte Nana, G.L., Bitom, D.L., Bilong, P. and Lecomte, G. (2012) Study of Physical and Mechanical Applications on Ceramics of the Lateritic and Alluvial Clayey Mixtures of the Yaoundé Region (Cameroon). *Construction and Building Materials*, **31**, 294-299. <https://doi.org/10.1016/j.conbuildmat.2011.12.108>
- [26] Nzeugang Nzeukou, A., Fagel, N., Njoya, A., Beyala Kamgang, V., Eko Medjo, R. and Chinje Melo, U. (2013) Mineralogy and Physico-Chemical Properties of Alluvial Clays from Sanaga Valley (Center, Cameroon): Suitability for Ceramic Application. *Applied Clay Science*, **83**, 238-243. <https://doi.org/10.1016/j.clay.2013.08.038>
- [27] Fadil-Djenabou, S., Ndjigui, P. and Mbey, J.A. (2015) Mineralogical and Physico-chemical Characterization of Ngaye Alluvial Clays (Northern Cameroon) and Assessment of Its Suitability in Ceramic Production. *Journal of Asian Ceramic Societies*, **3**, 50-58. <https://doi.org/10.1016/j.jasc.2014.10.008>
- [28] Ndjigui, P., Mbey, J.A. and Nzeukou, A.N. (2016) Mineralogical, Physical and

- Mechanical Features of Ceramic Products of the Alluvial Clastic Clays from the Ngog-Lituba Region, Southern Cameroon. *Journal of Building Engineering*, **5**, 151-157.
<https://doi.org/10.1016/j.jobe.2015.11.009>
- [29] Yongue-Fouateu, R., Ndimukong, F., Njoya, A., Kunyukubundo, F. and Mbih, P.K. (2016) The Ndop Plain Clayey Materials (Bamenda Area—NW Cameroon): Mineralogical, Geochemical, Physical Characteristics and Properties of Their Fired Products. *Journal of Asian Ceramic Societies*, **4**, 299-308.
<https://doi.org/10.1016/j.jascer.2016.05.008>
- [30] Tsozué, D., Nzeugang, A.N., Mache, J.R., Loweh, S. and Fagel, N. (2017) Mineralogical, Physico-Chemical and Technological Characterization of Clays from Maroua (Far-North, Cameroon) for Use in Ceramic Bricks Production. *Journal of Building Engineering*, **11**, 17-24. <https://doi.org/10.1016/j.jobe.2017.03.008>
- [31] Temga, J.P., Madi, A.B., Djakba, S.B., Zame, P.Z., Angue, M.A., Mache, J.R., *et al.* (2018) Lime- and Sand-Stabilization of Clayey Materials from the Logone Valley (Lake Chad Basin) for Their Utilisation as Building Materials. *Journal of Building Engineering*, **19**, 472-479. <https://doi.org/10.1016/j.jobe.2018.06.003>
- [32] Ekodeck, G.E. and Kamgang, K.B. (2011) Normative Alterology and Advanced Applications a Particular Facet of Aluminosilicate-Bearing Rocks Petrology, with Regard to Their Super-Genes Evolution. Presses Universitaires de Yaoundé, 225.
- [33] Assomo, P.S., Lawou, S.K., Bouba, L. and Beyala, V.K.K. (2022) Géochimie, minéralogie et sélection altérologique des argiles alluviales de la vallée du Nyong à Akonolinga (Cameroun) en vue de leur utilisation dans la production des briques cuites. *Journal of the Cameroon Academy of Sciences*, **18**, 419-436.
<https://doi.org/10.4314/jcas.v18i2.3>
- [34] Nyassa Ohandja, H., Ntouala, R.F.D., Onana, V.L., Ngo'o Ze, A., Ndzié Mvindi, A.T. and Ekodeck, G.E. (2020) Mineralogy, Geochemistry and Physico-Mechanical Characterization of Clay Mixtures from Sa'a (Center Cameroon): Possibly Use as Construction Materials. *SN Applied Sciences*, **2**, Article No. 1687.
<https://doi.org/10.1007/s42452-020-03365-y>
- [35] Nzenti, J.P., Bertrand, S.M. and Macaudière, J. (1994) La chaîne panafricaine au Cameroun: Cherchons suture et modèle. 15^e Réunion des Sciences de la Terre, Nancy, 99.
- [36] Nzenti, J.P. and Tchoua, F.M. (1995) Les gneiss scapolitiques de la chaîne panafricaine nord équatoriale au Cameroun: Témoins au Précambrien d'une sédimentation évaporitique en bordure nord du craton du Congo. *Comptes Rendus de l'Académie des Sciences*, **323**, 289-294
- [37] Vicat, J.P. (198) Esquisse géologique du Cameroun. Presses Universitaires de Yaoundé, 9.
- [38] Déruelle, B., Moreau, C., Nkoumbou, C., Kambou, R., Lissom, J., Njonfang, E., *et al.* (1991) The Cameroon Line: A Review. In: Kampunzu, A.B. and Lubala, R.T., Eds., *Magmatism in Extensional Structural Settings*, Springer, 274-327.
https://doi.org/10.1007/978-3-642-73966-8_12
- [39] Gountié Dedzo, M., Nédélec, A., Nono, A., Njanko, T., Font, E., Kamgang, P., *et al.* (2011) Magnetic Fabrics of the Miocene Ignimbrites from West-Cameroon: Implications for Pyroclastic Flow Source and Sedimentation. *Journal of Volcanology and Geothermal Research*, **203**, 113-132. <https://doi.org/10.1016/j.jvolgeores.2011.04.012>
- [40] Eslinger, E. and Peaver, D. (1998) Clay Minerals for Petroleum Geologist and Engineers. SEPM Short Course, Economic Paleontologists and Mineralogists, Tulsa, 41.

- [41] Nkalih Mefire, A., Njoya, A., Yongue Fouateu, R., Mache, J.R., Tapon, N.A., Nzeukou Nzeugang, A., *et al.* (2015) Occurrences of Kaolin in Koutaba (West Cameroon): Mineralogical and Physicochemical Characterization for Use in Ceramic Products. *Clay Minerals*, **50**, 593-606. <https://doi.org/10.1180/claymin.2015.050.5.04>
- [42] Njoya, A., Nkoumbou, C., Grosbois, C., Njopwouo, D., Njoya, D., Courtinmade, A., *et al.* (2006) Genesis of Mayouom Kaolin Deposit (Western Cameroon). *Applied Clay Science*, **32**, 125-140. <https://doi.org/10.1016/j.clay.2005.11.005>
- [43] CDI (1998) Compressed Earth Blocks: Standards Guide-Technology Series No. 11, CRA-Terre-EAG. Brussels-Belgium.
- [44] XP P13-901 (2001) Compressed Earth Blocks for Walls and Partitions: Definitions-Specifications-Test Methods. Delivery Acceptance Condition, French Standard, 20.
- [45] Oti, J.E. (2010) The Development of Unfired Clay Building Materials for Sustainable Building Construction. Ph.D. Thesis, University of Glamorgan.
- [46] Fernandes, J., Peixoto, M., Mateus, R. and Gervásio, H. (2019) Life Cycle Analysis of Environmental Impacts of Earthen Materials in the Portuguese Context: Rammed Earth and Compressed Earth Blocks. *Journal of Cleaner Production*, **241**, Article 118286. <https://doi.org/10.1016/j.jclepro.2019.118286>
- [47] Baccour, H., Medhioub, M., Jamoussi, F. and Mhiri, T. (2009) Influence of Firing Temperature on the Ceramic Properties of Triassic Clays from Tunisia. *Journal of Materials Processing Technology*, **209**, 2812-2817. <https://doi.org/10.1016/j.jmatprotec.2008.06.055>
- [48] Ouhadi, V.R., Yong, R.N., Goodarzi, A.R. and Safari-Zanjani, M. (2010) Effect of Temperature on the Re-Structuring of the Microstructure and Geo-Environmental Behaviour of Smectite. *Applied Clay Science*, **47**, 2-9. <https://doi.org/10.1016/j.clay.2008.08.008>
- [49] Padden, M. and Pavia, S. (2016) An Assessment of Raw Materials for Earth Construction in Co. Offaly, Ireland. Congreso Euro-Americano Rehabend, Patología de la Construcción, Tecnología de la Rehabilitación y Gestión del Patrimonio. Burgos, 121.
- [50] Mahmoudi, S., Srasra, E. and Zargouni, F. (2010) Firing Behaviour of the Lower Cretaceous Clays of Tunisia. *Journal of African Earth Sciences*, **58**, 235-241. <https://doi.org/10.1016/j.jafrearsci.2010.03.004>
- [51] Mahmoudi, S., Srasra, E. and Zargouni, F. (2014) Firing Behaviour Clays from Tunisia. *Journal of African Earth Sciences*, **50**, 237-242.
- [52] Mahmoudi, S., Bennour, A., Meguebli, A., Srasra, E. and Zargouni, F. (2016) Characterization and Traditional Ceramic Application of Clays from the Douiret Region in South Tunisia. *Applied Clay Science*, **127**, 78-87. <https://doi.org/10.1016/j.clay.2016.04.010>
- [53] Mahmoudi, S., Bennour, A., Srasra, E. and Zargouni, F. (2017) Characterization, Firing Behavior and Ceramic Application of Clays from the Gabes Region in South Tunisia. *Applied Clay Science*, **135**, 215-225. <https://doi.org/10.1016/j.clay.2016.09.023>
- [54] Seynou, M., Millogo, Y., Ouedraogo, R., Traoré, K. and Tirlocq, J. (2011) Firing Transformations and Properties of Tiles from a Clay from Burkina Faso. *Applied Clay Science*, **51**, 499-502. <https://doi.org/10.1016/j.clay.2011.01.002>
- [55] Milheiro, F.A.C., Freire, M.N., Silva, A.G.P. and Holanda, J.N.F. (2005) Densification Behaviour of a Red Firing Brazilian Kaolinitic Clay. *Ceramics International*, **31**, 757-763. <https://doi.org/10.1016/j.ceramint.2004.08.010>
- [56] Carretero, M.I., Dondi, M., Fabbri, B. and Raimondo, M. (2002) The Influence of Shaping and Firing Technology on Ceramic Properties of Calcareous and Non-

- Calcareous Illitic-Chloritic Clays. *Applied Clay Science*, **20**, 301-306.
[https://doi.org/10.1016/s0169-1317\(01\)00076-x](https://doi.org/10.1016/s0169-1317(01)00076-x)
- [57] Singh, N.B. (2022) Clays and Clay Minerals in the Construction Industry. *Minerals*, **12**, Article 301. <https://doi.org/10.3390/min12030301>
- [58] Ahmad, M. and Rashid, K. (2022) Novel Approach to Synthesize Clay-Based Geopolymer Brick: Optimizing Molding Pressure and Precursors' Proportioning. *Construction and Building Materials*, **322**, Article 126472.
<https://doi.org/10.1016/j.conbuildmat.2022.126472>
- [59] Bidoung, J.C., Mpoung, L.A., Mbey, J.A. and Meva'a, J.R.L. (2023) Experimental and Numerical Study of Mechanical Behaviour of Fired Clay Bricks after Exposure to High Temperatures. *Journal of Minerals and Materials Characterization and Engineering*, **11**, 143-160. <https://doi.org/10.4236/jmmce.2023.115012>
- [60] Makomra, V., Tapsia, L.K., Ndiwe, B., Kaoutoing, M.D., Konai, N., Njom, A., *et al.* (2022) Physico-Mechanical Properties of Bio-Based Bricks. *Journal of Materials Science and Chemical Engineering*, **10**, 16-29.
<https://doi.org/10.4236/msce.2022.104002>