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Characterization of Two Clay Raw Materials from Côte d'Ivoire with a View to Enhancing Them in Eco-Construction

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Abstract

This study was carried out with a view to appreciate the value of clay, raw materials in eco-construction. To achieve this, we sampled two clay raw materials denoted Aga and Bak and then characterized. The results obtained from geotechnical and mineralogical tests have shown that the clay samples Aga and Bak are fine soils moderately plastic class A soils consisting essentially of quartz with 73.13% and 74.56% respectively for Aga and Bak and clay minerals (kaolinite and illite) with 12.73% kaolinite and 8.55% illite for Aga against 8.31% kaolinite and 13.72% for Bak. Moreover, these samples do not contain swelling clays and contain a sufficient quantity of iron oxides which allows them to be valued in ceramics, in particular in compressed earth bricks (CEB).

Keywords

Clays, Compressed Earth Bricks, Eco-Material, Physico-Chemical and Geotechnical Properties

1. Introduction

Cement based materials are the most widely used in the building industry around the world. Global cement consumption is estimated at nearly 6 billion tons per annum, of which about 50% is consumed in developing countries [1]. This high cement consumption is impacting negatively our environment today. In fact, the share of cement production in global CO_2 emissions is estimated at 9% - 10% [2], which contributes to global warming. Also, the production of clinker, the main component of cement, obtained by firing the clay-lime mixture at 1450˚C is quite energy intensive with about 4.9 GJ of energy for a ton of cement. In addition, cement is a product that is not always accessible in developing countries due to soaring costs.

In view of this negative impact of cement based materials, the development of new alternative materials with low environmental impact is essential. In recent years, the clay material, abandoned in favor of cement blocks, has experienced renewed interest around the world. Indeed, this material has many advantages, in particular its availability, its environment friendly, its hygroscopic and thermal properties [1]. Despite these many advantages, many challenges remain for the clay material, namely low water resistance, often poor mechanical strength, the risk of cracking due to significant drying shrinkage. Several clay construction techniques have therefore been developed over time, they are rammed earth construction; adobe, cob and the most recent Compressed Earth Brick.

In several Sub-Saharan African countries including Côte d'Ivoire, several studies are being carried out with a view to appreciate the value of clay, raw materials in eco-construction [3] [4] [5]. In fact, the earth can only be used in building construction if its cohesion is sufficient [6], this property is mainly due to the presence of clay, which acts as a natural binder. The use of clay in house building is therefore linked to its geotechnical and physicochemical properties.

This present study is concerned with the characterization of the two clay raw materials from Côte d'Ivoire with a view to valuing them in eco-construction, it is based on the determination of the geotechnical and physicochemical properties of these two clays.

2. Raw Materials and Methods

2.1. Raw Materials

Two clay raw materials are used in this study, the clay denoted Bak was taken from the village of Becedi in the department of Sikensi in the southern region of Côte d'Ivoire, the coordinates of the sampling site are 5˚38'26.87737"N, 4˚34'51.7423"W. The second sample denoted Aga, was collected from the town of Gagnoa in the Central-West of Côte d'Ivoire, the coordinates of the sampling site are around 6˚07'37.6"N, 5˚56'15.0"W.

The different sampling sites are shown in **Figure 1**.

2.2. Experimental Methods

The particle size analysis of the clay samples was carried out by sieving and sedimentometry according to the NF P 94-056 and NF P 94-057 standards respectively.

The Atterberg limits were determined according to NF P 94-051 standard. The liquidity limit (W_L) was determined using the Casagrande disk method and the plasticity limit (W_P) by the repeated rolling method. The plasticity index (P_I) is obtained by the difference between these two quantities.

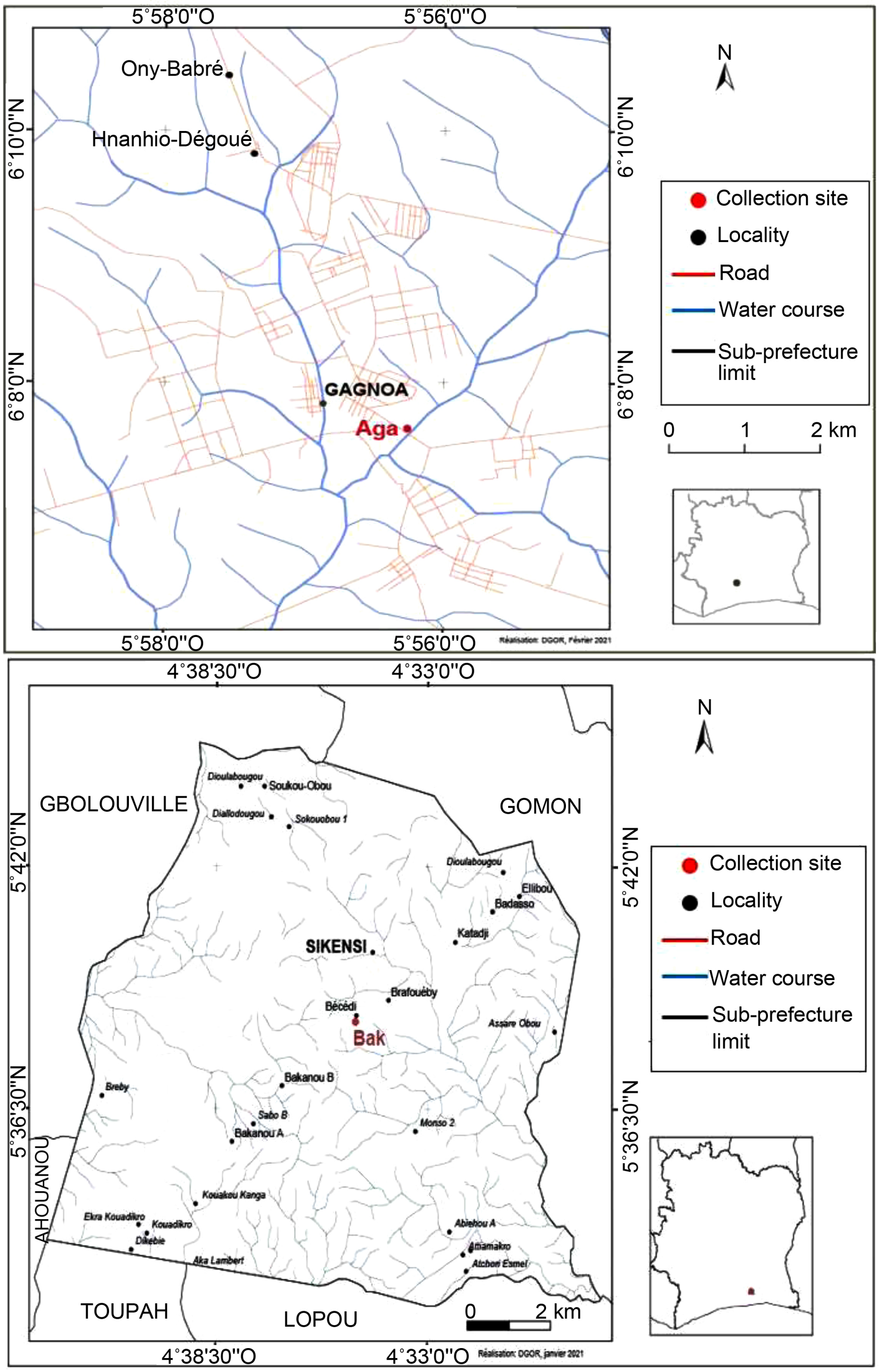

Figure 1. Sample collection sites.

The methylene blue value of the soil was determined by the methylene blue test according to NF P 94-068 standard.

The specific surface of the clay samples was determined by the Blaine method according to EN 196-6 standard.

The chemical composition of the two clay raw materials was determined by plasma emission spectrometry (ICP-AES) using the Anton Paar device.

The crystalline phases in the different samples were identified by X-ray diffraction on unoriented preparations of powder with a particle size of less than 100 µm. Diffractograms were obtained using the Bruker D8 ADVANCE diffractometer and then processed using the EVA Brukers AXS software.

The results of the chemical analysis combined with those of the X-ray diffraction made it possible to evaluate the semi-quantitative mineralogical composition using the following Equation (1):

$$T(a) = \sum M_i \times P_i(a) \quad (1)$$

$T(a)$: content (oxide %) of chemical element "a"; Mi: content (%) of mineral "i" in the material studied and containing the element "i"; $P_i(a)$: proportion of the element "a" in the mineral "i".

The thermal behavior of the samples (Differential Thermal Analysis and Thermogravimetric DTA/TGA) was recorded simultaneously using the NETZSCHSTA device from room temperature to 1100˚C, with a temperature rise of 5˚C/min.

The Perkin Elmer Spectrum 1000 brand Fourier transform spectrometer was used to perform the infrared spectra of the samples.

The microstructure of the clays was observed using an FEI Quanta FEG 450 brand scanning electron microscope.

3. Results and Discussion

3.1. Geotechnical Characterization of Clays

The results of the particle size analysis of the Aga and Bak samples are shown in **Table 1**.

These results showed that Aga is a sandy loam-clay soil and Bak is a sandy clay soil. The Aga sample exhibits better cohesion in the natural state than the Bak sample due to the clay content of between 5% and 30% [7]. In addition, these two samples contain the quantity of sand necessary to make mud bricks. Indeed, a sand content between 45% and 65% is necessary to produce mud bricks [8]. In general, the Aga and Bak samples exhibit good cohesion in the natural state, which would therefore be an asset for their use in the production of Compressed Earth Bricks (CEB).

Table 2 summarizes the other geotechnical parameters determined. The Aga and Bak samples are fine soils, moderately plastic due to 12 < IP < 25 [9] therefore class A. The greater value of the plasticity index of Bak (20%) compared to that of Aga (13%) is explained by the greater quantity of clay in this sample by referring to the results of the particle size analysis.

The liquidity limit of the two samples are found to be in the limit zone for

Table 1. Particle size distribution of the samples.

Sample	Silt (%)	Sand (%)	Clay (%)
Aga	23.7	54.94	21.36
Bak	14.6	54.45	30.95

Table 2. Geotechnical parameters of the samples.

Sample	Aga	Bak
Liquidity limit W_L (%)	27	37
Plasticity limit W_P (%)	14	17
Plasticity index I_P (%)	13	20
Consistency index Ic (%)	1.97	1.77
Methylene Blue Value MBV (g/100g)	1.21	0.5

CEB (25% - 50%), as for their plasticity limit, are found to be in the preferential zone for CEB (12% - 22%) [10]. The methylene blue value is low for the two samples and thus demonstrates on one hand the low activity of the clay fraction and on the other hand the absence of swelling clays liable to create cracks in the CEB. Furthermore, the results of the methylene blue value are relatively low and in agreement with those of the particle size analysis and Atterberg limits as to the nature and the class of the samples.

3.2. Physicochemical Characterizations of Clay Raw Materials

Table 3 shows the results of the chemical analysis of the two clay raw materials.

The results showed the predominance of silica in the two raw materials, combined with a lower alumina content. Minor oxides of iron; potassium; sodium and titanium are also present. The SiO_2/Al_2O_3 ratio is high in both samples, this suggests the presence in quantity of free silica which corroborates the results of the particle size analysis. As for the Al_2O_3/Fe_2O_3 ratio of 2.96 and 2.07 for Aga and Bak respectively, it is less than 5.5. These samples are therefore rich in iron and can be used in the manufacturing of building materials such as bricks and tiles [11].

The combined x-ray diffractograms of the two samples are shown in **Figure 2**.

It appears from the indexing of the various peaks that the samples consist of quartz (SiO_2), clay minerals namely kaolinite ($Si_2Al_2O_5(OH)_4$) and illite ($KAl_2(Si_3Al)O_{10}(OH)_2$); goethite (FeOOH) and rutile (TiO_2).

The combined results of chemical analysis and X-ray diffraction allowed the semi-quantitative mineralogical composition of the two samples to be determined. The results obtained are summarized in **Table 4**.

These results showed the predominance of quartz, which acts as a degreaser in ceramic materials, allowing plasticity to be reduced and thus facilitating their workability. The two samples also contain a good amount of clay minerals (kaolinite and illite) which will act as a natural binder, which gives the samples a good natural cohesion. Moreover, the minerals identified in Aga and Bak samples are identical to those generally observed in the clay raw materials of Côte d'Ivoire [12] [13] [14].

The DTA/TGA thermograms of the two samples are shown in **Figure 3**. The thermograms show the same thermal phenomena, namely three endothermic

Table 3. Chemical compositions (wt%).

Samples	SiO_2	Al_2O_3	Fe_2O_3	K_2O	Na_2O	TiO_2	SiO_2/Al_2O_3	Al_2O_3/Fe_2O_3
Aga	86.92	8.32	2.81	1.01	0.19	0.74	10.44	2.96
Bak	84.63	8.56	4.14	1.62	0.1	0.95	9.88	2.07

Table 4. Mineralogical composition (wt%).

Samples	Quartz	Kaolinite	Illite	Goethite	Rutile
Aga	77.13	12.73	8.55	3.13	0.74
Bak	74.56	8.31	13.72	4.6	0.95

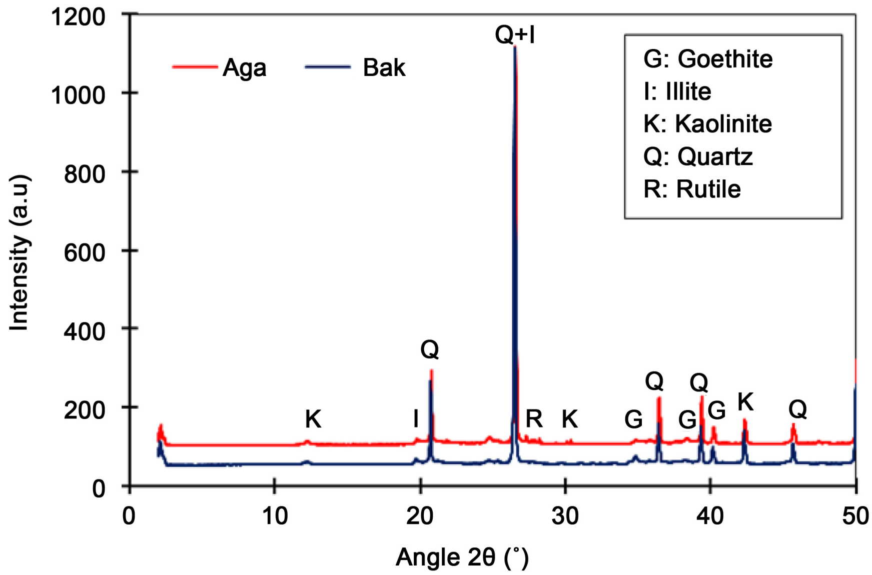

Figure 2. X-ray diffractograms of clay samples.

phenomena and one exothermic phenomenon. The first exothermic phenomenon around 70˚C with a mass loss of less than 1% corresponds to the loss of hygroscopic water, these are molecules retained on the surface of the mineral, the departure of which does not modify the structure of the material [15] [16]. At 478˚C and 495˚C respectively for Aga and Bak, a second endothermic phenomenon is observed and accompanied by a mass loss of 1.85% for Aga and 1.65% for Bak. This phenomenon is linked to the loss of structural hydroxides (OH), more precisely to the dehydroxylation of kaolinite and illite. The departure of these hydroxyls disrupts the crystal lattice of these minerals. For kaolinite, dehydroxylation results in the formation of an amorphous phase called metakaolinite [17] [18], this reaction is written according to Equation (2).

$$Si_2O_5Al_2(OH)_4 \rightarrow Si_2Al_2O_7 + 2H_2O \quad (2)$$

The endothermic peak around 560˚C for Aga and Bak is linked to the transition from α quartz to β quartz. Finally, at 933˚C for Aga and at 937˚C for Bak, the exothermic peak observed is associated with the structural reorganization of

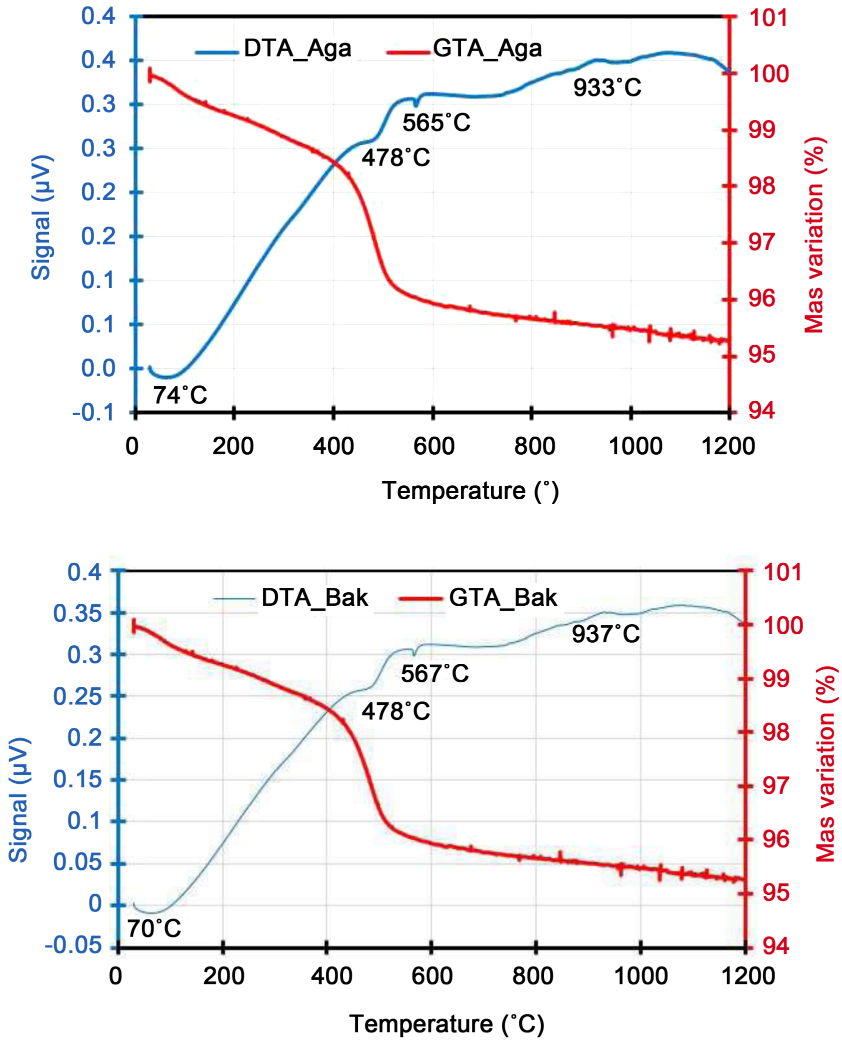

Figure 3. Differential thermal and thermogravimetric analyses of samples.

metakaolinite into spinel which is a more stable compound [19]. This reorganization of metakaolinite is done according to the following Equation (3):

$$2\left[Si_2Al_2O_7\right] \rightarrow Si_3Al_4O_{12} + SiO_2 \tag{3}$$

These thermograms confirm that the Aga and Bak samples are rich in quartz and clay minerals according to the mineralogical composition results.

Figure 4 shows the infrared spectra of the two samples. The spectra generally present the same appearance due to the similarity of the mineralogical composition of the two samples.

The results indicate the presence of clay minerals (kaolinite and illite) in both samples. In the area between 3800 and 3600 cm^{-1}, the vibration bands of the OH groups of kaolinite are observed. More precisely, it concerns the vibrations of elongation of the OH groups of kaolinite and illite, the bands of which appear around 3695 and 3620 cm^{-1} [6]. The bands at 1092 cm^{-1} for Aga and 1100 cm^{-1} for Bak correspond to the vibrations of elongation of the Si-O bonds of kaolinite.

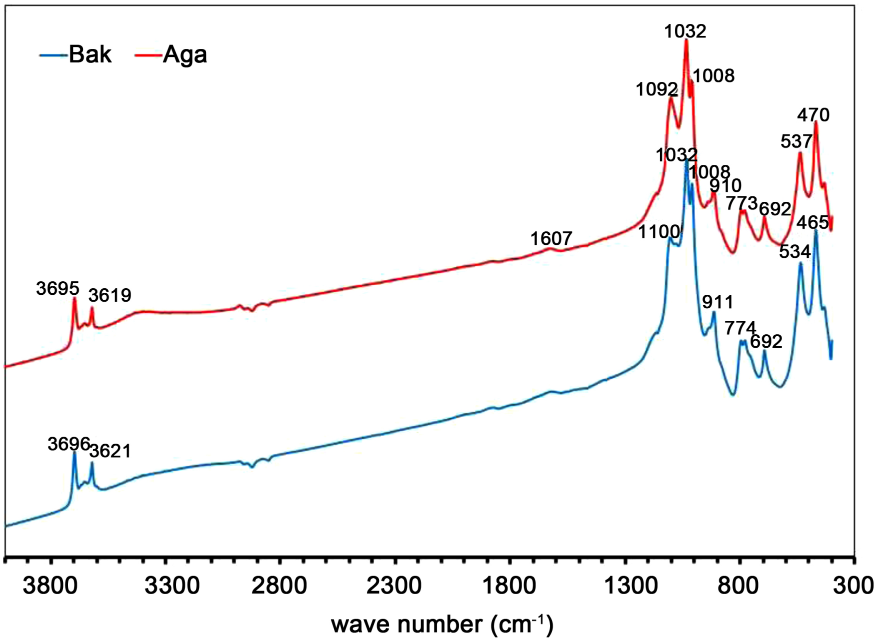

Figure 4. Infrared spectra of Aga and Bak samples.

The one observed at 1032 cm^{-1} on both spectra is attributed to the elongation vibrations of the Si-O-Si bonds of kaolinite and illite. The vibrations of deformation of Al-OH bonds in kaolinite are represented by the band observed around 910 cm^{-1} [20]. Finally, the bands around 770 and 530 cm^{-1} on the two spectra are associated with the Si-O-Al bonds of the kaolinite. Besides the presence of clay minerals, the spectra also showed bands of vibrations of quartz. The characteristic bands of Si-O-Si bonds in quartz were observed around 770; 692 and 465 cm^{-1} on the two spectra. The 1607 cm^{-1} band on the Aga sample spectrum is related to absorbed hygroscopic water [21]. The bands around 530 and 465 cm^{-1} can also be attributed to Fe-O bonds of goethite [22].

Figure 5 shows the microstructure of the samples, observed by scanning electron microscopy. On the SEM images, the minerals in the two samples cannot be distinguished. This can be explained on one hand by the presence of large quantities of quartz in these samples, the particles of which will drown the kaolinite platelets, thus making them invisible to the SEM and on the other hand, by the significant amount of illite [23]. EDS analysis could have helped identify minerals on SEM images.

4. Conclusions

The objective of this study was to characterize two clay raw materials from Côte d'Ivoire with a view to upgrading them in Compressed Earth Bricks (CEB). To do this, geotechnical and physico-chemical characterization tests were performed on these two samples in order to assess their suitability in the development of CEB. The results of the geotechnical characterizations showed that the Aga and Bak samples are fine sandy clayey soils with moderate plasticity. The

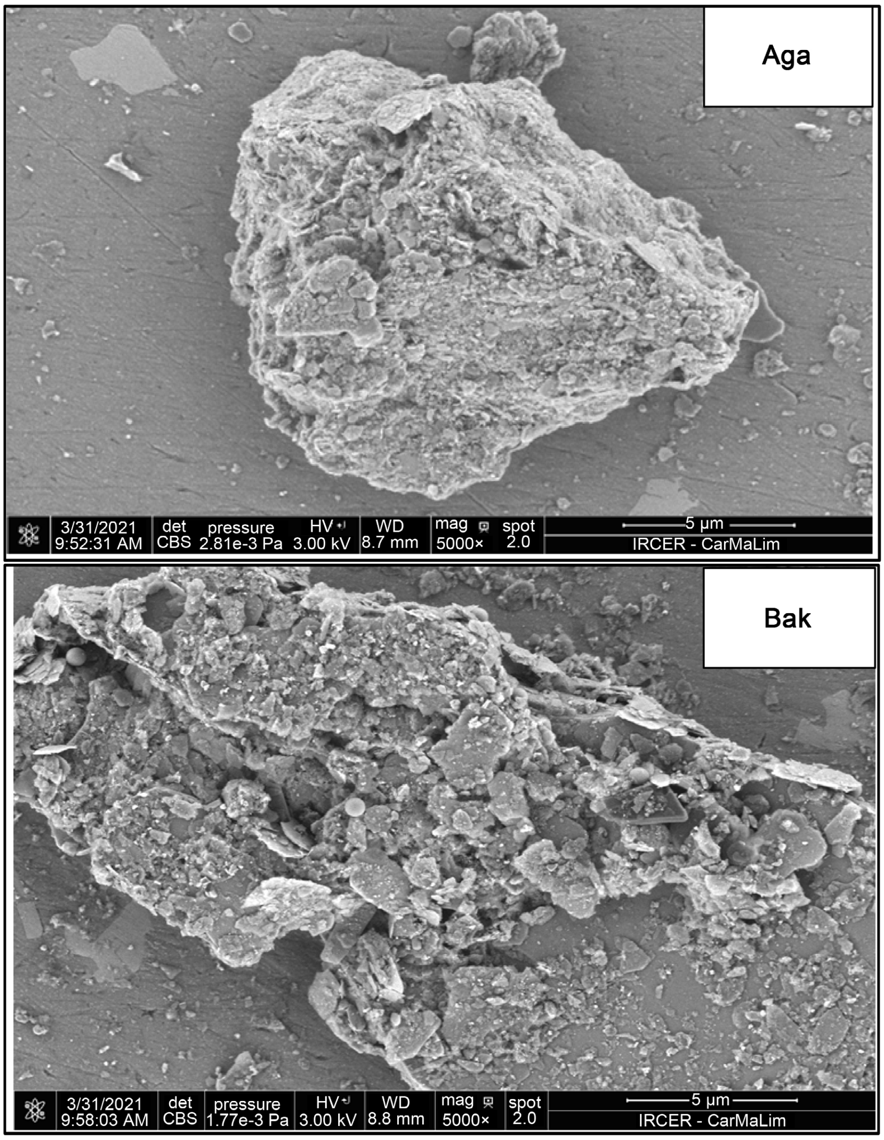

Figure 5. SEM images of the two clay samples.

results also demonstrated the low activity of the clay fraction and the absence of swelling clays, the presence of which could create risks of cracking. All the geotechnical results therefore showed that Aga and Bak could be used in the production of CEB due to their good cohesion in their natural state. The results of the physicochemical characterizations revealed that Aga and Bak are rich in quartz and clay minerals which will play a role of natural binder. Also, these samples are rich in iron and can therefore be used in the manufacture of building materials such as bricks and tiles.

In a nutshell, the clay raw materials Aga and Bak can therefore be used in eco-construction.

Conflicts of Interest

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

References

[1] Pacheco-Torgal, F. and Jalali, S. (2012) Earth Construction: Lessons from the Past for Future Eco-Efficient Construction. *Construction and Building Materials*, **29**, 512-519. https://doi.org/10.1016/j.conbuildmat.2011.10.054

[2] Taylor, M., Tam, C. and Gielen, D. (2006) Energy Efficiency and CO_2 Emissions from the Global Cement Industry. IEA, Paris.

[3] Kouamé, A.N., Konan, L.K., Doubi Gouré, B.I.H.G., Tognonvi, M.T. and Oyetola, S. (2020) Mechanical and Microstructural Properties of Compressed Earth Bricks (CEB) Incorporating Shea Butter Wastes and Stabilized with Cement. *Journal of Materials Physics and Chemistry*, **8**, 1-8.

[4] Sawadogo, M., Seynou, M., Zerbo, L., Sorgho, B., Lecomte-Nana, G.L., Blanchart, P. and Ouédraogo, R. (2020) Formulation of Clay Refractory Bricks: Influence of the Nature of Chamotte and the Alumina Content in the Clay. *Advances in Materials*, **9**, 59-67. https://doi.org/10.11648/j.am.20200904.11

[5] Laibi, A.B., Gomina, M., Sorgho, B., Sagbo, E., Blanchart, P., Boutouil, M. and Sohounhloule, D.K. (2017) Caractérisation physico-chimique et géotechnique de deux sites argileux du Bénin en vue de leur valorisation dans l'éco-construction. *International Journal of Biological and Chemical Science*, **11**, 499-514. https://doi.org/10.4314/ijbcs.v11i1.40

[6] Sorgho, B. (2013) Caractérisation et valorisation de quelques argiles du Burkina Faso: application au traitement des eaux et aux géomatériaux de construction. Thèse de Doctorat, Universite de Ouagadougou, Ouagadougou.

[7] Association Française de Normalisation (AFNOR) (2001) Blocs de terre comprimée pour murs et cloisons. AFNOR Éditions, Norme XP P13-901.

[8] Doat, P., Hays, A., Houben, H., Matuk, S. and Vitoux, F. (1979) Construire en terre. Editions Alternatives, Paris.

[9] Guide de Terrassement Routier (GTR) (1992) Guide technique: Réalisation des remblais et des couches de forme. LCPC-SETRA, Paris-Bagneux.

[10] Doat, P., Hays, A., Houben, H., Matur, S. and Vitoux, F. (1991) Construction en Terre par le CRA Terre. Edition Parenthèses, Marseille.

[11] Garcia-Valles M., Alfonso P., Martínez, S. and Roca, N. (2020) Mineralogical and Thermal Characterization of Kaolinitic Clays from Terra Alta (Catalonia, Spain). *Minerals*, **10**, Article No. 142. https://doi.org/10.3390/min10020142

[12] Kouamé, A.N., Konan, L.K. and Goure Doubi, B.I.H. (2021) Microstructure and Mineralogy of Compressed Earth Bricks Incorporating Shea Butter Wastes Stabilized with Cement. *Advances in Materials*, **10**, 67-74.

[13] Kouakou, L.P.M.S., Andji-Yapi, Y.J. and Coulibaly, Y. (2012) Mineralogy, Geochemistry of Clay Raw Material from Ivory Coast (West Africa) Used as Pharmaceutical Products. *Journal Société Ouest-Africaine de Chimie*, **34**, 38-44.

[14] Méité, N., Konan, L.K., Tognonvi, M.T., Goure Doubi, B.I.H., Gomina, M. and Oyetola, S. (2021) Properties of Hydric and Biodegradability of Cassava Starch-Based Bioplastics Reinforced with Thermally Modified Kaolin. *Carbohydrate Polymers*, **254**, Article ID: 117322. https://doi.org/10.1016/j.carbpol.2020.117322

[15] Ouattara, S. (2013) Recherche de briques légères: Conception et caractérisation de briques crues à base d'argile et de sciure de bois, stabilisées au ciment Portland. Thèse de Doctorat, Université Félix Houphouët Boigny, Abidjan.

[16] Sei, J., Jumas, J.C., Olivier-Fourcade, J., Quiquampoix, H. and Staunton, S. (2002) Role of Iron Oxides in the Phosphate Adsorption Properties of Kaolinites from the

Ivory Coast. *Clays and Clay Minerals*, **50**, 217-222. https://doi.org/10.1346/000986002760832810

[17] Brindley, G.W. and Nakahira, M. (1959) The Kaolinite-Mullite Reaction Series: II, Metakaolin. *Journal of the American Ceramic Society*, **42**, 314-318. https://doi.org/10.1111/j.1151-2916.1959.tb14315.x

[18] Chen, C.Y., Lan, G.S. and Tuan, W.H. (2000) Microstructural Evolution of Mullite during the Sintering of Kaolin Powder Compacts. *Ceramics International*, **26**, 715-720. https://doi.org/10.1016/S0272-8842(00)00009-2

[19] Hu, P. and Yang, H. (2013) Insight into the Physicochemical Aspects of Kaolins with Different Morphologies. *Applied Clay Science*, **74**, 58-65. https://doi.org/10.1016/j.clay.2012.10.003

[20] Bich, C., Ambroise, J. and Péra, J. (2009) Influence of Degree of Dehydroxylation on the Pozzolanic Activity of Metakaolin. *Applied Clay Science*, **44**, 194-200. https://doi.org/10.1016/j.clay.2009.01.014

[21] White, J.L. (1971) Interpretation of Infrared Spectra of Soil Minerals. *Soil Science*, **112**, 22-31. https://doi.org/10.1097/00010694-197107000-00005

[22] Schwertmann, U. and Cornell, R.M. (2008) Iron Oxides in the Laboratory: Preparation and Characterization. Wiley-VCH, New York.

[23] Konan, K.L. (2006) Interaction entre des matériaux argileux et un milieu basique riche en calcium. Thèse de Doctorat, Université de Limoges, Limoges.