International Journal of Chemistry and Materials Research
2023 Vol. 11, No. 2, pp. 23-31
ISSN(e): 2311-763X
ISSN(p): 2312-0991
DOI: 10.18488/64.v11i2.3581

Influence of the size of soursop seed granules on the mechanical and water properties of compressed earth bricks

Alfred Niamien Kouame[1+]
Moussa Ouedraogo[2]
Wedjers Max Robin Manouan[3]
Lebe Prisca Marie-Sandrine Kouakou[1]
Namory Meite[1]
Bi Irie Herve Goure Doubi[4]
Esmel Privat Zokobadi Zokou[1]
Leon Koffi Konan[1]

[1]*Laboratory of Constitution and Reaction of Matter, Félix Houphouet-Boigny University, 22 BP 582 Abidjan 22, Abidjan, Côte d'Ivoire.*
[1]*Email: kouame.alfred2@ufhb.edu.ci*
[1]*Email: priscacoakre@yahoo.fr*
[1]*Email: namorymeite2986@gmail.com*
[1]*Email: zokou90@gmail.com*
[1]*Email: leonkonan2000@yahoo.fr*
[2]*Laboratory of Chemistry and Renewable Energies, Department of Chemistry, Nazi BONI University, Bobo-Dioulasso 01 BP 1091, Burkina Faso.*
[2]*Email: ouedmoss@yahoo.fr*
[3]*Faculty of Sciences and Technologies, University of Man, BP 20 Man, Côte d'Ivoire.*
[3]*Email: robin.manouan@univ-man.edu.ci*
[4]*Faculty of Biological Sciences, Department of Mathematics, Physics and Chemistry, Peleforo Gon Coulibaly University, BP 1328 Korhogo, Côte d'ivoire.*
[4]*Email: goure_herve2610@yahoo.fr*

(+ Corresponding author)

Article History
Received: 11 October 2023
Revised: 8 December 2023
Accepted: 20 December 2023
Published: 29 December 2023

Keywords
Clay
Compressed earth bricks
Eco-material
Mechanical and water properties
Soursop seed granules.

ABSTRACT

The use of plant raw materials in Compressed Earth Bricks has become an increasingly a common practice. This present work is part of this approach; it aims to study the impact of the size of soursop seed granules on the mechanical and water properties of Compressed Earth Bricks (CEB). To do this, clay named Aga from Gagnoa consisting essentially of quartz (77.13 wt%) and clay minerals kaolinite and illite (21.28 wt%) and soursop seeds of fine particle size (d≤0.5 mm) and average (0.5<d<1mm) were used. The results of the mechanical tests showed a drop in compressive strength of 37% and 44% respectively for the formulations with fine granules and medium granules compared to the resistance of the formulation with raw clay. The formulation with fine granules ($A_{94}GF_6$) therefore presents the best compressive strength (3.58 MPa). In terms of water absorption by capillarity, the formulation with fine granules has greater absorption with an absorption coefficient of 0.2824 $kg.m^{-2}s^{-1/2}$ compared to the formulation with medium granules in which their absorption coefficient is 0.1143 $kg.m^{-2}s^{-1/2}$. All the results showed that seed granules can be used in compressed Earth Bricks, however it is recommended to use them with a fine particle size (d ≤ 0.5 mm).

Contribution/Originality: The originality of this work lies in the development of a biosourced material through the use of soursop seeds of different sizes in a clay matrix. Through this study, we evaluated the mechanical and water properties of this new material.

1. INTRODUCTION

Human activities today have impact on the acceleration of climate change. The construction sector is partly responsible for this phenomenon of climate change through the use of cement as the main material in construction. Indeed, the share of cement production in global CO_2 emissions is between 5 and 10% [1, 2]. In addition to its impact on global warming, the cost of cement remains high in developing countries, which makes access to decent housing a real challenge. Faced with this situation, the development of new construction materials with acceptable mechanical properties, low environmental impact and accessible to all appears essential.

Thanks to this context, clay, a natural material used since antiquity and abandoned in favor of cement-type materials, is experiencing renewed interest due to its availability, its abundance and its ecological nature. Also, recyclable clay raw materials have quite interesting hygroscopic and thermal properties. Over time, many earth products have been developed and used in construction, including adobe, rammed earth, cob and more recently compressed earth bricks.

Despite all the above-mentioned advantages, many challenges remain for better popularization of this material. In general, earth products have poor mechanical properties and poor water resistance unlike cement materials. To overcome these shortcomings, studies were carried out on stabilization with mineral binders (cement, lime) and the results show an improvement in the mechanical resistance and water resistance of the material. However, their use in quantity for stabilization, questions the ecological nature of the material [1]. Thus, these mineral binders are increasingly being replaced partially or completely by plant fibers with the aim of developing bio sourced materials [3-5].

Côte d'Ivoire is currently experiencing strong demographic growth, which gives rise to a strong demand for housing. Cement block construction remains the most common construction method in both rural and urban areas. Faced with the high cost of cement and the impact of its production on global warming, clay raw materials sufficiently widespread throughout the country could be used in home constructions. Furthermore, Côte d'Ivoire produces a wide variety of materials from food and export crops whose hulls and/or residues are not sufficiently valorized and can be used as bio-sourced additions to earth bricks. A large number of scientific works have focused on plant fibers because of the tensile strength of these fibers which are significant for low gauge lengths. Indeed, the work of Ouedraogo, et al. [6] showed that adobes with kenaf fibers of 3 cm length have better mechanical resistance. Also, the work of Kouakou, et al. [7] and Kouamé, et al. [4] showed that the use of shea cake in 6% mass improved the mechanical, water and thermal properties of Compressed Earth Bricks. In view of these results, it appears that small-sized plant waste such as plant aggregates could improve the mechanical resistance of adobes if they are added to them.

This is why this study focuses on the valorization of Ivorian clay and soursop seeds in eco-construction. More precisely, it is about studying the influence of the grain size of the seeds on the mechanical and water properties of compressed earth bricks.

2. RAW MATERIALS AND METHODS

2.1. Raw Materials

The clay raw material noted Aga has been the subject of a previous study [7]. It comes from the town of Gagnoa, located in the central-west of Côte d'Ivoire. The coordinates of the sampling site are located around 6°07'37.6" N, 5°56'15.0" W. Before use in the production of bricks, the Aga clay was dried then crushed and passed through a sieve with a diameter of less than one millimeter.

The soursop seeds used as a plant additive in the production of Compressed Earth Bricks (CEB), were obtained after drying, grinding and sieving the soursop grains. Seeds of different particle sizes were used in carrying out this work. We have small size seeds (GF) ($d \leq 0.5$ mm) and medium size seeds (GM) ($0.5 < d < 1$ mm). Seeds of different particle sizes are presented in Figure 1.

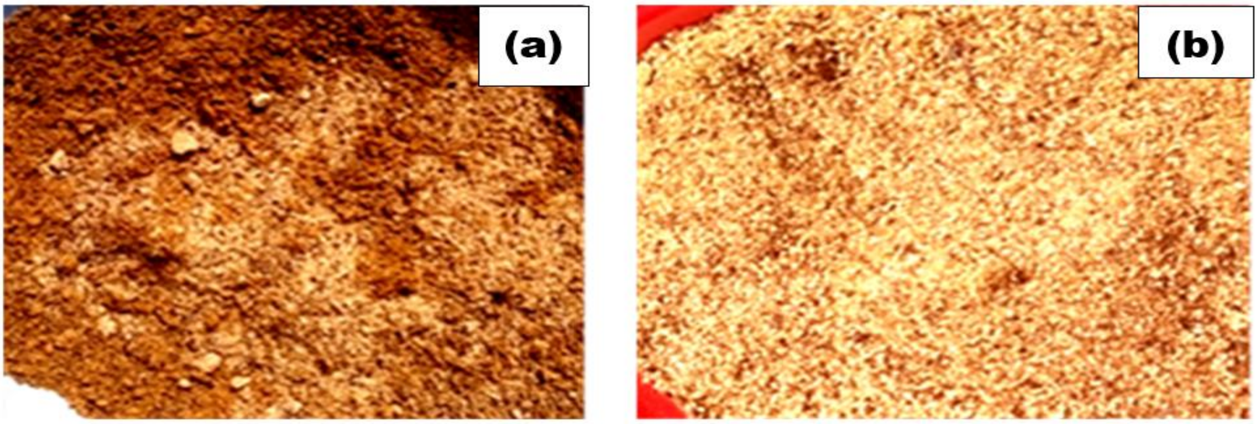

Figure 1. Soursop seed particles ((a) Fine granules (GF), (b) Medium granules (GM)).

2.2. Methods

The particle size of the clays was determined by sieving (Φ>80µm) and sedimentary (Φ≤80µm) according to the ASTM D 422 protocol.

The fine and medium granules of soursop seeds were obtained by sieving using a series of sieves with diameters varying from 2 to 0.25 mm

The plasticity of the clay was determined by measuring the Atterberg limits according to standard NF P 94-051. The liquid limit (W_L) was determined using the Cassagrande cup and the plasticity limit (W_P) using the roll method. The plasticity index is derived from Equation 1:

$$I_P=W_L-W_P \quad (1)$$

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

The optimal water content and the corresponding dry density were evaluated according to the modified Proctor test. This test was carried out according to standard NF P 94-093.

The Chemical composition of the clay used in this study was determined by Inductively Coupled Plasma Atomic Emission Spectrometry (ICP-AES) method.

The crystalline phases present in the sample were identified by X-Ray Diffraction (XRD) using the Bruker model D8 Advance multifunction diffractometer. The results combined with XRD and chemical analysis made it possible to evaluate the semi-quantitative mineralogical composition.

The biochemical composition of soursop seeds was determined by the Van Soest method.

The mechanical resistance to compression of the Compressed Earth Bricks was measured on half-test specimens of CEB measuring (4*4*8) cm^3 according to standard EN 196-1.

The water resistance of the CEB produced was evaluated by the water absorption test by capillary action. The tests were carried out according to the AFPC-AFREM protocol.

2.3. Production of Compressed Earth Bricks (CEB)

In order to study the influence of the particle size of soursop seeds on some physical properties of the CEB produced, different formulations were produced. Referring to literature data [8-10] relating to the use of plant materials in CEB, the quantity of soursop seeds or cement was set at 6%. For the production of CEB, the clay was dried, crushed and sieved with a diameter of less than 1mm. Subsequently, the clay and soursop granule seeds or cement were mixed dry and then kneaded for two minutes using an automatic mixer. Afterwards, the mixture was moistened with 12.2% by mass of water and kneaded again for 2 minutes. After this mixing, the mixture was introduced into the 4*4*16 cm^3 prismatic molds then was compressed to 10 MPa (MegaPascal) using an automatic press. Finally, unmolding was carried out 24 hours later and the CEB thus produced are stored at a temperature of 25°C dry. The different formulations produced are presented in Table 1.

Table 1. Composition of mixtures (wt%).

Formulations	Clay (%)	GF (%)	GM (%)	Ciment (%)
A_{100}	100	-	-	-
$A_{94}C_6$	94	-	-	6
$A_{94}GF_6$	94	6	-	-
$A_{94}GM_6$	94	-	6	-

Note: GF: Fine granules (d≤0.5 mm); GM: Medium granules (0.5<d<1 mm).

3. RESULTS AND DISCUSSION

3.1. Physico-Chemical and Geotechnical Properties of Raw Materials

The chemical and mineralogical compositions of Aga clay are presented in Table 2. Chemical analysis by ICP-AES made it possible to quantify the major chemical elements in the form of oxides. The major oxide in the sample is silica SiO_2 (86.92%) followed by alumina Al_2O_3 (8.32%). These major oxides are associated with oxides of relatively low contents (<3%), namely Fe_2O_3, K_2O, TiO_2 and Na_2O. The SiO_2/Al_2O_3 mass ratio of 10.45 is very high which suggests an excess of free silica in this sample and that of Al_2O_3/Fe_2O_3 of 2.96 less than 5 shows that this clay can be used in the production of construction materials (bricks, tiles, etc.) [11].

Table 2. Chemical and mineralogical compositions of clay (wt%).

Chemical composition (wt%)	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
	86.92	8.32	2.81	1.01	0.19	0.74	10.45	2.96
Mineralogical composition	Quartz	Kaolinite		Illite		Goethite		Rutile
	77.13	12.73		8.55		3.13		0.74

Figure 2 shows the results of the X-ray diffraction analysis of the clay sample. The indexing of the different peaks on the diffractogram using the software EVA highlighted the presence of two clay mineralogical phases, namely kaolinite ($Si_2Al_2O_5(OH)_4$) and illite ($KAl_2(Si_3Al)O_{10}(OH)_2$). These clay phases are associated with secondary minerals which are quartz (SiO_2), rutile (TiO_2) and a ferric phase goethite (FeOOH).

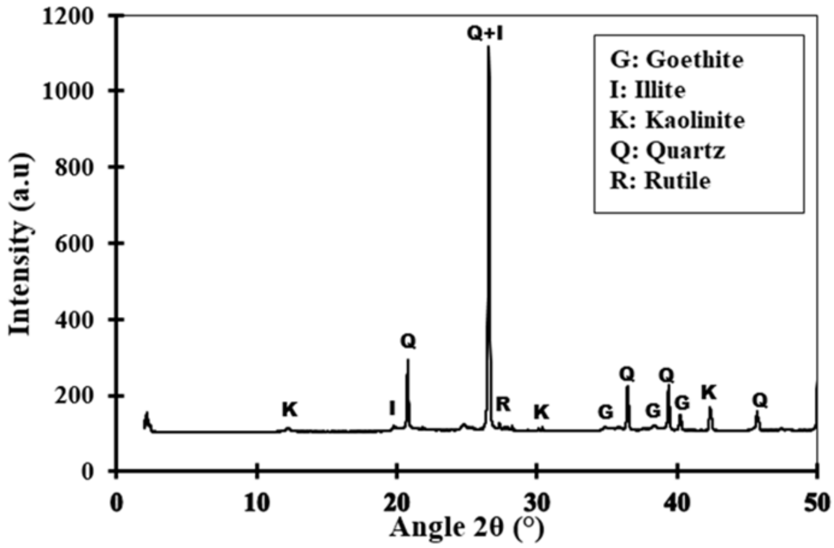

Figure 2. X-ray diffractogram of Aga clay.

The results of mineralogical composition recorded in Table 2, show that the sample contains a significant quantity of quartz (77.13 wt%) which plays a role as a degreaser in the development of ceramic materials. Also, it contains a good quantity of clay minerals, namely kaolinite and illite (21.28 wt%) which ensure natural cohesion of the clay.

The geotechnical characteristics of Aga clay are presented in Table 3.

Table 3. Geotechnical and physical characteristics of Aga clay.

Particle size distribution		
Sand (wt%)	Limon (wt%)	Clay (wt%)
23.7	57.94	21.36
Atterberg limits		
Liquidity limit W_L (%)	Plasticity limit W_P (%)	Plasticity index I_P (%)
27	14	13
Physical parameters		
Volumic mass (g/cm^3)	Porosity (%)	Methylene blue value (g/100g)
2.28	45.14	1.21
Modified proctor test		
Dry density (t/m^3)	Water content (wt%)	
1.93	12.2	

Aga clay has a spreading grain size, consisting of particles of silt (0.002-0.063 mm), sand (0.063-2 mm) and clay (<0.002 mm). By its constitution, the sample presents good cohesion in its natural state due to its clay content (21.36%).

The I_P plasticity index (13%) shows that Aga is a moderately plastic soil ($10\%<I_P<20\%$), which is in agreement with the results of the particle size analysis concerning the clay content (21.36%). Furthermore, the liquidity (27%) and plasticity (14%) limits of the sample are located respectively in the limit (25-50%) and preferential (12-22%) zones for Compressed Earth Bricks.

The measured density (2.28 g/cm^3) is in agreement with those of clay raw materials generally between 2.3 and 2.7 g/cm^3 [12]. As for the porosity (45.14%), it highlights the presence of coarse elements which justifies the presence of open pores in the sample.

The value for Methylene Blue (1.21 g/100g) is relatively low and suggests on the one hand a low activity of the clay fraction and on the other hand, the absence of swelling clay in this clay raw material.

The results of the Proctor test gave an optimal water content of 12.2 wt% corresponding to a dry density of 1.93 t/m^3. This result shows that the sample is a clay material with satisfactory mixing due to its dry density of between 1.76 and 2.1 t/m^3 [13].

All the results of physicochemical and geotechnical characterizations show that Aga clay, through its good cohesion in its natural state, can be used in the production of Compressed Earth Bricks.

For soursop seed granules, the biochemical composition was determined by the Van Soest method. The results presented in Table 4 show that the seeds have a low cellulose content (7.7%) compared to the cellulose contained in shea cake (28%), kenaf (71%) and sisal (70%). Ouedraogo, et al. [6]; Kouamé, et al. [14] and Toledo Filho, et al. [15] which have been valued in eco-construction materials. This low cellulose content could impact the resistance and thermal conductivity of the bricks produced.

Table 4. Biochemical composition of soursop seeds.

Biochemical composition	**Cellulose (%)**	**Hemicellulose (%)**	**Lignin (%)**
	7.7	19	2.4

3.2. Mechanical and Water Properties of CEB

The Compressed Earth Bricks made from the Aga clay sample and soursop seeds have undergone various mechanical and water tests which are essential properties for the use of a material in construction. The mechanical compressive strength of the different formulations is shown in Figure 3. The CEB produced with A_{100} raw clay have good compressive strength. This resistance value (5.69 MPa) is higher than that required by the African standard relating to construction materials above 2 MPa for non-load-bearing walls [16]. This good compressive strength could be due to the good cohesion of the clay raw material in its raw state.

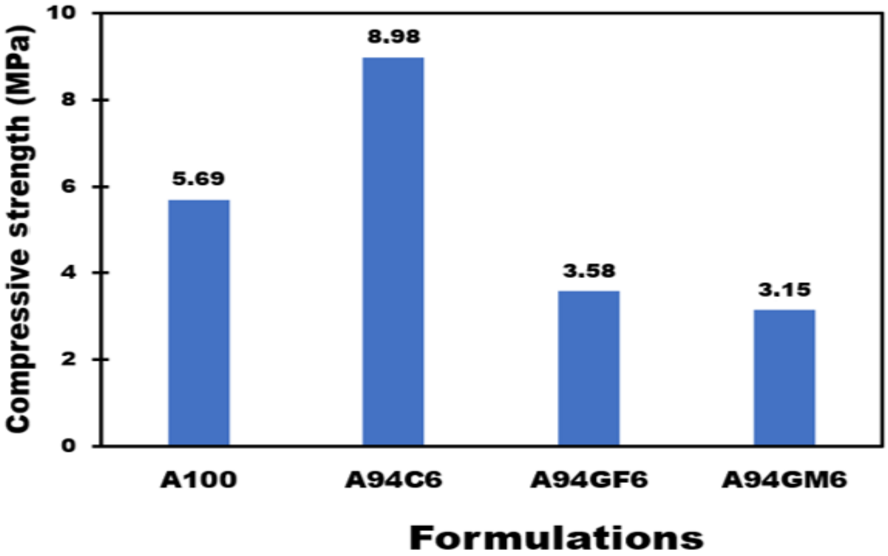

Figure 3. Mechanical resistance in compression.

With the addition of 6% of cement in the clay matrix (**$A_{94}C_6$**), an increase in the compressive strength of around 58% was observed and could be explained by the production of cement hydrates which bind particles isolated from the soil. Subsequently, when the seed granules are added to the clay matrix at a rate of 6%, a reduction in the compressive strength of the order of 37% and 44% with the fine granules and the medium granules respectively compared to the A_{100} formulation is observed. The less significant reduction in resistance with fine granules could be explained by better adhesion of fine granules in the clay matrix. The values obtained, however, remain consistent with those required by the African standard [16]. This drop in mechanical strength with the addition of plant materials or fibers in a clay matrix has been widely reported in the literature and mainly results from the increase in the porosity of the composite material [9, 17].

In order to evaluate the water behavior of the CEB produced, water absorption by capillarity was carried out. The results obtained are presented in Figure 4 which presents the evolution of the water absorbed by surface while Figure 5 shows the evolution of the absorption coefficient by capillarity which is the governing coefficient of the straight lines obtained. Overall, an increase in water absorption as a function of time is observed with all formulations. The $A_{94}GF_6$ formulation absorbs much more compared to other formulations with an absorption coefficient of 0.282 $kg.m^{-2}s^{-1/2}$. The $A_{94}GM_6$ formulation has a lower absorption coefficient (0.114 $kg.m^{-2}s^{-1/2}$) than $A_{94}GF_6$ despite the identical composition. Furthermore, the larger coefficients for the formulations with granules compared to that of the A_{100} formulation of 0.102 $kg.m^{-2}s^{-1/2}$ could be attributed to the water absorption capacity of the plant material. Indeed, due to their hydrophilic nature linked to the presence of large quantities of hydroxyl (OH) groups contained in cellulose, plant material is generally very absorbent [18].

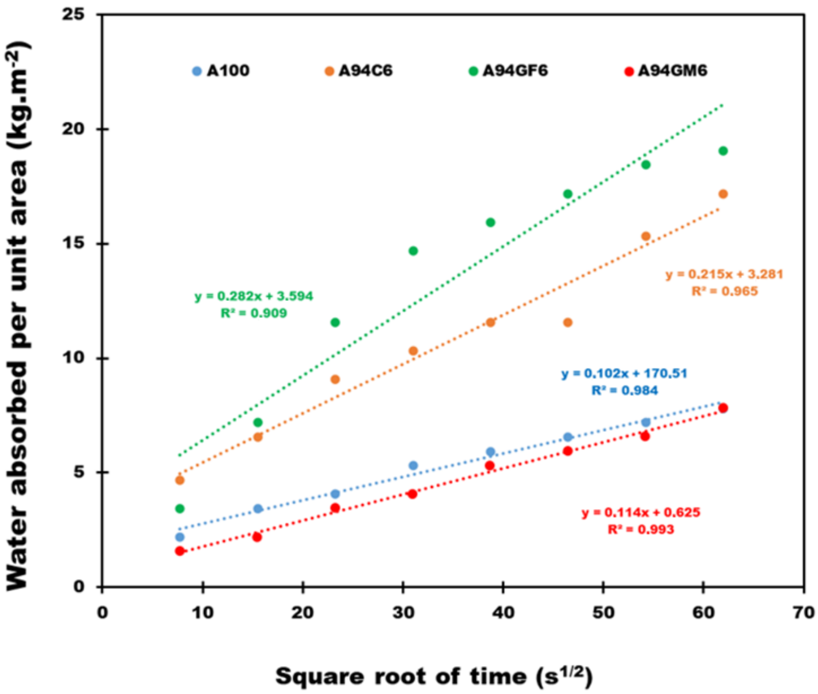

Figure 4. Evolution of water absorption by capillary action of CEB.

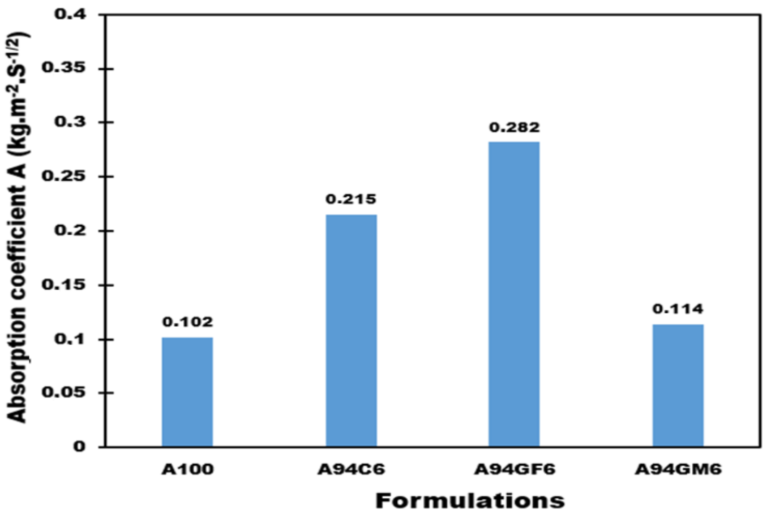

Figure 5. Water absorption coefficients by capillary action of CEB.

Also, for CEB adjuvant with the same content of soursop seed granules, we observed that those with fine granules ($A_{94}GF_6$) absorb in greater quantities than those with medium granules ($A_{94}GM_6$). This is due to the size of the granules. Indeed, the finer the granules, the higher the contact surface and therefore an increase in the water absorption content by capillarity.

4. CONCLUSION

The main objective of this work was to study the influence of the grain size of soursop seeds on the mechanical and water properties of Compressed Earth Bricks. To do this, a clay named as Aga and soursop seeds of fine and medium particle sizes were characterized and used to develop CEB. The results showed that Aga clay is mainly made up of quartz (77.13%) and kaolinite and illite clay minerals (21.28%). Regarding Geotechnical aspect, it is a moderately plastic clay (I_P=13%) with satisfactory mixture made up of silt (57.94%), sand (23.7%) and clay minerals (21.36%). As for the granules of seeds of soursop, they are made up of hemicellulose (19%), cellulose (7.7%) and lignin (2.4%). CEB with 6% fine and medium seed granules as well as CEB made up of 100% clay and 6% cement were developed and subjected to mechanical and water characterization. The results showed a reduction in compressive strength of 37% with fine granules compared to 44% with medium granules compared to the resistance with raw clay. The resistances obtained for the formulations despite the reduction, 3.58 MPa with the fine granules and 3.15 MPa for the medium granules, remain in compliance with the African standard. For water absorption by capillary action, the absorption coefficient is greater with fine granules (0.2824 $kg.m^{-2}s^{-1/2}$) than with medium granules (0.1143 $kg.m^{-2}s^{-1/2}$). All the results showed that seed granules can be used in compressed Earth Bricks, however it is recommended to use them with a fine particle size (d ≤ 0.5 mm).

Funding: This study received no specific financial support
Institutional Review Board Statement: Not applicable
Transparency: The authors state that the manuscript is honest, truthful, and transparent, that no key aspects of the investigation have been omitted, and that any differences from the study as planned have been clarified. This study followed all writing ethics.
Competing Interests: The authors declare that they have no competing interests
Authors' Contributions: All authors contributed equally to the conception and design of the study. All authors have read and agreed to the published version of the manuscript.

REFERENCES

[1] B. Emad, Z. Gholamreza, S. Ezzatollah, and B. Alireza, "Global strategies and potentials to curb CO2 emissions in cement industry," *Journal of Cleaner Production* vol. 51, pp. 142-161, 2013. https://doi.org/10.1016/j.jclepro.2012.10.049

[2] L. Barcelo, J. Kline, G. Walenta, and E. Gartner, "Cement and carbone missions," *Materials and Structures*, vol. 47, pp. 1055-1065, 2014. https://doi.org/10.1617/s11527-013-0114-5

[3] K. Dao, "Stabilization of adobes by cement and Kenaf fibers," Doctoral Thesis, Ouaga I University Pr Joseph Ki-ZERBO, 2018.

[4] A. N. Kouamé, L. K. Konan, B. I. H. G. Doubi Gouré, M. T. Tognonvi, and S. Oyetola, "Mechanical and microstructural properties of compressed earth bricks incorporating shea butter wastes and stabilized with cement," *Journal of Materials Physics and Chemistry*, vol. 8, pp. 1-8, 2020.

[5] H. Bamogo, M. Ouedraogo, I. Sanou, J.-E. Aubert, and Y. Millogo, "Physical, hydric, thermal and mechanical properties of earth renders amended with dolomitic lime," *Materials*, vol. 15, p. 4014, 2022. http://dx.doi.org/10.3390/ma15114014

[6] M. Ouedraogo, K. Dao, Y. Millogo, Y. Seynou, M., J. E. Aubert, and M. Gomina, "Influence of kenaf fibers (Hibiscus altissima) on the physical and mechanical properties of adobes," *Journal of the West African Society of Chemistry*, vol. 43, pp. 48-63, 2017.

[7] L. P. M.-S. Kouakou *et al.*, "Characterization of two clay raw materials from côte d'ivoire with a view to enhancing them in eco-construction," *Journal of Minerals and Materials Characterization and Engineering*, vol. 10, no. 2, pp. 198-208, 2022. https://doi.org/10.4236/jmmce.2022.102016

[8] A. N. Kouamé, "Stabilization, using cement, of blocks of clay soil incorporating shea cakes," Doctoral Thesis, Félix Houphouët-Boigny University, 2021.

[9] A. Laborel-Préneron, J. E. Aubert, C. Magniont, C. Tribout, and A. Bertron, "Plant aggregates and fibers in earth construction materials: A review," *Construction and Building Materials*, vol. 111, pp. 719-734, 2016. https://doi.org/10.1016/j.conbuildmat.2016.02.119

[10] R. Saiah, B. Perrin, and L. Rigal, "Improvement of thermal properties of fired clays by introduction of vegetable matter," *Journal of Building Physics*, vol. 34, no. 2, pp. 124-142, 2010. https://doi.org/10.1177/1744259109360059

[11] M. Garcia-Valles, P. Alfonso, S. Martínez, and N. Roca, "Mineralogical and thermal characterization of kaolinitic clays from Terra Alta Catalonia, Spain," *Minerals*, vol. 10, no. 2, p. 142, 2020. https://doi.org/10.3390/min10020142

[12] R. Lamloumi, "Behavior of widely distributed mineral materials during drying: Experimental study and modeling," Doctoral Thesis, University of Limoges, 2015.

[13] B. Laibi, "Hygro-thermo-mechanical behavior of structural materials for construction combining kenaf fibers with clayey soils," Doctoral Thesis, University of Caen Normandy, 2017.

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

[15] R. D. Toledo Filho, F. De Andrade Silva, E. M. R. Fairbairn, and J. De Almeida Melo Filho, "Durability of compression molded sisal fiber reinforced mortar laminates," *Construction and Building Materials*, vol. 23, pp. 2409-2420, 2009. https://doi.org/10.1016/j.conbuildmat.2008.10.012

[16] ARS, "African regional organization for standardization, Ed. Compressed earth blocks: Standard," Technology No. 11, CDI and CRATerre-EAG, Belgium, 1998.

[17] N. Benmansour, B. Agoudjil, A. Gherabli, A. Kareche, and A. Boudenne, "Thermal and mechanical performance of natural mortar reinforced with date palm fibers for use as insulating materials in building," *Energy and Buildings*, vol. 81, pp. 98-104, 2014. https://doi.org/10.1016/j.enbuild.2014.05.032

[18] C. H. Weng, D. F. Lin, and P. C. Chiang, "Utilization of sludge as brick materials," *Advances in Environmental Research*, vol. 7, no. 3, pp. 679-685, 2003. https://doi.org/10.1016/S1093-0191(02)00037-0