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Synthesis and Characterization of Local Bio-Sourced Geopolymer Binder: Application to Compressed Earth Blocs

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Abstract: The construction industry continues to rely on conventional materials like cement, which often can come with a high cost and significant environmental impact, particularly in terms of greenhouse gas emissions. To tackle the challenges of sustainable development, there is growing interest in using local available materials with low environmental impact. This study primarily focuses on synthesizing and characterizing a geopolymer binder made from local materials found in Benin to stabilize CEB (compressed earth brick). The synthesis involves combining amorphous aluminosilicate powder with a highly concentrated alkaline solution. Local calcined kaolinite clay (metakaolin) and corn cob ash obtained after calcination at 600 °C were used with a 12 M sodium hydroxide (NaOH) solution. Different mixtures of geopolymer were formulated substituting metakaolin by corn cob ash at rates of 0%, 5%, 10%, and 15% of the dry weight of the mixture. Thereafter physical and mechanical characterization tests were conducted on each formulation. Results showed that geopolymer binders containing 85% metakaolin and 15% corn cob ash exhibited the best physical and mechanical performance (e.g. 12.08 MPa for compression strength). Subsequently, this geopolymer formulation was used to stabilize CEB. Characterization revealed that CEBs stabilized with 10% geopolymer exhibit good mechanical properties (6.93 MPa), comparable to those of CEBs stabilized with 10% cement (7.40 MPa), justifying their use as load-bearing walls in construction.

Key words: Sustainable building materials, metakaolin, cob corn ash, geopolymer, CEB, eco-friendly construction.

Graphic Abstract

Nomenclature

GP	=	Geopolymer
PC	=	Portland Cement
CCA	=	Cob Corn Ash
CEB	=	Compressed Earth Bloc
GCEB	=	Geopolymer Compressed Earth Bloc

1. Introduction

Presently, conventional building materials such as cement are significantly expensive. In the Republic of Benin, the price of a ton of cement has nearly doubled in the past decade. As a result, the conventional construction materials remain financially out of reach for a sizable segment of the population. In this scenario, earth materials consistently represent the most financially viable option for these communities. Specifically, laterite and similar materials are readily accessible throughout most of the national territory. However, structures built with earth materials, laterite like adobes (banco), consistently encounter issues such as cracking and degradation, which undermine the long-term durability of the buildings [1-3]. For the long-term durability of the buildings, the CEBs (compressed earth bricks) can be stabilized with different process [4-6]. The mechanical stabilization is the overarching term used to describe soil stabilization through compaction [1, 7-9]. This method enhances soil properties such as density, compressibility, permeability, and porosity of the CEB. In physical stabilization, then laterite properties can be improved by manipulating its texture through a controlled mixture of different grain fractions, such as clay and sand. Thermal treatment stabilization involves heating the earth material to high temperatures, causing the clay particles to melt and form new bonds. Subsequent cooling can solidify the material, thereby enhancing its strength. The chemical stabilization of laterite is achieved by adding other materials or chemicals that alter its properties, either through a physicochemical reaction between the soil particles and the added substance, or by creating a matrix that binds or coats the particles. Notably, binders such as cement, lime, bitumen, and industrial by-products are commonly used for this purpose. The CEBs are used to be stabilized with the Portland cement in the Republic of Benin and other parts of Africa. Unfortunately, utilizing Portland cement for stabilizing CEBs results in the deterioration of their thermal properties, leading to thermal comfort issues. Furthermore, it carries negative environmental impact, notably through significant greenhouse gas emissions linked to clinker production. Indeed, one ton of cement production releases approximately one ton of CO_2.

Considering the shortcomings associated with cementitious materials namely, their high thermal conductivity, environmental impact, and cost, coupled with the underexploited laterite, clay and corn cob potential in Republic of Benin, it is crucial and imperative to seek out alternative construction methods that rely on these local biosourced materials. These methods should prioritize energy efficiency and minimize environmental impacts. One of these methods can consist to synthetize geopolymer binder based on these local materials and stabilize the CEB with this geopolymer.

Using geopolymer binder to stabilize laterite emerges as a promising solution for mitigating the production of greenhouse gases associated with cement manufacturing and addressing housing challenges. This innovative method of stabilizing earth blocks could also enhance the utilization of local materials resources such as laterite, clay and cob corn.

Discovered in the 1979s by Prof. Davidovits, geopolymers can be synthesized by the reaction of an amorphous aluminosilicate (silica, alumina) with an alkaline solution (NaOH or KOH) at low temperature temperatures (25-80 °C).

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Various aluminosilicate materials are suitable for synthesizing the geopolymer binder, including metakaolin, rice husk ash, fly ash, and volcanic slag. Metakaolin is particularly popular due to its ease of synthesis with low CO_2 emissions, global availability of its raw material (kaolin), and suitable chemical and mineralogical properties, such as an amorphous phase and appropriate silica and alumina content.

Sore et al. [1] developed a geopolymer binder based on local clay for stabilizing CEBs in Burkina Faso. They demonstrated the feasibility of a geopolymer binder using locally sourced clay activated by an alkaline solution of sodium hydroxide. This type of binder was used for stabilizing CEBs, which exhibited mechanical characteristics equivalent to those stabilized with cement.

Sangeethavani et al. [2] evaluated the performance of CSEBs (compressed stabilized earth bricks) using geopolymer binders. The CSEBs with geopolymer binders, approximately 20%-25% of the dry volume of soil is replaced by a combination of fly ash and GGBFS (ground granulated blast furnace slag) with the addition of a geopolymer solution. These two waste materials make the blocks environmentally friendly and cost-effective. The experimental study is based on the compressive strength and water absorption of CSEBs. According to the tests, the compressed stabilized earth bricks exhibit high strength, low creep, minimal water absorption, and good erosion resistance. Preethi and Reddy [15] used geopolymers to produce CEBs for building construction. The research focused on examining the influence of various parameters such as clay content, alkaline concentration, GGBFS, and fly ash on the strength of geopolymers stabilized compressed earth specimens. The strength of compressed earth is sensitive to the amount of GGBFS and fly ash added. It provides better strength than fly ash in geopolymers stabilized compressed earth specimens. The strength increases by 30% to 50% when the molarity of the alkaline solution changes from 8 to 12 M NaOH. The use of soil with clay fractions greater than 30% leads to a lumpy mixture, which poses issues during the compaction of soil mixes treated with geopolymers.

The main idea of this study is to increase the physical and the mechanical performance of the earth blocks by stabilizing them with geopolymer binder based on local bio-sourced materials, mainly clay, cob corn. The performances of the CEBs stabilized with the geopolymer binder are compared to those of CEBs stabilized with the Portland cement binder.

2. Experimental Tests

2.1 Materials

2.1.1 Laterite and Clay

The laterite used for this study is a sandy clay soil. The laterite constituting the main matrix of CEB was screened and sieved to 5 mm to obtain a material of 0/5 mm granular class according to the recommendations of the standard ARS 674 [18]. The raw laterite was extracted from a local laterite quarry in Tori Avamè (6.440989 N, 2.179386 E) in Benin. The kaolinite clay used for obtaining the metakaolin, was extracted from local quarry in Zogbodomey (7.0670° N and 2.33466 °E) in Benin. Table 1 presents the quantitative semi-composition of the clay that contains 40% of kaolinite and 39% of quartz. To increase the silica, the corn cobs ash was added to the metakaolin.

2.1.2 Geopolymer and Cement Binder

The metakaolin used for the synthesis of the geopolymer was obtained by calcining the local clay material at 600 °C for 4 h (10 °C/min). The clay was previously milled and sieved at 100 µm.

The cob corn ash was obtained by calcination the local cob corn material by 600 °C for 4 h (10 °C/min). The local corn was previously milled and sieved at 100 µm.

Table 1 Quantitative semi-composition of the Zogbodomey clay [5].

Kaolinite	Quartz	Goethite	Smectite	Illite	Anatase
40%	39%	10%	5%	4%	2%

A 12 M sodium hydroxide solution, prepared by dissolving 99% pure NaOH crystals in distilled water, was used as the activation solution for the calcined materials.

The synthesis of geopolymer binder was carried out in two distinct phases. Initially, aluminosilicate (metakaolin) and silicate powders (cob corn ash) were meticulously mixed and kneaded in a mixer for 10 min. Following this, the alkaline solution NaOH was added, and the fusion between the powder and the mixture was carefully homogenized with the mixer for another 10 min until the mixture was homogeneous. A mass ratio of 0.7 between the NaOH alkaline solution and the powder was utilized for the geopolymer binder. This ratio of 0.7 was determined based on the difference in density of the alkaline solution (1.13 for 12 M NaOH at 20 °C) to achieve consistent geopolymer binder [1]. The resulting geopolymer binder was then used to fill 4 × 4 × 16 cm^3 mold. Subsequently, the geopolymer in the mold was subjected to densification by a shock table. The specimen in the mold underwent 120 impacts to expel air trapped by the pores of the geopolymer. Fig. 1 illustrates the principle for the geopolymer synthesis.

Four formulations of geopolymer binders were carried out:

- Samples composed of metakaolin activated by alkaline NaOH solution: LG1.
- Samples elaborated with 95% metakaolin and 5% corn cob ash with alkaline NaOH solution: LG2.
- Samples formulated with 90% metakaolin and 10% corn cob ash with alkaline NaOH solution: LG3.
- Samples comprised of 85% metakaolin and 15% corn cob ash with alkaline NaOH solution: LG4.

Once the test specimens were prepared, they were covered with a polyethylene film to prevent water evaporation during the setting and hardening of the binder. They were left at laboratory ambient temperature approximately 30 °C for 7 days before undergoing a thermal treatment in accordance with the studies conducted by Ferone et al. in 2011 [10].

Furthermore, the Composite cement of type CEM II/B-LL 32.5 R was used for the stabilization of the reference CEB.

Fig. 1 Principle for geopolymer synthesis.

2.3 Stabilization Process

The stabilization method employed in this study was volumetric and accounted for the density of the various base materials (laterite, metakaolin, cob corn ash and cement). The optimum water content for the different dry mixtures was determined using the standard Proctor compaction test, as shown in Fig. 2. The increase in water content at the optimum leads to decrease in density for high metakaolin contents (10%-20%). That can be explained by the higher proportion of fine particles in the mixture and the larger surface area of the metakaolin particles.

For the stabilization with geopolymer, the CEB production mixture underwent a two-stage preparation process. Initially, the dry mixture (composed of laterite, metakaolin and cob corn ash) was homogenized for 10 min. Subsequently, water and an alkaline solution (NaOH) were added in a mass ratio of 0.7 (alkaline solution to metakaolin + cob corn ash). Determination of the required water content (EhG) involved adjusting the optimum water content of the dry mixture (WGi) based on the amount of metakaolin and cob corn ash present, using the alkaline solution quantity (Sa) (as per Eq. (1)). This procedure ensured stabilization of the CEB, with geopolymer content 10%. The equation used for calculating EhG is:

$$EhG = [((WGi \times Ms)/100) - Sa] \quad (1)$$

where EhG represents the mass of required moistening water for geopolymer stabilization (in grams), WGi is the optimum water content of the dry mixture (laterite + metakaolin + cob corn ash) (in percent), Ms is the mass of the dry mixture (laterite + metakaolin + cob corn ash) (in grams), and Sa is the mass of the alkaline solution (in grams).

For the stabilisation with Portland cement, the homogenization process described earlier was conducted for the dry mixture containing laterite and cement. The key difference lies in the determination of the required moisture for laterite and cement hydration (Ehc), which was directly derived from the optimum water content (Wopt) of the dry mixture (laterite and

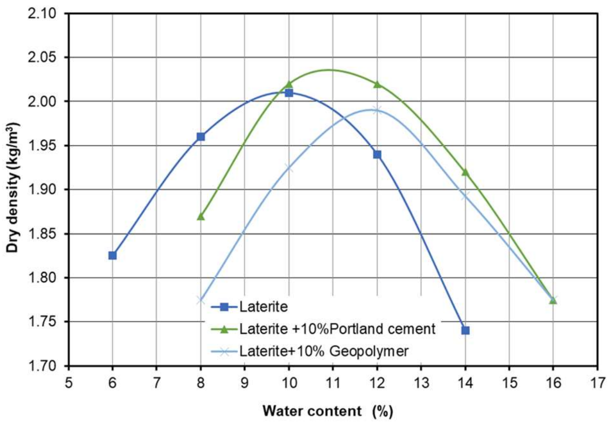

Fig. 2 Optimum water content of dry mixtures for CEB.

cement) using Eq. (2). In this method of stabilisation, a cement rate of 10% was utilized. Consequently, the resulting CEBs were stabilized with 10% cement. The equation used to calculate Ehc is:

$$Ehc = (Wopt \times Ms) / 100 \quad (2)$$

where Ehc represents the mass of moistening water required for cement stabilization (in grams), Wopt is the optimum water content of the dry mixture (laterite and cement) (in percent), and Ms is the mass of the dry mixture (laterite and cement) (in grams).

2.4 CEB Production and Curing Conditions

The CEBs were produced using the conventional technique involving mixing of dried materials (laterite, metakaolin, cob corn ash), adding required water, homogenizing, compacting, and demolding. Initially, the dry earth material is coarsely crushed and passing by 5 mm sieve to obtain particles with dimensions smaller than 5 mm. The preparation of the mixture was conducted by adding binder materials (metakaolin + cob corn ash) and earth soil (laterite) in a laboratory mixer. The mixture was homogenized to obtain a homogeneous distribution of the soil material and binder. Required water is then added, and the wet material corresponding to each type of stabilization was subsequently placed into prismatic molds for samples with dimensions of $4 \times 4 \times 16$ cm³. The sample is then compacted using a single-acting static mode press. Table 2 summarizes the nomenclature of the synthesized samples and the composition of their matrix formulation.

Table 2 Percentage of basic materials for each type of CEB.

Materials	CEB 0%	CEB 10% CP	CEB 10% GP
Earth soil (%)	100	90	90
Cement (%)	/	10	
Geopolymers (metakaolin + cob corn ash) (%)	/		10
Moisture content (%)			/
Concentration NaOH	/		12 M

The thermal treatment consists of exposing the samples to a temperature of 60 °C for a duration of 7 days using a laboratory oven with natural convection. This thermal curing was based on the findings of the study conducted by Muñiz et al. in 2011 [4], they investigated the effect of temperature on the geopolymerization process and demonstrated that the optimum temperature for good geopolymerization is 60 °C.

The geopolymer samples were synthesized using exclusively sodium hydroxide solution as the activating agent. These geopolymers were placed into molds with dimensions of 4 × 4 × 16 cm³, then covered with a polyethylene film and placed in the laboratory's ambient environment at a temperature of 30 ± 5 °C for 7 days. After removing the molds, the samples were subjected to a thermal curing condition. The thermal treatment at 60 °C for 7 days using a laboratory oven with natural convection was performed.

Each typical sample of geopolymers that underwent a 14-day curing period is then subjected to several characterization tests to highlight the influence of curing conditions and the addition rate of corn cob ash on the properties of geopolymer binders.

The determination of these properties was carried out through mass loss, apparent density, water-accessible porosity, compression, and bending strength measurements.

3. Results and Discussions

3.1 Characterization of Laterite and Clay

The geotechnical properties of the laterite are presented in Table 3. The laterite shows a plasticity index of 19%, therefore this laterite is plastic. The methylene blue value is 0.57 g/100g, indicating the absence of swelling clays in the sample. The grain size distribution shows that only 36.16% of fines (particles passing through a sieve of 80 µm) are present. The grain size distribution curve (Fig. 3) of this material falls within the granular range recommended by CRATerre [7, 8] for materials suitable for CEB construction. Additionally, the liquid limit and plasticity index fall within the recommended plasticity range on the CRATerre plasticity diagram for materials suitable for CEB construction.

The soil classification according to Refs. [7-11], that consider the grain size distribution, plasticity index, and methylene blue value, shows that the laterite is of type B6 (acceptable material but with too many fines).

Table 3 Geotechnical characteristics of laterite.

Granulometric distribution of laterite		Plasticity of laterite	
Coarse sand (%) (> 2 mm)	0%	Limit of liquidity W_L (%)	41.30
Finer (%) (< 80 µm)	36.16%	Limit of plasticity W_P (%)	22
		Index of plasticity I_P (%)	19.30
Value of methylene blue (g/100g) 0.57			

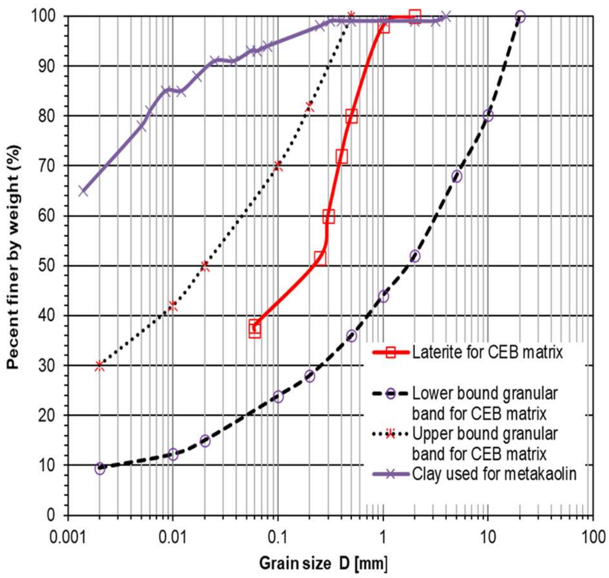

Fig. 3 Grain size distribution of laterite and clay used.

3.2 Physical and Mechanical Characterization of Geopolymer

Fig. 4 depicts the results of mass loss for the various geopolymer binder samples after thermal curing at 60 °C for 7 days. The respective mass loss of 26.76%, 14.78%, 10.94%, and 8.23% for geopolymer binders LG1, LG2, LG3, and LG4 was measured. This mass loss can be attributed to the evaporation of water from the alkaline solution. Additionally, the mass loss decreases as the partial substitution of metakaolin by corn cob ash increases. This decrease can be explained by the fact that the silica in corn cob ash is soluble in hot water than in cold water. Consequently, this silica migrates out of the geopolymer during thermal curing, reducing the porosity of the geopolymer and limiting the amount of water that can be trapped inside. In general, the addition of the cob corn ash to metakaolin increased the amount of amorphous silica in the aluminosilicate complex mixture. This possibly boosted the release of silicate ($SiO(OH)_3$) species during the dissolution stage induced by alkaline hydrolysis [13].

Fig. 6 presents the apparent density ranging from 1.30 to 1.61 for the geopolymer binders for a curing temperature of 60 °C. The maximum density was obtained with the formulation LG4 (85% metakaolin + 15% CCA + NaOH). That can be related to the gelation and good condensation of the geopolymer gel at this temperature, as well as the more developed geopolymer phase. However, the lower density observed for samples LG1, LG2, and LG3 is due to a slower dissolution of the raw materials and lower gel condensation, resulting in lower densities and higher porosity. This higher density of sample LG4 could lead to higher mechanical strength. The apparent densities of the three types of geopolymer samples (LG1, LG2, LG3) presented in this study are slightly lower than those obtained by Gao et al. [18]. These lower densities of the samples could also result in lower mechanical strength. The relationship between apparent density and water-accessible porosity of geopolymer binders for different formulations is also shown in Fig. 6. In general, the water accessible porosity increases as density decreases, regardless of the geopolymer samples. The water accessible porosity ranges from 30.35% to 41.11%, while the density varies from 1.30 to 1.61.

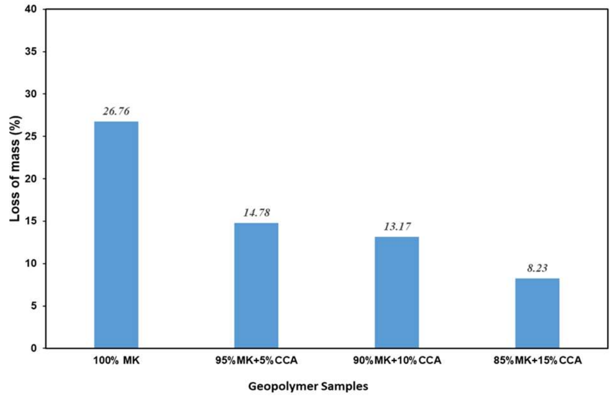

Fig. 4 Loss of mass for geopolymer samples.

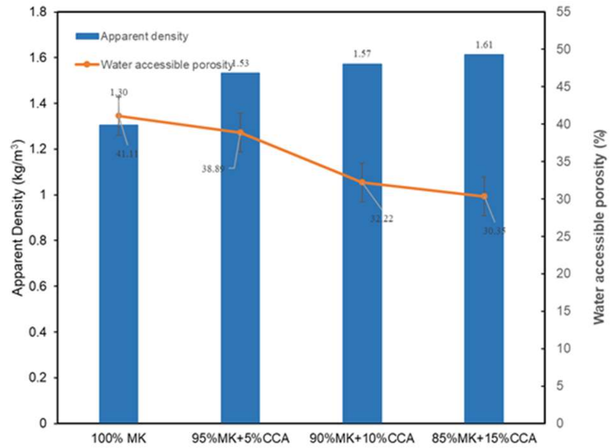

Fig. 5 Relation between density and porosity for geopolymer sample.

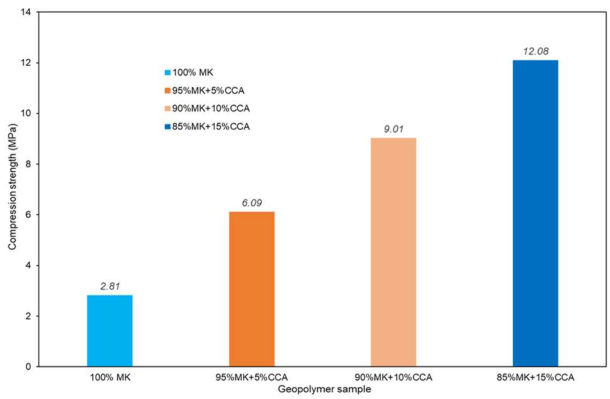

Fig. 6 Compression strength of geopolymer sample after 14 days of curing.

3.3 Physical and Mechanical Characterization of CEB

To better understand the behavior of CEB samples in contact with water, it is necessary to evaluate additional physical properties such as the coefficient of capillary water absorption and the water absorption by total immersion. Figs. 7 and 8 show water absorption by total immersion of stabilized CEBs (with cement and geopolymers) and the coefficients of the capillary water absorption as a function of the square root of time (in hours), respectively.

The water absorption curves reach a plateau beyond 15 h of immersion, with variable absorption rate. Indeed, after 5 h to 24 h of immersion, the absorption rate ranges from 11.54% to 13.96% for CEB stabilized with 10% geopolymers. For CEB stabilized with 10% cement the absorption rate is lower, between 10.26% and 12.83%. The lower water absorption observed in the case of CEBs stabilized with cement can be attributed to their reduced porosity. CEBs stabilized with geopolymers show curves that lie above those of CEBs stabilized with cement and increase with the duration of partial immersion. This phenomenon can also be associated with a higher porosity of these blocks. It is important to note that the water absorption at 24 h for all stabilized CEBs (10% cement and 10% geopolymers) remains below 15%-20%, which corresponds to the recommended values for use in a humid environment, as noted by Abhilasch et al. [16].

Regarding the evolution of the coefficient of capillary water absorption, CEBs stabilized with cement lead to low absorption coefficient. This result is consistent with the findings obtained on the water-accessible porosity of CEBs described above. CEBs stabilized with geopolymers experience higher capillary absorption than those of CEBs stabilized with cement. This phenomenon can also be linked to the higher porosity of these blocks. According to standard XP P 13-901 [17], CEBs with $Cb10min$ value less than 20 g/cm² are classified as CEBs with very low capillary absorption. This is the case for these CEBs stabilized at 10% with geopolymers (13.54 g/cm²) and 10% with cement (11.87 g/cm²).

Fig. 9 shows the results of mass loss for the CEBs after curing, which corresponds to the variation in mass between the end of the curing period of each sample and 7 days after the start of hardening, for various samples. As expected, the unstabilized CEBs showed the lowest mass loss, closely followed by the cement stabilized CEBs. These limited weight reductions are mainly attributed to the respective treatment conditions, including wet curing for cement stabilized CEBs (CEB 10%) and ambient temperature curing for CEB without binder addition (CEB 0%). However, the maximum mass loss was observed for the geopolymer stabilized CEB. It is possible that these significant mass losses for geopolymer CEB were due to thermal curing, leading to significant evapotranspiration of geopolymer CEB.

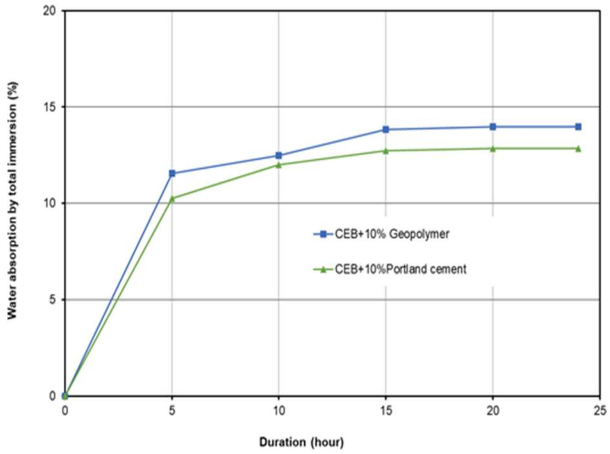

Fig. 7 Water absorption by total immersion of CEBs.

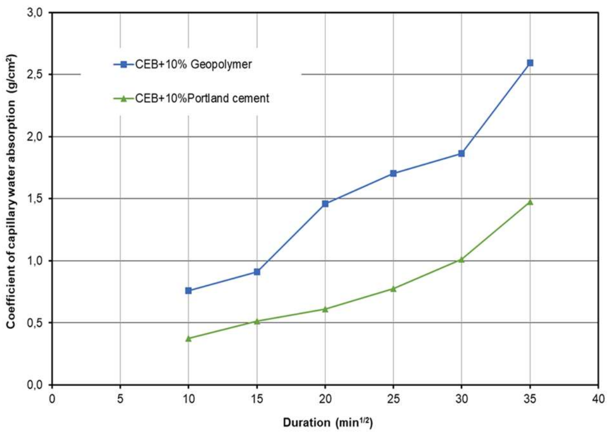

Fig. 8 Coefficient of capillary water absorption of CEBs.

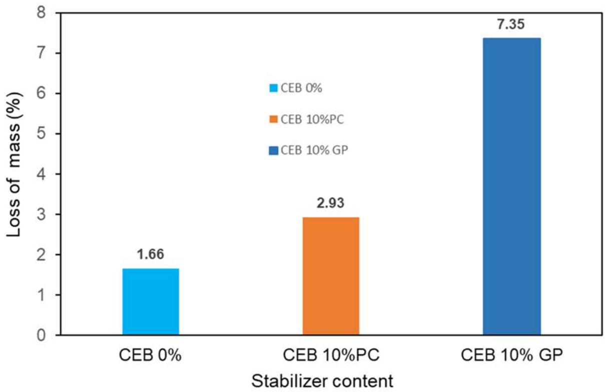

Fig. 9 Mass loss of CEB samples.

Fig. 10 depicts the water accessible porosity for the CEBs. The fragile nature of unstabilized CEB in the presence of water has made it difficult to quantify their water accessible porosity. The analysis reveals that cement stabilized CEBs are characterized by lower porosity and higher density. This lower porosity can be explained by the hydration of the cementitious binder and the formation of C-S-H (calcium silicate hydrate), facilitated by adequate curing that does not result in water loss. The water accessible porosity for geopolymer-stabilized CEBs is higher than that of cement stabilized CEB due to the high porosity of the geopolymer binder. The apparent density of geopolymer and cement-stabilized CEB follows an inverse trend to their water-accessible porosity, which is consistent: the more porous the sample, the lower its density, and vice versa.

The higher density and low porosity of cement-stabilized CEB could be explained by the hydration of the cementitious binder and the formation of calcium silicate hydrates (C-S-H), which binds to the matrix grains of the laterite, thus densifying the geocomposite. As for geopolymer stabilized CEB, their low density would be due to water loss during thermal curing. The densest CEBs are less porous (as in the case of cement-stabilized CEB), and vice versa, which is evidenced by geopolymer-stabilized CEB.

Fig. 11 illustrates the sensitivity of CEBs to water after being saturated in water for a period of 72 h. The vulnerability of unstabilized compressed earth blocks (CEB 0%) is evident, as these CEBs experience complete disintegration in water and become mud. However, cement stabilized CEBs and geopolymer stabilized CEBs show excellent resistance to water. These blocks keep well their integrity, remain stable in clear surrounding water, making them very robust in the presence of water. Moreover, the geopolymer CEBs maintain their stability, although the surrounding water becomes lightly yellow-tinted, likely due to the presence of fine clay particles from laterite in suspension. These observations are indications of a good resistance to rainwater for building walls constructed with CEBs stabilized with 10% geopolymer content.

Fig. 12 represents the results of dry and wet compression strength of the studied CEB. The unstabilized CEBs show the lowest value of 0.83 MPa for dry compression strength, while 10% cement stabilized CEBs exhibit dry compression strength of 7.39 MPa. Geopolymer stabilized CEBs (10%) show dry compression strength of 6.92 MPa. Regarding wet

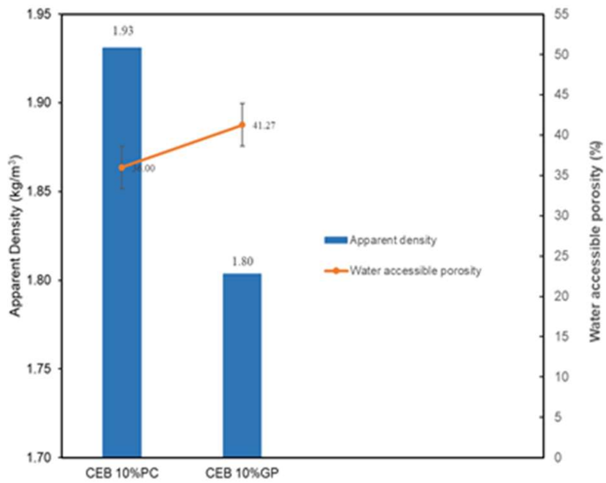

Fig. 10 Apparent density and porosity of CEB samples.

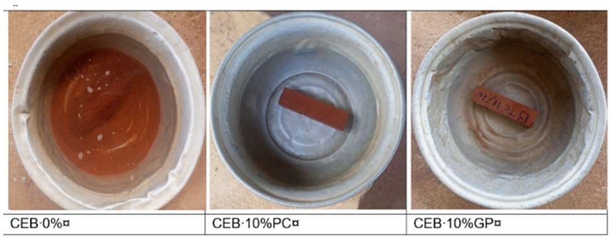

Fig. 11 Sensitivity of CEB samples to water.

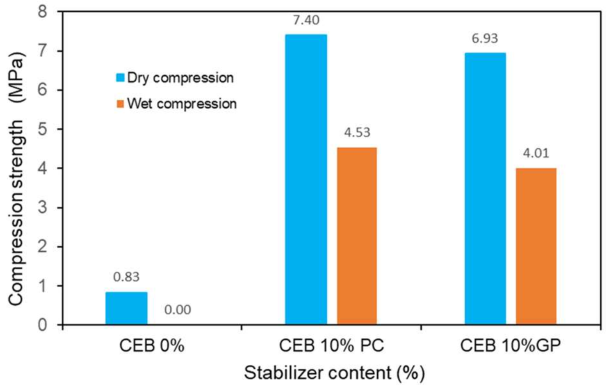

Fig. 12 Dry and wet compressive strength of CEB samples.

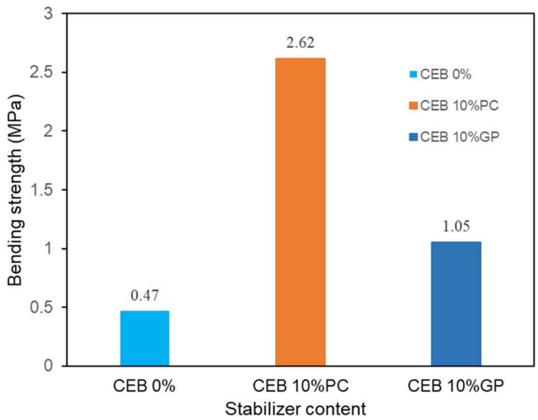

Fig. 13 Bending strength of CEB samples.

compression strength, the stabilized blocks lose half of their strength (4.01 MPa for 10% geopolymer content and 4.53 MPa for 10% cement content), while the compression strength of unstabilized CEBs could not be evaluated due to complete disintegration during the saturation phase.

The flexural strength of CEB follows a similar trend to compression strength, with an increase based on the nature and rate of stabilisation (Fig. 13). The maximum values for flexural strength of 2.61 MPa for cement stabilized CEB and 1.05 MPa for geopolymer stabilized CEB are obtained.

The increase in strength of geopolymer stabilized CEB can be explained by the formation of a geopolymer gel that binds the matrix grains, making the geomaterial denser and stronger. This geopolymer gel forms through the polymerization reaction between the alkaline solution, the metakaolin and the additional silica (provided by corn ash) incorporated in the raw earth material. The amount of gel produced depends on both the concentration of the activating solution and the amount of metakaolin and additional silica in the CEB. That explains the improved results obtained with 10% geopolymer stabilisation for the compressed earth blocks.

For cement stabilized samples, the improvement in strength would be due to the formation of bonds between the matrix grains of laterite and the hydrates formed during cement hydration. When Portland cement hydrates, in addition to CSH (calcium silicate hydrate), it also forms CAH (calcium aluminate hydrate) and $Ca(OH)_2$, thus forming a compact and stronger matrix.

According to standard ARS 674 [12], CEB stabilized with 10% cement and therefore 10% geopolymer, which exhibited dry compression strengths exceeding 4 MPa, could be used for load-bearing walls. However, unstabilized CEB, which showed the lowest strength of 0.83 MPa, does not meet this standard for earth construction.

Furthermore, the ratio between wet and dry compression strength defines the water resistance coefficient. This ratio is 0.58 for geopolymer stabilized CEB with 10% content and 0.62 for 10% cement stabilized CEB. According to standard XP P13-901 [14, 15], CEB is considered durable when the water resistance coefficient is greater than or equal to 0.5, therefore the formulated and analyzed geopolymer with resistance coefficient of 0.58 (> 0.50) is durable and can be used for load-bearing walls.

4. Conclusions

This paper presents a valorization possibility for the unexploited laterite, clay potential of Benin and the agricultural waste or industrial by-product (cob corn) by synthesizing a new, cheaper, and more environmentally friendly construction material than similar materials containing cement. It highlights the possibility of stabilizing CEBs with a bio-sourced geopolymer that emits less CO_2 than the conventional Portland cement.

This geopolymer is synthetized with metakaolin plus cob corn ash using hydroxide sodium (NaOH) as activation solution.

The specific objectives of the study were to evaluate the physico-mechanical performances of the geopolymer and of this new method of stabilizing earth blocks compared to cement stabilization. To achieve this, the properties of the geopolymer and these types of CEBs relevant to their use in construction were determined. The following conclusions can be drawn:

- The result of substitution of the metakaolin by the con corn ash shows that the mixture of 85% metakaolin 15% con corn ash leads to less porosity and high compression strength for the geopolymer synthesized. The addition of the cob corn ash to metakaolin increased the amount of amorphous silica in the aluminosilicate complex mixture, and boosted the release of silicate ($SiO(OH)_3$) species during the dissolution stage induced by alkaline hydrolysis. This increased the physical and mechanical performance of the geopolymer. Moreover, the mass of hydroxide sodium (NaOH) solution to the mass of dry mixture (metakaolin + cob corn) varied between 0.6 and 0.8. In result, the geopolymer with mass ratio of 0.7 exhibits more consistency and hardening within 24 h and 48 h.
- Despite the maximum density and minimum water accessible porosity of cement stabilized CEBs, an average geopolymer content of 10% ensures good bond of the CEB particles, allowing them to withstand the high stress during the compressive test. As expected, unstabilized CEBs exhibit poor performance.
- CEBs stabilized with 10% geopolymer binder (metakaolin + cob corn ash) and thermally treated at 60 °C show very good mechanical properties with a compression strength of at least 4 MPa, as recommended by standard XP P13-901 [17] for earth construction.

For the future, it would be important to assess the environmental impact (life cycle analysis) and the durability of this new stabilisation method compared to cement stabilization.

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