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Original Article

Physicomechanical and Durability Properties of Compressed Earth Blocks Stabilized with Grewia Bicolour Bark Powder and Cement

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Abstract *- This study examines the performance of Compressed Earth Blocks (CEBs) stabilized with Grewia Bicolor Bark Powder (GBBP) and Ordinary Portland Cement (OPC). The research aims to evaluate the physical, mechanical and durability performances of these CEBs to determine their suitability for sustainable construction practices. The experimental procedures involved categorizing GBBP and formulating CEB samples with 2% OPC and different percentages of GBBP from 0 to 6% in 2% steps. The results demonstrate a significant improvement in compressive strength of up to 33.74% compared to typical CEBs containing 2% OPC. The dry density of the blocks decreased after 2% GBBP, but the water absorption increased with increasing GBBP content, making the blocks unsuitable for use in constantly humid environments. Adding 2% GBBP improved the erosion resistance of the blocks by 4.7 times, and this increased with increasing GBBP content. Blocks stabilized with 2% OPC and 2% GBBP have been shown to perform optimally, achieving better mechanical, durability and physical properties. The results indicated that GBBP can be used as a stabilizer with low cement content to obtain earth blocks, contributing to sustainable and environmentally friendly construction materials.*

Keywords *- Grewia Bicolour Bark, Compressed Stabilised Earth Blocks, Compressive strength, Dry density, Water absorption, Erosion resistance.*

1. Introduction

Many environmental issues are associated with the building sector due to the materials and their production process. Certain materials, such as steel, cement, and many others, produce carbon dioxide and other pollutants during their production. These pollutants can affect soil, water, air, plants, animals, and aquatic life and harm human health [1]. It is also observed that the construction field is one of those consuming more energy worldwide.

According to the Global Alliance for Buildings [2], nearly 55% of all electricity consumed worldwide is used for building operations. This contributes to the high price of some conventional building materials and increases housing problems in many African countries. These challenges have generated the interest of researchers in ecologic building materials, particularly earthen. Earth is a traditional and modern building material for constructing houses, offices, and religious buildings [3]. Earth construction is reported to be vital for growing the building sector and respecting the environment [4]. The usage of earth in construction presents several challenges, including shrinkage, poor strength, dimensional instability, rain erosion, and cracking at low compressive and tensile strengths [5–7]. In other words, the durability of earth blocks is the main issue to be solved. Stabilizing the soil to make strong and durable blocks is essential.

To develop sustainable structures, several stabilizers have been used for soils, including lime, fly ash, and cement [6, 8]. Cement is the most used among those mentioned above. Still, as said earlier, the use of cement has many environmental problems, and cement is neither renewable nor accessible to everyone everywhere. Researchers have been looking into alternative stabilizing techniques using modern, primarily synthetic, and vernacular materials that have traditionally been used [7]. Much research has been conducted on replacing partially cement with other materials. Using cement alone as a stabilizer, Shehu Waziri et al. [9] produced earth blocks with local soil. The results indicated an increase in blocks' compressive strength up to 2.48 MPa at a stabilization level of 7.5% after 28 days of curing. Sathiparan et al. [10] mentioned that some industrial wastes are not widely available, particularly in underdeveloped countries.

In line with this, Rimbarngaye et al. [11] demonstrated that Gum Arabic (GA) can stabilize earth blocks with lower cement content. Paa et al. [12] examined the structural and durability performances of CEBs stabilized with cow dung. The study found that compressive strength was remarkably increased when 20% of the soil's dry weight was replaced with cow dung. Chang et al. [13] examined the effect of Xanthan Gum (XG) on the diffusing properties of soil and discovered that 1% of XG provided the highest performance, increasing strength from 200 to 610 kPa. Banakinao et al. [14] found that the powder of Néré's husk is suitable for earth blocks with good mechanical and durability performances.

Although several biopolymers have been investigated for stabilization, exploring others that are widely available and have significant potential is still a need. Yèyimè et al. [15] evaluated the viability of using Grewia Bicolor Bark Juice (GBBJ) to partially replace OPC in soil stabilization for road bases. A UCS of 1.98 MPa was achieved with 2% GBBJ added to 4% cement.

The study has shown the effective use of GBBJ as a partial replacement of OPC in road bases. However, the results found are not suitable for CEBs. The findings show that further research is needed to use Grewia Bicolour as a cementitious material, especially to meet the block requirements.

Grewia Bicolour (GB), also called bastard brandy bush or two-coloured, is a many-stemmed shrub, usually a small tree, but can grow up to 7 m in height. The tree is very drought-resistant and is present in many African countries. Grewia Bicolour makes picture frames, house frames, and poles for nomadic tents [16]. In some West African countries, indigenous use GBBP for plastering walls, missing it with soil. Following the promising results obtained from the study of Yèyimè et al. [15] utilizing GBBJ, this study seeks to assess the performance of the same plant extract in its powder form.

Additionally, while the survey conducted by Yèyimè et al. [15] dealt with stabilizing soils for road construction, this research aims to investigate the impact of GBBP on CEBs. Road bases and subgrades must meet specific load-bearing capacity, stability, and durability standards to withstand traffic loads, moisture, and environmental conditions. In contrast, CEB used in construction has structural considerations specific to building construction rather than roads. This work aims to assess the physicomechanical and durability performances of CEBs stabilized with GBBP and lower cement content.

2. Material and Methods

2.1. Materials

The materials utilized in this research are laterite, OPC, GBBP, and water. The laterite used was acquired in Juja (Kenya) at the location 1°05'34.5"S 37°00'34.5"E. Before its use, the laterite was air-dried and sieved through 5 mm according to ARS 1333:2018 [17]. The OPC is CEM I/42.5R, purchased from Bamburi cement in Kenya. The OPC has been stored in the laboratory at ambient temperature. The GBBP has been purchased in Chad. The bark was oven-dried at 100°C for 24h, crushed into powder using a ball mill shown in Figure 1(a) and sieved through 105μm.

Fig. 1 Preparation of GBBP: (a) Ball mill used in the study, (b) Grinding of GBB, and (c) GBBP sieved through 105μm.

2.2. Methods

2.2.1. Characterization of Materials

The chemical composition of the laterite, OPC and GBBP was determined with X-ray fluorescence. The portable XRF analyzer S1 TITAN (model S1 TITAN 600) was used to test each sample.

X-Ray Diffraction (XRD) technique was used to analyze the mineral composition of lateritic soil and GBBP. The test was carried out using the Rigaku Miniflex. Its measurement range (2θ) extends from 2° to 145°. The X-ray source used is a copper anode (λ Cu Kα = 1.5418 Å) with a fixed current (I) of 15 mA and a fixed voltage (U) of 30 kV. In addition, the measurement speed varies from 0.01 to 100°/min.

The Fourier Transform Infrared Spectroscopy (FTIR) was conducted on the laterite and the GBBP. Spectral data were acquired using an IRAffinity-1S FTIR spectrophotometer. The apparatus was configured to execute a cumulative of 20 scans at a spectral resolution 4cm^{-1} for background and sample spectra, swiftly captured between the 4000 - 400cm^{-1} range.

The size distribution of the laterite was determined through sieving and Hydrometer analysis according to BS 1377, 2 [18]. The specific gravity of the laterite, the bulk density of GBBP, the natural moisture content and Atterberg Limits were determined according to BS 1377, 2 [18]. The compaction, which is Optimum Moisture Content (OMC) and Maximum Dry Density (MDD) of raw soil as well as mixtures, was obtained by compaction test according to BS 1377,4 [19].

2.2.2. Production of Blocks

The blocks of 290 x 140 x 120 mm were made with laterite, 2% OPC and different percentages of GBBP, as summarized in Table 1. The study aims to reduce cement usage to produce affordable earth blocks. In existing literature, optimal performances of earth blocks have been observed within the range of 5% to 8% cement. Therefore, this research aims to employ significantly reduced cement content to enhance the use of local, cheap, environmentally friendly material (GBBP). Rimbarngaye et al. [10] utilized 2% OPC and varying GA content in a related study.

Table 1. Mix proportions of compressed stabilized laterite blocks

Label	Laterite (%)	OPC (%)	GBBP (%)
S+2%C+0%GBBP	Fixed	2	0
S+2%C+2%GBBP			2
S+2%C+4%GBBP			4
S+2%C+6%GBBP			6

To produce the blocks, the soil (sieved through 5 mm) was first spread in a tray, and then the stabilizers were added and mixed manually to obtain a uniform mixture. Water was sprinkled to reach the OMC obtained from the compaction test. The soil mixture with the stabilizers was covered in the hand-press mould. The block was then squeezed and ejected. The wet weight was recorded and compared to the wet weight corresponding to the MDD for quality control. The curing of the blocks was done by covering the blocks with polystyrene.

2.2.3. Physical Properties Tests

The physical properties in this study were the dry density and the water absorption. The dry density was determined following WD-ARS 1333 [17]. To conduct this test, the blocks were dried in the oven for 24 hours at 105°C ± 5°C before being weighed according to conventional procedures. It was determined after 28 days of curing. The dry density γd (kg/m^3) was determined using Equation 1 where W_d is the dried mass (Kg), and V is the volume of the block (m^3).

$$\gamma_d = \frac{W_d}{V} \quad (1)$$

The water absorption of the blocks was determined on the same date as the dry density. The test was conducted according to WD-ARS 1333 [17]. The dry weight of the samples was recorded after 24 hours of drying in the oven at 105°C ± 5°C. The wet weight of the samples was obtained after 24 hours of total immersion in water. The water absorption (ω) was calculated using Equation 2, where Wb is the weight before immersion and Wa is the weight after immersion.

$$\omega = \frac{W_a - W_b}{W_b} \quad (2)$$

2.2.4. Compressive Strength Tests

The compressive strength of the blocks was determined according to XP P 13-901 [20] after 28 days of curing. The test was conducted using the Universal Testing Machine (UTM) shown in Figure 2. The weight of the block was recorded, and the block was placed between the trays of the UTM. The load was then applied at a rate of 0.05 N/mm^2/s until the failure of the block. The blocks' maximum load and compressive strength were obtained and recorded, as shown in Figure 2.

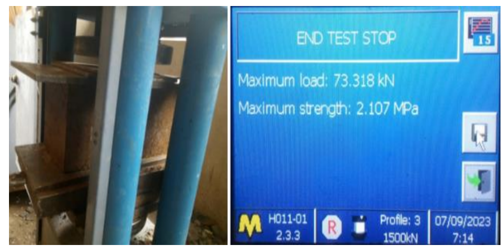

Fig. 2 Compressive strength set-up

2.2.5. Durability Properties Tests

The erosion test involved spraying the blocks with water following NZS 4298 [21] to assess their resistance to continuous rain conditions. It should be noted that the water spray method more effectively reproduces the field conditions in terms of resistance to erosion [22]. The test consisted of spraying water onto the sample through a 150 mm diameter hole at a pressure of 50 kPa. As shown in Figure 3, the pressure spray nozzle was positioned 470 mm from the shield.

According to Cid-Falceto et al. [23], optimal testing conditions occur when the most prominent face (290 x 140 mm) is exposed to water. Despite the NZS 4298 [21] recommending a hole of 150 mm in diameter, we opted for a diameter of 100 mm in our study, aligned with the block's width (140 mm). This decision is supported by the findings of Cid-Falceto et al. [19], who demonstrated that the test represents the field conditions when the diameter is less than the block's width. Water was sprayed onto the exposed surface of the block for 60 minutes.

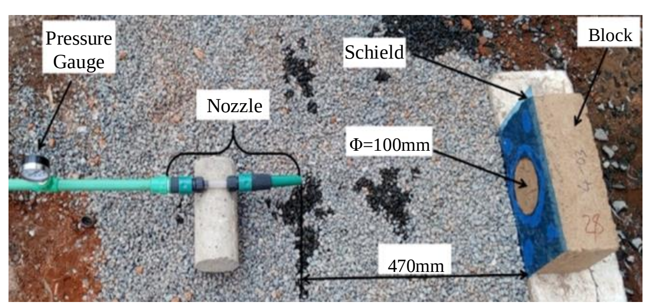

Fig. 3 Erosion test set-up

3. Results and Discussion

3.1. Geotechnical and Chemical Characterization of Raw Materials

Each material in the study has its geotechnical properties. On the laterite, the geotechnical tests conducted include Particle Size Distribution (PSD), natural moisture content, specific gravity, Atterberg limits and the Maximum dry density corresponding to the optimum moisture content. The supplier gave the properties of the OPC used, as shown in Table 2. The physical properties of GBBP determined were the bulk density and the initial moisture content of GBBP, which are 0.512 g/cm^3 and 10.32%, respectively.

Table 2. Physical and mechanical properties of OPC

Parameter		Specification	Unit	Value
Specific Surface		-	cm^2/g	3129
Soundness		≤ 10	mm	0.5
Setting Time	Initial	≥ 60	min	176
	Final	-	min	270
Compressive Strength	At Two Days	≤ 10	MPa	20.80
	At 28 Days	≤ 42	MPa	50.78

Figure 4 shows the particle size distribution of the studied soil. It shows that the laterite soil is composed of 42% gravel, 33% sand, 6% silt and 19% clay. According to BS 1377,4 [19], the soil is classified as Clayey Sandy Gravel. As per the guidelines outlined in the WD-ARS 1333 [17], for soil to be good for CSEB, the proportion of fine gravel and sand is 50% - 70%, Silt 15% - 30%, Clay 5% - 30% and organic matter 2% - 4%. The soil satisfies some requirements but is slightly out of the range for others, hence the need for stabilization. The physical performances of the laterite soil are summarized in Table 3.

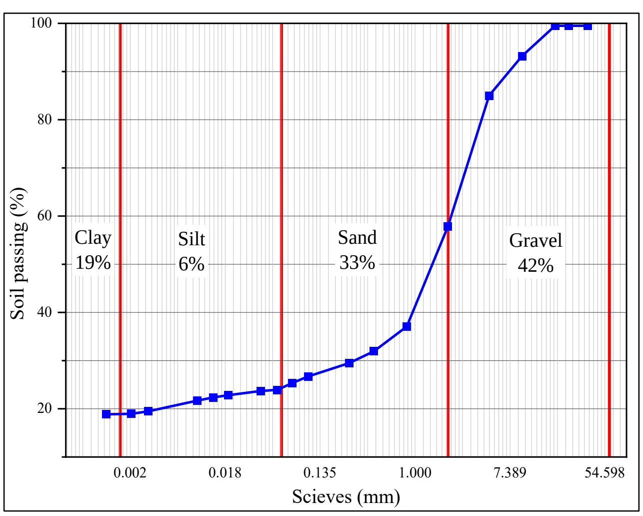

Fig. 4 Particle size distribution of the soil

Table 3. Physical properties of the soil

Properties	Value
Natural Moisture Content	15.67
Specific Gravity	2.45
Passing through BS Sieve 75µ	28.52%
Liquid Limit	53.09%
Plastic Limit	20.56%
Plasticity Index	32.52%
Linear Shrinkage	16.21%
Optimum Moisture Content	20.15%
Maximum Dry Density	1.638 g/cm^3

The chemical composition of the laterite soil, OPC and GBBP is given in Table 4. The results of the chemical composition of the laterite show that Silicate Oxide (SiO_2) is the most dominant in the soil. From the results, the ratio of SiO_2/Al_2O_3=3.87 (>3) and the sum of $SiO_2+Al_2O_3+Fe_2O_3$=93.718 (>75) as recommended by Murmu et al. [24] for good Laterite soil. It aligns with the previous chemical composition of laterite [11, 15, 25].

The chemical composition of GBBP shows the major oxides, which are Calcium (CaO=56.767%), Potassium (K_2O = 14.377%) and Silicate Oxide (SiO_2=4.76%). The free lime in GBBPs is expected to react with the silicate dioxide to produce the Calcium Silicate Hydrate (C-S-H) in the presence of water, contributing to cementitious materials' strength and durability.

Table 4. X-Ray fluorescence on laterite soil, OPC and GBBP

Oxides and Elements	Soil (%)	OPC (%)	GBBP (%)
Aluminium (Al_2O_3)	15.886	5.634	2.159
Silica (SiO_2)	61.538	21.644	4.760
Phosphorus (P_2O_5)	-	0.390	2.689
Sulphur (S)	-	3.202	1.687
Chlorine (Cl)	0.114	-	0.687
Potassium (K_2O)	1.010	0.364	14.377
Calcium (CaO)	0.429	65.602	56.767
Titanium (Ti)	1.662	0.178	0.359
Chromium (Cr)	0.000	0.006	0.085
Manganese (Mn)	2.504	0.019	0.108
Ferric (Fe_2O_3)	16.294	2.681	2.26
Copper (Cu)	-	0.038	0.011
Zinc (Zn)	0.016	0.038	0.009
Strontium (Sr)	0.005	0.122	0.083

3.2. Mineralogic and Morphologic Characteristics of Raw Materials

The XRD pattern of the laterite soil is presented in Figure 5; the figure shows the presence of quartz (56%), Orthoclase (41.3%) and traces of Geothite and Muscovite, proving that quartz is the most dominant mineral. This confirms previous works [26-28], which found similar minerals in laterite soil.

According to Cornelis Klein et al. [29], the specific gravity and hardness (on the Mohs scale) of minerals present in the soil are Quartz (2.67, 7), Orthoclase (2.55-2.63, 6), Goethite (4.1-4.3, 5-5.5) and Muscovite (2.76-3.0, 2-2.25). The abundance of quartz and Orthoclase shows that the laterite has high hardness.

Figure 6 illustrates the composition of GBBP, indicating that it primarily consists of Silicon Oxide (39%), followed by Whewellite (29%), Orthoclase (19%), and Albite (13%). Albite and Orthoclave might be due to the grinding process using a ball mill machine.

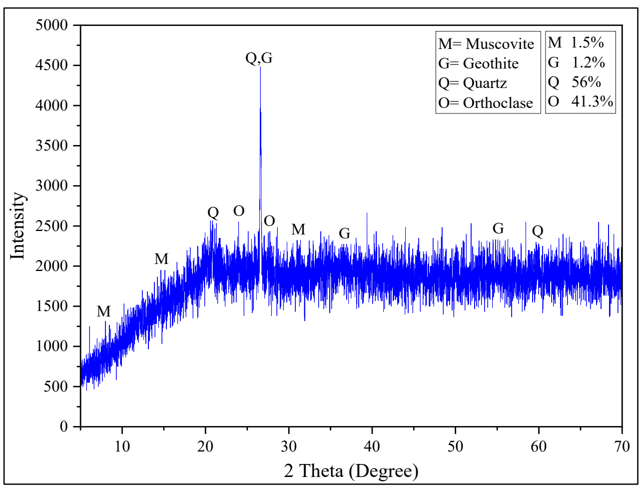

Fig. 5 X-Ray Diffraction of the laterite soil

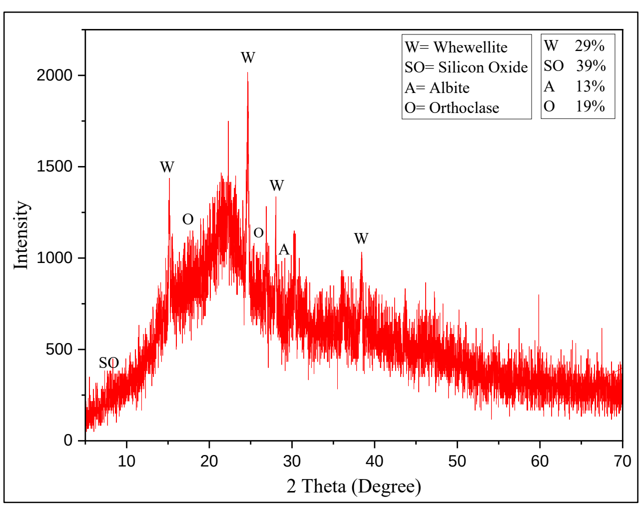

Fig. 6 X-Ray Diffraction on the GBBP

The FTIR spectrum of the laterite is shown in Figure 7. The peaks at 525, 789 and 912 cm^{-1} correspond to the vibration of Si-O, establishing quartz's presence in the soil [27]. The emergence of the δ (Si–O) and ν (Si–O–Si) bands further confirm the existence of quartz [30, 31]. The apparition of a strong band at 3620 cm^{-1} and 3371 cm^{-1} suggests the existence of a hydroxyl linkage (O-H groups) [32]. On the other hand, the spectrum exhibits large bands at 3371 cm^{-1} and 1633 cm^{-1}, which points to the potential for water hydration in the adsorbent [25, 33].

Figure 8 shows the FTIR spectrum of GBBP. The peak at 3301 cm^{-1} indicates the presence of O-H bonds, typically associated with Hydroxyl (OH) functional groups [34]. The peak at 1607 cm^{-1} corresponds to the stretching vibration of C=O bonds, indicating the presence of carbonyl groups [32]. The peak at 1313 cm^{-1} and 775 cm^{-1} is related to the vibrations of C-H bonds. The presence of C-H bonds contributes to the material's structure and stability in the earth block [25]. The peaks at 576 and 551 cm^{-1} are likely attributable to bending vibration modes in aromatic compounds, as suggested by [35, 36].

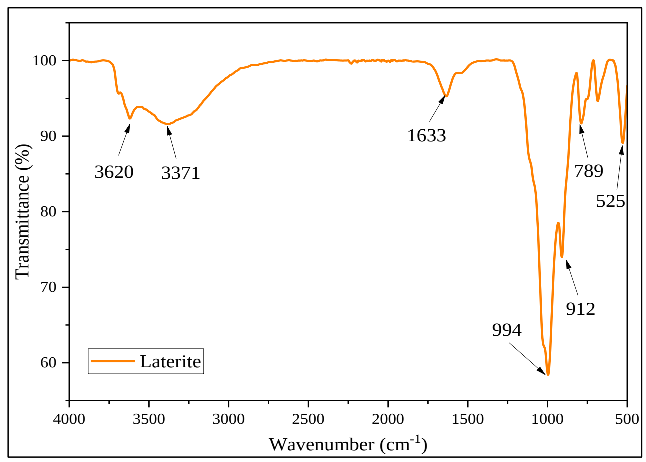

Fig. 7 FTIR of laterite

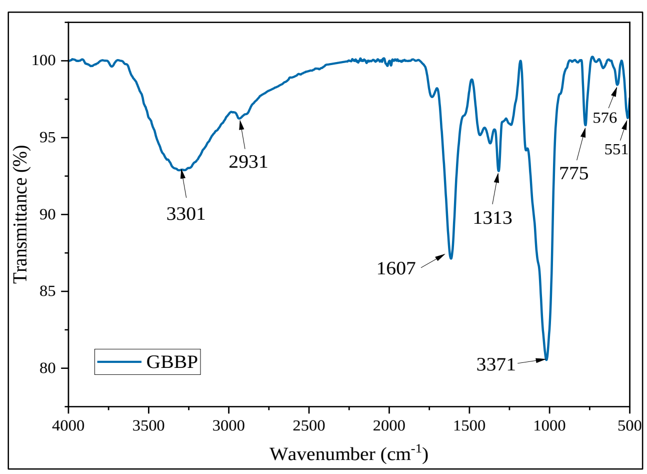

Fig. 8 FTIR of GBBP

Figure 9 shows the morphology of the laterite. The results show irregular shapes and rough surfaces, confirming the heterogeneous nature of the soil. Some areas on the surface seem shiny, which might result from iron oxides or a dispersed pattern of iron atoms in the sample.

The Energy Dispersive X-ray Spectroscopy (EDS) was used to assess the element composition of the laterite (Figure 10). The elements Oxygen (O), Iron (Fe), Silicon (Si), Aluminium (al), Carbon (c), traces of Manganese (mn) and Titanium (Ti) were found to be predominant, according to the results. The high concentrations of iron, silicon, and oxygen are consistent with the findings of [25, 37].

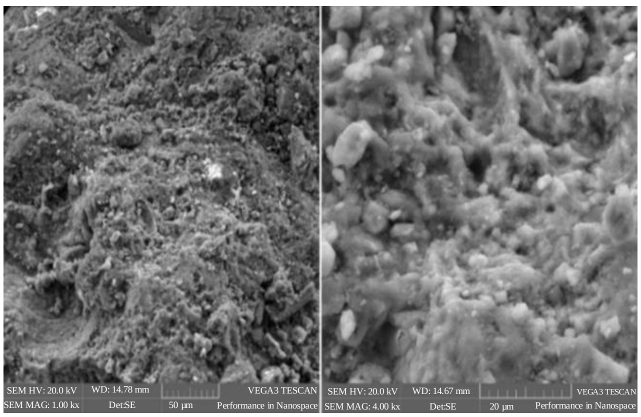

Fig. 9 SEM spectrum of laterite soil

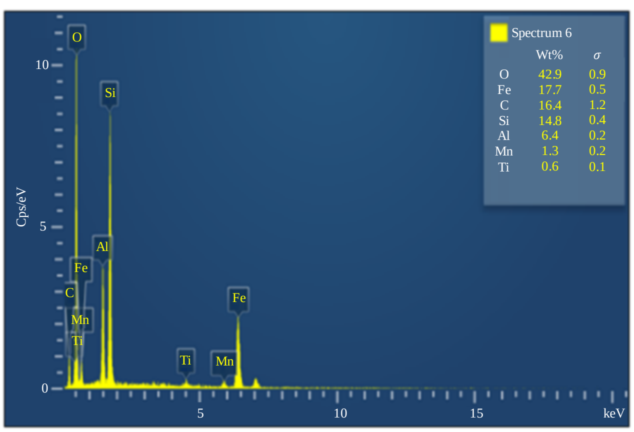

Fig. 10 EDS spectra of laterite acquired under 20 keV

The morphology of the GBBP particles is shown in Figure 11 via Scanning Electron Microscopic (SEM) at magnifications x1 and x4 which showed irregular shapes forms, rough surfaces and some micropores. The EDS result on GBBP (Figure 12) shows the abundance of Carbon (C), Oxygen (O), Calcium (Ca), traces of Potassium (K), Magnesium (Mg) and Silicon (Si). The high quantity of CaO shown by the XRF is confirmed by the EDS test, which shows the abundant presence of carbon, oxygen, and calcium. The same was found by Millogo et al. [38] on the cow dung.

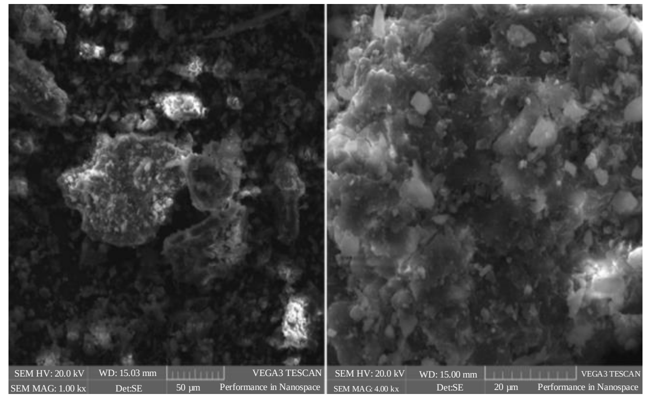

Fig. 11 SEM spectrum of GBBP

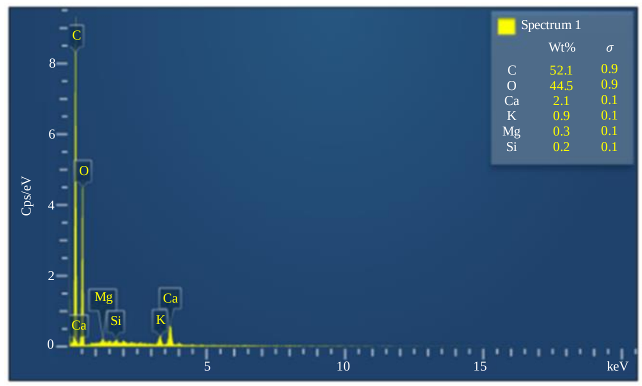

Fig. 12 EDS spectrum of GBBP acquired under 20 keV

3.3. Physical Properties of the Blocks Stabilized with OPC and GBBP

The two physical properties most investigated by previous researchers on earth blocks are dry density and water absorption. The results of water absorption of the blocks stabilized with low OPC content (2%) and different GBBP content are shown in Figure 13.

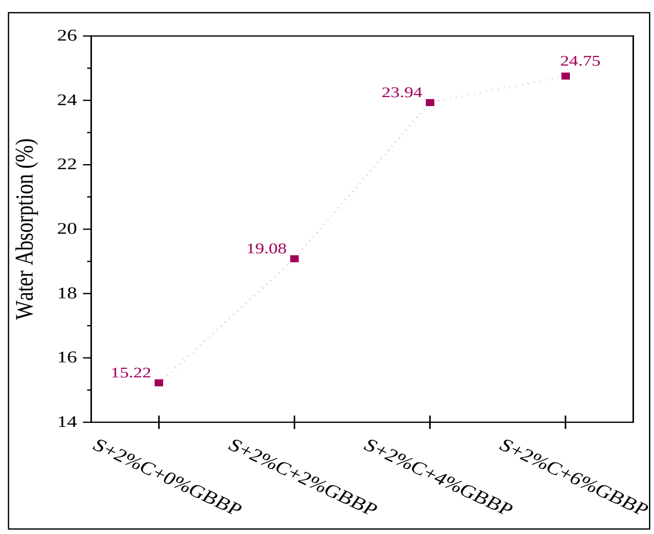

Fig. 13 Water absorption of blocks stabilized with OPC and GBBP

The findings indicate that an increase in GBBP causes an increase in water absorption. The blocks' water absorption is above 15%, which is the maximum water absorption specified in ARS 1333:2018 [17]. The trend of the water absorption observed might be due to the organic nature of GBBP and its porosity, as shown by the SEM test results. Specific organic stabilizers can also contribute to increased water absorption in the blocks. This phenomenon is supported by Rimbarngaye et al. [11], who found that GA up to 6% with 2% OPC was not favourable for the blocks, all the blocks crumbled before the end of 24 hours of immersion. Ngowi [39] found an increase in water absorption for an increase in cow dung content.

Additionally, James et al. [40] found that adding Sugarcane Bagasse Ash (SBA) increased the water absorption of cement-stabilized soil blocks. Furthermore, Jannat et al. [41] demonstrated that the water absorption rate was increased when different residues were added to unfired earth blocks. The results indicate that the blocks produced with GBBP should not be used in a consistently wet environment without a protective coating.The dry density of the CSEBs is shown in Figure 14. The dry density of the CEBs stabilized with 2% OPC and 2% GBBP is slightly (0.55%) above the one of the blocks with 2% OPC. It is noticed that the use of more than 2% GBBP leads to a decrease in dry density by up to 10% at 6% GBBP content. As GBBP is less dense, its inclusion has reduced the compacity of the blocks. Various previous research works have found a decrease in dry density resulting from using some organic stabilizers.

Jonas et al. [42] found that as the quantity of diatomite in CEBs increased, its dry density was significantly reduced. The same was observed by Danso [43] with the inclusion of Pidiproof LW+ in earth blocks. However, all the blocks' dry densities are within the range (1500 to 2000 Kg/m³) recommended by Fetra Venny Riza et al. [44]. The addition of 2% GBBP has an insignificant effect on the dry density of the blocks; however, the increase in GBBP content leads to a decrease in the dry density of the blocks and obtention of lightweight blocks.

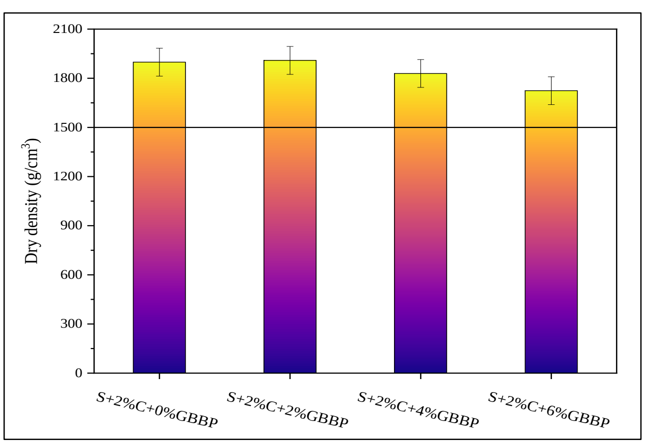

Fig. 14 Dry density of blocks stabilized with OPC and GBBP

3.4. Compressive Strength of the Blocks with OPC and GBBP

The evolution of the compressive strength is presented in Figure 15. The result shows an increase in compressive strength from 1.63 MPa for the blocks stabilized with 2% OPC to 2.46 MPa for the blocks stabilized with 2% OPC + 2% GBBP, representing a 33.74% increase. Above 2% of GBBP, the compressive strength decreases as GBBP content increases. Losini et al. [45] found that incorporating natural additives, such as fibres, leads to decreased compressive strength attributed to forming of porosity clusters. This is confirmed by Chindaprasirt [46], who noted a decline in compressive strength when adding more than 1% of fly ash latex. The highest value of dry compressive strength is obtained with the blocks stabilized with 2% OPC and 2% GBBP. This improvement might be due to the interaction between Silica Dioxide (SiO_2) and Calcium Oxide (CaO), the major constituents in laterite soil and GBBP.

According to Bonnaud et al. [47], the interaction of Calcium Oxide (CaO) and Silicon Dioxide (SiO_2) with Water (H_2O) leads to the formation of Calcium Silicate Hydrate (C-S-H) gel as shown in Equation 3, which is a critical step in the development of strength and durability of cementitious materials. This gel has a crucial function in binding the cement paste together, influenced by the presence of calcium ions within the C-S-H, while water aids in causing a separation or disjoining effect within the grain structure of C-S-H [47]

$$CaO+SiO_2+H_2O \rightarrow CaO.SiO_2.H_2O \text{ (C-S-H)} \quad (3)$$

Previous researchers found the same improvement, resulting in the formation of C-S-H with natural stabilizers like GA [11], GBBJ [15], and cow dung [48]. The blocks stabilized with 2% OPC cannot be utilized in construction due to their lower compressive strength (1.63 MPa), which falls below the minimum (2 MPa) recommended by Hugo Houben et al. [49] and several standards, including XP P 19-90 [20]. However, adding 2% GBBP with its increase in compressive strength (2.46 MPa) makes the blocks worthwhile in construction.

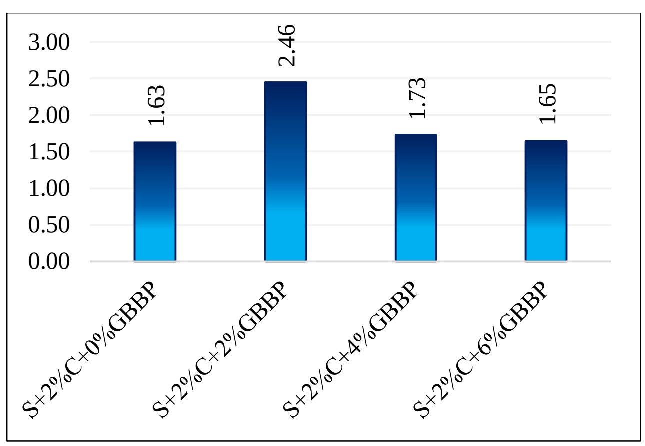

Fig. 15 Compressive strength of the blocks with OPC and GBBP

3.5. Durability Properties of the Blocks

According to Elenga et al. [50], CEBs' resistance to water erodibility simulates the effects of wind-driven rain. The results of the Erosion test by water spray test carried out according to NZS 4298 are presented in Figure 16; EI represents the Erodibility Index depending on the depth (D) of erosion (EI 1 for 0 mm/hr ≤ D < 20 mm/hr and EI 2 for 20 mm/hr ≤ D < 50 mm/hr).

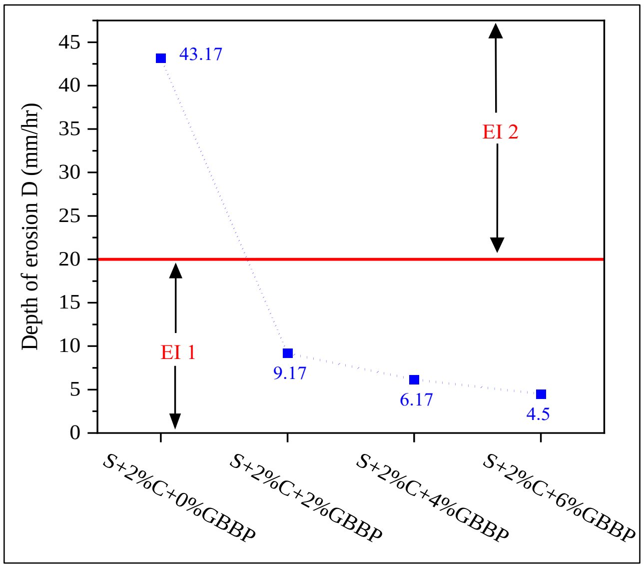

Fig. 16 Erosion test on the blocks with OPC and GBBP

The blocks stabilized with 2% OPC have an erosion depth of 43.17 mm/hr, 4.7 times higher than the ones stabilized with 2% OPC and 2% GBBP. The latter (2% OPC + 2% GBBP) resists 4.7 times erosion compared to the former (2% OPC). It is also noticed that the increase in GBBP content leads to an increase in erosion resistance.

For instance, the blocks stabilized with 2% OPC + 4% GBBP have a depth of erosion 32.71% lower than the one of 2% OPC + 2% GBBP and the blocks with 2% OPC + 6% GBBP have an erosion depth representing 27.06% decrease compared to the blocks with 2% OPC + 4% GBBP.

The results indicate that all blocks stabilized with GBBP are in the first pass (0 mm/hr ≤ D < 20 mm/hr), while blocks stabilized with 2% OPC alone are in the second pass (20 mm/hr ≤ D < 50 mm/hr). It can be concluded that GBBP is a good material for earth block resistance to water spray. This improvement in the water resistance of the blocks may be due to many phenomena. The formation of C-S-H leads to a higher cohesion between the grain of the soil and, therefore, less impact from water on pressure. Danso [22] states soil with high plasticity has lower erosion depth when stabilized. Millogo et al. [38] showed that silicate amine in some organic materials holds the soil particles when combined with kaolinite and quartz. Many other researchers found the same improvement in durability, especially against water spray with organic stabilizers and/or stabilizers having a mineralogy and chemical composition similar to GBBP [38, 51, 52].

4. Conclusion

This study assessed the effective use of GBBP as a stabilizer to make CEBs. Blocks were made with 2% OPC and different percentages of GBBP. Physical properties (dry density and water absorption), mechanical properties (compressive strength) and durability properties (Erosion resistance) were studied. The results show that:

- The blocks stabilized with 2% OPC + 2% GBBP have a compressive strength of 2.46 MPa, representing a 33.74% increase compared to the one stabilized with 2% OPC (1.63 MPa). Combining 2% OPC + 2% GBBP is optimal to achieve better mechanical, durability, and physical properties.
- An augmentation in GBBP content increases water absorption, making blocks manufactured with GBBP unsuitable for use in consistently wet environments without a protective coating.
- The dry density of the blocks decreased after 2% of GBBP; however, all the blocks have a dry density higher than the minimum required.
- The blocks stabilized with 2% OPC + 2% GBBP have an erosion depth 4.7 times lower than the ones with 2% OPC, showing that the blocks can be used as external walls exposed to rain without plastering.

The study findings suggest that employing earth blocks stabilized with 2% OPC and 2% GBBP presents a viable option for environmentally friendly, cost-effective construction practices.

However, higher water absorption indicates these blocks are unsuitable for use in consistently wet environments. Further study could assess the efficacy of GBBP in conjunction with alternative natural stabilizers and investigate the standalone performance of GBBP as an earth block stabilizer.

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