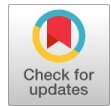


Performance Assessment of Coconut Shell Ash as Partial Replacement of Cement in Compressed Earth Blocks



Maman Oumarou Aboubacar, Joseph Ng'ang'a Thuo, Owayo Alphonse

Abstract: Earth construction represents the oldest recognized building technique employed by humanity. However, the use of earth resources in construction is limited due to their inherent weakness and durability issues. The two most widely utilised binders to enhance the characteristics of these blocks are cement and lime; however, these are expensive and sources of CO₂ emissions. This study aims to evaluate the effectiveness of coconut shell ash (CSA) as a replacement for cement in compressed earth blocks (CEBs). The microstructure test was conducted on laterite soil, cement, and CSA samples, and the blocks were tested in terms of dry density, water absorption, and compressive strength at 7, 14, and 28 days. The blocks were stabilised with various cement contents ranging from 0 to 8%. After testing, blocks with 6% cement showed good performances, taking into account the economic aspect. The optimal 6% cement was substituted with 2%, 4%, and 6% coconut shell ash (CSA) as replacements. CSA has improved the properties of CEBs. There was an increase in dry density and compressive strength, accompanied by a reduction in water absorption. The highest strength was recorded with blocks stabilised with 4% C + 2% CSA at 28 days. Based on the results of this study, an optimum of 2% CSA can be recommended as a substitute for cement in making CEBs.

Keywords: Dry density, Compressed Earth Blocks, Coconut Shell ash, Compressive strength, Water Absorption.

I. INTRODUCTION

Building with earth is the earliest known construction method to humanity [1]. Nowadays, earth-based building is a viable option because it's less expensive, more environmentally friendly, and offers higher energy efficiency, thereby supporting sustainable development. Moreover, structures made from

Earth provides effective thermal and acoustic insulation in housing [2]. They also have the potential to assist in maintaining indoor humidity levels [3, 4]. However, these materials have low strength and durability, which limit their

use in construction [5, 6]. Soil stabilization involves enhancing the characteristics of natural soil using a particular method and continues to be investigated in the building sector. Studies on improving the qualities of soil are still using this technique [7]. The two most common binders used to stabilize CEBs are cement and lime [8]. Although numerous studies have suggested that these inorganic binders enhance the performance of CEBs, they are linked to production procedures that significantly increase industrial CO₂ emissions [9, 10]. It has been suggested that natural biopolymers be used to stabilise soil, thereby mitigating the harmful environmental effects of binder production and promoting the use of sustainable building materials.

The coconut tree, commonly known as the coconut palm, grows on the coasts of many countries [11]. These trees are a key part of the regional agricultural systems of Kenya, where they have been grown for many years along the country's coast [12]. After the coconut meat was removed, the shells remained as waste. While they have various uses in many tropical regions, a substantial quantity is still disposed of in the environment, rendering them among the prevalent forms of agricultural and industrial byproducts. The use of waste in the construction industry has social, economic and environmental benefits [2, 13, 14].

Additionally, coconut shell ash exhibits good pozzolanic properties, making it suitable for use as a cement replacement. It has been reported that coconut shell ash (CSA) has the potential to be one of the most effective waste materials for reinforcing soil [13]. According to [15], CSA had a significant impact on the clay-CSA mixture. Therefore, this study aimed to assess the performance of CSA as a partial substitute for cement in stabilising compressed earth blocks (CEBs).

II. LITERATURE REVIEW

The effectiveness of cement stabilization was attributed to its enhanced strength and durability, as well as the readily available nature of cement [2]. It was reported that using lime up to 30% in place of cement can also have advantages [16].

However, there is a growing preference for sustainable alternative cementitious materials due to the substantial carbon dioxide emissions associated with traditional binders. [17].

The waste from agriculture varies by country, depending on the prevalent crops, such as coconut husks, sugarcane residue, and oil palm fruit residue. These wastes are utilized to enhance soil block properties in different nations, attracting significant attention as alternative building materials in recent years [18]. Previous

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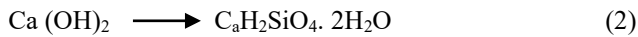
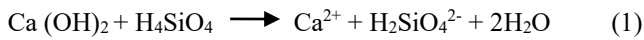
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studies have shown the suitability of CSA as a cement substitute due to its pozzolanic properties. The presence of a considerable quantity of silica in CSA indicated its cementitious properties, making it a viable alternative to Ordinary Portland cement (OPC) [19].

Therefore, high SiO₂ content reacts with Ca(OH)₂ in the cement to form calcium silicate hydrate (CSH) [17]. The effect of cement with the addition of CSA in soil is given by equations (1) and (2):



A study by [19], concluded that 10% cement substitution in CSA is an effective pozzolan that doesn't reduce concrete's compressive strength or sulphate attack resistance. It was also recommended that when making sandcrete blocks, 10% CSA substitution can be taken into consideration to produce higher compressive strength, lower absorption, and less sorptivity [20]. According to [21]. The addition of 10% CSA was the most suitable value for producing eco-friendly, cost-effective alternative cement blocks, as indicated by the test results on the properties of the cement blocks.

In addition, burned clay bricks containing 2% CSA revealed improved properties. The results showed ideal performance with an increase of 8% in compressive strength, a reduction of 6% in water absorption and 4% in density when compared to 0% CSA [11] [16]. The study investigated the effect of coconut shell ash on lime-stabilised laterite, and the results showed that CSA is an essential additive in increasing the stability of lime-stabilised soil. Furthermore, the inclusion of CSA in the lime-stabilised soils resulted in an increase in the CBR (California Bearing Ratio) and UCS (Unconfined Compressive Strength) values. [13] Has also demonstrated the effectiveness of CSA in soil stabilization.

III. MATERIALS AND METHODS

A. Materials

This research was conducted at the Jomo Kenyatta University of Agriculture and Technology (JKUAT) Civil Engineering Laboratory in Juja, Kenya. The materials used in this study are laterite soil, cement, and coconut shell ash (CSA).

Laterite soil was obtained from JKUAT and sieved through a 5 mm sieve. Coconut shells were obtained from Mombasa, a coastal region of Kenya. The cement was CEM IV/32.5R pozzolan cement adhering to Kenyan standards (KS EAS 18-1: 2001). The materials were mixed using tap water.

B. Methods

i. Burning of Coconut Shell Ash

After collecting the waste materials, all fibres were removed from the shells before being subjected to open-air burning. Once the shells were wholly burned, the resulting charcoal was allowed to cool for at least 24 hours. A ball mill machine was used to grind this charcoal into powder. The ash from the grading was heated to 650°C for four hours in a furnace to enhance its characteristics and make it suitable as a pozzolanic material, as specified by ASTM standards. After

calcination, the ash is allowed to cool and then sieved through a 0.3 mm sieve, as shown in Fig. 1. To examine the chemical characteristics of the materials, the X-ray fluorescence (XRF) method was used to determine the main chemical content in the cement, CSA, and laterite soil. Table 1 shows the chemical composition of cement and CSA, while the oxides in soil are given in Table 2.



[Fig.1: Burning of Coconut Shells]

Table 1: Chemical Composition of Cement and CSA

Composition	OPC (%)	CSA (%)
SiO ₂	45.65	44.75
AL ₂ O ₃	8.77	14.24
Fe ₂ O ₃	3.69	12.5
CaO	36.29	6.39
MgO	-	8.23
Na ₂ O	-	0.49
K ₂ O	2.74	2.86
P ₂ O ₅	0.22	5.66
SO ₃	1.86	0.87
LoI	0.59	7.34

Table 2: Chemical Composition of Soil

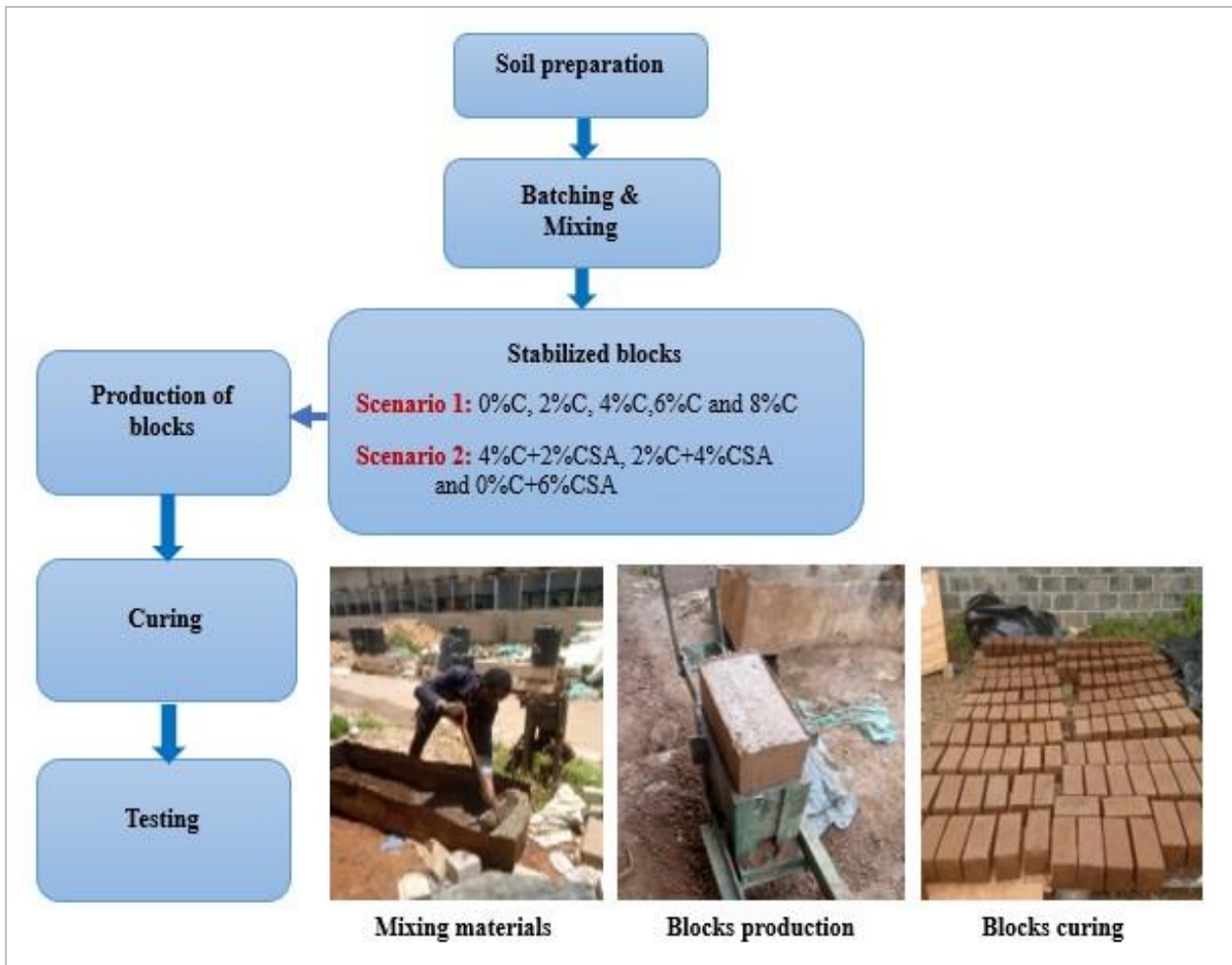
Composition	Percentage (%)
Al ₂ O ₃	15.886
SiO ₂	61.538
Cl	0.114
K ₂ O	1.01
CaO	0.429
Ti	1.662
Mn	2.504
Fe ₂ O ₃	16.294
Zn	0.016

ii. Blocks production

The process of making blocks involved a few steps. First, the laterite soil from the field had to be sieved through a 5 mm sieve and taken to the laboratory. The second was the preparation of the mix. The soil was mixed with various proportions of stabilizers. After the dry mix was completed, water was added to achieve the ideal moisture content determined by the compaction test. In the third step, the blocks were made using a manual press machine. The machine is lubricated with flowing oil, and a uniform mixture is compressed into the mould to shape the blocks. The curing of the blocks constituted the final process. The blocks were covered with polyethene for 7 days and then air-dried until testing. The experimental work is divided into two scenarios. Firstly, the determination of the ideal cement content to stabilise blocks was examined by measuring the dry density,

water absorption, and compressive strength of the blocks. CEBs were stabilized with 2%, 4%, 6% and 8% cement by weight of laterite. Secondly, the replacement of the optimum

cement content found with CSA was noted. The optimum 6% cement was replaced with 2%, 4% and 6% CSA. Fig. 2 shows the process of blocks production.

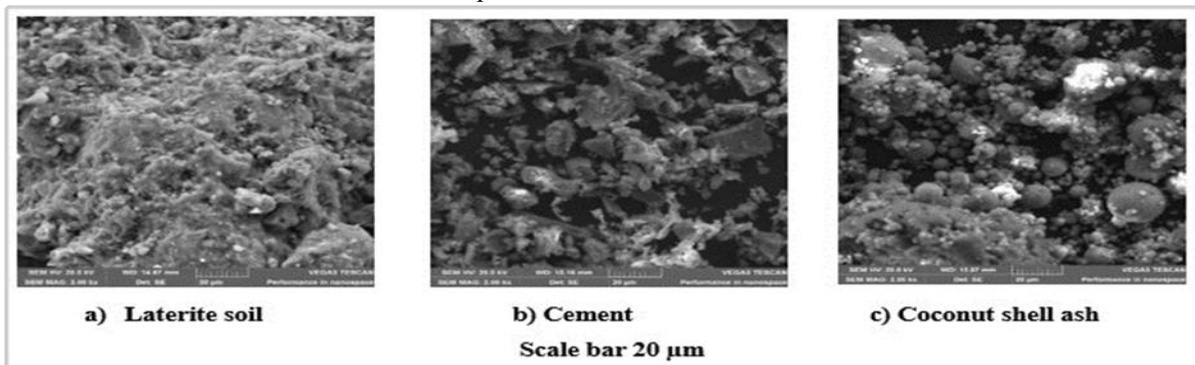


[Fig.2: Process of Blocks Production]

iii. SEM Analysis

A Scanning Electron Microscopy (SEM) test was performed on the laterite, cement, and CSA samples. This

method allowed the analysis of the microstructure of the materials used in this study. Fig. 3 shows the SEM images of laterite soil, cement, and CSA.



[Fig.3: SEM Images of Laterite Soil, Cement and CSA]

iv. Determination of the dry density

According to BS EN 771-1, the dry density of CEBs was measured at 7, 14, and 28 days. The process of determining the dry density of blocks is illustrated in Fig. 4. The blocks are weighed, dried, and then reweighed according to a standard procedure. The dry density of CEB is determined using Equation 3:

$$Y_d = \frac{W_d}{V} \tag{3}$$

Where: γ_d is the dry density (kg/m^3), W_d is the dry weight (kg), and V is the volume of block (m^3).



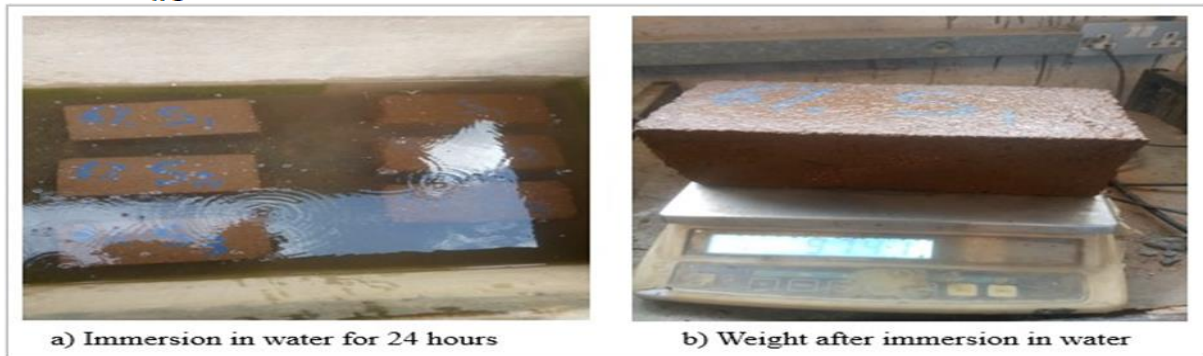
[Fig.4: Determination of Dry Density]

v. Water absorption test

The water absorption test was conducted by British Standard 1377. The blocks were oven-dried for 24 hours at 105 °C ± 5 °C in an oven and weighed (Wb). The blocks were then submerged in water for 24 hours and subsequently weighed again (Wa). Equation 4 is used to get the percentage of water absorption:

$$Mc = \frac{(Wa - Wb)}{Wb} \times 100 \quad (4)$$

where Mc is the water absorption rate (%), Wa is the weight of the block after immersion, and Wb is the weight of the block before immersion. The steps involved in conducting the water absorption test are shown in Fig. 5.



[Fig.5: Water Absorption Test Procedure]

vi. Compressive Strength Test

The compressive strength test was conducted to evaluate the mechanical properties of the compressed earth blocks (CEBs). The test was performed on the blocks after 7, 14, and 28 days, by the British Standard (BS EN 772-1, 2011). The Universal Testing Machine was used for the experiment

(UTM) as shown in Fig. 6. The compressive strength was obtained using Equation 5:

$$\sigma = \frac{F}{S} \quad (5)$$

where σ was the strength; F was the maximum load; and S was the loaded area.



[Fig.6: Compressive Strength Test]

IV. RESULTS AND DISCUSSION

A. SEM Analysis

SEM results showed that the laterite had a rough surface and a smaller size. Cement had the most prominent pores and

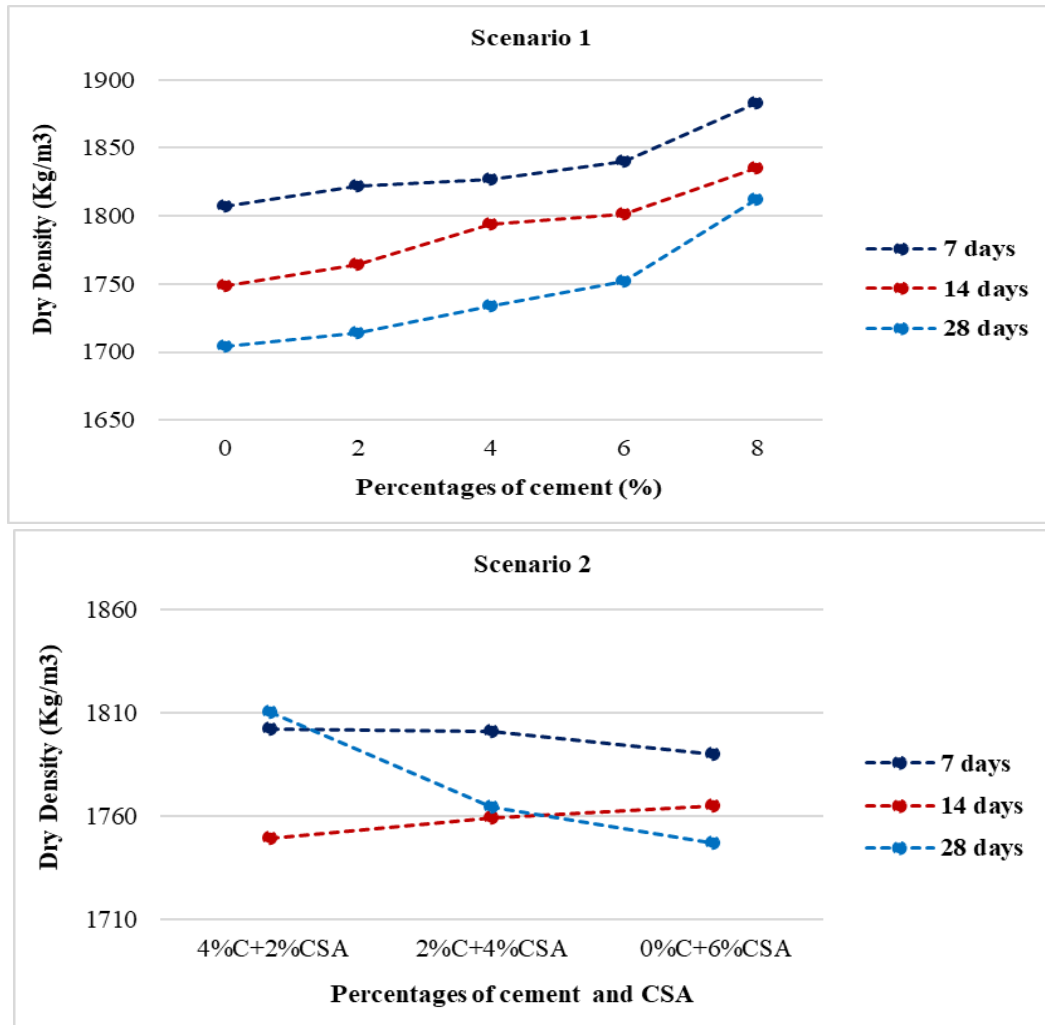
size, while CSA had a spherical shape with large pores. [22] It was also stated that some CSA particles have a spherical shape, while most particles exhibit irregular shapes. Additionally, the physical and chemical properties of CSA

are influenced by its origin and the production process used. A practical method can enhance various properties, including particle size, particle shape, and the presence of reactive oxides, which are crucial for pozzolanic reactions. It can be seen that from the loss of ignition results, CSA had a higher carbon content compared to cement. [23] noted that Carbon particles have a greater capacity to absorb water from concrete mixes, thereby diminishing the amount of free water present.

B. Dry density

The dry density testing is performed to evaluate whether the stabilizer content affects the dry density of the blocks. It has been demonstrated that the density and cement content are the main factors influencing the strength of the blocks [24]. The dry density values of CEBs for each mix at the curing phases are displayed in Fig. 7.

These values ranged from 1704 kg/m³ to 1883 kg/m³ for all blocks. It was found that a higher cement content resulted in a higher block density. This aligned with similar findings shown in prior research focused on soil stabilization using cement [25].



[Fig.7: Dry Density of CEBs]

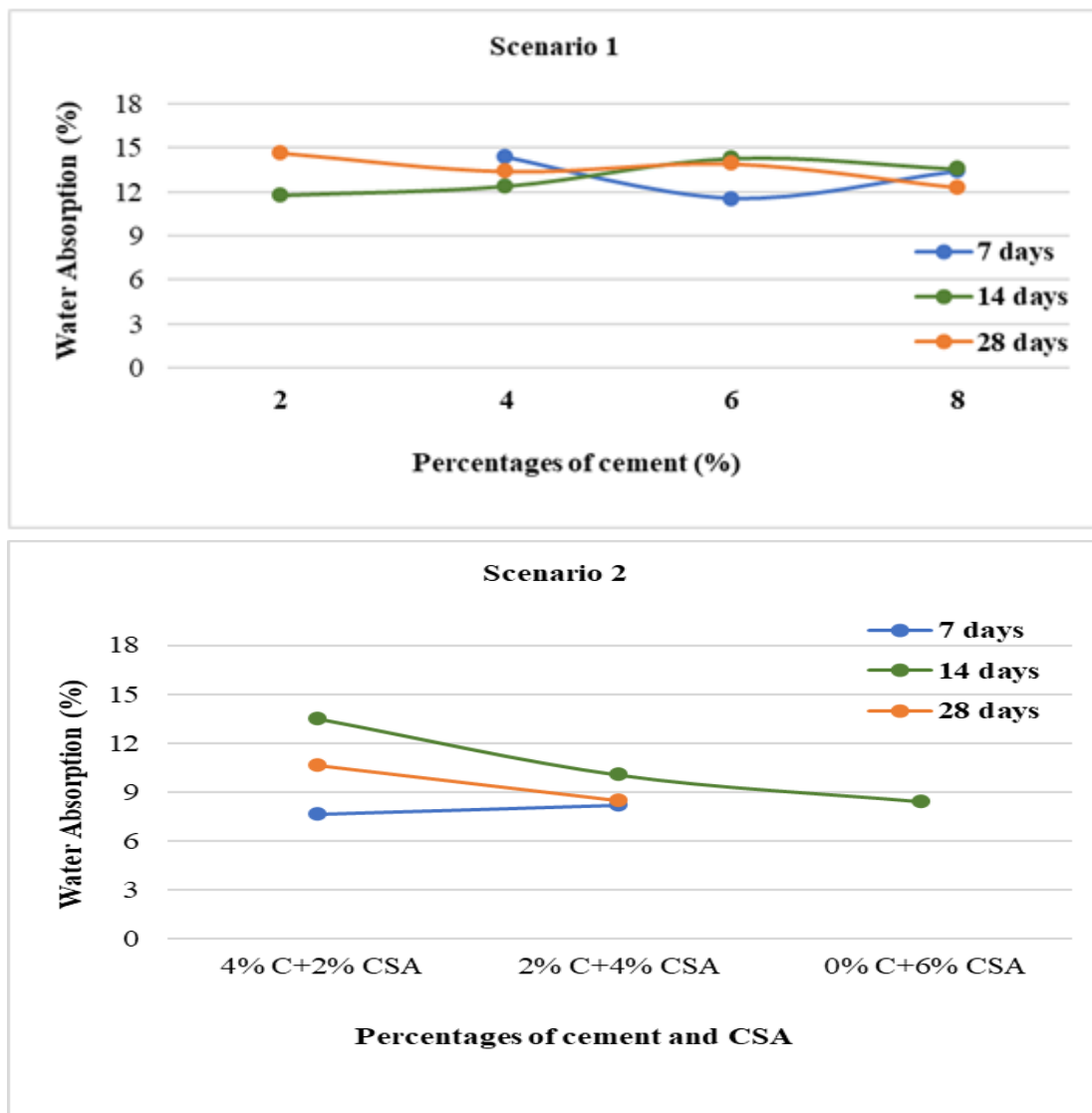
After replacing cement with CSA there was an increase in dry density compared to control blocks with 6% cement up to 28 days. The rise in dry density was due to CSA particles filling voids and pores, thereby increasing the overall mass of the blocks. The highest dry density value was obtained for blocks stabilised with 4% C + 2% CSA, and the lowest value was obtained with 0% C + 6% CSA at 28 days. The dry density of CEBs increased by 3% with the addition of 2% CSA. However, adding 6% CSA to the soil resulted in a decrease in dry density compared to the addition of 6% C. The lower density of CSA can explain this in comparison to the soil. It reported that the density of fired clay brick gradually decreased with increasing CSA content [11, 15].

In general, the dry density properties of all the CEBs aligned with the findings of [26], which established the appropriate dry density range for earthen blocks as being between 1500 kg/m³ and 2000 kg/m³.

C. Water absorption

The evaluation of water absorption is essential in assessing the stability of earthen blocks in moist environments, indicating the resistance of blocks after immersion [27]. The findings of water absorption tests conducted at 7, 14, and 28 days for each mix are shown in Fig. 8.





[Fig.8: Water Absorption of CEBs]

In the first scenario, the unstabilized blocks did not withstand being completely submerged in water for 24 hours at any age. These results indicated that CEBs without stabilisers were unstable in water, making it impossible to determine their water absorption. In addition, CEBs stabilized with 2% cement were not stable after removed from water at 7 days. However, all blocks stabilized with cement resisted immersion in water at different ages with water absorption levels below the limit value of 15% established by the Kenyan standard. After 28 days, the blocks contained 2% cement had a maximum water absorption of 15%, whereas the blocks stabilized with 8% cement had the lowest value of 12%. The addition of cement for stabilization has enhanced the water absorption characteristics of CEBs by forming bonds among soil particles, thereby reducing the voids between them [28].

In the second scenario, where the optimum cement was replaced with CSA, the water absorption of CEBs stabilised with (0%C+6%CSA) was only satisfactory at 14 days. However, the water absorption was improved with the addition of CSA for the others blocks. It was noted that the CEBs' water absorption decreased as the cement content decreased, with an increase in CSA through replacement. The water absorption values ranged from 8 to 11% at 7, 14, and 28

days. Thus, CSA as cement substitute reduced the water absorption of CEBs.

D. Compressive strength

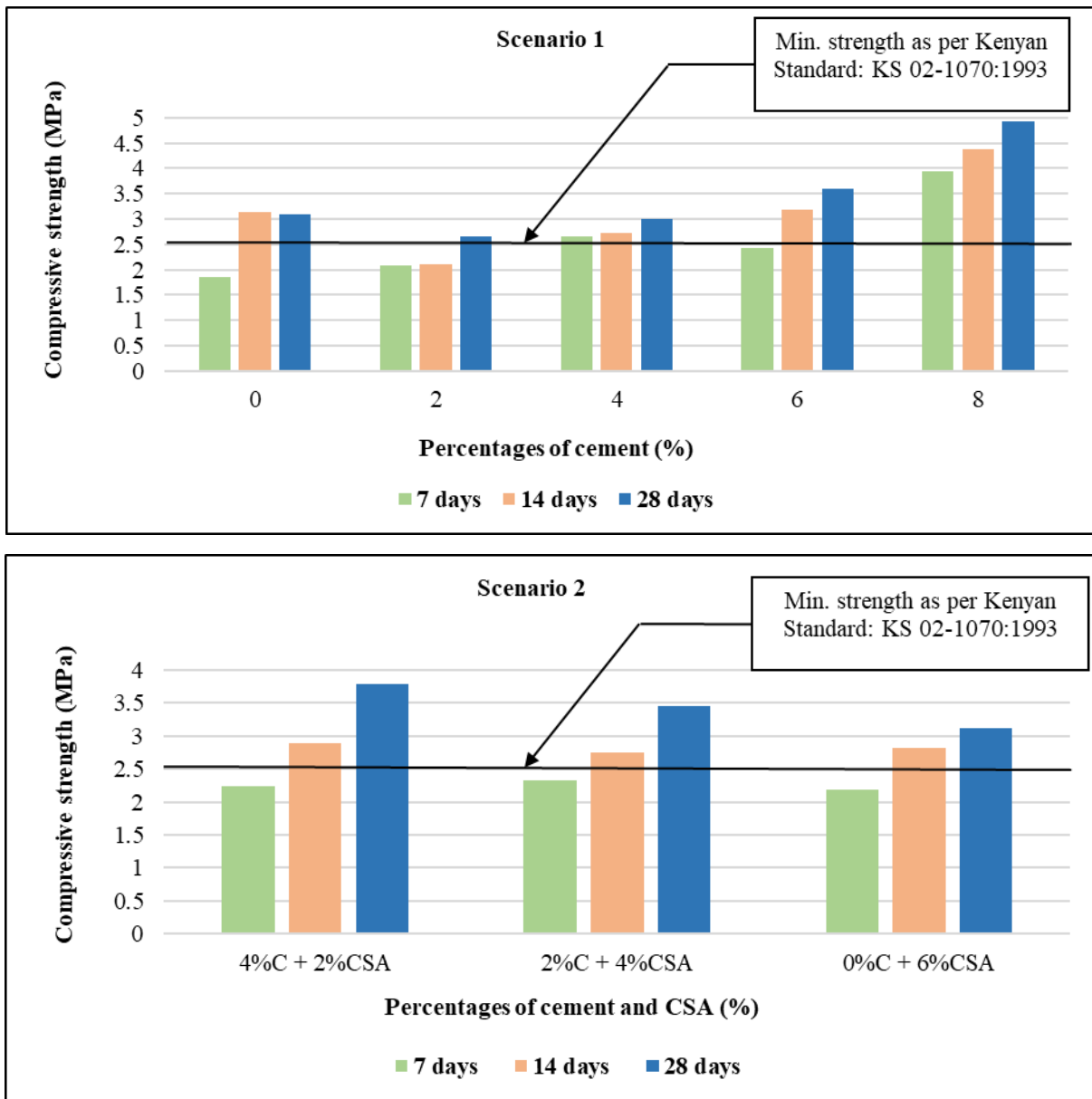
The mechanical qualities of CEBs are evaluated based on several factors, one of which is compressive strength. [29]. A minimum compressive strength of 2.5 MPa is required for earth blocks according to the Kenyan standard (KS 02-1070: 1993).

Fig. 9 displayed the values obtained from the compressive strength tests. At 7, 14, and 28 days, the compressive strength values of the unstabilized blocks ranged from 2 to 3 MPa. The high value was obtained at 14 days for the un-stabilized blocks. A similar observation was made in the study of [30], where a decrease in strength was noted for un-stabilized blocks after 14 days.

After 28 days, the compressive strength of CEBs with cement contents of 2%, 4%, 6%, and 8% ranged from 3 to 5 MPa. It was found that the compressive strength of all CEBs increased with cement content and curing time. The CEBs stabilised with cement demonstrated enhanced compressive strength, consistent with the findings of [4, 31]. Additionally, blocks

stabilised with 6% cement showed good performance. The compressive strength of these blocks was 3.59 MPa at 28 days, which exceeds the minimum recommended strength of 2.5 MPa as specified in the Kenyan standard. For economic

reasons and to reduce cement production, the optimum 6% cement content was found to be the most suitable for making CEBs.



[Fig.9: Compressive Strength of CEBs]

After the optimum cement was identified for the stabilisation of CEBs, the control blocks were designated as (6%C+0%CSA). Then the blocks were stabilized with (4%C+2%CSA), (2%C+4%CSA) and (0%C+6%CSA).

The compressive strength of these blocks was less than 2.5 MPa at 7 days. This phenomenon was due to the slow pozzolanic reaction of the combined binders. Blocks stabilized with cement alone gain increased strength early in the ageing process due to the rapid hydration of cement, allowing the creation of cementitious compounds within the blocks [32]. After 14 days, there was a rise in strength up to 3 MPa for the three combinations. At 28 days, the maximum compressive strengths of 3.78, 3.46, and 3.12 were obtained for the blocks, respectively. Blocks stabilised with (4C+2 % CSA) exhibited a 5% increase compared to the control blocks. However, compressive strength of the remaining blocks increased with age and decreased with the addition of

CSA content. This finding aligns with previous studies on fired bricks, where the compressive strength initially rose to 2% and then declined with an increase in CSA [11, 15]. In addition, this outcome aligns with the findings of [28], which demonstrated that increasing the amount of rice husk ash reduces the compressive strength. This means that the increase in ash did not facilitate a good pozzolanic process and has reduced the strength by occupying space in the soil [30]. It should be noted that the stabilisation of CEBs with (4%C+2CSA) enhanced their compressive strength more than others. Beyond 2% of CSA, the CEBs' compressive strength dropped. The blocks stabilised with (4%C+2%CSA) exhibited a compressive strength of 3.78 MPa at 28 days, indicating that a 2% replacement of cement by CSA is the optimum amount for replacement. As a result, this

value is 51% higher than the minimum compressive strength recommended by the Kenyan standard for earth blocks.

E. Limitations of the study

The temperature can influence the pozzolanic characteristics of coconut shell ash. In this research, the temperature for burning the ash was 650°C. Hence, it is crucial to consider the optimal temperature for generating ash with desirable pozzolanic properties. Scanning Electron Microscopy was performed on the samples separately. Further studies should conduct the SEM test on the materials mix to understand the real pattern of binder's microstructure in the blocks.

V. CONCLUSION

Based on this study, it can be concluded that CSA is an effective pozzolanic material and is suitable for partial substitution of cement in CEBs. The findings indicated that replacing cement with CSA improved the properties of CEBs such as dry density, water absorption and compressive strength. The following conclusions can be made:

- SEM analysis shown that the laterite had a rough surface and a smaller size. Cement had the most prominent pores and size, while CSA had a spherical shape with large pores.
- The addition of cement in soil increased the dry density and enhanced the water absorption of CEBs.
- The compressive strength of CEBs increased with the increase in cement content. An optimal cement content of 6% was considered in making CEBs with cement alone, resulting in a compressive strength of 3.59 MPa at 28 days.
- After replacing cement with CSA, the results showed good performances for the blocks stabilised with 4%C+2%CSA. At 28 days, an increase of 5% in compressive strength, a 6% increase in dry density, and a 3% reduction in water absorption were observed compared to the control blocks.
- An optimal of 2%CSA was recommended as a substitute for cement in making CEBs. Based on the findings of this research, blocks stabilised with a combination of 4% C and 2% CSA could be suitable for potential utilisation in construction.

The use of CSA can help mitigate environmental waste. CSA is an eco-friendly, low-carbon material that is cost-effective, with the potential to contribute to the construction of sustainable and affordable housing.

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DECLARATION STATEMENT

After aggregating input from all authors, I must verify the accuracy of the following information as the article's author.

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- **Funding Support:** This article has not been funded by any organizations or agencies. This independence

ensures that the research is conducted with objectivity and without any external influence.

- **Ethical Approval and Consent to Participate:** The content of this article does not necessitate ethical approval or consent to participate with supporting documentation.
- **Data Access Statement and Material Availability:** The adequate resources of this article are publicly accessible.
- **Author's Contributions:** The authorship of this article is contributed equally to all participating individuals.

REFERENCES

1. O. Ige and H. Danso, "Physico-mechanical and thermal gravimetric analysis of adobe masonry units reinforced with plantain pseudo-stem fibres for sustainable construction," *Construction and Building Materials*, vol. 273, p. 121686, 2021. <http://dx.doi.org/10.1016/j.conbuildmat.2020.121686>
2. D. C. Sekhar and S. Nayak, "Utilization of granulated blast furnace slag and cement in the manufacture of compressed stabilized earth blocks," *Construction and Building Materials*, vol. 166, pp. 531-536, 2018, doi: 10.1016/j.conbuildmat.2018.01.125. <http://dx.doi.org/10.1016/j.conbuildmat.2018.01.125>
3. S. H. Sameh, "Promoting earth architecture as a sustainable construction technique in Egypt," *Journal of Cleaner Production*, vol. 65, pp. 362-373, 2014. <https://doi.org/10.1016/j.jclepro.2013.08.046>
4. L. Zhang, A. Gustavsen, B. P. Jelle, L. Yang, T. Gao, and Y. Wang, "Thermal conductivity of cement stabilized earth blocks," *Construction and Building Materials*, vol. 151, pp. 504-511, 2017. <http://dx.doi.org/10.1016/j.conbuildmat.2017.06.047>
5. E.A. Chaibeddra, "Performance of Compressed Stabilised Earth Blocks in sulphated medium," *Journal of Building Engineering*, vol. 25, 2019, <http://doi.org/10.1016/j.jobbe.2019.100814>
6. Danso, "Performance characteristics of enhanced soil blocks: a quantitative review." *Building Research & Information* 43.2 (2015): 253-262., 2015. <https://doi.org/10.1080/09613218.2014.933293>
7. H. Danso and D. Manu, "Influence of coconut fibres and lime on the properties of soil-cement mortar," *Case Studies in Construction Materials*, vol. 12, 2020, <http://doi.org/10.1016/j.cscm.2019.e00316>
8. R. Bahar, M. Benazzoug, and S. Kenai, "Performance of compacted cement-stabilised soil," *Cement and Concrete Composites*, vol. 26, no. 7, pp. 811-820, 2004, <http://doi.org/10.1016/j.cemconcomp.2004.01.003>
9. Y. Shan, Z. Liu, and D. Guan, "CO2 emissions from China's lime industry," *Applied Energy*, vol. 166, pp. 245-252, 2016, <http://doi.org/10.1016/j.apenergy.2015.04.091>
10. J. Zhang, G. Liu, B. Chen, D. Song, J. Qi, and X. Liu, "Analysis of CO2 Emission for the Cement Manufacturing with Alternative Raw Materials: A LCA-based Framework," *Energy Procedia*, vol. 61, pp. 2541-2545, 2014, <http://doi.org/10.1016/j.egypro.2014.12.041>
11. B. W. Isah, "Effect of coconut shell ash on properties of fired clay brick," *Journal of Civil Engineering and Environmental Technology*, vol. 1, no. 6, pp. 7-11, 2014. https://www.researchgate.net/publication/328738919_Effect_of_Coconut_Shell_Ash_on_Properties_of_Fired_Clay_Brick
12. F. Pole, B. Nguma, and N. Mohammed, "Status of coconut farming and the associated challenges in Kenya," *CORD*, vol. 30, no. 2, pp. 11-11, 2014. <http://dx.doi.org/10.37833/cord.v30i2.79>
13. S. Prasanna and P. Kumar, "Soil reinforcement using coconut shell ash: A case study of indian soil," *Journal of Civil Engineering and Construction*, vol. 6, no. 2, pp. 73-78, 2017. https://www.researchgate.net/publication/347489154_Soil_Reinforcement_Using_Coconut_Shell_Ash_A_Case_Study_of_Indian_Soil
14. G. Subashi De Silva and S. Singhapura, "STRUCTURAL PERFORMANCES OF SOLID MASONRY BLOCKS MADE USING CRUSHED COCONUT SHELL AGGREGATES," https://www.researchgate.net/publication/326622491_STRUCTUREL_PERFORMANCES_OF_SOLID_MASONRY_BLOCKS_MADE

USING CRUSHED COCONUT SHELL AGGREGATES

15. P. R. Fernando, "Mechanical and physical properties of fired clay brick partial doped with coconut shell ash," *J Energy Nat Resour*, vol. 6, no. 5, pp. 58-63, 2017. <http://dx.doi.org/10.11648/j.jenr.20170605.11>
16. N. Segun and E. Oluymisi, "Effects of coconut shell ash on lime-stabilized lateritic soil," *MOJ Civil Engineering*, vol. 2, no. 4, pp. 140-143, 2017. <http://dx.doi.org/10.15406/mojce.2017.02.00042>
17. V. Charitha, V. Athira, V. Jittin, A. Bahurudeen, and P. Nanthagopalan, "Use of different agro-waste ashes in concrete for effective upcycling of locally available resources," *Construction and Building Materials*, vol. 285, p. 122851, 2021. <https://doi.org/10.1016/j.conbuildmat.2021.122851>
18. H. Danso, D. B. Martinson, M. Ali, and J. B. Williams, "Physical, mechanical and durability properties of soil building blocks reinforced with natural fibres," *Construction and Building Materials*, vol. 101, pp. 797-809, 2015. <http://doi.org/10.1016/j.conbuildmat.2015.10.069>
19. M. A. Adajar, J. Galupino, C. Frianeza, J. F. Aguilon, J. B. Sy, and P. A. Tan, "Compressive strength and durability of concrete with coconut shell ash as cement replacement," *GEOMATE Journal*, vol. 18, no. 70, pp. 183-190, 2020. <http://dx.doi.org/10.21660/2020.70.9132>
20. I. C. Christopher, O. I. Ndubuisi, N. D. Chimobi, O. V. Arinze, and J. N. Ezema, "Partial replacement of cement with coconut shell ash in sandcrete block," *Research Journal of Applied Sciences, Engineering and Technology*, vol. 15, no. 6, pp. 206-211, 2018. <http://dx.doi.org/10.19026/rjaset.15.5859>
21. P. R. Fernando, S. M. Aazir, N. Pushpalatha, N. Puvanathan, and V. H. T. Nishantha, "The performance of the low-cost masonry cement blocks as a partial substitution of coconut shell ash," *American Journal of Mechanical and Industrial Engineering*, vol. 2, no. 6, pp. 212-220, 2017. <http://dx.doi.org/10.11648/j.ajmie.20170206.12>
22. P. Madakson, D. Yawas, and A. Apasi, "Characterization of coconut shell ash for potential utilization in metal matrix composites for automotive applications," *International journal of engineering science and technology*, vol. 4, no. 3, pp. 1190-1198, 2012. https://www.researchgate.net/publication/267227175_Characterization_of_Coconut_Shell_Ash_for_Potential_Utilization_in_Metal_Matrix_Composites_for_Automotive_Applications
23. K. S. Ranatunga, E. del Rey Castillo, and C. L. Toma, "Evaluation of the optimal concrete mix design with coconut shell ash as a partial cement replacement," *Construction and Building Materials*, vol. 401, p. 132978, 2023. <https://eprints.kingston.ac.uk/id/eprint/54334/1/Ranatunga-K-54334-VoR.pdf>
24. K. Heathcote, "Compressive strength of cement stabilized pressed earth blocks: strength of cement stabilized pressed earth blocks depends on cement content and compacted density—simple formula presented to predict strength based on variables," *Building Research and Information*, vol. 19, no. 2, pp. 101-105, 1991. <http://dx.doi.org/10.1016/j.conbuildmat.2005.08.021>
25. J. Alex and K. Ayikkara, "Stabilization of lateritic soil for masonry applications," *Magazine of Civil Engineering*, no. 1 (101), p. 10109, 2021. <https://doi.org/10.34910/MCE.101.9>
26. F. V. Riza, I. A. Rahman, and A. M. A. Zaidi, "A brief review of compressed stabilized earth brick (CSEB)," in 2010 International Conference on Science and Social Research (CSSR 2010), 2010: IEEE, pp. 999-1004. <http://dx.doi.org/10.1109/CSSR.2010.5773936>
27. M. M. Salih, A. I. Osofero, and M. S. Imbabi, "Critical review of recent development in fibre reinforced adobe bricks for sustainable construction," *Frontiers of Structural and Civil Engineering*, vol. 14, no. 4, pp. 839-854, 2020. <http://dx.doi.org/10.1007/s11709-020-0630-7>
28. S. I. Fundi, J. W. Kaluli, and J. Kinuthia, "Performance of interlocking laterite soil block walls under static loading," *Construction and Building Materials*, vol. 171, pp. 75-82, 2018. <http://doi.org/10.1016/j.conbuildmat.2018.03.115>
29. I. Dabakuyo, R. N. Mutuku, and R. O. Onchiri, "Mechanical Properties of Compressed Earth Block Stabilized with Sugarcane Molasses and Metakaolin-Based Geopolymer," *Civil Engineering Journal*, vol. 8, no. 04, 2022. <https://www.civilejournal.org/index.php/cej/article/view/3416>
30. Mbakbaye et al, "Potential use of Shea nutshell ash as partial replacement of Portland cement in interlocking earth blocks.," *International Journal of Advanced Technology and Engineering Exploration*, 9(90), 687., vol. 9, no. 90, 2022. <http://doi.org/10.19101/ijatee.2021.875482>
31. N. Zakham et al., "The effect of cement content on the thermo-mechanical performance of compressed earth block,"

- International Review of Civil Engineering (IRECE), vol. 11, no. 6, pp. 249-254, 2020. <http://dx.doi.org/10.15866/irece.v11i6.17438>
32. H. B. Nagaraj, M. V. Sravan, T. G. Arun, and K. S. Jagadish, "Role of lime with cement in long-term strength of Compressed Stabilized Earth Blocks," *International Journal of Sustainable Built Environment*, vol. 3, no. 1, pp. 54-61, 2014. <http://doi.org/10.1016/j.ijse.2014.03.001>

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