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PERFORMANCE ASSESSMENT OF COCONUT SHELL ASH AS PARTIAL REPLACEMENT OF CEMENT IN COMPRESSED EARTH BLOCKS

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Abstract

Earth construction represents the oldest recognized building technique employed by humanity. However, the poor strength and durability of earth blocks limit their use in construction. The two most widely utilized binders to improve the characteristics of these blocks are cement and lime but these are expensive and sources of CO_2 emissions. The objective of this study was to assess the performance of coconut shell ash (CSA) as partial replacement of 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 stabilized with various cement content from 0 to 8%. After testing blocks with 6% cement showed good performances taken into account the economic aspect. The substitute of cement was carried out by replacing the optimum 6% cement with 2%, 4% and 6% of coconut shell ash (CSA). CSA has improved the dry density, water absorption and compressive strength of CEBs. The highest strength was recorded for blocks stabilized with 4%C+2%CSA at 28 days. Based on the results of this study, an optimum of 2%CSA can be recommended as substitute for cement in making CEBs.

Keywords: Dry Density; Compressed Earth Blocks; Compressive Strength; Coconut Shell Ash; Water Absorption.

1. INTRODUCTION

Building with earth is the earliest known construction method to humanity [1]. Nowadays, earth-based building is a good option because it's less expensive, more environmentally friendly, and has higher energy efficiency, supporting the sustainable development. Moreover, structures made from earth provide effective thermal and acoustic insulation in housing [2]. They have also 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 is 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 greatly

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increase industrial CO_2 emissions [9, 10]. It has been suggested that natural biopolymers be used in stabilizing soil in order to mitigate the harmful effects that the production of these binders has on the environment and promote the use of environmentally friendly construction 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 wastes. While they have various uses in many tropical regions, a substantial quantity is still disposed in the environment, rendering them among the prevalent forms of agricultural and industrial byproducts. The use of industrial wastes in construction activities offers social, economic, and environmental advantages [2, 13, 14].

In addition, coconut shell ash has good pozzolanic qualities, which makes it suitable for 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 at assessing the performance of CSA as partial alternative to cement in stabilizing compressed earth blocks (CEBs).

2. 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 preference for sustainable alternative cementitious materials due to the substantial carbon dioxide emissions linked to traditional binders [17]. The wastes from agriculture vary by country based on 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 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]. As a results calcium silicate hydrate (CSH) is produced by a reaction between a high concentration of SiO_2 and with $Ca(OH)_2$ in cement [17].The effect of CSA combined with cement in soil is given by Equation (1) and (2):

$$Ca\,(OH)_2 + H_4SiO_4 \longrightarrow Ca^{2+} + H_2SiO_4^{2-} + 2H_2O \quad (1)$$

$$Ca\,(OH)_2 \longrightarrow C_aH_2SiO_4.\ 2H_2O \quad (2)$$

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, a 10% substitution can be taken into consideration in order 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 making eco-friendly, cost-effective alternative cement blocks as showed the tests results on the properties of cement blocks. In addition, burned clay bricks containing 2%CSA revealed improved properties. The results showed ideal performance with an increase of 8% in

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compressive strength, a reduction of 6% in water absorption and 4% in density when compared to 0%CSA [11]. The influence of coconut shell ash on laterite soil stabilized with lime was investigated by [16], and the findings indicated that CSA was a significant supplement to enhance the stabilizing of laterite soil using lime. Furthermore, the inclusion of CSA in the lime-stabilized soils led to an augmentation of the CBR (California Bearing Ratio) and UCS (Unconfined Compressive Strength) values. [13] Has also demonstrated the effectiveness of CSA in soil stabilization.

3. MATERIALS AND METHODS

3.1 Materials

This research was conducted at the Civil Engineering Laboratory of Jomo Kenyatta University of Agriculture and Technology (JKUAT) in Juja, Kenya. The materials utilized in this study were laterite soil, cement, and coconut shell ash (CSA). The laterite soil was obtained from JKUAT and sieved through a 5 mm sieve. Coconut shells were obtained from Mombassa, which is the costal region of the country. The cement was type CEM IV/32.5R pozzolanic cement in accordance with the standards in the Kenyan regulation (KS EAS 18-1:2001). Tap water was used to mix the materials.

3.2 Methods

3.2.1 Burning of Coconut Shell Ash

After the collection of the waste materials, all fibers were removed from the shells before subjected to open air burning. Once the shells were completely burn, the charcoal obtained is allowed to cool for at least 24 hours. Ball Mill Machine was used to grade this charcoal into powder. The ash from the grading was heated using furnace at 650°C for 4 hours in order to enhance its characteristics and make it suitable as pozzolanic material according to ASTM specifications. After the calcination, the ash is also allowed to cool before being sieved through a 0.3 mm sieve as shown in Fig. 1.

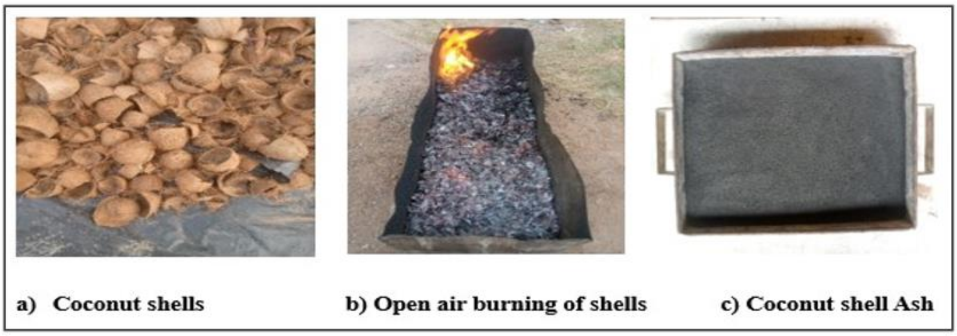

Figure 1: Burning of Coconut Shells

To examine the chemical characteristics of the materials, the X-ray fluorescence (XRF) analysis was conducted to determine the chemical composition of cement, CSA, and laterite soil. The chemical composition of cement and CSA are given Table 1.

Table 1: Chemical Composition of Cement and CSA

Composition	OPC (%)	CSA (%)
SiO_2	45.65	44.75
AL_2O_3	8.77	14.24
Fe_2O_3	3.69	12.5
CaO	36.29	6.39
MgO	-	8.23
Na_2O	-	0.49
K_2O	2.74	2.86
P_2O_5	0.22	5.66
SO3	1.86	0.87
LoI	0.59	7.34

The chemical elements of the laterite soil are given in Table 2:

Table 2: Chemical composition of soil

Composition	Percentage (%)
Al2O3	15.886
SiO2	61.538
Cl	0.114
K2O	1.01
CaO	0.429
Ti	1.662
Mn	2.504
Fe2O3	16.294
Zn	0.016

3.2.2 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 mix was prepared in the second step. The soil was mixed with various proportions of stabilizers. After the dry mix was completed, water was added according to the optimum moisture content determined through compaction test. The blocks were produced using a manual press machine during the third step. The machine is lubricated with oil before pressing the mixture poured into the mold to form blocks. The curing of the CEBs constituted the final process.

The blocks were covered with polyethylene for 7 days and then air dried until testing. The experimental work was divided into two scenarios. Firstly, was the determination of the ideal cement content to stabilize blocks by examining their properties such as dry density, water absorption and compressive strength. The compressed earth blocks were stabilized with 2%, 4%, 6% and 8% of cement by weight of laterite. Secondly was the replacement of optimum cement content found with CSA. The optimum of 6% cement was replaced with 2%, 4% and 6% of CSA. Fig. 2 shows the process of blocks production.

3.2.3 SEM Analysis

Scanning Electron Microscopy (SEM) test was done on the laterite, cement and CSA samples. This method allowed the analysis of the microstructure of the materials used in this study. Fig. 2 shows the images of laterite soil, cement and CSA from the SEM analysis.

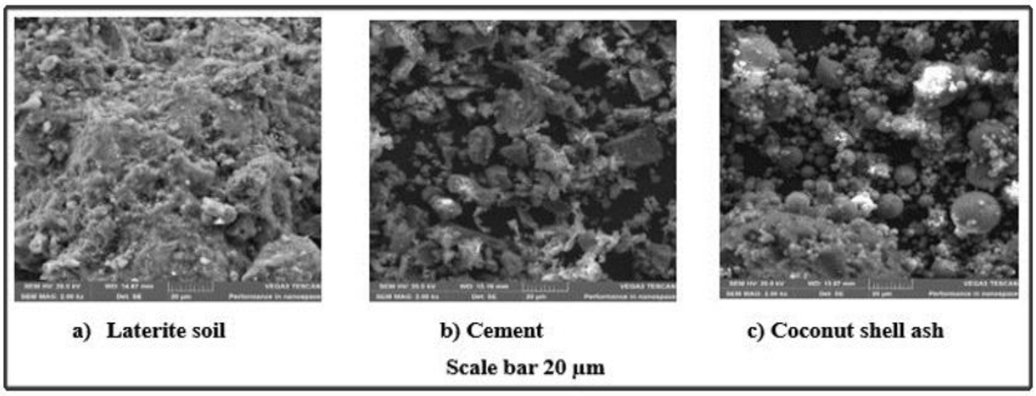

Figure 2: SEM images of laterite soil, cement and CSA.

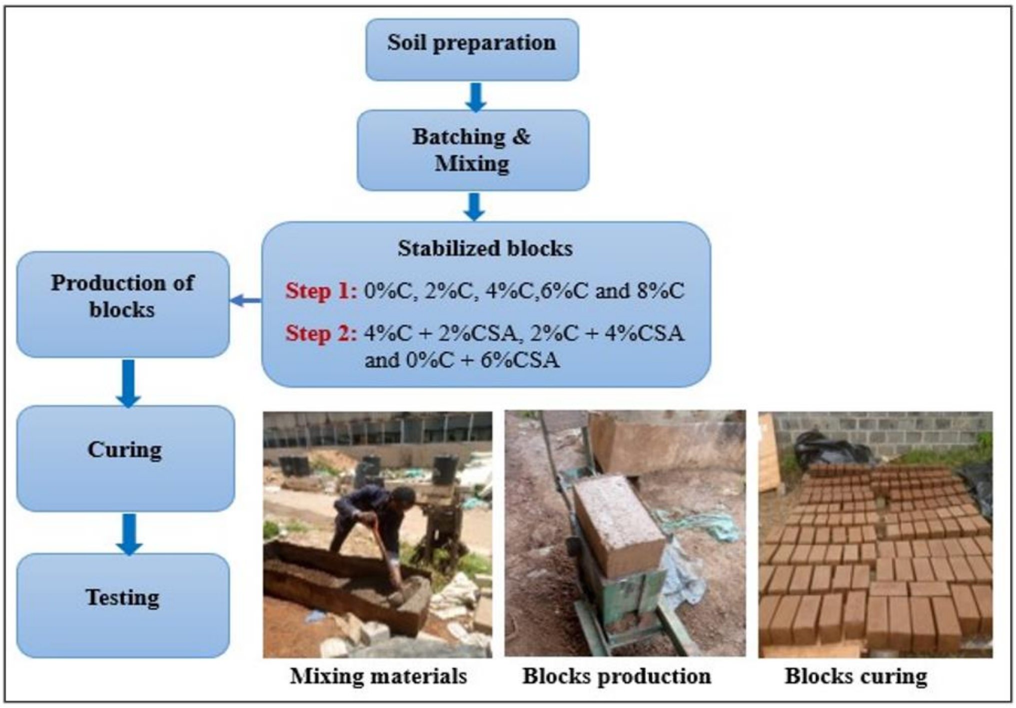

Figure 3: Block Manufacturing Process

3.2.4 Determination of the Dry Density

The evaluation of dry density was carried out at 7, 14, and 28 days in accordance with the BS EN 771-1 procedures. The process of determining the dry density of blocks is shown in fig. 4.

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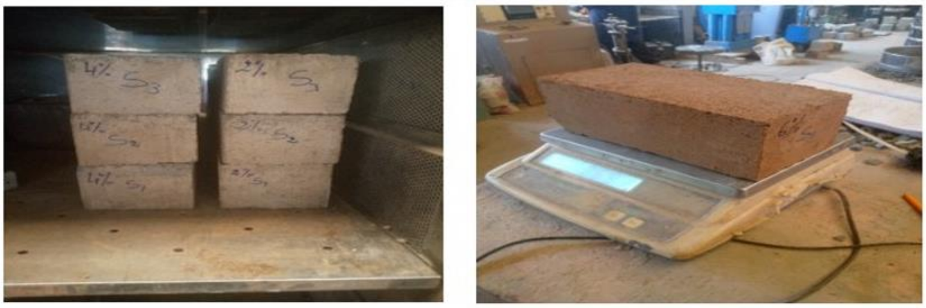
The blocks are weighed, dried and then reweighed in accordance with established standard. The dry density of CEBs was determined using Equation 3:

$$\Upsilon d = \frac{Wd}{V} \qquad (3)$$

Where: γd is the dry density (kg/m^3), Wd is the weight of the dried block (kg) and V is the block's volume (m^3).



a) Drying in oven b) Dry weight

Figure 4: Determination of Dry Density

3.2.5 Water Absorption Test

The water absorption test of the CEBs was carried out in accordance with British Standard 1377. The blocks were dried in an oven at 105°C ± 5°C for 24 hours and weighed (Wb). The blocks were then submerged in water for 24 hours, then taken out and weighed again (Wa). Equation 4 is used to get the percentage of water absorption:

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

Where Mc is the percentage of water absorption on dry basis (%), Wa is the weight of the block after absorption and Wb is the weight of the block before absorption. The steps involved in conducting the water absorption test are shown in Fig. 5.

a) Immersion in water for 24 hours b) Weight after immersion in water

Figure 5: Water Absorption Test Procedure

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3.2.6 Compressive Strength Test

The compressive strength test was conducted to assess the mechanical characteristics of the compressed earth blocks (CEBs). The test was done on the blocks after 7, 14, and 28 days according to the 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 compressive strength; F was the maximum load; and S was the area loaded.

Figure 6: Compressive Strength Test

4. RESULTS AND DISCUSSION

4.1 SEM Analysis

From Fig. 3 SEM results shown that the laterite had a rough surface and a smaller size. Cement had the largest pores and size, while CSA had a spherical shape with large pores. It was also mentioned by [22] that some CSA particles had a spherical form, while the majority of the particles showed a very irregular shape. In addition, the physical and chemical attributes of CSA are influenced by both its source and the method used for the production process. An effectivee method can enhance various properties, including particle size, particle shape, and the presence of reactive oxides 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.

4.2 Dry Density

The dry density test was performed to evaluate the effect of the binder on the mass of CEBs. 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 for each combination at different curing phases are displayed in Fig. 7. These values were ranging from 1704 kg/m^3 to 1883 kg/m^3 for

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all blocks. It was observed that an increase in cement content led to a higher density of blocks. Comparable findings were also identified in prior research focused on soil stabilization using cement [25].

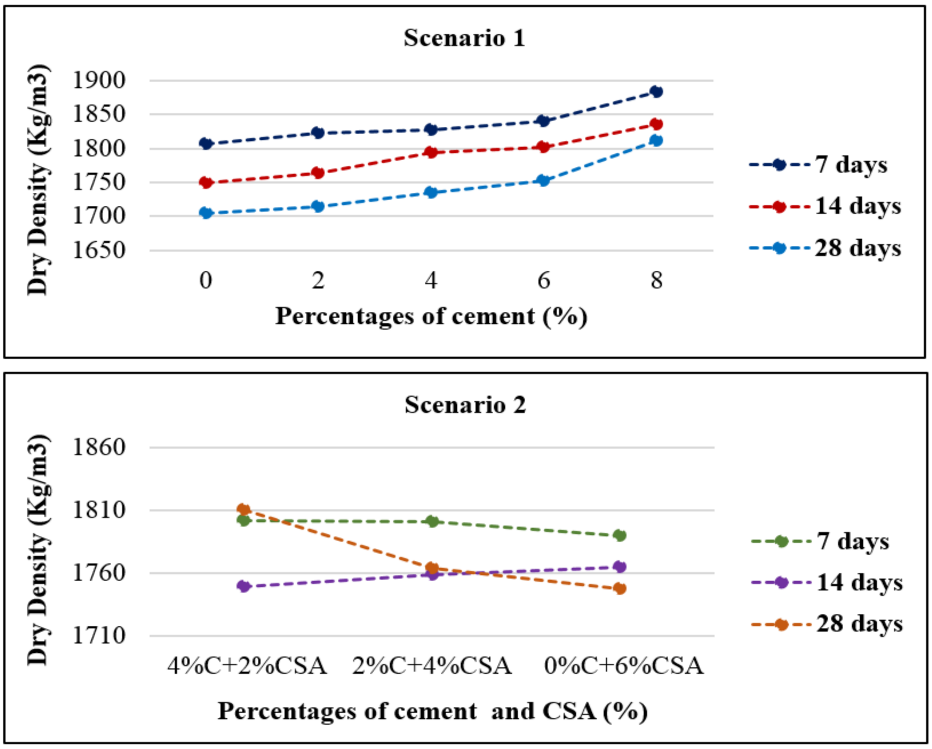

Figure 7: Dry Density of CEBs

After replacing cement with CSA there was increase in dry, density compared to control blocks with 6% cement up to 28 days. The increase in dry density was due filled voids and pores by CSA in the mix, thereby increasing the overall mass of the blocks. The highest dry density value was obtained for blocks stabilized with 4%C+2%CSA and the lowest value with 0%C+6%CSA at 28 days. The addition of 2%CSA led to an increase of 3% in dry density. However, adding 6%CSA to the soil showed a decrease in dry density compared to 6%C. This can be explained by the lower density of CSA in comparison to the soil. It reported that the density of fired clay brick gradually decreased with an increase in the percentage of CSA [11, 15]. In general, the dry density values of all the blocks were consistent with the findings of [26] ,which established the appropriate dry density range for earthen blocks as being between 1500 kg/m³ and 2000 kg/m.

4.3 Water Absorption

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

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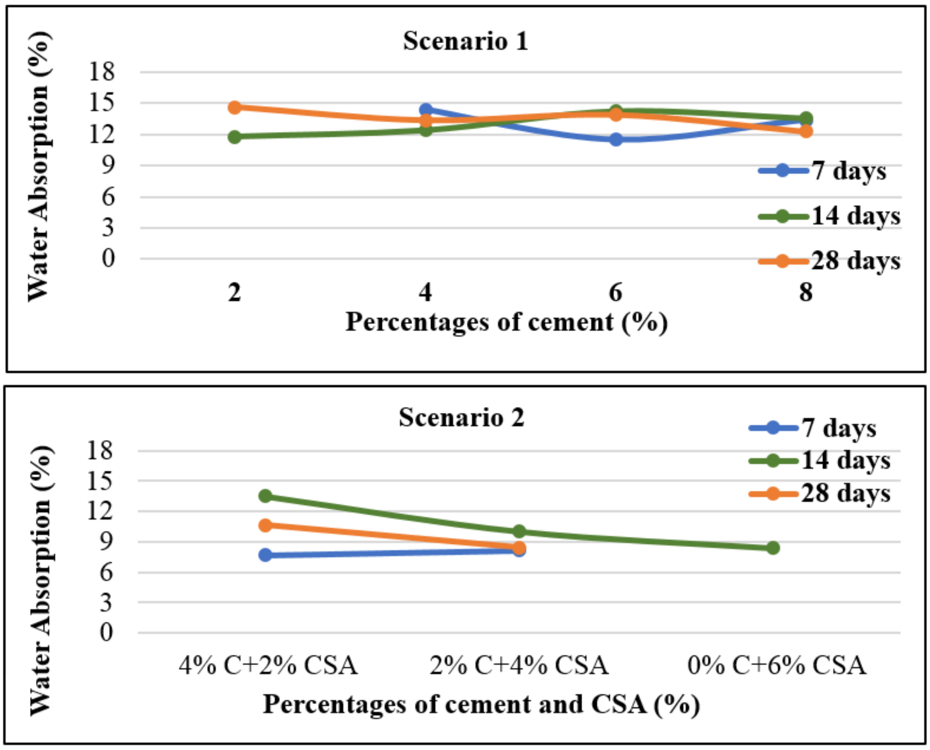

Figure 8: Water absorption of CSEBs

In first scenario for a 24-hour period, the unstabilized blocks did not withstand after being completely submerged in water at all ages. These results indicated that CEBs were not stable in water and therefore their water absorption cannot be measured. In addition, CEBs stabilized with 2% cement were 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 containing 2% cement had the highest 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 second scenario where the optimum cement was replaced with CSA, the water absorption of the blocks with the combination of (0%C+6%CSA) was only miserable at 14 days. However, the water absorption of the others blocks was improved with the addition of CSA. It was observed from this study that the water absorption of CEBs decreased as the cement content decreased with increasing in CSA through replacement. All the water absorption values were ranged from 8 to 11% at 7, 14 and 28 days. Thus, CSA as cement substitute reduced the water absorption of CEBs.

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4.4 Compressive Strength

The mechanical qualities of CEBs are evaluated based on several factors, one of which is compressive strength [29]. The minimum compressive strength required for soil blocks is 2.5 MPa according to Kenya Standards (KS 02-1070:1993). Fig. 9 displayed the values obtained from the compressive strength tests. After 7, 14, and 28 days, the strength values of the unstabilized blocks were between 2 to 3 MPa. The high value was obtained at 14 days for the un-stabilized blocks. Similar observation was made in the study of [30], where a decrease in strength was noted for un-stabilized blocks at 14 days.

After 28 days, the values of compressive strength for blocks stabilized with 2%, 4%, 6% and 8% cement content were ranged from 3 to and 5MPa. It was found that the compressive strength of all CEBs increased with cement content and the curing period. The CEBs stabilized with cement demonstrated an increase in compressive strength aligned with the findings of [4, 31]. Blocks stabilized with 6% cement showed good performances. The compressive strength of these blocks was 3.59 MPa at 28 days. This value exceeds the minimum strength required by Kenyan standards. For the economic reason and the need to reduce the cement production the optimum of 6% cement content was found to be the best in making CEBs.

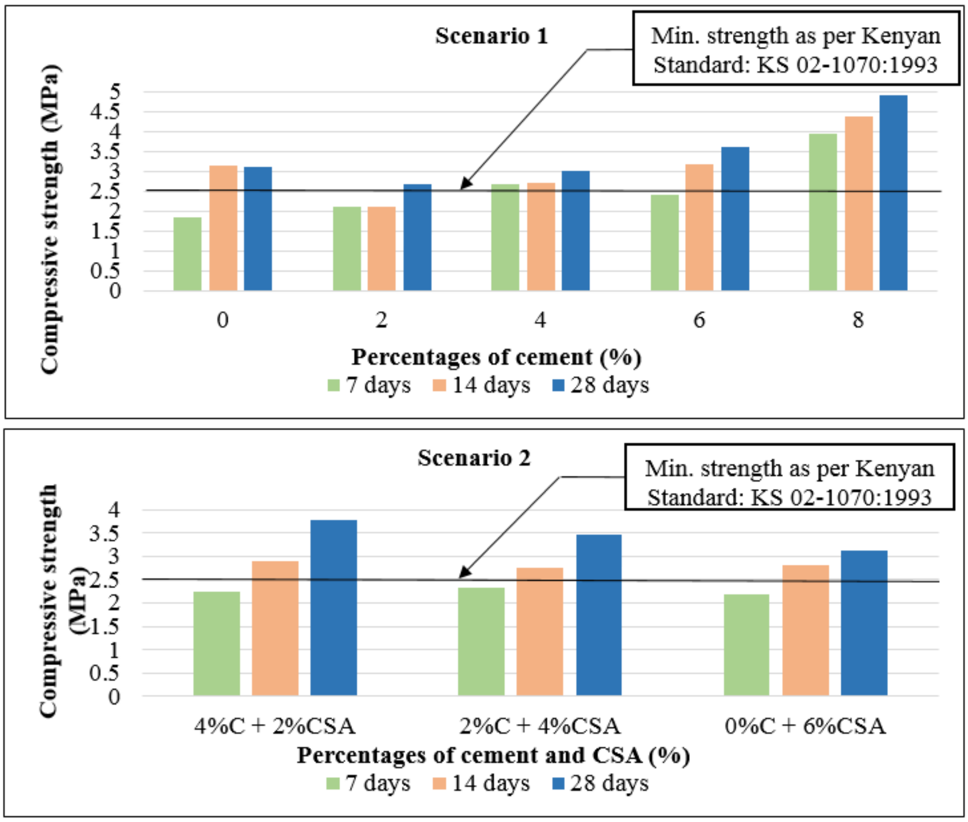

Figure 9: Compressive Strength of CSEBs

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After the optimum cement was known for the stabilization of CEBs, the control blocks were denoted as (6%C+0%CSA). Then the blocks were stabilized with (4%C+2%CSA), (2%C+4%CSA) and (0%C+6%CSA). At 7 days the compressive strength of all blocks was below 2.5 MPa.

This phenomenon was due to the slow pozzolanic reaction of the combined binders. Blocks stabilized with cement alone gain increased strength early in the aging process due to the rapid hydration of cement, which helped in the formation of cementitious compounds within the blocks [32]. After 14 days, the compressive strength was increased up to 3 MPa for the three combinations. At 28 days the maximum compressive strength of 3.78, 3.46 and 3.12 was obtained for the blocks respectively.

An increase of 5% was observed for blocks stabilized with (4C+2%CSA) in comparison to the control blocks. However, compressive strength of the remaining blocks increased with the age and decreased with the addition of CSA content. This aligned with the previous studies on fired bricks where the compressive strength has raised up to 2% and then declined with an increase in CSA [11, 15].

In addition, this outcome agreed with the findings of [28], which showed that increasing rice husk ash reduced compressive strength. It means that the increase in ash did not allow a good pozzolanic process and has reduced the strength by taking up space in the soil [30].Then, it should be highlighted that the stabilization of CEBs with (4%C+2CSA) enhanced their compressed strength more than others. Beyond 2% of CSA, the CEBs' compressive strength dropped. The blocks stabilized with (4%C+2%CSA) exhibited a compressive strength of 3.78 MPa at 28 days, indicating that 2% replacement of cement by CSA is the optimum amount for the replacement. As a results, this value is 51% higher than the minimum compressive strength of 2.5 MPa recommended by the Kenyan standard for earth blocks.

4.5 Limitations of the Study

The temperature can have impact on pozzolanic properties of the coconut shell ash. In this research the temperature for burning the ash into furnace was 650°C. Hence, it is crucial to take into account the optimal temperature for generating ash with desirable pozzolanic characteristics. Scanning Electron Micron was done on 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.

5. CONCLUSION

From this study, it can be concluded that CSA is an effective pozzolanic materials which can be used to partially replace cement in CEBs. The findings indicated that replacing cement with CSA improved the properties of compressed earth blocks such as dry density, water absorption and compressive strength.

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The following conclusions can be drawn:

- SEM analysis shown that the laterite had a rough surface and a smaller size. Cement had the largest 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 of 6% cement content was considered in making CEBs with cement alone given a compressive strength of 3.59 MPa at 28 days.
- After replacing cement with CSA, the results shown good performances for the blocks stabilized with 4%C+2%CSA. An increase of 5% in compressive strength, 6% in dry density and reduction of 3% in water absorption were observed compared to the control blocks at 28 days.
- An optimal of 2%CSA was recommended as substitute to cement in making CEBs. Based on the results of this study blocks stabilized with the combination of 4%C+2%CSA could be suitable for potential utilization in construction.

The use of CSA can mitigate the wastes from environment. CSA is an eco-friendly, low-carbon material and cost-effective which has the potential to contribute to the construction of sustainable and affordable housing.

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Conflicts of Interest

The authors don't have declaration for conflicts of interest.

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