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Compressed Stabilized Earth Brick (CSEB) As Building Construction Elements

Mbuh Moses Kuma[1,2*], Kagou Dongmo[1], Ngapgue Francois[1], Mofor Nelson Alakeh[3], Manefouet Bertille Eulalie[1]andYamb Emmanuel[4]

[1]*(Department of Earth Science, Faculty of Science, University of Dschang, Dschang, Cameroon)*
[2]*(Department of Civil Engineering and Forestry Techniques, Higher Technical Teacher Training College, The University of Bamenda, Bambili, Cameroon)*
[3]*(Department of Civil Engineering and Architecture, National Higher Polytechnic Institute (NAHPI), The University of Bamenda, Bambili, Cameroon)*
[4]*(Department of Civil Engineering, Ecole Normale SupérieureEnseignement Technique (ENSET), University of Douala, Douala, Cameroon)*
Corresponding author email: mbuhmoses@yahoo.com

Abstract:
Background*: The durability and affordability of buildings could be attained in a more environmentally friendly manner if Compressed Stabilized Earth Bricks (CSEB) are used. These bricks, when appropriately dosed with the right amount of stabilizer and pressure, could be more sustainable. The aim of this study was to examine the behaviour of CSEB subjected to elevated temperatures.*
Materials and Methods*: Soil samples were taken from Menjung-Nkwen, Bamenda III in the North West Region of Cameroon and analyzed using standard methods. The bricks were stabilized with cement CPJ 35, with an Initial setting time of 2hrs 50 mins, Final setting time of 3 hrs 40 mins, Standard consistency of 35% and subjected to elevated temperatures. The bricks were fabricated at the following stabilization percentages: 0%, 5.56%, 6.25%, 7.14%, 8.33% and 9.17%. Curing was done at 7 days and 28 days, and later subjected to temperatures ranging from 25 to 900 ℃.*
Results and discussion*: The compressive resistance showed that bricks of rich mixture (9.17%) had a high resistance at low temperatures. Bricks of 0% stabilization had a higher resistance at high temperatures compared to brick batch at 9.17% stabilization. A significant positive correlation* $(r = 0.97,\ p = 0.000 < 0.01)$ *was recorded between stabilizer dosage and mean resistance of bricks for 7 days and 28 days. Also, analysis between temperature and resistance revealed that as stabilization dosage increases, an increase in temperature lead to a low resistance of the bricks both after 7 days and 28 days.*
Conclusion: *This study suggested that CSEB with 5.56% stabilization should be used for thermal comfort because of its resistance to elevated temperatures.*
Keywords:*Temperature, Resistance, Dosage, CSEB, Menjung-Nkwen*

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I. Introduction

With an ever growing environmental threat due to the activities of man, it is essential to sustainably manage our environment. One of such measures is the implementation of Compressed Stabilized Earth Brick (CSEB), which is an energy efficient, cheap and environmentally friendly building material. Soils are the main construction materials in CSEB and is easily affordable. It is used in more than 30 countries around the world, amongst them Mexico, USA, South Africa, India and Thailand. It is easy to make and a substitute for concrete, been tested to identify the strength and the properties used as a load bearing material in the construction industry[1,2,3,4]. Compressed Stabilized Earth Brick is the modern descendent of the molded earth block, more commonly known as the adobe block. It is a combination from three different materials which are cement, soil, and sand, that are mixed together with water in definite proportions. These blocks use the same parent material as unstabilized mud bricks, but offer the significant advantage of wet compressive strength. The addition of Ordinary Portland Cement (OPC) to soil changes the properties of soil and this is mainly due to the formation of various compounds such as Calcium Silicate Hydrate (CSH), Calcium Aluminates Hydrate (CAH) and micro fabric changes (Pozzolanicreaction). CSH and CAH are cementitious products similar to those formed in Portland cement. They form the matrix that contributes to the strength of cement stabilized soil layers. One of the methods of stabilization is to compact a soil sample to reduce the voids in the finished block, consequently increasing contact between particles. Compaction is achieved by applying some manual or mechanical force to the soil, which in turn reduces the voids. The strength of CSEB can be improved by the process of compaction which leads to higher densities, thereby higher compressive strength and better resistance to erosion[5]. In exploring the stabilization and compacting techniques, a cheap, yet strong and durable material for wall construction is the CSEB. The merits of these blocks are low-cost, use of locally available material, blocks can be made at site with no transportation cost and simplicity in the manufacturing process[4,6]. The strength of CSEB increases with density and requires compaction whether it is static, dynamic or vibro-static methods[7]. In this study we considered the methods of production and stabilization of CSEB. Compaction was achieved by applying some manual or mechanical force to the soil, which in turn reduced the voids. The principal objective of this research was to investigate the resistance of CSEB when subjected to varying temperature conditions.

II. Material And Methods

2.1. Materials

The three main constituent materials used in the production of CSEB were: Ordinary Portland Cement (for binding the soil particles), soil (for the skeletal structure of the block), and water (for the hydration of cement and lubrication of soil particles). Soil samples for the experiment were collected from Menjung-Nkwen in Bamenda III (UTM 32, E0632814, N0662929 with Elevation 1277 m) in the North West Region of Cameroon. During sampling, the organic part of the soil was removed by digging 1.00 m deep to expose the sub-soil. The sub-soil samples were then collected and air dried. The soil was homogenized by removing coarse fragments and sieved using a 5 mm mesh sieve. Ordinary Portland Cement was that of CIMENCAM with an initial setting time of 2 hrs 50 mins, final setting time of 3 hrs 40 mins and a standard consistency of 35%. Although dosage amount is not commonly recommended, amounts as low as 3% and as high as 10% have been used depending on the nature of the soil requiring stabilization[8]. Pipe borne water was used for hydration reactions leading to the gradual hardening of Portland cement.

2.2. Methods

The soil samples were identified following the Cameroonian norms (NC 102-114, 2002) and were tested in the Material and Geotechnical Laboratories of BEGL, GTHS Bamenda and MIPROMALO Yaounde-Cameroon. Physical test such as smell (organic matter), touch (texture), hand washing (stickiness), cigar (clay content), sedimentation (average clay content), grain size distribution (percentage of sand, silt and clay portions) and Atterberg's limits were performed. Mechanical tests were performed using the proctor test (optimum water and maximum dry density). Chemical analysis was done by x-ray fluorescence spectrometry using an S4 pioneer Bruker spectrometer. Finally, mineralogical analyses were performed using X-ray diffractometry with a D8 advanced Brucker. The soil was then carefully mixed with 0%, 5.56%, 6.25%, 7.14%, 8.33% and 9.17% of cement CPJ 35 (with an initial setting time of 2 hrs 50 mins, final setting time of 3 hrs, 40 mins, Standard consistency of 35%) and water of about 1 L/100 kg of soil was added. The resulting mixture was then poured into the mould of the TERSTARAM press which produces bricks in triplets (dimensions 8.4×10×22 cm) and compressed with a pressure of 1.40 N/cm^2. After fabrication, the bricks were divided into two groups. Bricks in group 1 were cured for 7 days while those in group 2 were cured for 28 days. After curing, the bricks were heated in a kiln for two hours at varying temperatures of 25, 105, 200, 300, 400, 500, 600, 700, 800 and 900 ℃. Following heating, the bricks were allowed to cool for an hour and then the crushing test was done with a Brazilian compressive machine to get the resistance of failure of the samples. On group 2 samples (cured for 28 days), abrasion, erosion and absorption test was performed to evaluate the resistance of the bricks. Correlation analyses between stabilizer dosage and mean resistance of bricks was carried out for 7 days and 28 days using Statistical Package for Social Science (SPSS) version 20.0 software.

III. Results

3.1. Physical parameters

The soil had a dusty smell which implies it didn't contain organic material. This type of soil is good for brick production. The soil was not too sharp to touch which implies that the sand content of the soil wasn't too high. Hand washing revealed that the soil was not sticky and washed off easily indicating the presence of gravel and/or sand content and silt. Average cigar values for the soil sample stood at 7.2 cm and it showed that the soil fell within the Cameroonian norms of CSEB. Average sedimentation values gave 3.96 which are in conformity with Cameroonian norms. Attterberg limits indicated that liquid limit measure to 25 shocks was LL = 50.18%. The plastic limit gave PL = 37.20% and index of plasticity (IP) = 13.00%. Grain size distribution (Figure 1) indicated that the soil was well graded with a wide range of particle sizes.

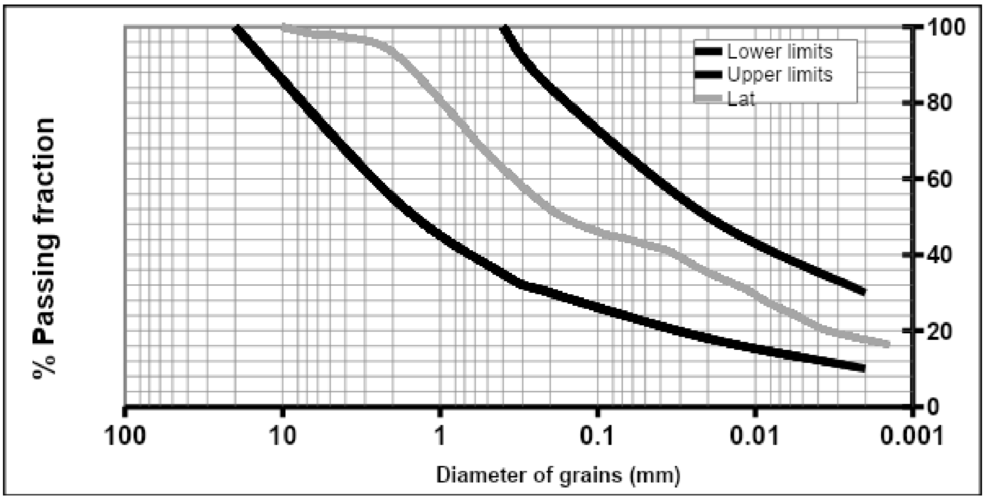

Figure 1: Grain size distribution of soil samples (*Lower and upper limit curves have been established following the Cameroonian Standards for Compressed Earth Blocks (NC 102-114, 2006)).*

The soil also presented a Methylene blue (MBV) test value of 1.13 and a Specific gravity (Gs) value of 2.25. For the compaction test (proctor test) of the soil, it showed that the maximum dry density (γ_{dmax}) was 1.780 t/m^3 and the optimum water content (W_{opt}) was equal to 15.5%.

3.2. Soil chemistry and mineralogy

Soil chemistry revealed the abundance of oxides such as silicon dioxide (63.69 mg/L), aluminum oxide (18.86 mg/L), iron (III) oxide (5.42 mg/L), titanium dioxide (0.72 mg/L), potassium oxide (0.47 mg/L), magnesium oxide (0.08 mg/L), diphosphoruspentoxide (0.06 mg/L), sulphur trioxide (0.03), dichromium (III) oxide (0.02 mg/L), zirconium dioxide (0.02), calcium oxide (0.02 mg/L), manganese (IV)oxide (0.01 mg/L), nickel (II) oxide (0.01 mg/L). Digallilium (III) oxide and zinc (II) oxide occurred in traces. The major mineral components in the soil were kaolinite $Al_4(OH)_8$ (Si_4O_{10}), quartz (SiO_2), and Gibbsite (Al $(OH)_3$.

The parameters of optimum Proctor were 15.4% for the optimal water content and 1.78 t/m^3 for the maximum dry density as shown on Figure 2.

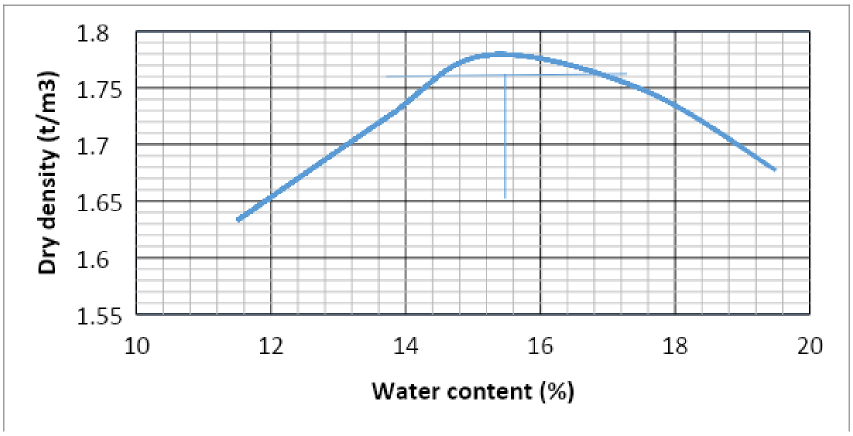

Figure 2: Proctor curve of the soil

3.3. Evaluation of CSEB resistance

This test expresses the resistance of the CSEB to temperature. Water was poured at a point on the CSEB using a watering can. The resistances of the soil samples were evaluated for group 1 (after 7 days curing) and group 2 (after 28 days curing) samples.

Group 1 samples, after subjecting them to varying temperatures, showed similar patterns. They showed an increase in resistance relative to temperature up to a certain threshold value before losing resistance to further heating. Generally, resistance of the soil increased proportionately with increase in temperature and percentage stabilization from 0% to 9.17% with resistance values of 0.8 and 2.8 MPa respectively. Prior to testing, samples with 9.17% stabilizer presented the highest resistance of 2.40 MPa while samples with 0% stabilizer presented the lowest resistance of 0.80 MPa. With increasing temperatures, the resistance of the brick samples increased to an average maximum value of 500 °C before dropping with further increase in temperature up to 900 °C (Figure

3). Conversely at higher temperatures, the resistance of the brick samples reduced with increasing stabilizer percentage. For samples with 9.17% stabilizer, maximum resistance of 3 MPa was achieved at 400 ℃. Further increase in temperatures from this point saw a drastic drop in resistance to 1 MPa. Samples with 0% stabilizer achieved maximum resistance values of 2.8 MPa at 600 ℃ before dropping with further increase in temperature to 1.8 MPa.

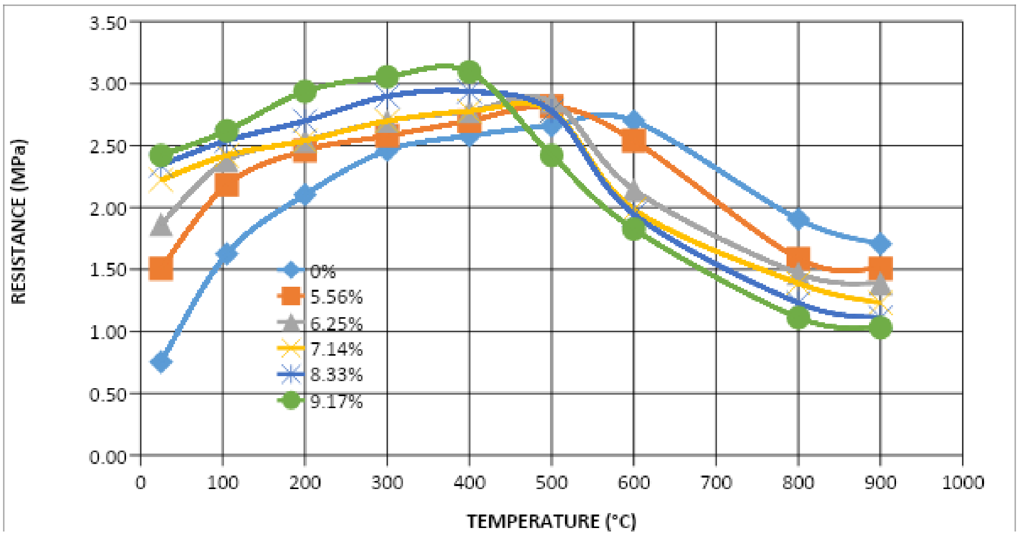

Figure 3: Combined graph for resistance against temperature after 7 days of curing and subjecting to various elevated temperatures for various dosages

Group 2 samples had higher initial resistance values (1.1 to 3.1 MPa) prior to heating relative to group 1 samples. This meant that after 28 days of curing, the soil and stabilizer had bound enough to produce a more resistant brick. Similar to group 1 samples, the resistance of group 2 samples increased proportionately with temperature, attaining average maximum values of 500 ℃. After this point, the resistance of the samples dropped with increase in temperature. It was also observed that samples with lower percentages of stabilizers were more resistant at higher temperatures relative to those with higher stabilizers and vice versa (Figure 4). Soil samples with 9.17% stabilizer had the highest resistance (3.6 MPa) at lower temperatures and as temperature increased, its maximum resistance (4.6 MPa)was achieved at 400 ℃ and from this point, further increase in temperature resulted to a drop in the resistance of the bricks. Generally, when stabilizers are added to soils and heated, the soil becomes more compact and resistant when subjected to high temperatures. Conversely when stabilizers are introduced into soils, it increases the resistance at lower temperatures, however at higher temperature, they tend to loss the resistance.

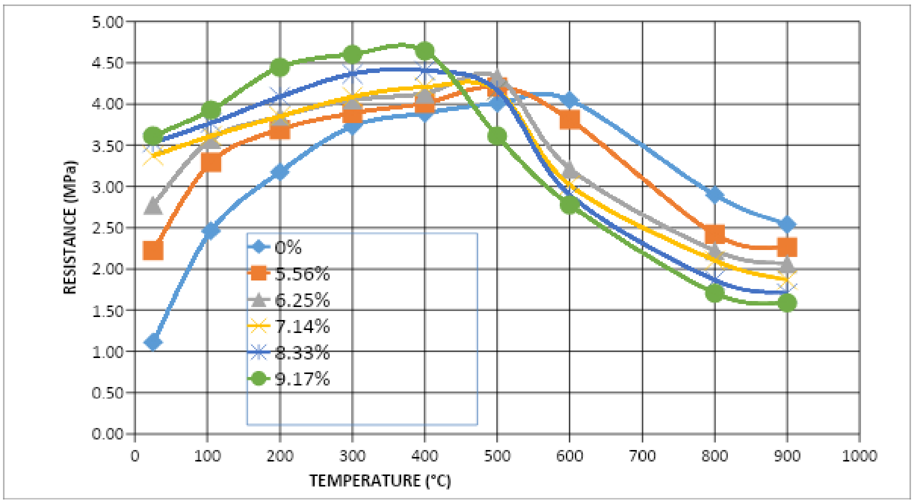

Figure 4: Combined graph for resistance against temperature after 28 days of curing and subjecting to various elevated temperatures for various dosages

Mean resistance values indicated a general increase in resistance with increase in stabilizer percentage (Table 2).

Table 1: Compressive strength of CSEB stabilized with cement depending on the firing temperature

Stabilizer dosage (%)	Temperature (°C)										R	p
	25	105	200	300	400	500	600	700	800	900		
	Compressive strength (MPa) at 7 days											
0.00	0.75	1.65	2.1	2.46	2.58	2.66	2.7	2.42	1.9	1.7	**0.369**	**0.147**
5.56	1.51	2.18	2.46	1.58	2.7	2.82	2.54	1.79	1.59	1.51	**-0.167**	**0.322**
6.26	1.87	2.38	2.54	2.7	2.78	2.86	2.14	2.71	1.47	1.39	**-0.399**	**0.127**
7.14	2.22	2.42	2.54	2.7	2.78	2.78	1.98	1.59	1.39	1.23	**-0.731**	**0.008**
8.33	2.34	2.54	2.7	2.9	2.94	2.78	1.94	1.43	1.23	1.11	**-0.774**	**0.004**
9.17	2.42	2.62	2.94	3.06	3.1	2.42	1.83	1.35	1.11	1.03	**-0.819**	**0.002**
	Compressive strength (MPa) at 28 days											
0.00	1.11	2.46	3.17	3.73	3.89	4.01	4.05	3.65	2.9	2.54	**0.368**	**0.148**
5.56	2.22	3.29	3.69	3.89	4.01	4.21	3.81	2.74	2.42	2.26	**-0.265**	**0.229**
6.26	2.78	3.57	3.85	4.05	4.13	4.33	3.21	2.58	2.22	2.06	**-0.558**	**0.047**
7.14	3.37	3.61	3.85	4.09	4.21	4.17	3.02	2.34	2.1	1.87	**-0.731**	**0.008**
8.33	3.53	3.77	4.09	4.37	4.4	4.17	2.9	2.18	1.87	1.71	**-0.773**	**0.004**
9.17	3.61	3.93	4.44	4.6	4.64	3.61	2.78	2.06	1.71	1.59	**-0.816**	**0.002**

This can be explained by the fact that the immediate action (flocculation of clays) of cement on clays was limited[9,10,11]. In addition, the chemical reaction of the cement with water is exothermic, which explains why high temperatures rather reduce the resistance, because the density is reduced. Also the treatment of clays during cooking gives the best resistances, compared to grainy soils (sandy and gravelly soils) which have the best resistances when they are treated with hydraulic binders[4,12].

The stabilizer dosage against mean resistance for 7 days and 28 days at 99% confidence interval is presented in Table 2.

Table 2: Stabilizer dosage (%) against mean resistance (MPa) for 7 days and 28 days.

Stabilizer dosage (%)	After 7 days		After 28 days	
	Mean Temp. (°C)	Mean resistance	Mean Temp. (°C)	Mean resistance
0.00	453	2.09	453	3.15
5.56	453	2.07	453	3.25
6.26	453	2.28	453	3.28
7.14	453	2.16	453	3.26
8.33	453	2.19	453	3.30
9.17	453	2.19	453	3.30

3.4. Correlation between temperature and compressive resistance of bricks

Analysis of stabilization dosage and mean resistance at 99% confidence interval for group 1 samples gave a Pearson correlation coefficient, $r = 0.526$ and probability value, $p = 0.142$ (for 7 days), and $r = 0.976$ and $p = 0.000$ (for 28 days). At 99% confidence interval, r is significant when $p < 0.01$, therefore, r was only significant after 28 days. This means that as stabilization dosage is increased, the resistance of the bricks increases, if left for a longer period to harden. This is logical since it is admitted that after 28 days almost all cement reacted, that is to say the characteristics of the brick were almost final[9].

IV. Discussion

Following the curves on Figures 3 and 4, at 7 days as well as at 28 days of age, the CSEB reached the summit at the cooking temperature of almost 400 °C. Before this temperature, the resistances changed with the temperatures in the same manner they changed with cement dosage. On the other hand, after this temperature, the resistances decrease with increasing temperatures. In the same manner, the resistances decrease when cement dosage was increased after the summit temperature.

Compression resistance values were relatively low compared to those of lateritic clay soils in the lower zone of the southern slope of the Bambouto Mountains which are a balanced sandy-clay texture, more or less plastic, and gravel-clay plastic[4]. These bricks could have better resistances in LTGS geopolymeric crosslinking if it contained more clay[13]. These bricks could be used as load-bearing masonry elements without plaster; according to standards[14]. The dosage of 8% cement at 25 ℃ is recommended because it is more economical in energy and is of good resistance (3.5 MPa). The behaviour of Menjung-Nkwen soils (Bamenda III in the North West region of Cameroon) can be justified by its nature. Indeed, the results of particle size analysis showed that they were silty-sand in texture. The limits of Atterberg, thanks to the Casagrande diagram, showed that these soils were fine silty-sand. The USCS classification confirms that this soil was predominantly medium to fine sand (class S) and contained a little silt and clay. Following soil classification, the soil was of medium clay and medium plasticity. This confirms that the soil had a low clay fraction. Therefore, the Menjung-Nkwen soils were moderately clayey and moderately plastic loam sand. Thus, the impact of baking on them was low and the impact of cement treatment acceptable.

Soils needs to be stabilized because in their natural state, they are not durable for long term use in buildings. Hence their properties need to be modified to enhance its long-term performance[15,16,17]. Stabilization is essential as it reduces the volume of the interstitial voids, fills empty voids, and improves bonding between the soil grains. In this way, better mechanical properties, reduced porosity, limited dimensional changes, and enhanced resistance to normal and severe exposure conditions can be achieved[18]. The individual properties of soils are essential to be assessed as the quality of soil used and their proportioning can significantly affect the durability of bricks[19]. The experimental value obtained (1.146 MPa) however, compared well with most current CSEB standards. Some recommended minimum values are: 1.2 MPa[20], 1.4 MPa[21] and 2.8 MPa[22]. The value of 1.2 MPa is now more widely used[23]. Other studies by Kerali[1] indicated an increase in the stabilizer percentage of up to 11% and an increase in compaction pressure lead to a higher resistance (8.3 MPa) of the bricks after 28 days of curing. Bricks with 5.56% stabilizer should be used for thermal comfort because of their resistance to elevated temperatures. This shows that for a building or structure exposed to high temperatures, the elements with high cement content are the most affected and those elements with more cement content propagates heat more than those with less cement content.

V. Conclusion

The main objective of this study was to investigate the resistance of CSEB when subjected to varying temperature conditions. The soils were moderately clayey and moderately plastic loam sand. The impact of baking on them was low and the impact of cement treatment showed that if stabilization dosage is increased, the bricks should be left to harden for a longer period at low temperatures. These bricks could be used as load-bearing masonry elements without plaster. According to standards[14], the dosage of 8% cement at 25 ℃ is recommended because it is more economical in energy and is of good resistance (3.5 MPa). The results also revealed that the strengths and stiffness of CSEB at 0% stabilization increases with increase in temperature up to 600 ℃. This result is in good agreement with those of Ravindrarajah *et al*[24] who worked on concrete and showed that the binder material type has a significant influence on the performance of high strength concrete particularly at temperatures below 800 ℃ and that the strengths and stiffness of high-strength concrete are reduced with increase in temperature. From the results, we recommend that CSEB with 5.56% stabilization should be used for thermal comfort.

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Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this article.

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