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CHARACTERISTICS OF HOLLOW COMPRESSED EARTH BLOCK STABILIZED USING CEMENT, LIME, AND SODIUM SILICATE

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Abstract

This research aims to produce a Compressed Earth Block (CEB) product using locally available soil collected from northern Jordan. The CEB mixture was further stabilized using Portland cement, lime, and sodium silicate. The research significance is based upon the urgent need of most developing countries (e.g. Jordan, Egypt…etc) to build more durable and low-cost houses by using locally available materials. As a result, CEB was identified as a cheap and environmentally friendly construction material. CEB specimens were thoroughly characterized by studying the mechanical properties and durability characteristics. Blocks of 30 x 15 x 8 cm with two holes of 7.5 cm in diameter have a potential for higher enduring, higher compressive strength, better thermal insulation, and lower production cost. Blocks were manufactured with an addition of 8 % for either Portland cement or lime, as well as 2 % of sodium silicate to the soil. The results showed that the addition of 8 % of cement to the CEB achieves satisfactory results in both mechanical and durability properties. Also, the addition of sodium silicate was found to enhance the early-age compressive strength however it affected negatively the durable properties of blocks by increasing the erosion rate and deterioration when exposed to water.

Keywords:

CEB;
Cement;
Lime;
Sodium silicate;
Stabilization.

1 Introduction

Compressed earth blocks are represented as cost-effective, sustainable, and environmentally friendly building materials in comparison with traditional building elements. Other building technologies such as concrete, burnt earth bricks, and cement-based bricks are considered to be high-cost, high-energy, and associated with adverse environmental aspects [1]. The production of cement is one of the major sources of carbon dioxide emissions which contribute to 60 % of global warming when it binds to greenhouse gases [2].

Many countries now have earth building standards, most of which deal with one technique or more among these three techniques: adobe rammed earth and CEB. The CEB is stated as the most studied technique which is found in almost 75 % of the standards under consideration [3].

Cement, which is one of the different used soils, is considered the most popular stabilizer in the manufacture of CEB. Whereas cement is more effective with coarse particles (e.g. sandy soil), lime performs better with very fine particles (e.g. clay soil) [4, 5]. Cement contents can be 6 % or more. Higher cement contents leading to higher compressive strengths and by consequent increasing the safety factor [6]. Cement-stabilized mixtures show the lowest and total porosity, which is mainly affected by the different degrees of compaction during production. In the early stages of production, cement stabilization is more effects than lime stabilization on the mechanical and durable properties of

CEB [7]. Lime enhances the strengthening of soil by pozzolanic reactions and is used to reduce soil plasticity [8]. Lime reduces the linear shrinkage of the soil and also greatly reduces clay swelling when added to it [9, 10].

Considerable variations in the composition of earth measure compressive strength and other physical characteristics of compressed earth block an important qualified control measurement for manufacturers and builders. Compaction of moist soil is often combined with 4 – 10 % cement stabilization, which significantly improves compressive strength and water resistance in comparison with traditional adobe blocks [11]. The compressive strength of bricks is correlated with the density of bricks [12].

Sodium silicate, which is one of the oldest commercial chemical products, as a result of the reaction of the alkali found in the cement with the sodium silicate, used to obtaining fast-setting cement and at the same time shrinkage cracks [13]. Alkalis have some effects on the engineering properties of cement such as setting time, strength development, shrinkage, and volume expansion, etc. They affect the rate of hydration and the nature of hydration products [14].

The main thrust of the work presented herein is to evaluate the effects of several stabilizers (Cement, Lime, and Sodium Silicate) on the mechanical properties and durability characteristics of the resultant compressed earth blocks.

2 Materials and methods

2.1 Materials

The soil used in this investigation was collected from Wadi Rajab (Ajloun – North Jordan) and was selected after conducting the necessary tests (e.g. sieve analysis test, liquid limit, and plastic limit test [15,16]. To improve the mechanical and durability of compressed earth blocks, several additives were used as described. Portland cement Type I, per ASTM [17], was used at 8 wt. %. Lime (CaO), per ASTM [18], was used at 8 % wt. Sodium silicate as a chemical additive was also used at a solid percentage of 2 % wt. The sodium silicate had a density of 1.37 g/cm^3, and pH of 11-11.5 with M of 122.07 g/mol.

2.2 Methods

2.2.1 Block manufacturing

The main purpose behind the use of the compressed earth block is based on the production of a block from the locally available soil. Manufacturing the block passed through several stages. Started with drying the soil, and then sieved to obtain the soil that passes through a sieve #10 measuring 2 mm. The soil was then used to produce the CEB with the mix proportions presented in Table 1.

Table 1: Mixtures used for block manufacturing.

Mixture code	Soil [g]	Cement [g]	Lime [g]	Sodium silicate [g]	Water [g]
TC (Soil-cement)	4800	384	----	----	1250
TL (Soil-lime)	4800	----	384	----	1250
TCS (Soil-cement-Sodium Silicate)	4800	384	----	92	1250

T: Soil, C: Cement, L: Lime, S: Sodium Silicate.

A quantity of water was replaced by sodium silicate and mixed well. To ensure the homogeneity of the fresh mix, sodium silicate solution was first added to the water and then mixed with the soil. The fresh mix was manually mixed for 2 minutes before it was placed in the mold. A compaction machine was used to produce the hollow blocks with a mold's dimensions of 30 × 15 × 8 cm, and the diameter of the circles' whole is 7.5 cm as shown in Fig. 1. In the production stage, the block was pressed with a pressure of 1.5 kg/cm² so the final thickness resulted is 8 cm.

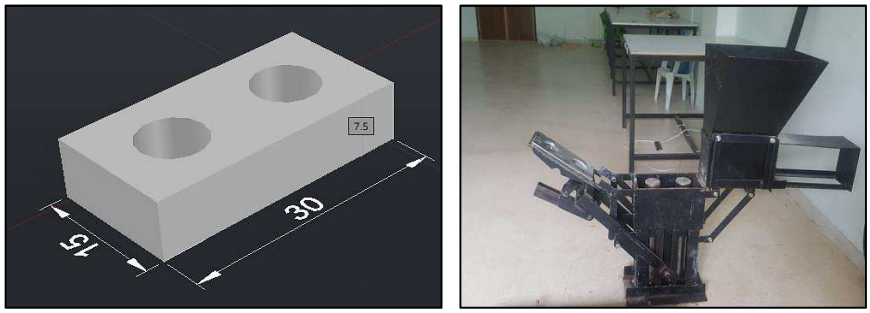


Fig. 1: Block dimension and CEB manufacture machine.

After block manufacturing, the specimens were cured by using water sprinkling to prevent shrinkage cracks. Then, they were sealed using plastic sheets and cured at room temperature for the testing age as shown in Fig. 2.



Fig. 2: Curing process of CEB.

2.2.2 Experimental program tests

Compressive strength test was carried out using a Matest Compression Machine of 2000 kN as shown in Fig. 3. The test was performed under a loading rate of 0.05 MPa/s, [19]. During preparation for each test, the dry densities were routinely measured using the averaged external dimensions and oven-dried mass of each specimen. The dried specimens were placed in an oven at 110 ±5 °C for 24 hours and then left in the air for approximately 2 hours before being tested [20]. To take a true and accurate reading for compressive strength value, all blocks were tested in compression capped with 4 [mm] thick sheets of rubber, the plain contact surface between the CEB specimens, and the steel plates for reducing friction between the machine plate and the block [21]. Three specimens were tested after 7 days and the other three were tested after 28 days from the manufacturing; the average value was recorded.

Modulus of rupture test was performed on the full-size block [5, 22]. The test was performed using a Matest compression machine of 2000 kN as shown in Fig. 3. The test was carried out at a loading rate of 0.05 MPa/s. The dried specimens were placed in an oven set at 110 ±5°C for 24 hours and then left in the air for approximately 2 hours before being tested. Three specimens were tested after 7 days and the other three were tested after 28 days from the manufacturing; the average value was recorded.



Fig. 3: Mechanical properties testing of CEB.

The absorption test was carried out by immersing a block in water for 24 hours as shown in Fig. 4 then measuring the wet block weight W_h after being removed from the water and put in an oven for 24 hours to measure its dry weight W_s. The relative difference in percentage in weight which is compared to the dry block weight gave the percentage of water absorbed as shown in the following formula [25]: A [%] = (W_h - W_s) ×100/W_s.

Erosion test was performed according to the Australian standard [23]. The block was placed at a 45 degrees angle, using 1000 ml of water dropped on the middle of the specimen which is 400 mm high in a period of 20-60 minutes as shown in Fig. 4. After that, the penetration depth was measured and the block was then divided into two halves to measure the depth of water.



Fig. 4: Durability tests (absorption and erosion).

3 Results and discussion

As for UNE 41410 [24] standard of practice for the production of compressed earth blocks recommendations, the granular composition of the selected soil falls within the shaded area on the diagram of texture given in this standard; it gives satisfactory results. The grain size distribution is shown in Fig. 5.

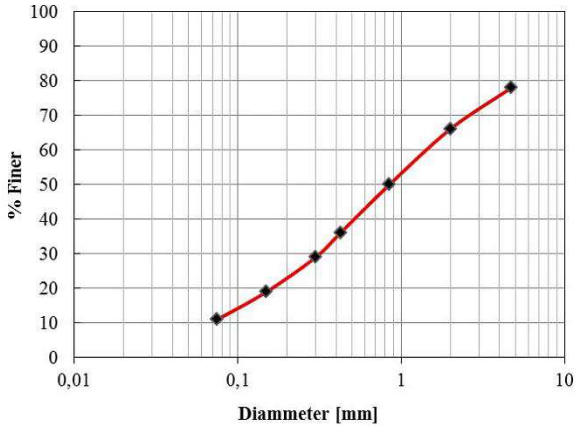


Fig. 5: Grain size distribution.

The liquid and plastic limits were performed on the selected soil per ASTM D4318-10 [16]. Three samples were tested by the selected soil. Liquid limit LL = 36 %, plastic limit PL = 13.33 % and plasticity index PI = 22.67 %. The liquid limit and plasticity index for the sample used in this project fall in the range of [12, 25, 26]. Based on the standard of Spain UNE 41410 [24], the soil sample was checked for suitability in the plasticity chart by using the Atterberg limits values. The value of the plasticity index of 22.67 and liquid limit of 36 indicates the suitability of the soil for compressed earth block manufacturing. The classification of soil is A-1-a according to AASHTO system [27].

3.1 Mechanical properties

3.1.1 Compressive strength

The compressive strength test results are presented in Fig. 6. According to the results, the TC mixture produces a higher compressive strength value compared to the TL mixture. The reason could

be the type of soil used and classified by Indian classification standard most of whose components are sand [28]. It is easy to form the bonds through bonding between the coarse particles in the soil and the cement by hydration reactions. Unlike the lime which forms a strong bond with the clay soil. The compressive strength after 7 days increased by 1.45 times but TL decreased by 0.87 times after 28 days. The blocks stabilized with lime TL had low strength values 1.69 MPa. These relatively low strength values can be attributed to the presence of clay minerals in the soil about 12 %. The addition of sodium silicate TCS was found to substantially enhance the 7-days compressive strength reaching 4.4 MPa. The high-early strength could be due to the increase in the hydration rate due to high alkali content. The compressive strength values for mixtures TC and TCS increased at age of 28 days, whereas mixture TL slightly decreased

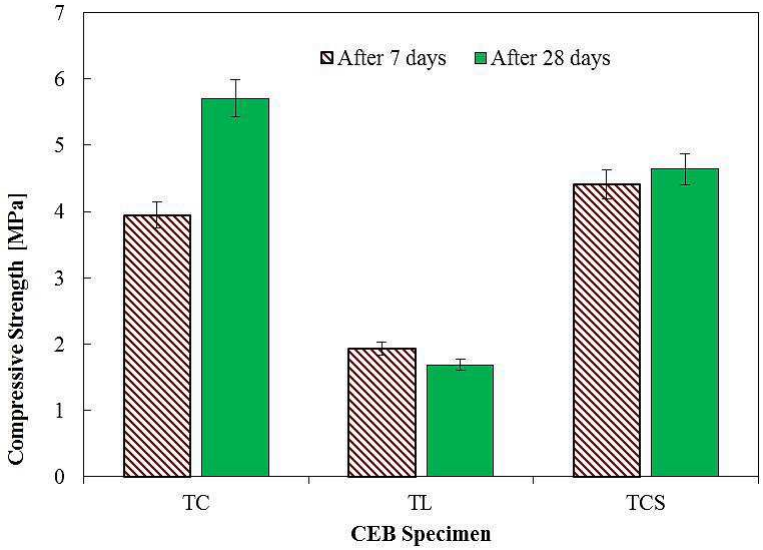


Fig. 6: Compressive strength results of CEB.

Fig. 7 presents the load-time curve for the compressive strength test. It was found the addition of sodium silicate to the mixture has increased the ductility of the specimen, whereas the specimens stabilized using lime exhibited brittle-mode failure.

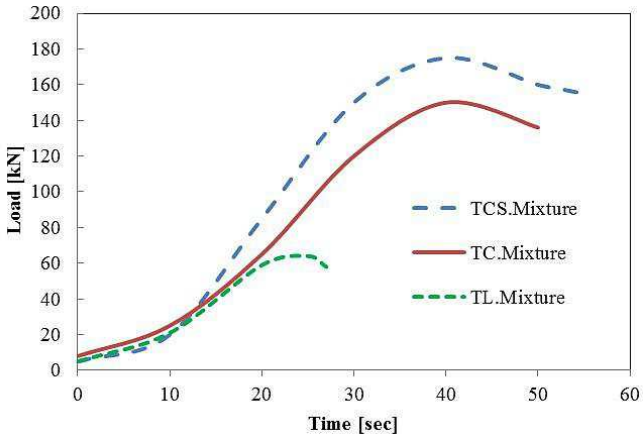


Fig. 7: Load-time curve of different CEB under compression testing.

The block failure mode is presented in Fig. 8, where the failure accrued for the whole specimen as a result of using the rubber caps that uniformly distributes the load on the block surface and reduces friction between the compression plate and block surface.



Fig. 8: Block failure mode.

3.1.2 Flexural strength

Fig. 9 compares the flexural strength of mixtures of TC, TCS, and TL after 28 days. The highest value was achieved by the mixture stabilized using cement TC, followed by mixture stabilized using sodium silicate TCS, and then the mixture stabilized using lime TL. It has been reported that cement stabilization improves the mechanical strength and water resistance through bonding between the aggregate particles by hydration reactions [4, 6] and [7, 8].

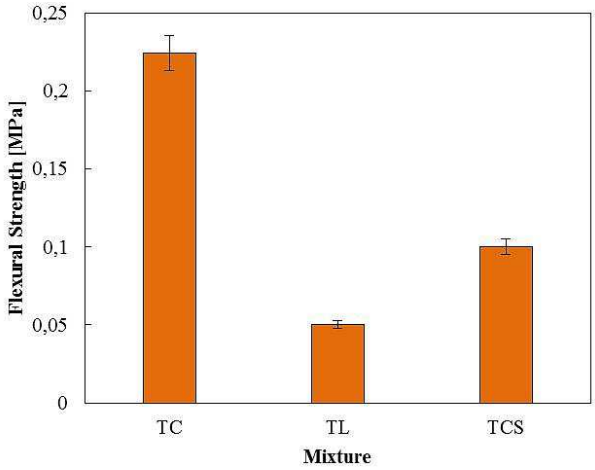


Fig. 9: Flexural strength test results.

3.2 Durability tests

3.2.1 Absorption test

Water absorption is one of the most important characteristics that can be taken into account while designing the buildings. Table 3 compares the absorption ratios and the erosion penetration depth for the compressed earth block specimens. Specimen TC had the lowest absorption ratio 23.9 % with almost no erosion penetration was detected followed by specimen TL and TCS.

Table 3: Durability test result.

Mixture	Absorption		Erosion		
	Ratio [%]	Status	Penetration [mm]	Pitting depth [cm]	Status
TC	23.9	Good	0	1	Excellent
TL	27.6	Good	0	1.5	Good
TCS	36.5	Poor	10	2.5	Good

Fig. 10 compares the visual appearance of the block specimens after performing the absorption tests. Specimens TC and TL were found to be more stable whereas specimen TCS had significant surface damage. The bond between soil and the hydrated cement paste is stronger than the bond between the soil and other stabilizers. This is because the presence of C_2S in cement, which gives late resistance to cement and works to bind molecules with curing. Besides, the water absorption was reported to decrease with increases in lime content [29].

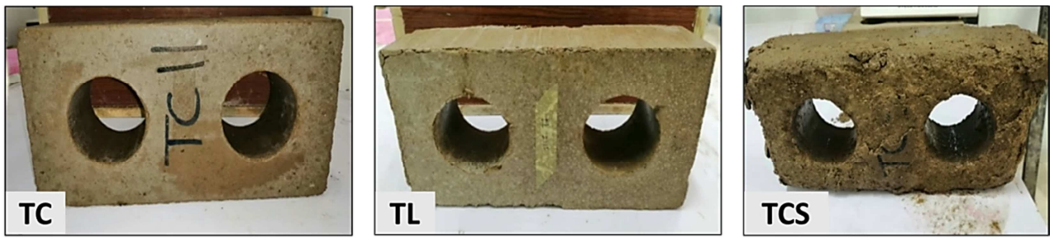


Fig. 10: Specimens appearance after subjected to absorption test.

Fig. 11 shows the extent of efflorescence at the TCS specimen's surface. The presence of whitish powder can be explained by the migration of moisture with soluble alkalis (such as Na) to the specimen's surface where they carbonated [30].



Fig. 11: Efflorescence on the surface of TCS blocks.

3.2.2 Erosion test

Erosion result is related to absorption; when the absorption increases, the penetration and pitting depth increases as well. As shown in Table 3, Speciem TC exhibited high resistance to erosion with less penetration and pitting depth compared to other specimens. Fig. 12 compares pitting depth for the block specimens, where TSC had the lowest erosion resistance. The high alkali content might hinder the hydration reaction of cement particles and reduce the binding stability in water immersing conditions [14]. Additionally, the use of sodium silicate as a stabilizer has negatively affected the hydration stability via supplies excess soluble alkalis that are not chemically bonded. It was reported that the bond between the clay structures is likely to lose and cause a significant decrease in sample size [31].

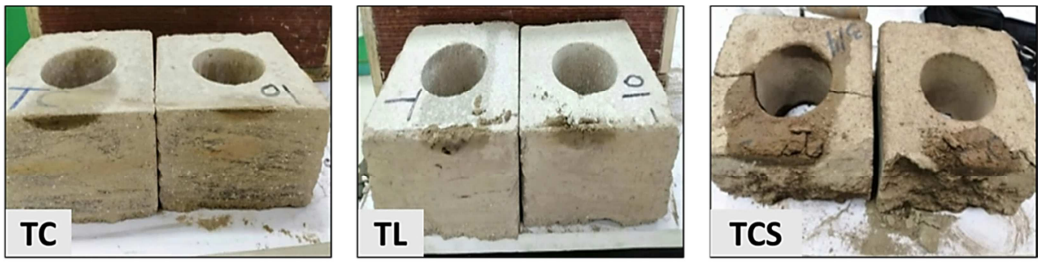


Fig. 12: Erosion test result.

4 Conclusions

The presented investigation aimed to use the locally available soil in Jordan and chooses the appropriate stabilizer for the manufacturing of compressed earth blocks (CEB). Based on the experimental results, the following conclusions can be drawn:

- The type of soil is an important factor for the selection of an appropriate stabilizer. Cement was preferred to use in the soil with high sand content. The adequate stabilizer for soil A-1-a is cement.

- The soil fineness affects the compressive strength of the resulted CEB. With finer soil particles, the compaction was found to be more efficient and the block fewer voids were found in the CEB.
- Soil stabilized using 8 % of cement produced good mechanical properties and durability characteristics. The use of sodium silicate, however, enhanced the early-age strength values, it has substantially reduced the durability of the CEB.
- The Presence of alkaline content in CEB stabilized with sodium silicate showed some efflorescence (carbonate compounds) on the surface of blocks.
- The use of lime as a stabilizing agent was found to be relatively good. Considering that the soil used in this investigation had clay minerals.

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