Development of Compressed Stabilized Earth Block as an Eco-Friendly and Sustainable Wall Making Material

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***Abstract*—This experimental study investigates the development of compressed stabilized earth block (CSEB) as an eco-friendly and sustainable wall making material. In the study, three different types of stabilizers of cement, lime, and wood ash with 5%, 10%, and 15% replacement of soil are used as stabilizers. Moreover, lime and wood ash were blended with cement with 2.5%, 5%, and 7.5% of each in order to improve their efficiency. The CSEBs with dimensions of 300×150×100mm were prepared and cured for 28 days. Finally, the compressive strength, density, and water absorption of the CSEB were analyzed. Cement stabilized blocks had the better compressive strength and density and low water absorption rate but cement is environmentally unfriendly and consumes energy. Lime stabilized blocks showed good compressive strength and density but high water absorption. While wood ash stabilized blocks exhibited the poor strength and density and high water absorption but these properties were improved when wood ash was blended with cement. As the results, the optimum proportion was found to be L5C (5% lime and 5% cement) or WA5C (5 % wood ash and 5% cement).**

***Index Terms*—compressed stabilized earth block, compressive strength, density, water absorption, wall making material, stabilization**

I. Introduction

The construction industry heavily demands earth's resources, e.g. cement, pozzolans, fine aggregate, coarse aggregate, etc. for making building blocks and other civil engineering applications. Nevertheless, these materials are energy intensive and thus the production of these building blocks has a negative impact on the degradation of the environment. Transportation of the materials to the actual construction site is also another energy-demanding activity [1].

Earth is an alternative economically, eco-friendly, and plentifully available building material and is perhaps mankind's used to build their shelter very long time before. It was abundantly used for the construction of walls and other structures for 1000 years around the world [2, 3]. The ancient Greeks, Yemen, Egyptians, and the Mesopotamians were amongst pioneers in the area. At some point in the era of civilization and the invention of new materials, earth blocks lose popularity. Nowadays, compressed stabilized earth block/ brick (CSEB) is becoming an area of growing interest, both for the restoration of heritage, ecological, and reversing sociocultural assets. Compressed stabilized earth bricks are ultimately greener, environmentally friendly, competitively in compressive strength, density, durability, and good in thermal conductivity as compared to fired bricks [4, 5].

Yu *et al.* [6] studied the development of CSEB using activation pretreated coastal solonchak, saline soil, lime, cement, and sand. Their results showed that the CSEB with 50% activation pretreated saline soil had compressive strength and water absorption values of 28-55% and 44-66% higher than the reference mix with untreated saline soil. Taallah and Guettala [7] investigated the effect of curing methods and curing time on physical and mechanical properties of compressed earth block (CEB) produced using quicklime and date palm fibers. They reported that fiber surface treatment did not improve the fiber/ matrix adhesion and thus decreasing the strength of the block. Using date palm fibers reduced thermal conductivity and bulk density and increased the capillary absorption of the CEB. Nagaraj and Shreyasvi [8] produced CSEB from various proportions of iron mine spoil waste (MSW), cement, and lime. Test results showed that the wet compressive strength of the CSEB was greater than 5 MPa after 6 months. This value is suitable for the CSEB that is used for residential buildings. Mansour *et*

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al. [9] studied the effect of compaction pressure on bulk density, as well as the effect of bulk density on mechanical properties and thermal performance of the CEB. They found that compaction pressure affected the bulk density of the CEB significantly. In addition, both thermal conductivity and thermal diffusivity decreased with bulk density. Nagaraj *et al.* [10] investigated the role of lime with cement in the long-term strength of the CSEB. The authors reported that the CSEB produced with the optimal content of lime and cement resulted in long-term (>2 years) strength development. Whereas, the strength of the CSEB with only cement did not develop after 6 months.

In order to provide more information regarding this topic, the present study was conducted to emphasize on the advantages of using CSEB as alternative sustainable wall making material through protecting the environment and earth's precious natural resources. In this study, three different types of stabilizers (cement, lime, and wood ash) with different combinations of themselves are used to prepare sixteen block mixtures. The compressive strength, density, and water absorption of each mixture were then examined and the best stabilizer, as well as optimum combination of stabilizers, are pointed out.

II. Material and Experimental Works

A. Materials

In this study, locally available red soil, wood ash, type-42.5 ordinary Portland cement, and lime were used for the preparation of CSEBs. Physical properties of the red soil were tested according to their respective test standards and procedures, with the results as given in Table I. These results are satisfactory to fulfill the clay soil. Moreover, the gradation test result indicates that all of the soil particles passed through 4.75 mm sieve size and 65% of the soil passed 2 mm sieve size. Thus, it satisfied for this research purpose of soil. On the other hand, major chemical compositions of the wood ash are shown in Table II. As shown, the wood ash is found to be silicate source, which is good for pozzolanic reactivity during the stabilization process.

TABLE I. Characteristics of Red Soil

Item	Value
Liquid limit	51
Plastic limit	23
Plastic index	28
Optimum moisture content (%)	32
Maximum dry density (g/cm^3)	1.41

TABLE II. Chemical Composition of Wood Ash for Major Oxides

Oxide	Amount (wt.%)
SiO_2	35
Al_2O_3	15
Fe_2O_3	1.3
CaO	4.5
MgO	2.54

B. Nature of the Mixture and Ingredient Proportions

In the present study, there are 6 groups of mixtures, including (1) Unstabilized or 100% soil; (2) Cement stabilized blocks with 5%, 10%, and 15% replacement of soil; (3) Lime stabilized blocks with 5%, 10%, and 15% replacement of soil; (4) Wood ash stabilized blocks with 5%, 10%, and 15% replacement of soil; (5) Cement and lime stabilized blocks with 2.5%, 5%, and 7.5% of cement replaced by lime; and (6) Cement and wood ash stabilized blocks with 2.5%, 5%, and 7.5% of cement replaced by wood ash. The ingredients proportion per block were determined by using the maximum dry density of soil. The size of the block was determined to be 300×150×100 mm.

C. Samples Preparation, Curing, and Schedule of Testing

Firstly, all of the block ingredients were mixed in the dry state. Water was then gradually added to the dry mixture until a uniform mix was obtained. Hence, the uniform mixture immediately received compaction by a mechanical machine designed for this purpose as shown in Fig. 1. Six blocks were prepared for each mixture and a total of 96 blocks were cast. After casting, the CSEBs were cured under plastic shelter as shown in Fig. 2 for 21 days to keep the moisture until the hydration reaction completes [11]. After 21 days of curing, the blocks were exposed to air for 7 days to get dry and ready for the tests. Finally, the tests of compressive strength, density, and water absorption were conducted at 28-day-old of the CSEBs.

Figure 1. CSEB compaction machine.

Figure 2. Plastic curing shelter.

III. Material and Experimental Works

A. Compressive Strength of CSEB

The average compressive strength value of six block mixtures is shown in Fig. 3. It is noted that the compressive strength test was conducted based on the ASTM 1984, which a standard test method for compressive strength of fired brick.

It can be seen clearly in Fig. 3 that compressive strength of the CSEB increased as the percentage of stabilizers increased. Lime stabilized CSEB gained the peak compressive strength at the proportion of 5% and 10%. This is due to the effectiveness of the reaction between lime ($Ca(OH)_2$) and silicates that are available in clay. As a result, calcium silicate compound would be formed. Such the calcium silicate compound plays a major role in binding the soil particles together and ultimately increases the compressive strength of the CSEB [1, 12]. The 28-day compressive strength value of the unstabilized soil CESB was about 0.8 MPa. Whereas, the compressive strength values of the stabilized blocks, excepting the wood ash stabilized blocks, were much higher than that of the unstabilized soil CESB. This may due to the contribution of binding agents formed during stabilization ignite hydration process [10]. Since wood ash is a less active pozzolanic material, it sufficiently inhibits calcium silicate reaction and consequently results in the lowest strength among all of the stabilized blocks. The compressive strength of all stabilized blocks increased slightly after 10% of stabilizers since there will be free lime or silicate, which would not generate C-S-H gel to improve the strength. The cement stabilized blocks had the best compressive strength values at all different proportions since cement can undergoes self-hydration with water [1]. Wood ash stabilized block produced much lower compressive strength than other blocks, but the strength significantly improved when wood ash was mixed with cement. This may due to the calcium and silicate reaction [13]. However, there was no significant difference in the increased strength after 10% because silicate content might over the optimum amount.

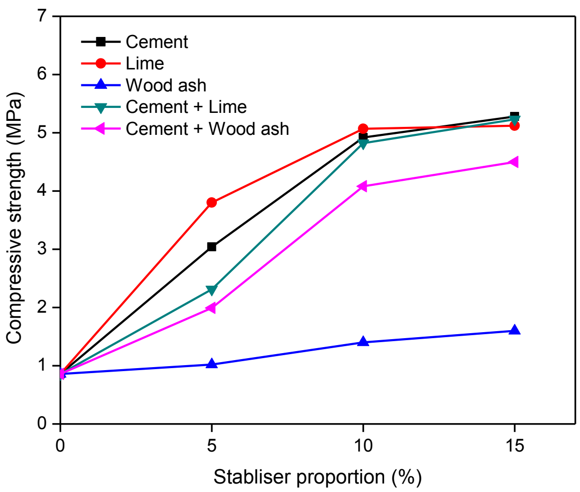

Figure 3. Compressive strength of CSEB at 28 days.

Even though cement is a good stabilizer, it is energy consuming, costly, and environmentally unfriendly [14, 15]. Thus, it is better to combine with wood ash and lime so as to reduce cost and to protect the environment. The results of this study recommend the optimum combinations of stabilizers to be L5C (5% lime and 5% cement) or WA5C (5% wood ash and 5% cement).

B. Dry Density of CSEB

The density of the CSEB was measured in accordance with ASTM C140, with the results are summarized in Fig. 4. The unstabilized pure soil block had a dry density value of 1590 kg/m^3, whereas all types and proportions of the stabilized blocks obtained the dry density values of above 1590 kg/m^3, with a maximum of 1826 kg/m^3. As aforementioned, this is attributable to the support of hydration products formed during the stabilization process, which created a denser structure and thus a higher density of the CSEB blocks. Additionally, a combination of lime and cement (L7.5C) achieved the highest dry density of block, while density values of the stabilized wood ash blocks were the lowest. The density of all blocks increased as the percentage of stabilizers increased. However, the increased density between 5% and 10% stabilizers was significant. However, there is no significant increase in density at higher than 10% stabilizers. Apparently, the dry density of blocks has a direct relation with compressive strength. This study found that CSEB blocks are more condensed than some lightweight and foamed concrete but less dense than normal concrete [11].

C. Water Absorption of CSEB

The levels of water absorption of all CSEB blocks are presented in Fig. 5. As shown in the figure, the water absorption of the CSEB block was significantly improved across different types and proportions of stabilizers. The highest water absorption level of 22.5% was recorded on the unstabilized pure soil blocks, while the lowest water absorption rate of 9.6% was obtained on the cement stabilized blocks. Lime stabilized blocks had higher water absorption rate than the cement stabilized ones. This may due to the limited hydro silicate reaction in lime-stabilized blocks and the presence of free lime inside the blocks, which is going to absorb more water and thus increased the water absorption rate of the blocks. Among all of the blocks, the water absorption rate of the wood ash stabilized blocks was highest because of the low pozzolanic reaction rate of the wood ash, which provided a limited hydration rate to form calcium-silicate for binding soil particles together and form a solid water expelling substance. Hence, wood ash and lime stabilized blocks would sack more water, which will be exposed for shrinkage when the blocks got dry. This may reduce the strength and durability of the CSEB blocks. However, water absorption of both wood ash and lime stabilized blocks was improved significantly by combining with cement (Fig. 5). In this study, the optimum combination was found to be L5C (5% lime and 5% cement) or WA5C (5% wood ash and 5% cement).

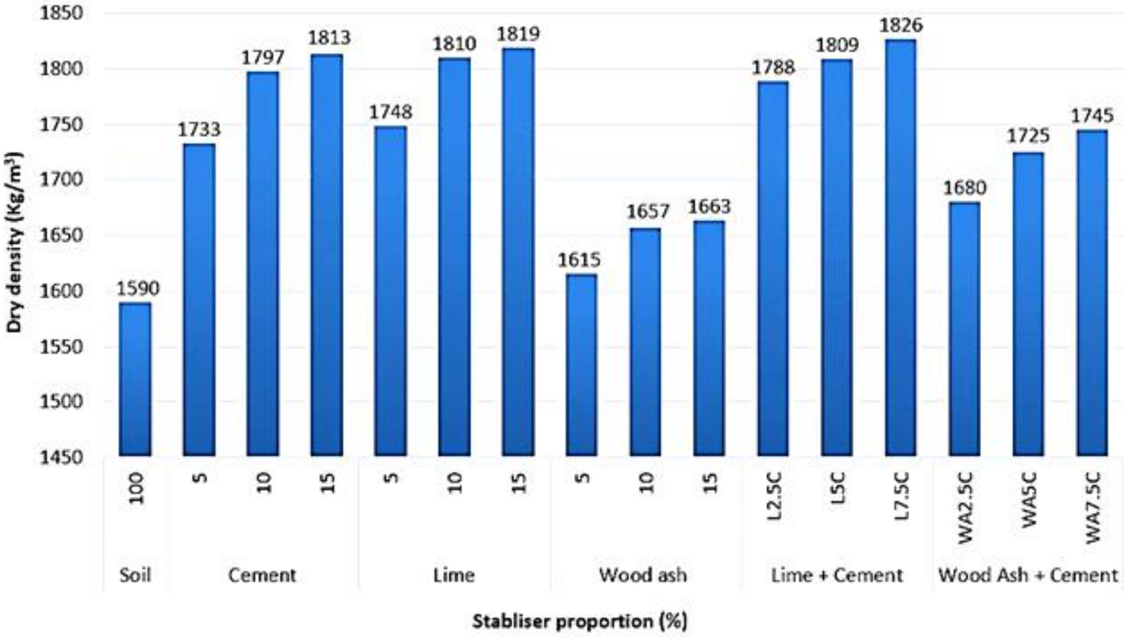

Figure 4. Summary of dry density of CSEB

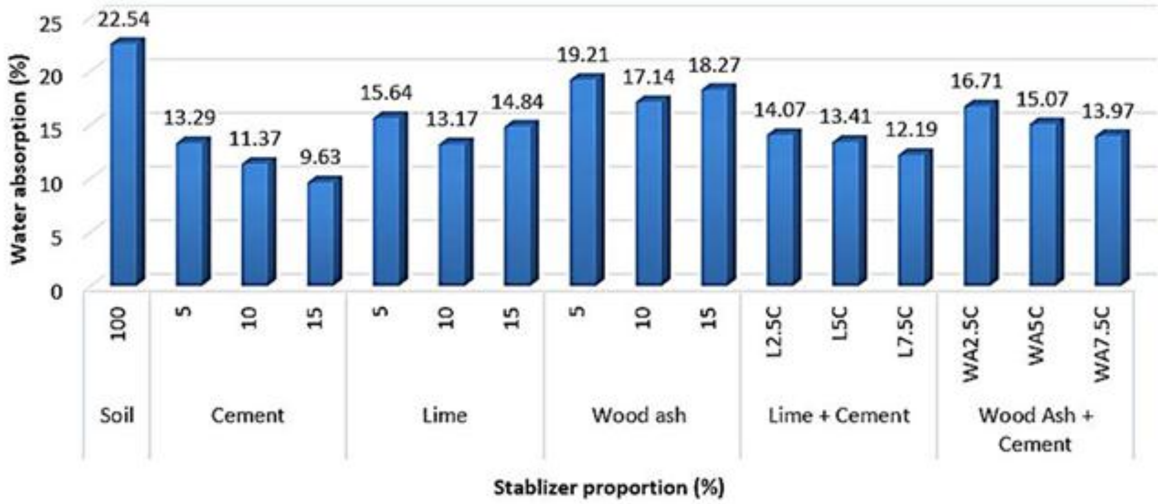

Figure 5. Summary of water absorption of CSEB

IV. Summary and Conclusion

This study evaluated the performance of the CSEB by using different types and proportions of stabilizers. Based on the test results, the following conclusions may be drawn:

Wood ash and lime were good stabilizers for the production of CSEB. They were more effective when they were combined with cement.

Cement stabilized blocks had the higher compressive strength and density and lower water absorption rate in comparison with that of other blocks.

Lime stabilized blocks showed good compressive strength and density but high water absorption rate. Wood ash stabilized blocks exhibited the poor strength and density and high water absorption.

L5C (5% lime and 5% cement) and WA5C (5% wood ash and 5% cement) were the optimum mixtures to produce good quality of CSEB.

Nowadays, CSEB can be a potential alternative eco-friendly and sustainable making material. It is preferable than other wall making materials due to the low cost of materials, local skills, and simple to manufacturing and constructing.

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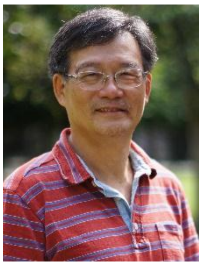

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