

Enhancement of the Properties of Compressed Stabilized Earth Blocks through the Replacement of Clay and Silt with Fly Ash

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Abstract—The use of earth as a building material, in different forms, such as unburnt and burnt bricks, rammed earth, mud blocks, and soil blocks, is a common practice globally. This study is focused on soil blocks stabilized with cement which are referred to as Cement Stabilized Earth Blocks (CSEBs). The strength and durability of CSEBs are primarily governed by the amount of silt and clay content (finer) in the soil. Many researchers have shown that low finer content improves the properties of CSEB and they have altered the finer content by adding different additives. The current study used a washing method to reduce the finer content and fly ash was utilized as finer to re-fill the soil to the required finer content amount. Also, soil grading was modified by adding larger particles that were separated from the same soil to fit the soil grading to the optimization curves mentioned in the literature. The finer content was changed to 5%, 7.5%, and 10%. Blocks were made by stabilizing the soil with 6%, 8%, and 10% cement and with the size of 150mm×150mm×150mm. The results revealed that fly ash addition up to 10% improves the properties of CSEBs and compressive strength changes from 4.28N/mm² to 13.43N/mm².

Keywords—cement stabilized earth blocks; fly ash; reduced silt and clay; improved properties

I. INTRODUCTION

Earth is one of the oldest and most widespread construction materials [1]. Raw earth as a building material has many advantages [2–5]. Soils in their natural state lack in strength, durability, and dimension stability. Authors in [6] showed the mechanical weakness and the absence of standard procedures to measure strength and stiffness as some demerits of earth-based constructions. These deficiencies can be overcome by stabilizing the soil to produce building materials [7]. Compressed Stabilized Earth Blocks (CSEBs) are one such building material. Authors in [8] used soil to produce mud

concrete blocks. Authors in [9], on their extensive literature survey, have shown the advantages and disadvantages of using earth-based building materials. They have the inherent advantages of being eco-friendly, having low thermal conductivity, while they are abundantly available in nature. However, the loss of strength and dimensional stability when in contact with water for a long time, is a serious disadvantage. Due to these disadvantages, the use of CSEBs as a common building material is not as expected. The use of burnt bricks and cement blocks is popular in Sri Lankan housing construction also. As per statistics, the construction industry consumes a huge cost for burnt bricks and soil blocks usage is not even mentioned in the statistics [10]. The two main challenges of CSEBs are durability and compressive strength. The main variable for both these critical parameters is related to the amount of silt and clay (finer) in CSEBs. Past research work established the optimum finer in the region ranging from 5% to 20% related to compressive strength but no firm indication of the range was associated with the durability of CSEBs. Lateritic soil is used for the production of CSEBs and the content of silt and clay in lateritic soils is generally around the range from 20 to 35% [11].

CSEBs can be used to overcome the problems associated with burnt bricks such as material availability and the economic viability. Generally, many researchers have shown the effect of finer content to the properties of CSEBs. The effect of soil grading to enhance the CSEB properties was examined in [12]. The authors showed that the particle size distribution of soil can be modified to fit into the theoretical distribution suggested by particle packing theories. Based on that, particle packing concepts suggested in [13–15] are valid for CSEB production. Crushed construction waste also can be used to modify the particle size distribution of the soil [16]. For

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other soil-based products like mud concrete also, particle percentages in the different ranges need to be controlled [8].

The current research examined the reduction of finer content by washing the soil for the production of CSEBs. Removing finer content to a certain extent may improve durability. Production practicability is another concern. With high clay content, the production process may face problems. Therefore, removing finer may help the production process and lower its cost. With this finer reduction, there can be more voids in the soil mix. Therefore, the study suggests the addition of fly ash to act as finer. With this background, the objective of the study is to check the suitability of using fly ash as a replacement for finer content in the soil to produce CSEBs.

II. USE OF FLY ASH FOR CSEB PRODUCTION

Fly ash is a fine, glass-like powder recovered from gases created by coal-fired electric power generation and its particles are generally spherical in shape and range in size from $0.5\mu\text{m}$ to $100\mu\text{m}$ [17]. SiO_2 , Al_2O_3 , Fe_2O_3 , and occasionally CaO are the main chemical components present in fly ash [18]. It has a long history of use as an engineering material and has been successfully employed in geotechnical applications [19]. Additionally, the use of fly ash to enhance the properties of concrete is not rare. Authors in [20] have used fly ash/rice husk ash mixture to enhance the properties of concrete. Authors in [21] showed the effect of using fly ash on the compressive strength of green concrete. Most of the times, fly ash is classified as secondary binder and cannot induce the desired effect by itself. However, with the presence of activators can form a cementitious compound which can improve the strength of the soil [22]. Highest compressive strength of CSEBs can be achieved when they were incorporated with 10% fly ash. The lowest water absorption was experienced by CSEBs when the fly ash percentage was 15% [23]. Authors in [24] have used high carbon fly ash for compressed earth blocks. As per their studies, they have varied the fly ash content from 0% to 50% in 10% intervals keeping the cement content constant. Blocks with 0% fly ash have shown the maximum compressive strength and the lowest water absorption. They concluded that 25% fly ash content gives the optimum compressive strength. Authors in [25] used lime and fly ash for soil blocks. Their study showed that the unconfined compression strength of the laterite soil with 5% fly ash and 15% lime was found to be around 2.5 times more than the strength of natural laterite soil. Also, they have shown that the average compressive strength of the blocks tested after 28 days of curing was more than the minimum compressive strength of fired bricks as per IS: 1077 (1992). The water absorption value obtained for 28 days of curing was below the minimum value as specified in IS: 1077(1992).

III. RESEARCH METHODOLOGY

Soil is the dominant part of CSEBs. Geotechnical analysis was carried out to analyze the characteristics of the soil. Wet sieve analysis as per [26] was conducted to identify the silt and clay content accurately. Atterberg test was conducted as per [27]. Specific gravity test also was performed to identify the physical properties of the soil. Wet sieve analysis showed that the soil contains 28% silt and clay. Therefore, to reduce the silt

and clay content, the soil was washed. The washed soil consisted of nearly 5% silt and clay content.

This particle size distribution of the soil revealed that modification is needed to get its particle distribution to fit into the optimization curves as described by the particle packing theories. Also, finer content was changed to 5%, 7.5%, and 10% by adding fly ash. This fly ash was taken from Norechcholai Lakvijaya Power Plant, Sri Lanka. Fly ash was tested for its particle size distribution and chemical composition. Table I shows the chemical composition of the fly ash. Earlier separated larger particles in the range of 2.0-6.0mm and 6.0-12.0mm as in Figure 1(a) and 1(b) were also added to get the soil particle size distribution as per optimization curves. As per the objective of the study, cement was used as stabilizer in 6%, 8%, and 10% proportions.

TABLE I. CHEMICAL ANALYSIS OF FLY ASH

| Constituents determined | Content % | Test method |
|--------------------------------------|-----------|---|
| Calcium as CaO | 5.63 | Acid digestion and atomic absorption spectrometry |
| Magnesium as MgO | 1.59 | |
| Iron as Fe_2O_3 | 3.35 | |
| Aluminum as Al_2O_3 | 19.74 | |
| Potassium as K_2O | 0.47 | |
| Sodium as Na_2O | 0.95 | |
| Manganese as MnO | 0.05 | Acid digestion and UV/VIS |
| Phosphorus as P_2O_5 | 1.89 | |
| Titanium as TiO_2 | 1.98 | Gravimetry |
| Silicon as SiO_2 | 47.48 | |
| Loss on ignition | 16.79 | |

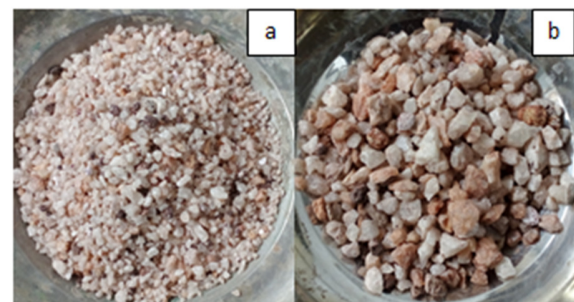


Fig. 1. (a) Gravel 2.0-6.0mm, (b) Gravel 6.0-12.0mm.

Since the mixture of soil has more gravel parts and the casting was carried out using a cement sand block-making machine, the water requirement was comparatively less. For the practical easiness of casting 8-10% water (by soil weight) was sufficient. For each combination, 10 blocks were cast resulting to a total of 90 blocks. The $150\text{mm}\times 150\text{mm}\times 150\text{mm}$ blocks were prepared using the cement sand block-making machine shown in Figure 2. Both vibration and compaction were applied to block casting. Vibration time was regulated based on the preliminary conducted test. Casted blocks were cured using wet gunny bags and water for 7 and 28 days. Cast blocks were tested to determine their dry and wet compressive strengths, dry density, and water absorption, as per SLS 1382 (Part 2) [28] as strength-related tests. Each block was placed carefully in the testing machine below the center of the upper bearing block and load was added until failure. The compressive strength was determined using the load at failure. Figure 3 shows the testing procedure and the cast blocks.



Fig. 2. Use of block making machine for CSEB production.



Fig. 3. Cast blocks and compressive test procedure.

The dry density of the blocks was determined after keeping the blocks in the oven for more than 24 hours at 105°C. Each specimen was oven-dried to a constant mass, weighed and measured to determine its dry density which was calculated by:

$$D_d = \frac{\text{Dry mass (Kg)}}{\text{Volume (m}^3)} \times 10^6 \quad (1)$$

To determine the water absorption of the blocks, oven-dried test specimens were immersed in water for 24 hours, and the increase in the mass of each specimen was calculated and expressed as a percentage of the specimen's initial dry mass.

$$W = \frac{\text{Saturated surface dry mass (g)} - \text{Oven dry mass (g)}}{\text{Oven dry mass (g)}} \times 100 \quad (2)$$

IV. RESULTS AND DISCUSSION

The used original soil consists of 5% finer and its grading shows it as a fine-grained soil. So, gravel had to be added to fit the grading into the optimization curve. Then, finer content got to be reduced, hence separated finer should be added. Fly ash

was added to the mix as finer, and the prepared CSEBs were tested. The fly ash used for the blocks was sieved through a 0.425mm sieve. In this study, the purpose of using fly ash is to replace finer particles. Other than that, its binding properties were not considered. The specific gravity of fly ash is 2.2 and it is less than that of original soil (2.7) resulting in reduced specific gravity for the soil-fly ash mix. When mixing the soil and fly ash, the expected final particle size distribution was determined as per the power line. A maximum density line has been proposed in [29]. It gives a direction to select a correct proportion of aggregates to get the maximum density. So, to match with the power line, other than the fly ash, different size larger particles were also added to the mixture. These larger particles were earlier extracted from the same soil. Figure 4 shows the particle size distribution for fly ash, used soil, reconstitute soil and its comparison to the power line.

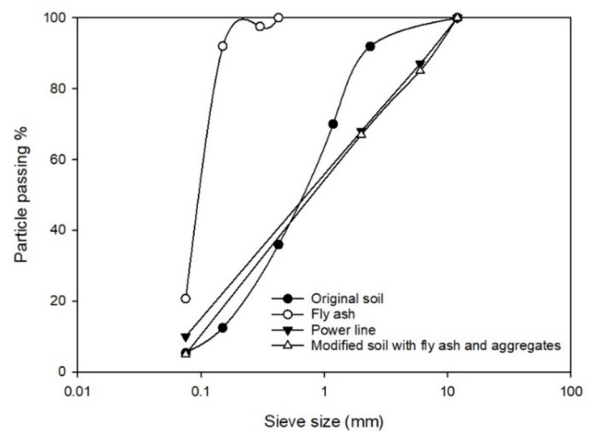


Fig. 4. Comparison of particle size distribution.

A. Properties of CSEBs with Fly Ash Replacement

Finer content was changed to 5%, 7.5%, and 10% by adding fly ash. Blocks were made with 6%, 8%, and 10% cement stabilizer. The dry compressive strength (at 7 and 28 days) and the wet compressive strength (at 28 days) of blocks made with fly ash as finer are shown in Figures 5-7. Considering the compressive strength results of blocks with fly ash replacement, when the cement content is 10%, high compressive strength can be achieved, irrespective of the finer content. Among the tested samples, 7.5% finer with fly ash replacement has given the highest compressive strength. The test results were compared with SLS 1382 specification for CSEBs and SLS 855 specification for cement blocks. According to the test results shown in Table II, when the cement content is 10% for all the selected finer contents, compressive strength values are above the limiting value for grade 1 CSEB (6.0N/mm² and 2.4N/mm² for dry and wet compressive strength respectively). For 5% and 7.5% finer and 8% cement, compressive strength values reached grade 2 CSEB (4.0 - 6.0N/mm² for dry compressive strength and 1.6 - 2.4N/mm² for wet compressive strength). Even with 6% cement, 7.5% finer can produce grade 3 CSEB (2.8 - 4.0N/mm² for dry compressive strength and 1.2 - 1.6N/mm² for wet compressive strength).

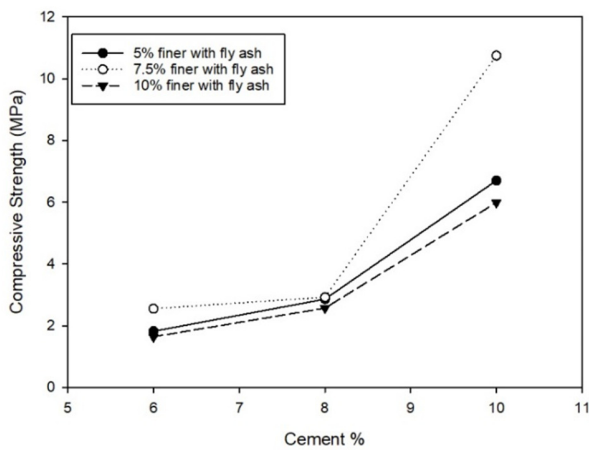


Fig. 5. 7-day dry compressive strength results of soil blocks with fly ash.

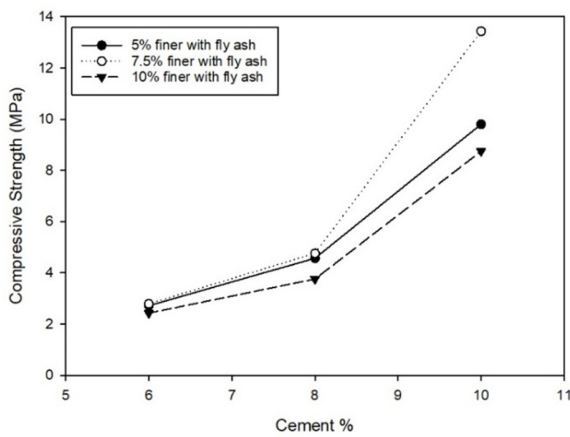


Fig. 6. 28-day dry compressive strength results of soil blocks with fly ash.

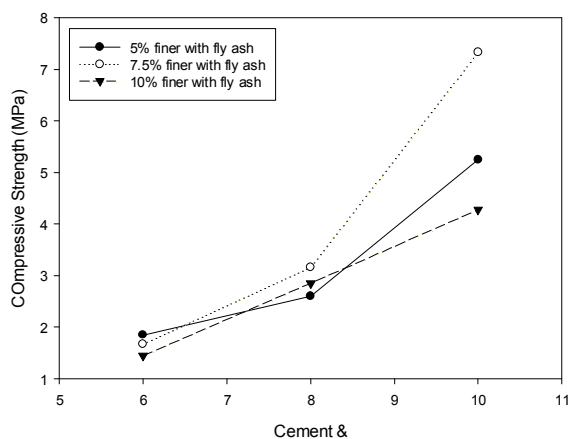


Fig. 7. 28-day wet compressive strength results of soil blocks with fly ash.

Also, the density and water absorption values (Table III) are satisfied with the specified value (1750kg/m³ and 15% respectively) in SLS 1382 Part 1. Out of all the finer contents,

7.5% finer replacement has the highest density and lowest water absorption when the cement replacement is 10%.

TABLE II. COMPRESSIVE STRENGTH RESULTS

| Cement % | | 6 | 8 | 10 |
|-------------------------|---------|-------|-------|-------|
| 5% finer with fly ash | Dry | 2.72 | 4.57 | 9.8 |
| | Wet | 1.85 | 2.6 | 5.25 |
| | Dry/wet | 0.680 | 0.569 | 0.536 |
| 7.5% finer with fly ash | Dry | 2.79 | 4.76 | 13.43 |
| | Wet | 1.67 | 3.16 | 7.35 |
| | Dry/wet | 0.599 | 0.664 | 0.546 |
| 10% finer with fly ash | Dry | 2.43 | 3.76 | 8.75 |
| | Wet | 1.45 | 2.85 | 4.28 |
| | Dry/wet | 0.597 | 0.758 | 0.489 |

TABLE III. DENSITY AND WATER ABSORPTION RESULTS

| Cement % | | 6 | 8 | 10 |
|-------------------------|------------------------------|-------|-------|-------|
| 5% finer with fly ash | Density (kg/m ³) | 1968 | 1903 | 1943 |
| | Water absorption % | 10.33 | 11.28 | 9.34 |
| 7.5% finer with fly ash | Density (kg/m ³) | 1865 | 1833 | 2074 |
| | Water absorption % | 11.40 | 12.40 | 6.32 |
| 10% finer with fly ash | Density (kg/m ³) | 1761 | 1778 | 1912 |
| | Water absorption % | 13.89 | 13.77 | 11.54 |

V. CONCLUSIONS

The current study used the abundantly available soil with high silt and clay (finer) content. The reduction of excessive finer was done by washing the soil. Then, the study focused on replacing the silt and clay content in the soil with fly ash for CSEB production. Also, soil grading was modified to fit into the optimization curves as explained in particle packing theories. The use of the washing method for finer reduction and the use of traditional cement sand block making machines for block production do not require highly technical skills. Hence, the local construction industry can use this method easily. The most notable findings of the present study are:

- With 10% cement stabilization, CSEBs with all fly ash addition achieved high values of dry and wet compressive strengths, satisfying the Grade 1 requirements.
- 8% cement stabilization gives compressive strength values of Grade 2 blocks for all fly ash addition percentages.
- Even with 6% cement stabilization, 7.5% fly ash addition gives compressive strength in the Grade 3 range.
- All the blocks, irrespective of the cement and fly ash content, have densities and water absorption values that satisfy the SLS 1382 requirements.

The studies [12, 16] showed similar behavior of blocks' compressive strengths. Both studies showed that 10% cement usage for block production leads to high compressive strength. Authors in [7] also recommended 10% as the highest cement percentage considering the financial aspect. Further, 7.5% finer contained soil contributes to improved properties compared to

5% and 10% finer contributions. Based on the obtained results, this study suggests the washing of soil as a novel method to reduce its finer content for soil block production. Finally, it can be concluded that the addition of fly ash as finer results to the improvement of the properties of CSEBs.

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