Enhancing Properties of Compressed Stabilized Earth Blocks Using Pet Fibres

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Abstract. Compressed stabilized earth blocks (CSEBs) are an earthen building material made from soil, cement, and water. CSEB can be considered as an environmentally friendly and sustainable alternative to traditional bricks and cement blocks. Since the main raw material of CSEB is soil, the clay content in the soil greatly affects its strength and durability. Hence fibre can be used to improve ductility and toughness. This study provides an experimental analysis of the properties of CSEBs reinforced with PET (Polyethylene Terephthalate) fibres. Further controlling of soil gradation was carried out by using construction waste and applying the particle packing optimization concept. Furthermore, the study highlights soil gradation was adjusted to match the optimization curve for producing CSEBs. To compare dry and wet compressive strength, water absorption, and dry density with SLS 1382:PART 1 requirement, test cubes (150mmx150mmx150mm) were cast with 20% finer content and 10% cement for different PET fibre lengths (1cm, 2cm, 3cm,4cm) and different PET fibre percentages by weight (0.1%,0.2%,0.3%,0.4%). Out of the test cubes, 0.4 weight percentage and 2cm length PET-reinforced CSEB were selected as optimum. So, with those results optimum industrial blocks(356mmx178mmx102mm), were cast and industrial scale blocks results satisfied Grade 1 SLS 1382: PART 1 requirement. This study also concerns the cost-effectiveness of the blocks.

Keywords: Compressed stabilized earth blocks · Compressive strength · Construction waste · Particle packing optimization · Soil modification · PET fibres

1 Introduction

Earth is the oldest building material known. For centuries, earth has been used in different forms such as mud, adobe, rammed earth and bricks. With the growing concern of awareness regarding environmental and ecological issues, the possible alternatives for traditional building materials such as burnt bricks, and cement blocks are compressed earth cement blocks or cement-stabilized earth blocks (CSEB) (Thanushan and

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Sathiparan, 2022). CSEBs possess high compressive strength, similar to conventional masonry materials, and can be used for load-bearing walls. Since the main raw material for CSEB production is soil, the clay content in the soil greatly affects its strength and durability (Malkanthi and Perera, 2018). Moisture causes for reducing the strength of CSEB. However, past research stated that compressive strength increased with decreasing clay content and higher cement content. These studies set a minimum limit of 15% for clay content (Heathcote, 1991). According to their experiments, compressive strength increases with decreasing finer content for varying amounts of cement. (Walker, 1995) concluded that high compressive strength can be achieved with a low plasticity index and 10% cement content, however only when the soil has a minimum clay content of 15%. A compressive strength of over 10 N/mm2 has also been found when the clay content is between 10% and 15%, even with a low plasticity index.

On the other hand, PET contributes a more significant percentage to the plastic waste stream. The concept of using fibres as reinforcement is not a new concept for CSEB. The incorporation of fibres into the soil can significantly enhance its resistance against non-elastic shrinkage, cracking, and impacts, thereby increasing its rigidity (Jesudass et al., 2021). Reduced clay and silt content in the soil is a critical factor in enhancing the durability issues associated with CSEB. Hence, adjusting soil gradation to match the optimization curve for producing CSEB is an advantageous concept (Malkanthi and Perera, 2019), (Malkanthi, Wickramasinghe and Perera, 2021). However, the reduction of clay and silt content has limitations. Hence, adding natural or synthetic fibers enhances the properties of CSEB (Malkanthi et al., 2024). It was likely that further research was needed to investigate the specific use of PET fibres in combination with the modification of soil gradation for CSEB production.

The main aim of this research is to investigate the suitability of using construction waste and waste fibre to enhance the properties of the CSEB with the concern of cost. Further, the study focused on applying the particle packing optimization concept for soil grade modification. Construction waste mainly with crushed concrete was used to modify the soil gradation while PET fibre was used as reinforcement to enhance the properties of CSEB. With that background, the research objectives are, to identify the optimum PET fibre content to enhance the properties of CSEB and to determine the cost-effectiveness of CSEB with PET fibre.

2 Research Methodology

2.1 Soil Selection

The soil samples were taken from a borrow pit in Hapugala, Galle, Southern Province of Sri Lanka. Dry and wet sieve analysis and Atterberg tests were performed to determine the finer percentage, total particle size distribution, specific gravity, and plasticity index (PI) of soil. The selected soil showed 30.7% clay and silt content. Furthermore, it had a Plasticity Index of 8. According to the SLS1382:PART 1 requirements (Sri Lanka Standard Institution, 2010), Soil should be selected with a finer percentage of less than 35% and PI of less than 12. Past studies also mentioned that soil with a plasticity index of less than 15 is suitable for CSEB production (Walker, 1995), (Raj et al., 2017). So, the selected soil is suitable for CSEB production. Many previous studies have proven that the clay and slit content in the soil should be less than 35% (Nagaraj, Rajesh and Sravan, 2016), (Venkatarama Reddy and Latha, 2014), (Jayasinghe and Perera, 1999).

2.2 Soil Modification by Particle Packing Optimization

Since the low clay and silt content in the soil is preferred for CSEB production, past researchers have suggested different methods to modify the soil gradation. (Fitzmaurice, 1958) says, there is a possibility that unsuitable soil could be modified by adding sand when there is an excess of clay or silt. However, there could be economic issues since sand is comparatively expensive. Some researchers have studied alternative materials such as coal ash and cassava peels (Villamizar et al., 2012), sugarcane bagasse and lime (Alavéz-Ramírez et al., 2012), cork granules (Guettala, 2016) that can be used to lower the clay and silt content instead of adding sand to reduce the finer content. Preliminary testing carried out by (Malkanthi and Perera, 2018) has shown that soil washing can be used to reduce the clay and silt content in the soil. They showed that soil having up to a minimum of 5% clay and silt content could be used for CSEB production and it gives significant strength and durability properties.

Other than the amount of clay and silt content, the soil gradation is also an influential factor for the properties of CSEB. Even if the soil properties are dominant, different particle combinations are available here. For the appropriate sizes and shapes of aggregates, particle packing technology is vital in concrete technology. This particle packing technology considers optimizing the correct sizes and amounts of various particles to increase particle density (Fenis and Walraven 2010). So this concept which is shown in Figure is used to adjust the particle size distribution of soil to the ideal grading curve which indicates grading with the greatest density (Senthil Kumar V and Manu Santhanam, 2003) (Fig. 1).

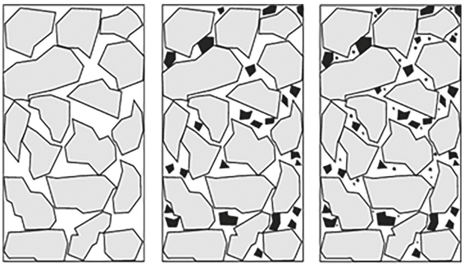

Fig. 1. The concept of particle packing

When considering optimization curves, optimum packing grading curves were tried by many researchers for different purposes (Wong and Chan, 2013), (Hettiarachchi and Mampearachchi, 2019). So, Fuller's curve is based on a correlation between the small and large particle distribution in the soil (Fennis and Walraven, 2012), (Borges et al., 2014). The Fuller's curve theory is shown in Eq. 1 and its modification performed by Funk and Dinger is shown in Eq. 2. (Malkanthi and Perera, 2019) have proved this concept is applicable to CSEB production too.

$$\mathrm{P}(d) = \left(\frac{d}{d_{\max}}\right)^{q} \quad (1)$$

$$P(d) = \frac{d_{\max}^{q} - d_{\min}^{q}}{d^{q} - d_{\min}^{q}} \quad (2)$$

P(d) = size cumulative distribution function.
d = considered particle diameter.
d_{max}= maximum particle diameter in the mixture.
q = parameter (0.33–0.5) which adjusts the curve for fineness or coarseness.
$d_{\min}$=minimum particle diameter in the mixture (m).

By using these equations, optimization curves were drawn and the particle size distribution of the selected soil sample was also plotted in the same plot which is shown in Fig. 2.

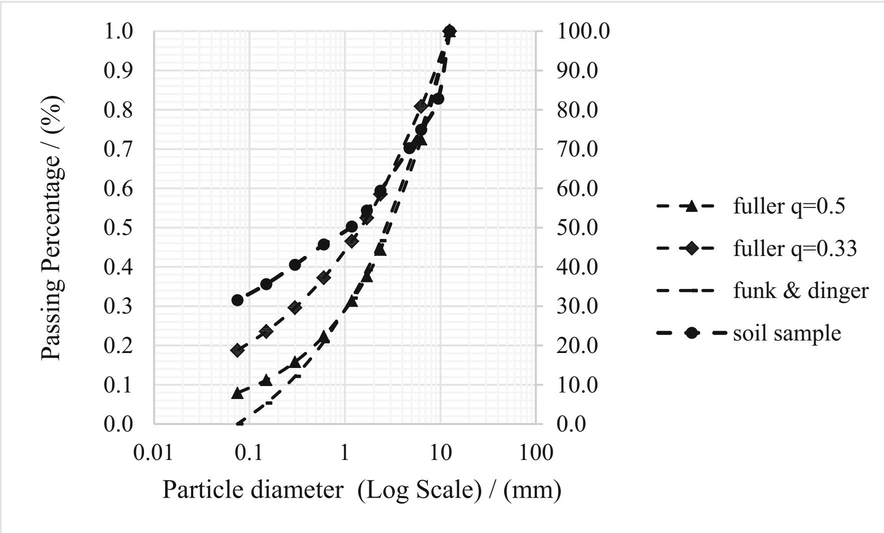

Fig. 2. Particle size distribution of soils with theoretical curves

By comparing these optimization curves, soil modification was carried out by adding construction waste to reduce the clay and silt content from 30.7% to 20%.

2.3 CSEBs Casting

CSEB cube was cast for the selected mix design in the size of 150mm × 150mm × 150mm mold, For preliminary laboratory testing, the control cube was cast only by mixing construction waste with soil and cement. So, sixteen mix proportions were designed with 20% clay and silt contents in the modified soil with a cement content of 10%.

PET fibres were used with different lengths (1cm, 2cm, 3cm, 4cm) and different fibre percentages by weight (0.1%,0.2%,0.3%,0.4%). 10% of water of total weight was used for mixing. Initial curing was carried out within 7 days by using gunny bags and final curing was performed within 28 days by exposing them to the environment.

2.4 Testing of Test Blocks

Cast blocks were tested for 28 days of dry and wet compressive strength, dry density and water absorption. The cubes were placed in a water bath for 24 h before wet compressive strength testing. The results were compared with the requirements in SLS 1382 Part 1.

The optimal mix proportion of the CSEB was used to cast blocks on an industrial scale. The cost estimation was then carried out for these industrial-scale blocks. Finally, it was compared to the market-available cement sand block and brick. The proposed final dimensions for the CSEB block are 356 $mm\times$ 178 $mm\times$ 356 mm. Moreover, the cost estimation for wall construction was calculated for a unit area for CSEB, cement block and burnt brick.

3 Results and Discussion

Table 1 shows the results of the control blocks. Figure 3 and Fig. 4 show the dry and wet compressive strengths of blocks for different weight percentages and different lengths of PET fibre. It has been realized that all the results are greater than the control sample's results.

Table 1. Properties of the control samples

Dry compressive strength (MPa)	Wet compressive strength (MPa)	Dry weight (g)	Dry density (kg/m^3)	Water absorption (%)
3.5	2.0	5,354	1,586	6.75

The dry and wet compressive strengths exhibit similar trends. The results indicate that cubes reinforced with a low weight percentage of PET fibers have lower dry and wet compressive strengths. However, as the fiber weight percentage increases, both strengths improve. This trend is particularly noticeable for shorter PET fibers. For 1 cm PET fibers, the dry compressive strength values for 0.1 wt.%, 0.2 wt.%, 0.3 wt.%, and 0.4 wt.% are 4 MPa, 7.75 MPa, 10.67 MPa, and 13.20 MPa, respectively. A similar relationship is observed for 2 cm fibers. Likewise, the wet compressive strength values for 1 cm PET fibers at the same weight percentages are 3.3 MPa, 4.7 MPa, 7.47 MPa, and 9.6 MPa, with 2 cm fibers following the same pattern. The highest dry and wet compressive strengths were achieved with 2 cm fibers for all fiber percentages except 0.1%. However, for fiber percentage optimization, the maximum strength was recorded at a fiber length of 3 cm.

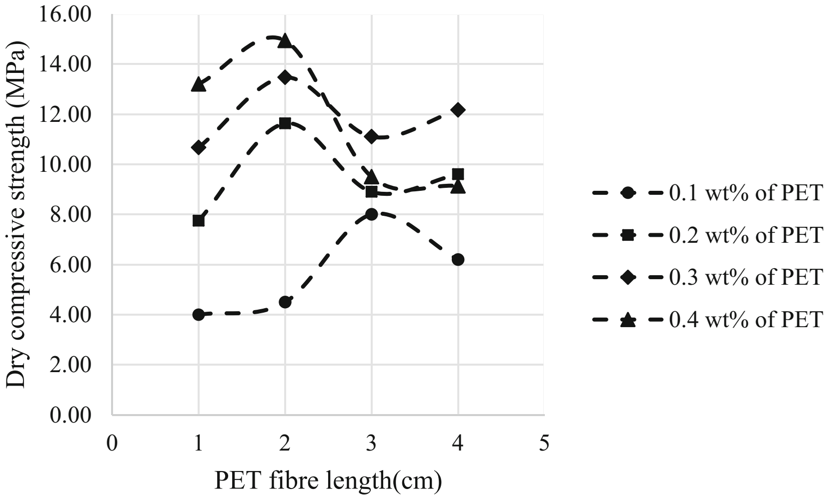

Fig. 3. Dry compressive strength of soil blocks with varying fibre length and weight

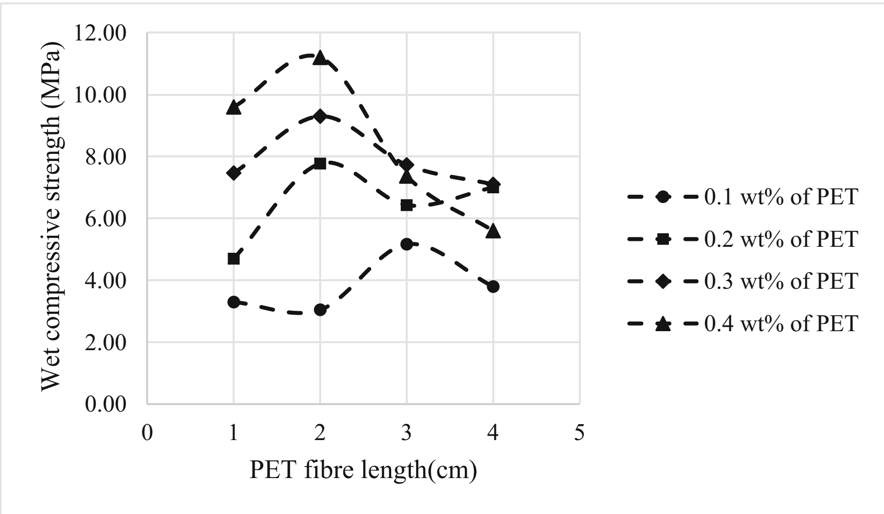

Fig. 4. Wet compressive strength of soil blocks with varying fibre length and weight

These findings suggest that, for shorter PET fibers, increasing fiber content leads to an improvement in both dry and wet compressive strengths. That is because shorter PET fibers are more evenly distributed throughout the matrix, creating a denser and more interconnected network. This improved distribution enhances the bond between the fibers and the cementitious material, allowing for better stress transfer and resistance to cracking. Further, PET fibers act as reinforcement within the matrix by bridging microcracks. As fiber content increases, more fibers are available to resist crack propagation, thereby improving the overall strength of the material. This relationship was proved by Muhit by using plastic dust (Muhit, 2013).

But in a particular length, there are some variations when the fiber content increases. When weight percentage increases from 0.1% to 0.4%, first it indicates a significant increase and then a notable drop then it completes with a marginal uptick. So the reason for this is when it comes to the 0.3% or 0.4% with a long length the PET fiber clumps together and forms a large ball (Muhit, 2013). So, 0.3% of combinations have this problem in 2cm, 3cm and 4cm CSEBs. But comparatively 1cm fibres neither formed a ball nor clamped together. The reason for the marginal uptick is when mixing it's easy to find the bigger ball which is made by 4cm PET than 3cm.

According to SLS 1382 requirements, 6.0 MPa, 4.0 MPa, and 2.8 MPa are the dry compressive strength limits for Grade 1, Grade 2, and Grade 3, respectively. 2.4 MPa, 1.6 MPa, and 1.2 MPa are the wet compressive strength limits for Grade 1, Grade 2. And Grade 3, respectively. Therefore, it can be concluded that dry and wet compressive strength values of this CSEB fall at least under Grade 3 blocks.

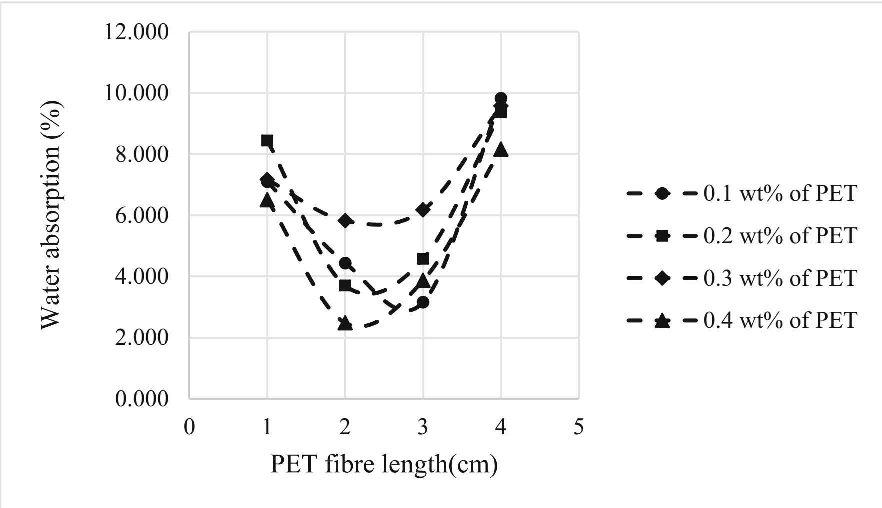

Fig. 5. Water absorption of soil blocks with varying fibre length and weight

Water absorption is the main parameter to measure the durability of blocks. The amount of water absorption depends on the type of soil used and is related to the compressive strength (Malkanthi and Perera, 2018). Figure 5 shows the water absorption variation of soil blocks with varying fibre lengths and weights. So, because of the same soil used in these blocks, it can be concluded that the water absorption changes relate to the compressive strength and it can be seen that the optimum value among 16 combinations for dry and wet strength have the least water absorption and lesser compressive strength also has higher water absorption. According to Fig. 5, all the water absorption values are less than 15% which satisfies the SLS 1382 requirements.

For all the combinations except one (2 cm length and 0.1 wt%) dry density values are between 1,887 kg/m^3 (for 4 cm and 0.1wt%) and 2,138 kg/m^3 (2cm and 0.4wt%). From these results, 0.4wt.% 2 cm combination was selected as the optimum mix proportion (design). Industrial blocks were cast with this optimum combination and the results are shown in Table 2.

Table 2. Results of the industrial-scale CSEB block

Dry compressive strength (MPa)	Wet compressive strength (MPa)	Water absorption (%)	Dry density (kg/m^3)	Grade according to SLS standard
9.13	7.10	9.8	1436.8	Grade 1

According to the cost estimation, unit CSEB manufacturing cost is Rs.89.00 and it is around 22% price reduction of the present market price of cement blocks in Sri Lanka. The unit rate calculation of 1m^2 wall panel with 4-inch thickness of CSEB, cement block and brick were Rs.2,923.00, Rs.3,000.00, and Rs.3,478.00 respectively. Comparing the cost of 1m^2 wall panel from CSEB, the cost reduction percentages of cement block wall and brick wall are 2.63% and 18.96% respectively.

4 Conclusion and Future Directions

The experimental results obtained through the research study showed that the optimum values for dry compressive strength, wet compressive strength, dry density and water absorption were achieved for 0.4wt % and 2 cm length PET fibre-reinforced CSEB. Further, results highlighted that compressive strengths increase with the increase of fibre content when the fibre length is small. Industrially CSEB can have significant production cost reduction compared to cement blocks. The cost reduction compared to cement block and brick is 2.63% and 18.96% respectively for wall construction.

Further, the value of the dry and wet compressive strengths is relatively higher than the SLS Grade 1 standard. So, reducing the cement percentage from 10% to 8% also can achieve the grade 1 SLS recommended CSEBs. So, this will help to further reduce the cost. In this research, PET fiber didn't blend with the mix. So, Investigating PET fiber blending techniques and blending effect to strength variation will be conducted as future research.

Because of the cement addition for stabilization purposes PET fibers have the opportunity to degrade in the long term. Therefore, investigations of degradation and its impact on the CSEBs can be carried out in the future. The PET fiber-reinforced CSEBs have more strength than other fiber-reinforced CSEBs compared to the past literature. Thus, it is crucial to conduct long-term durability and water erosion tests before introducing it to the industry. Additionally, some difficulties came across during the casting process, particularly in maintaining the uniform distribution of PET fibers and generation of dust during production. So, research addressing these issues will be welcomed.

Finally, for a sustainable future, social awareness should be spread to increase confidence in CSEBs presenting successful projects.

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