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Optimising the mix design of earth blocks using recylced clay brick aggregate

Karel van Rooyen (1), Griffin Surendra (1) Janina P. Kanjee (1) and Ryan A. Bradley (1)

(1) School of Civil and Environmental Engineering, University of Witwatersrand

Abstract

This study focuses on the production of compressed stabilised earth blocks (CSEBs) incorporating waste in the form of crushed recycled masonry clay bricks. The primary aim is to optimise the mix design of earth blocks by improving the particle size distribution of the constituent soil. Herein, the effect of modifying a soil deficient in fine particles, i.e., a poorly graded soil, is considered. The earth blocks were produced with soil classified as SW (USCS), obtained from a construction site located on the premises of the University of Witwatersrand, Johannesburg. Waste clay bricks were obtained from a local demolition site and were, subsequently, crushed and separated according to particle size. The earth blocks were produced with a constant 5% cement, by mass, with different amounts of waste materials substituted for soil, i.e., crushed masonry brick incorporated at 20%, 30% and 40% by dry mass. The compressive strength, water absorption, and wetting and drying deformation tests were conducted after 28 days of curing to assess the performance of the earth blocks. In all cases, the addition of waste clay brick particles resulted in increased compressive strength of CSEBs. The optimum addition of waste material was observed at 30%, which yielded a compressive strength of 2.9 MPa. The water absorption and the wetting and drying deformations were only affected with waste additions in excess of 30% to the soil mixture. It can be concluded that incorporating recycled crushed masonry clay brick particles in the production of CSEBs resulted in an improvement of the soil grading as well as the mechanical properties of the units.

Keywords: Earth blocks, masonry clay bricks, construction waste, sustainability, recycling

1. INTRODUCTION

Addressing the insufficient availability and quality of affordable housing is a critical concern for the expanding population of South Africa. Utilising local soil and waste to produce good quality bricks is one low-cost solution that may help in tackling the problem. The South African state of waste report indicates that there are 55 million tonnes of waste in the country, with 8% coming from construction and demolition waste, amounting to roughly 4.4 million tonnes [1]. As more buildings are constructed and demolished due to industrialisation, waste materials such as clay masonry bricks are becoming more abundant. However, by finding uses for these materials, we can encourage better sustainability by reducing the amount of waste in landfills [2]. This can be achieved by incorporating recycled construction waste into the production of new construction materials, thus reducing the demand for natural resources.

Compressed earth blocks are made from inorganic subsoil. These blocks can be made by mechanically compressing damp soil in a mould and then leaving them to air dry. Stabilisation with a chemical binder like Portland cement or lime can increase the strength and durability of the blocks and make them more water resistant [3].

This study aims to explore the potential of using recycled clay masonry brick aggregate in the production of earth blocks. To achieve this, the mix design of the soil is optimised by carefully considering the particle size distribution of the soil and adding recycled clay masonry bricks to fill the missing particle sizes, thereby creating a more well-graded soil. Through this process, we aim to investigate how modifying the soil grading affects the properties of the blocks. By using this approach, we can potentially contribute towards addressing the housing shortage in South Africa, while simultaneously promoting sustainability and reducing waste.

2. MATERIALS AND TEST METHODS

2.1 Characterisation of Inorganic Subsoil Used in Earth Blocks

Soil located more than 1 meter below the surface and free from organic materials was sourced from a construction site, located at The University of the Witwatersrand, for use in the production of earth blocks. The soil was sieved through an 8-10mm aperture size to remove large rocks and other unwanted debris, such as organic materials. A sieve analysis was then conducted according to SANS 1083 [4] to determine the particle size distribution and identify any missing particle sizes. The soil was also classified using the Unified Soil Classification System (USCS), and it was found to be SW, which is well-graded sands and gravelly sands with little or no fines.

Furthermore, the Atterberg limits of the soil were determined and are presented in Table 1. According to Burroughs [5], the most suitable soils for earth block production should have a plasticity index (PI) of less than 15%, sand content of less than 64%, and clay and silt content between 20% and 35%. Based on the broad criteria outlined by Burroughs [5], the soil obtained from the construction site is lacking in fines content but is otherwise suitable for the production of earth bricks.

Table 1: Soil characteristics of inorganic subsoil used in Earth Blocks

LL (%)	PL (%)	PI (%)	Fines (%)	Sand (%)	Gravel (%)	USCS
27	22	4	1	60	39	SW

2.2 Optimised Soil Grading Curve of Inorganic Subsoil Used in Earth Blocks

The soil grading was optimised by determining the maximum density grading using Equation 1 (which is the size cumulative distribution function). The resulting curves are plotted in Figure 1.

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

Where: d = particle diameter being considered
d_{max} = maximum particle diameter in the mixture
n = exponent (0.33–0.5), which adjusts the curve for fineness or coarseness.

To optimise the particle size distribution of the soil, crushed clay masonry rubble bricks (CMRB) were added in varying proportions. This was done to adjust the particle distribution curve so that it would align as closely as possible with the optimisation Fuller curves. Specifically, the particle sizes between 1.18mm and 0.075mm were targeted for an increase, with proportions of 20%, 30%, and 40% of the total soil mass utilised.

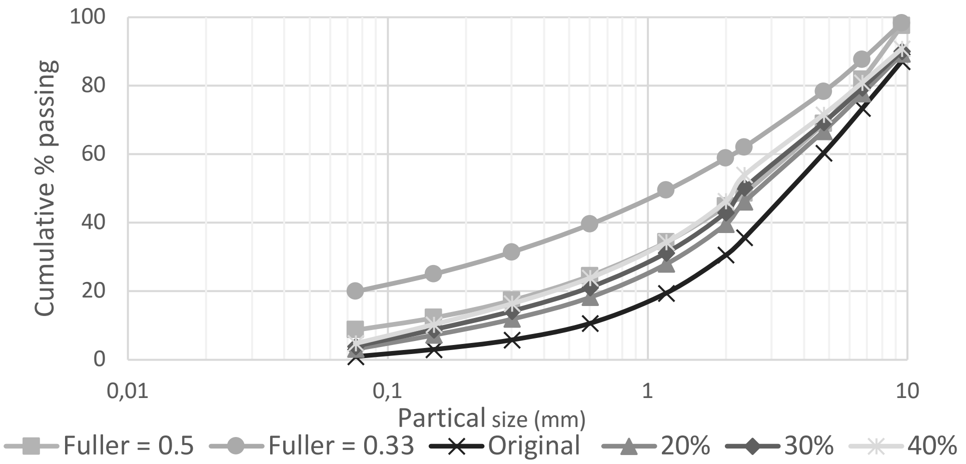

Figure 1: Optimised soil grading curves incorporating crushed clay masonry rubble bricks in proportions based on maximum density grading

2.3 Compressed Stabilised Earth Blocks (CSEB)

2.3.1 Clay masonry rubble bricks (CMRB) as fine particle addition in earth blocks

Recycled clay masonry rubble bricks were sourced from a local demolition site, crushed and used in the production of the earth blocks. Prior to crushing the bricks, excess mortar and paint (physical impurities) were removed from the CMRB using a hammer and chisel. The CMRB were then mechanically crushed to produce particle size varying from 1.18mm to the pan (<0.075mm).

2.3.2 Stabiliser used in the production of earth blocks

To bind the earth blocks, 42.5R Portland cement was used. Literature has shown an optimal cement content of 5 – 12%; however, a decision has been made to use the lowest amount of 5% as the overall objective is to reduce cost and be more sustainable.

2.3.3 Production of compressed stabilised earth blocks (CSEB)

Five different earth block mixes were investigated, and Table 2 provides a summary of the details of the mix design. Three earth blocks per mix were used for each test type to get an average result. To prepare the Earth block mixture, soil was mixed in a pan-mixer and water was subsequently added by sprinkling over the top to avoid “balling” of the material. The water content was determined to be 18%. For the production of each blocks, approximately

6kg of material was loaded into a Hydraform M7E380V block-making machine and pressed at 10MPa (or 100 bar) from the bottom up. A masonry unit with size 250×140×90 mm was adopted in the present study.

Table 2: Compressed stabilised earth blocks proportions

Mix no.	Label	Stabiliser	CMRB
Mix 1	0C0	0% Cement	0%
Mix 2	5C0	5% Cement	0%
Mix 3	5C20	5% Cement	20%
Mix 4	5C30	5% Cement	30%
Mix 5	5C40	5% Cement	40%

2.3.4 Curing of compressed stabilised earth blocks (CSEB)

The compressed stabilised earth blocks were moist cured by spraying water on them using a watering canister at the same time each day for 28 days.

2.4 Testing Approach

2.4.1 Compressive strength

The compressive strength of Compressed Stabilized Earth Blocks (CSEB) is a crucial mechanical characteristic that determines their suitability for construction. The compression strength test is the most widely used method for evaluating this parameter, as noted by Fetra [6]. Both the 28-day wet and dry compressive strength tests were performed. The blocks used for the wet compression test were submerged in water for 24-hours on 27th day of curing before being crushed. The blocks were loaded using a Amsler compression machine, which has a maximum loading capacity of 2 000 kN.

2.4.2 Water absorption

Measuring moisture content is critical, and the parameter is influenced by the clay and cement content in the soil. To determine the moisture content, the weights of the earth blocks were measured in their cured state at 28 days. Subsequently, the blocks were placed in an oven at 70°C for 24 hours to dry out, and were then allowed to stabilize for an hour before being weighed again. To evaluate the ability of the blocks to absorb water, the units were submerged in water for 24 hours, and any excess water was removed with a cloth before weighing. To ensure that accurate saturation conditions were achieved, the blocks were weighed within a minute of being removed from the water. Equation 2 was used to calculate the moisture content in both the cured and wet states.

$$Moisture\ content\ (\%) = \frac{(M_W - M_0)}{M_0} X\ 100 \quad (2)$$

Where: M_w - mass of the saturated block

M_o - mass of the oven dry block

2.4.3 Deformation

Wet and dry deformations are useful parameters because they reveal the extremities of dimensional changes under certain conditions. To measure dimensional deformation, both drying and wetting conditions were evaluated after 28 days. A digital vernier caliper was used to measure the length, width, and height of the blocks. For the drying shrinkage assessment, dimensional changes were recorded for the cured earth blocks at 28 days. The blocks were then placed in an oven at 70°C for 24 hours to dry out and were allowed to stabilize for an hour before being measured again.

To assess wetting shrinkage, the dimensional changes were measured after the dry earth blocks were submerged in water for 24 hours. The blocks were then removed from the water, excess water was removed with a cloth, and they were measured again. Equations 3 & 4 were used to calculate both wetting and drying deformations.

$$Wetting\ deformation = W - D \tag{3}$$

$$Drying\ deformation = D - W \tag{4}$$

Where: D - oven dry length
W - wet length
C - length in cured state

3. RESULTS AND DISCUSSION

3.1 Compressive Strength of Compressed Stabilised Earth Blocks

In general, the compressive strength is observed to be higher in dry specimens compared to the wet specimen. This results can be attributed to development of pore water pressure which decreases the contact forces between particles and also the effective stress in wet specimens. The largest reduction is strength, due to wetting, corresponds to the 5C40 specimens (Figure 3), which may be explained by the adsorptive nature of clay particles. This aspect is discussed further in section 3.2.

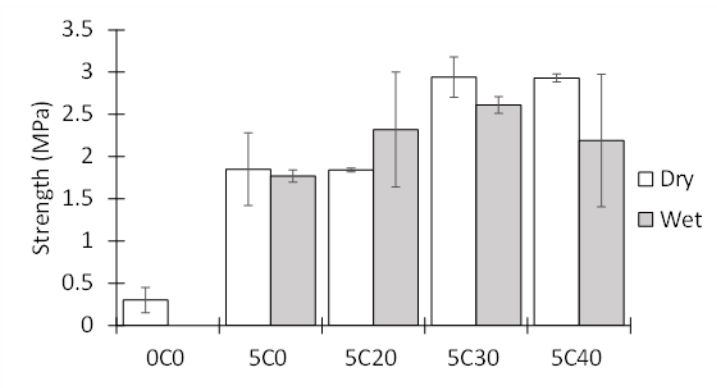

Figure 2: Compressive strength of compressed stabilised earth blocks incorporating 20%, 30% and 40% of the total soil mass as CMRB as fines aggregates at 28 days

From Figure 3, for the dry CSEBs, there is a drastic increase in compressive strength is observed from 0% cement to 5% cement being added. This is due to the hydration of Portland cement leading to the formation of calcium silicate hydrates particles, contributing to the hardening of the CSEB. Compared to the 5C0 mix there was a 0.01 MPa decrease, 1.09 MPa increase and 1.08 MPa increase for 5C20, 5C30 and 5C40 mixes respectively.

It is notable that there was no compressive strength recorded for 0% cement wet specimens as these specimens dissolved in the water baths due to there being no binder present. For the wet CSEBs, there is a gradual increase in compressive strength from 5% cement + soil to 30% waste addition and then a decrease in compressive strength of the 40% waste mixture. This observation indicates that the optimum percentage of CMRB to incorporate is 30% for both dry and wet blocks. There lies a discrepancy within the 5C20 specimen group as the wet compressive strength is higher than the dry strength, which is opposed to the expected trend observed for the other specimens. A larger sample size would better elucidate such discrepancies in future studies.

3.2 Water Absorption of Compressed Stabilised Earth Blocks

A general trend can be seen that the wet state blocks have a higher water content percentage than the cured state blocks due to them being submerged in water.

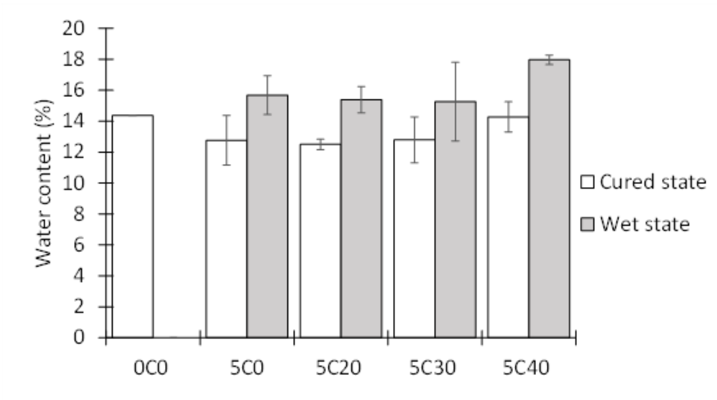

Figure 3: Water content % of compressed stabilised earth blocks incorporating 20%, 30% and 40% of the total soil mass as CMRB as fines aggregates at 28 days

The cured state blocks experienced no more than 2% change in water content when comparing the 5C20, 5C30 and 5C40 specimens to the 5C0 CMRB. For the wet state blocks, the water content percentage remained fairly constant for the first three 5% cement subgroups but increased by approximately 2% in water content for the 5C40 specimens. This shows that CMBR added between 20 and 30 % does not affect water absorption but is affected by adding waste in excess of 30%. This is possibly due to water being absorbed by the high amount of clay content from the clay masonry bricks added. Kesegic [7] noted the problem of using recycled clay bricks as an aggregate in concrete is that it has high water absorption. Zhu[8] agrees with this and noted that the porosity increased resulting in an increase in water absorption.

3.3 Deformation of Compressed Stabilised Earth Blocks

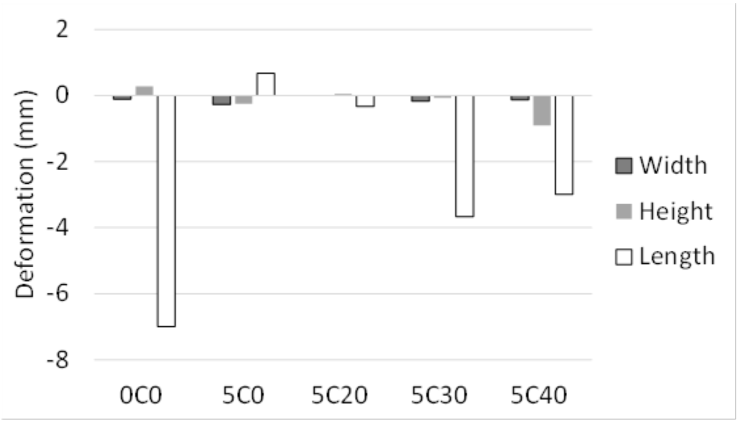

Figure 4: Drying deformation of compressed stabilised earth blocks incorporating 20%, 30% and 40% of the total soil mass as CMRB as fines aggregates at 28 days

There is a decrease in width, height and specifically the length for majority of the CSEBs for drying deformations with addition of CMRBs.

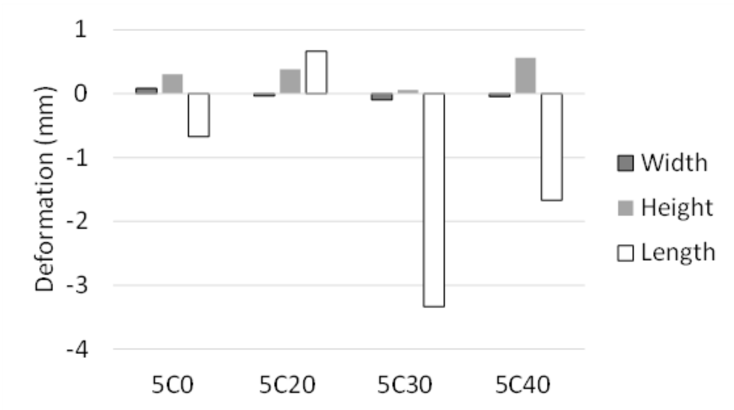

Figure 5: Wetting deformation of compressed stabilised earth blocks incorporating 20%, 30% and 40% of the total soil mass as CMRB as fines aggregates at 28 days

There is a decrease in length for bricks 5C30 and 5C40. A further investigation is needed to provide a clear and plausible explanation for these results.

4. CONCLUSIONS

This research project examined incorporating recycled CMRBs in the production of earth blocks. The mix design was optimised by giving attention to the particle size distribution of the soil. The effects of modifying the soil grading by adding recycled clay masonry bricks for the missing particle sizes forming a more well-graded soil were investigated. The properties tested include compressive strength, water absorption and deformation. The results are summarised below:

- There was an increase in compressive strength from the mixes containing CMRB compared to the mix with no CMRB addition. This is possibly due to the particle packing theory being applied which increased the density and also due to the pozzolanic activity of the calcined clay brick powder. The optimum mixture for a 5% cement content earth block was found to be 30% of CMRB addition which yielded a compressive strength of 2.94 MPa: a roughly 50 % increase in strength over the control specimen.

- The CSEBs with 20% and 30% of CMRBs were not significantly affected by water absorption. The results, however, do show that water absorption and strength reduction were greatest for the 5C40 specimens. The results indicate possible durability issues with high concentration of CMRB replacement, which warrants further study.

In summary, the results suggest that recycled CMRB has the potential to be used as a constituent in optimising the mix design of compressed stabilised earth blocks, resulting in improved mechanical properties of the units. However, further testing is necessary to assess the long-term mechanical and durability properties of earth blocks incorporating CMRB.

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