

Determining the Optimal Percentage of Rice Husk Ash for Compressed Earth Blocks: To Enhance the Compressive Strength and Thermal Insulation Properties

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Abstract

This study investigates the potential of using Rice Husk Ash (RHA) in the production of Compressed Stabilized Earth Blocks (CSEBs) as a sustainable alternative to traditional building materials. RHA, a waste product from rice production offers both environmental and economic benefits when used as a stabilizer in compressed earth blocks. The performance of CSEBs was assessed in terms of compressive strength at various percentages of RHA by weight of dry soil. The results showed significant improvements in compressive strength compared to unstabilized samples due to the addition of RHA and the optimal RHA content was found to be 7.5% at which the compressive strength was found as 2.51 N/mm². Furthermore, the effect of RHA on dimensional characteristics, shrinkage analysis, and thermal conductivity of CSEBs was studied. CSEBs had a non-linear effect on dimensional characteristics as initially the block volume decreased upto the inclusion of 3.5% of RHA content but then it gradually increased and for RHA of 11.5 % the volume of CSEBs was similar to the block volume observed before the curing period. The shrinkage analysis showed that CSEBs with 0% RHA experienced the highest shrinkage of 8.15 % of its original volume. By increasing the percentage of RHA, shrinkage was reduced and for RHA content of 11.5%, shrinkage was almost zero. Thermal conductivity of CSEB samples was also measured and the results showed that the values ranged from 0.68 – 0.84 W/m.K. The minimum thermal conductivity was observed for 9.5 % RHA enhanced CSEBs, with a value of 0.68 W/m.K. Also the manually compacted CSEB samples outperformed the blocks where no compaction load was applied in terms of compressive strength and thermal conductivity. Therefore, an optimum RHA percentage of 7.5 % was found to offer a favourable balance between compressive strength and thermal insulation, with a thermal conductivity of 0.71 W/m.K.

Keywords: Compressed stabilized earth blocks, Rice husk ash, Compressive strength, Thermal conductivity, Sustainable construction, Stabilization, Agricultural waste utilization.

1. Introduction

Bricks have been a cornerstone of construction for centuries, providing structural integrity, aesthetic appeal and durability to buildings across cultures and civilizations (Almusaed and Almssad 2023; Yadav 2023; Omondi 2024; Ugochukwu and Chukwuma 2025). From ancient monuments to modern skyscrapers, bricks have played an important role in shaping the architectural world (Yavuz and Sađirođlu 2016; Yue et al. 2024). The manufacturing of traditional construction materials such as concrete, steel, fired brick, plastic, etc., is cumbersome, costly and produce huge greenhouse gases which have adverse effect on our environment. The traditional burnt or fired clay bricks are manufactured in the brick kilns (Dalkılıç and Nabikođlu 2017; Souza et al. 2021; Blanca et al. 2025). The manufacturing procedure involves clay preparation, moulding, drying, and burning of bricks (Kazmi et al. 2017; Lissy et al. 2018). During the burning process, very harmful gases are emitted in the air due to burning of fuel, coal, etc., which in turn is polluting the environment at an alarming rate (Tahir and Rafique 2009; Afroz et al. 2012; Nath et al. 2018; Khan et al. 2019). It has been estimated that burning of fuel is responsible for over 90% of particulate matter (PM) emissions. Also, the brick kiln owners have been using wood for the burning process, as a result of which, there has been mass cutting of trees to obtain wood (Sampe and Pakiding 2015; Saha et al. 2021; Swaron and Uddin 2023; Nicolaou et al. 2024). Although the fired bricks are fundamental to modern construction but are associated with considerable environmental costs (Parth Vishnubhai Prajapati 2024; Olsson et al. 2025). Therefore, a sustainable alternative solution is required that reduces environmental degradation, production cost and encourages future development.

The use of Compressed Earth Blocks (CEB) as an alternative to fired bricks is gaining popularity now a days in the construction industry. CEBs offer a variety of advantages in construction including less energy consumption, easy customization, cost reduction, fire resistance and environmental sustainability (Bredenoord and Kulshreshtha 2023; Valenzuela et al. 2024). The earthen construction began to progress with the development of compressed earth blocks, resulting from a research program for affordable housing in Colombia in the 1950's (Mañi 2005; Asha Sapna and Anbalagan 2023; Pawar et al. 2023). CEBs are manufactured by following a simple procedure that involves dry and wet mixing of soil, compacting the mixed soil either with manual or mechanical press and eliminating the need for burning stage of the manufacturing process, thereby reducing the greenhouse gas emissions (E.A. Adam 2001; Chaibeddra and Kharchi 2019; Stevenson and Latif 2020; Asha Sapna and Anbalagan 2023). Compared to traditional fired bricks, CEBs can offer similar or superior thermal and acoustic properties (Srivastava et al. 2020; Stevenson and Latif 2020; Souza et al. 2021). On comparing with concrete blocks and burnt clay bricks that release 143 and 200 kg of CO₂ per ton respectively, CEBs produce only 22 kg of CO₂ per ton (Oyelami and Rooy 2016; Saeed et al. 2020; Asha Sapna and Anbalagan 2023; Tazwar et al. 2025). Several studies have reported that in most cases, CEBs are dimensionally more uniform and deliver higher strength than other earthen construction methods like adobe, cob etc. (Van Damme and Houben

2018; Stevenson and Latif 2020). However, the unstabilized CEBs are less durable. Whether by absorbing water from the ground or when exposed to rain, the durability of buildings incorporating CEBs is seriously affected leading to deterioration or erosion in the masonry (Bogas et al. 2019; Stevenson and Latif 2020; Cruz et al. 2024). Therefore, to address this problem, the soil needs to be stabilized. Stabilization improves the durability and other properties of CEBs (Stevenson and Latif 2020; Asha Sapna and Anbalagan 2023; Valenzuela et al. 2024; Cruz and Bogas 2024). Several studies have reported that by adding various natural or waste stabilizers possessing pozzolanic properties, these blocks could be stabilized without compromising their qualitative properties (Stevenson and Latif 2020; Asha Sapna and Anbalagan 2023). Some of the agricultural wastes including sugar bagasse ash, rice husk ash and palm oil fuel ash can be utilized in the form of stabilizers (Onchiri et al. 2014; Stevenson and Latif 2020; Charitha et al. 2021; Soni 2024)

Rice husk ash (RHA) is classified as a pozzolanic material due to the possession of binding enhancement properties. The chemical composition of RHA available in different countries has been studied by various researchers and it is reported that RHA comprises of more than 85-90% of amorphous silica, a non-crystalline form of silicon dioxide, comparatively higher than other agricultural wastes, constituting as an outstanding pozzolanic material (Hossain et al. 2018; Thiedeitz et al. 2020; Nzereogu et al. 2023; Barbhuiya et al. 2025). In most of the countries around the world, Rice husk is often cast aside without proper utilization. Due to this, large amount of rice husk emerging as a waste poses serious threat to the environment (Goodman 2020; Fathurahman and Surjosatyo 2022; Pradeepkumar et al. 2023; Miah et al. 2025). By utilizing rice husk in construction instead of treating it as a waste, not only it offers benefits in terms of construction but also prevents the threats to the environment associated with its disposal (Indumathi et al. 2024; Miah et al. 2025; Blayi et al. 2025). RHA is obtained from burning of rice husk at controlled or uncontrolled temperature in order to satisfy the chemical and physical requirements of mineral admixtures. Controlled combustion eliminates the carbon content, producing residue, rich in silica. The burning process is very important as it affects the grade of resulting ash (Pushpakumara and De Silva 2012; Stevenson and Latif 2020; Mounika et al. 2022; Ullah et al. 2025). The resulting material, known as rice husk ash is a valuable material with diverse applications (Adedamola Mobolanle Ojerinde 2018; Stevenson and Latif 2020; Oli and Sharma 2026).

Although previous studies have investigated the effects of RHA on various properties of CSEBs, however most of these studies are based on using RHA as a replacement (partial) for cement or clay, not as a stabilizer of its own right. Also there is a lack of comprehensive research on optimal proportion of RHA that can be used to achieve maximum strength.

The present study was aimed at assessing the effects of using RHA solely as a stabilizer (at different %ages) in the manufacturing of CSEBs so as to determine the optimum percentage of RHA at which maximum compressive strength

can be achieved and evaluate the difference between ordinary and improved CSEBs. The study was done on different parameters such as compressive strength, density, thermal conductivity, shrinkage analysis and dimensional characteristics of compressed stabilized earth blocks.

2. Materials and Methodology

2.1 Materials

2.1.1 Soil

The clayey soil which has been used in the present study was obtained from M/s Sofi Brick Kiln, Summer Burgh, Budgam, Kashmir as shown in **Fig. 1**. Initially, the collected soil was pulverized using a wooden hammer in order to ensure a uniform texture as shown in **Fig. 2**. The pulverized soil was then air dried for at least 24 hours before performing tests on the soil in order to remove excess moisture. Some laboratory tests were conducted on the soil sample as per IS (Indian Standard) codal provisions to determine the index properties of soil such as particle size distribution (**Fig. 3**), optimum moisture content and maximum dry density, specific gravity, liquid limit (**Fig. 4**) and plastic limit of soil. The index properties of the selected soil are shown in Table 1.



Fig.1 Clayey soil selected for compressed earth block manufacturing process



Fig. 2 Pulverization of soil using wooden hammer to ensure a uniform texture

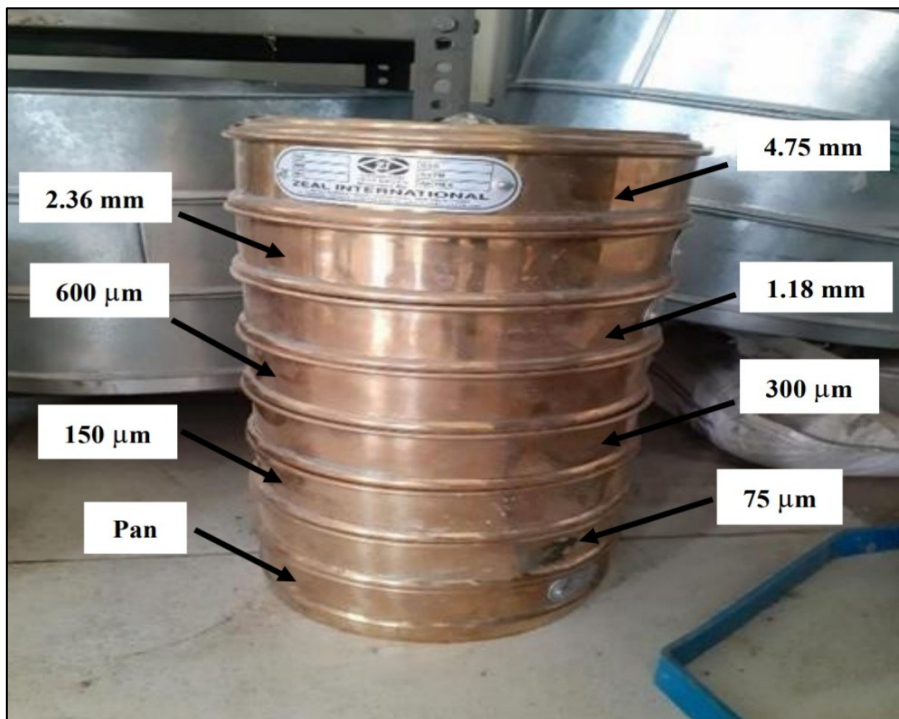


Fig. 3 Sieve sets used to perform sieve analysis of the selected soil

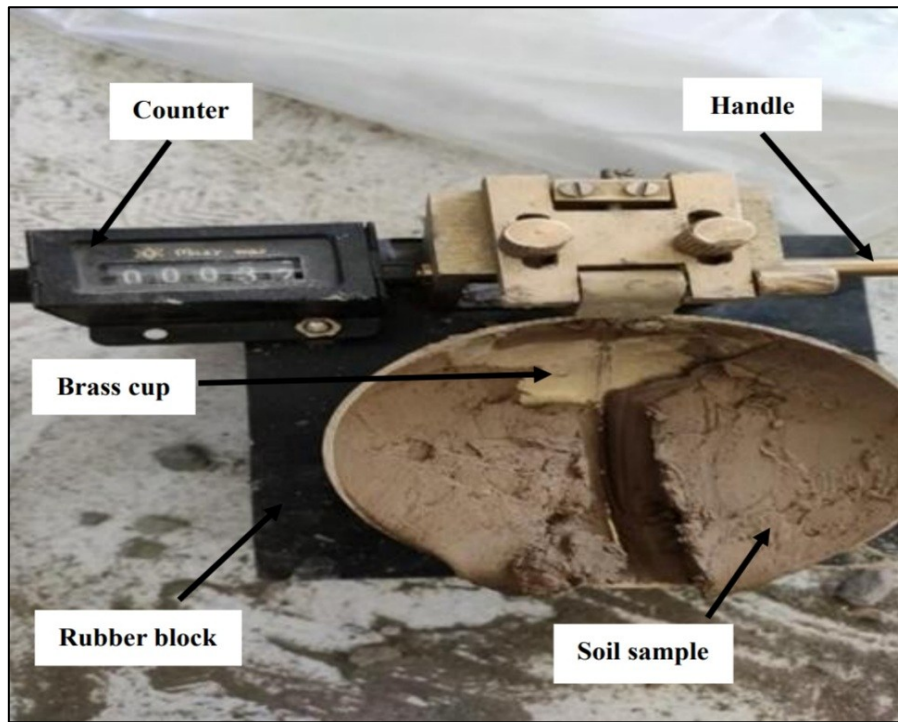


Fig. 4 Casagrande apparatus used to perform liquid limit test on soil

Table 1
Index properties of soil selected for block manufacturing

Soil Parameters	Value
Specific gravity	1.57
Sand (%)	89.3
Fines (%)	7.7
Co-efficient of uniformity (Cu)	3.74
Co-efficient of curvature (Cc)	0.96
Maximum dry density (MDD), (g/cc)	1.87
Optimum moisture content (OMC), (%)	20
Liquid Limit (%)	42.52
Plastic Limit (%)	21.07
Plasticity Index (%)	21.45
Soil classification	SP-CI

2.1.2 Rice Husk

The Rice Husk shown in **Fig. 5** which was used for the present investigation was brought from a local supplier in Wathoora, Kashmir. Rice Husk Ash was obtained by burning rice husk at controlled temperature as shown in **Fig. 6** as burning activates its pozzolanic properties (Rasoul 2018; Gunarathne et al. 2019; Singh and Singh 2020). The residue, known as rice husk ash shown in **Fig. 7** was passed through 150 μ m sieve size and the retained portion on the 75 μ m sieve pan was collected and was used in the present study (Singh 2018).



Fig. 5 Kashmir rice husk selected for soil stabilization



Fig. 6 Burning of rice husk to activate its pozzolanic properties



Fig. 7 Rice husk ash obtained after burning of rice husk

2.2 Methodology

2.2.1 Block Manufacturing

In the present investigation, the CSEB samples of size 300 mm x 150 mm x 100 mm were manufactured in two series (series B and series C). Series B included 6 batches (B₀, B₁, B₂, B₃, B₄ and B₅), and series C also included 6 batches (C₀, C₁, C₂, C₃, C₄ and C₅). Different percentages of RHA addition with respect to weight of soil were used for different batches of CSEBs (0% RHA for B₀ and C₀, 3.5% RHA for B₁ and C₁, 5.5% RHA for B₂ and C₂, 7.5% RHA for B₃ and C₃, 9.5% RHA for B₄ and C₄ and 11.5% RHA for B₅ and C₅). The predefined quantities of materials were measured with the help of a weighing balance. The soil and RHA were thoroughly mixed to prepare the Soil-RHA mixture. Predetermined OMC (optimum moisture content) of 20 % was added by weight of Soil-RHA mixture and mixed well in order to make the mixture workable and maintain the moisture content in the mixture. The prepared mixture was placed in the mould of internal dimensions 300 mm x 150 mm x 100 mm in three layers. Manual compaction was applied using a proctor hammer of weight 2.5 kg as shown in **Fig. 8** with a drop height of 310 mm by giving 25 blows to each layer of the mixture while placing in the mould, in order to ensure uniform compaction and prevent any air voids in the mixture (Shantanu Paul 2023). The excess mixture was scrapped off the mould using any sharp scale or ruler and the top layer was levelled to ensure a uniform surface. The same procedure was applied for series C with the only difference that in series C no compression load was applied for compacting the mixture. The prepared samples shown in **Fig. 9** were left undisturbed, protected from direct sunlight for a period of 24 hours, placing a damp cloth over them. After 24 hours, the samples were carefully demoulded and wrapped in plastic sheets to avoid any moisture loss and transported to a humid environment

away from direct sunlight for a curing period of 28 days because the strength achieved by the blocks depends upon the curing period (Adedamola Mobolanle Ojerinde 2018; Shantanu Paul 2023).



Fig. 8 Proctor hammer of 2.5 kg used for manual compaction of the mixture in the mould



Fig. 9 Prepared sample of compressed stabilized earth block in mould of dimensions 300 mm x 150 mm x 100 mm

2.3 Experimental evaluation of the properties of RHA modified CSEBs

2.3.1 Dimensional analysis of blocks

Linear measurements of the CSEB samples were taken after 28 days of curing period (Wakjira Hode 2015). The initial volume of all CSEB samples (measured before the curing period) was equal to the internal volume of the block mould, i.e. 4,500,000 mm or 0.00450 m³.

2.3.2 Density

Density is defined as the ratio of weight of block in kg to the volume of block in m³. The CSEB samples were oven dried at 105 degrees Celsius until a constant weight was attained. The blocks were then cooled to surrounding room temperature by keeping in the same oven. Weight and volume of the CSEB samples were measured. The same method was performed but without oven drying the blocks in order to determine bulk density of the CSEB samples.

2.3.3 Compressive strength

After the curing period of 28 days, the CSEB samples of series B and C were tested in the automatic compression testing machine (ACTM) as shown in **Fig. 10** in order to evaluate their compressive strength, determine the effect of stabilizing the soil with RHA and determine the optimum RHA percentage at which maximum compressive strength is gained. Also, the compressive strength values of CSEB samples from series B were compared to the compressive strength values of series C in order to show the significance of applying compression load for compacting the soil-RHA mixture during the manufacturing process on the compressive strength of CSEBs.

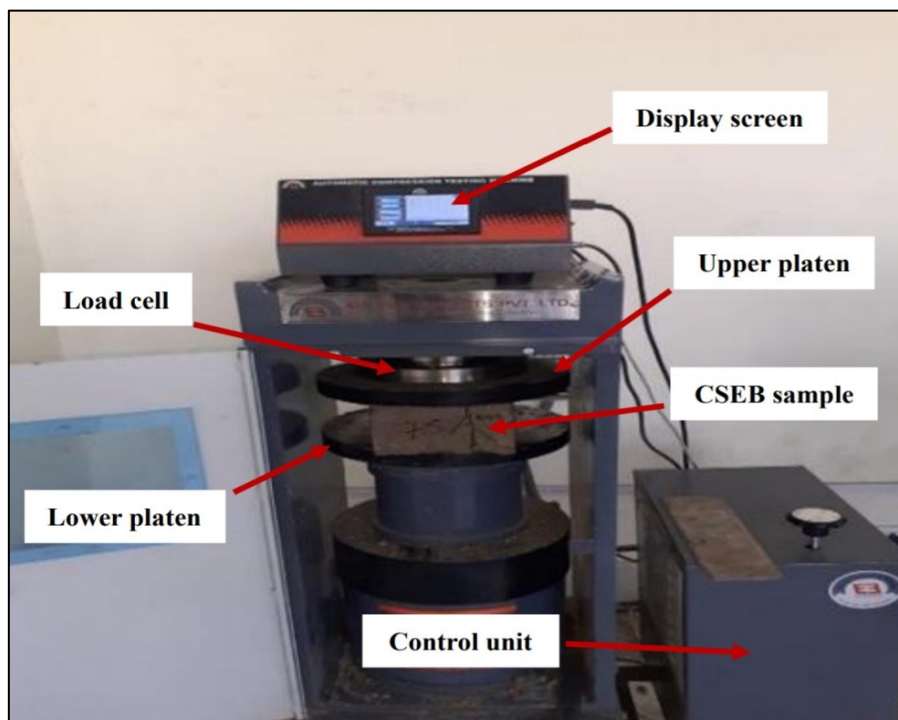


Fig. 10 Compression testing of CSEB samples in ACTM to determine their compressive strength after 28 days of curing

2.3.4 Shrinkage analysis

During the drying process, change in volume or shrinkage occur in the block samples that can affect its suitability for construction. Therefore, the shrinkage percentage of CSEB samples was evaluated using the below equation (Wakjira Hode 2015).

$$Sp = \frac{(V_m - V_b)}{V_m} \times 100$$

Where, Sp = Shrinkage percentage

V_b = Volume of the block sample in mm^3

V_m = Volume of mould in mm^3

$$= 300 \text{ mm} \times 150 \text{ mm} \times 100 \text{ mm} = 4,500,000 \text{ mm}^3$$

2.3.5 Thermal performance

In the present investigation, thermal conductivity of CSEB samples of series B and C at different RHA percentages were studied and the results were compared between the stabilized and unstabilized CSEB samples to determine the effect of RHA inclusion on the thermal properties of the blocks. Also, the CSEB samples from series B and C were compared to determine the significance of compacting the mixture by applying compression load on the thermal properties of CSEBs.

3. Results and Discussion

In this chapter, results of the various laboratory tests performed on the CSEB samples have been listed along with their tabular form, graphs, and bar charts.

3.1 Effect of RHA inclusion on compressive strength of CEBs.

The RHA stabilized CSEB samples were placed in the automatic compression testing machine and the corresponding compressive strength results were recorded for each CSEB sample. These samples were prepared with different percentages of RHA addition. Tables 2 and 3 show the average compressive strength values for different percentages of RHA stabilized CSEB samples of series B and series C respectively after 28 days of curing. It can be seen from table 2 that the average compressive strength abruptly increases after the inclusion of the stabilizer RHA (3.5%) from 0.43 N/mm^2 to 1.34 N/mm^2 , indicating that stabilization enhances the compressive strength of the compressed earth blocks. Also, figure 4a shows that with increase in the RHA content from 3.5% to 5.5% and 7.5%, the average compressive strength kept on increasing from 1.34 N/mm^2 to 2.27 N/mm^2 and 2.51 N/mm^2 respectively. However, with further increase in RHA content beyond 7.5 %, the average compressive strength of CSEB samples decreased by more than 50%. The average compressive strength value after 28 days of curing is greatest for B₃ (blocks prepared with 7.5% RHA) which is 2.51

N/mm². Table 3 shows the average compressive strength of CSEB samples of series C in which no compression load was applied for compacting the soil-RHA mixture. **Fig. 11** compares the average compressive strength values of CSEBs obtained from series B with those obtained from Series C. The figure shows that even though the average compressive strength values of the CSEB samples in series C increased on increasing the RHA content, with the highest compressive strength achieved by block C₃ which is 1.32 N/mm², however on comparing these values with the CSEB samples of series B, the average compressive strength values obtained for series B in which compression load was applied to compact the soil-RHA mixture is much greater than the average compressive strength values obtained for series C for every percentage of RHA additions, thus showing that the compressive strength of CSEBs significantly increase by applying compression load for compacting the mixture. The compressive strength results in the present study were compared with the previous studies and also with the building codes of Australia, New Mexico, Spain, UNESCO, Indian and African Regional standards, which reports a minimum requirement of compressive strength of at least 2 N/mm² for non-load bearing walls and at least 2-4 N/mm² for load bearing walls which is met by the average compressive strength values achieved by B₂ and B₃ CSEB samples i.e. 2.27 N/mm² and 2.51 N/mm² respectively (Wakjira Hode 2015; Stevenson and Latif 2020; Nshimiyimana et al. 2020; Kamalizad and Morshed 2024). Also, the optimum RHA percentage at which maximum compressive strength of 2.51 N/mm² was achieved is 7.5 %.

Table 2

Average compressive strength values of CSEB samples for different RHA contents after 28 days of curing (compaction load applied)

Batches	RHA content (%)	Average compressive strength (N/mm ³)
B ₀	0	0.43
B ₁	3.5	1.34
B ₂	5.5	2.27
B ₃	7.5	2.51
B ₄	9.5	1.27
B ₅	11.5	0.99

Table 3

Average compressive strength values of CSEB samples for different RHA contents after 28 days of curing (no compaction load applied)

Batches	RHA content (%)	Average compressive strength (N/mm ³)
C ₀	0	0.29
C ₁	3.5	0.63
C ₂	5.5	1.18
C ₃	7.5	1.32
C ₄	9.5	0.74
C ₅	11.5	0.42

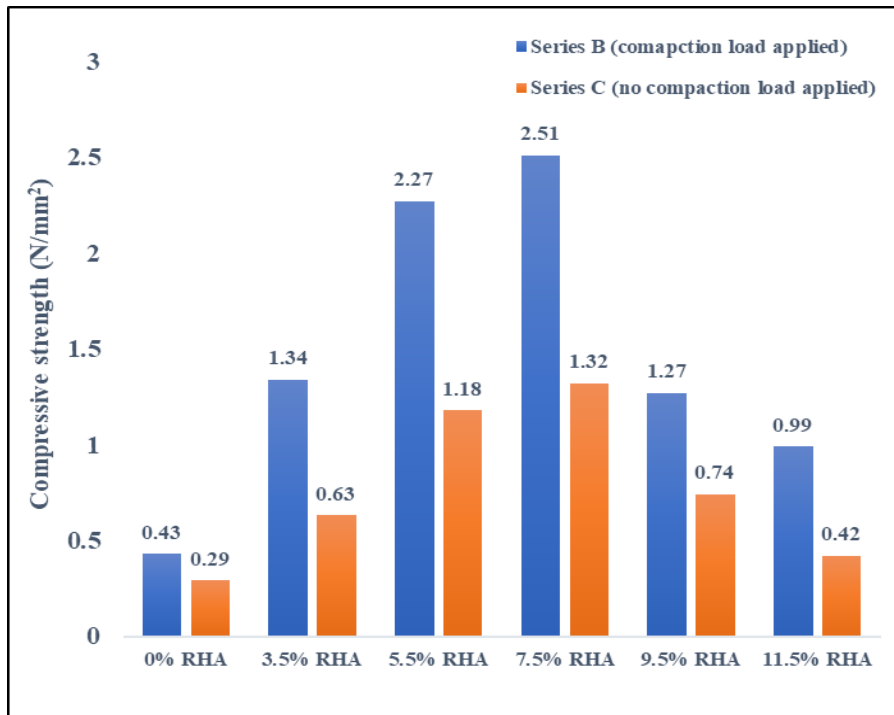


Fig. 11 Bar chart comparing average compressive strength values of CSEB samples from series A and B for various percentages of RHA after 28 days of curing

3.2 Effect of RHA inclusion on Density of CSEB samples.

Dry and bulk densities of the CSEB samples were studied for varying percentages of RHA addition. Tables 4 and 5 show the average bulk and dry density values of the CSEB samples studied after 28 days of curing respectively. In the current investigation, the average bulk density varied from 1771.11 to 1891.28 kg/m³ while the average dry density varied from 1496.03 to 1601.03 kg/m³ with the addition of varying percentages of RHA. These results affirmed the previous studies by (Mujahid et al. 2011; Wakjira Hode 2015; Stevenson and Latif 2020; Yatawara and Athukorala 2021; Asha Sapna and Anbalagan 2023) reporting that the density of Compressed Stabilized Earth Blocks lies in the range of 1500 to 2000 kg/m³. Tables 4 and 5 show that with inclusion of RHA, the average bulk and dry density values of the CSEB samples increased with upto 7.5% RHA content, indicating that stabilization enhances the density of CSEBs. However, with further increase in RHA content beyond 7.5%, the CSEB samples witnessed a decline in the bulk and dry density values. The compressive strength and compaction load applied during production are directly associated with the density of the compressed earth block (Riza et al. 2011). The average bulk and dry density values were greatest for B₃ (CSEB samples prepared with 7.5 % RHA) which is 1891.28 kg/m³ and 1601.03 kg/m³ respectively.

Table 4

Average bulk density values of CSEB samples for different RHA contents after 28 days of curing

Batches	RHA content (%)	Average bulk block density (kg/m ³)
B ₀	0	1830.14
B ₁	3.5	1862.98
B ₂	5.5	1878.50
B ₃	7.5	1848.28
B ₄	9.5	1760.27
B ₅	11.5	1771.11

Table 5

Average dry density values of CSEB samples for different RHA contents after 28 days of curing

Batches	RHA content (%)	Average dry block density (kg/m ³)
B ₀	0	1555.62
B ₁	3.5	1583.53
B ₂	5.5	1596.73
B ₃	7.5	1571.03
B ₄	9.5	1496.03
B ₅	11.5	1505.44

3.3 Dimensional characteristics of CSEB samples.

Table 6 shows the average length, width, height, weight and volume of the CSEB samples obtained from the measurement of size of blocks of different batches (with different RHA content) after 28 days of curing. Table 6 shows a non-linear effect on the dimensional characteristics of CSEB samples. The results showed that initially the average volume of blocks significantly decreased upto 3.5% of RHA inclusion, but then it gradually increased upto 11.5% of RHA content inclusion. Blocks B₃, B₄ and B₅ showed significant improvement in the dimensional characteristics. Also, the volume of the CSEB samples measured before the curing period was similar to the average volume of 11.5% RHA enhanced CSEB samples measured after the curing period of 28 days i.e. 4,500,000 mm³.

Table 6

Average values obtained from measurement of size of blocks of different batches after 28 days of curing

Batches	Average length (mm)	Average width (mm)	Average height (mm)	Average weight (kg)	Average volume (mm ³)
B ₀	294	148	95	7.65	4,133,640
B ₁	295	150	94	7.75	4,159,500
B ₂	297	150	96	8.04	4,276,800
B ₃	297	150	97	8.04	4,321,350
B ₄	300	150	97	7.71	4,365,000
B ₅	300	150	100	7.97	4,500,000

3.4 Thermal performance of CSEB samples.

The CSEB samples with different percentages of RHA were taken each from series B and series C. The thermal conductivity test was performed on these samples. Thermal conductivity values for each of these samples were measured

and the results for CSEB samples from series B and C are shown in tables 7 and 8 respectively. The results reported a decrease in thermal conductivity of the CSEB samples with the inclusion of stabilizer (RHA) showing that stabilization enhances the thermal performance of CSEBs. Table 7 shows variation in thermal conductivity values of the CSEB samples with different compositions of RHA for series B, as the thermal conductivity decreased upto the inclusion of 9.5 % RHA content, but then it increased with further RHA inclusion beyond 9.5%. Similarly, table 8 shows that the thermal conductivity values of CSEB samples for series C decreased upto the inclusion of 9.5% RHA content, but increased beyond the inclusion of 9.5% of RHA. However, on comparing the thermal conductivity values of CSEB samples of series B and C, it can be seen from **Fig. 12** that the thermal conductivity values of CSEB samples obtained from series C in which no compression load was applied for compacting the soil-RHA mixture is much higher than the values obtained for the CSEB samples from series B for every percentage of RHA additions, thus indicating that the thermal performance of CSEBs is significantly enhanced by applying compression load for compacting the mixture. In the present investigation, the thermal conductivity values of CSEB samples ranged from 0.68 to 0.84 W/m.K for series B and from 0.94 to 1.22 W/m.K for series C. These values were compared with the previous studies by several researchers and the values reported include 0.55 to 0.87 W/m.K by (Stevenson and Latif 2020) and 0.79 to 1.10 W/m.K by (Mansour et al. 2016; Saidi et al. 2018; Nshimiyimana et al. 2020; Turco et al. 2024). Notably, the thermal conductivity values of CSEBs from series B obtained in the present investigation lied within the ranges reported in the literature.

Table 7

Average thermal conductivity values of CSEB samples for different RHA contents after 28 days of curing (compaction load applied)

Batches	RHA content (%)	Average thermal conductivity (W/m.K)
B ₀	0	0.84
B ₁	3.5	0.79
B ₂	5.5	0.76
B ₃	7.5	0.72
B ₄	9.5	0.68
B ₅	11.5	0.71

Table 8

Average thermal conductivity values of CSEB samples for different RHA contents after 28 days of curing (no compaction load applied)

Batches	RHA content (%)	Average thermal conductivity (W/m.K)
B ₀	0	1.22
B ₁	3.5	1.13
B ₂	5.5	1.08
B ₃	7.5	1.01
B ₄	9.5	0.94
B ₅	11.5	0.97

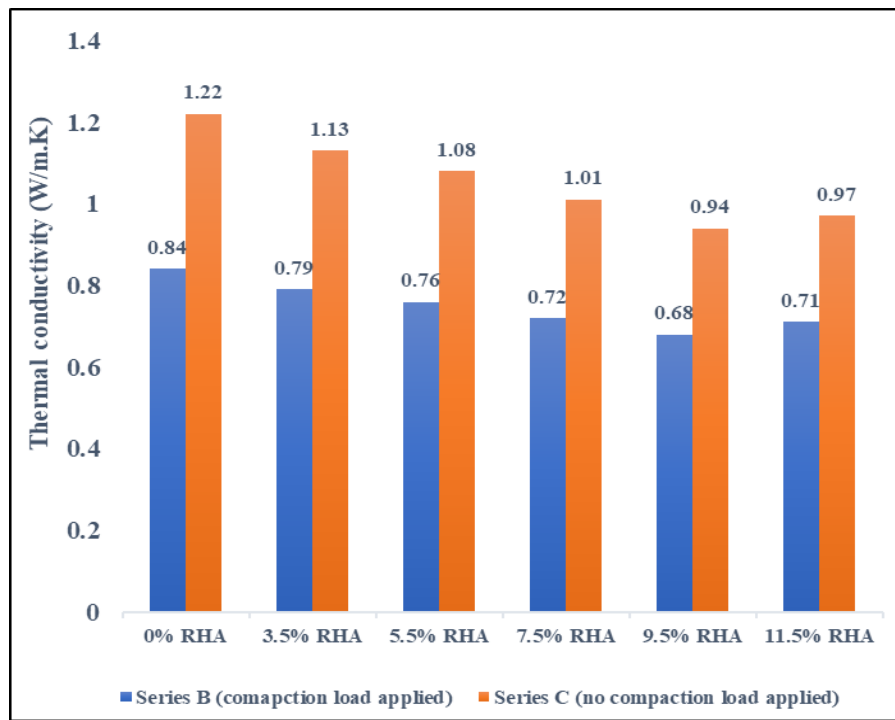


Fig. 12 Bar chart comparing average thermal conductivity values of CSEB samples from series A and B for various percentages of RHA after 28 days of curing

3.5 Shrinkage or volume change.

Once the average shrinkage (mm^3) and mean shrinkage (%) values of unstabilized and stabilized blocks were evaluated after 28 days of curing, the results were recorded and are shown in Table 9. The results showed that with the inclusion of stabilizer (RHA) the shrinkage value of CSEB samples significantly decreased from 8.14 % of average shrinkage in unstabilized CSEB samples to upto 0 % of average shrinkage in RHA stabilized CSEB samples, indicating that stabilizing the CSEBs with RHA reduces their shrinkage value which directly affects the final dimensions of the CSEBs. **Fig. 13** compares the average shrinkage values of the CSEB samples obtained with different compositions of RHA additions. Figure 6 shows that the CSEB samples in B₅ with the highest RHA content (11.5% RHA) showed the lowest shrinkage percentage value of 0 %, whereas the CSEB samples in B₀ with no RHA inclusion showed the highest shrinkage percentage value of 8.14 %.

Table 9

Mean shrinkage percentages of CSEB samples from series B after 28 days of curing

Batches	Average shrinkage (mm^3)	Mean shrinkage (%)
B ₀	366360	8.14
B ₁	340500	7.57
B ₂	223200	4.96
B ₃	178650	3.97
B ₄	135000	3
B ₅	0	0

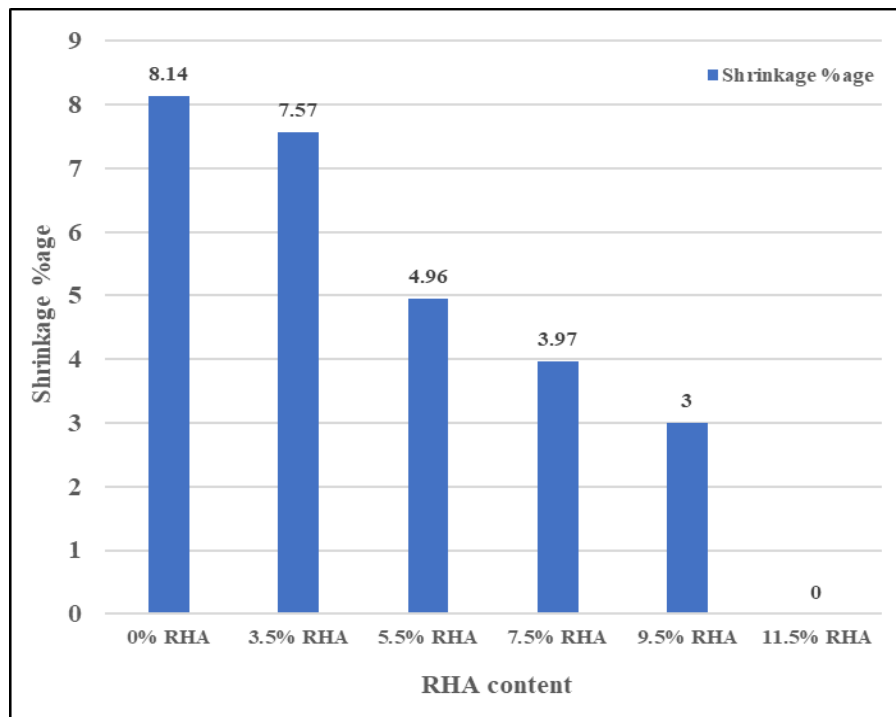


Fig. 13 Bar chart showing mean shrinkage percentages of CSEB samples from series B after 28 days of curing

4. Conclusion

4.1 Following are the main conclusions that can be drawn from the findings of the present study:

1. The waste Rice Husk can be utilized as a stabilizer in the form of rice husk ash in manufacturing of CSEBs, thus improving the physio-mechanical properties of the earth blocks and reducing the environmental threat related to its disposal.
2. The CEBs stabilized with RHA performed better in terms of the various parameters investigated in the present research than the unstabilized CEBs.
3. On comparing the average compressive strength values obtained from the CSEB samples of series B in which compression load was applied for compaction of soil-RHA mixture to the CSEB samples of series C in which no compression load was applied for compacting the mixture, the average compressive strength values of CSEBs of series B were higher for every percentage of RHA additions, thus indicating that the compressive strength of CSEBs is significantly enhanced by applying compression load for compacting the mixture during the manufacturing of CSEBs.
4. The compressive strength of the CSEBs of series B significantly increased with the inclusion of RHA from 0.43 N/mm² for unstabilized blocks to more than 2 N/mm² for the CSEBs stabilized with 5.5% and 7.5% of RHA content. The average compressive strength values of 2.27 N/mm² and 2.51 N/mm² achieved by B₂ and B₃ blocks respectively were met by the building standard codes that reports a minimum compressive strength of at least 2

- N/mm² for non-load bearing walls. Also, the optimum RHA content for CSEBs is found as 7.5% (B₃ blocks), which yielded the highest compressive strength of 2.51 N/mm² after 28 days of curing.
5. The addition of RHA increased the density of CSEBs, with the highest bulk and dry densities of 1891.28 kg/m³ and 1601.03 kg/m³ respectively achieved on the inclusion of 7.5 % RHA content. The bulk densities (1771.11 – 1891.28 kg/m³) and dry densities (1496.03 – 1601.03 kg/m³) obtained in the present study were met by the previous findings that reported a range of 1500 to 2000 kg/m³ of density for CSEBs.
 6. The shrinkage value of the CSEB samples significantly reduced with the increasing percentages of RHA addition, with the highest shrinkage value of 8.14 % observed in unstabilized blocks and the lowest shrinkage value of 0 % observed in the CSEBs stabilized with 11.5 % RHA content, suggesting increased dimensional stability.
 7. On comparing the thermal conductivity values of unstabilized and stabilized CEB samples, it was observed that the thermal conductivity of the blocks decreased upon addition of RHA as stabilizer, indicating that RHA significantly enhances the thermal performance of CSEBs. When the thermal conductivity values of CSEB samples of series B and series C were compared, the thermal conductivity values obtained from the CSEB samples of series C in which no compression load was applied for compacting the soil-RHA mixture were higher than those obtained from series B in which compression load was applied for compacting the mixture, indicating that the thermal performance of CSEBs significantly improves by applying compression load for compacting the mixture during manufacturing of CSEBs. The lowest thermal conductivity values of 0.71 and 0.68 W/m.K were observed for B₃ and B₄ blocks stabilized with 7.5% and 9.5% RHA respectively. The values obtained by CSEBs from series B (0.68 – 0.84 W/m.K) in the present research were met by the previous findings which reported a range of 0.55 to 0.87 W/m.K.

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