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Rice husk ash reduces damage rate of CEB under uniaxial compression

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Abstract

To address the current environmental challenges of reducing atmospheric pollutants and contributing to recycling, this work reuses waste residues from the agroindustrial sector for manufacturing compressed earth blocks (CEBs). The main objective of this study is to evaluate rice husk ash (RHA) stabilizer as damage rate reducer in CEBs under uniaxial compressive loads. The methodology includes the fabrication of cylindrical samples of CEB densified at a pressure of 10 MPa using a laboratory compactor. The samples are tested in uniaxial compressive loadings using a universal testing machine to produce failure. The CEB samples without RHA are compared to the samples showing maximum strength manufactured with RHA. The experimental engineering stress-strain curves were analyzed to determine the damage rate as a function of strain. The results show that incorporating RHA as a stabilizer reduces the damage rate of compressed earth blocks (CEB) under uniaxial compression from 3.04 to 0.36, representing an 88% reduction.

Keywords: Compressed earth block; rice husk ash; damage rate; strain; fracture

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1. Introduction

Compressed earth blocks are a sustainable building material that can be used as an alternative to traditional fired bricks (Dabai et al., 2010; Farooq & Danish, 2018; Valenzuela et al., 2023, 2024; Zareei et al., 2017). However, their use is limited due to their susceptibility to damage and cracking (Murmu & Patel, 2018; Valenzuela et al., 2023, 2024). To address this issue, various stabilization techniques have been explored, including the use of rice husk ash.

This study investigates the damage ratio, fracture patterns, and crack resistance of compressed earth blocks made from soil alone and CEBs stabilized with rice husk ash.

CEB are a type of unfired brick made from a mixture of soil, water, and sometimes a stabilizer. The use of earthen materials for construction is advantageous due to their low environmental impact, low thermal conductivity, and abundant availability (Murmu & Patel, 2018; Valenzuela et al., 2023, 2024). One promising stabilizer for improving the properties of CEBs is rice husk ash (Asha et al., 2020). Rice husk ash is a waste product from the burning of rice husks, which are the protective coverings removed from harvested rice grains. Studies have shown that incorporating rice husk ash into CEBs can enhance their compressive strength, water resistance, and durability (Asha et al., 2020; Kumar et al., 2016).

The key factors that affect the performance of stabilized CEBs include soil gradation, mixing water content, compaction energy, and the type and amount of stabilizer used (Elahi et al., 2021; Valenzuela et al., 2023, 2024). Cement, lime, and gypsum have all been evaluated as potential stabilizers for CEBs, but the use of rice husk ash as a partial cement replacement has also shown promising results (Kumar et al., 2016). According to the literature, compressed earth blocks under uniaxial compression shows brittle failure characterized by low damage tolerance and limited resistance to cracking (Lawson et al., 2011; Ruiz et al., 2018; Valenzuela et al., 2023). To overcome these limitations, the use of various stabilizers such as cement, lime, and more recently, rice husk ash has been explored (Cid-Falceto et al., 2012; Elahi et al., 2021; Ruiz et al., 2018). Rice husk ash is a waste product from the rice milling industry and has been found to be an effective stabilizer for improving the durability and strength of compressed earth blocks (Elahi et al., 2021; Murmu & Patel, 2018). However, the evaluation of rice husk ash in compressed earth block as a damage retardant is scarce in the literature. While previous studies have examined the strength properties and performance of CEBs incorporating cement, lime, and other stabilizers, there is limited research on the comparative analysis of the damage rate and crack resistance between CEBs made from soil alone and those stabilized with rice husk ash (Cid-Falceto et al., 2012; Elahi et al., 2021; Sitton et al., 2018). This research gap is addressed in this work, focusing on investigating the effect of rice husk ash stabilization on damage ratio, fracture patterns, and crack resistance of CEB. The potential of rice husk ash could provide sustainable and effective stabilizer for improving the overall performance and resilience of compressed earth construction.

2. Methodology

This study utilized both experimental and analytical approaches. To assess the damage rate and crack resistance of compressed earth blocks, the key steps in the methodology included:

- Preparation of cylindrical CEB samples with and without rice husk ash, soil, and water applying a compaction pressure and a drying stage.
- Conducting uniaxial compression tests to failure and monitoring the resulting damage patterns.
- Calculating the damage evolution based on the relationship between peak load and damage load.
- Analyzing the crack patterns and resistance to cracking using a damage rate index to assess the extent of damage in the CEB samples. The damage rate is computed as the ratio of the increase of the damage value to the increase of deformation.

To manufacture the laboratory CEB samples, a prepared hydrated soil-RHA mixture in proportions of 0.857:0.143 was compacted using a uniaxial electrical universal testing machine. A dedicated 3D-printed mold, specially fabricated from polylactic acid was used to form cylindrical samples of 30 mm diameter. The mixture was carefully loaded into the mold, and a controlled compressive pressure of 10 MPa was applied via the uniaxial machine at a rate of 0.1 kN/s. Following compaction, the CEB was demolded from the 3D-printed mold, cut to a height of 60 mm, and left to cure and dry for a month.

Uniaxial compression tests were performed on the manufactured CEB samples, both with and without RHA stabilization, to monitor the damage and cracking patterns. The specimens were loaded axially at a rate of 1 mm/min until failure, the load-displacement data was recorded, and the sample failure characteristics were observed from high-resolution imagery captured during the tests. Data was processed using Excell and the results were analyzed to determine the impact of rice husk ash stabilization on the CEB damage rate and crack resistance. A lower damage rate indicates greater resistance to damage.

3. Results and Discussion

Figure 1 shows the comparison of the damage tolerance between CEB made from soil alone (Figure 1 a-c) and those stabilized with rice husk (Figure 1 d-f) under uniaxial compressive loading.

The CEB made without rice husk ash shows typical brittle behavior in Zone III (Figure 1 a-c). The stress-strain curve (Figure 1 a) shows that after an initial elastic phase (Zone I), there is a hardening phase (Zone II), followed by a sharp drop in ultimate stress in Zone III, where cracking dominates (Figure c). The relatively low ultimate stress and strain at failure indicate that this CEB made only with soil has limited strength and toughness. Without stabilization, soil-based CEBs tend to fail more abruptly under load, which aligns with the high rate of damage accumulation seen in Figure 1 b.

The stress-strain curve in Figure 1 d, indicates higher ultimate stress and strain at failure for the CEB with rice husk ash stabilizer. This shows a marked improvement in both strength and ductility compared to the unstabilized sample. The hardening phase (Zone II) is longer, reflecting the increased strain the material can handle before significant damage occurs. The addition of RHA contributes to a more resilient structure, attributed to the pozzolanic reactions between silica in RHA and calcium in the soil forming additional calcium silicate hydrates (Valenzuela et al., 2023, 2024). This secondary binder strengthens the microstructure, resulting in higher compressive strength and strain tolerance.

In Zone III of Figure 1 b, the damage curve of CEB without rice husk ash rises sharply, with a damage rate of 3.04, indicating that once the material begins to fail, it does so rapidly. This behavior is characteristic of materials with limited internal binding strength and little ability to absorb or redistribute strain energy as cracks propagate. The rapid damage accumulation is consistent with the absence of stabilizers. Without RHA, there is limited resistance to crack propagation, leading to a brittle fracture where microcracks quickly coalesce and propagate, resulting in catastrophic failure. In contrast, CEB with RHA shows a slower increase in damage, with a rate of 0.36 (Figure 1 e). The pozzolanic reaction between RHA and soil strengthens the material, allowing it to sustain a greater degree of deformation before critical damage occurs. This slower rate of damage accumulation reflects the presence of silica-based bonds, improving the material toughness by enhancing its crack-bridging capability (Figure f). The additional calcium silicate hydrate phases likely provide better crack resistance, allowing the material to deform more uniformly rather than localized cracking (Hastuty et al., 2017; Sanou et al., 2019; Wei et al., 2020; YAMAMOTO & LAKHO, 1982). These previous studies demonstrated that pozzolanic reaction from the silica in RHA contributes to the formation of calcium silicate hydrate, responsible for enhancing the inter-particle binding and crack-bridging capacity. This results in a more resilient, durable material than soil-only CEB, and better suited for structural applications where both strength and ductility are important.

Compressed earth blocks made from soil alone exhibited a higher damage rate and more severe cracking under compressive loads, indicating their susceptibility to premature failure. This has been demonstrated in this study as CEB samples stabilized with rice husk ash exhibited a lower damage rate and more uniform crack patterns, suggesting that the ash acted as an effective stabilizer in enhancing the durability and load-bearing capacity of the blocks. Other research attributed the improved performance of the rice husk ash-stabilized CEBs to the pozzolanic reaction between the ash and the soil, which led to the formation of cementitious compounds that improved the overall strength and cohesion of the material (Asha et al., 2020; Dabai et al., 2010; Kumar et al., 2016; Valenzuela et al., 2023). Additionally, the presence of silica in the rice husk ash may have contributed to the increased crack resistance by inhibiting the propagation of cracks through the material (Elahi et al., 2021).

In conclusion, the results of this study show that Incorporating rice husk ash in the CEB mixture not only significantly improves the strength of CEBs, as shown here and in previous studies (Cid-Falceto et al., 2012; Sitton et al., 2018), but also enhances the damage tolerant performance of compressed earth blocks. Further work should compare these results with CEB using energy-intensive ordinary Portland cement under similar manufacturing and loading conditions.

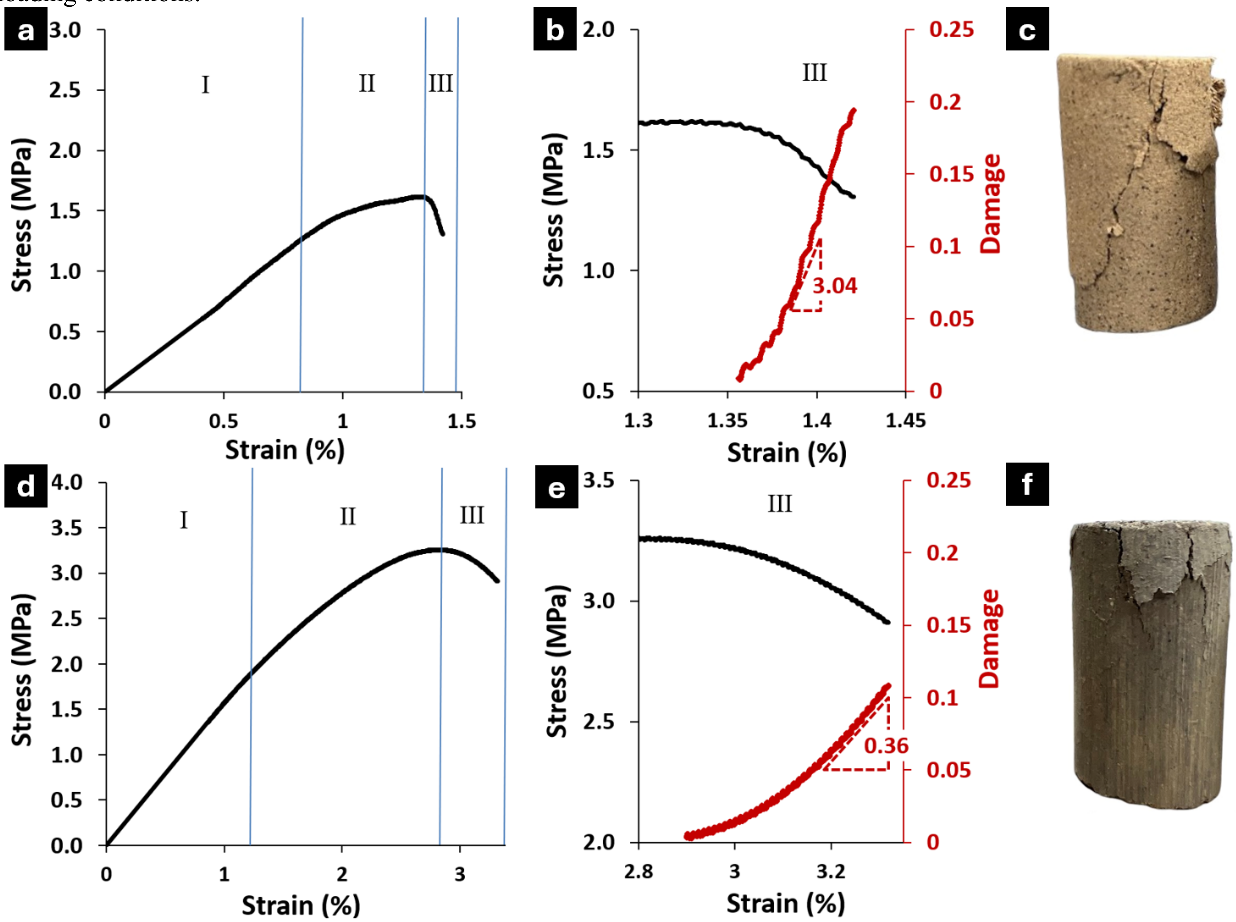

Fig. 1. Stress-strain curves of tested CEB samples: (a-c) soil-only and (d-f) with rice husk ash and; (a,d) Stress-strain curves under uniaxial compressive loading showing elastic zone I, hardening dominated zone II, and cracked-dominant response (zone III). (b,e) Zone III with progressive damage value and damage rate. (c,f) Crack pattern.

4. Conclusions

This study has demonstrated the potential of using rice husk ash as a stabilizer for compressed earth blocks, as it significantly improved the damage and crack resistance of the blocks compared to those made from soil alone. The key findings of this research are:

- CEB samples stabilized with rice husk ash exhibited a lower damage rate under compressive loading, indicating improved resistance to damage and cracking.
- The compressed earth blocks containing rice husk ash demonstrated a markedly higher damage-rate value of 3, in contrast to the 0.3 damage-rate observed in the compressed earth blocks made solely from soil.
- From literature review, the higher strength and damage rate retardant effect of rice husk ask on the CEB behavior is attributed to the pozzolanic reactions between the silica in the ash and the soil, which form additional cementitious compounds that enhance the overall cohesion and durability of the material, improving the crack-bridging and crack-resistance properties of the compressed earth blocks. This leads to a more uniform and gradual mode of failure compared to the brittle fracture characteristic of the unstabilized CEBs.

Overall, this study suggests that the incorporation of rice husk ash is an effective way to enhance the performance and sustainability of compressed earth blocks as a construction material, providing improved strength, ductility and damage resistance compared to traditional soil-only CEB. Additional research is required to investigate the long-term performance of the rice husk ash-stabilized compressed earth blocks under diverse environmental conditions to ensure the required stabilization of CEB for the construction industry.

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