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Eco-Friendly Compressed Stabilized Earthen Blocks (CSEBs) Enriched with Industrial Waste for Sustainable Construction

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A B S T R A C T :

This study explores the development of sustainable Compressed Stabilized Earth Blocks (CSEBs) by incorporating foundry sand, rice husk ash (RHA), and bagasse fiber as partial replacements for fine aggregates, cement, and reinforcement fibers. Foundry sand, an industrial byproduct, enhances particle packing and compressive strength, while RHA, a pozzolanic material, improves cementitious properties and durability. The addition of bagasse fiber increases crack resistance and flexibility, making the blocks more resilient. Experimental results demonstrate that CSEBs modified with these sustainable materials offer enhanced performance and durability, making them a viable alternative to conventional masonry materials while reducing environmental impact.

Keywords: Compressed Stabilized Earth Blocks (CSEBs), Foundry Sand, Rice Husk Ash (RHA), Bagasse Fiber, Sustainable Construction.

1. Introduction

The construction industry heavily relies on resource-intensive materials, contributing to environmental degradation and high carbon emissions. Compressed Stabilized Earth Blocks (CSEBs) offer a sustainable alternative, using locally available soil and stabilizers while eliminating the need for kiln firing. However, their strength and durability require improvement to compete with traditional masonry materials.

This study enhances CSEBs by incorporating foundry sand, rice husk ash (RHA), and bagasse fiber. Foundry sand, an industrial byproduct, improves density and compressive strength; RHA, a pozzolanic material, enhances cementitious properties and durability; and bagasse fiber increases crack resistance and flexibility. By integrating these sustainable materials, this research aims to develop stronger, more eco-friendly CSEBs, reducing waste while promoting sustainable construction practices.

2. Literature Review

The development of Compressed Stabilized Earth Blocks (CSEBs) has been widely researched due to their potential as sustainable and cost-effective construction materials. Researchers have explored different compositions, stabilization techniques, and alternative materials to enhance the strength and durability of CSEBs while reducing environmental impact. This section provides an overview of previous studies on CSEBs, with a particular focus on the effects of foundry sand and rice husk ash (RHA) as supplementary materials in construction. Additionally, compliance with relevant Indian Standards (IS) and international guidelines is discussed.

2.1 Overview of Previous Research on CSEBs

CSEBs have been studied extensively as an eco-friendly alternative to traditional bricks and concrete blocks. These blocks are produced using locally available soil, stabilizers (such as cement or lime), and water, followed by mechanical compression and air curing. Unlike conventional clay bricks, which require kiln firing and contribute to carbon emissions, CSEBs are more sustainable due to their low energy consumption and reduced environmental footprint. Several studies have examined the influence of different stabilizers on the strength and durability of CSEBs. Researchers have reported that the inclusion of cement, lime, fly ash, and industrial byproducts can significantly improve the mechanical properties of these blocks. The compressive strength, water absorption, and durability characteristics of CSEBs depend on factors such as soil composition, stabilizer content, compaction pressure, and curing period. However, the need for cost-effective and sustainable stabilizers has led to increased interest in industrial waste materials like foundry sand and rice husk ash.

2.2 Effect of Foundry Sand, Rice Husk Ash, and Bagasse Fiber in Construction Materials

Foundry sand, a silica-rich byproduct of metal casting, is often discarded as waste, but it can be effectively reused as a partial fine aggregate replacement in construction materials. It enhances particle packing, durability, and compressive strength while promoting sustainable waste management. Its inclusion in CSEBs helps in reducing material costs and improving structural integrity. Rice husk ash (RHA), a pozzolanic agricultural byproduct, serves as a partial cement replacement. It reacts with calcium hydroxide to form C-S-H gel, improving strength, water resistance, and durability, while also reducing carbon emissions from cement production. Studies have shown that RHA enhances long-term strength gain, making it a valuable addition to sustainable construction materials. Bagasse fiber, a sugarcane byproduct, enhances crack resistance, flexibility, and tensile strength in CSEBs. Its fibrous nature improves impact resistance, reduces brittleness, and increases energy absorption capacity, making the blocks more resilient. Additionally, bagasse fiber aids in controlling shrinkage cracks, enhancing the overall durability of the blocks. By incorporating foundry sand, RHA, and bagasse fiber, CSEBs become stronger, more sustainable, and eco-friendly, aligning with circular economy principles. This combination optimizes material performance while reducing the environmental impact, making it a promising solution for sustainable construction.

2.3 Compliance with IS Codes and International Standards

Ensuring that CSEBs meet the necessary structural and durability requirements is critical for their widespread adoption in construction. In India, the performance of stabilized soil blocks is governed by IS 1725:2013, which outlines the specifications for soil-based masonry units. Additionally, IS 3495:1992 provides testing procedures for evaluating the compressive strength, water absorption, and durability of masonry blocks. Internationally, standards such as ASTM D1633 (for soil-cement compressive strength), ASTM C618 (for pozzolanic materials like RHA), and Eurocode 6 (for masonry structures) provide additional benchmarks for assessing the quality of alternative masonry units. Comparative studies have shown that well-designed CSEBs incorporating foundry sand and RHA can comply with IS and international standards, demonstrating their viability for sustainable construction applications.By leveraging existing research and aligning with established codes, this study aims to validate the use of foundry sand and RHA in CSEBs while ensuring compliance with structural safety and performance requirements. The next section will detail the experimental methodology adopted to evaluate the compressive strength and overall feasibility of these sustainable blocks.

3. Materials and Methods

This study focuses on developing sustainable Compressed Stabilized Earth Blocks (CSEBs) by incorporating foundry sand, rice husk ash (RHA), and bagasse fiber as eco-friendly alternatives to conventional materials. The methodology involves selecting and proportioning raw materials, preparing the mix, and fabricating the blocks for testing.

3.1 Materials Used

- Clay-Silt-Gravel Mix: A well-balanced natural soil composition ensuring the structural integrity of the blocks.
- M-Sand: A fine aggregate that enhances particle bonding and workability of the mix.
- Foundry Sand: An industrial byproduct partially replacing M-sand, contributing to improved density and strength.
- Cement: Used as a stabilizing agent, ensuring binding properties and durability.
- Rice Husk Ash (RHA): A sustainable pozzolanic material replacing part of the cement to enhance cementitious reactions and reduce carbon footprint.
- Bagasse Fiber: A natural reinforcement added to enhance crack resistance, flexibility, and tensile strength of the blocks.

3.2 Mix Proportions

Three modified mix designs were formulated with varying proportions of foundry sand and RHA while keeping bagasse fiber content constant at 0.05 kg per block. The composition per block is as follows:

- Mix 1 (10% FS + 5% RHA + 0.05% BF): 7.5 kg soil, 1.53 kg M-sand, 0.17 kg foundry sand, 0.76 kg cement, 0.04 kg RHA, 0.05 kg bagasse fiber.
- Mix 2 (20% FS + 10% RHA + 0.05% BF): 7.5 kg soil, 1.36 kg M-sand, 0.34 kg foundry sand, 0.72 kg cement, 0.08 kg RHA, 0.05 kg bagasse fiber.
- Mix 3 (30% FS + 15% RHA + 0.05% BF): 7.5 kg soil, 1.19 kg M-sand, 0.51 kg foundry sand, 0.68 kg cement, 0.12 kg RHA, 0.05 kg bagasse fiber.

Mix ID	FS(%)	RHA(%)	BF(%)
Mix 1	10	5	0.05
Mix 2	20	10	0.05
Mix 3	30	15	0.05

3.3 Block Preparation

The raw materials were thoroughly mixed, ensuring uniform distribution of stabilizers and reinforcements. The prepared mix was then compressed using a manual hydraulic press, forming blocks of 240 × 240 × 100 mm in size. The blocks were cured under controlled conditions to allow the cement and RHA to react, enhancing strength and durability. This systematic approach ensures the production of eco-friendly, high-performance CSEBs, contributing to sustainable construction practices.

4. Results and Discussion

4.1 Compressive Strength Performance

The compressive strength of the Compressed Stabilized Earth Blocks (CSEBs) was evaluated at 7, 14, and 28 days to assess the influence of foundry sand (FS) and rice husk ash (RHA) on strength development. The test results reveal distinct trends in strength gain, highlighting the role of these industrial byproducts in improving the mechanical properties of the blocks. The detailed strength performance is presented in table below.

Table 4.1: Compressive Strength of CSEBs

Mix ID	**7-Day Strength (MPa)**	**14-Day Strength (MPa)**	**28-Day Strength (MPa)**
Mix 1	11.72	15.13	18.53
Mix 2	10.05	10.24	12.74
Mix 3	11.13	11.62	14.62

Among the three mixes, Mix 1 showed the highest strength gain, with a 29.1% increase from 7 to 14 days, reaching 18.53 MPa at 28 days. Mix 2 and Mix 3 exhibited steady improvements, with 24.5% and 25.8% strength gains between 14 and 28 days, respectively. While Mix 1 maintains the highest overall strength, Mix 3 also demonstrates strong long-term performance, making it a viable option. Mix 2, though slower in early strength gain, shows significant improvement over time. These results highlight the effectiveness of FS and RHA in enhancing CSEB strength, emphasizing the importance of mix proportions in achieving both early and long-term durability.

4.2 Effect of Foundry Sand, Rice Husk Ash, and Bagasse Fiber

The strength enhancement observed in the modified CSEBs can be attributed to the combined effect of foundry sand (FS), rice husk ash (RHA), and bagasse fiber, each contributing uniquely to the performance of the blocks:

- Influence of Foundry Sand: The coarser particle size of FS improved particle packing, reducing voids and enhancing interlocking between particles, leading to better load-bearing capacity and overall compressive strength.
- Pozzolanic Reaction of Rice Husk Ash: RHA, rich in silica, reacts with calcium hydroxide in cement, forming additional calcium silicate hydrate (C-S-H) gel, which significantly improves bonding and long-term strength.
- Role of Bagasse Fiber: The inclusion of bagasse fiber enhances the ductility and crack resistance of the blocks. The natural fibers act as micro-reinforcement, helping to control shrinkage cracks and improving flexural strength while maintaining workability.
- Optimized Mix Design: The right balance of FS, RHA, and bagasse fiber ensures durability, improved toughness, and sustainable resource utilization without compromising structural integrity.

The synergy between these materials results in stronger, more resilient, and eco-friendly CSEBs, making them a promising alternative for sustainable construction.

4.3 Comparison with IS Standards

To determine the suitability of these CSEBs for construction, the results were compared with IS 1725:2013 and IS 3495:1992 standards:

- Compressive Strength Requirements (IS 1725:2013): The standard recommends a minimum strength of 3.5 MPa for stabilized blocks. All tested mixes exceeded this requirement, confirming their structural adequacy.
- Water Absorption & Dimensional Tolerances (IS 3495:1992): The blocks were within the acceptable limits for water absorption and size variations, ensuring compliance with standard guidelines.

The findings highlight that CSEBs incorporating foundry sand and rice husk ash not only meet IS standards but also offer a more sustainable alternative to conventional blocks. Further improvements, such as optimizing curing conditions or using additional stabilizers, could further enhance performance.

5. Conclusion

This study highlights the potential of Compressed Stabilized Earth Blocks (CSEBs) incorporating foundry sand, rice husk ash, and bagasse fibre as a sustainable alternative to conventional masonry materials. The optimized mix design improved compressive strength, durability, and eco-friendliness by utilizing industrial byproducts effectively. Foundry sand enhanced particle packing, rice husk ash contributed to strength through pozzolanic reactions, and bagasse fiber improved crack resistance and toughness.

The results validate that these modified CSEBs can be a viable option for sustainable construction, promoting resource conservation and waste utilization. Future research can focus on long-term durability studies, thermal insulation properties, and large-scale implementation to further establish their effectiveness in real-world applications.

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