DEVELOPMENT OF LOW-CARBON SOIL-FREE MASONRY UNITS USING CONSTRUCTION AND AGRICULTURAL WASTE MATERIALS

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Abstract The construction industry plays an important role in the development of modern infrastructure. However, it is also one of the largest consumers of natural resources and a major source of environmental pollution. Conventional building materials such as fired clay bricks require large quantities of fertile soil and high-temperature burning during manufacturing. These processes result in the depletion of natural resources, high energy consumption, and the release of greenhouse gases. At the same time, construction and demolition activities generate a large amount of waste, which is often dumped in landfills. Similarly, agricultural activities produce huge quantities of crop residues every year, and most of these residues are burned in open fields, causing serious air pollution and environmental damage. Therefore, there is a growing need to develop sustainable construction materials that can reduce waste generation and minimize the environmental impact of the construction industry.

The present study focuses on the development of a low-carbon, soil-free masonry unit by using construction waste and agricultural waste materials. Instead of using natural clay, recycled construction waste such as crushed concrete, brick waste, and ceramic waste is used as the primary material. Agricultural fibres, namely Sunn Hemp fibre, Cotton Stalk fibre, and Maize Straw fibre, are incorporated as natural reinforcement materials to improve the performance of the masonry units. Ground Granulated Blast Furnace Slag (GGBS) and hydrated lime are selected as low-carbon binder materials because they produce lower carbon emissions than ordinary cement and help in improving the strength and durability of the developed bricks.

The main objective of this research is to produce an eco-friendly masonry unit that can serve as an alternative to conventional fired clay bricks while reducing the consumption of natural resources. Different mix proportions are prepared by varying the percentage of agricultural fibres to identify the most suitable combination. The manufactured masonry units are cured under normal conditions and evaluated through a series of laboratory tests. Physical properties such as density and water absorption are studied to understand the quality of the developed bricks. Mechanical properties including compressive strength and flexural strength are determined to evaluate their load-carrying capacity and crack resistance. Durability tests such as efflorescence, water resistance, and wet-dry cycle tests are also carried out to examine the long-term performance of the masonry units under different environmental conditions.

In addition to engineering performance, the study also evaluates the environmental benefits of utilizing construction and agricultural waste materials. The proposed masonry unit helps in reducing landfill disposal of construction waste, minimizes the burning of agricultural residues, conserves fertile soil, and decreases carbon emissions by eliminating the firing process used in conventional brick manufacturing. The use of GGBS and lime further contributes to lowering the carbon footprint by reducing dependence on cement. This approach supports the principles of sustainable development and promotes the concept of a circular economy by converting waste materials into valuable construction products.

The expected outcome of this research is the development of a strong, durable, and environmentally friendly soil-free masonry unit that can meet the basic requirements of modern construction. The study also aims to demonstrate that locally available waste materials can be effectively utilized to produce sustainable building materials without compromising engineering performance. If successful, the developed masonry units can provide an economical and eco-friendly solution for the construction industry while addressing the problems associated with waste management and resource depletion. Furthermore, this research encourages the adoption of sustainable construction practices and highlights the importance of using alternative materials for future infrastructure development.

Overall, this study contributes to the ongoing efforts to reduce the environmental impact of the construction sector by promoting the efficient use of waste resources and developing low-carbon building materials. The findings of this research may provide useful information for researchers, engineers, and the construction industry in developing sustainable masonry products suitable for future applications.

Keywords: Low-carbon masonry units, Soil-free bricks, Construction and demolition waste, Agricultural fibres, Sunn Hemp fibre, Cotton Stalk fibre, Maize Straw fibre, GGBS, Lime, Sustainable construction, Circular economy.

1. Introduction

The construction industry is one of the largest consumers of natural resources and a major contributor to global environmental degradation. Rapid urbanization, population growth, and infrastructure development have significantly increased the demand for construction materials such as cement, concrete, steel, aggregates, and fired clay bricks. While these materials have enabled modern development, their production and consumption have also resulted in substantial depletion of natural resources, high energy consumption, and increased greenhouse gas emissions.

Among the various building materials used worldwide, conventional fired clay bricks remain one of the most commonly utilized masonry units. However, the manufacturing of clay bricks involves the extraction of fertile topsoil and high-temperature kiln firing, both of which contribute to environmental deterioration. Continuous removal of topsoil adversely affects agricultural productivity, while brick kilns consume large quantities of fuel and release significant amounts of carbon dioxide and particulate pollutants into the atmosphere.

Simultaneously, the construction sector generates enormous quantities of Construction and Demolition (C&D) waste, including concrete debris, broken bricks, ceramic waste, mortar waste, and other discarded materials. A significant portion of this waste is disposed of in landfills or dumped in open areas, causing environmental and land management challenges. The accumulation of construction waste not only occupies valuable land resources but also represents a loss of potentially reusable materials.

In parallel with construction waste generation, agricultural activities produce substantial quantities of crop residues every year. Farmers often dispose of these residues through open-field burning due to the lack of economically viable utilization methods. Such practices contribute to air pollution, greenhouse gas emissions, and loss of valuable biomass resources. Therefore, the effective utilization of agricultural residues has become an important aspect of sustainable development and environmental conservation.

The convergence of these two waste streams—construction waste and agricultural residues—presents a unique opportunity to develop innovative and sustainable construction materials. By converting these wastes into value-added products, it is possible to reduce environmental burdens while simultaneously conserving natural resources.

The continuous extraction of clay for brick manufacturing, coupled with increasing volumes of construction waste and agricultural residue generation, has created significant environmental concerns. Existing masonry products depend heavily on virgin raw materials and energy-intensive manufacturing processes. Furthermore, the disposal of construction waste and agricultural residues continues to impose environmental and economic burdens.

There is therefore a need to develop a sustainable, soil-free, and low-carbon masonry unit that effectively utilizes construction waste and agricultural fibres while providing adequate mechanical strength, durability, and serviceability for construction applications.

Objectives of the study

1. To identify suitable construction waste materials for brick production.
2. To evaluate the suitability of Sunn Hemp, Cotton Stalk Fibre, and Maize Straw Fibre as reinforcement materials.
3. To develop soil-free brick mixtures using waste-derived materials.
4. To investigate the mechanical properties of the developed bricks.
5. To evaluate durability and water absorption characteristics.
6. To assess the environmental benefits of waste utilization.
7. To compare the developed bricks with conventional masonry units.
8. To study the carbon footprint reduced by the waste management.

2. Literature Reviews

Kazmi et al. (2016) investigated the effect of incorporating Sugarcane Bagasse Ash (SBA) and Rice Husk Ash (RHA) into clay brick manufacturing. Brick specimens were produced with varying replacement levels of 5%, 10%, and 15%. The study evaluated compressive strength, durability, unit weight, and efflorescence characteristics. Results showed that bricks containing lower dosages (5%) of SBA and RHA satisfied building code requirements while exhibiting lower density and improved resistance to efflorescence. The authors concluded that agricultural wastes can successfully be incorporated into brick production, resulting in sustainable and economical construction materials.

Khrissi and Tilioua (2025) developed stabilized earth bricks reinforced with date palm waste Fibres. Fibre contents ranging from 0% to 5% were investigated to evaluate thermal, mechanical, and water absorption properties. Experimental results revealed that Fibre addition improved thermal insulation and flexural strength, with optimum performance achieved at approximately 3% Fibre content. However, excessive Fibre incorporation increased water absorption and reduced compressive strength. The study demonstrated that agricultural waste Fibres can effectively improve the performance of eco-friendly masonry materials when incorporated at optimum levels.

3. Materials used in the study

3.1 Materials Used

Construction Waste

Construction waste acts as the primary structural matrix of the proposed masonry unit. High compressive strength, Reduced landfill disposal, Conservation of natural aggregates and Reducing natural clay usage, Abundantly available and Almost Zero cost.

Ground Granulated Blast Furnace Slag (GGBS)

Ground Granulated Blast Furnace Slag (GGBS) is a by-product obtained during the manufacture of iron in blast furnaces. It possesses cementitious and pozzolanic properties, making it an effective low-carbon alternative to conventional cement. The use of GGBS improves durability, enhances long-term strength, and significantly reduces carbon emissions associated with masonry products.

Hydrated Lime

Hydrated lime, also known as calcium hydroxide ($Ca(OH)_2$), is a widely used construction material produced by adding water to quicklime. In brick and concrete production, it improves workability, enhances bonding, increases durability, reduces shrinkage, and contributes to strength development through pozzolanic reactions with supplementary cementitious materials such as GGBS.

Sunn Hemp Fibre

Sunn Hemp Fibre (50 words):

Sunn hemp fibre is a natural, biodegradable fibre obtained from the *Crotalaria juncea* plant. It is lightweight, renewable, and possesses good tensile strength. In construction materials, sunn hemp fibre improves crack resistance, ductility, and toughness while reducing shrinkage, making it an eco-friendly reinforcement for sustainable bricks and concrete composites.

Cotton Stalk Fibre

Cotton stalk fibre is a natural lignocellulosic fibre obtained from the stems of cotton plants after harvesting. It is lightweight, renewable, biodegradable, and readily available as agricultural waste. In construction materials, cotton stalk fibre enhances crack resistance, toughness, and durability while promoting sustainable waste utilization and reducing environmental impact.

Maize Fibre

Maize fibre is a natural, biodegradable fibre derived from the stalks, leaves, or husks of maize (corn) plants. It is lightweight, renewable, and abundantly available as agricultural residue. In construction materials, maize fibre enhances toughness, crack resistance, and thermal insulation while promoting sustainable waste utilization and environmentally friendly building practices.

3.2 MATERIAL PROCESSING

Construction Waste Processing

1. Collection of waste materials.
2. Segregation (if needed)
3. Removal of impurities.
4. Crushing using jaw crusher.
5. Grinding.
6. Sieving through 4.75 mm sieve.
7. Storage in dry conditions.

Fibre Processing

1. Collection of Fibres.
2. Segregation (if needed)
3. Washing to remove impurities.
4. Sun drying.
5. Cutting into 10–20 mm lengths. (or)
6. Extracting fibres.
7. Storage in dry condition.

Proposed Mix Proportions used in the study

Mix ID	Construction Waste (%)	GGBS (%)	Lime (%)	Sunn Hemp (%)	Cotton Fibre (%)	Maize Fibre (%)
M1	0	0	0	0	0	0
M2	85.00	10.00	5.00	0	0	0
M3	82.00	10.00	5.00	3.0	0	0
M4	84.00	10.00	5.00	0	1.00	0
M5	84.00	10.00	5.00	0	0	1.00
M6	80.00	10.00	5.00	3.00	1.00	1.00

Brick manufacturing procedure

Step 1:Collection of raw materials.

Step 2:Crushing and sieving of construction waste.

Step 3:Fibre preparation.

Step 4:Dry mixing of waste materials.

Step 5:Addition of GGBS and lime.

Step 6:Addition of Fibres.

Step 7:Addition of water.

Step 8:Mechanical mixing.

Step 9:Mould filling.

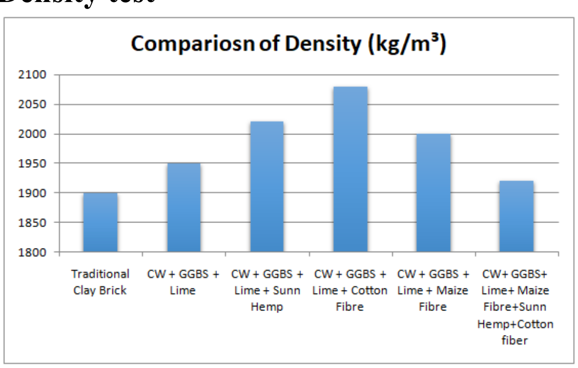
Step 10:Compaction using hydraulic press.

Step 11:Demoulding.

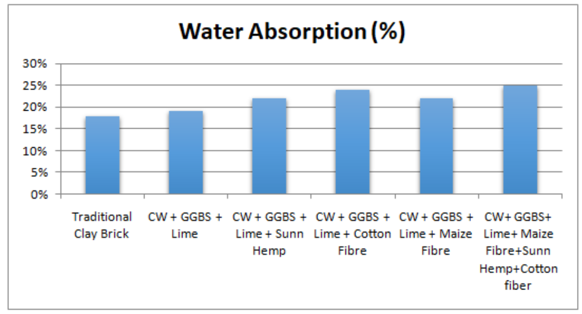
Step 12:Ambient curing for 28 days.

4. Results and discussion

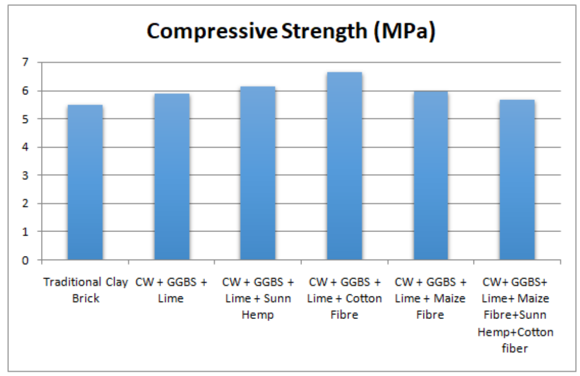
Density test



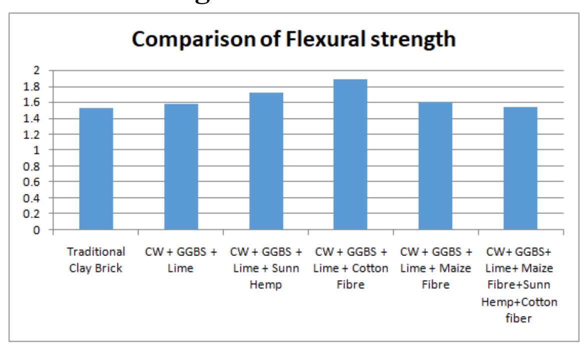
Water absorption test



Compressive strength



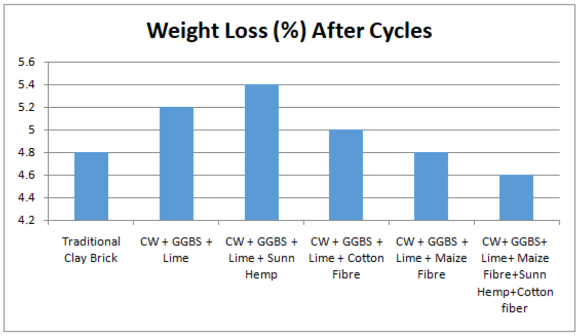
Flexural strength



Efflorescence test

S. No	Mix Type	Efflorescence Rating
1	Traditional Clay Brick	Moderate
2	CW + GGBS + Lime	Moderate
3	CW + GGBS + Lime + Sunn Hemp	Slight
4	CW + GGBS + Lime + Cotton Fibre	Slight
5	CW + GGBS + Lime + Maize Fibre	Moderate
6	CW+ GGBS+ Lime+ Maize Fibre+Sunn Hemp+Cotton fiber	Nil

Wet-dry cycle test



Water resistance test

S. No	Mix Type	Water Resistance Performance
1	Traditional Clay Brick	Moderate
2	CW + GGBS + Lime	Moderate
3	CW + GGBS + Lime + Sunn Hemp	Low
4	CW + GGBS + Lime + Cotton Fibre	Low
5	CW + GGBS + Lime + Maize Fibre	Moderate
6	CW+ GGBS+ Lime+ Maize Fibre+Sunn Hemp+Cotton fiber	Moderate

Sustainability assessment

S. No	Parameter	Traditional Brick	Developed Bricks
1	Topsoil Consumption	High	Nil
2	Construction Waste Utilization	Nil	High
3	Agricultural Waste Utilization	Nil	High
4	Firing Requirement	Required	Not Required
5	Energy Consumption	High	Low
6	Resource Conservation	Moderate	Excellent

Carbon Emission Comparison

S. No	Mix Type	Estimated Carbon Emission (kg CO_2/1000 Bricks)
1	Traditional Clay Brick	250–300
2	CW + GGBS + Lime	260-320
3	CW + GGBS + Lime + Sunn Hemp	270-340
4	CW + GGBS + Lime + Cotton Fibre	280-340
5	CW + GGBS + Lime + Maize Fibre	300-340
6	CW+ GGBS+ Lime+ Maize Fibre+Sunn Hemp+Cotton fiber	320-360

5. Conclusions

Based on the results and discussions presented in the previous chapters, the following conclusions can be drawn:

1. The utilization of construction waste as a primary constituent successfully eliminated the need for natural topsoil, thereby promoting sustainable resource conservation.
2. The combination of GGBS and lime proved to be an effective low-carbon binder system capable of providing adequate strength and durability to the developed masonry units.
3. The incorporation of natural agricultural fibres such as Sunn Hemp fibre, Cotton Stalk fibre, and Maize Straw fibre enhanced crack resistance and improved the overall performance of the masonry units.
4. The developed masonry units exhibited lower water absorption compared to conventional fired clay bricks, indicating improved resistance to moisture penetration.
5. The compressive strength of the developed bricks was found to be comparable to or higher than that of conventional clay bricks, demonstrating their suitability for masonry applications.
6. Fibre reinforcement contributed to improved flexural strength by reducing brittleness and enhancing toughness.
7. The developed masonry units exhibited satisfactory performance under wet-dry cycle exposure, indicating good durability under varying environmental conditions.
8. Efflorescence formation was minimal in the developed bricks, suggesting improved surface quality and long-term durability.
9. The elimination of the firing process significantly reduced energy consumption and greenhouse gas emissions associated with brick production.
10. The utilization of construction waste and agricultural residues provided an effective waste management solution while creating value-added construction materials.
11. The developed masonry units demonstrated superior sustainability performance compared to

conventional fired clay bricks due to reduced resource consumption and lower environmental impact.

12. Among the investigated mixes, the optimal mix exhibited the best balance of strength, durability, water resistance, sustainability, and carbon reduction potential.

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