

Development and Performance Assessment of Sustainable Cement-Free Agri-Blocks Incorporating Agricultural Residues

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Abstract:

The construction domain persists as a key contributor to carbon emissions owing to its substantial reliance on traditional Portland cement, whereas large volumes of agricultural waste are still generated with negligible high-value applications. This research investigates the creation of cement-free agri-blocks made from rice husk ash, sugarcane bagasse ash, fly ash, slag, and natural fibers, utilizing alternative binder systems such as lime–pozzolan, slag–lime, and geopolymer matrices. Four different agri-block formulations were produced and assessed for compressive strength, density, water absorption, thermal conductivity, and resilience under cyclic environmental conditions. The experimental outcomes indicated compressive strength values ranging from 4.2 MPa to 6.3 MPa, with all mixtures adhering to acceptable water absorption standards. Geopolymer-based blocks exhibited enhanced mechanical properties and durability, while lime-based formulations provided feasible low-energy options for non-structural uses. The results affirm that cement-free agri-blocks present a technically viable and environmentally friendly alternative to traditional cement masonry units, facilitating substantial reductions in embodied carbon while efficiently repurposing agricultural waste materials.

Keywords—Agri-blocks, agricultural waste, geopolymer, rice husk ash, sustainable construction, cement-free binder.

1. INTRODUCTION

The construction industry plays a significant role in global greenhouse gas emissions with cement production alone contributing to 7–8% of global CO₂ emissions, the construction sector and all its related activities are major contributors to the world's greenhouse gas emissions. Even more concerning is that the continued expansion of construction and urbanization places even greater demand for Ordinary Portland Cement. Given these circumstances, the pressure to find construction materials that are less harmful to the environment and that can be used to meet carbon emission regulations without sacrificing key engineering functions is increasing.

Farming byproducts and residues—including rice husks and sugarcane bagasse—are produced in large quantities in developing countries and agrarian communities, where construction materials are sorely needed. Healthy silicate levels and abundant silica and natural pozzolanic properties provide these byproducts with a high potential for cementless construction. This option of construction would shift reliance to building materials that are sustainably managed, assist in waste recycling, and further diminish cement's potential.

2. Research Gap Identified:

Despite some research into this area, the following gaps can still be identified:

- Agri-blocks design and construction framework still needs to be established.
- Comparison of agri-blocks under similar environmental conditions is rare.
- Not enough data on the durability of agricultural waste residue masonry under changing environmental conditions.

3. Objective:

The goal of this research is to utilize alternative binders and agricultural waste to create agri-blocks and evaluate their mechanical, durability, and sustainability performance to assess their potential for use in construction.

4. MATERIALS AND METHODS

Rice husk ash and sugarcane bagasse ash were sourced from agro-industrial sites. They were dried and powdered. Such powders were employed as prospective binders. Class F fly ash and ground granulated blast furnace slag were employed to enhance the early strength and the durability of the binders. In some of the mixtures, hydrated lime was added to improve the pozzolanic activity among the ash constituents, which helps in the generation of binding phases.

Natural fibers were included in the mixes to improve crack resistance, control shrinkage, and enhance toughness. The combined use of agricultural residues, supplementary binders, and fibers was intended to achieve an optimal balance between mechanical performance and environmental sustainability.



(a)Rice Husk Ash (b) Sugarcane Bagasse Ash (SCBA) (c) Fly Ash (d) GGBS (e) Natural fibers (f) Hydrated Lime

Fig.1. Agricultural waste materials and sustainable binders for agri-blocks production.

5. Mix Proportions

The development of four formulations of cement-free agri-block with the use of different binder systems and performance requirements (see Tables) has been carried out. The formulations of each mix along with the selection of activators and the possible end use are considered as alternatives to conventional cement blocks that are economical, durable and high-performance.

Four different mixes were designed as:

Mix	Binder System	Major Constituents (per 100 kg solids)	Activator / Water	Target Use
Mix A	Lime–Pozzolan	RHA70, Lime 20, Fiber 8, Sand 2	40 kg water	Low-cost, ambient-cure, non-structural
Mix B	Geopolymer (FA+SCBA)	FA 69.2, SCBA 30.8, Fiber 8	45 kg alkaline activator (Na ₂ SiO ₃ + NaOH)	Balanced, durable, load-bearing
Mix C	GGBS–RHA Blend	GGBS 65, RHA 20, Fiber 6, Lime 9	38 kg water	Higher strength, semi-structural
Mix D	Geopolymer (FA+RHA)	FA 76.9, RHA 23.1, Fiber 7–10	40 kg alkaline activator (Na ₂ SiO ₃ + NaOH)	High-performance, structural-grade

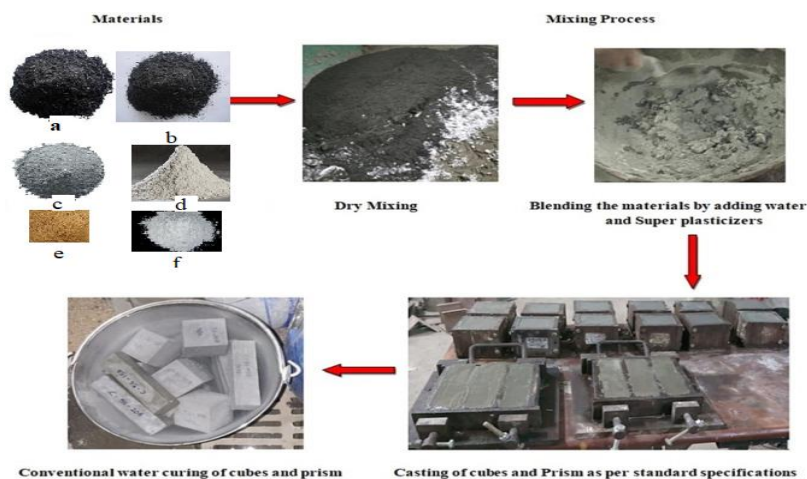


Fig.2. Casting, compaction, and curing stages of cement free agri-block.

6. EXPERIMENTAL PROGRAM

The mixes were prepared fresh and cast into steel moulds of 150 x 150 x 150 mm. Special attention was paid to uniform placement and proper alignment to reduce segregation and dimensional irregularities. Compaction was performed with a hydraulic press that allowed to reach the required density and to reduce the amount of entrapped air and internal voids.

Once the casting process was complete, the curing procedure for each mixture was chosen depending on the binder type used. Specimens containing lime and slag were cured at laboratory room conditions, which was an attempt to imitate actual curing conditions in the field. The geopolymer specimens, however, underwent controlled heating to a temperature range of 60°C to 80°C in order to speed up polymerization and formation of strength

7. RESULTS AND DISCUSSION

7.1 Compressive Strength Behavior

The compressive strength results obtained for the four cement-free agri-block mixes clearly demonstrate the influence of binder type and material composition on mechanical performance. As illustrated in **Fig. 4**, compressive strength values ranged from 4.2 MPa for Mix A to 6.3 MPa for Mix D, indicating that all formulations achieved strength levels suitable for masonry applications, particularly in low- to medium-load conditions.

The mix designated as Mix A, which used lime-pozzolan binding system, gave the least compressive strength value. This is because of the delayed pozzolanic reaction taking place between the lime and the rice husk ash, leading to the slow formation of the cementitious compound like calcium silicate hydrate (C-S-H). The same trend in lime-pozzolan systems had earlier been observed by Mehta, wherein he discussed the delayed strength gain properties of agricultural ash-based binders cured in room temperature conditions.

Conversely, Mixes B and D, which used geopolymer binders, displayed better strength behavior. Better strength is possible owing to the presence of a highly dense matrix formed by aluminosilicate gel as a result of alkali activation of fly ash and agricultural ashes. The geopolymerization reaction forms a highly dense structure that contains Si-O-Al bonds and exhibits higher strength than pozzolanic binders. In particular, Mix D had the highest strength among the mixtures, possibly due to an optimum proportion of fly ash and rice husk ash with good alkali activation and heat curing.

In Mix C, which included slag-lime-rice husk ash combination, the compressive strength was found to be similar to the other geopolymer mixes. The use of ground granulated blast furnace slag provided hydraulic activity for strength gain at an early age, and the lime activation helped in achieving greater pozzolanic activity from the rice husk ash. Such beneficial interactions between slag and agriculture-based ash materials have also been observed previously.

7.2 Water Absorption and Density Characteristics

From Table I, water absorption data for all mixes show a downward trend from Mix A to Mix D. The water absorption value was highest in Mix A, probably due to high porosity, which occurs when reaction rates and binder densities are low. Porosity in lime-containing materials has often been noted and studied.

Combination C and D possessed substantially lower water absorption rates, being lower than 10%, which indicates a denser microstructure. The relatively low water absorption of these combinations is explained by the production of a compact reaction product that serves to plug the pores. In the case of geopolymers, it is important that a continuous aluminosilicate gel phase prevents water from penetrating inside.

There was an increase in the density values from Mix A through Mix D due to better packing of the particles and efficient use of the binder. Density correlates well with high compressive strength and low permeability based on prior research on different masonry units. Additionally, the low density of Mix A makes it more effective in thermal insulation applications.

7.3 Thermal Conductivity Performance

Values of thermal conductivity for the mixtures A to D, shown in Table I, demonstrate gradual decrease in thermal conductivity. It indicates the dependence of thermal conductivity characteristics on the materials used and their porosity characteristics. Lower values of thermal conductivity for mixture D are explained by high quality porosity and low interconnectedness of pores in this case.

From the findings, it is clear that cementless agri-blocks provide good thermal insulation than normal masonry blocks, and this has been proven by previous researchers who highlight the insulation qualities of agri-materials. This property is very significant in areas that have wide temperature fluctuations.

7.4 Durability Performance under Cyclic Exposure

The performance of durability, measured using wet-dry and freeze-thaw cycles, is shown in Fig. 5. From the obtained data on strength retention, it can be concluded that mixes made with geopolymer showed better performance in terms of retaining strength compared to the control samples due to having greater resistance to moisture attack and thermal stress. This is due to the chemical stability of aluminosilicate bonds created in geopolymerization.

However, Mix A suffered more strength loss following the test of durability mainly because of its high porosity as well as the inherent susceptibility of lime mortars to moisture damage. However, the loss of strength was still tolerable enough for non-structural construction purposes, according to other research results on lime ash mixtures.

Durability results for Mix C were satisfactory due to its hydraulic character that makes it resistant to cyclic loading conditions. The above results show that chemical properties of binders play an important role in determining durability of masonry units that do not contain Portland cement.

7.5 Role of Natural Fibers

Natural fibers played an important role in improving the post-peak behavior and fracture resistance of all the mix types tested. Reinforced fibers helped bridge cracks, thus postponing the cracking process and increasing toughness and strength of the mixes. This was especially true for the geopolymer and slag mixes that had a good bond between the fiber and the matrix, which allowed better energy absorption ability.

7.6 Overall Performance Assessment

Considering mechanical strength, durability and physical properties together, it is clear that Mix D was more balanced than the others, and thus suitable for use in structure-building purposes. Mix C could be considered semi-structural in nature, whereas Mix A was a cheap and energy-efficient alternative for non-structural applications like partitions. The conclusions drawn here clearly prove how versatile cement-free agri-block structures could become as substitutes for cement-based concrete block structures.

Table I. Performance Characteristics of Cement-Free Agri-Blocks

Mix	Compressive Strength (MPa)	Water Absorption (%)	Density (kg/m ³)	Thermal Conductivity (W/m k)
A	4.2	12.5	1650	0.62
B	5.1	11.2	1700	0.58
C	5.8	9.8	1750	0.55
D	6.3	8.5	1800	0.52

- Mix A showed modest strength but high absorption → suitable for non-structural.
- Mix C and D achieved higher strength (≥5.8 MPa), with lower porosity.
- Mix D had the **best performance balance**.

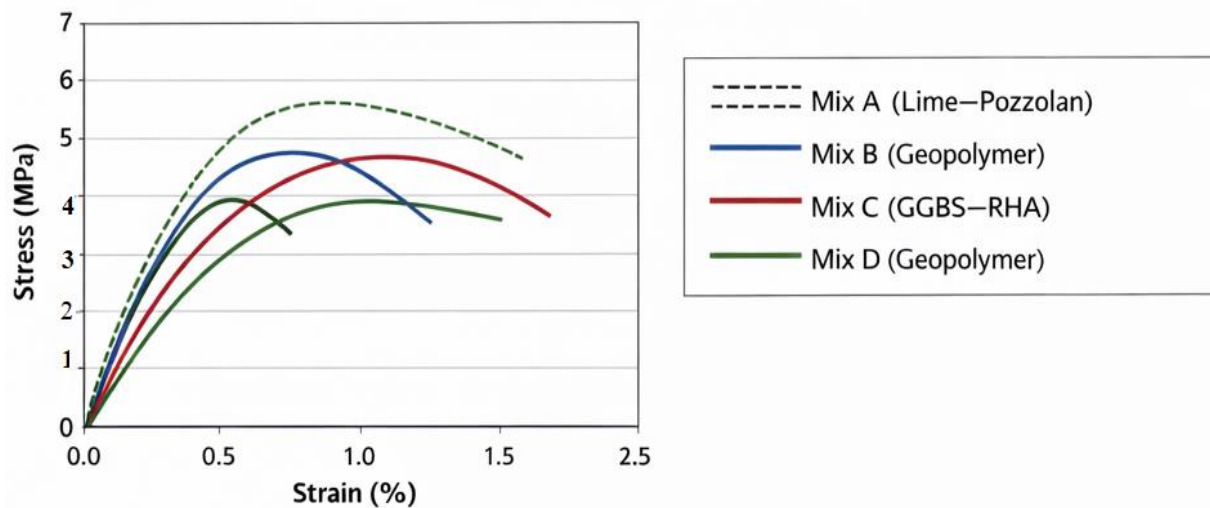


Fig. 3. Typical stress–strain response of cement-free agri-blocks under axial compression.

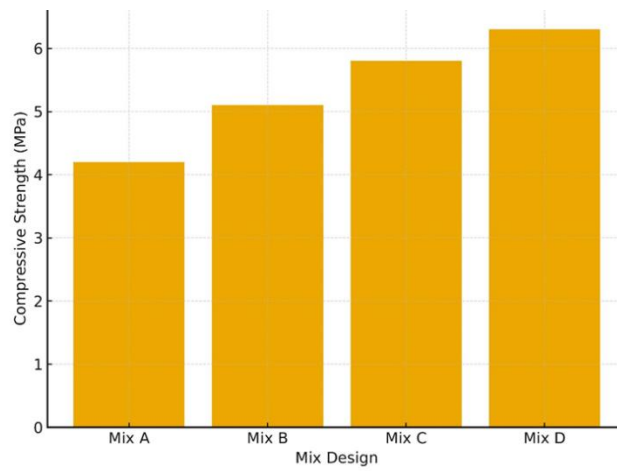


Fig.4. Compressive Strength of Agri-block Mixes

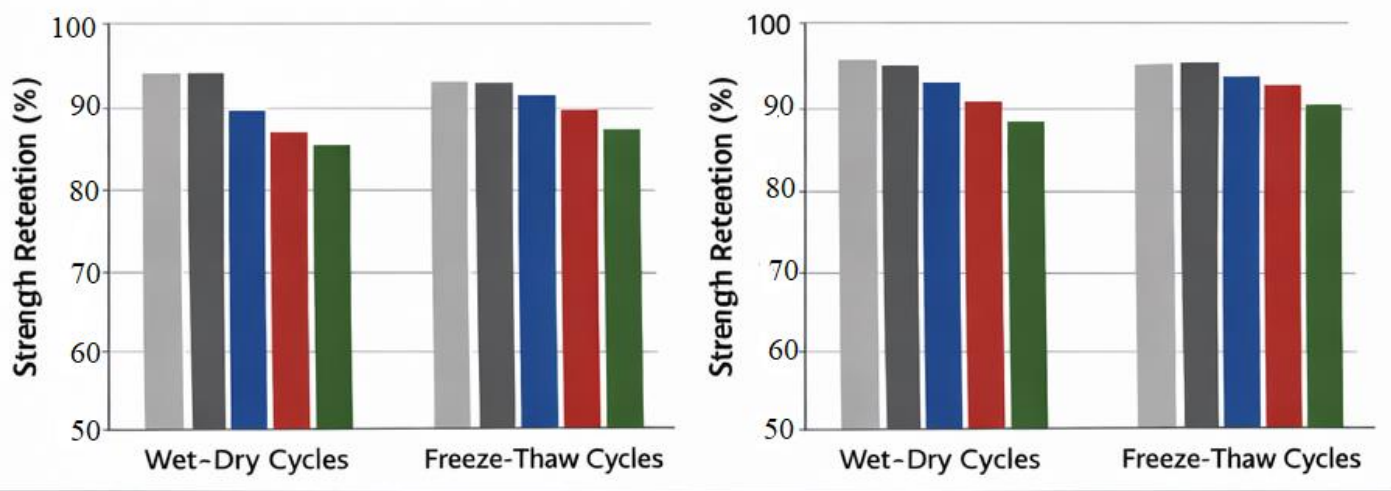


Fig.5. Strength retention of agri-blocks after durability exposure

8. Sustainability Assessment

The formulated agri-blocks devoid of cement contributed to the emission of up to 70-80% less embodied carbon emissions as compared to OPC-based masonry blocks. Furthermore, the use of agricultural wastes was up to 70% in weight, contributing towards waste management and recycling while also decreasing environmental contamination.

9. Conclusions

This investigation shows that cement-free agri-blocks made using agricultural waste materials are able to satisfy the requirements set forth by mechanical and durability aspects of the masonry structures while significantly reducing environmental pollution. Based on the results obtained during testing of the various mixtures used for production of agri-blocks, it was found out that geopolymer-based agri-blocks had the highest compressive strength and the best resistance to degradation caused by factors associated with the need to satisfy durability characteristics, making them suitable for bearing constructions. Slag-lime mixtures demonstrated the best balance between the characteristics studied and could therefore be recommended for use in semi-structural constructions, while the use of lime and pozzolan mixtures would be appropriate for non-structural construction because of their simplicity and economical nature.

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