OXFORD JOURNAL
OF STUDENT
SCHOLARSHIP

Sustainable Carbonaceous Bricks from Biochar and Rice Husk Ash: Proof of Concept Study on Biocomposites and Frugal Construction

Noe Noe Eaint Chue
noenoeeaintchue8@gmail.com

ABSTRACT

The construction industry's reliance on traditional fired-clay bricks contributes significantly to global CO2 emission. While sustainable alternatives exist, they are often exorbitant and inaccessible in developing nations and conflict-affected regions where rapid, low-cost shelter is a necessity. This research investigates cheaper and sustainable brick prototypes, using rice husk ash, cornflour, lime, and charcoal, with different volumetric ratios, low energy thermal curing, impact drop and water absorption test. This research indicates that a 1:1:1 ratio (RHA:cornflour:lime) with thermal treatment showed improved resistance to immersion but identified the constraint of localized thermal curing. These findings are essential for pursuing low-cost and frugal construction for conflict-affected areas while maintaining sustainable development.

INTRODUCTION

The construction industry is a major contributor to global carbon emission, where industries and cities widespreadly rely on non-renewable energy sources, leading to the increase in greenhouse gases emission and ongoing environmental problems. One of the causes is traditional portland cement production accounting for approximately 8% of CO2 emission globally (Barbulescu & Hosen, 2021). Carbon rich materials such as RHA can be used as a low-cost, sustainable alternative in construction because they are abundant, porous, and require minimal processing, leading to reduced CO2 emission. The use of carbon rich materials also introduces a balance between sustainability and performance, as their porous nature contributes to insulation while requiring optimization to maintain structural strength.

While various sustainable bricks alternatives such as hempcrete and compressed earth blocks have been suggested, they often remain inaccessible and hard to produce due to high manufacturing cost and requirement for specialized industrial machinery. For instance, hempcrete demonstrates poor mechanical strength, has high moisture sensitivity and needs to be kept dry during construction

(Steyn, de Villiers, Babafemi, 2025), making it harder for construction in tropical (the hot and humid) regions. Therefore, there is an urgent need for an alternative that is not only eco-friendly but also economically viable for local production.

This research focuses on the integration of composite bricks utilizing rice husk ash (RHA) as a primary aggregate which is balanced by a hybrid binder system of lime and cornflour. RHA is an abundant agricultural waste product with high-silica and high pozzolanic potential, reacts chemically with lime, while cornflour serves as an accessible biopolymer that can be thermally activated in low temperature in order to enhance structural consistency.

Although high-pressure, industrially cured RHA bricks are well-documented, a significant research gap remains regarding their performance under stringent resource conditions. Current research often underestimates the functionality of low-energy thermal curing and the use of simple volumetric proportions. The majority of existing studies rely on standardised laboratory conditions, leave a gap in data regarding frugal construction methods where minimal energy input and locally available material are used.

The study addresses these gaps by exploring the limit of bio-based masonry through a repetitious, low-resource experimental framework. This research fills a vital data void regarding the post-thermal mechanical limit of frugal construction.

METHODOLOGY

This study investigates how material composition, porosity, and structural configuration influence the impact resistance of eco-friendly bricks synthesized from RHA, lime, and cornflour. Five samples with different ratios of RHA, lime, cornflour and additionally a sample of charcoal, the mixtures were mixed via manual stirring. Each sample was dropped from a height of 3ft onto the flat surface of the ceramic tile to test the impact resistance, dropped flat on its bottom surface. The sample (2) was exposed to 11 minutes of thermal curing at a roughly 800 degree Celsius heat source to observe the effect of low energy thermal curing. To align with frugal innovation and non-standardized manufacture, the specimens were produced using accessible household tools rather than industrial machinery. The amount of raw materials were determined using a plastic cup of a standard 60ml lens cleaner bottle as baseline. To maintain a 1:1:1 ratio for sample (1) and (2), water was added at an equivalent 1:1:1 volumetric ratio to ensure consistency of the binder matrix.

For sample (3), (4), and (5) water was added to the dry mixture until it forms a pliable paste, total water volume was not strictly measured. All the mixtures were hand shaped without physical mold into small block prototypes rather than standard-sized building blocks. All samples were air-dried indoors for approximately 24 hours, this duration was selected based on empirical measurement to ensure the binder matrix reached a stable state before experimentation. To assess the moisture resistance of the composite bricks, specimens were submerged in room-temperature water for 10 hours, the methodology was designed to provide qualitative evaluation. The pass criteria is defined when the specimen is able to maintain its structure after impact drop test and water immersion without breaking into fragments, the fail criteria is defined when the specimen fails to maintain its structure after the mentioned tests. This investigation provided a groundwork testing of material compositions. Due to equipment malfunction, the exact dimensions of specimens, before and after immersion were not measured. Limited sample size of one specimen per formulation, the study provides observational data rather than statistically reliable data.

Table 1 Composition in ratios

Constituents	Rice husk ash	Cornflour	Lime	charcoal
Sample 1 (equal parts rice husk ash, cornflour, lime)	1:	1:	1:	None
Sample 2 (testing effect of heat treatment)	1:	1:	1:	None
Sample 3 (testing effect of higher binder ratio)	1:	1:	1.5:	None
Sample 4 (testing effect of ash dominance)	2:	1:	0.5:	None
Sample 5 (testing effect of carbon inclusion)	2:	1:	1:	1

CHARECTARIZATION

Sample (1) is characterized by a stoichiometric balance 1:1:1 ratio, by reducing the RHA content, and balancing with two binders, appearing less porous . It was the only specimen to maintain geometric integrity during a 3ft drop test. Suggesting that equal volumetric ratio may offer cohesion distribution, though further standard microporosity testing is required to calm this mechanism.

Sample (2) which shared the optimal 1:1:1 ratio of sample (1) but underwent thermal treatment, while the specimen remained structurally sound during 3ft impact drop test, however, the occurrence of minor peripheral fragmentation indicates a shift toward a more brittle failure mode. This minor fragmentation could indicate thermal curing may increase in brittleness.

Sample (3) was formulated using a volumetric ratio of 1:1:1.5 (RHA, cornflour, lime), while sample (3) exhibited higher compaction density, it demonstrated significant brittleness. The excessive lime and the geometric irregularities and jagged edges demonstrated poor dimensional stability, leading to premature structural failure despite the denser matrix.

Sample (4) was prepared with an increased RHA-to-binder ratio (2:1:0.5), while this formulation achieved dimensional stability and geometric uniformly compared to sample (3), excessive aggregate loading (RHA) and insufficient binder matrix (lime and cornflour), resulted in interstitial void and structural discontinuity.

Sample (5) utilized a 2:1:1:1 ratio (RHA, charcoal, lime, cornflour), highly porous carbonaceous fillers and the addition of charcoal, resulted in a significant increase in porosity of the composite. This created a binder-deficient matrix, where the two binders were unable to epitomize the particles effectively. Leaving the overall structure friable and brittle.

Water absorption test of Sample (1) and (2)

Water absorption serves as a critical indicator of the porosity and durability of sustainable bio-composite materials. In the context of conflict-affected regions, where infrastructure is exposed to extreme weather changes, the rate of moisture intake determines the lifespan of the structure.

Sample (1) failed the immersion test due to the high solubility of the uncured cornflour binder. Hypothetically, the lack of heat meant that intermolecular bonds between the starch and the RHA were observed to be purely physical rather than chemical. Upon exposure to water, the binder underwent the hydrolytic degradation, making the structure vulnerable to capillary suction and eventual dissolution.

Sample (2) demonstrated water stability compared to the unheated control. The application of localized heat (approx 800 degree Celsius at the source) for 11 minutes likely initiated the gelatinization and subsequent retrogradation of the cornflour. This created an improved resistance to immersion compared to the unheated control, although the specimen exhibited an increase in mass due to absorption into the interstitial pores, the core structural integrity remained intact.While Sample (2) could indicate that low-energy thermal activation may offer the increase in resistance of water solubility, post-immersion, the specimen became structurally fragile, resulting in failure during the handling phase.

RESULTS

A direct comparison between Sample (1) and Sample (2) demonstrated a significant shift in failure modes.Sample (1) passed impact absorption but failed in water due to hydrolysis of the uncured cornstarch. In essence, the unheated binder bonded physically then chemically, leading to high solubility in water. Sample (2), however, achieved water stability through localized thermal treatment. Although the specimen maintained its geometry during a 10-hours immersion. However, the following fracture reveals that internal moisture acts as a softener. The water filled the pores and reduced the bonding between the RHA and the binder, which lowers the brick's strength and leads to failure under impact when saturated.

When comparing the failed prototypes (Sample 3 to 5), a clear pattern of binder deficiency appears. Sample (3) suggests that structure stability matters and excessive lime increases brittleness. In Sample (4) and (5), excessive amounts of rice husk ash or charcoal reduced structural integrity, resulting in weak bonding and reduced structural continuity within the composite. Hence, the 1:1:1 ratio of sample (1) and (2) stands as the efficient configuration for balancing cost and durability.

DISCUSSION

Strength & Limitation

This study successfully demonstrates the viability of a frugal innovation framework, as the traditional masonry relies on heavy industrial plants, this framework lies in its profound utility for emergency shelter provision within conflict zones. By avoiding high temperature methods and shifting the manufacturing paradigm away from energy-intensive industrial outputs toward locally sourced, bio-based inputs and accessible biopolymer, demonstrates the possibility of a highly resilient, frugal blueprint for localized humanitarian response.

While these findings highlight the potential of natural building materials, still this cannot be recommended for construction until standardized assessment, crushing strength, standardized water and fire resistance. The Critical limitations must be acknowledged regarding the experimental execution. Because this was a student-led experiment conducted in a non-standardized environment, the result serves as a **qualitativ**e **proof of concept** rather than a final material certification. Further empirical testing is required to map the time-dependent deformation, durability under cyclic environmental exposure to ensure greater humanitarian safety.

Comparison Table

Sample	Thermal Treatment	Drop Test	Water Absorption Test	Primary Failure
1	N/A	Passed	Failed	Water-Based Decomposition
2	11 minutes	Passed	Passed	Structural Weakening(Post-handling phase)
3	N/A	Failed	None	Crumbling
4	N/A	Failed	None	Friability
5	N/A	Failed	None	Fragmentation

CONCLUSION

While the prototype aligns with frugal construction principles, it is currently limited by reduced strength, water vulnerability and lack of standardization, indicating the need for further optimization before large-scale application. The future vision for this material extends beyond traditional housing to emergency humanitarian relief. Post-conflict reconstruction to help regions affected by war and natural disasters. Aiming for decentralized manufacturing to produce temporary, semi-permanent housing to regain safety. Eventually, this exploratory study highlights that low-cost, locally sourced materials warrant further look into as potential sustainable building materials.

REFERENCES

[1] Osman, A.I., Farghali, M., Dong, Y. *et al.* Reducing the carbon footprint of buildings using biochar-based bricks and insulating materials: a review. *Environ Chem Lett* 22, 71–104 (2024). https://doi.org/10.1007/s10311-023-01662-7

[2] Zahra Shamsollahi, Ali Partovinia. Recent advances on pollutants removal by rice husk as a bio-based adsorbent: A critical review. Received 28 February 2019, Revised 25 May 2019, Accepted

28 May 2019, Available online 8 June 2019, Version of Record 8 June 2019. https://doi.org/10.1016/j.jenvman.2019.05.145

[3] Mariachiara Spennato, Anamaria Todea, Livia Corici, Fioretta Asaro, Nicola Cefarin, Gilda Savonitto, Caterina Deganutti, Lucia Gardossi. Turning biomass into functional composite materials: Rice husk for fully renewable immobilized biocatalysts. Received 23 March 2021, Revised 26 May 2021, Accepted 26 May 2021, Available online 6 June 2021, Version of Record 17 June 2021. https://doi.org/10.1016/j.bioeco.2021.100008

[4] Alina Barbulescu, Kamal Hosen. Cement Industry Pollution and Its Impact on the Environment and Population Health: A Review. Received 23 March 2021, Revised 26 May 2021, Accepted 26 May 2021, Available online 6 June 2021, Version of Record 17 June 2021. https://doi.org/10.3390/toxics13070587

[5] Jiarong Wang a b 1, Weihua Huang b 1, Xuemei Wang b, Yuhong Zhao a b, Ligang Zhang c. Modulating the gelatinization and retrogradation characteristics of corn starch by controlling pine kernel protein/egg white protein thermal co-aggregation. Received 6 May 2025, Revised 15 June 2025, Accepted 1 July 2025, Available online 3 July 2025, Version of Record 9 July 2025. https://doi.org/10.1016/j.carbpol.2025.124005

[6] Steyn, K., de Villiers, W. & Babafemi, A.J. A comprehensive review of hempcrete as a sustainable building material. *Innov. Infrastruct. Solut.* 10, 97 (2025). Published: 13 February 2025, volume 10, article number 97 (2025). https://doi.org/10.1007/s41062-025-01906-1

[7] Xiaowei Ouyang a, Jiongqi Chen a, Jiaming Li a, Kai Wu b, Yuwei Ma a, Jiyang Fu a. Mechanical, mineralogical and microstructure properties. Received 24 September 2023, Revised 4 November 2023, Accepted 28 November 2023, Available online 5 December 2023, Version of Record 5 December 2023. https://doi.org/10.1016/j.conbuildmat.2023.134385

[8] What is an Impact Resistance Test, and Why is it Important for Building Material? BET (A Phenna Group Company). February 7, 2025. https://betetechnologies.ie/news/what-is-an-impact-resistance-test-and-why-is-it-important-for-building-materials/