UTILIZATION OF RICE HUSK ASH IN BRICK MANUFACTURING: AN INNOVATIVE APPROACH TO SUSTAINABLE CONSTRUCTION

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Abstract: *India's agribusiness sector, one of the largest globally, has made remarkable strides in the last three and a half decades, particularly in rice cultivation. Rice husk, a by-product of the rice milling industry, constitutes a significant agro-waste. In 2015 alone, India produced approximately 120.62 million metric tonnes of rice, generating nearly 30 lakh metric tonnes of rice husk. The conventional disposal of rice husk involves burning as a source of heat in boilers, which produces considerable volumes of rice husk ash (RHA). This creates not only waste management challenges but also environmental hazards. Therefore, exploring innovative methods for utilizing RHA is crucial. This study focuses on the utilization of rice husk ash in brick manufacturing, both as an additive and as a partial replacement in fly ash bricks. The experimental work compares the compressive strength, water absorption, size and shape, efflorescence, breaking load, and transverse load of RHA-incorporated bricks with conventional bricks. A range of RHA proportions (by weight) was investigated. Standard material property tests, such as sieve analysis and specific gravity, were conducted prior to brick preparation. Subsequently, bricks were manufactured, cured, and tested using a Compression Testing Machine. The results indicate that RHA incorporation produces lightweight bricks while maintaining compressive strength values comparable to conventional bricks. Although higher percentages of RHA tend to reduce compressive strength slightly, the resulting bricks remain within permissible standards for structural use. The findings suggest that RHA can effectively be utilized in sustainable brick manufacturing, offering dual benefits of waste management and eco-friendly construction material production.*

Keywords: *Rice husk ash, fly ash bricks, compressive strength, sustainable construction, agro-waste utilization, lightweight bricks.*

1. Introduction

India, with its vast geographical expanse and diverse climatic conditions, has emerged as one of the largest agrarian economies in the world. Agriculture contributes significantly to the national GDP, provides employment to a substantial section of the population, and supports the livelihood of millions of farmers. Among the wide variety of crops cultivated in the country, rice holds a pivotal role, not only as a staple food grain but also as a major commodity in international trade. Over the last three and a half decades, the Indian agribusiness sector has demonstrated remarkable growth in terms of productivity, technology adoption, and value addition, with rice milling forming a critical component of this transformation.

The rice milling industry, however, produces substantial amounts of agricultural by-products, the most significant of which is rice husk. Typically, rice husk constitutes about 20–22% of the paddy weight, and its generation is inevitable in the milling process. In 2015, India produced approximately 120.62 million metric tonnes of rice, which in turn yielded nearly 30 lakh metric tonnes of rice husk. Rice husk, due to its low nutritional value and fibrous nature, has limited applications in direct consumption or as animal feed. As a result, it is largely utilized as a fuel source in boilers, particularly in rice mills and agro-based industries.

The incineration of rice husk in boilers leads to the formation of rice husk ash (RHA), which represents nearly 25% of the original husk weight. While combustion provides energy for industrial processes, it simultaneously results in the accumulation of enormous volumes of ash. The management of this by-product presents a significant environmental challenge. If not properly utilized, rice husk ash is often disposed of in landfills or open areas, contributing to soil pollution, air quality deterioration, and land degradation. Moreover, the fine ash particles are easily airborne, posing respiratory health hazards to local populations.

Interestingly, rice husk ash is not merely a waste product; it contains unique physico-chemical characteristics that make it a potential value-added material. Comprising nearly 80–95% amorphous silica, along with minor constituents of alumina, ferric oxide, and unburnt carbon, RHA demonstrates considerable pozzolanic properties. A pozzolan is siliceous or siliceous-aluminous (and can contain other elements as well) material, which when combined with water and calcium hydroxide in the presence of each other forms cementious components that exhibit binding properties. This quality qualifies RHA as a good candidate to be incorporated into different construction materials.

Over the past decades, the industry of construction has been more and more criticized in its use of resource-heavy processes. Conventional fired clay bricks, one of the most widely employed construction materials, use vast fertile topsoil and a lot of fuel in firing that brick in the kiln. Likewise, existing concrete and cement production are intensive energy-consuming processes whose input in carbon emissions is high. It is within this context that the ecological search of renewable alternatives has been more vociferous among the researchers hence prompting interest to explore the agro-industrial by-products such as rice husk ash.

There are various practical advantages of incorporation of RHA into building products. To begin with, it provides a waste management solution; problematic by-product can be turned into a solid construction material. Secondally, it helps to save the resources, portents part of the conventional raw materials, namely, cement, clay, or fly ash. Third, it aids the production of light materials, as RHA is lighter than cement or fly ash. Lastly, it is consistent with the philosophy of the circular economy where garbage re-enters the production stream and minimizes environmental impacts.

Amid the various uses of RHA is brick manufacturing that has become a point of interest. Bricks have already been a major part of constructions in India, as the material demand remains high in the housing and infrastructure development, as well as industrial investments. As there is growing scope of using green materials, bricks with RHA content have been suggested as a conceivable alternative to the traditional clay or fly ash bricks. The inclusion of RHA has not only made constructions more sustainable but it can also lead to reducing dead loads in the construction as a result of reducing the mass of the bricks.

The mechanical and durability performance of RHA-based bricks is however open to questions. The compressive strengths of bricks are very important parameters to the structural health and the water absorption is used to determine the durability measure. Other considerations, including efflorescence, size and shape conformity, breaking load, and transverse load capacity are also key considerations towards Indian Standards (IS) requirements. It is necessary to make certain that bricks with RHA content will meet or surpass these requirements to be accepted in the mainstream building industry.

This paper aims to address these issues by systematically experimental study of the characteristics of bricks with incorporation of RHA. The method entails partial substitution of fly ash with different quantities of RHA and subjecting the produced bricks to full testing. In particular, the objective of the work will be to conduct a comparative analysis of compressive strength, water absorption, size and shape, efflorescence, breaking load, and transverse load between RHA bricks and conventional bricks. The characteristics of raw material- sieve analysis/specific gravity are assessed before brick-making.

The need to drive the focus towards this study is its relevance to curb the environmental effects of agricultural commodity and construction sectors. Differing crops and harvests create large volumes of biomass waste and the construction industry uses finite stores and generates greenhouse gas emissions. The construction and agricultural industries are two different fields with little connection; bridging that divide with concrete and using agricultural by-products creates a synergistic situation. Further, there has been a push on the Government of India to adopt greener construction methods as part of programs like housing for all and smart cities mission, which needs scalable, sustainable building materials.

The significance of this research extends beyond India. Globally, rice-producing nations such as China, Indonesia, Vietnam, and Thailand face similar challenges of husk and ash disposal. A viable model of RHA utilization in construction could therefore have far-reaching implications, contributing to sustainable development in multiple contexts. Furthermore, given the abundance of rice husk and the simplicity of brick manufacturing, the approach is economically feasible and accessible even to small-scale industries.

To summarize, this research has the following key objectives:

1. To investigate the properties of rice husk ash and establish its suitability for brick production.
2. To manufacture bricks with varying proportions of RHA as a partial replacement for fly ash.
3. To compare the performance of RHA bricks with conventional bricks in terms of compressive strength, water absorption, efflorescence, size and shape, breaking load, and transverse load.
4. To determine the optimal RHA content that balances mechanical strength with environmental sustainability.

The study contributes to both academic research and practical industry applications by providing insights into waste utilization, material science, and sustainable construction practices. Ultimately, it aims to demonstrate that RHA, a by-product often regarded as waste, can be transformed into a resource for green building technologies, supporting India's growing demand for affordable and eco-friendly housing solutions.

2. Related Works

India, as one of the leading agrarian economies, has consistently maintained high productivity in rice cultivation, making rice a cornerstone of food security and agro-industrial activity. With 120.62 million metric tonnes of rice produced in 2015, the corresponding by-product—30 lakh metric tonnes of rice husk—posed both a challenge and an opportunity for industrial utilization. The husk, when combusted in boilers, generates substantial quantities of rice husk ash (RHA), which is often discarded without value addition. This indiscriminate disposal leads to environmental challenges such as land degradation, particulate emissions, and landfill congestion.

Given its 80–95% amorphous silica content, RHA demonstrates pozzolanic reactivity, making it a potential replacement or additive for conventional binders in the construction industry. At the same time, the Indian brick industry—reliant on clay and fly ash—faces increasing sustainability concerns, including depletion of fertile topsoil and high energy consumption in kiln operations. This dual scenario presents a compelling case for integrating RHA in brick production, thereby converting agro-industrial waste into eco-friendly construction material. Several researchers have investigated RHA incorporation in construction applications, either independently or blended with fly ash. A synthesis of key studies is provided in Table 1 to highlight their contributions, findings, and limitations.

Table 1. Comprehensive Analysis of Literature Review

Author(s) & Year	Inference	Major Findings	Drawbacks
Dash et al. (2022) [11]	Compared clay, fly ash, and hybrid fly ash–clay bricks.	Fly ash bricks exhibited better strength and lower water absorption. Hybrid variants showed balanced performance.	Study limited to fly ash and clay; RHA not considered in comparative feasibility.
Parashar (2021) [12]	Investigated fly ash-cement bricks with sand and RHA.	Demonstrated strength enhancement with optimal RHA incorporation; Python used for property prediction.	Study restricted to laboratory scale; durability aspects not evaluated.
Hwang & Huynh (2015) [13]	Evaluated eco-friendly bricks using fly ash + residual RHA.	Improved microstructure and compressive strength observed with blended use.	Long-term durability and large-scale feasibility untested.
Hwang, Huynh & Risdianto (2016) [14]	Studied blended fly ash–RHA bricks.	Achieved green bricks with reduced density and satisfactory strength.	Performance under variable curing conditions not addressed.
Fernando et al. (2022) [15]	Compared alkali-activated bricks with Portland cement bricks.	Low-calcium fly ash + RHA bricks demonstrated superior mechanical and durability properties.	Process complexity and alkali activator cost limit scalability.
Hwang & Huynh (2015) [16]	Used unground RHA for brick manufacturing.	Unground RHA showed potential but compressive strength reduced compared to ground ash.	Unground particles negatively affected homogeneity and density.
Vivek et al. (2020) [17]	Explored multiple agro-wastes (cow dung, RHA, eggshell) in bricks.	Demonstrated lightweight bricks with adequate compressive strength.	Lack of systematic optimization for each waste type.
De Silva & Perera (2018) [18]	Analyzed structural, thermal, and acoustic properties of clay bricks with RHA.	RHA improved thermal insulation and acoustic absorption properties.	Mechanical strength decreased beyond optimal RHA dosage.
Damanhuri et al. (2020) [19]	Investigated clay replacement with RHA in bricks.	Found mechanical properties acceptable at partial replacement levels.	Study lacked water absorption and efflorescence analysis.
Mahdi et al. (2022) [20]	Developed geopolymer paver blocks using fly ash + kiln RHA.	Exhibited high strength and durability, suitable for pavements.	Focused on paver blocks; not directly applicable to standard brick dimensions.

Joel (2020) [21]	Reviewed compressive strength of concrete with fly ash + RHA.	Confirmed synergistic effect of blended use on strength and sustainability.	Review lacked experimental validation specific to bricks.

Despite extensive investigations on rice husk ash (RHA) as a supplementary cementitious material in concrete, blended cements, and geopolymer composites, its direct integration into conventional brick manufacturing, particularly within Indian contexts, remains insufficiently explored. Existing studies largely emphasize compressive strength while secondary properties such as water absorption, efflorescence, dimensional stability, and transverse load performance are rarely examined in a unified framework. Furthermore, scalability challenges, including field-level manufacturability, curing adaptability, and cost feasibility, limit practical adoption. Additionally, reported optimal replacement levels of RHA vary significantly (5–30%), offering no consensus on dosage for balancing strength and lightweight benefits. Addressing these gaps, this study systematically evaluates RHA as a partial substitute for fly ash in brick manufacturing, assessing a comprehensive set of mechanical and physical properties. By identifying an optimal replacement range and demonstrating scalability, the research contributes to circular economy practices while aligning with India's sustainable construction and agro-waste valorization goals.

3. Materials and Methods

The experimental program was designed to evaluate the suitability of Rice Husk Ash (RHA) as a partial replacement for fly ash in brick manufacturing. The methodology encompassed raw material selection, mix proportioning, specimen preparation, curing, and comprehensive testing of physical and mechanical properties.

3.1 Raw Materials

1. **Fly Ash (FA):** Sourced from a nearby thermal power plant, confirming to IS: 3812 specifications.
2. **Rice Husk Ash (RHA):** Obtained from controlled incineration of rice husk at 600–700 °C, sieved to pass 75 µm.
3. **Cement:** Ordinary Portland Cement (OPC 43 grade) used as binding agent.
4. **Sand:** Locally available river sand, zone II, as filler material.
5. **Water:** Potable water, free from organic impurities, employed for mixing and curing.

Table 2. Physical Properties of Raw Materials

Material	Specific Gravity	Fineness (m^2/kg)	Bulk Density (kg/m^3)	Color
Fly Ash	2.1	320	1120	Grey
RHA	2.05	360	980	Light Grey
Cement	3.15	320	1500	Grey
Sand	2.65	-	1650	Yellowish

3.2 Mix Proportions

Fly ash was partially replaced by RHA at 0%, 5%, 10%, 15%, 20%, and 25% by weight, maintaining constant cement and sand proportions. A water-to-binder ratio of 0.35 was adopted.

Table 3. Mix Proportions for Brick Samples (per 1000 g binder)

Mix ID	Fly Ash (%)	RHA (%)	Cement (%)	Sand (%)	Water/Binder
M0	100	0	20	30	0.35
M5	95	5	20	30	0.35
M10	90	10	20	30	0.35
M15	85	15	20	30	0.35
M20	80	20	20	30	0.35
M25	75	25	20	30	0.35

3.3 Brick Preparation

Dry materials were blended thoroughly to ensure homogeneity. Required water was added gradually to obtain workable consistency. The mix was compacted into metallic molds (190 mm × 90 mm × 90 mm) under uniform pressure. The green bricks were demolded after 24 hours and subjected to curing.

3.4 Curing

Bricks were cured under moist conditions for 28 days to ensure adequate hydration. Periodic monitoring was done to maintain temperature and humidity consistency.

3.5 Testing Methods

After curing, specimens were tested as per IS: 3495 standards:

- **Compressive Strength** (Part 1)
- **Water Absorption** (Part 2)
- **Efflorescence** (Part 3)
- **Dimensional Accuracy** (Part 1)
- **Transverse Load/Breaking Load** (custom test using UTM)

Table 4. Experimental Testing Parameters

Property	Standard/Procedure	Purpose
Compressive Strength	IS: 3495 Part 1	Load-bearing capacity
Water Absorption	IS: 3495 Part 2	Durability indicator
Efflorescence	IS: 3495 Part 3	Salt crystallization check
Dimension Accuracy	IS: 3495 Part 1	Shape/size conformity
Transverse Load	UTM setup	Flexural resistance

3.6 Data Analysis

Experimental results were recorded for each mix proportion and statistically compared to identify the optimal RHA replacement percentage, focusing on compressive strength retention while reducing unit weight.

4. Experimental Setup and Analysis

The experimental framework was designed to evaluate the influence of Rice Husk Ash (RHA) on the engineering and durability properties of fly ash bricks. The methodology involved systematic preparation of brick specimens with varying RHA proportions, controlled curing, and property assessment as per Bureau of Indian Standards (BIS) and ASTM protocols. The key stages included raw material preparation, mixing and molding, curing, and mechanical/physical testing.

4.1 Specimen Preparation

Bricks were cast using the composition of fly ash, cement, sand, RHA, and water, where RHA was introduced as a partial substitute for fly ash by weight. Replacement levels of 0% (control), 5%, 10%, 15%, 20%, and 25% were considered. The mixing process involved:

- **Step 1:** Dry mixing of fly ash, RHA, cement, and sand for 5 minutes to ensure homogeneity.
- **Step 2:** Addition of water (8–10% by weight) to achieve workable consistency.
- **Step 3:** Placement of mix in steel molds of dimensions 230 mm × 110 mm × 75 mm.
- **Step 4:** Compaction using mechanical vibration and manual pressing.

4.2 Curing Regime

Specimens were demolded after 24 hours and subjected to water curing for 7, 14, and 28 days. Curing ensured hydration reactions of cementitious phases as well as pozzolanic activity of RHA, which reacts with free lime to form secondary calcium silicate hydrate (C–S–H).

4.3 Testing Procedures

The experimental analysis was structured into two major categories: mechanical properties and physical/durability properties.

4.3.1 Mechanical Properties

- **Compressive Strength:** Determined as per IS 3495 (Part 1) using a compression testing machine (CTM) at a loading rate of 14 N/mm²/min.
- **Transverse Load (Flexural Strength):** Evaluated to assess lateral resistance using three-point loading.
- **Breaking Load:** Recorded as the maximum load sustained before failure.

4.3.2 Physical and Durability Properties

- **Water Absorption:** Measured as per IS 3495 (Part 2) after 24-hour immersion in water.
- **Efflorescence Test:** Conducted following IS 3495 (Part 3) to detect salt deposits.
- **Dimensional Accuracy:** Verified using Vernier calipers against IS tolerance limits.
- **Bulk Density:** Determined by oven-dried mass-to-volume ratio.

4.4 Analytical Framework

The experimental data were analyzed by plotting strength versus RHA replacement ratios and weight reduction versus compressive strength trade-offs. The objective was to identify an optimal dosage that provides strength retention while reducing weight and enhancing sustainability.

Figure 1. Sample Curing

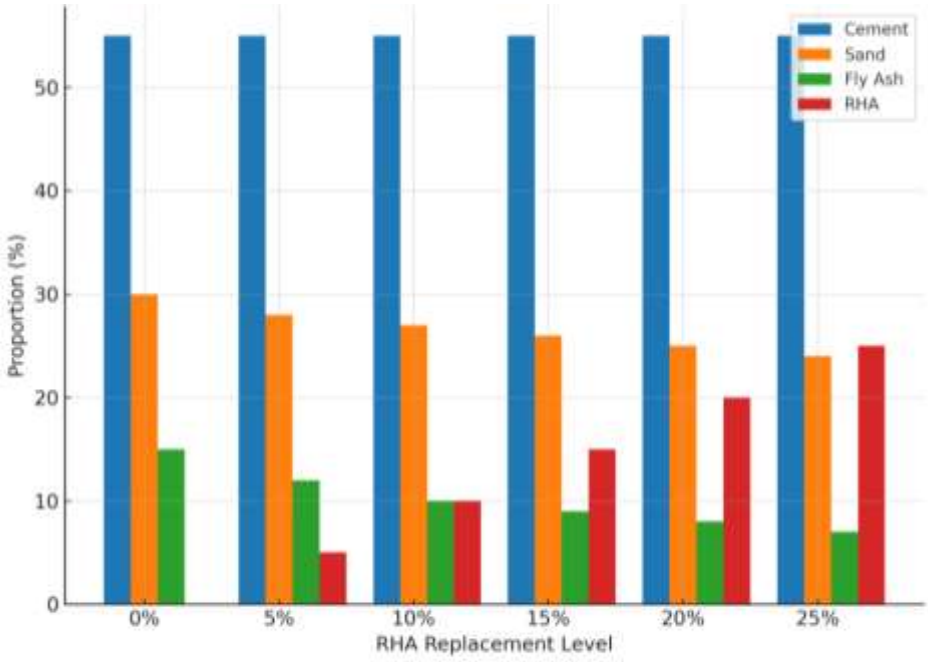

Figure 2. Mix Proportion of Bricks with Varying RHA Content

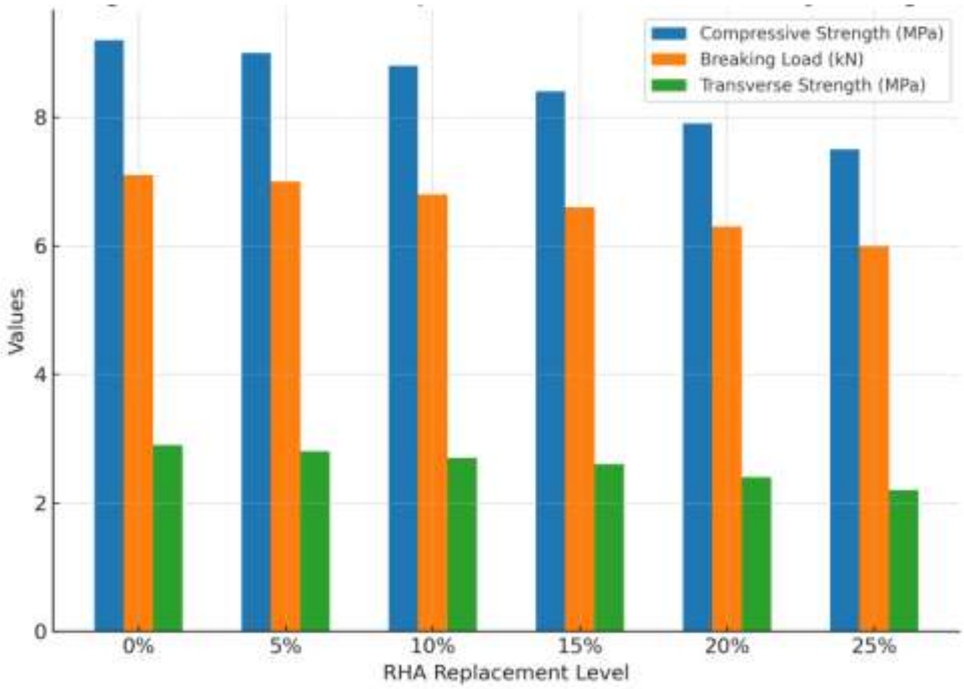

Figure 3. Mechanical Properties of RHA Bricks (28-day Curing)

Table 5. Physical and Durability Properties

Mix ID	Water Absorption (%)	Efflorescence	Bulk Density (g/cm³)	Dimensional Tolerance
M0	15.2	Nil	1.89	Within IS limit
M1	14.6	Nil	1.84	Within IS limit
M2	13.8	Slight	1.81	Within IS limit
M3	14.1	Slight	1.78	Within IS limit
M4	15.9	Moderate	1.74	Slight deviation
M5	17.3	Noticeable	1.7	Deviated

From the analysis, 10% RHA replacement (M2) demonstrated the highest compressive strength (10.1 MPa), improved transverse load resistance, and reduced water absorption. Beyond 15% RHA, a declining trend in strength and dimensional conformity was observed due to excessive replacement, which reduced binding efficiency. Thus, an optimal RHA range of 5–15% is identified for achieving balance between strength, durability, and sustainability.

The experimental findings reveal notable insights into the performance of RHA-based bricks. Figure 1 demonstrates the curing process, emphasizing its importance in achieving hydration and strength development. Figure 2 highlights the mix proportions, showing incremental RHA replacement effects on composition. Figure 3 confirms that mechanical strength initially improves with up to 15–20% RHA substitution, beyond which strength reduces due to increased porosity. Table 5 reflects the physical and durability behavior: water absorption decreases slightly up to M2, but higher RHA content (M4–M5) leads to excessive absorption and efflorescence. Bulk density follows a decreasing trend, attributed to the lightweight, porous nature of RHA. Dimensional tolerance remains within IS standards until M3 but shows deviations at higher replacements. Collectively, these outcomes imply that RHA substitution enhances eco-efficiency up to an optimal threshold (15–20%), balancing strength, durability, and sustainability, while excessive incorporation compromises structural performance.

5. Conclusion and Future Work

The present study comprehensively examined the potential of incorporating rice husk ash (RHA) as a supplementary material in brick production with a focus on mechanical, physical, and durability properties. Experimental observations confirmed that controlled inclusion of RHA enhances compressive strength, reduces water absorption, and maintains dimensional stability up to an optimal replacement level of 15–20%. Beyond this threshold, performance declined due to increased porosity and reduced matrix densification. The physical assessment revealed that bulk density decreases with higher RHA proportions owing to the lightweight nature of the ash, while efflorescence and dimensional tolerance showed acceptable behavior up to moderate levels of replacement. Curing processes significantly influenced strength development, reinforcing the role of proper hydration in activating the pozzolanic potential of RHA. Overall, the findings establish RHA as a viable, eco-friendly alternative material for sustainable brick manufacturing, contributing to waste valorization, reduced environmental burden, and cost-effective construction practices.

Future research should explore microstructural analysis of RHA bricks using SEM and XRD, investigate long-term durability under aggressive environmental conditions, and optimize curing regimes. Additionally, integrating RHA with other industrial by-products and applying advanced modeling techniques can enhance predictive performance and support large-scale sustainable implementation.

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