

Comparative Analysis of Characteristics of Modified Masonry Unit with Infused Additives: Coal, RHA, and Sawdust

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Abstract

Brick is one of the most commonly used construction materials. The performance, age, and economy of a project are hugely impacted by brick characteristics. This study aimed to investigate the behavior of modified bricks in terms of compressive strength, porosity, and economic perspectives. Fifteen brick formulations were investigated: a Coal-based series (five variants: 2–10% coal by weight), RHA+Sawdust combinations (four variants with varying RHA:SD ratios totaling 8%), a Sawdust-only series (four variants: 2–8% sawdust), and reference samples (Traditional Dachii Appa and Modern machine-made bricks). All specimens were tested in the laboratory as per IS 3495:1992 for compressive strength, water absorption, porosity, bulk density, and durability. Compressive strength was enhanced by adding 6% coal, yielding 8.282 MPa; the RHA+SD combination of 6% RHA and 2% SD achieved the highest modified-brick strength of 9.662 MPa. All formulations met the minimum strength requirement (≥ 3.5 MPa) of NBC 109:1994. The average water absorption of coal-based bricks was 20.359%, with an average group porosity of 29.469%, whereas the RHA+SD group showed an average porosity of 36.189% (individual values ranging up to 39.3%) with enhanced strength but higher porosity. By integrating industrial and agricultural by-products into bricks, structural integrity can be maintained while achieving sustainable solutions for brick manufacturing. Additionally, these bricks contribute to resource efficiency and eco-friendly building practices in the Nepalese construction industry.

Keywords: Clay bricks, Coal addition, Rice husk ash, Sawdust modification, Compressive strength, Porosity, Water absorption

1. Introduction

Clay bricks continue to be key structural and aesthetic building elements worldwide, as their intrinsic properties can have major impacts on load distribution, mechanical strength, and durability [2,3]. With respect to the construction sector of Nepal, the need for sustainable building materials has been further highlighted by environmental concerns and the necessity to optimise resources. Studies show that manufacturing bricks traditionally consumes large amounts of energy and natural resources and creates substantial emissions; therefore, new methods to incorporate waste materials are needed without compromising brick performance [1].

Overall waste reduction and improved material properties are advantages of using industrial and agricultural waste materials as additives in clay brick production. Combustible additives such as coal dust can also be used to minimize firing energy demand while improving brick properties. Coal dust is produced in large quantities through activities such as those performed by thermal power plants and industrial processes. Conversely, rice husk ash (RHA), generated from rice processing, and sawdust from timber industries are agricultural and wood-processing wastes that are abundant in Nepal and can potentially be used in large-scale brick manufacturing. Recent studies have demonstrated the potential of utilising waste materials for clay brick formulation. Studies found that the introduction of natural fibres could increase compressive strength from 2.67 MPa to 16.53 MPa, depending on the type and content of fibre added [1]. The relationship of physical properties and compressive

strength in clay bricks was observed to vary from 16.10 to 28.90 MPa by brick type [2]. Studies found that water absorption and total porosity were 10–28% and 17–33%, respectively, with compressive strength in the range of 5–23 MPa for ancient clay bricks [3].

This study fills the research gap in the systematic analysis of coal-based and RHA/sawdust-added bricks in the context of the Nepalese construction industry. It seeks to establish optimum additive percentages, analyse conformity to national standards (NBC 109:1994 and IS 3495:1992), and provide evidence-based suggestions for environmentally friendly brick production.

2. Literature Review

The performance of clay brick masonry depends strongly on the compressive strength and deformation behaviour of individual units [2]. Studies have shown that compressive strengths vary between 16.10 and 28.90 MPa for clay brick masonry prisms, highlighting the critical influence of brick quality and mortar type on ultimate strength and stiffness. Researchers examined ancient bricks from Kathmandu Valley heritage structures and found compressive strengths of 5–23 MPa, water absorption of 10–28%, and apparent porosity of 17–33%, showcasing the broad variability associated with traditional production practices and firing regimes [3]. These existing local data provide a useful background for evaluating newly developed brick formulations.

IS 3495:1992 specifies procedures for determining compressive strength, water absorption, efflorescence, and dimensions of burnt clay bricks [5]. IS 1528 (Part 15):2007 and ISO 5017:1998 define methods for measuring bulk density and apparent porosity [14, 15]. NBC 109:1994 sets a minimum compressive strength requirement of 3.5 MPa for bricks used in unreinforced masonry, and NBC 202:2015 provides guidelines for load-bearing masonry design [12, 13]. Water absorption and porosity are key indicators of durability; bricks with high absorption generally exhibit lower frost resistance and are more susceptible to moisture-related deterioration [17].

The fusion of industrial and agricultural wastes into clay bricks has been widely explored as a strategy to reduce environmental impact and conserve natural resources [1, 18, 19]. Researchers reinforced mud bricks with natural additives such as straw, wood chips, rice husk, and palm fibres and obtained compressive strengths up to 16.53 MPa compared with 4.4 MPa for unmodified units [1]. Reviews on sustainable brick manufacture report that integrating wastes such as fly ash, RHA, sawdust, and other biomass residues can reduce firing energy by about 10–20% and significantly lower life-cycle emissions when additive contents are optimised [18–20].

RHA is a widely available by-product in rice-producing countries and typically contains 80–95% amorphous silica, giving it strong pozzolanic reactivity [16]. A 4% RHA addition was found to increase compressive strength by about one-third and reduce water absorption by 19% relative to control bricks [8]. Incorporating 2–10% RHA in fired bricks increased density and compressive strength while lowering firing energy demand, with optimum performance observed at the lower end of this range [11]. A 10% RHA substitution for clay was shown to reduce unit production cost by more than 40% [9]. However, high RHA dosages tend to increase total pore volume and water absorption, which may affect durability in wet or freeze–thaw environments [8, 19, 20].

Sawdust has been widely studied as a lightweight additive in clay bricks. Incorporating wood sawdust reduced bulk density and thermal conductivity while increasing total porosity, thereby improving insulation performance [10,17]. Small additions can produce remarkable density reductions with acceptable mechanical performance, whereas larger additions lead to excessive porosity and strength loss [17]. Coal dust is sometimes incorporated directly into the clay mix as internal fuel to reduce external kiln fuel consumption [1]. Moderate amounts of internal combustible material can produce lighter units with adequate strength and improved energy efficiency at kiln level [18]. However, brick kilns relying heavily on coal combustion are major sources of particulate matter and sulphur dioxide in South Asia, including Nepal [3].

Most published work investigates single-additive systems [1, 8–10]. Evidence on combined systems, particularly bricks containing both RHA and sawdust, is comparatively limited [8, 10, 19]. A case study of brick

manufacturing in Bhaktapur highlighted variability in locally produced bricks but did not investigate multi-additive formulations [6]. Recent reviews on circular economy in brick manufacturing emphasise the need for region-specific experimental programmes that link physical properties, mechanical performance, and environmental considerations within a single framework [20]. The present study responds to this gap by developing coal-based, RHA+sawdust, and sawdust-only bricks, testing them alongside reference bricks using IS 3495 and related standards, and applying one-way ANOVA to identify statistically distinct performance groups under NBC 109:1994 requirements [?, 3, 12].

While current literature provides significant insights into individual brick properties, there is little research on a thorough comparative analysis of different brick types used in Nepal's construction sector. Bricks with RHA and sawdust individually have been studied, but the benefit of using these additives in combination has not been rigorously established. This study fills that gap by providing new multi-additive brick specimens with systematic comparative analysis and robust statistical evaluation.

3. Research Questions

1. How does varying additive percentage from 2% to 10% affect the properties of brick?
2. Can the combination of RHA and sawdust lead to better performance?
3. How do these modified bricks compare to traditional and modern alternatives in real-world applications?

4. Materials and Methods

4.1 Physical and Mechanical Properties of Common Clay Bricks in Nepal

A seven-step protocol (Figure 1) was followed for property comparisons under different conditions. Physical tests included water absorption, porosity, and bulk density (IS 1528 Pt.15; ISO 5017), and mechanical tests included unconfined compressive strength using a Universal Testing Machine (UTM) per IS 3495 and a durability assessment. To validate property–performance links, one-way ANOVA ($\alpha = 0.05$) was applied, and results were cross-checked with [5], yielding consistent outcomes that complied with standards and facilitated material selection.

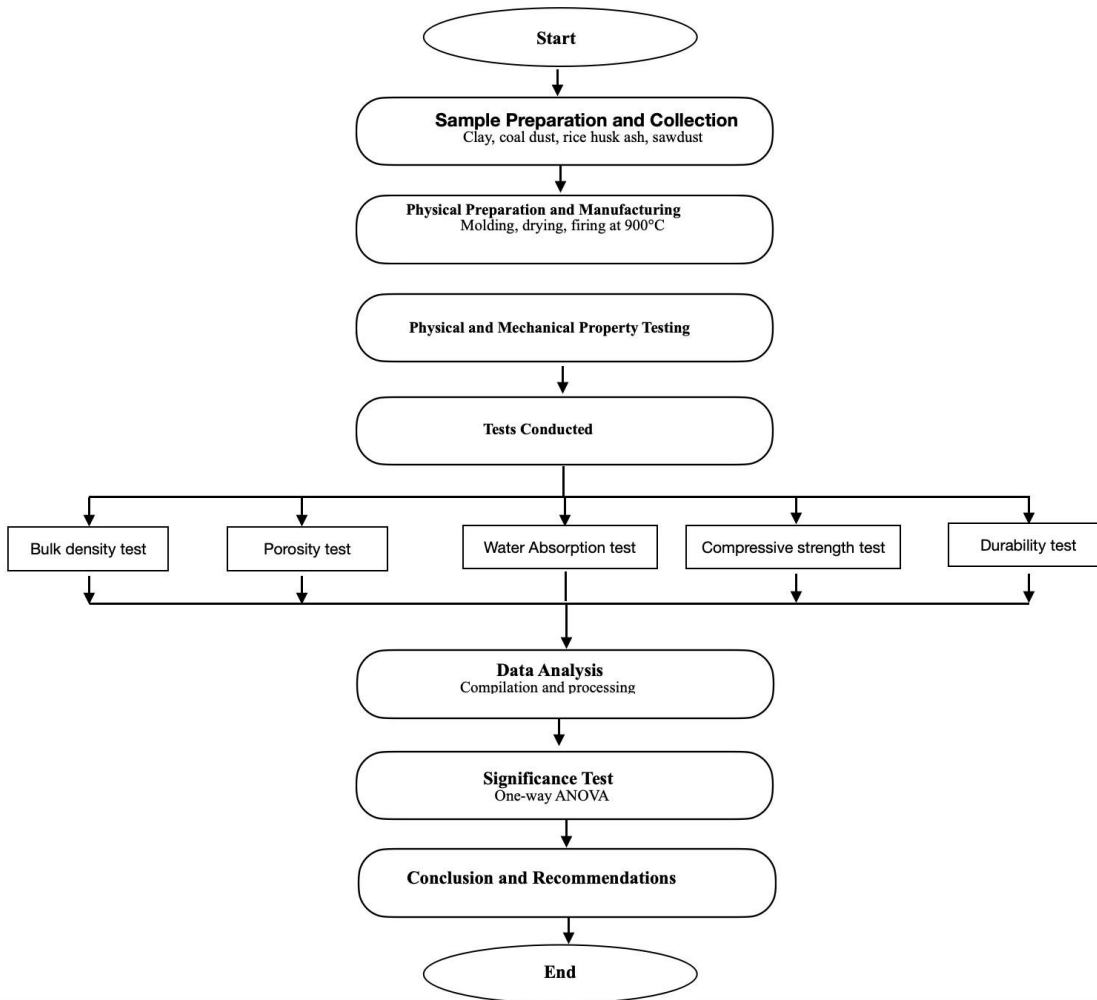


Figure 1. Methodology flowchart for experimental brick study

4.2 Material Sourcing and Preparation

Clay material was collected from a local brick factory to maintain uniform mineralogical composition throughout the experiment (Figure 2). Coal dust was collected as industrial waste; rice husk ash was collected from local rice mills in Bhaktapur and processed by 300-micron sieving for uniform particle size distribution. Sawdust was supplied directly from the brick factory through wood-processing activities.

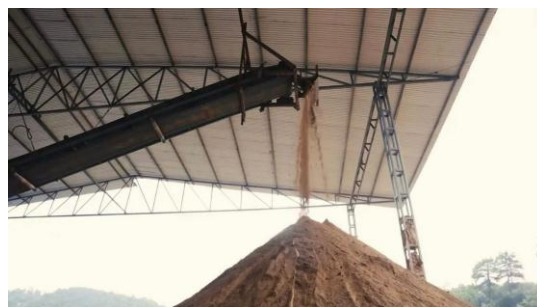


Figure 2. Clay material collected from local brick factory

4.2.1 Sample Design and Preparation

Fifteen brick formulations were prepared with systematic additive combinations. Each brick was prepared maintaining a distinctive proportion of components:

(i) **Coal-based Series (5 variants):** Specimens with 2%, 4%, 6%, 8%, and 10% coal content by weight.

(ii) **RHA+SD Combinations (4 variants):** Specimens with:

- 2% RHA + 6% SD
- 4% RHA + 4% SD
- 6% RHA + 2% SD
- 3% RHA + 3% SD

(iii) **Sawdust-only Series (4 variants):** Specimens with 2%, 4%, 6%, and 8% sawdust content by weight.

(iv) **Reference Samples (2 variants):** Traditional Dachii Appa brick and Modern machine-made brick.

Clay mixtures were developed by adding water to obtain workability limits for consistent moulding properties. Standard brick moulds (23×10.5×5.7 cm and 20×10×5 cm) were used. Sun drying was carried out for 3–4 days under controlled conditions after moulding.

4.2.1.1 Firing Process

All samples were fired in controlled kilns at 900 °C with even temperature distribution and firing time. The temperature was chosen with reference to local practice and the ideal sintering condition for the clay body composition used.

4.2.1.2 Testing Methodology

A series of tests was performed to analyze physical and mechanical properties of brick specimens. Properties such as dimensions, impact resistance, and soundness were assessed manually. An experimental research design was employed to determine and compare the strength of specimens; a comparative analysis was then conducted to ascertain variations in permeability. Randomized sampling, controlled variables, and repetitions were used to minimize errors and ensure data validity. The methodology is described in Figure 1.

(i) **Dimensional Analysis:** Length, breadth, and height were measured using precision calipers to determine uniformity of shape and size, and to obtain specimen volume.

(ii) **Weight Determination:** Dry weight was recorded post-firing; saturated weight was measured after 24-hour water immersion (Figure 3).



Figure 3. Curing of brick samples (24-hour water immersion)

The following tests were carried out:

(i) **Bulk Density Test:** Bulk density is the ratio of mass to total volume (including voids). It directly influences mechanical, thermal, and durability behaviour. Calculated using Equation (1):

$$\text{Bulk Density} = \frac{\text{Dry Weight}}{\text{Volume}} \quad (\text{g/cm}^3) \quad \text{Equation (1)}$$

(ii) Porosity Test: Apparent porosity is the ratio of void volume to total bulk volume, expressed as a percentage. It directly influences bulk density, water absorption, and compressive strength. Measured per IS 3495(Pt.2):1992 using Equation (2):

$$\text{Apparent Porosity} = \frac{\text{Saturated Weight} - \text{Dry Weight}}{\text{Volume}} \times 100\% \quad \text{Equation (2)}$$

(iii) Water Absorption Test: Water absorption is the percentage increase in mass of a dry brick after immersion in water, indicating pore connectivity and durability. Measured per IS 3495(Pt.2) using Equation (3):

$$\text{Water Absorption} = \frac{\text{Saturated Weight} - \text{Dry Weight}}{\text{Dry Weight}} \times 100\% \quad \text{Equation (3)}$$

(iv) Compressive Strength Test: Compressive strength is the maximum compressive stress a brick can withstand before failure under axial loading, expressed in MPa (N/mm²). Specimens were loaded on a Universal Testing Machine (UTM) per IS 3495:1992 using Equation (4):

$$\text{Compressive Strength} = \frac{\text{Maximum Load at Failure}}{\text{Average Cross-sectional Area(N/mm}^2)} \quad \text{Equation (4)}$$

(v) Durability Assessment: Impact resistance (1-metre drop test) and soundness evaluation (strike test), shown in Figure 4, were conducted to assess long-term performance characteristics.



Figure 4. Strike testing on brick specimen

5. Results and Discussions

5.1 Physical Properties Analysis

The experimental test findings for bulk density, porosity, and water absorption are tabulated in Table 1.

Table 1. Physical Properties Summary of Brick Specimens

Sample Category	Avg Bulk Density (g/cm ³)	Avg Porosity (%)	Water Absorption (%)
Coal-based (2–10%)	1.449 ± 0.043	29.469 ± 1.244	20.359 ± 1.029
RHA + SD combinations	1.245 ± 0.042	36.189 ± 2.400	29.139 ± 2.947
Sawdust-only	1.295 ± 0.105	32.496 ± 2.277	25.200 ± 2.342
Traditional [†]	2.066	8.90	4.62
Modern [†]	1.804	7.77	6.02

[†]Single representative specimen; standard deviation not applicable.

As tabulated in Table 1, the bulk density test shows clear trends across brick categories. Coal-based bricks had moderate density values (average 1.449 g/cm³), whereas RHA+SD mixes had lower density (1.245 g/cm³), which may bring advantages in structural weight saving. Traditional bricks had the highest density (2.066 g/cm³), reflecting their dense matrix structure.

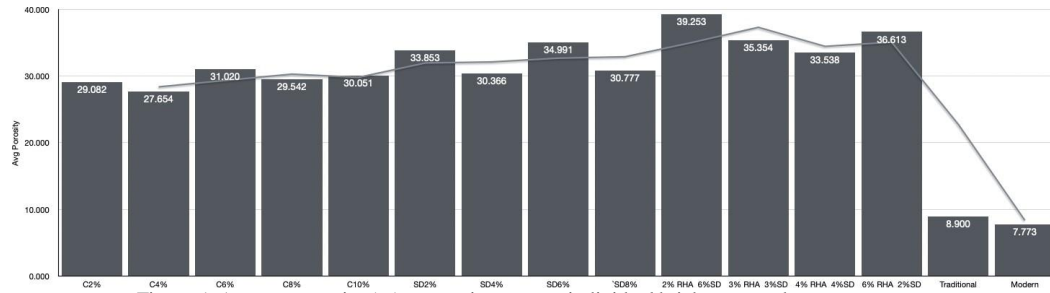


Figure 5. Average porosity (%) comparison across individual brick types and category groups

As shown in Figure 5, porosity tests depict inverse trends relative to density values. RHA+SD mixtures had the highest average group porosity (36.189%, Table 1), with the 2% RHA+6% SD variant reaching a peak individual value of 39.253%, due to the cellular nature of organic additives and their burn-out during firing. Coal-based bricks had moderate average porosity (29.469%), while Traditional and Modern reference bricks had very low porosity (8.90% and 7.77%, respectively).

5.2 Compressive Strength Performance

Compressive strength is the primary indicator of load-bearing capacity and structural viability. Table 2 presents the detailed results obtained with reference to national building codes and the corresponding standard deviation. Table 2 shows that the best coal-series performance occurs at 6% coal content (8.282 MPa), a 15.4% improvement over the lowest-performing coal variant (10% coal, 7.177 MPa) and a 24.2% improvement over the Traditional reference brick (6.667 MPa). The variation in result occurred due to excessive porosity from complete coal combustion in 10% coal which weakens the matrix. The comparison of the best performing coal-series masonry i.e. (6% coal) with the tradition Dachii Appa brick, shows 24.2% improvement in compressive strength. The trend indicates that moderate coal percentages yield optimum strengthening, but higher quantities can induce structural flaws through excessive porosity caused by coal combustion. Among the RHA+SD combinations, the 6% RHA+2% SD mix achieved the highest strength (9.662 MPa), exceeding the Traditional brick (6.667 MPa) and approaching the Modern brick (8.834 MPa) level. The superior performance is attributed to the pozzolanic nature of RHA, which improves matrix bonding via secondary cementing reactions that densify pore walls even as total porosity increases.

Table 2. Compressive Strength Analysis

Brick Type	Compressive Strength (MPa)	Standard Deviation (MPa)	Compliance Status
Coal (2%)	7.591	0.239	NBC 109:1994
Coal (4%)	7.867	0.414	NBC 109:1994
Coal (6%)	8.282	0.414	NBC 109:1994
Coal (8%)	7.591	0.239	NBC 109:1994
Coal (10%)	7.177	0.239	NBC 109:1994
RHA+SD (2%+6%)	7.867	0.414	NBC 109:1994
RHA+SD (3%+3%)	8.420	0.239	NBC 109:1994
RHA+SD (4%+4%)	8.558	0.633	NBC 109:1994
RHA+SD (6%+2%)	9.662	0.478	NBC 109:1994
Sawdust (2%)	7.177	0.239	NBC 109:1994
Sawdust (4%)	7.729	0.478	NBC 109:1994
Sawdust (6%)	7.591	0.478	NBC 109:1994
Sawdust (8%)	6.625	0.414	NBC 109:1994
Traditional	6.667	0.289	NBC 109:1994
Modern	8.834	0.239	NBC 109:1994

5.3 Mechanical Properties Analysis

The mechanical performance of the bricks reveals the impact of integrating organic and industrial additives on structural integrity, as revealed by soundness and impact tests. The performance of the coal bricks was non-linear: the 2% and 10% coal concentrations produced bricks rated “Very Sound” with high impact resistance, while the 6% coal bricks failed the impact test by shattering, rated “Unsound.”

This apparent contradiction arises from the difference between static axial loading and dynamic impact loading. Under uniaxial static compression, the moderate pore structure resulting from 6% coal burn-out does not significantly impair load-bearing capacity. However, under sudden impact, the same pore distribution creates stress concentrations that promote brittle fracture. This behavior is consistent with literature on porous ceramics and fired clay materials, where static compressive strength and dynamic impact resistance can diverge significantly when pore structure is altered by internal combustible additives [1,17]. These results indicate that Coal (6%) is suitable for static structural applications but should not be used in applications subject to repeated impact or dynamic loading.

The performance of the RHA+sawdust combinations was also non-linear: the 2% RHA+6% SD combination was structurally sound but brittle during the impact test, while the 4% RHA+4% SD combination failed both the impact and soundness tests. The performance of Traditional and Modern bricks was used as a benchmark; they generally exhibited high density and stability. The sawdust and coal bricks performed comparably in static strength, with the added advantages of reduced weight and improved thermal potential.

5.4 Statistical Correlation Analysis

One-way ANOVA ($\alpha = 0.05$) was used to establish statistical significance between brick categories using post-hoc turkey’s analysis. All statistical tests were performed using SPSS with diagnostic tests for normality and homogeneity of variance. ANOVA results indicate statistically significant variation between brick types ($p < 0.05$). Post-hoc Tukey HSD analysis revealed three distinct performance groups: (1) High-strength group (RHA+SD combinations, Modern), (2) Medium-strength group (Coal-based variants), and (3) Lower-strength group (Traditional, high sawdust content). The ANOVA p-values are tabulated in Table 3.

Table 3. ANOVA *p*-Value Summary of Brick Specimens ($\alpha = 0.05$)

Sample Category	Bulk Density	Porosity	Water Absorption	Compressive Strength
Coal-based (2–10%)	0.040	0.044	0.035	0.020
RHA+SD combinations	0.002	0.003	≤ 0.001	0.016
Sawdust-only	≤ 0.001	0.002	≤ 0.001	0.044

All *p*-values are below 0.05, confirming statistically significant differences in bulk density, porosity, water absorption, and compressive strength among the brick types. Coal-based bricks exhibit moderate but consistent changes across all properties. RHA+sawdust combinations show strong significance, particularly in reducing water absorption ($p \leq 0.001$). Sawdust-only bricks display lower density but reduced compressive strength, indicating the adverse effect of high organic content on the load-bearing matrix. Overall, the results highlight clear performance differences among specimens and support the use of optimized coal and agro-waste additives for producing lightweight bricks with acceptable strength.

5.5 Practical Approximations Using Unitary Method

In order to demonstrate the practical implications of experimental findings, load-bearing capacity approximations were derived from unit compressive strength using the unitary method. Based on standard brick dimensions (23 cm × 10.5 cm × 5.7 cm) with 10 mm mortar joints, approximately 37 effective bricks are required per square meter of single-leaf wall area (derived from standard laying practice). Load-bearing capacity was approximated for each brick type from these parameters.

The 6% RHA+2% SD specimen demonstrated the highest structural capacity at approximately 233.3 kN/m². Traditional bricks demonstrated approximately 133.3 kN/m² structural capacity. For typical residential construction requiring 80 kN/m² load capacity, the 6% RHA+2% SD brick exceeds requirements with a safety margin of approximately 192%, while Traditional bricks exceed the threshold with a 67% safety margin.

Note: These approximations are based on unit compressive strength alone and do not account for slender-ratio, mortar quality, or workmanship reduction factors as specified in NBC 109:1994 and NBC 202:2015. Actual wall capacities will be lower. These values are indicative only and should not replace structural design calculations.

6. Conclusions

The overall assessment of coal-based and RHA/sawdust-reinforced clay bricks proves their feasibility as environmentally friendly construction materials. The following conclusions are drawn:

- 6% coal addition provides the best strength-to-weight ratio (8.282 MPa) among the coal series while maintaining acceptable physical properties but the specimen may not be suitable for application involving impact load or dynamic stresses.
- The combination of 6% RHA + 2% SD recorded the highest compressive strength (9.662 MPa) among all modified bricks, approaching the performance of Modern machine-made bricks (8.834 MPa).
- All 15 formulations exceeded the NBC 109:1994 minimum compressive strength requirement of 3.5 MPa. Compliance was verified using the testing procedures of IS 3495:1992.
- Incorporating waste materials (coal dust, RHA, sawdust) alleviates environmental impact such as landfill burdens and topsoil excavation while preserving structural integrity, reinforcing the principles of a circular economy.
- Increased porosity in RHA+SD and sawdust-modified bricks promotes water absorption, necessitating se-

lective applications such as internal partitions or external walls with cement-based plaster surface treatment to mitigate capillary action.

7. Recommendations for Implementation

Priority should be given to the 6% coal formulation and the 6% RHA+2% SD combination for structural applications, as these show the strongest potential. Modified bricks should be used in moisture-protected conditions or with suitable surface treatments to reduce water-related deterioration. Long-term durability testing is advised to verify performance over time. Development of quality control protocols during modified brick production is important to maintain consistency when scaling up.

8. Limitations and Future Work

The sample size ($n = 3-5$ per category) limits the statistical power of results. Single-parameter regression models explain only approximately 50% of the strength variation, suggesting additional variables such as firing temperature uniformity and clay mineralogy are important. A full regression analysis with multiple predictors is recommended for future work. Economic feasibility of large-scale production was not assessed and represents an important next step. Future research should investigate other additive combinations, weathering criteria, real-world durability, and system-level wall testing to understand how modified masonry behaves as an integrated structural unit.

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References

- [1] A. V. Oskouei, M. Afzali, and M. Madadipour, "Experimental investigation on mud bricks reinforced with natural additives under compressive and tensile tests," *Construction and Building Materials*, vol. 142, pp. 137–147, 2017.
- [2] H. B. Kaushik, D. C. Rai, and S. K. Jain, "Stress-strain characteristics of clay brick masonry under uniaxial compression," *Journal of Materials in Civil Engineering*, vol. 19, no. 9, pp. 728–739, 2007.
- [3] J. Bhattarai, D. B. Ghale, Y. P. Chapagain, N. B. Bohara, and N. Duwal, "Study on the physical and mechanical properties of ancient clay brick samples of Kathmandu valley, Nepal," *Tribhuvan University Journal*, vol. 32, no. 2, pp. 1–18, 2018.
- [4] A. Heath, P. Walker, C. Fourie, and M. Lawrence, "Compressive strength of extruded unfired clay masonry units," *Proceedings of the Institution of Civil Engineers—Construction Materials*, vol. 162, no. 3, pp. 105–112, 2009.
- [5] Bureau of Indian Standards, "Methods of Tests of Burnt Clay Building Bricks (Parts 1–4)," IS 3495:1992, New Delhi, 1992.
- [6] S. Shrestha, "A case study of brick properties manufacture in Bhaktapur," *Journal of Science and Engineering*, vol. 7, pp. 27–33, 2019.
- [7] A. K. Parashar and R. Parashar, "Comparative study of compressive strength of bricks made with various materials to clay bricks," *International Journal of Scientific and Research Publications*, vol. 2, no. 7, pp. 1–

4, 2012.

- [8] G. S. De Silva and B. Perera, “Effect of waste rice husk ash (RHA) on structural, thermal and acoustic properties of fired clay bricks,” *Journal of Building Engineering*, vol. 18, pp. 252–259, 2018.
- [9] A. I. Hafez, M. M. Khedr, R. M. Osman, R. Sabry, and M. S. Mohammed, “A comparative investigation of the unit cost for the preparation of modified sand and clay bricks from rice husk waste,” *Journal of Building Engineering*, vol. 32, p. 101765, 2020.
- [10] O. Benjeddou, “Experimental investigation of the impact of wood sawdust incorporation on the physical and thermal properties of fired clay bricks,” *Scientific Reports*, vol. 15, no. 1, p. 30855, 2025.
- [11] X. Lingling, G. Wei, W. Tao, and Y. Nanru, “Study on fired bricks with replacing clay by fly ash in high volume ratio,” *Construction and Building Materials*, vol. 19, no. 3, pp. 243–247, 2005.
- [12] Government of Nepal, “NBC 109:1994—Masonry: Unreinforced,” *Nepal National Building Code*, 1994.
- [13] Institute of Builders Nepal, “NBC 202:2015—Guidelines on Load Bearing Masonry,” 2015.
- [14] Bureau of Indian Standards, “IS 1528 (Part 15):2007—Methods of Test for Stone Used in Civil Engineering Construction,” New Delhi, 2007.
- [15] International Organization for Standardization, “ISO 5017:1998—Refractory Products: Determination of Apparent Density and Apparent Porosity,” Geneva, 1998.
- [16] P. K. Mehta and P. J. M. Monteiro, *Concrete: Microstructure, Properties, and Materials*, 3rd ed., McGraw-Hill, 2006.
- [17] G. Cultrone, E. Sebastian, K. Elert, M. J. de la Torre, O. Cazalla, and C. Rodriguez-Navarro, “Influence of mineralogy and firing temperature on the porosity of bricks,” *Journal of the European Ceramic Society*, vol. 24, no. 3, pp. 547–564, 2004.
- [18] K. Saranya *et al.*, “Recycling of bagasse ash and rice husk ash in production of bricks,” *International Journal of Emerging Technologies in Computer Science and Electronics*, vol. 21, no. 4, pp. 61–67, 2016.
- [19] S. Fawzy *et al.*, “Eco-friendly bricks and tuff tiles from agricultural and industrial waste: advancing the UN sustainable development goals,” *Scientific Reports*, vol. 15, 2025.
- [20] A. K. Krishnan *et al.*, “A transition towards circular economy with utilisation of recycled fly ash and waste materials in clay, concrete and fly ash bricks: A review,” *Sustainable Materials and Technologies*, 2025.