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Comparative Analysis of the Properties of Various Clay Bricks for Optimal Construction Material Selection

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Abstract

This study addresses a critical research gap in Nepal's construction sector by providing the systematic comparison of three locally used clay bricks (Traditional, Chinese Red, and Hollow) against international and national standards. Through rigorous laboratory testing of compressive strength, water absorption, and porosity (following IS 3495:1992), the research reveals distinct performance characteristics: Chinese Red Bricks emerge as superior for structural applications (16.78 MPa strength, 10.11% absorption), Traditional Bricks offer reliable general-purpose performance (16.24 MPa strength, absorption-dependent quality), while Hollow Bricks serve best in non-structural roles due to their thermal properties (23.19% porosity) despite lower strength (11.01 MPa). The findings provide evidence-based selection criteria for Nepalese builders, with regression analysis ($R^2 = 0.349$ for Traditional Bricks) offering new insights into property-performance relationships, ultimately promoting more sustainable and optimized construction practices in the region.

Keywords: Clay Brick, Porosity, Crushing Strength, Water Absorption, Hardness, Soundness, Impact.

1. Introduction

Considering durability, versatility, and appeal, clay bricks are a ubiquitous construction material and remain one of the most popularly used construction materials from ancient times up to the present. The properties of clay bricks are determined by composition and the method of manufacture. This research investigates the physical and mechanical properties of clay bricks (traditional, Chinese red, and hollow) to assess their suitability for different applications.

Bricks are one of the most essential building blocks in structural fields. The quality of the bricks will define the strength of the bricks. Substandard brick quality compromises structural integrity, potentially causing severe damage. Therefore, it is essential to determine the various properties of bricks before usage. Brick quality correlates directly with material properties. The properties of clay bricks, such as compressive strength, water absorption, density, porosity, hardness, and impact resistance, are influenced by a variety of factors, including the chemical composition of the raw materials, the manufacturing process, and the firing temperature (Vatani Oskouei et al., 2017). Additionally, an experimental study was conducted to examine the properties of extruded unfired clay bricks, including their compressive strength (Heath et al., 2009). This study examines how material composition influences the compressive strength of clay bricks.

Physical properties concern the distinguishable and measurable characteristics of bricks, and their reactions against external conditions excluding the application of forces. These properties must be valued because most of them determine the performance and brick durability during the structural application. While Mechanical properties define the reaction of materials to loads applied from the outside, they include a range of characteristics; elastic properties, which represent material resistance to deformation, and strength properties, which show the ability of the material to resist an applied force. In this study, the physical and mechanical

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properties of different types of clay bricks, including traditional bricks, Chinese red bricks, and hollow bricks, will be investigated comprehensively to assess their suitability for various construction applications.

2. Research Questions

At the end of this study answers to the following questions were expected:

- Does the variation in physical properties (such as water absorption and porosity) significantly influence the compressive strength of different clay bricks?
- How do Traditional, Chinese Red, and Hollow bricks compare in terms of suitability for structural and non-structural applications?

3. Literature Review

Various papers and literature were reviewed regarding the properties of bricks influencing the crushing strength of bricks. (Vatani Oskouei et al., 2017), this experiment measured the compressive strength of mud bricks reinforced with natural fibers like straw, wood chips, rice husk, and palm fibers. The investigation determined the compressive strength of mud bricks at different fiber content levels, specifically 0.3%, 0.6%, and 0.9% of the weight of the specimen. The compressive strength of plain mud bricks was determined as 4.4 MPa, and the compressive strengths of samples with natural additives varied between 2.67 MPa and 16.53 MPa, depending on the fiber type and addition ratio.

Kaushik et al. (2007) experimentally explored the uniaxial monotonic compressive stress-strain behavior and properties of unreinforced masonry, including solid clay bricks and mortar. This investigation focused on finding the uniaxial compressive stress-strain curves for the brick units, mortar cubes, and masonry prisms built by various combinations of brick-and-mortar grades. In tests conducted for brick water absorption, the result was 12.30%. The average compressive strength of bricks ranged from 16.10 MPa to 28.90 MPa, depending on the brick type.

(Bhattarai et al., 2018) have tested the physical properties of mechanical strength for seven ancient clay brick samples, collected from Kathmandu Valley and prepared according to ASTM standards. The results showed the water absorption to lie in a range of 10%-28%, apparent porosity in a range of 17%-33%, and bulk density in a range of 1.20gm/cm^3-1.80 g/cm^3. Compressive strength was from 5 MPa to 23 MPa for the analyzed samples of bricks. The compressive strength of fired clay bricks was related to their physical properties.

4. Methodology

The objective of these tests was to analyze and investigate the physical properties and mechanical properties of the different types of bricks.

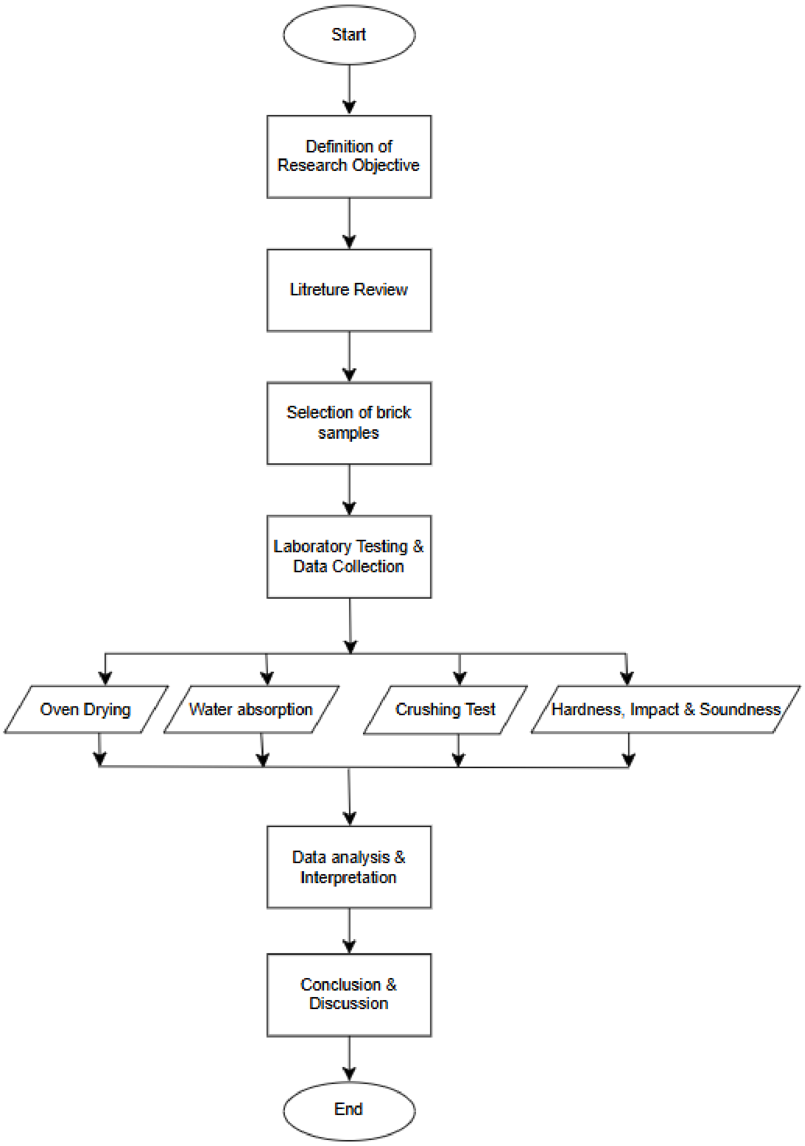
Based on different samples collection, testing of bricks was carried out in the laboratories. Physical and mechanical tests were done for the determination of these properties in laboratory according to different standard codes. Using IS 1528 (part 15): 2007, ISO 5017:1998, density and porosity were determined. Using IS 3495 (Parts 1 to 4):1992, crushing strength and water absorption of different bricks were determined.

4.1. Study Area and Sample collection

Traditional bricks were sourced from Bhaktapur, Nepal; Chinese red bricks and Hollow bricks were sourced from Gorkha Eco Red Bricks, Basdol-Banepa. The diversity in manufacturing processes and materials in this region provides a valuable context for analyzing and comparing the physical and mechanical properties of clay bricks, thereby supporting the optimal selection of construction materials in both modern and traditional construction practices.

4.1.1. Sampling methods, Population and Sample size

The study employed a random sampling approach to ensure an unbiased selection of bricks. To achieve statistically significant and comparable results, the samples were stratified based on different brick types. A total population consisted of 60 brick samples: 20 traditional bricks, 20 Chinese red bricks, and 20 hollow bricks for Crushing Strength test and 45 more samples of each type: 15-15 numbers were tested for hardness, Soundness, Impact and Color properties. The selection criteria were based on availability, consistency in manufacturing processes, and compliance with standard brick dimensions. This method ensures that the study findings are broadly applicable across similar manufacturing conditions.



4.2. Mechanical Properties

Mechanical tests on the brick sample included the crushing strength of the brick. Crushing strength (compressive strength) helps determine the quality and durability of bricks used in construction. As per IS 3495 (Parts 1 to 4):1992, the crushing strength/compressive strength of the brick can be determined by using following formula,

$$\text{Compressive strength (N/mm}^2\text{)} = \frac{Maximum\ Load\ at\ Failure}{Average\ Net\ Area\ of\ two\ faces\ under\ Compression} \quad (1)$$

4.3. Physical Properties

Physical test conducted on the brick sample include porosity, specific gravity, dimensions, density, hardness test, impact test, soundness test, color test, and water absorption test.
The physical properties are determined using the following relation:

Water absorption= $\frac{(Saturated\ wt.of\ brick - Dry\ wt.of\ brick)}{Dry\ wt.of\ brick} * 100\%$ (2)

Apparent Porosity, P = $\frac{(Saturated\ wt.of\ brick - Dry\ wt.of\ brick)}{Volume\ of\ the\ brick} * 100\%$ (3)

Density (gm/cc) = $\frac{Dry\ wt.of\ brick}{Volume\ of\ the\ brick}$ (4)

4.4. Statistical Analysis

The study employed separate linear regression analyses for each brick type (traditional, Chinese red, and hollow) to examine potential relationships between crushing strength and physical properties (water absorption, porosity). For each model, we assessed goodness-of-fit using R^2 values and evaluated overall significance through ANOVA F-tests of the complete regression model. Regression coefficients with standard errors were examined to quantify potential predictor effects. All analyses were conducted in Microsoft Excel at $\alpha = 0.05$ significance level, with diagnostic checks performed to verify assumptions of linearity, normal distribution of residuals, and homoscedasticity. This approach allowed for type-specific characterization of strength determinants while accounting for fundamental material differences between brick categories.

Figure 2. Crushing Strength test of brick samples

5. Experimental results and observations

5.1. Mechanical properties of brick sample

5.1.1. Crushing Strength

The crushing strength of different brick samples was tested using uniaxial compressive strength tests. The test was done in the lab as per the IS 3495:1992. The test was conducted precisely among different types of clay brick samples. The Compressive strength or Crushing strength (N/mm2) is calculated using equation (1). The result was then plotted in the bar graph. The crushing strength of these samples are shown in Figure. 3, 4 and 5.

It is clear from figure 3, 4, and 5 that the Crushing Strength of these bricks samples varies from 13.016 MPa to 20.321 MPa, 13.785 MPa to 18.397 MPa and 7.490 MPa to 13.681 MPa for Traditional bricks, Chinese red bricks and Hollow bricks respectively. The crushing strength of the bricks should not be less than 3.5 MPa, as provided in NBC 109- 1994, The findings showed that the crushing strength was at least 3.5 MPa, which was satisfactory.

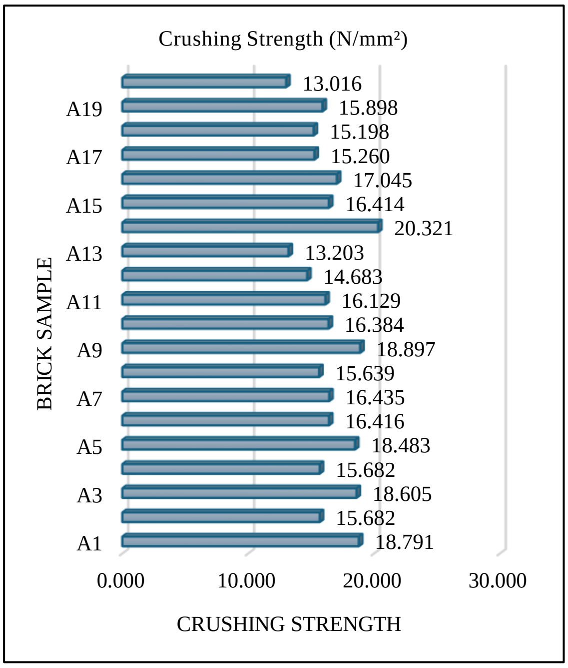


Figure 3. Crushing Strength of Traditional bricks

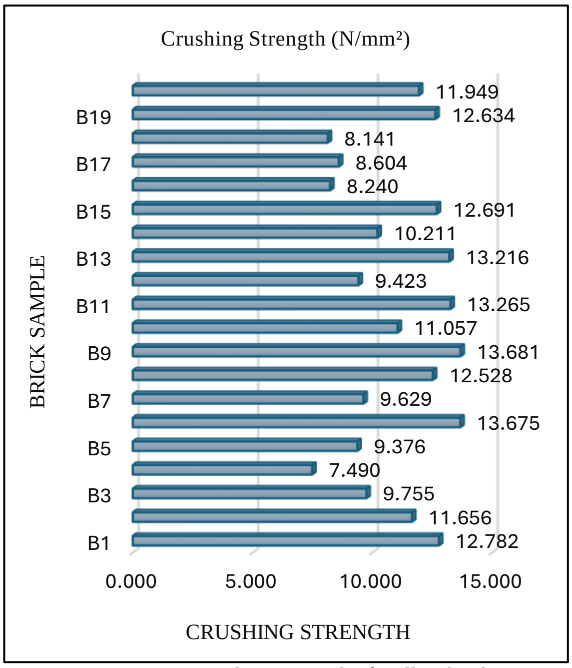


Figure 4. Crushing Strength of Hollow bricks

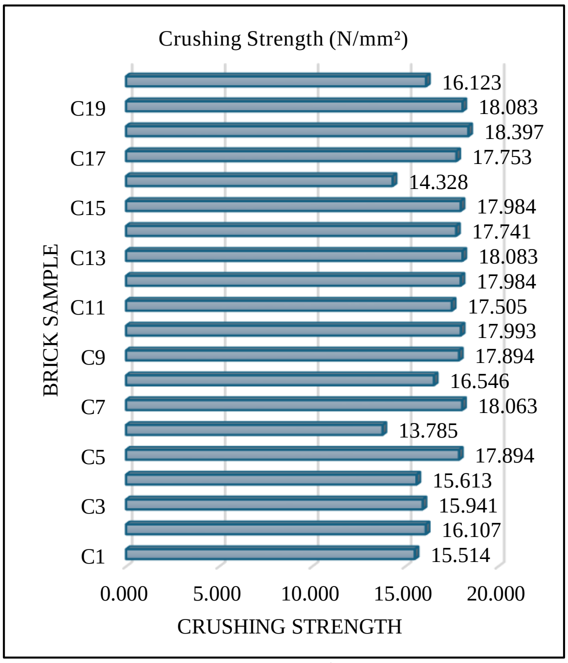


Figure 5. Crushing Strength of Chinese red bricks

5.2. Physical properties of brick samples

5.2.1. Water Absorption test on bricks and porosity

The water absorption test on brick samples determines the moisture content absorbed by bricks under excessive conditions. Low water absorption property of bricks represents high compressive strength, durability, and good quality bricks. The samples were dried in an oven at 105°C to 110°C until a constant weight was obtained. The dry weight of the brick sample was then measured. The brick samples were immersed in water for 24 hours and then weighed after the surface of the sample was wiped dry.

5.2.2. Hardness

Bricks are generally hard due to kiln baking and scratching them with fingernails or knife as per IS 1077:1992, should not leave any impressions. This is one of the important properties of brick as it defined the durability of brick. 15 samples each of Traditional Bricks, Chinese red Bricks and Hollow Bricks were taken for tests.

5.2.3. Impact test

In this test, the bricks are dropped from a height of 1 meter onto the ground. Good quality brick shouldn't break. In case it breaks, it should not be used for construction. The impact test results for 15 sample bricks of different types are shown in Table 1.

5.2.4. Soundness test

The soundness test of a brick is performed to understand the quality of bricks. In this test, two bricks are struck with each other. Good quality bricks usually don't break and should produce a metallic sound when struck with each other. The soundness test results for 15 sample bricks are shown in Table 1.

5.2.5. Color

Well-burnt clay bricks have a uniform, bright red appearance throughout their cross-section. The color test results for 15 sample bricks are shown in Table 1.

Table 1. Table showing properties such as Hardness, Soundness, Impact, and Color of 15-15 numbers of brick samples

Physical Properties		Traditional Bricks	Chinese red Bricks	Hollow Bricks
Hardness	Scratch	6	7	9
	Non-Scratch	9	8	6
Impact	Break	5	6	13
	No-Break	10	9	2
Soundness	Metallic	8	11	9
	Non-Metallic	7	4	6
Color	Bright	8	7	5
	Dull	7	8	10

Table 2. Regression Analysis Summary

Parameter Model Fit	Traditional Bricks	Chinese Red Bricks	Hollow Bricks
R^2	0.349	0.072	0.521
Adjusted R^2	0.272	-0.037	0.465
ANOVA			
F-statistic	4.555	0.660	9.259
p-value	0.026	0.530	0.002
Coefficients			
Intercept	26.499 (SE=3.569, p<0.001)	13.696 (SE=3.411, p=0.001)	33.351 (SE=5.452, p<0.001)
Water Absorption (β)	-1.316 (SE=0.745, p=0.095)	-0.865 (SE=1.122, p=0.451)	-0.869 (SE=0.852, p=0.322)
Porosity (β)	0.399 (SE=0.491, p=0.428)	0.656 (SE=0.673, p=0.343)	-0.340 (SE=0.669, p=0.618)

Table 3. Compliance with regional standards

Parameter	IS 1077:1992	NBC 109:1994	Traditional Bricks	Chinese Red Bricks	Hollow Bricks
Compressive Strength (MPa)	≥ 3.5	≥ 3.5	16.24	16.78	11.01
Water Absorption (%)	≤ 20	Not Specified	13.02	10.11	16.66
Compliance Status	Exceeds Class 15	Exceeds Requirements	Exceeds Class 15	Exceeds Class 15	Exceeds Class 10

6. Conclusion and Discussion

This study evaluated the physical and mechanical properties of Traditional, Chinese Red, and Hollow clay bricks to guide their optimal use in construction. Chinese Red Bricks demonstrated superior performance, with the highest compressive strength (16.78 ± 1.7 MPa) and lowest water absorption (10.11 ± 1.6%), meeting IS 1077:1992 standards for structural applications i.e. Heavily loaded structures, multi-storey buildings, industrial buildings, foundations, and pavements. Traditional Bricks showed moderate strength (16.24 ± 2.1 MPa), with water absorption marginally impacting strength (β = -1.316, p = 0.095), suggesting targeted reductions in absorption could enhance durability. Hollow Bricks, though weakest (11.01 ± 1.4 MPa), complied with NBC 109:1994 standards for non-structural uses such as Partition walls, balancing porosity (23.19 ± 2.6%) and lightweight design. Regression models revealed water absorption as the primary predictor for Traditional Bricks (R^2 = 0.349), while Chinese Red Bricks' performance remained unexplained by absorption or porosity (p > 0.343), implicating unmeasured factors like clay quality, manufacturing process, firing etc. Hollow Bricks' model (R^2 = 0.521) lacked individual predictor significance, suggesting synergistic interactions.

The physical property evaluation (Table 1) further validates compliance with national and international standards. Chinese Red Bricks' superior scratch resistance (7/15) and metallic soundness (11/15) align with IS 1077:1992 requirements for structural durability, ensuring suitability for heavy-load applications. Traditional Bricks' moderate hardness (non-scratch: 9/15) and impact resistance (no-break: 10/15) meet the same standard's criteria for general construction, while their marginal water absorption effects emphasize the need for quality control. Hollow Bricks' high impact fragility (break: 13/15) and thermal-efficient dull coloration (10/15) satisfy NBC 109:1994 specifications for lightweight, non-structural partitions.

Future studies should explore nonlinear porosity effects and industrial-scale validation to address lab-to-field gaps. Furthermore, different clay materials can be varied to see the effect on the properties of the brick. By aligning brick selection with application-specific needs and standards, this work enhances construction efficiency and resilience in Nepal's built environment.

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