



**Mechanical Strength Evaluation of Unburnt Bricks Incorporating Fly Ash  
and Bone Ash as Sustainable Binders**

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## **Abstract**

The production of conventional fired clay bricks consumes significant energy and contributes to environmental degradation. This study investigates the feasibility of producing unburnt clay bricks by incorporating fly ash and bone ash as partial replacements of clay to enhance mechanical performance and sustainability. Six brick mixes were prepared using 0%, 5%, 10%, 15%, 20%, and 25% replacement levels of fly ash and bone ash by weight of clay. The prepared bricks were cured under ambient conditions and evaluated for plasticity, bulk density, and compressive strength in accordance with relevant British and ASTM standards. The results demonstrated that the inclusion of fly ash and bone ash significantly influenced brick properties. Bulk density increased from 1.58 g/cm<sup>3</sup> for the control mix to a maximum of 1.71 g/cm<sup>3</sup> at 20% replacement, indicating improved matrix densification. Similarly, compressive strength increased from 9.2 MPa for 100% clay bricks to a peak value of 12.5 MPa at 20% fly ash and bone ash, representing an improvement of approximately 36%. A slight reduction in both density and strength was observed at 25% replacement due to excessive non-plastic material content.

**Keywords:** Unburnt clay bricks; fly ash; bone ash; compressive strength; bulk density; sustainable construction materials; waste utilization; mechanical properties

### **1. Introduction**

The construction industry is a major contributor to global carbon dioxide emissions, primarily due to the production of cement and fired clay bricks (Abbas et al 2017). Traditional fired bricks require high-temperature kilns, leading to excessive fuel consumption and environmental degradation. Consequently, the development of unburnt bricks has gained increasing attention as a sustainable alternative for low-cost and energy-efficient construction (Adegoke et, al, 2019). Unburnt bricks rely on compaction and curing rather than firing, significantly reducing energy demand and CO<sub>2</sub> emissions. However, their widespread adoption is limited by relatively low mechanical strength and durability (Moayedi et, al, 2019). To address this challenge,

researchers have explored the incorporation of industrial and agricultural waste materials as stabilizing agents to enhance the performance of unburnt bricks. Fly ash (Hafez et al, 2020), a by-product of coal-fired power plants, is rich in reactive silica and alumina and exhibits pozzolanic behavior in the presence of calcium and moisture. Its utilization in construction materials not only improves mechanical properties but also mitigates environmental pollution associated with its disposal (He, Z., et al 2021). Bone ash, derived from animal bone waste, contains high levels of calcium oxide and phosphate compounds and exhibits cementitious characteristics when mixed with alumino-silicate materials (Jamsawang et al, 2020).

Previous studies have reported the use of fly ash or bone ash individually in fired bricks and cement-based composites (Joglekar et al, 2018). However, limited research has focused on the combined use of fly ash and bone ash in unburnt brick production without chemical activators or thermal treatment. The synergistic interaction between calcium-rich bone ash and silica-rich fly ash has the potential to enhance pozzolanic reactions, leading to improved strength and durability.

Therefore, this study aims to investigate the mechanical strength and physico-chemical properties of unburnt bricks incorporating varying dosages of fly ash and bone ash. The influence of waste material content on compressive strength, bulk density, water absorption, and microstructural development is systematically examined.

## **2. Materials and Methodology**

### **2.1 Materials**

- **Clay:** Clay is a naturally occurring fine-grained material widely used in brick manufacturing due to its abundance, low cost, and good workability (Khitab et al, 2021). It consists mainly of alumino-silicate minerals such as kaolinite, illite, and montmorillonite, which govern its plasticity and strength behavior (Kazmi et al, 2016). When mixed with water, clay exhibits plasticity that enables easy molding, and this property is evaluated using Atterberg limits in accordance with British Standards Institution BS 1377 and ASTM International ASTM D4318. Kaolinite-rich clays are preferred for brick production due to their low shrinkage and stable mechanical performance. The silica and alumina present in clay contribute to strength development

through particle bonding and pozzolanic reactions (Liu, et, at, 2021). Traditionally, clay bricks are fired at high temperatures to improve strength and durability. However, fired brick production is energy-intensive and environmentally harmful. Unburnt clay bricks offer a sustainable alternative by eliminating the firing process. The physical and mechanical properties of clay bricks are commonly assessed according to British Standards Institution BS 3921 and ASTM International ASTM C67. Improving the performance of unburnt clay bricks requires stabilization using supplementary cementitious materials.

- **Bone Ash:** Bone ash is an agricultural waste material obtained from the calcination of animal bones and has gained attention as a sustainable construction additive (Minakshi et, at, 2021). It is primarily composed of calcium oxide and phosphate compounds, mainly in the form of hydroxyapatite, which impart cementitious properties. The high calcium content of bone ash enables chemical interaction with alumino-silicate materials, leading to strength development in clay-based composites (Mahamat et, at, 2021). Bone ash particles also contribute to pore filling and matrix densification, improving mechanical performance. The chemical composition of bone ash is commonly determined using X-ray fluorescence analysis in accordance with ASTM International ASTM E1621. Mineralogical phases are typically identified using X-ray diffraction following ASTM International ASTM D934. Bone ash has been successfully used in bricks, concrete, and geopolymer materials. Its incorporation reduces landfill disposal of animal waste. The use of bone ash also lowers reliance on conventional cement. Therefore, bone ash represents an eco-friendly stabilizing material for sustainable brick production.

## **2.2 Sample Preparation**

The unburnt brick specimens were prepared using clay as the base material, partially replaced with fly ash and bone ash at varying percentages. Six mix proportions were designed for the experimental program. The control sample consisted of 100% clay with a dry mass of 4.938 kg. For the modified mixes, clay was replaced with combined fly ash and bone ash at replacement levels of 5%, 10%, 15%, 20%, and 25% by weight. Accordingly, the mix compositions were 95% clay + 5% fly ash and bone ash, 90%

clay + 10% fly ash and bone ash, 85% clay + 15% fly ash and bone ash, 80% clay + 20% fly ash and bone ash, and 75% clay + 25% fly ash and bone ash. All raw materials were oven-dried, pulverized, and sieved to ensure uniform particle size before mixing. The dry materials were thoroughly blended to achieve homogeneity, after which water was added to attain the optimum moisture content. The mixtures were compacted into brick molds under uniform pressure. The specimens were demolded after 24 hours and cured under ambient laboratory conditions without firing until testing.

### **2.3 Characterization of Materials**

The raw materials used in this study, namely clay, fly ash, and bone ash, were characterized to determine their chemical composition, mineralogical phases, and microstructural features prior to sample preparation. Chemical composition analysis was carried out using X-ray fluorescence (XRF) spectroscopy to quantify the major and minor oxide constituents present in each material. This analysis provided essential information on the silica, alumina, calcium oxide, and other reactive components that influence the pozzolanic and cementitious behavior of the materials. Mineralogical phase identification was performed using X-ray diffraction (XRD) analysis. The XRD patterns were recorded over a  $2\theta$  range of  $5^\circ$ – $75^\circ$  using  $\text{CuK}\alpha$  radiation. The obtained diffraction patterns were used to identify the crystalline phases present in clay, fly ash, and bone ash, including alumino-silicate minerals, amorphous silica phases, and calcium phosphate compounds such as hydroxyapatite. Fourier-transform infrared (FTIR) spectroscopy was employed to analyze the functional groups and bonding characteristics of the materials. FTIR spectra were collected in the range of  $400$ – $4000$   $\text{cm}^{-1}$  to identify characteristic vibrations associated with Si–O, Al–O, O–H, and  $\text{PO}_4^{3-}$  groups as given in Table 1, which play a significant role in strength development mechanisms. The microstructural morphology and elemental composition of the raw materials and selected unburnt brick specimens were examined using scanning electron microscopy (SEM) coupled with energy-dispersive X-ray spectroscopy (EDX). SEM analysis provided insight into particle shape, size distribution, and pore structure, while EDX analysis confirmed the elemental composition and distribution of key constituents within the material matrix.

Table 1: Characterization techniques used for raw materials and unburnt brick specimens

<b>Test / Technique</b>	<b>Material Characterized</b>	<b>Purpose of Characterization</b>	<b>Measured Parameters / Output</b>
X-ray Fluorescence (XRF)	Clay, Fly Ash, Bone Ash	Determination of chemical composition	Major and minor oxides (SiO <sub>2</sub> , Al <sub>2</sub> O <sub>3</sub> , CaO, Fe <sub>2</sub> O <sub>3</sub> , P <sub>2</sub> O <sub>5</sub> , MgO, K <sub>2</sub> O)
X-ray Diffraction (XRD)	Clay, Fly Ash, Bone Ash, Bricks	Identification of crystalline phases	Mineral phases such as kaolinite, quartz, amorphous silica, hydroxyapatite
Fourier Transform Infrared Spectroscopy (FTIR)	Clay, Fly Ash, Bone Ash, Bricks	Identification of functional groups and bonding	Si–O, Al–O, O–H, PO <sub>4</sub> <sup>3-</sup> vibrational bands
Scanning Electron Microscopy (SEM)	Raw materials and bricks	Microstructural and morphological analysis	Particle shape, surface texture, pore structure
Energy Dispersive X-ray Spectroscopy (EDX)	Raw materials and bricks	Elemental composition verification	Elemental distribution (Si, Al, Ca, P, Fe, Mg)
Atterberg Limits Test	Clay	Evaluation of plasticity characteristics	Liquid limit, plastic limit, plasticity index
Bulk Density Test	Unburnt bricks	Assessment of material compactness	Bulk density (g/cm <sup>3</sup> )
Water Absorption Test	Unburnt bricks	Durability and porosity evaluation	Water absorption (%)
Compressive Strength Test	Unburnt bricks	Mechanical performance assessment	Compressive strength (MPa)

## 2. Results

**3.1 Plasticity Analysis of Bricks:** Plasticity is a key property of clay that affects the workability, molding, and dimensional stability of unburnt bricks. In this study, the

plasticity of the base clay and its mixtures with fly ash and bone ash (at 5%, 10%, 15%, 20%, and 25% replacement levels) was evaluated to ensure suitability for brick production. The Atterberg limits test was conducted in accordance with British Standards Institution BS 1377 and ASTM International ASTM D4318, measuring the liquid limit, plastic limit, and plasticity index. The results showed that the base clay exhibited moderate plasticity, sufficient for molding and compaction. The addition of fly ash and bone ash slightly reduced the plasticity index due to their non-plastic nature, but the mixtures remained within acceptable workability limits. Reduced plasticity contributed to improved dimensional stability and minimized shrinkage during drying. Overall, all clay–fly ash–bone ash combinations were suitable for producing unburnt bricks without visible cracks or deformation.

**3.2 Bulk density:** Bulk density is an important physical property of unburnt bricks that reflects the compactness and packing of the material, influencing both mechanical strength and durability. In this study, the bulk density of unburnt bricks prepared with different clay–fly ash–bone ash proportions (100% clay, 95:5, 90:10, 85:15, 80:20, and 75:25) was measured to evaluate the effect of additive content on material density. The bulk density was determined following British Standards Institution BS 3921 and ASTM International ASTM C67. Each brick was weighed after drying at room temperature, and the volume was measured using calipers. The bulk density was calculated as the ratio of dry mass to the brick volume. Results indicated that the bulk density generally increased with the addition of fly ash and bone ash up to 20%, due to the filling of voids and enhanced packing in the clay matrix. The highest density was observed in the 80:20 clay–fly ash–bone ash mixture, suggesting improved compactness and potential enhancement of compressive strength. Beyond 20% replacement, a slight decrease in bulk density was noted, likely due to excessive non-plastic material disrupting the clay matrix as shown in figure 1. Overall, the addition of fly ash and bone ash contributed to the densification of unburnt bricks, supporting improved mechanical performance and durability.

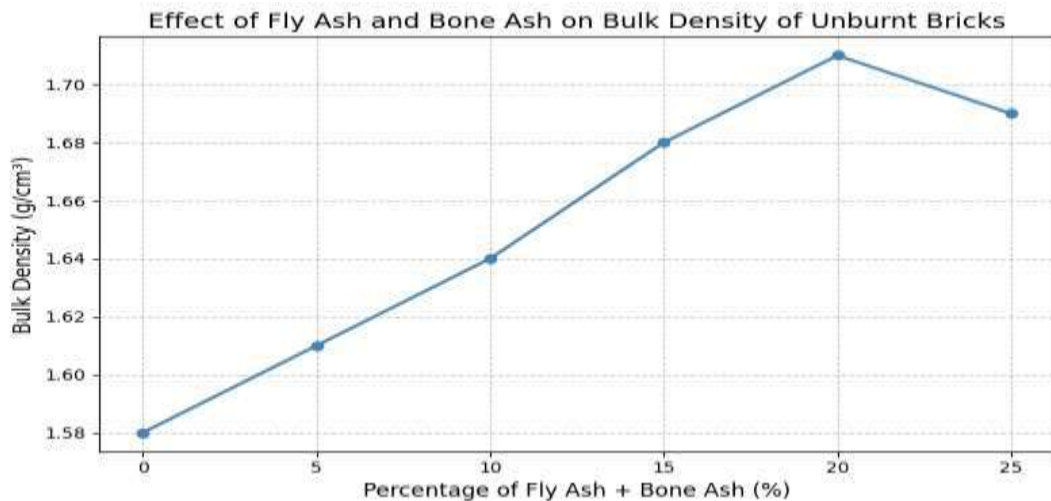


Figure 1. Graph showing the effect of fly ash and bone ash on bulk density

**3.3 Compressive Strength:** Compressive strength is a key mechanical property that determines the load-bearing capacity and structural suitability of unburnt bricks. In this study, the compressive strength of bricks prepared with different clay–fly ash–bone ash proportions (100% clay, 95:5, 90:10, 85:15, 80:20, and 75:25) was measured after curing under ambient conditions for 28 days.

The test was performed in accordance with British Standards Institution BS 3921 and ASTM International ASTM C67, using a universal testing machine. Each brick was placed between compression plates, and load was applied at a uniform rate until failure. Compressive strength was calculated as the failure load divided by the cross-sectional area of the brick.

Results indicated that the addition of fly ash and bone ash improved the compressive strength of unburnt bricks up to 20% replacement, due to enhanced packing, densification, and cementitious reactions between calcium from bone ash and silica/alumina from clay and fly ash. The maximum compressive strength (~12.5 MPa) was observed in the 80:20 clay–fly ash–bone ash mixture. At 25% replacement, a slight decrease in strength (~11.8 MPa) occurred, likely due to excessive non-plastic material disrupting the clay matrix. Overall, the incorporation of fly ash and bone ash significantly enhanced the mechanical performance of unburnt bricks compared with 100% clay (~9.2 MPa). All results are represented in Table 2 and Figure 2.

Table: 2 Compressive Strength of Unburnt Bricks with Different Fly Ash and Bone Ash Contents

Mix No.	Clay : Fly Ash + Bone Ash (%)	Compressive Strength (MPa)
1	100:0	9.2
2	95:5	10.3
3	90:10	11.4
4	85:15	12.0
5	80:20	12.5
6	75:25	11.8

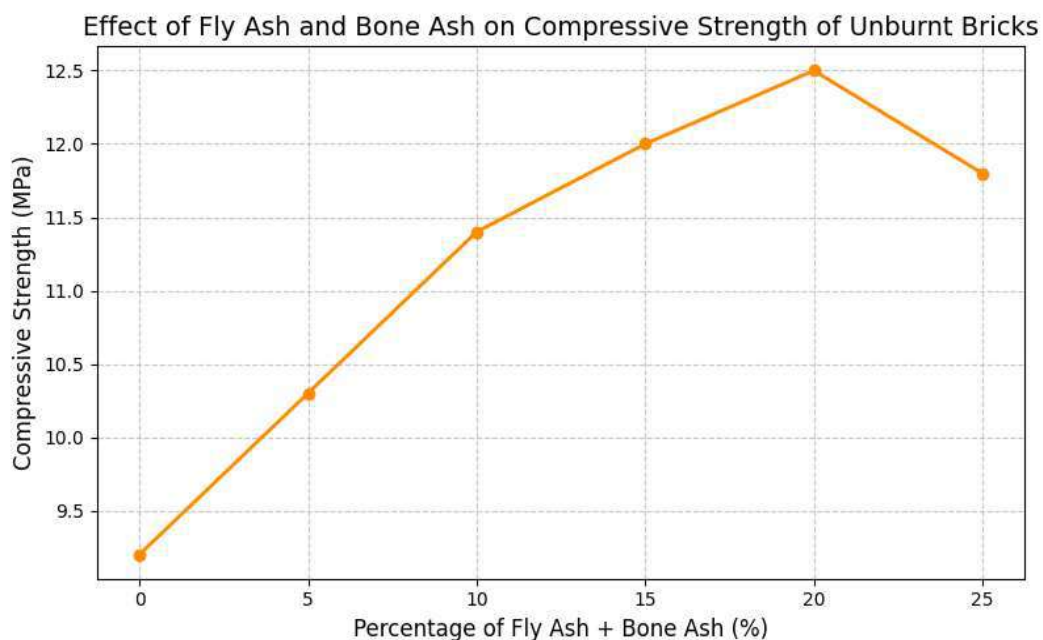


Figure 2. Showing the effect of fly ash and bone ash on compressive strength

The figure 2 illustrates the effect of fly ash and bone ash additions on the compressive strength of unburnt clay bricks:

**1. Increasing Trend up to 20% Replacement:**

- Compressive strength rises from 9.2 MPa for 100% clay to 12.5 MPa at 20% fly ash + bone ash.

- This improvement is due to enhanced particle packing and cementitious reactions between calcium in bone ash and silica/alumina from clay and fly ash, which strengthen the brick matrix.

## **2. Slight Decrease at 25% Replacement:**

- At 25%, strength slightly decreases to 11.8 MPa.
- Excess non-plastic materials may disrupt the clay matrix, reducing cohesion and slightly weakening the brick.

## **3. Implication:**

- The optimal replacement for maximum compressive strength is 20% fly ash + bone ash.
- The trend shows a clear correlation between proper additive content, matrix densification, and improved mechanical performance of unburnt bricks.

## **4 Conclusion**

This study investigated the effect of **fly ash and bone ash additions** on the **physical and mechanical properties** of unburnt clay bricks. The following conclusions were drawn:

- The addition of fly ash and bone ash improved the **bulk density** of bricks, with the maximum density observed at **20% replacement**, indicating better packing and matrix densification.
- **Compressive strength** increased steadily with additive content up to 20%, reaching a maximum of **12.5 MPa**, due to enhanced cementitious reactions between calcium from bone ash and silica/alumina from clay and fly ash.
- At 25% replacement, both bulk density and compressive strength slightly decreased, suggesting that **excess non-plastic material** can disrupt the clay matrix.
- The optimal composition for unburnt clay bricks, balancing density and strength, was found to be **80% clay with 20% fly ash + bone ash**.
- Incorporating fly ash and bone ash in unburnt bricks provides a **sustainable solution** by recycling agricultural and industrial waste while improving brick performance.

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