SciEn

*Proceedings of 8th International Conference on Mechanical Engineering and Renewable Energy 2025*
*10-12 December, 2025, Chattogram, BANGLADESH*

SciEn Conference Series: Engineering Vol. 4, 2026, pp 351-355 https://doi.org/10.38032/scse.2026.4.158

# Experimental Investigation on Physical Properties of Local Furnace Bricks

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**ABSTRACT**

Furnace bricks are vital for ensuring both structural integrity and thermal insulation in furnaces, kilns, and other industrial applications that involve high temperatures. To optimize the design, select suitable materials, and ensure the efficient and reliable operation of industrial processes, it is essential to comprehend the physical characteristics of furnace bricks. This study examines the physical attributes of furnace bricks and evaluates their performance in different thermal and mechanical conditions. This work utilizes a methodical experimental methodology to analyze and describe the fundamental physical properties, including bulk density, apparent porosity, thermal conductivity, and compressive strength of three distinct local furnace bricks. Test samples for compressive strength and water immersion were examined among three distinct furnace bricks and regular bricks. It was found that when perceived porosity and water absorption increased, bulk density decreased. While furnace brick types two and three satisfied the water absorption requirements and provided adequate porosity for use in furnaces, furnace brick type one had the highest density and strength.

Keywords: Furnace Brick, Porosity, Water Absorption, Wet, Compressive Strength



## 1. Introduction

Bricks are the predominant choice for constructing buildings, second only to wood. Thanks to the progress in contemporary machinery, the use of earth-moving equipment, powerful electric motors, and sophisticated tunnel kilns, the process of brick-making has significantly increased in productivity and efficiency [1]. Furnace bricks, or refractory bricks, are specifically engineered bricks utilized in high-temperature settings, such as furnaces, kilns, and other thermal equipment. Refractories are a type of ceramic materials that have the ability to endure extremely high temperatures without melting or deforming when subjected to a load. Furnace bricks are indispensable in various industrial processes, such as those in the glass, ceramic, and metallurgical sectors. These bricks are exposed to extreme temperatures, harsh chemical conditions, and mechanical stresses. To optimize their lifespan and efficiency, it is crucial to understand their physical attributes. This literature review aims to gather and assess prior research on the physical properties of furnace bricks.

Bricks, rather than being a typical building material, are utilized in furnace applications to offer thermal insulation. A thermal insulator is characterized by its low thermal conductivity, which indicates its limited ability to conduct heat. Insulation is employed in both building construction and manufacturing operations to mitigate thermal transfer, hence reducing heat loss or heat gain. While its main objective is economic, it also offers enhanced precision in regulating process temperatures and ensuring staff safety. It inhibits the formation of condensation on low-temperature surfaces and the subsequent occurrence of corrosion [2]. These materials have a porous structure, consisting of many inactive air cells. Pores in a material can give it certain advantageous qualities that the solid form of the material would lack. In addition, qualities such as bulk density, water absorption, compressive strength, and others are influenced by the porous characteristics of a material.

Although furnace bricks play a crucial role in industrial processes, there is still ongoing progress in fully understanding the relationship between their physical qualities and performance. This study seeks to enhance the existing information by performing an experimental inquiry into the physical characteristics of different types of furnace bricks.

This study aims to analyze these qualities systematically to establish correlations, detect trends, and offer significant insights for the selection and optimization of furnace bricks in various industrial contexts. In the subsequent sections, we provide a comprehensive description of the experimental technique, provide the outcomes of our testing, and analyze the potential consequences. The objective of this experiment is to ascertain the bulk density, apparent porosity, and compressive strength of three distinct local furnace bricks and one local ordinary brick. The compressive strength has been measured for both dry and wet circumstances.

## 2. Experimental Details

Three types of furnace bricks (Fig. 1a-c) and a conventional furnace brick (Fig. 1d) are collected. The bricks were cut into 1×1×4 inch3 dimensions for making specimens (Fig. 1e-h) for testing. Two specimens were prepared for each type of brick and a total of 8 specimens were prepared. The weight and volume of the specimens were measured to determine bulk density. One sample from each type of brick and a total of 4 specimens were soaked in the water (Fig. 1i) for 24 hours to determine compressive strength in wet condition. Then the weight of the soaked specimens was measured to determine apparent porosity. Finally, the compressive strength of all the dry and wet specimens was tested using a Universal Testing Machine (Fig. 1j).

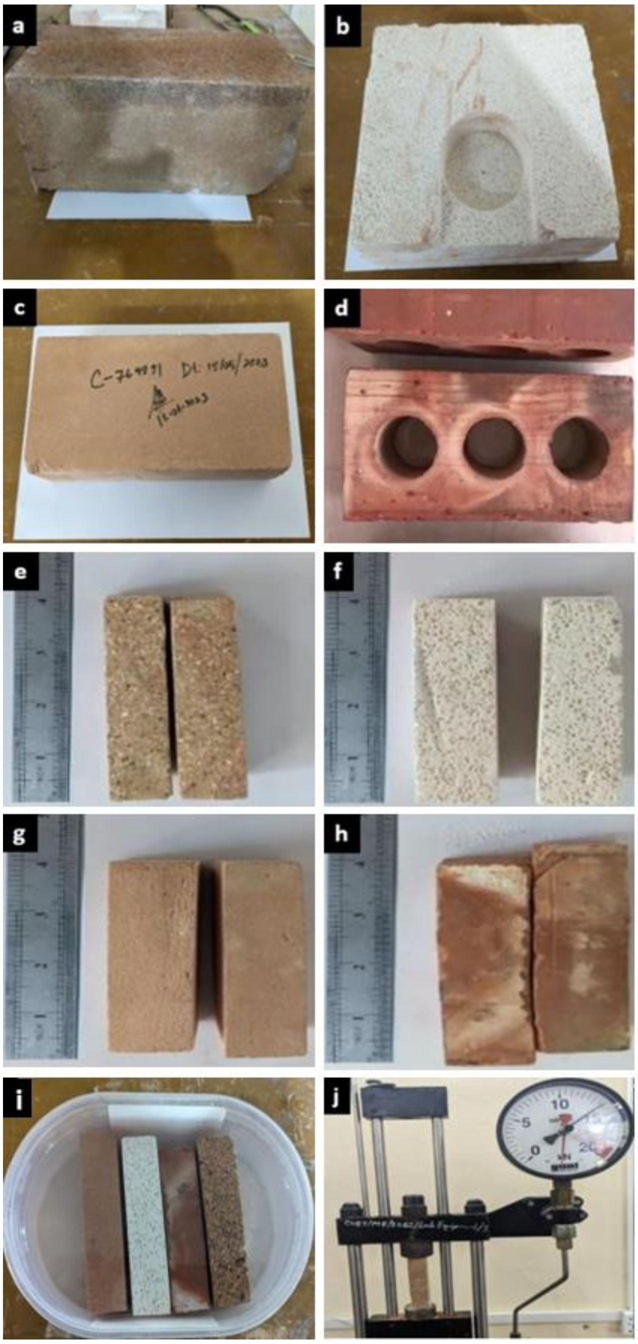


**Fig. 1:** Images of a) furnace brick type-1(FB1), b) furnace brick type-2(FB2), c) furnace brick type-3(FB3), d) conventional brick (CB). Test specimens of e) FB1, f) FB2, g) FB3, h) CB. i) brick specimens soaking in water. j) compressive strength test using Universal Testing Machine.

## 3. Results and Discussion

Table 1 represents data obtained in the experiment. Based on the data, bulk density, apparent porosity (AP), Water absorption (WA) are determined.

Bulk density refers to the amount of mass or weight contained inside a given volume of a collection of particle elements. Moisture content, porosity, particle size, and the density of individual particles are among the various elements that determine bulk density [3]. Bulk density (B) is calculated by dividing the mass of a substance by its total volume, including the volume of the material particles and the pores between particles.

$$B = \frac{M}{V} \tag{1}$$

Where M = mass of dry specimen, V = volume of the specimen. For all the specimens, $V = 6.555 \times 10^{-5}$ m$^3$. Porosity is the measurement of the proportion of empty spaces within bricks.

**Table 1.** Weight and compressive load of the specimens in dry and wet conditions

| Specimen | Weight (dry condition) (gm) | Weight (wet condition) (gm) | Compressive load (dry condition) (kN) | Compressive load (wet condition) (kN) |
|---|---|---|---|---|
| FB1 | 148.86 | 157.30 | 15 | 13.4 |
| FB2 | 73.28 | 98.26 | 3 | 3 |
| FB3 | 79.81 | 105.84 | 2 | 3 |
| CB | 111.64 | 127.81 | 13 | 2.5 |

This parameter is a crucial attribute that has a significant impact on the mechanical strength, durability, and thermal conductivity of brick products [4]. The porosity of brick is heavily influenced by the mineralogical composition of the initial clay mixture and the temperature at which it is fired [5]. Some pores are closed inside the material, they are not open to the material's surface. Apparent porosity considers only the open pores that are connected to the exterior surface of the material and does not include closed pores. The AP is simply calculated using, the expression:

$$AP(\%) = \frac{mass_{wet} - mass_{dry}}{V\,\rho_w} \tag{2}$$

Here, $mass_{wet}$, $mass_{dry}$, $\rho_w$ are mass measured in soaked condition, mass measured in dry condition, and bulk density of water, respectively. The WA of a brick is the amount of water absorbed by the brick when it is immersed in water for a specified period. Typically, it is quantified as a proportion of the brick's dry weight, often represented as a percentage.

$$WA(\%) = \frac{mass_{wet} - mass_{dry}}{mass_{dry}} \tag{3}$$

Compressive strength indicates bricks' ability to withstand axial loads without failing. It is an essential parameter for assessing the suitability of bricks for various construction purposes, ensuring the safety and stability of structures. If F is the load at which crack appears and A is the cross-sectional area of the specimen (in this study, A= $6.4514 \times 10^{-4}$ m$^2$), compressive strength (CS) is determined by the following equation:

$$CS = \frac{F}{A} \tag{4}$$

Fig. 2a describes bulk density and apparent porosity of the 4 types of bricks. Bulk density varies from 1118 kg/m$^3$ to 2271 kg/m$^3$. The highest and lowest bulk density have been obtained for FB1 and FB2 respectively. The CB and FB3 showed the second (1704 kg/m$^3$) and third (1218 kg/m$^3$) highest bulk density. And apparent porosity varies from 12.87% to 39.71%. FB1 and FB3 showed the lowest and highest apparent porosity respectively. FB2 and CB were in the second and third-highest positions and showed apparent porosity of 38.10% and 24.67% respectively. Water absorption varies from 5.66% to 34.08%. FB1 and FB2 showed the lowest and highest water absorption respectively. FB3 and CB were in the second and third-highest positions and showed water absorption of 32.61% and 14.48% respectively.

**Table 2.** Bulk density, apparent porosity, and compressive strength of the specimens

| Specimen | Bulk density ($kg/m^3$) | Apparent porosity (%) | Water absorption (%) | Compressive strength (dry condition) (MPa) | Compressive strength (wet condition) (MPa) |
|---|---|---|---|---|---|
| FB1 | 2271 | 12.87 | 5.66 | 23.25 | 20.77 |
| FB2 | 1118 | 38.10 | 34.08 | 4.65 | 4.65 |
| FB3 | 1218 | 39.71 | 32.61 | 3.10 | 4.65 |
| CB | 1704 | 24.67 | 14.48 | 20.15 | 3.87 |

Although our study isn't focused on composition of the brick materials, we suggest the possible composition of the brick materials. The distinguishing properties of all the bricks clearly depict variation of chemical composition, fabrication parameters, and firing temperature. In fact, clay mineralogy, size of particles, and sintering nature during firing attribute variation in both physical and mechanical properties. As we collected samples from 4 different local plants, the materials are of different chemical compositions. Lawanwadeekul et al. [6] depicted that smaller particle sizes and increased firing temperatures would typically result in denser microstructures with decreased porosity, thus higher mechanical strength—a trend well realized within FB1. FB2 and FB3 might, however, have the presence of coarser clay particles or organic additives that burn out upon firing to leave behind the interconnected pore networks that increase porosity but decrease compressive strength. However, we hope to perform future investigations on the chemical composition of the brick materials to specify the exact compound affecting all the properties.

From Fig. 2a, it is crystal clear that there is an inverse relation between bulk density and apparent porosity, water absorption. The presence of pores reduces the overall mass of the material for a given volume. As the apparent porosity increases (more and larger pores within the material), the bulk density decreases because the material's mass is spread out over a larger volume that includes the pores.

Higher bulk density means the soil is more compacted, with less pore space. This leads to a lower apparent porosity and lower water absorption. The order of bulk density of the bricks is FB1>CB>FB3>FB2. The order of water absorption is just the reverse: FB2>FB3>CB>FB1. And there is a direct correlation between apparent porosity and water absorption. Materials with higher apparent porosity tend to have higher water absorption because they have more and/or larger pores that can take in water. That's why, FB1 has the highest bulk density but has the lowest apparent porosity and water absorption. Reducing pores, holes, voids, or cavities in clay brick leads to an increase in density and strength, while decreasing water absorption [7-8]. For top-quality bricks, it is advised to keep water absorption below 20 percent. As for regular building bricks, the water absorption should be limited to 25 % [9]. In their study, Munir et al. confirmed that the water absorption values within the range of 15-22% meet the requirements set by ASTM C62-13a [10].

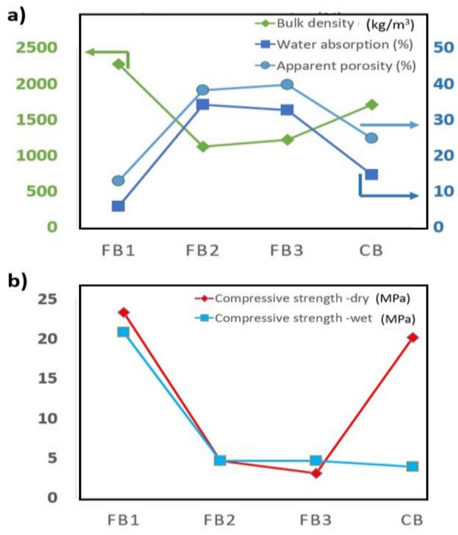


**Fig. 2.** Graphical illustration of a) bulk density and apparent porosity of the bricks, b) compressive strength of the bricks in dry and wet conditions.

These requirements are met by FB2 and FB3. Apparent porosity is crucial for preserving thermal conductivity. Heat transfer in materials is often described using thermal conductivity. Lower conductivity is preferred for furnace bricks [11]. Porous materials possess a highly insulated area, resulting in a reduction of thermal conductivity. FB2 and FB3 are suitable for furnace applications. As apparent porosity increases, the water absorption of the brick also increases. This is because a higher apparent porosity indicates a larger volume of open pores that can absorb water. The extent to which pores are interconnected affects water absorption. Even if the apparent porosity is high, if the pores are not well-connected, water absorption may be limited. Increased absorption leads to greater infiltration of water, resulting in the occurrence of moisture. The apparent porosity of bricks has a direct impact on their longevity and ability to absorb water. The elevated porosity renders it susceptible to weathering and chemical assaults.

Fig. 2b illustrates the compressive strength of the bricks in dry and wet conditions. In general, the CS of FB2 and FB3 are lowest as an increase in porosity causes less density of brick, resulting in lower mechanical strength. FB1 and FB3 showed the highest and lowest CS (dry). They have strengths of 23.25 MPa and 3.10 MPa, respectively. CB and FB2 have strengths of 20.15 MPa and 4.65 MPa. Like CS (dry) FB1 has the highest CS (wet). However, CS (wet) is slightly less than CS (dry). CB shows a similar phenomenon. However, CS (wet) of CB is very small, almost one-fifth of CS (dry). FB2 and FB3 show different phenomena. CS (wet) and CS (dry) remain identical. And, CS (wet) of FB3 is larger than CS (dry), which is the reverse of the whole scenario. Wet compressive strength is generally lower than dry compressive strength. The presence of water in the pores of the brick can weaken the material, reducing its ability to withstand compressive forces. Water filling the pores leads to internal pressure and weakening of the material structure. In some cases, water dissolves or weakens the binding materials in the brick, reducing its overall strength. As to the ASTM C62-13a standard, the minimum compressive strength requirement for clay bricks is 17.2 MPa [12]. FB1 meets this requirement in both dry and wet conditions. CB also meets this requirement, but only in dry conditions. When CB is wet, it experiences a significant decrease in CS. FB1 offers the best solution for the construction of primary furnace walls where structural performance and load-carrying capacity are of the highest priority because of its superior compressive strength and elevated bulk density. For materials used in thermal high-stress environments, such specifications closely follow industry standards. Furthermore, FB1's lower water uptake decreases its vulnerability to freeze-thaw deterioration and slows the travel of corrosive gases or molten slags, both of which are essential for furnaces' long-term stability [13].

Alternatively, FB2 and FB3 contain insulating thermal capacities that make them suitable for application as supplemental or reserve insulation layers in furnace systems, despite their higher apparent porosity and corresponding higher water absorption values [14]. Though FB2 and FB3 possess moderate porosity relative to speciality insulating refractories, its higher porosity relative to FB1 indicates superior heat retaining properties, which improves the overall furnace operation energy efficiency. The lower compressive strength of FB2 and FB3, however, restricts its use in load-bearing sections. Porosity impacts strength, thermal conductivity, resistance to slag, and thermal shock resistance in refractory materials; higher porosity leads to lower strength essentially because porosity is a material defect that concentrates stress [15].

## 4. Conclusion

This study extensively examined the physical properties of furnace bricks, with a specific focus on bulk density, apparent porosity, water absorption, and compressive strength. The analysis yields significant novel insights into the unique characteristics of each furnace brick variant. These findings emphasize the significance of tailored compositions and manufacturing methods in influencing the physical properties of furnace bricks. Notable discrepancies were observed in comparison to traditional bricks, particularly in terms of compressive strength. Furnace bricks consistently exhibited higher compressive strengths, indicating their suitability for applications that demand resistance to elevated temperatures and pressures.

The compressive strength of furnace brick type-1 and normal brick is higher. They are appropriate for bigger structural applications where thermal isolation is not a key factor. Once again, it is advisable to avoid using conventional brick in situations where the presence of water is guaranteed. Furnace brick type-2 and furnace brick type-3 are highly effective for thermal insulation in a furnace. However, it is crucial to consider the size of the furnace before using them.

This work contributes valuable insights into the domains of construction engineering and materials science, assisting industries and professionals in making informed decisions on material selection. The observed disparities underscore the critical importance of taking project requirements into account when choosing between furnace bricks and regular bricks.

## 5. Acknowledgement

This work is financially supported by Nanomaterials & Energy Storage System Laboratory (NESS Lab) of Department of Mechanical Engineering at Chittagong University of Engineering & Technology (CUET) through undergraduate thesis fund.

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