

PHYSICAL AND MECHANICAL PROPERTIES OF HOLLOW CLAY BURNT BLOCKS

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ABSTRACT

The very light and ventilated Perforated Ceramic Blocks allow reduction in structural stress, increased thermal and acoustic insulation, and fire-resistance, as well as a significant decrease in mortar amounts. This work experimentally investigates physical and mechanical parameters of hollow clay-burnt ceramic blocks as potentially used in building construction in Bangladesh. This experimental program included five types of blocks with various geometrical dimensions. The blocks were primarily tested under axial loading condition as per ASTM C67-08, both confined and unconfined state to assess their load-carrying behavior. Their practical behavior in wall applications was additionally studied with the aid of the confined wall test specimen, in relation to lateral restraint. Moreover, absorption rate and density tests were performed to obtain the basic physical parameters of specimens. The blocks had a compressive strength of 10-20 MPa, with the confinement increasing their capacity substantially as was supported by wall tests on laterally confined reinforced concrete (RC) beam arrangements. The most effective block's density was 736.5 kg/m³ and the absorption rate were 10.3 %, and its net compressive strength was 24.7 MPa. The hollow clay ceramic block has a lower density, lower absorption, and higher strength-to-weight efficiency than traditional bricks or wall units, highlighting its structural and economic advantages. These studies demonstrate the potential of hollow clay ceramic blocks as a low-cost and structurally sound masonry construction material.

Keywords: *Hollow clay ceramic blocks, Lightweight masonry, Compressive strength, Mechanical performance, Masonry construction*

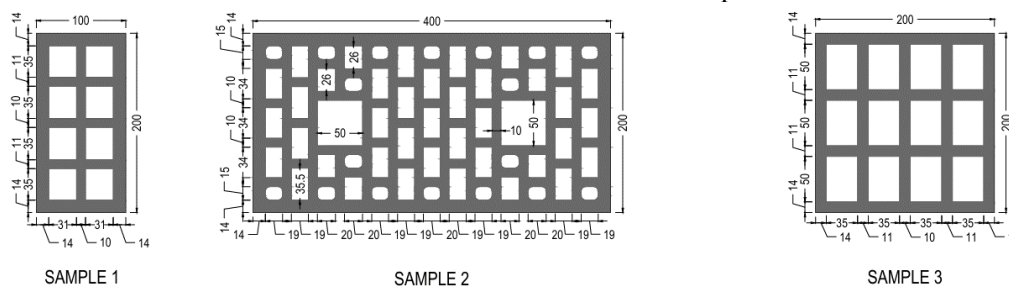
1 INTRODUCTION

Hollow clay blocks are massive masonry units composed of natural clay, baked in kilns, and built with cavities or perforations. They function as wall units. They are similar to concrete blocks, but “producing ordinary Portland cement will cause the emission of pollutants, which results in environmental pollution” (Shahen, 2024). Clay burnt blocks are lighter and more environmentally friendly. Hollow clay blocks are larger in size; thus, one block can replace several bricks in the process. Besides, they use less mortar and less energy to produce, with improved fire resistance and sound insulation (Lima, Rigão, Mohamad, Kirchof, & Santos Neto, 2018). Thus, the physical, mechanical properties of hollow clay blocks have been investigated over the years to make them more usable in masonry construction (Islam, Hasnat, Ahsan, & Alam, 2023). Hollow clay blocks have been used in masonry buildings for a long time, especially as walling units in old and traditional buildings. Particularly, the parameters such as compressive strength, modulus of elasticity, initial rate of absorption, and density must be assessed to properly comprehend their structural behavior (Habib, Sharif, Manjur, & Hoque; Khalifa & Al-Wazni, 2021). Several researchers have employed various experimental approaches to evaluate these characteristics. In many cases, walls bonded with mortar were constructed and subsequently tested under axial loading. To get the maximum strength, Jayasinghe created two kinds of bonded walls using two kinds of burned bricks (Jayasinghe, 2007). In his studies, Al-Amoudi et al. (2014) stressed, “The behavior of masonry structure cannot be sufficiently understood on the basic level unless the behavior of masonry constituents is completely specified.” Accordingly, they constructed six wallettes to examine compressive strength, modulus, and other properties, along with a corresponding mortar mix design (Al-Amoudi & Alwathaf, 2014). However, limited studies have attempted to measure compressive strength and generate stress–strain curves using both confined beam–wall setups and unconfined mortar–layer setups. Therefore, this study aims to replicate both a realistic beam–wall setup and an unconfined mortar–layer setup, and to compare their structural strength to promote the standardized use of hollow clay burnt blocks in the masonry construction industry of Bangladesh.

2 METHODOLOGY

2.1 Test Specimen Detailing

In this experimental study, five types of hollow clay burnt blocks with different geometric configurations were tested to evaluate their structural performance. Each block type featured unique dimensions and hollow patterns, designed to assess the influence of geometry on load-carrying capacity, weight reduction, and overall structural performance. The specimens were tested under axial compression following ASTM C67-08 to determine their behavior in both unconfined and confined conditions. For the confined tests, the blocks were placed within reinforced concrete (RC) beam frames to simulate lateral restraint similar to real masonry wall conditions. Figure 1 illustrates the geometric configuration of the blocks. The detailed dimensions of all block samples are summarized in Table 1.



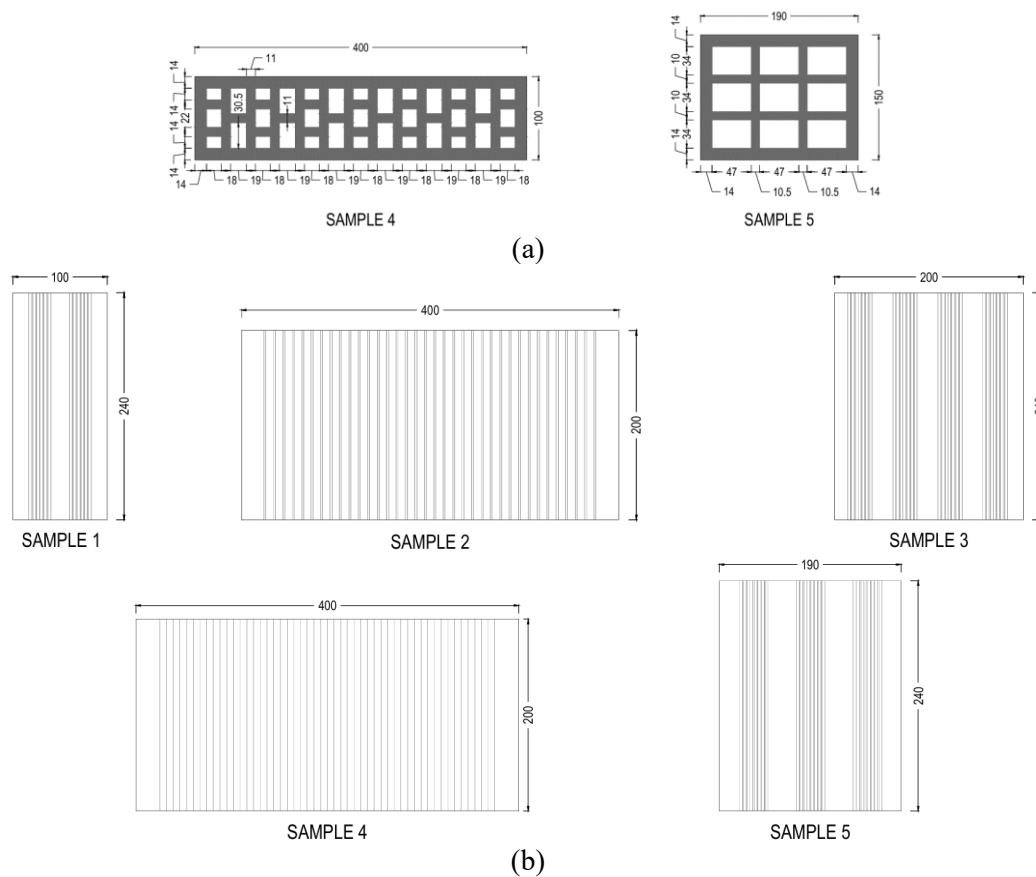


Figure 1: Geometric configuration of the hollow clay blocks, (a) Top view, (b) Longitudinal view.

Table 1: Dimensions of hollow clay ceramic blocks

Sample No	Dimension			$A_g \times 10^3 \text{ (mm}^2\text{)}$	$A_{net} \times 10^3 \text{ (mm}^2\text{)}$
	L(mm)	B(mm)	H(mm)		
S1	200	100	240	20	10.85
S2	400	200	200	80	40.20
S3	200	200	240	40	18.15
S4	400	100	200	40	26.65
S5	190	150	240	28.50	13.50

2.2 Material Properties

2.2.1 Concrete

ACI 211.1-91 was followed to prepare the concrete mix design. The desired compressive strength for the specimen was set at 27.8 MPa (4025 psi). The concrete mixture incorporates Type II Portland cement. The mixture contained river sand and coarse aggregate, with a sand-aggregate ratio of 0.9 and a maximum coarse aggregate size of 25 mm (1 in.). The water-cementitious materials ratio (w/cm) of 0.45 was adequately low to provide the desired compressive strength. Three cylindrical specimens, measuring 100 mm in diameter and 200 mm in height, were tested according to the ASTM C 39/C 39 M, and the compressive strength was found to be 25.73 MPa (3730 psi). Parallely, the tensile split test was also conducted to understand the tensile strength capacity by following ASTM C 496/C 496M– 04, and the tensile strength was found to be 2.81 MPa (408 psi), which is more than 10% of its compressive strength. The detailed test results are given in Table 2.

Table 2: Compressive strength of the concrete cylinder

Sample number	C1	C2	C3
Strength (MPa)	25.01	24.31	27.89
Standard Deviation (%)	1.54	1.47	1.07
Average Strength (MPa)	25.73		

2.2.2 Mortar

ASTM C109-12 was followed to test the compressive strength of mortar. To achieve the suitable compressive strength of the mortar cube for masonry works, it was set at 15 MPa (2175 psi). The mix consisted of Type II Portland cement and river sand, with a cement-to-sand ratio of 1:3, to achieve the required workability and strength. The water-cement ratio (w/c) was maintained at 0.5, providing adequate consistency while ensuring the target strength was attainable. Three mortar cubes were tested under uniaxial compression according to ASTM C109/C109M standards. The testing setup ensured uniform load application and precise measurement of compressive strength. The failure pattern on the mortar cube is illustrated in Figure 2. The detailed test results of the mortar cubes are summarized in Table 3.

Table 3: Compressive strength of mortar cube

Sample number	CP1	CP2	CP3	
Strength (MPa)	3 Days	27.23	30.46	27.27
	7 Days	32.91	33.11	32.53
	28 Days	36.18	40.53	36.98



(a)

(b)

Figure 2: (a) Uncracked before loading, (b) Cracked after loading on the mortar cube

2.3 Experimental Testing Procedure

By following ASTM C140-20, the bulk density of hollow clay ceramic blocks was determined. Water absorption and compression tests of hollow clay ceramic blocks were evaluated according to ASTM C 67-08 to understand the load-bearing capacity and mechanical response of the hollow clay ceramic blocks under confined and unconfined conditions, as well as lateral compression under unconfined conditions.

2.3.1 Confined Compression (CC) Test

A spreader beam system was designed to evaluate the compressive behavior of hollow clay ceramic blocks under confined loading conditions. Two different lengths of reinforced concrete (R.C.C.) beams

were designed while maintaining the same cross-sectional configuration, as illustrated in Figure 3. A total of five beams were cast, each corresponding to one of the five geometric types of hollow clay ceramic blocks. Each beam incorporated three blocks of identical geometry, placed side by side with 12 mm (1/2 in.) mortar joints between them. The central block, identified as the target specimen, was designated for load application and observation. On the top surface of the target specimen, a 25 mm (1 in.) thick mortar layer was placed to make a base for the steel plate to ensure uniform distribution of the load, followed by a 25 mm thick steel plate. All beams were cured for 28 days under standard laboratory conditions before testing. Figure 3 illustrates the test setup for the compression test under confined condition.

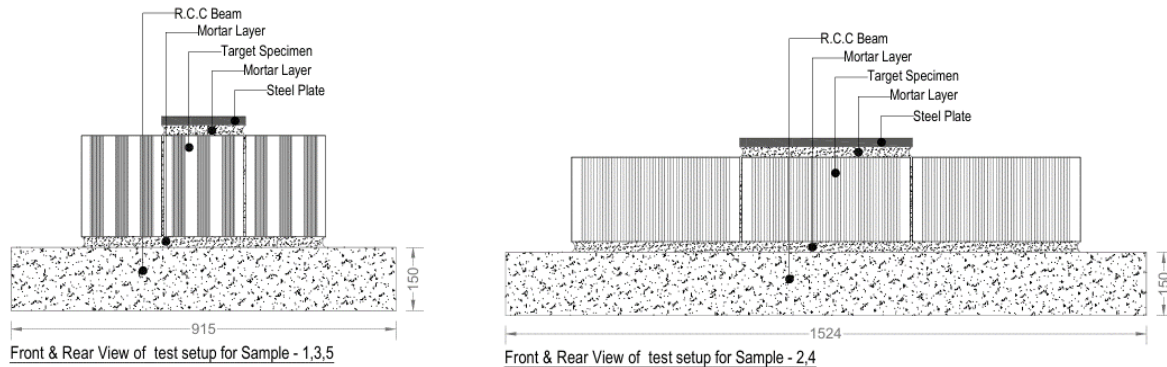


Figure 3: Schematic diagram of the specimen for compression test under confined condition

2.3.2 Unconfined Compression (UC) Test

The hollow clay ceramic blocks were tested individually to evaluate their compressive strength and deformation under direct axial loading. The top and bottom faces of each specimen were sealed with a thin layer of mortar to ensure surface regularity and uniform stress distribution. On the top surface of each block, a 25 mm (1 in.) thick steel plate was placed to facilitate the even transfer of load from the testing machine to the specimen. All specimens were cured for 28 days under standard laboratory conditions before testing. Figure 4 shows the test setup for the compression test under confined condition.

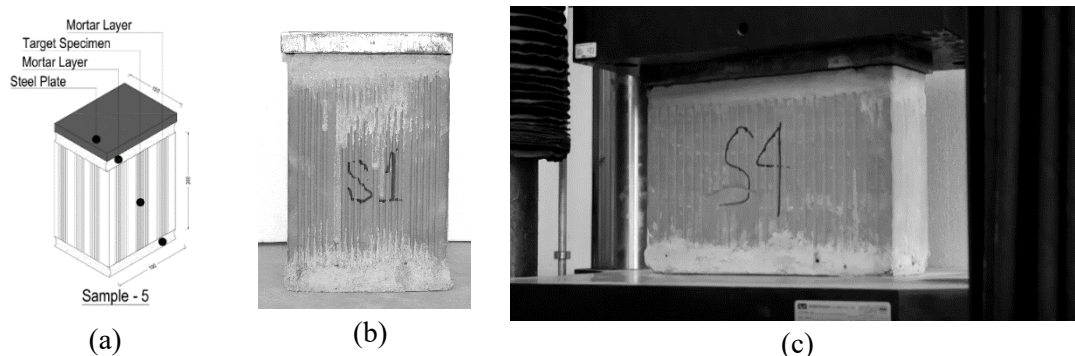


Figure 4: (a) Schematic diagram of the sample (not to scale), (b) Photo of prepared load sample, (c) Test setup for compression test under unconfined condition

2.3.3 Unconfined Lateral Compression (ULC) Test

To assess the mechanical reaction under transverse force, unconfined lateral compression tests were conducted on the lateral faces of samples 1, 3, and 5. A thin pad on the lateral face was placed on the lateral face of the blocks. A 25 mm thick steel plate was placed on the pad, ensuring uniform distribution. These tests provide the overall mechanical properties and transverse compressive strength under lateral loading conditions. Figure 5 shows the test setup for the lateral compression test under unconfined condition.

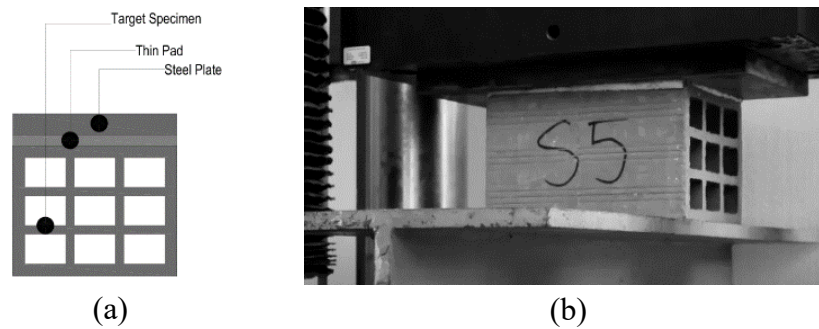


Figure 5:(a) Schematic diagram of the sample, (b) Test setup for the lateral compression test under unconfined conditions

2.4 Loading protocol

The loading was controlled by displacement, with a constant rate of 1 mm/min maintained throughout the tests. For the individual specimen, the load was applied until it failed. The failure patterns ensure a global stress within the hollow clay ceramic blocks. Displacements were recorded with Linear Variable Differential Transformers (LVDTs), and the applied loads were captured through the UTM's built-in load cell. All test data were digitally collected throughout the testing process.

3 RESULTS AND DISCUSSIONS

3.1 Density

The solid brick showed the highest density of 1675.00 kg/m³, though the hollow clay ceramic blocks showed comparatively lower density values ranging from 736.45 kg/m³ to 1124.60 kg/m³. The hollow clay ceramic blocks offer a significant structural and mechanical advantage by decreasing both partition wall and load-bearing wall loads due to lower unit weight. As a consequence, a substantial reduction in the overall dead load transmitted to the building framework. Figure 6(a) illustrates the difference in density between the solid brick and the hollow clay ceramic blocks.

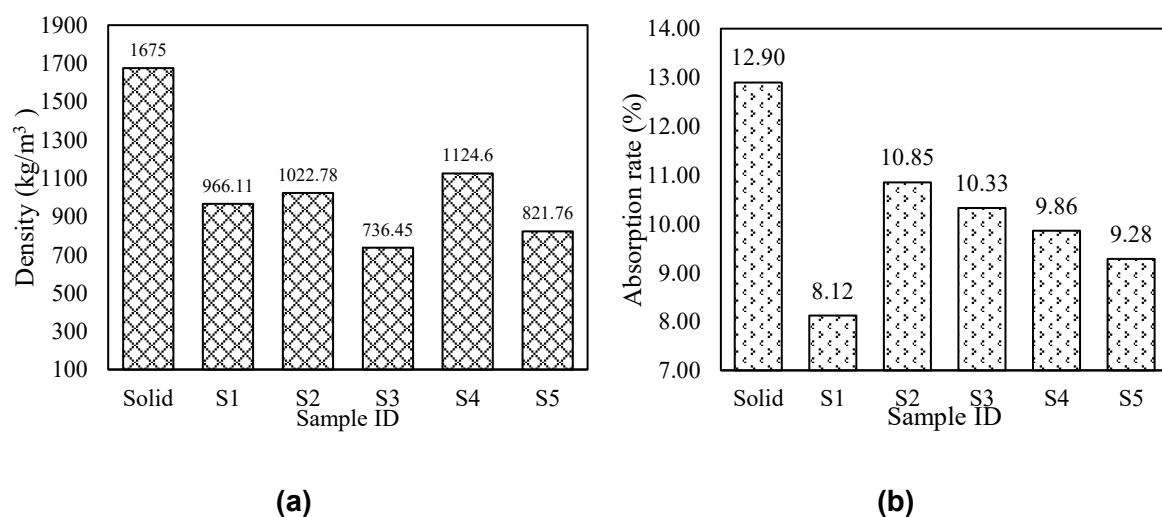


Figure 6: Comparison of (a) Density & (b) Water absorption rate between solid brick and hollow clay ceramic blocks.

3.2 Water Absorption Rate

Among the hollow clay block samples, sample 1 exhibited the lowest absorption rate of 8.12%, while sample 2 had the highest among the hollow samples at 10.85%. The solid brick sample showed a significantly higher absorption rate of 12.90%, indicating greater porosity and water uptake compared to hollow blocks, showing that hollow clay blocks generally exhibit lower water absorption, which can be advantageous in reducing moisture-related issues in building partitions while also contributing to a lighter structural load. The water absorption rates of the tested samples are presented in Figure 6(b).

3.3 Compression Test

3.3.1 Characteristics of first crack formation

For the unconfined compression test, S1, S2, S3, S4 & S5 first crack occurred at 105.56 kN, 496.65 kN, 108.43 kN, 210.9 kN, and 117.5 kN when displacements were 1.31 mm, 4.99 mm, 3.70 mm, 3.05 mm, and 3.83 mm, respectively. For confined compression test, S1, S2, S3, S4 & S5 first crack occurred at 221.53 kN, 708.1 kN, 412.52 kN, 465.89 kN, and 240.9 kN when displacements were 2.07 mm, 3.8 mm, 3.25 mm, 2.01 mm, and 1.81 mm, respectively. For the lateral unconfined compression test, S1, S3 & S5 first crack occurred at 157.98 kN, 53.99 kN, and 61.76 kN when displacements were 3.3 mm, 1.99 mm, and 2.77 mm, respectively. The load at the first crack formation of all five samples is visualized in Figure 7. The First crack was initiated at the lateral face for all the samples.

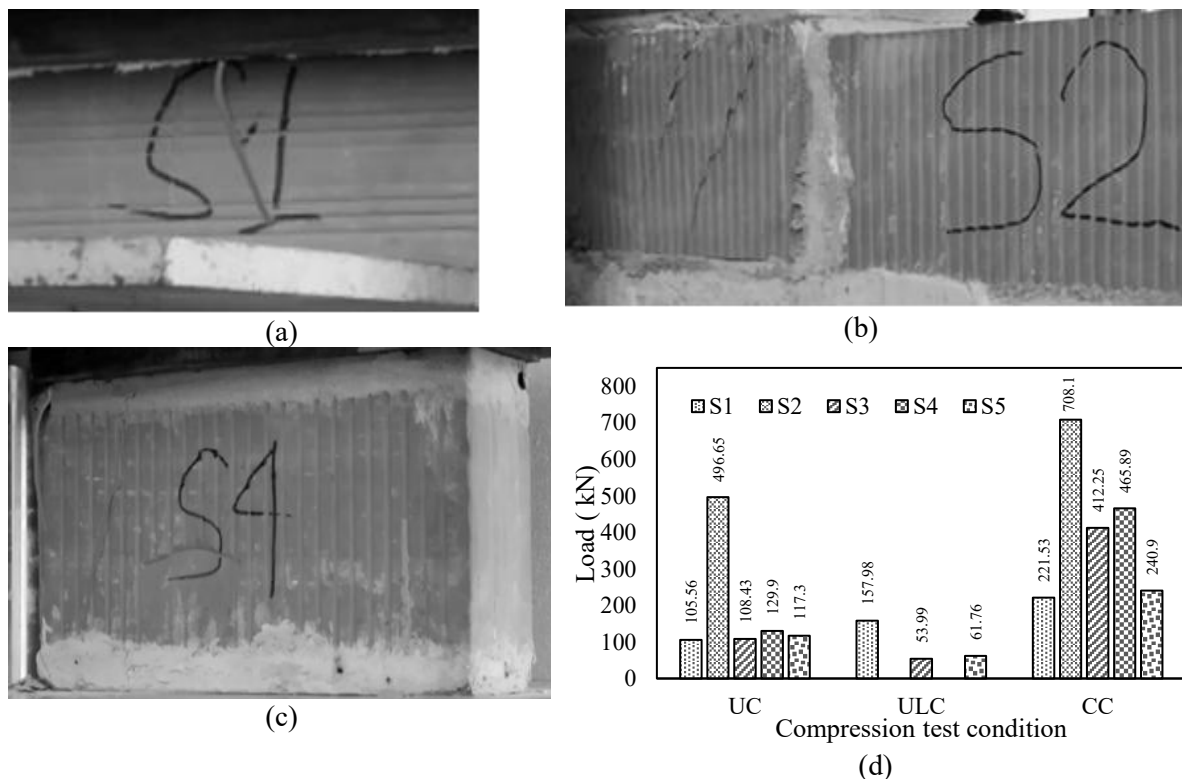


Figure 7: Initial crack under (a) Unconfined lateral compression (b) Confined compression (c) Unconfined compression (d) Load at First Crack Formation

3.4 Failure Mechanism

The hollow clay ceramic blocks exhibited brittle failure under all conditions. In unconfined compression, the blocks failed by vertical tensile splitting across the full height. In lateral unconfined compression, cracks formed perpendicular to the perforation lines, resulting in full-height tensile splitting. Under confined compression, a single crack developed directly from top to bottom, producing abrupt, full-section tensile splitting (bursting) failure despite the surrounding confinement.

3.5 Key Findings

Hollow clay ceramic blocks serve as a substitute for traditional solid bricks. In order to assess the confinement effect during the compression test, beam setups were constructed. The load-bearing capacity of the blocks in a confined state exceeds that of their unconfined state. The ceramic block with the highest load-bearing capacity is S2, displaying Gross compressive strength under UC (f_{gcu}), Gross compressive strength under CC (f_{gcc}), Net compressive strength under UC (f_{ncu}), and Net compressive strength under CC (f_{ncc}) values of 6.98 MPa, 9.74 MPa, 19.38 MPa, and 13.89 MPa, respectively. And S4 also showed notable mechanical performance regarding maximum net compressive stress with a load-bearing capacities of 578.48 kN and 261.02 kN under confined and unconfined conditions, respectively. S1 exhibited strong performance with a maximum compressive strength, supporting a transverse load of 229.17 kN. Figure 8 demonstrates the relationship between the load and deformation of the blocks and the net and gross compressive strength of individual samples in different loading conditions.

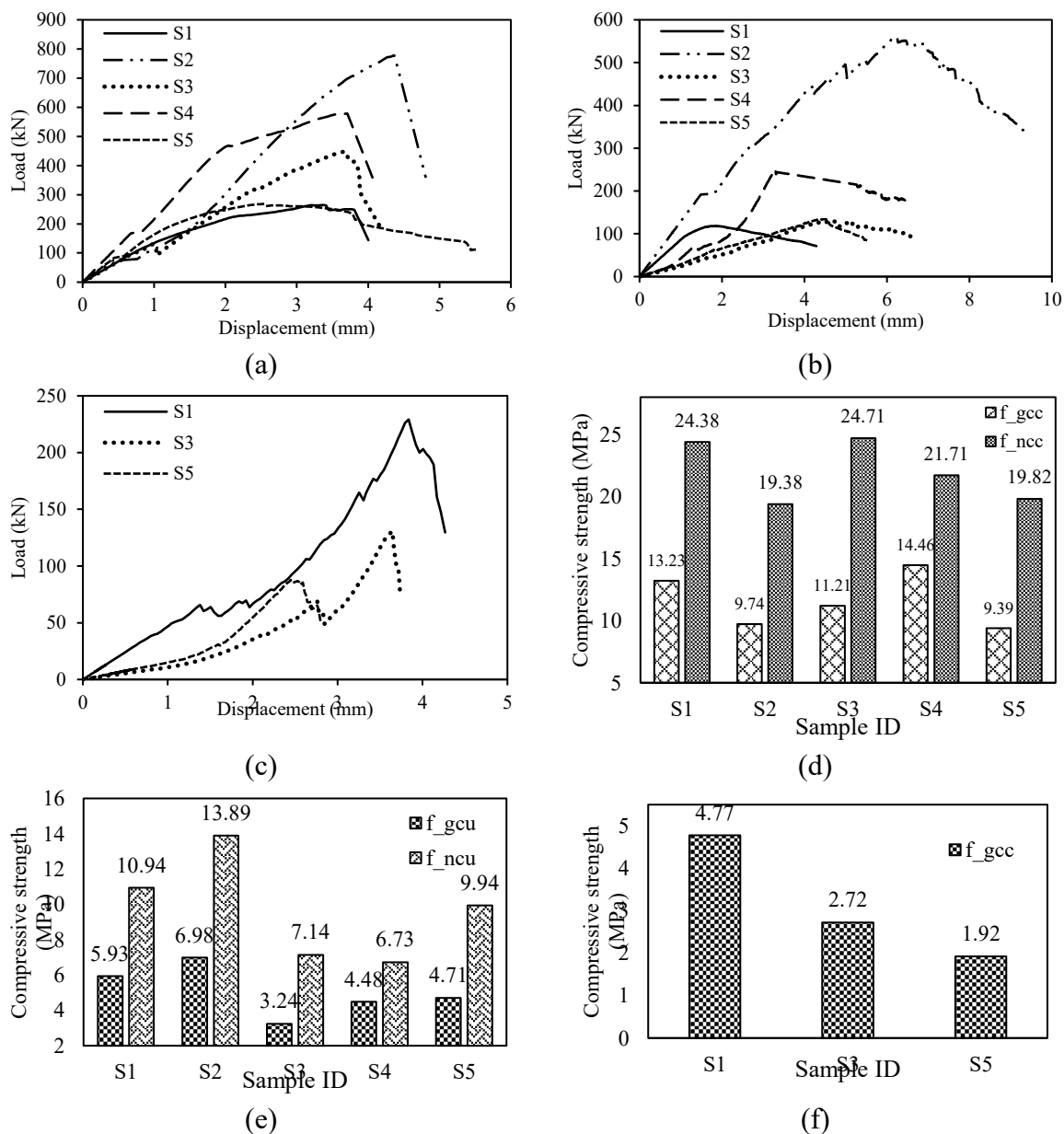


Figure 8: Relationship between load and displacement under (a) CC, (b) UC, (c) ULC; Compressive Strength under (d) CC, (e) UC, (f) ULC of the tested samples.

4 CONCLUSION

The hollow clay ceramic blocks offer substantial advantages over conventional solid clay bricks in terms of mechanical performance, cost-effectiveness, and sustainability. The behaviour of the ceramic blocks under axial compression loading was investigated in the study. Based on the results obtained from the experiments on the specimens, the following observations can be drawn:

1. The density of the hollow clay ceramic block ranged from 736.45-1124.60 kg/m³, while the solid brick registered 1675.00 kg/m³, reflecting an approximate reduction of 33-56% in unit weight compared to the conventional bricks. The lower unit weight significantly reduces the self-weight; nevertheless, the dead load is imposed on the beams, columns, and foundations. It allows for optimizing the section of structural elements and reducing overall material consumption in reinforced concrete components.
2. Water absorption results demonstrated the durability of the hollow blocks, with values between 8.12-10.85% compared to 12.90% for solid bricks. The reduction of 3-5% in absorption implies lower porosity, improved moisture resistance, and attenuated susceptibility to efflorescence or freeze-thaw degradation, all of which are essential for long-term performance in humid and monsoon-prone environments.
3. The assessment of the compressive strength showed that unconfined specimens sustained considerable axial loads before failure, with initial crack formations occurring in the range of 105.56 to 496.65 kN. Depending on geometry, the confined specimens displayed significantly improved performance, resisting between 221.53 and 708.10 kN at the first crack. In comparison, S2 achieved gross unconfined and confined compressive strengths of 6.98 MPa and 9.74 MPa, respectively. With corresponding net unconfined and confined compressive strengths of 19.38 and 13.89 MPa, respectively. These values clearly illustrate the beneficial influence of lateral support and confirm the efficiency of the hollow block geometry in confined masonry systems.
4. The characteristic brittle failure was observed in all test conditions, and the blocks exhibited predictable cracking patterns. It suggests that reliable structural performance can be ensured with appropriate confinement design and detailing.

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The authors confirm their contribution to the paper as follows: M. M. Islam: data collection, analysis, draft manuscript preparation, and interpretation of results; L. Kabir: data collection; M. L. Mustofa: data collection; K. S. Ahmed: conception and design of the study.

REFERENCES

- Al-Amoudi, M. A., & Alwathaf, A. H. J. J. o. E. S. (2014). The behavior of hollow concrete block masonry under axial compression. *3*(2), 32-53.
- Habib, M., Sharif, N., Manjur, K., & Hoque, M. Compressive Stress-Strain Characteristics of Brick Masonry Used in Bangladesh.
- Islam, M. R., Hasnat, A., Ahsan, R., & Alam, A. T. J. J. o. R. i. C. E. (2023). Strength Comparison of Unreinforced Masonry Wall made of Different Types of Brick. *11*(4), 159-179.
- Jayasinghe, C. J. E. J. o. t. I. o. E., Sri Lanka. (2007). Comparative performance of burnt clay bricks and compressed stabilized earth bricks and blocks. *40*(2).
- Khalifa, H., & Al-Wazni, S. (2021). *Experimental testing and comparison between historical and traditional masonry brick*. Paper presented at the Journal of Physics: Conference Series.
- Lima, R. C. A. d., Rigão, A. O., Mohamad, G., Kirchhof, L. D., & Santos Neto, A. B. d. S. J. M. (2018). Assess of hollow clay block masonry wallets under high temperature. *23*, e12191.
- Shahen, M. A. J. A. J. E. E. (2024). Market Feasibility and Strategies for the Environment-Friendly Bricks in Bangladesh: A Learning from the Southern Part of Bangladesh. *3*(1), 50-58.