



RESEARCH ARTICLE

Towards a better living environment-compressive strength and water absorption testing of mini compressed stabilized earth blocks and fired bricks

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Abstract

The escalating demand for eco-friendly and energy-efficient building materials underscores a pivotal shift towards sustainable development catalyzed by heightened public consciousness. Leveraging community production optimizes local resources and curtails transportation overheads, fostering broader access to superior housing solutions. Emphasizing less-intensive construction techniques enhances material strength, insulation, and thermal attributes while significantly shrinking carbon footprints and waste generation. Particularly vital during crises, these methods invigorate local employment and champion environmental conservation. This study juxtaposes the performance metrics of mini compressed stabilized earth blocks (MCSEB) and fire-burned clay bricks, focusing primarily on their compressive strength. The conventional production of fire-burned clay bricks poses notable challenges, especially regarding energy consumption and pollution. Their manufacturing, anchored in coal utilization, directly exacerbates greenhouse gas emissions. CSEBs emerge as a promising alternative in this context. Crafted by pressure on soil, their production eschews the need for coal or other combustibles, resulting in a significantly reduced carbon and energy footprint. When benchmarked against traditional fire-burned bricks, CSEBs, if demonstrating analogous compressive strengths, emerge as a viable replacement. A pivotal element in assessing compressive strength lies in factoring in the specimen's dimensions, with platen restraint effects as a crucial metric. This research harnesses the platen test to comprehensively compare the compressive strengths of fire burnt clay bricks and MCSEB. This correlation suggests that MCSEB, when adjusted for size, can be deemed comparable in strength to fire fire-burnt clay bricks, making them a promising sustainable alternative in construction.

Keywords: Sustainability, Compressive strength, Compressed stabilized earth blocks, Fire burnt clay bricks, Aspect ratio.

Introduction

Compressed stabilized earth brick (CSEB) emerges as an innovative, environmentally friendly construction methodology, leveraging indigenous resources. This construction modality, introduced by Raul Ramirez in

Bogota, Colombia, in the 1950s, has brought about earth-sheltered homes. The advent of compressive strength has revolutionized fundamental masonry structures, including load-bearing walls, arches, and vaults. The cumulative compressive capability of masonry is contingent upon the individual power of its constituents, the mortar, and bonding arrangements, among other influencing factors. While various metrics like density, resistance, and water absorption are pivotal in architectural design, compressive strength stands out as the predominant gauge of the quality of masonry units. Its ubiquitous utilization in laboratory testing is attributed to the straightforwardness of the method, serving as a reliable indicator of material quality. Historically, Adobes-hand-shaped, unburned earth bricks-have been integral to constructing load-bearing masonry structures for thousands of years. This is evident in multi-storied facilities in Yemen and predominantly in single and double-story residences. The transformation and proliferation of compressed earth bricks have been significant over the preceding half-century. The proportion and quality of

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Figure 1: Fire-burned clay bricks

clayey soil are site-specific, typically constituting less than a quarter of the dry weight. Given the variability in earth compositions, determining the optimal block composition by expert masons and understanding the compressive strength of compacted earth blocks become imperative. Integrating 4 to 10% cement stabilization in moist soil enhances compressive strength and water resistance and offers an advantageous comparison to conventional adobe bricks Lachheb *et al.*, (2023). This refinement has ushered in enhanced dimensional stability and tolerances, allowing for construction techniques akin to those used with fired clay and concrete blocks, replacing the traditional wet hand-molded adobe methodology. This investigation delves into contemporary scenarios and aims to augment the discourse surrounding the development of compressive strength testing methodologies for compressed earth blocks and fire-hardened clay bricks, all substantiated by empirical findings.

Case Report

Fire burnt clay bricks

Clay bricks have long held prominence as a primary construction material. With a storied legacy spanning 5,000 years, masonry's roots run deep in architectural history. India significantly contributes to this legacy, accounting for approximately 10% of global burnt clay brick production. The country boasts over 100 million brick kilns, churning out 150 to 200 billion bricks annually and providing employment to more than ten million individuals. However, India's brick sector presents challenges. It is marked by environmental concerns, a heavy reliance on manual labor, and a notably low degree of automation. Predominantly, the industry is composed of small-scale brick kilns. These often need more financial, technical, and managerial prowess, coupled with an absence of robust institutional frameworks, which pose a constraint to the sector's growth and modernization (Figure 1).

Clay is molded into homogeneous rectangular blocks and burned at 900–1200°C Sarani *et al.*, (2023). Clay or shale may become durable ceramics after drying and firing. Energy usage and pollution are significant masonry

manufacturing challenges. According to 2013 data, India's brick kiln utilization rose by 3% annually. Brick kilns' fuels included rubber, weak coal, oil, and wood. Inefficient fuel burning produces toxic fumes that harm brick kiln employees and the environment Sapna & Anbalagan (2023). The nation has made bricks for years without focusing on improving or standardizing their physical properties. Lack of affordable fuelwood and coal for buildings and power plants puts the firm at risk. The industry is unorganized and technologically unready, and few engineers and scientists are interested in it.

Compressed stabilized earth blocks

Up to 30% of the world's population lives in earth-built dwellings. Raw or stabilized soil is wet and crushed in a manual or mechanical press with a stabilizer to create a compressed earth block. There are varied techniques available to shape compressed stabilized earth blocks (CSEB) into diverse forms and dimensions. Stabilizing the soil notably enhances the blocks' compressive strength and water resilience. Following cement stabilization, CSEB blocks must undergo a curing process spanning four weeks before their utilization. Historically, the creation of compressed earth bricks leveraged wooden tamps, a method adopted over the years to augment their overall quality and performance Franco *et al.*, (2020). In the 18th century, soil-compressing machines were developed. Presses and compressed earth bricks were frequently employed in building and architecture in the 1950s (Figure 2).

Its manufacturing procedure distinguishes it from typically burnt bricks. CSEB bricks need static, dynamic, or vibro-static compaction, plus a stabilizer to be strong. Production energy and carbon dioxide emissions vary between CSEB and regular bricks. CSEB bricks release 22 kg of CO₂ every ton, compared to 200 kg Thennarasan *et al.*, (2023). Cement-stabilized earth bricks use 10% less energy than burned clay and concrete masonry units. The simple procedure requires little talent from staff to manufacture CSEB, which is a significant benefit. The earth must be prepared, the mixture compressed, and the result cured. Place the soil mixture in the mold with enough compressive stress to prepare it. CSEB curing uses naturally humid conditions, enabling bricks to be placed quickly after



Figure 2: Compressed stabilized earth blocks

compaction. Curing bricks with moisture under polythene (or damp gunny in India) prevents quick evaporation and maintains strength.

CSEBs bring a multitude of advantages to the table. Predominantly, as they are primarily made from soil, an abundantly available material, supply is assured. Moreover, given that the required material is typically sourced from subterranean layers, the topsoil remains undisturbed, leaving it open for agricultural purposes. The ability to produce these bricks on-site eradicates the need for transportation and extensive manufacturing, translating into tangible operational cost savings. Should the CSEBs meet essential performance benchmarks—including wet compressive strength (WCS), dimensional consistency, total water absorption (TWA), and block dry density more individuals could realize the dream of homeownership, bolstered by the efficiency and cost-effectiveness of this material. CSEB-built homes provide a better interior environment than other modern construction materials. Therefore, residents have more direct and indirect job prospects than if CSEBs were built with other materials. The item improves community social, cultural, and educational health. A building with excellent structural integrity and thermal properties, low carbon emissions and embodied energy, and controllable waste was built with less specialist labor. CSEB absorbs atmospheric moisture, making it a healthy building material. Here, mini-compressed earth blocks are used for the study. They are sourced from Earth Institute Auroville.

Materials and Methods

Background

The compressive strength derived from experimental testing on materials like concrete, stone, and both fired and unfired clay is intrinsically linked to the dimensions of the test specimen. Generally, an even force is applied through two rigid, flat, and tempered steel platens. As the compressive tension intensifies, the test specimen has lateral expansion. This expansion, however, is curbed due to the frictional resistance between the platen and the model. This confinement effect of the platen enhances the perceived strength of the material under test. Notably, as the spacing between the platens increases relative to the specimen's thickness—termed the aspect ratio—the influence of platen restraint starts to wane Marx *et al.*, (2023). For materials easily molded, such as concrete and mortar, accommodating this increase in compressive strength is managed by standardizing the size and shape of the test specimen, typically using a cube or cylinder format. While these test outcomes don't reflect the material's absolute (unconfined) compressive strength, they enable a consistent comparison across diverse samples, given the uniform test geometry. The challenge amplifies when evaluating pre-cast specimens with varied dimensions, like masonry units. In

such cases, factoring in the influence of specimen geometry on its strength becomes complex. An in-depth exploration of the methodologies adopted for assessing the resilience of burnt clay and compressed earth blocks follows.

Compressive Strength Testing

Determining the compressive strength of masonry units involves subjecting individual units to load testing inside compression testing equipment, using a methodology similar to that used for evaluating cast concrete and mortar cubes. To address the irregularities on the surface, units are temporarily covered with plywood or a similar sheeting, typically measuring 3–4 mm in thickness. Alternatively, a thin cementitious or gypsum-based mortar coating may be used as a cap. Units that meet dimensional specifications may often be evaluated by placing temporary caps. Typically, bricks that include recesses and cavities, including those accommodating frogs, are often filled with mortar of appropriate strength. However, cellular and hollow bricks are typically evaluated without filling the voids, and their power is quantified based on the overall cross-sectional area rather than the net area. In countries such as Australia, the compressive strength of hollow concrete blocks is ascertained by channeling the test load across the two parallel face shell capping strips. This method involves laying the blocks on two parallel thin mortar beds along their faces, a technique known as face shell bedding.

In nations where burnt clay bricks are commonly produced in a single standardized dimension, such as the United Kingdom, where most of the bricks measure around 215 x 102.5 x 65 mm, the influence of geometrical factors on the perceived strength of bricks is disregarded



Figure 3: Compressive strength testing of mini compressed earth blocks

due to the consistent geometry of the specimens, like the testing of concrete cubes or cylinders Dauda *et al.*, (2021). Similarly, using a standardized test geometry to get design values for material attributes is standard practice. These values are often represented as a function of the strength of concrete cylinders or unit bricks. Concrete masonry units display diverse dimensions and designs, encompassing solid, cellular, and hollow forms Kontoleon *et al.*, (2023). In line with the prevailing British Standard for masonry, unit geometry is factored in when deducing the composition compressive strength of such block masonry. This determination is formulated by amalgamating the overt block strength with its geometric properties. The upcoming Eurocode for structural masonry intends to standardize block strengths by introducing a shape factor that encapsulates the nuances of aspect ratio variations. Meanwhile, a geometric correction coefficient is employed in Australia, where burnt clay and concrete blocks present similar geometric variances Helmy *et al.*, (2023). This coefficient, rooted in data-driven findings, seeks to counterbalance the effects of platen restraint. It does so by translating the test data into what is termed as unconfined strengths—strengths representative of specimens boasting an aspect ratio exceeding 5.

Evaluating the Compressive Strength of Mini-Compressed Earth Blocks

Direct unit strength

The direct unit strength methodology, commonly referenced in the International standards and best practices, echoes the protocols for assessing fired clay and concrete blocks. Each unit is subjected to a capping process followed by direct compression testing between two platens. The surfaces of these blocks usually maintain a commendable degree of flatness and parallelism, warranting only a slender plywood sheet for capping. Given that these blocks are predominantly solid, there's a diminished necessity for intricate preparations for any indentations or voids. In testing, the force is typically applied in a direction congruent with the block's expected post-installation orientation. This study's test array comprised 20 blocks measuring 140 x 70 x 50 mm (Figure 3).

While there may be slight variations in block sizes, this research ensured uniformity in dimensions for consistency. The artisanal nature of the manufacturing process lends flexibility, allowing tailoring of block dimensions and shapes based on specific mold inserts.

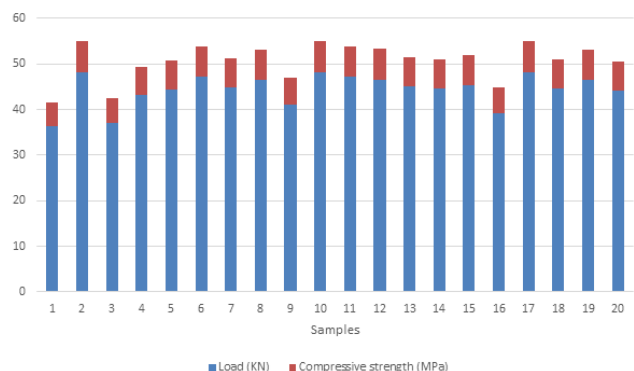
$$\text{Compressive Strength } \left(\frac{N}{\text{mm}^2} \right) = \left(\frac{\text{Maximum load at failure (N)}}{\text{Average area of bed faces (mm}^2)} \right)$$

A bifurcated approach is generally adopted to gauge the impact of geometric attributes on a block's compressive strength. One way involves statistical analysis of individual test data to derive an average or representative compressive

strength. In regions like Australia and New Zealand, a divergent strategy is embraced, where the ramifications of platen restraint are accounted for using an aspect correction coefficient in the analysis. The correction factors used for compressed earth blocks are often similar to those determined for burned clay units. The testing of cubes may effectively facilitate the examination of the impact of geometric factors on compressive strength. Further, inquiry is necessary to examine the consequences of material non-uniformity that result from the production process. Here, the bed faces are taken as 140 and 50 mm. The result based on that surface is given in Table 1 and Graph 1.

Table1: Compressive strength testing of mini compressed stabilized earth blocks

Sample	Size (mm)	Surface area (mm ²)	Load (KN)	Compressive strength (MPa)
1	140 x 70 x 50	7000	36.3	5.18
2	140 x 70 x 50	7000	48.2	6.88
3	140 x 70 x 50	7000	37.1	5.30
4	140 x 70 x 50	7000	43.2	6.17
5	140 x 70 x 50	7000	44.5	6.35
6	140 x 70 x 50	7000	47.2	6.74
7	140 x 70 x 50	7000	44.8	6.40
8	140 x 70 x 50	7000	46.5	6.64
9	140 x 70 x 50	7000	41.2	5.88
10	140 x 70 x 50	7000	48.1	6.87
11	140 x 70 x 50	7000	47.2	6.74
12	140 x 70 x 50	7000	46.6	6.66
13	140 x 70 x 50	7000	45.1	6.44
14	140 x 70 x 50	7000	44.6	6.37
15	140 x 70 x 50	7000	45.4	6.48
16	140 x 70 x 50	7000	39.2	5.60
17	140 x 70 x 50	7000	48.2	6.88
18	140 x 70 x 50	7000	44.7	6.38
19	140 x 70 x 50	7000	46.5	6.64
20	140 x 70 x 50	7000	44.2	6.31



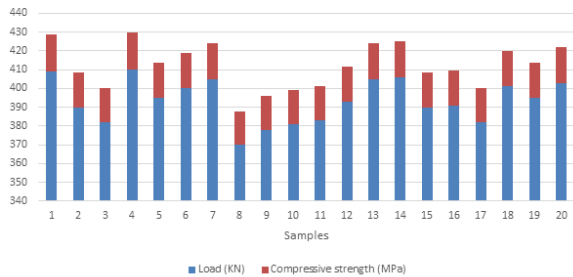
Graph 1: Compressive strength testing of mini compressed stabilized earth blocks

Compressive strength testing of fired clay bricks

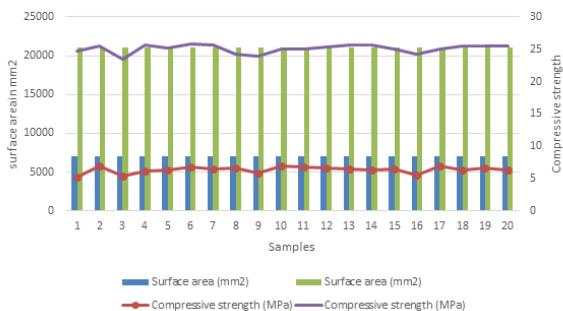
Twenty test samples of fired clay bricks were taken. The fired clay blocks' dimensions were 210 x 100 x 75 mm. Here, the bed faces are taken as 210 and 100 mm. The result based on that surface is given in Table 2 and Graph 2.

Table 2: Compressive strength testing of fired bricks

Sample	Size (mm)	Surface area (mm ²)	Load (KN)	Compressive strength (MPa)
1	210 x 100 x 75	21000	409	19.47
2	210 x 100 x 75	21000	390	18.57
3	210 x 100 x 75	21000	382	18.19
4	210 x 100 x 75	21000	410	19.52
5	210 x 100 x 75	21000	395	18.80
6	210 x 100 x 75	21000	400	19.04
7	210 x 100 x 75	21000	405	19.28
8	210 x 100 x 75	21000	370	17.61
9	210 x 100 x 75	21000	378	18.00
10	210 x 100 x 75	21000	381	18.14
11	210 x 100 x 75	21000	383	18.23
12	210 x 100 x 75	21000	393	18.71
13	210 x 100 x 75	21000	405	19.28
14	210 x 100 x 75	21000	406	19.33
15	210 x 100 x 75	21000	390	18.57
16	210 x 100 x 75	21000	391	18.61
17	210 x 100 x 75	21000	382	18.19
18	210 x 100 x 75	21000	401	19.09
19	210 x 100 x 75	21000	395	18.80
20	210 x 100 x 75	21000	403	19.19



Graph 2: Compressive strength testing of fired bricks



Graph 3: Comparison of compressive strength of mini compressed earth blocks and fired bricks

Discussion

The ever-evolving landscape of construction materials has spotlighted the relevance of CSEBs. Uniquely, CSEBs are produced in a more varied assortment of unit sizes compared to several other masonry blocks. This diversification raises pertinent questions about the consistency and reliability of performance metrics, primarily compressive strength. Suppose compressive strength is to serve as a robust indicator, elucidating the quality and suitability of CSEBs. In that case, the nuances of unit geometry influencing performance must be astutely addressed. Moreover, our experiment underscores that compressive strength is not a sole function of geometry. Several factors, including test procedures, dry density, cement content, and moisture content, intricately influence the results Zhi *et al.*, (2023). Our study meticulously considers the geometry of samples, ensuring a methodical comparison between CSEBs and fired clay bricks. While the two models differed in size, it's enlightening to observe that the surface area of the fired clay bricks was approximately thrice that of CSEBs. And true to this geometric comparison, the resultant compressive strength of fired clay bricks was about three times higher than that of the CSEBs. This observation is revelatory. When normalized against the surface area, the mini CSEBs demonstrate a compressive strength that is remarkably comparable to traditional fired clay bricks (Graph 3).

Breaking down the data, both sets of experiments utilized 20 samples. The CSEBs had dimensions of 140 x 70 x 50 mm, culminating in an average compressive strength of 6.4 MPa against a surface area of 7000 mm². Contrarily, the fired clay bricks, measured at 210 x 100 x 75 mm, delivered an average compressive strength of 18.7 MPa for a substantially larger surface area of 21000 mm². This correlation, where a tripling of the surface area resulted in a corresponding tripling of compressive strength, emphasizes that CSEBs, when accounting for their size, stand shoulder to shoulder with the compressive strength of fired clay bricks. In sum, while traditional metrics and perceptions might initially favor the conventional fired clay bricks, a more in-depth and nuanced analysis, like the one undertaken here, unravels the latent potential of CSEBs. When size and geometry are factored into the evaluation, CSEBs hold their ground and emerge as a promising and sustainable alternative in the masonry landscape.

Conclusion

The research juxtaposes the compressive strength of traditional fired bricks against the sustainable mini CSEB. While fired bricks appear to possess a clear edge in terms of power at first glance, a detailed analysis that accounts for geometry and surface area evens the playing field. With considerations for their respective sizes, CSEBs showcase a compressive force that is notably on par with their traditional counterparts. Furthermore, the correspondence between

a tripling of the surface area and a matching tripling of compressive strength underscores the latent potential of CSEBs. This evidence suggests that when size and geometry are equitably factored, CSEBs not only hold their ground but emerge as a commendable, sustainable alternative in the vast realm of masonry.

However, while these findings provide a compelling narrative, it is essential to acknowledge the multifaceted nature of compressive strength as a metric. Parameters such as dry density, cement content, and moisture content remain uncharted territories in this study. A comprehensive understanding of these elements is paramount to cement the potential of CSEBs in practical applications. In wrapping up, the evidence points towards the significant potential of mini CSEBs. Their comparable compressive strength makes them viable candidates for scenarios traditionally dominated by fired clay bricks. Nonetheless, the call for further research is evident, primarily to dissect the nuanced factors influencing compressive strength. As we forge ahead in our quest for sustainable construction solutions, it's anticipated that materials like CSEBs will find broader acceptance backed by empirical evidence and comprehensive research.

While conducting our study on the compressive strength of mini compressed earth blocks, we consciously decided to hone in on this specific mechanical property due to its pivotal role in assessing the material's primary utility in construction, especially for load-bearing structures. It's worth noting that while other automated tests, such as flexural strength and tensile strength, are indeed invaluable in offering a holistic understanding of a material's performance, they were outside the ambit of this particular research. Our primary objective was to delve deep into the compressive attributes of the mini CSEBs, thereby providing detailed insights into their load-bearing capabilities. We could provide more nuanced and in-depth findings by focusing on this singular aspect. Future research endeavors might explore the broader mechanical properties to comprehensively view the material's potential applications in varied construction scenarios. However, for the scope of this study, we concentrated exclusively on compressive strength.

References

- Dauda, J. A., Silva, L. C., Lourenço, P. B., & Iuorio, O. (2021). Out-of-plane loaded masonry walls retrofitted with oriented strand boards: Numerical analysis and influencing parameters. *Engineering Structures*, 243, 112683.
- Franco, W., Barbera, F., Bartolucci, L., Felizia, T., & Focanti, F. (2020). Developing intermediate machines for high-land agriculture. *Development Engineering*, 5, 100050.
- Helmy, S. H., Tahwia, A. M., Mahdy, M. G., Abd Elrahman, M., Abed, M. A., & Youssef, O. (2023). The Use of Recycled Tire Rubber, Crushed Glass, and Crushed Clay Brick in Lightweight Concrete Production: A Review. *Sustainability*, 15(13), 10060.
- Kontoleon, K. J., Saboor, S., Mazzeo, D., Pirouz, B., Benzaama, M. H., Kotsovinos, P., & Arıcı, M. (2023). The impact of thermal insulation on the vulnerability of hollow masonry walls under elevated temperatures. *Energy and Buildings*, 113522.
- Lachheb, M., Youssef, N., & Younsi, Z. (2023). A Comprehensive Review of the Improvement of the Thermal and Mechanical Properties of Unfired Clay Bricks by Incorporating Waste Materials. *Buildings*, 13(9), 2314.
- Marx, D. H., Kumar, K., & Zornberg, J. G. (2023). Quantification of geogrid lateral restraint using transparent sand and deep learning-based image segmentation. *Geotextiles and Geomembranes*.
- Sapna, A. A., & Anbalagan, C. (2023, July). Sustainable Eco-Friendly Building Material—A Review Towards Compressed Stabilized Earth Blocks and Fire Burnt Clay Bricks. *IOP Conference Series: Earth and Environmental Science*, 1210(1), 012023.
- Sarani, N. A., Kadir, A. A., Din, M. F. M., Hashim, A. A., Hassan, M. I. H., Hamid, N. J. A., ... & Johan, S. F. S. (2023). Physical-mechanical properties and thermogravimetric analysis of fired clay brick incorporating palm kernel shell for alternative raw materials. *Construction and Building Materials*, 376, 131032.
- Thenarasan Latha, A., Murugesan, B., & Thomas, B. S. (2023). Compressed Stabilized Earth Block Incorporating Municipal Solid Waste Incinerator Bottom Ash as a Partial Replacement for Fine Aggregates. *Buildings*, 13(5), 1114.
- Yang, X., Lyu, H., Li, J., Fu, F., & Zhou, H. (2022). Comprehensive design for a vernacular wood house with energy-saving process. *Sustainable Energy Technologies and Assessments*, 53, 102571.
- Zhi, X., Aminu, U. F., Hua, W., Huang, Y., Li, T., Deng, P., ... & Ali, J. (2023). Modeling the Dynamic Behavior of Recycled Concrete Aggregate-Virgin Aggregates Blend Using Artificial Neural Network. *Sustainability*, 15(19), 14228.