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Comparison of Compressive Strength of Compressed Earth Blocks under Extended Immersion Periods

Nirmal Burlakoti [a], Sanjeev Maharjan [b]

[a, b] *Department of Mechanical and Aerospace Engineering, Pulchowk Campus, IOE, Tribhuvan University, Nepal*
[a] 078msree015.nirmal@pcampus.edu.np, [b] mechsanjeev@ioe.edu.np

Abstract
Compressed earth blocks (CEBs) are gaining popularity as a sustainable construction material. However, the effect of prolonged moisture exposure on the compressive strength of CEBs requires further study. This paper presents the methodology and preliminary findings of an experimental investigation analyzing compressive strength variation in CEBs subjected to extended immersion periods of up to 28 days. CEB samples were fabricated using standard techniques and tested after immersion duration of 1, 4, 7, 10 days and so on. Tests were conducted following IS 3495:1992 procedures. The study provided insights into the long-term performance of CEBs under moisture exposure. The findings suggest that the compressive strength rose during prolonged curing for a specific duration, followed by a decline. Analysis of density and water absorption shows that denser CEBs absorb less water. Understanding the influence of prolonged conditioning is vital for optimizing manufacturing processes and facilitating the widespread adoption of CEBs in sustainable construction globally.

Keywords
compressed earth block, compressive strength, moisture exposure, sustainability

1. Introduction

Compressed earth blocks (CEBs) have gained growing recognition as an environmentally sustainable and cost-effective building material. CEBs are produced by applying mechanical pressure to a blend of soil, sand, and stabilizing agents to create masonry blocks. [1, 2]. Compared to conventional fired clay bricks, CEBs offer advantages such as reduced embodied energy, decreased transportation costs due to utilizing local soils, and lower manufacturing emissions [3, 4].

However, despite the increasing popularity of CEBs, there remain gaps in understanding regarding their long-term performance, especially when subjected to prolonged exposure to moisture. Moisture absorption can potentially impact the structural integrity and compressive strength properties of CEBs over time. Systematically analyzing the effects of extended immersion periods can provide valuable insights into the durability and reliability of CEBs in real-world construction applications where moisture ingress is a concern.

This paper presents the methodology and the findings of an experimental study focused on investigating the variations in compressive strength of CEBs when immersed in water for prolonged duration of up to 28 days. By comparing the compressive strength values across different immersion periods, the effects of moisture conditioning on the load-bearing capacity and mechanical performance of CEBs can be assessed. The completed study will generate new knowledge regarding the long-term behaviour of CEBs under wet conditions.

Additionally, this research analyzes the weathering resistance of CEBs which is vital for ensuring their durability and reliability in actual field conditions [5]. Accelerated weathering tests through repeated wet-dry and abrasion cycles model real-world exposure to moisture, rain, humidity variations and abrasive winds. Such tests determine the maximum mass loss and changes in properties like compressive strength and water absorption after simulated aging. IS 1725 [6] limits the allowable mass loss to 3% over 12 cycles.

Understanding the relationship between moisture exposure and compressive strength is vital for optimizing the manufacturing processes, stabilization methods, and curing practices for CEBs. The research findings can facilitate the effective adoption of appropriate quality control and performance enhancement strategies by CEB manufacturers and construction professionals. Overall, this study will make notable contributions to promoting the widespread utilization of CEBs as a sustainable mainstream building material globally.

2. Materials and Methods

2.1 Sample

Samples of bricks from Chandeshwori Eco Bricks were taken for this study. The samples were produced in their factory in Panchkhal, Kavrepalanchok and transported to Central Material Testing Laboratory, Pulchowk Campus, Institute of Engineering for the experiment.

2.2 Production

A soil-sand mixture and the stabilizer was used to create compressed earth blocks. Soil containing at least 15% clay and 20% silt was used for the production of the sample. This soil underwent a process of drying, sifting, and pulverization. Screening was done to eliminate all undesirable components (roots, leaves, etc.). Pulverizing was done to break down lumps made up of coarse material and/or fines. Soil (90%) is then mixed with cement (9.8%) and soil stabilizer[1] (0.2%). To boost the strength of CEBs, builders have investigated the incorporation of cement, a technique referred to as "stabilization"[7]. In our samples, an additional stabilizer is used. Mixing is carried out using a mixer. The mix was then pressed using a mechanical and hydraulic system which pressed the mix into a standard mould. Pressure was applied through the hydraulic system to attain the required shape, size, and density. The pressured blocks were then ejected from the mould and stacked in a dark room for 24 hours. The bricks are then cured for 10 days using wet jute bags in the same dark room. The bricks were then ready to be tested.

Figure 1: Production : Soil Processing and Mixing

Figure 2: Production : Pressing and Stacking

2.3 Physical Properties

The physical characteristics such as bulk density, and moisture content of the CEB samples were examined in accordance with IS 3495-1 to 4 (1992) guidelines.

The samples were desiccated in a well-ventilated oven at 115°C until they reached a state of substantially constant mass. Following this, the samples were allowed to cool to room temperature, and their weight (M_1) was recorded. Specimens that were still warm to the touch were excluded from the analysis. The fully desiccated samples were then submerged in clean water at 27°C for a duration of 24 hours. After removing the samples from the water, any residual moisture was carefully wiped away with a damp cloth, and the samples were reweighed. The weighing process was concluded three minutes after removing the samples from the water (M_2). This testing procedure involved a total of 30 samples, consisting of 10 full-sized samples selected at random, along with an additional set of 10 full-sized samples that were subsequently cut into 20 half-bats.

[1]The soil stabilizer is a secret sauce supplied by InnoCSR whose ingredient they were reluctant to provide

The water absorption capacity of the samples was determined using the formula provided in equation 1.

$$\text{Water Absorption}(\%) = \frac{M_2 - M_1}{M_1} \times 100 \qquad (1)$$

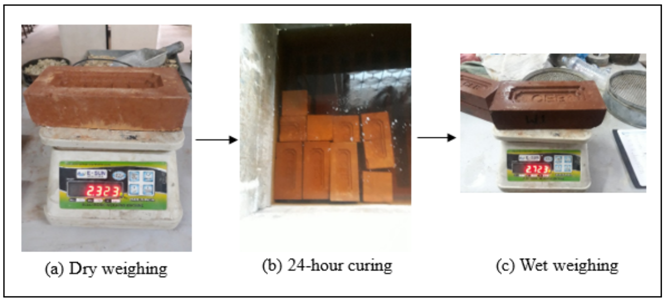

Figure 3: Water Absorption Testing

2.4 Compressive Strength Testing

IS 3495-1 to 4 (1992) was followed as a guideline for the methods of testing the brick for the compressive strength. The identical set of 30 samples utilized for determining the physical properties of the CEBs were also employed in this testing procedure.

2.4.1 Preconditioning

Irregularities noted on the bed faces were eliminated through grinding, resulting in the creation of two smooth and parallel faces. Subsequently, the samples were subjected to a 24-hour drying period in a well-ventilated oven at 250°F. This was followed by immersing the samples in room-temperature water for a duration of 24 hours. Upon removal from the water, any excess moisture was allowed to drain away at room temperature. The frog and all voids on the bed face were filled to the level of the surface using a cement mortar mixture (consisting of 1 part cement and 3 part clean coarse sand graded at 3 mm and below). The samples were then placed under damp jute bags for 24 hours and subsequently immersed in clean water for a span of 3 days. After this immersion period, any remaining traces of moisture were carefully wiped away.

2.4.2 Testing Procedure

The samples were positioned horizontally with their flat faces down, and the face filled with mortar was oriented upwards. They were sandwiched between two 3-ply plywood sheets, each with a thickness of 3 mm, and meticulously aligned between the plates of the testing machine. An axial load was steadily applied at a consistent rate of 14 N/mm^2 (equivalent to 140 kgf/cm^2) per minute until the point of failure was reached, and the maximum load at that moment was recorded. The load at failure represented the maximum load at which the specimens could no longer generate any further increase in the indicator reading on the testing machine.

Figure 4: Compressive strength testing

The formula given in equation 2 was used to determine the compressive strength of the specimens.

$$\text{Compressive strength in N/mm}^2(\%) = \frac{\text{Maximum load at failure in N}}{\text{Average area of the bed faces in mm}^2} \times 100 \quad (2)$$

2.5 Weathering Test

Various accelerated test methods have been suggested and put into practice to assess block durability, including the spray erosion test, the drip test, the alternate wetting and drying test, and the linear expansion on saturation. Among these, ASTM D559-03 [8] has incorporated the alternate wetting and drying test approach. It involves monitoring weight reduction after 12 cycles of alternate wetting and drying. During this testing, flawed bricks could disintegrate or even rupture [9]. In this research, a similar, albeit slightly modified, technique, as adopted in IS : 1725-2023 [6], was applied. This testing procedure involved the use of three full-sized samples selected at random.

2.5.1 Testing Procedure

The specimens were subjected to a sequence of treatments. Initially, they were dried in an oven at 65°C until a consistent mass was achieved. The weight of each specimen at its initial constant mass was recorded as W_i. Subsequently, the specimens were immersed in water at room temperature for 5 hours. Following this, they were taken out, and a drying process in an oven at 75°C for 42 hours was carried out. The partially dried blocks underwent further treatment, where all six faces of the specimens were subjected to two rounds of scrubbing with a wire scratch brush. This process involved approximately eighteen to twenty brush strokes for the broader sides of the specimen, conducted twice, and four strokes for each end. The pressure applied during the brush stroke was determined by clamping the wider face of the specimen at one corner of the platform scale, which was zeroed after placing the sample and weighed to a standard mass of 1.5 kg on applying the brush. This entire procedure constituted one cycle of the weathering test.

The process was reiterated 12 times to finalize 12 cycles. Following the 12 cycles, the specimens were subjected to a 48-hour drying period at 65°C. The last constant mass of the oven-dried specimens was recorded as W_f for each individual sample. The formula given in equation 3 was used to determine the mass loss of the specimens.

$$\text{Mass Loss}(\%) = \frac{W_i - W_f}{W_i} \times 100 \quad (3)$$

3. Results and Discussion

Initially, the examination focused on the physical characteristics of the bricks, which included bulk density and water absorption. Subsequently, compressive strength testing was conducted. Simultaneously, a weathering test was performed on additional specimens.

3.1 Physical Properties

The experimental results revealed that the average bulk density of CEB was determined to be 1847.28 kg/m3, surpassing the specified limit of 1750 kg/m3 as outlined in the Indian Standard [6]. Likewise, the average water absorption was measured at 9.77%, which falls below the prescribed limit of 18% set by the Indian Standard [6]. This suggests that the bricks meet the required standards for use in building construction.

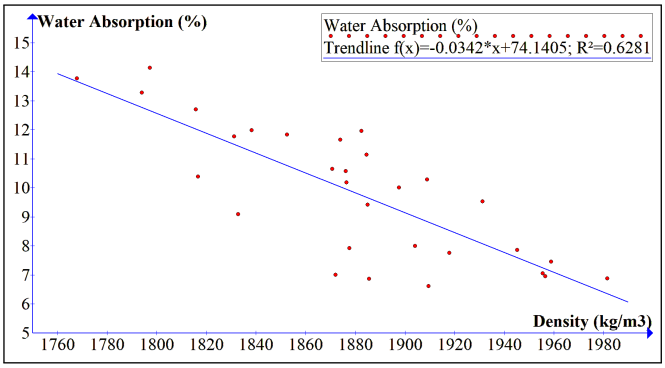

Figure 5: Density versus Water Absorption

In comparison to block density, the study revealed that water absorption increased for less dense blocks while it decreased for denser blocks, as illustrated in Figure 5 below. This phenomenon can be attributed to the reduced presence of pores in denser blocks. A similar trend in the relationship between water absorption and density has been documented in the research conducted by Myoaye et al. [10].

3.2 Compressive Strength

Figure 6 depicted below presents the graph illustrating the average wet compressive strength of the specimens concerning the duration of immersion in days. Initially, the compressive strength increased to 12.3 MPa within the first sixteen days of immersing the specimens in water. Subsequently, the compressive strength decreased and stabilized at approximately 10 MPa. This observation is in line with the findings of Nagaraj et al. [11], who noted that blocks prepared with cement alone as a stabilizer exhibit higher wet compressive strength for up to one month of aging. The abrupt decline in compressive strength after sixteen days might be attributed to the incorporation of a proprietary additive aimed at enhancing the soil's binding characteristics.

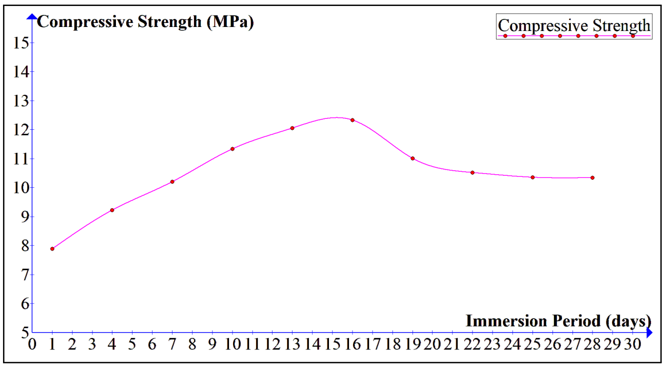

Figure 6: Wet compressive strength versus Immersion Periods

NBC 202: 2015 guides that the bricks for load bearing structure of 2 storey buildings should have a minimum crushing strength of 7.5 N/mm^2 [12]. Similarly, according to the classification shown in table 1 below provided in Standard Norms and Specification for CSEB block, the samples fall under Class A brick and hence can be used in construction industries. However, it can be suggested that the bricks can be cured in water for up to two weeks after completing all the manufacturing process to further increase the strength of the bricks.

Table 1: Classes of CSEB [13]

Property	Class A	Class B
Dry Compressive Strength (MPa)	5–7	2–5
Wet Compressive Strength (MPa)	2–3	1–2
Water Absorption(% by weight)	5–10	10–20

3.3 Weathering Test

From the experiment, it was observed that the brick samples resisted well under the weathering condition of alternate wetting and drying. The average mass loss after 12 cycles was found to be 0.29%. Figure 7 below shows the loss of mass for each sample. The average mass loss of the specimen was found to be lower than the limiting value guided by IS : 1725-2023. This shows that the brick samples are weather resistant and is good material for building construction.

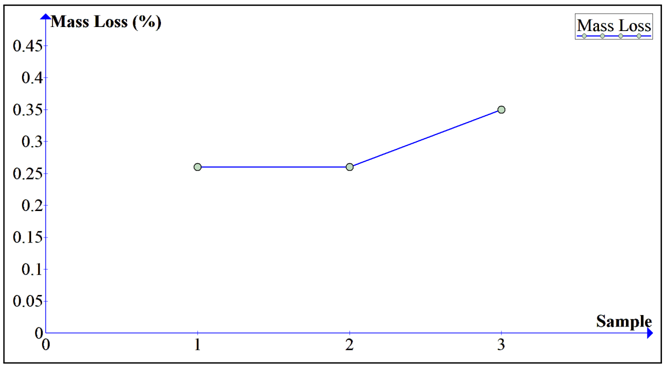

Figure 7: Mass loss in % of each sample

Water absorption in each cycle was similar. It indicated that exposing the internal surface of the samples did not cause the brick samples to absorb more water. This supports the structural integrity of the brick samples. Figure 8 below displays the average water absorption in each cycle during the whole process.

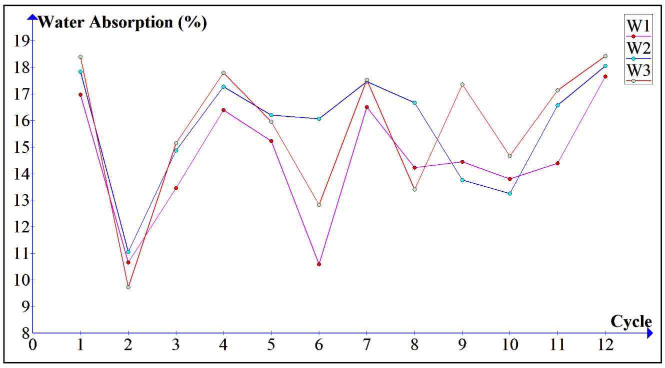

Figure 8: Water absorption in different cycles

4. Conclusion

This experimental study analyzed the compressive strength and durability properties of compressed earth blocks subjected to prolonged moisture exposure through immersion and weathering testing. The results indicate that the CEB samples met standard requirements for bulk density and water absorption. The compressive strength increased with extended curing up to 16 days, reaching 12.3 MPa, before decreasing likely due to the soil stabilizer used. However, the strength remained above accepted limits for structural masonry applications. The weathering test demonstrated high resistance to deterioration with average mass loss far below the 3% allowable limit after 12 wet-dry cycles.

Overall, the study provides valuable insights into the long-term performance of CEBs under moisture ingress and weathering actions. It indicates optimized curing can enhance strength while the composition resists deterioration. With appropriate manufacturing practices, CEBs can fulfil engineering reliability criteria for sustainable mainstream construction. Further research could investigate freeze-thaw resilience, thermal conductivity, and environmental impacts using life cycle assessment. Promoting the adoption of quality-assured CEBs can support affordable, low-carbon construction globally.

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