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Experimental Analysis of Compressive Strength Variation in Compressed Earth Blocks through Extended Immersion Periods

by

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A THESIS

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ABSTRACT

Compressed earth blocks (CEBs) are gaining recognition as an eco-friendly building material. However, the long-term impact of moisture exposure on their structural integrity is uncertain. This study experimentally investigates the variations in compressive strength and fracture characteristics of cement stabilized CEBs under extended immersion periods. CEB samples were subjected to water immersion for 1 – 28 days. Compressive strength tests per IS 3495:1992 were conducted at progressive curing ages. The density, water absorption, compressive strength, failure patterns and accelerated weathering response were evaluated. The results show that compressive strength of both full-sized and half-bat samples increased up to 16 days, reaching 13.64 MPa and 11.03 MPa respectively, before decreasing gradually. The characteristic axial splitting and multiple fractures following prolonged immersion substantiate the decline in strength from internal deterioration over time. Samples exhibited excellent durability under 12 wet-dry cycles with minimal mass loss and marginal increase in water absorption. Relationships were established between moisture exposure duration, density, strength, and fracture behaviour. The findings demonstrate the initial enhancement and subsequent deterioration of CEBs under sustained moisture ingress, highlighting the necessity of adequate weather protection. The study provides a systematic basis for evaluating long-term performance of CEBs, validating their suitability for durable, sustainable construction. It advances the knowledge on stabilized earthen materials, promoting further research into suitable protection techniques and optimized manufacturing to harness the full potential of CEBs as an eco-friendly building solution.

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Nirmal Burlakoti

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LIST OF ACRONYMS AND ABBREVIATIONS

ASTM	American Society for Testing and Materials
CEBs	Compressed Earth Blocks
CO_2	Carbon Dioxide
CSEBs	Compressed Stabilized Earth Blocks
CTM	Compressive Testing Machine
IS	Indian Standard
kg/m^3	kilogram per cubic meter
kgf/cm^2	kilogram-force per square centimeter
MPa	MegaPascal
N/mm^2	Newton per square millimeter
psi	Pound-force per square inch
SEBs	Stabilized Earth Blocks

CHAPTER 1 INTRODUCTION

1.1 Background

Nepal is developing in a rapid progress and is moving away from Least Developed Countries (Nepali, 2023). The establishment of infrastructure plays a pivotal role in the progress and development of a nation. The building materials for the construction are demanded to have very good quality. Brick is a type of building material used for walls, pavements, and other masonry construction components. Because of their endurance, brick has been utilized for thousands of years (Wikipedia, 2023). Fired bricks have been widely used as building materials for centuries due to their durability and strength. They are produced by firing clay or shale in kilns at high temperatures, resulting in a hardened and stable product. Despite their excellent properties, the production of fired bricks comes with environmental challenges, particularly related to air pollution. Embracing greener brick manufacturing methods can contribute to mitigating climate change and creating healthier living environments for communities around the world. Compressed Earth Blocks (CEBs) have gained significant attention as an environmentally friendly and cost-effective alternative in the construction industry. Producing CEBs involves using earth along with a binder. While some studies (Nagaraj et al., 2016), propose using unmodified earth or increasing the stabilizer content, others suggest incorporating binders enhances the geotechnical properties of the earth, including compressibility, strength, permeability, and durability (Venkatarama Reddy, 2012). The compressive strength of CEBs is a critical parameter that determines their structural integrity and suitability for various applications. Understanding the long-term performance of CEBs is crucial for ensuring their durability and reliability in real-world conditions. One factor that can potentially affect the compressive strength of CEBs is their exposure to moisture over extended periods. Moisture absorption and subsequent drying can lead to changes in the material properties and overall strength of the bricks.

This research aims to investigate the variation in compressive strength of CEBs through extended immersion periods. The study will involve subjecting different samples of CEBs to immersion in water for varying durations, such as 1, 4, 7, 10, and subsequent increment of three up to 28 days. By systematically analysing the compressive strength of the bricks at different soaking intervals, valuable insights can be gained regarding their long-term performance and the effects of moisture exposure on their structural characteristics.

The research will involve fabricating CEB samples using standard manufacturing techniques and quality control measures to ensure consistency. The compressive strength of the bricks will be determined using standardized testing methods, such as the IS 3495:1992 standard. The immersion process will simulate real-world conditions, allowing for an assessment of the bricks' performance in environments where moisture penetration is a concern.

The findings of this study will contribute to the existing body of knowledge on CEBs and their suitability for sustainable construction practices. By examining the effects of prolonged conditioning periods on the compressive strength of CEBs, recommendations can be made regarding optimal curing durations and moisture protection measures. This research will be valuable for engineers, architects, and construction professionals involved in utilizing CEBs for environmentally friendly and resilient construction projects.

Overall, this investigation into the compressive strength variation in CEBs through prolonged immersion periods will shed light on the durability and performance characteristics of this eco-friendly building material, advancing our understanding of its long-term behaviour and supporting its wider adoption in the construction industry.

1.2 Problem Statement

Compressed Earth Blocks are increasingly recognized as an eco-friendly and cost-effective option in the construction industry, owing to their environmental advantages. However, despite their growing popularity, there is limited knowledge about the long-term performance and durability of CEBs when exposed to moisture. The effects of extended immersion periods on key properties such as compressive strength and fracture characteristics of CEBs have not been thoroughly examined. There are even lesser examinations of these properties by cutting the bricks in halves. Cutting the bricks exposes the internal surface to the surrounding and might change the properties of the bricks. Gaining a comprehensive understanding of how moisture impacts the structural integrity and behaviour of CEBs is essential for optimizing their manufacturing processes and ensuring their long-term reliability in various applications.

Considering these knowledge gaps, it is crucial to undertake a systematic investigation into the variations in compressive strength and fracture analysis of CEBs during prolonged conditioning periods under different moisture exposure scenarios. This research endeavour aims to provide valuable insights into the response of CEBs to moisture and its potential implications for their performance in real-world construction settings. By shedding light on the behaviour of CEBs when subjected to moisture, this study seeks to contribute to the advancement of sustainable construction practices and facilitate the wider adoption of CEBs as a viable and resilient construction material.

1.3 Objective

This research aims to work on the following areas:

1.3.1 Main Objective

The main objective of this research is:

- To assess the impact of extended immersion periods on the compressive strength of Compressed Earth Blocks and understand how moisture exposure influences their long-term performance and durability.

1.3.2 Specific Objectives

The specific objectives of this research are:

- To evaluate the relationship between bulk density, moisture exposure, and analyze the compressive strength of Compressed Earth Blocks.
- To investigate the fracture pattern of Compressed Earth Blocks under compressive loading.
- To analyse the durability of Compressed Earth Blocks using alternate wetting and drying method.

1.4 Limitation of Study

While the research yielded useful findings within its defined scope, testing under broader conditions and parameters can build on the insights gained in this initial investigation.

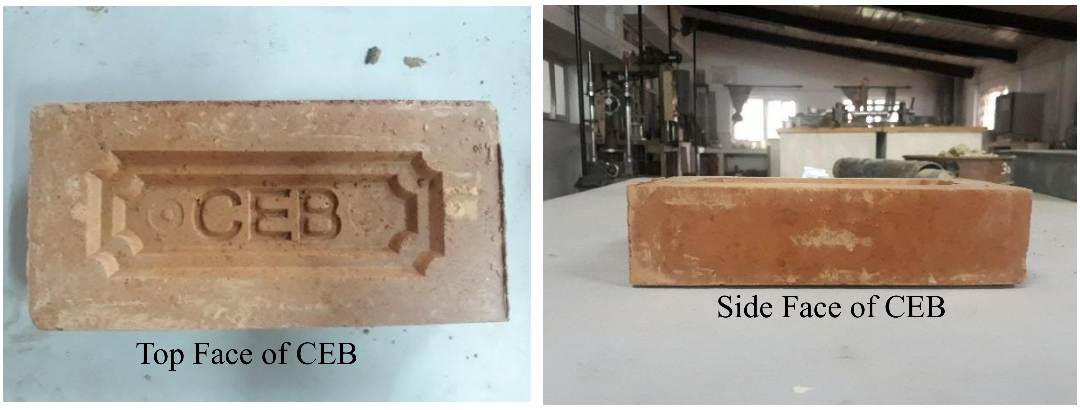
- Only one soil type and stabilization method (cement) were evaluated. Testing on CEBs made with different soils and stabilizers can reveal the effects of these parameters.
- The study was limited to compressive strength testing. Evaluating other mechanical properties such as flexural strength and modulus of elasticity could provide additional performance insights of CEBs.
- Long-term natural weathering tests were not conducted. Accelerated lab tests have limitations in simulating real-world weathering over months or years.
- Only water immersion conditioning was performed. Testing moisture resistance under pressure, freeze-thaw cycles, etc. could give further information.
- Only one cement-soil ratio and manufacturing process was adopted. Varying these parameters can affect CEB properties.
- The study tested CEBs under laboratory conditions. In-situ testing of constructed CEB walls over time can reveal real-world performance.

CHAPTER 2 LITERATURE REVIEW

2.1 Introduction

Earth is one of the earliest building materials employed by humans, and it is estimated that around 30% of the global population resides in structures constructed from earth (Coffman et al., 1990). Building with earth can manifest in diverse forms, encompassing adobe, rammed earth, compressed earth blocks, and fired bricks. Since its development in the 1950s, CEBs, which are manufactured by compressing earth until it develops structural cohesiveness, have gained popularity, and are utilized all over the world (Minke, 2005). Although earthen building has traditionally been more common in developing countries, there is a growing trend towards adopting more sustainable building practices in developed countries. The use of concrete and steel has been the norm in developed countries for centuries, leading to a bias against living in an earthen home and a lack of awareness about the benefits of earth as a building material. As a result, expertise in building with earthen materials has been lost, and the use of timber, concrete, and steel remains widespread due to existing building codes and standards. CEBs provide a promising alternative to conventional building materials in both developed and developing countries. They make use of regional resources, contributing to their affordability and energy efficiency. Additionally, CEBs can be developed using established masonry methods, rendering them a feasible and competitive choice for sustainable construction. As the demand for more eco-friendly building practices grows, CEBs may see increased usage and contribute to the broader adoption of sustainable construction methods worldwide. CEBs offer several advantages, such as utilizing local materials and reducing the energy needed compared to conventional materials. To enhance the strength of CEBs, builders have explored the addition of cement, a process known as ‘stabilizing’ (Walker, 1995). However, given the energy-intensive process involved in cement production, there is a preference to reduce the use of cement.

Figure 1 below shows a sample of CEB collected from Chandeshowri Eco Bricks in Panchkhal, Kavrepalanchowk.


Top Face of CEB

Side Face of CEB

Figure 1 CEB block collected from Chandeshwori Eco Bricks

Compressed Earth Blocks are a type of building material made from a mixture of dry inorganic subsoil, non-expansive clay, sand, and aggregate. These blocks are formed by dampening the mixture, mechanically pressing it at high pressure, and then allowing it to dry. When chemical binders like Portland cement are added, they are referred to as Compressed Stabilized Earth Blocks (CSEBs) or Stabilized Earth Blocks (SEBs). In areas with cold and rainy climates, where freezing and thawing cycles are frequent, stabilized blocks are the favoured option. Un-stabilized blocks in such environments may be susceptible to water penetration, leading to weathering and premature failure (Minke, 2000). Therefore, the use of stabilized blocks helps to enhance the durability and performance of the construction in these challenging conditions. The usage of stabilizers is a crucial factor to consider since they can raise the initial expense of the blocks. However, it facilitates easy construction and reduces the need for long-term maintenance. All the blocks in this thesis have had cement (9.8% by weight) added to stabilize them.

2.2 Advantages and Disadvantages

Comparing CSEBs to other widely used materials, there are benefits and drawbacks to using them as building materials. Some common drawbacks of earth construction, including CSEBs, are the lack of standardized building codes, shrinkage during drying, and susceptibility to water intrusion (Minke, 2000). However, the numerous advantages of earthen block construction outweigh these drawbacks. CSEBs boast a prolonged durability, cost and energy efficiency, efficient control of indoor temperatures and humidity, resistance to fire and pests, as well as notable sound resistance. Furthermore, their local availability reduces material transportation costs, and they are easily adaptable to traditional masonry construction methods (Krosnowski, 2011).

The concern of shrinkage in CSEBs leading to cracking can be addressed by adjusting the mix to reduce clay content or initial water content and optimizing the distribution of grain sizes. Additionally, introducing additives to the soil mixture may help combat shrinkage (Minke, 2005).

CSEBs are not fully impermeable to water due to soil nature and void spaces formed during curing. Unstabilized CEBs require protection from rain and proper surface coatings to prevent erosion. Although stabilized CEBs show enhanced resistance to erosion, it is uncertain how frequent wetting and drying as well as cycles of freezing and thawing may affect the integrity of the block. (Minke, 2000).

CSEB technology and other earthen building methods offer unique energy efficiency advantages not found in other construction materials. Because of their capacity to both absorb and hold heat, CSEBs can control temperature variations and create a more comfortable interior atmosphere. They demonstrate phase change behaviour, absorbing water vapor when relative humidity is high and releasing it when relative humidity drops, resulting in temperature regulation (Worrell et al., 2001).

From an environmental standpoint, CSEB construction promotes better resource utilization and reduces carbon dioxide (CO_2) emissions. Local sourcing of materials reduces transportation costs and emissions. Additionally, on-site production eliminates shipping and material transportation costs. While CSEBs require a fraction of the cement used in concrete, the overall CO_2 emissions associated with CSEBs are significantly lower than those of concrete (Worrell et al., 2001).

2.3 Production

A soil-sand mixture and the stabilizer can be used to create stabilized CEBs. Using a machine, a consistent soil-sand-stabilizer mixture is crushed into a high-density CEB at the ideal moisture content. The following crucial procedures must be completed to produce the stabilized CEB.

a) Selecting an appropriate soil, digging, and transportation
b) Processing the stabilized soil mixture
c) Compacting, ejecting, and stacking the CEB
d) Curing

The factory or a construction site where the building or other structure is being built can both be used to generate the stabilized CEBs. The CEBs can be made using a fully manual method, a semi-manual technique, or a fully mechanical process. The tasks required and the equipment used will vary depending on the kind of production method used. The process of manufacturing CEB in factory is displayed below in Figure 2. The essential raw components needed to make stabilized CEB are potable water, stabilizers (such as lime or cement), sand, or inert industrial by-products like crushed rock dust. When diluting natural soil, the inert material crushed rock dust can be used in place of sand to control the clay fraction and alter the grain size distribution (Venkatarama Reddy, 2012).

The compression process for the blocks typically requires around 3,000 psi (21 MPa) of pressure, resulting in a reduction in the original material volume by approximately half. Unlike rammed earth construction, which involves pouring and manually tamping down earth into larger formworks, CEBs are smaller building blocks that are assembled using standard bricklaying and masonry techniques. While mud bricks solidify through chemical changes during air drying, CEBs are compressed and have higher compression strength compared to traditional mud bricks (Wikipedia, 2023).

Water quality and quantity at compaction has a significant impact on the quality of earth construction. For easy compaction, the soil mix for stabilized soil blocks needs somewhat higher water content than ideal. To avoid “lump” formation after dry mixing, water is supplied evenly throughout the soil mass, ideally using sprinklers. The mixture should be blended completely. Field tests or laboratory studies are used to determine the ideal water content (Niazi et al., 2020).

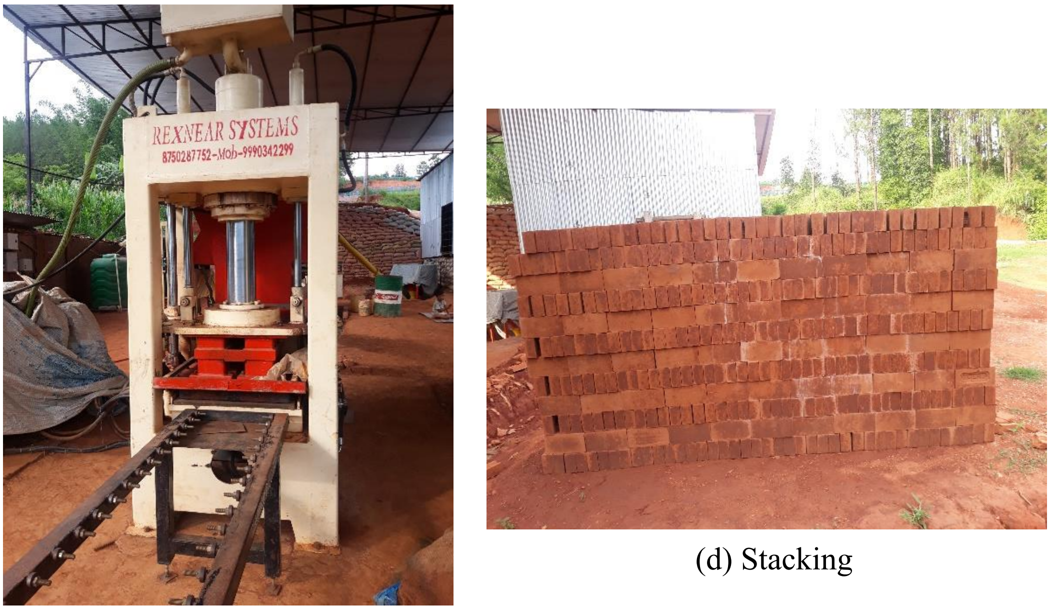
The sand employed in CSEBs must be natural, well-graded, and devoid of impurities such as dust, clay, soft or flaky particles, salts, organic matter, and other harmful substances. In case of uncertainty regarding the quality of the fine aggregate, tests for clay, organic impurities, and other deleterious substances are conducted. Furthermore, the production of CSEBs should use Ordinary Portland cement of grade 53, adhering to the appropriate standards. The cement should be fresh and stored properly to prevent deterioration. Damaged or deteriorated cement should not be used (Shrestha, 2012).

(a) Processing soil mixture

(b) Mixing soil, cement, and additives

Figure 2 Production process of CEB in Chandeshwori Eco Bricks (a → b)

Stabilizers are essential for enhancing soils, especially in harsh weather conditions, to achieve the best possible quality of the block. Proper mixing of the stabilizer is crucial to maximize its impact on the final product. The choice of stabilizer depends on the soil quality and project requirements. Cement is suitable for sandy soils, providing quick strength, while lime is preferred for clayey soils, although it takes longer to harden and achieve strong blocks (Shrestha, 2012). When using cement stabilization, it is important to make the blocks before the cement fully sets, ideally within 30 minutes of mixing. Weighing the stabilizer before mixing allows for accurate measurement of the required quantity (Niazi et al., 2020).



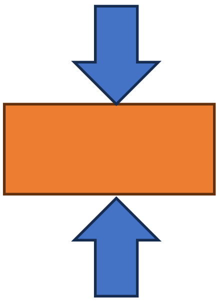
(c) Compacting

(d) Stacking

Figure 3 Production process of CEB in Chandeshwori Eco Bricks (c → d)

2.4 Water Absorption and Compressive Strength Test

Compressive strength characterizes a material's resilience against a compressive load, signifying its capacity to endure such pressure without undergoing failure. In the context of bricks, compressive strength pertains to the brick's ability to withstand the applied compression load during testing on a compressive testing machine (CTM). Essentially, it measures the material's robustness and ability to resist deformation or cracking under compressive forces. The overall compressive strength of a material is determined by its inherent capability to withstand failure in the form of cracks or fissures, serving as a critical indicator of the material's structural integrity and durability (Krishna, 2020). This property is pivotal in various engineering applications, particularly in construction, where materials need to endure significant loads without compromising their structural integrity.



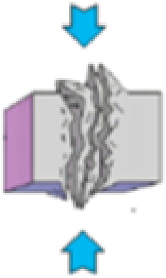
Compression force is the force that
squeezes the material together.

or

The pushing force applied on two
faces of the specimen.

Figure 4 Compressive strength on brick

During this examination, the brick undergoes compression between the machine's two surfaces until it eventually fractures and fails. The application of forces to the samples is illustrated in Figure 4, showcasing the procedure. The test involves observing and recording the level of compression force the brick can withstand before experiencing cracking. Figure 5, presented below, elucidates the loading process of the samples and the subsequent failure, providing insight into the compressive strength of the sample.



The loading must be applied axially on
specimen without any shock and increased
at the rate of 14 N/sq. mm./min. till the
specimen collapses.

Figure 5 Cracking due to compression force

CSEB is categorized into distinct classes determined by average compressive strength and water absorption. The classifications outlined for CSEB are presented in Table 1 in accordance with the Standard Norms and Specifications for CSEB.

Table 1 Classes of CSEB (Shrestha, 2012)

	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

Research conducted by Ahmed et al., (2020) evaluating the compressive strength of CSEBs with different stabilizers and soil compositions indicated that specimens containing 50% ground silt, 7.5% cement as a stabilizer, and 42.5% sand exhibited the highest compressive strength at both 7 and 28 days of curing, compared to mixes using bitumen, gluten, varying silt percentages, and cement contents. The study found that cement took time to fully hydrate and reach maximum strength, with 28-day strength exceeding that at 7 days. While bitumen and gluten imparted early strength, cement stabilization yielded higher long-term compressive strength. The optimized mix ratio with 50% silt and 7.5% cement consistently performed the best irrespective of stabilizer type or silt grading, highlighting the importance of using the appropriate soil composition and cement content in manufactured CSEBs.

In another research by Garg et al. (2014) on CSEBs stabilized with 9% cement demonstrated favorable engineering properties, including a 28-day compressive strength of 3.2 MPa and flexural strength of 1 MPa along with low water absorption around 7.5%. The study highlights that adequate cement stabilization yields CSEBs with suitable strength for masonry applications and resistance to environmental exposure, while avoiding excessive cement. The research affirms that CSEBs with proper stabilization can balance sustainability, strength, and durability requirements.

This research is necessary in the context of Nepal due to the recent introduction and accelerated production and usage of CSEBs in the country. With the development and provision of a soil binder solution for CSEBs by InnoCSR[1], there is a growing need to assess the compressive strength of these bricks specifically in the Nepalese context. By conducting comprehensive testing and analysis, this research will provide valuable insights into the performance and viability of CSEBs in the local context, supporting informed decision-making and promoting the adoption of this eco-friendly building solution in Nepal's construction industry.

Water absorption, percent by mass, after 24-hour immersion in cold water is given by the following formula (IS 3495-1 to 4, 1992):

$$\text{Water absorption (\% by mass)} = \frac{\mathrm{M_2} - \mathrm{M_1}}{\mathrm{M_1}} \times 100$$

where,

M_2 = Mass of sample 3 minutes after the specimen has been removed from water

M_1 = Mass of dried sample

The compressive strength of the brick sample can be calculated using the following formula (IS 3495-1 to 4, 1992):

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

2.5 Weathering Test

The durability test in bricks is another important test as it assesses the ability of bricks to withstand adverse environmental conditions and the effects of weathering over time. This test provides valuable insights into the long-term performance and reliability of bricks in various exposure conditions, such as moisture, freeze-thaw cycles, and other environmental factors.

The results of the durability test help to determine the resistance of bricks to deterioration, cracking, and erosion caused by repeated exposure to moisture and other environmental

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[1] A Global Corporate Social Responsibility Strategy Consulting Firm with expertise in Asian Countries

elements. It aids in evaluating the long-term structural integrity of bricks, which is crucial for ensuring the safety and longevity of buildings constructed with these materials.

During the test, three representative CEBs will incorporate cycles of wetting, drying, and scratching of brick surface with metal brush. The repeated cycle provides insights on the integrity of the blocks. Defective bricks may fall to pieces, or even burst (Herbold, 2003). The test will also evaluate the wet compressive strength and water absorption of the CEB blocks after 10 cycles of wetting and drying. This will help determine any improvements in strength and reduction in water absorption that may occur because of the weathering test. CSEB samples subjected to weathering tests by Garg et al. (2014) exhibited negligible degradation (<3%) and weight loss (<1%), indicating excellent durability. Based on the results, the researchers inferred that cement-stabilized CSEBs have immense potential as eco-friendly construction materials that could transform the industry given their green credentials, subject to large-scale implementation.

Overall, the weathering test is a critical aspect of brick quality assessment, as it ensures that the bricks used in construction projects can maintain their strength and integrity over an extended period, contributing to the overall sustainability and resilience of buildings and infrastructure.

CHAPTER 3 RESEARCH METHODOLOGY

3.1 Research Design

The research was based on the experiment carried out in the laboratory and its overall flow is given as follows:

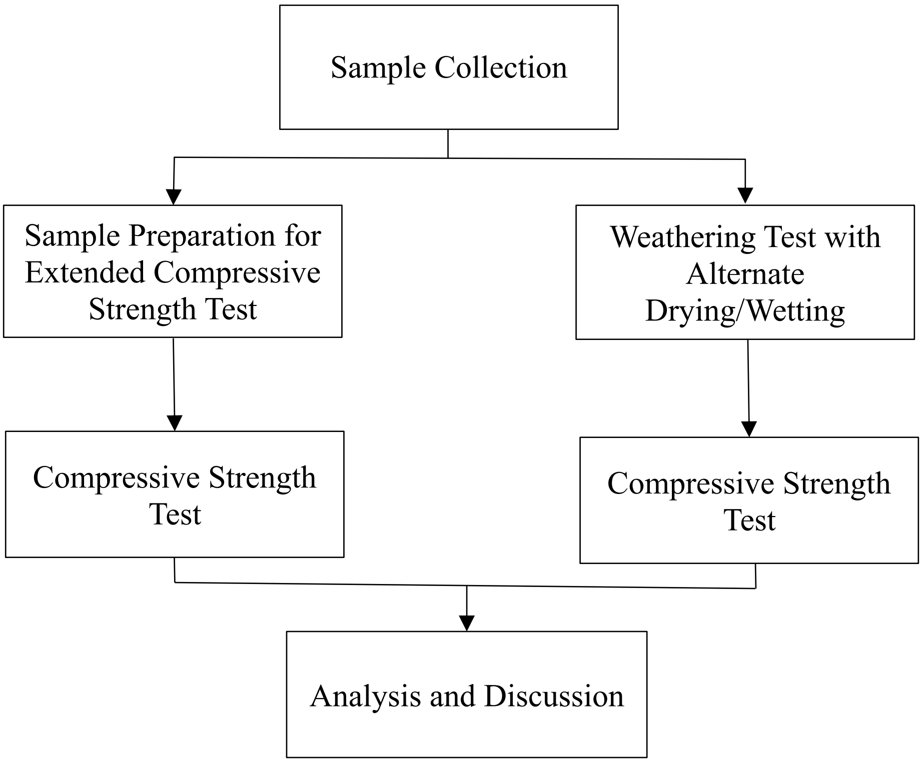

Figure 6 Research methodology framework

3.2 Sample Collection

The samples of CEBs were collected from Chandeshwori Eco Bricks, a manufacturer utilizing the CEB technology for production. The sample collection followed a random sampling from a stack method (IS : 5454, 1978), ensuring a representative selection of bricks from the factory in Panchkhal, Kavrepalanchowk. These samples were then carefully transported to the Central Material Testing Lab located in Pulchowk Campus for further testing and analysis. The use of random sampling from a stack method allowed for an unbiased and comprehensive collection of CEB samples, ensuring that the study's findings are based on a diverse and reliable dataset.

Chandeshwori Eco Bricks first prepare the soil by drying, screening, and pulverizing. Screening is done to eliminate all undesirable components (roots, leaves, etc.). Pulverizing is done to break down lumps made up of coarse material and/or fines. It is also be used to split coarse material to reduce it to smaller diameter aggregates. Soil having at least 15% clay is used to produce the brick. Soil (90%) is then mixed with cement (9.8%) and soil binder[2] (0.2%). Mixing is carried out using a mixer. Mixing most often takes place in two stages: dry mixing before adding water and wet mixing after adding water. The mix is then pressed using a mechanical and hydraulic system which presses the mix into a standard mould. Pressure is applied through the hydraulic system to attain the required shape, size, and density. The pressured blocks are then ejected from the mould and stacked for 24 hours. The bricks are then cured for 7 – 10 days. The bricks are hardened and cured using Soil Stabilizers instead of baking bricks in Kilns.

3.3 Materials

Materials like Chandeshwori Eco Bricks, Ordinary Portland Cement, Sand, and Water were used in the research. Various equipment and machines available in Central Material Testing Lab in Institute of Engineering, Pulchowk Campus were also used for the experiment works. They were as follows:

- Sieve sets as per Indian Standard
- Sieve Shaking Machine
- Oven
- Cutter
- Electronic Balance
- Curing Tank
- Buckets
- Trowel
- Compressive Strength Testing Machine

Materials are displayed in Annex.

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[2] The soil binder is a secret sauce supplied by InnoCSR whose ingredient they were reluctant to provide.

3.4 Sample Preparation for Wet Compressive Strength Test

3.4.1 Drying of Bricks

Among the samples transported to the lab, 20 samples were selected. They were placed in an air oven and dried at a specific temperature of 250°F for 24 hours. This controlled drying process aimed to eliminate any moisture content from the bricks and ensure uniformity in the test samples. This process helped to attain a constant weight of the brick samples.

Figure 7 Air oven drying of bricks at 250°F

3.4.2 Cooling of Bricks

After the drying process, the bricks were taken out of the oven and allowed to cool naturally at room temperature for more than 1 hour. The bricks were cooled till they could be easily handled. This cooling period was crucial to avoid any heat-related effects on the experimental results and to stabilize the bricks at room temperature.

3.4.3 Weighing and Dimensioning

Weighing and dimensioning of the samples are necessary to calculate the bulk density of the samples. The bulk density is a crucial parameter that helps to assess the compactness and density of the material. By measuring the weight and dimensions of the samples, the bulk density can be determined using the formula:

$$\text{Bulk Density} = \frac{\text{Mass of the Sample (kg)}}{\text{Volume of the Sample }(\text{m}^3)}$$

$$\text{Volume of the Sample} = \text{Length (m)} \times \text{Breadth (m)} \times \text{Height (m)}$$

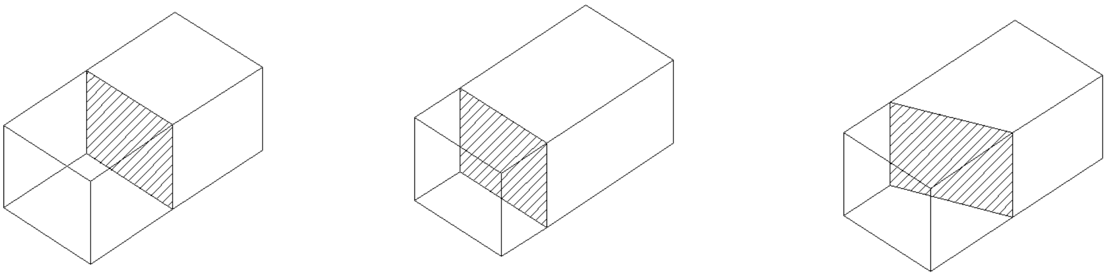
To characterize the physical properties of the bricks, ten samples were marked with unique sample numbers. The weight of each sample was obtained through weighing using an electronic balance, and the volume of the sample was calculated based on its dimensions (length, breadth, and height) that were measured using a steel scale at three different locations for each face.

The bulk density calculation is important in understanding the material's structural and mechanical properties, as well as its suitability for construction purposes. It is a fundamental parameter in analysing the performance and behaviour of the CSEB bricks during testing and subsequent use in building applications.

3.4.4 Cutting, Weighing and Dimensioning

Cutting the samples in half using a cutting machine is a crucial step in the methodology as it provides understandings into the internal integrity and behaviour of the samples. This process allows for a detailed examination of the internal structure, homogeneity, and any potential defects or variations within the bricks. This step also helps in understanding how the water absorption and compressive strength vary when the samples are broken into smaller pieces, simulating real-world scenarios where bricks might undergo stress or damage during construction or use.

Thus, another set of ten samples from the dried bricks was cut in half using a cutting machine. The brick samples were cut to form a half bat. When a brick is cut across the width, resulting in a smaller length than the full brick is called bat and if the length of the bat is equal to half the length of the original brick, it is known as half bat (Suryakanta, 2015). Figure 8 shows different forms of brick bat that are in use in the field.



(a) Half Bat (b) Three Quarter Bat (c) Beveled Bat

Figure 8 Different forms of brick bat

The sample cut into half bat is demonstrated in Figure 9. Like the previous step, the cut samples were marked with sample numbers, weighed in an electronic balance, and dimensioned using the steel scale at three different locations for each face. The average of the three measurements was taken as the dimension of each face. Bulk density of the cut sample pieces was calculated as in the previous step.

(a) Cutting machine (b) Cut bricks (half bat)

Figure 9 Cutting of bricks to form half bat

3.4.5 Water Absorption Test

During curing, both the whole and cut samples of CEB bricks (totalling 30 samples, 10 whole and 20 cut samples) were completely immersed in water in a curing tank at a constant temperature of 26°C for 24 hours. This immersion period allowed the bricks to absorb water and reach their maximum water absorption capacity.

The water absorption test is essential in assessing the durability property of the bricks. It provides valuable information about the degree of compactness of the bricks and the presence of pores within them. The test involves measuring the amount of water absorbed by the bricks, which directly correlates with the number and size of pores present in the material.

As the water is absorbed into the pores of the bricks, it helps determine the brick's porosity and permeability. Bricks with higher porosity and larger pores tend to absorb more water, indicating a less compact and potentially less durable material. On the other hand, bricks with lower water absorption rates are likely to have fewer and smaller pores, indicating better compaction and higher durability.

The water absorption test is crucial in understanding how the bricks will perform under different environmental conditions, especially when exposed to moisture or rain. It provides valuable insights into the bricks' resistance to water penetration and potential damage due to freeze-thaw cycles or other environmental factors.

(a) Dry weighing

(b) 24-hour curing

(c) Wet weighing

Figure 10 Water absorption test procedure (a → b → c)

After the 24-hour curing, the samples were taken out of the curing tank. The surface of the samples was allowed to dry naturally at room temperature for a short period (less than half an hour). The samples were then re-weighed using the same electronic balance. The difference in weight before and after water immersion was used to calculate the 24-hour water absorption rate of the bricks as per IS 3495 1-4. Figure 10 above shows the steps involved in measuring water absorption of bricks in this research.

3.4.6 Punning of Bricks

The filling of the frog on the surface called punning of the bricks was essential to achieve a uniform distribution of force during the compressive strength testing. The frog, being a depression or indentation, does not allow for uniform application of force, which can affect the accuracy of the test results. To overcome this limitation, the frog was filled with a mortar mixture following IS 3495 1-4.

The mortar was prepared by combining 43 grade Ordinary Portland Cement and sand passing through a 1.7 mm sieve in a specific mixing ratio of 1:3. This ensured that the mortar had the right strength and consistency to provide a stable and uniform surface on both sides of the brick sample. The sand was sieved using a sieve set and sieve shaking machine.

By filling the frog with mortar, a smooth and even surface was created on both sides of the sample, allowing the testing apparatus to apply force uniformly during the compressive strength test. This uniform application of force is crucial in obtaining accurate and reliable results, as it ensures that the brick sample is subjected to equal pressure from all directions.

Moreover, the use of the specified mortar mixture provided adequate bonding between the mortar and the brick, enhancing the overall stability and integrity of the sample during the test. This ensured that the compressive strength testing was carried out under controlled conditions, minimizing any potential variations that could arise due to the presence of the frog.

(a) Mortar preparation (b) Punning

Figure 11 Punning of bricks

After filling the frog with mortar, the samples were left undisturbed at room temperature for a period of 24 hours. This time allowed the mortar to set. The samples were then immersed in water in curing tank to gain sufficient strength, ensuring that the samples were ready for the subsequent compressive strength test. One whole sample and two cut samples were then taken out of the curing tank every two days. The samples were allowed to dry at room temperature for less than 24 hours and then tested for compressive strength separately. Figure 11 shows the punning process of the bricks adopted in this research.

Overall, the filling of the frog with the appropriate mortar mixture played a vital role in ensuring the accuracy and consistency of the compressive strength testing of the bricks, making the test results reliable for further analysis and evaluation of the brick’s mechanical properties.

3.5 Weathering Test

Weathering test was performed in accordance with IS 1725:2023. The maximum loss of mass, being the average of three specimens, when determined in accordance with the procedure described in Annex E of IS 1725:2023 shall not exceed 3 percent.

3.5.1 Sample Selection

Three full size specimens from the original sample collection of blocks which had been found satisfactory in respect of dimensional and visual assessment were randomly selected. The blocks were assigned sample numbers. Three other specimens were selected in similar manner and were cut to form half bat. A total of 9 specimens were prepared.

3.5.2 Apparatus

Following apparatus were used for weathering test:

- Electronic balance
- Ventilated air oven
- Wire scratch brush
- Curing tank

3.5.3 Procedure

Following procedure was followed for weathering test (IS 1725, 2023):

a) The specimens were subjected to an oven-drying process at 60°C until a consistent mass was achieved, ensuring that successive masses measured at 2-hour intervals did not deviate by more than 0.05 percent.

b) The initial stable mass of each individual specimen was recorded and denoted as W_i for each respective sample.

c) The specimens underwent a water soaking process at room temperature for 5 hours. Following removal from water, the samples were weighed to ascertain water absorption. Subsequently, the wet specimens were subjected to drying in an oven at 75°C for 42 hours. Partially dried blocks were then taken from the oven and systematically scratched on all six faces using a wire scratch brush. This involved applying approximately eighteen to twenty brush strokes for the broader sides of the specimen and four strokes for each end. The pressure of the brush strokes was measured by securing the wider face of the specimen on one corner of a platform scale, with the scale zeroed using a standard mass of 1.5 kg on the brush. This entire process constituted one cycle of the weathering test.

d) The procedure outlined in step c was iterated 12 times to accomplish a total of 12 cycles.

e) Following the completion of 12 cycles, the samples underwent drying at 65°C for more than 48 hours, ensuring that successive masses measured at 2-hour intervals did not vary by more than 0.05 percent.

f) The final constant mass achieved through oven drying was recorded and denoted as W_f for each respective sample.

3.5.4 Calculation

The percentage loss of mass of each sample was calculated as the difference between the initial constant mass (W_i) and final oven dried constant mass after conducting 12 cycles of weathering (W_f) expressed as a percentage of the initial constant mass.

$$\text{Percentage loss} = \frac{W_i - W_f}{W_i} \times 100$$

3.5.5 Punning of Bricks

The punning of weathered brick samples was performed in a similar manner as mentioned above in 3.4.6. This was done so that weathered brick samples could also be tested for the compressive strength using standard procedure.

3.6 Compressive Strength Testing

Compressive strength tests were conducted on all the conditioned CEB samples following standardized procedures, IS 3495:1992. A calibrated Aimil Compressive Strength Testing Machine was used to apply a compressive load gradually to the samples until failure occurred.

3.6.1 Procedure

Figure 12 shows the lab setup of the compressive strength test adopted during this research.

Figure 12 Compressive strength testing of brick

The procedure outlined in IS 3495-1 to 4 (1992) was followed during the conduct of the compressive strength test. The procedure is described below:

a) The specimen was positioned with flat faces horizontally, and the face filled with mortar was oriented upwards.
b) The specimen was enclosed between 3-ply plywood sheets, each 3 mm thick, and centred between the plates of the testing machine.
c) An axial load was uniformly applied at a rate of 14 N/mm^2 (140 kgf/cm^2) per minute until failure ensued.
d) The maximum load at failure was recorded, signifying the point at which the specimen ceased to exhibit any further increase in the indicator reading on the

testing machine or when cracks on the samples became visible and were deemed unacceptable for the intended building component.

3.7 Fracture Analysis

In addition to assessing the compressive strength of the CEBs, a comprehensive fracture analysis was conducted on the CEB samples. This fracture analysis involved the examination of the fracture characteristics exhibited by the CEBs following the completion of the compressive strength tests. The objective of this analysis was to gain a thorough understanding of the structural behaviour of the CEBs under varying conditioning periods and loading conditions.

The fracture analysis encompassed a detailed investigation of several key aspects, including crack propagation, fracture patterns, and any discernible differences or variations observed among the CEB samples subjected to different conditioning periods.

The fracture analysis not only contributed to a deeper understanding of the CEBs' structural integrity but also provided essential data for assessing their long-term performance and durability. By systematically analysing fracture behaviour, this study aimed to uncover valuable information that could inform decisions related to CEB manufacturing practices, material optimization, and sustainable building solutions.

3.8 Data Analysis

The data collected from the compressive strength test, water absorption test, weathering test, and fracture analysis were methodically compiled and systematically organized to facilitate comprehensive analysis. This organized dataset allowed for a rigorous investigation into the variations in compressive strength concerning the distinct conditioning periods. Concurrently, the fracture characteristics noted at each specific conditioning duration were subjected to a comparative analysis, followed by insightful interpretation.

By conducting this comprehensive analysis, the study aimed to unveil critical information about the behaviour of the tested materials under varying conditions. This analytical process was instrumental in drawing meaningful conclusions regarding the compressive strength, fracture characteristics, and overall performance of the materials.

CHAPTER 4 RESULTS AND DISCUSSION

4.1 Bulk Density Data

The blocks were kept in the oven for drying until constant weight was obtained. The dimensions of the blocks and volume were measured and calculated as following the formula below after drying.

Bulk density was calculated after the block was removed from the oven. The bulk density γ in kg/m^3 was calculated as:

$$\gamma = \frac{W}{V}$$

where,

W = dry weight in kg, and

V = volume in m^3

The average bulk density of full-size samples (1 – 10) was found to be 1847.28 kg/m^3 whereas the average bulk density of half bat samples (1A – 10B) was found to be 1896.17 kg/m^3. Both values exceed the acceptable value per IS:1725-2023 of 1750 kg/m^3 (IS 1725, 2023), making the CEBs used in this experiment suitable for use in building construction.

The samples fall under Class B (1700 – 200kg/m^3) (Shrestha, 2012) according to the classification in Standard Norms and Specification for CSEB Blocks.

4.2 Water Absorption Test

After drying the blocks in oven to attain constant weight, the blocks were immersed in water using curing tank for 24 hours at constant 26°C temperature. The blocks were then removed from the tank and surface was let dry for half an hour before they were weighed again to calculate the weight along with water absorbed by the blocks. Water absorptions were then calculated using the formula mentioned in 2.4 above.

The average water absorption of full-size samples was found to be 9.77% and that of half bat samples were found to be 9.86%. When compared to the density of blocks, it was found that the water absorption appeared to be higher for less dense blocks and lesser for more dense blocks as indicated in both Figure 13 and Figure 14 below. Even though the bricks were cut in half and the internal surfaces were exposed to water, there was only a little change in water absorption indicating good internal integrity of the materials.

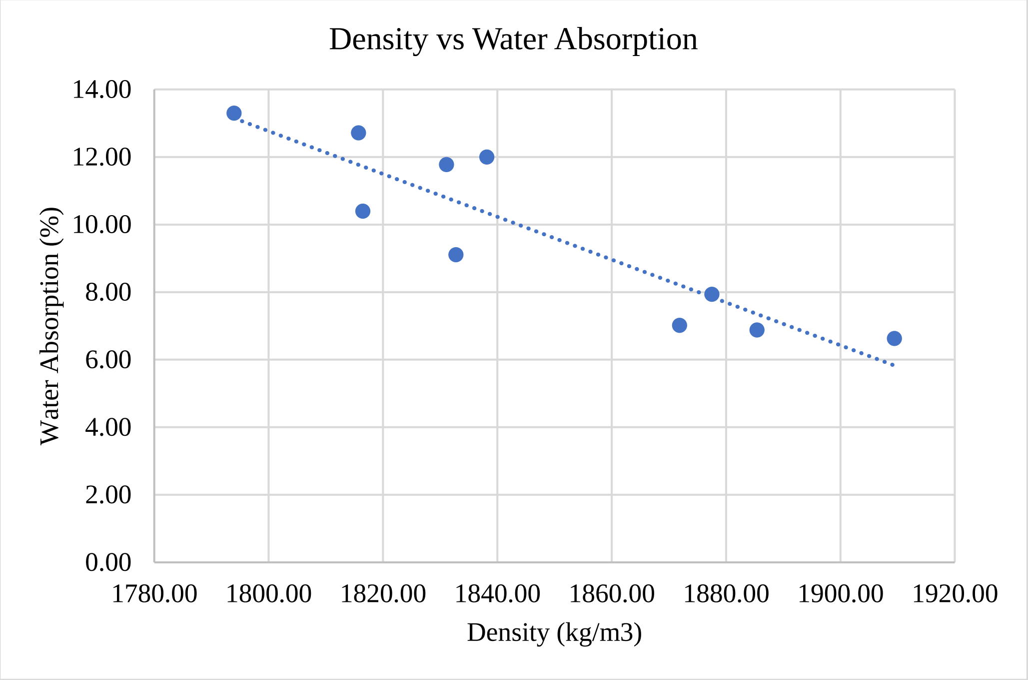


Figure 13 Chart showing relation between density vs water absorption for full-size bricks

Figure 13 and Figure 14 showed that with increasing density there was decrease in water absorption. But Figure 15 indicates that even with increasing density between two types of samples, there was more water absorption in higher density samples i.e., half bat samples. Exposing the internal surface by cutting the samples in half can have caused this discrepancy. So, even though the water absorption is comparable between the two sample types, there is evidence that half bat samples absorb more water than the full-size samples.

The water absorption of all the full-size samples and the half-bat samples were far less than the standard value of 18% set by IS:1725-2023. This indicates that the good soil preparation and compaction procedure were adopted during the construction of the brick samples. The samples fall under both Class A (5 – 10%) and Class B (10 – 20%) according to the Standard Norms and Specification for CSEB Blocks (Shrestha, 2012).

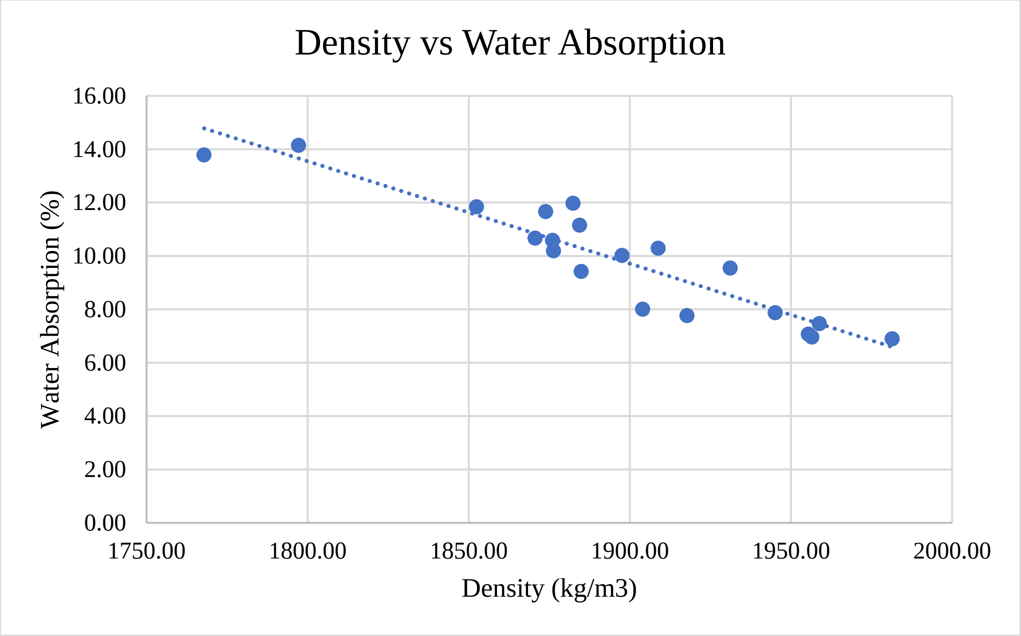


Figure 14 Chart showing relation between density vs water absorption for half-bat bricks

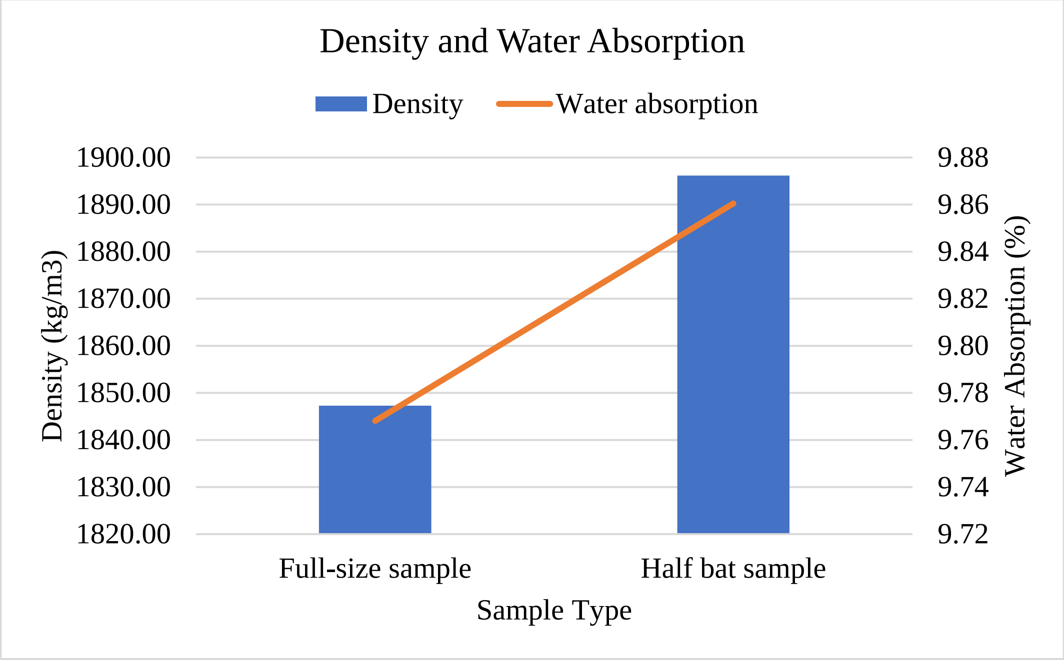


Figure 15 Density and water absorption of full-size and half bat samples

4.3 Compressive Strength Test

After the bricks underwent punning, a series of compressive strength tests were conducted to assess their structural integrity. The initial test occurred after just one day of curing for the punned bricks, followed by subsequent tests every third day. This systematic testing schedule covered intervals of 1, 4, 7, 10 days, and so forth. The application of a uniform axial load continued until the samples either ruptured or exhibited visible fractures.

The collected data reveals a noteworthy trend in the compressive strength of full-size samples with increasing immersion periods. Up to the 16th day, there is a discernible rise in compressive strength, suggesting a positive correlation between immersion duration and strength enhancement. However, beyond this point, a gradual decline in strength becomes apparent, signifying a deterioration in the samples as the immersion period extends. This trend is graphically depicted in Figure 16.

Interestingly, this finding aligns with the observations documented by Venkatarama Reddy and Latha (2014) in their study titled "Influence of soil grading on the characteristics of cement-stabilized soil compacts". They noted a similar pattern of an initial strength increase followed by a subsequent decrease when the clay content exceeded 14%. Additionally, another study conducted by Nagaraj et al., (2016) in a different setup reported an increase in the strength of compressed blocks with an 8% cement content for up to 28 days.

The behavior of half-sized brick samples mirrors that of their full-sized counterparts in a compelling manner. Initially, these smaller samples exhibit a relatively modest compressive strength, but intriguingly, there is a notable improvement after just one week of immersion in water. Following this initial enhancement, the compressive strength stabilizes at an impressive level, reaching approximately 11 MPa, and maintains this consistency for a noteworthy 16-day period.

This stability in strength underscores the resilience of the half-sized samples under the influence of water immersion. However, in a parallel trend to the full-sized samples, there is a subsequent decline in strength after this 16-day mark. Despite this decrease, the diminished strength eventually reaches a plateau, settling at a value close to the initial strength of 9 MPa.

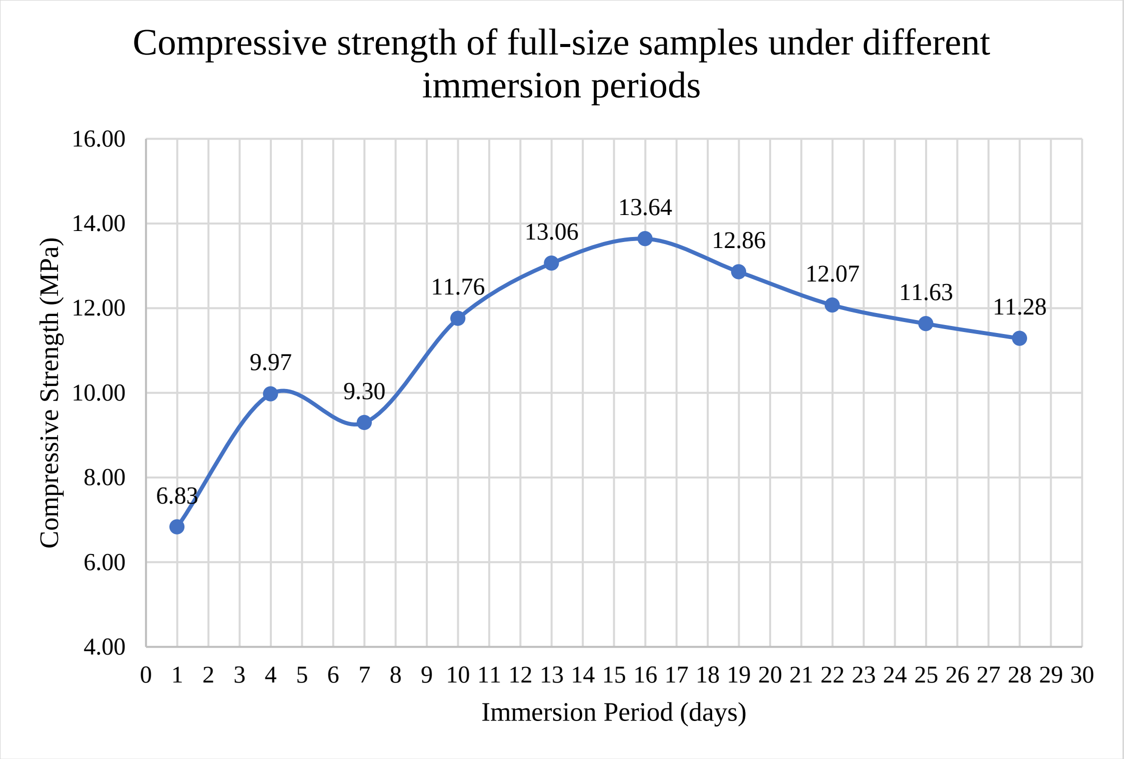


Figure 16 Compressive strength of full-size samples

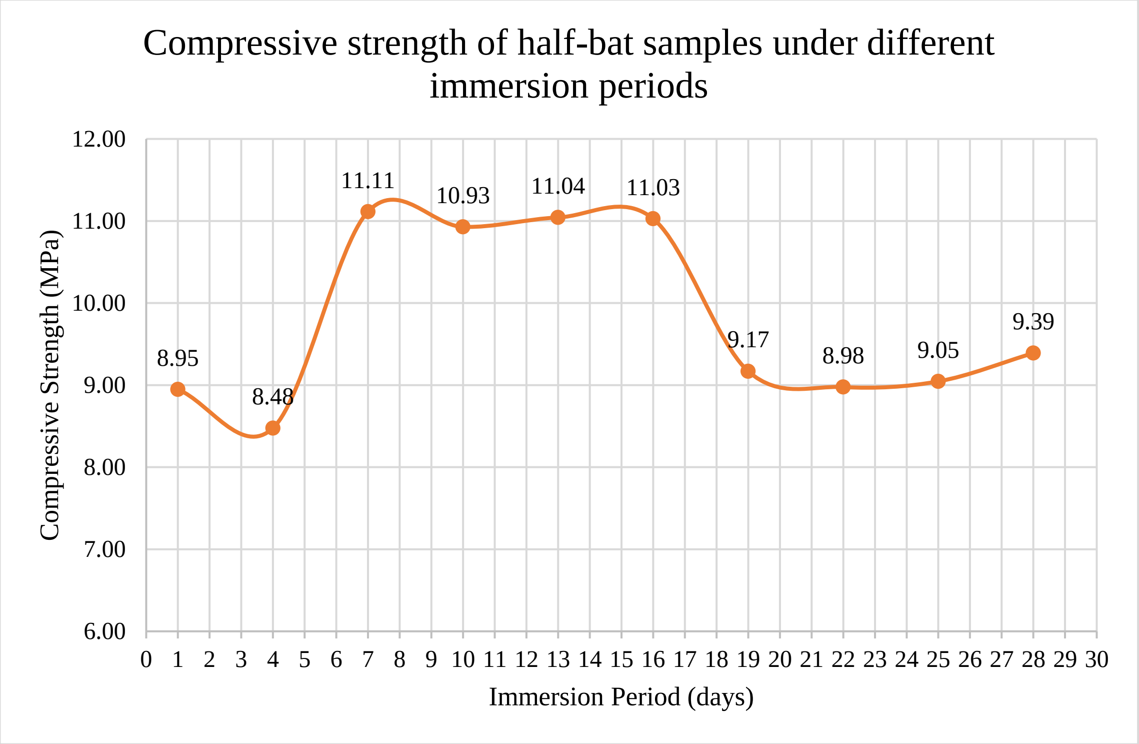
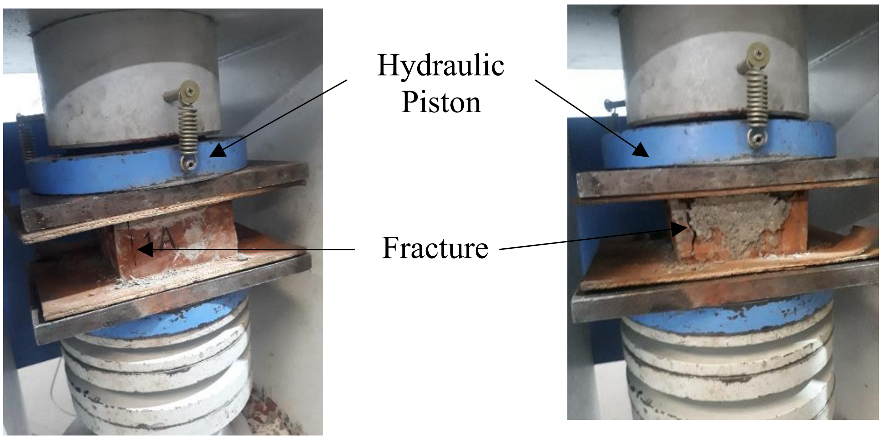


Figure 17 Compressive strength of half-bat samples

This pattern of strength variation over time, graphically illustrated in Figure 17, reinforces the intriguing similarity in behavior between the larger and smaller brick samples. The findings suggest that the initial immersion period yields favorable enhancements in compressive strength for both full-sized and half-sized bricks. However, prolonged exposure to water leads to a gradual decline in strength, emphasizing the importance of understanding the temporal dynamics of strength development in bricks subjected to varying immersion periods.

4.4 Fracture Analysis

In the initial stages of the immersion period, when the samples were subjected to compressive strength testing, the failure mode was characterized by the rupture occurring along one of the faces of the samples. This rupture resulted in the detachment of the damaged face from the rest of the sample. During this early phase, the middle section of the samples remained intact and showed no signs of damage. This consistent pattern was observed in both the larger, full-size samples and the smaller, half-bat samples. Figure 18 illustrates the distinct failure planes observed in the samples.



(a) (b)

Figure 18 Rupture pattern of samples

As the immersion period progressed, there was a notable shift in the failure pattern. The samples not only continued to fail along the faces but also began to fail along the middle section. This change indicated a deterioration in the structural integrity of the samples with an increase in the immersion period. Importantly, this shift in failure mode was consistently observed in both the full-size and half-bat samples.

This observation suggests that the samples exhibit vulnerability on the faces while maintaining structural strength internally. However, as the immersion period extends, there is a noticeable reduction in the structural integrity of the internal components, leading to failures occurring along the center of the samples.

In summary, the observed patterns of failure suggest a dynamic response of the samples to the immersion period, with changes in failure modes indicating alterations in structural integrity over time.

4.5 Weathering Test

The samples underwent repeated cycles of drying and wetting to assess the impact of weathering on their long-term exposure to diverse climatic conditions. Following each wetting and drying cycle, the samples were meticulously weighed to determine water absorption and mass loss. The collective mass loss across all samples averaged at 1%, with individual samples not exceeding the permissible upper limit of 3% stipulated by the Indian Standard IS:1725-2023. Notably, half-bat samples exhibited a comparatively higher mass loss than their full-sized counterparts; however, this remained within the acceptable limit set by the Indian Standard.

Throughout the complete 12 cycles, water absorption of the samples remained consistent. Even after the twelfth cycle, the average water absorption measured at 18.04%, marginally exceeding the standard recommended in IS:1725-2023. Importantly, five out of nine samples had water absorption below 18%, with only four samples surpassing the limit. The results of both mass loss and water absorption serve as indicators of the material soundness of the CEB samples, reflecting the efficacy of material selection and manufacturing processes.

Subsequently, the weathered samples underwent compressive strength testing under axial loading, adhering to the guidelines outlined in IS 3495-1 to 4, 1992. The results revealed a slightly diminished compressive strength in samples with higher mass loss, evident in both full-sized and half-bat samples. This underscores the impact of weathering on the strength of bricks, emphasizing a reduction in strength for weathered samples compared to their un-weathered counterparts. These findings contribute valuable insights into the material durability and performance of the CEB samples under varying weathering conditions.

The outcomes derived from the assessments of mass loss and water absorption serve as crucial indicators of the overall material soundness exhibited by the CEBs. By referencing these results, one can glean valuable insights into the integrity and quality of the CEB samples. The minimal mass loss and controlled water absorption levels signify a robust material constitution, reflecting the effectiveness of prudent material selection and a meticulous manufacturing process. These findings underscore the soundness of the CEBs, affirming that the chosen materials and manufacturing techniques align with established standards and contribute to the production of high-quality, durable construction materials.

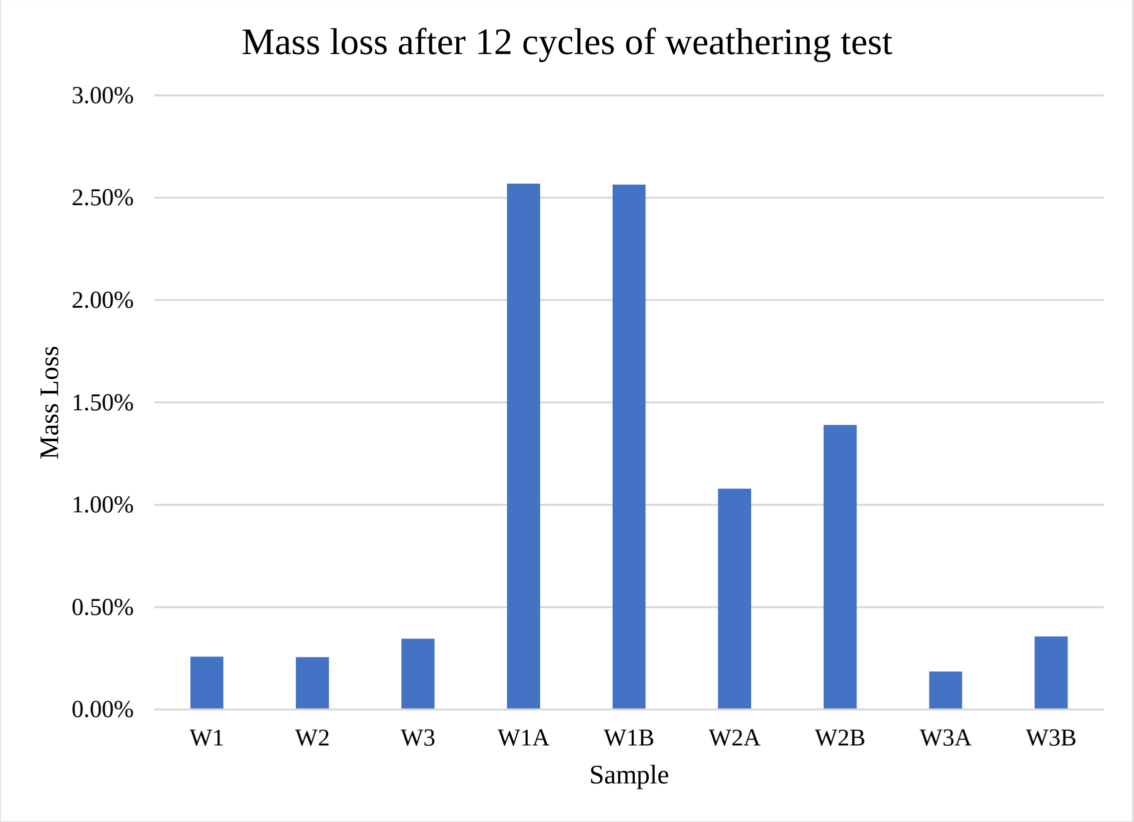


Figure 19 Mass loss from weathering test

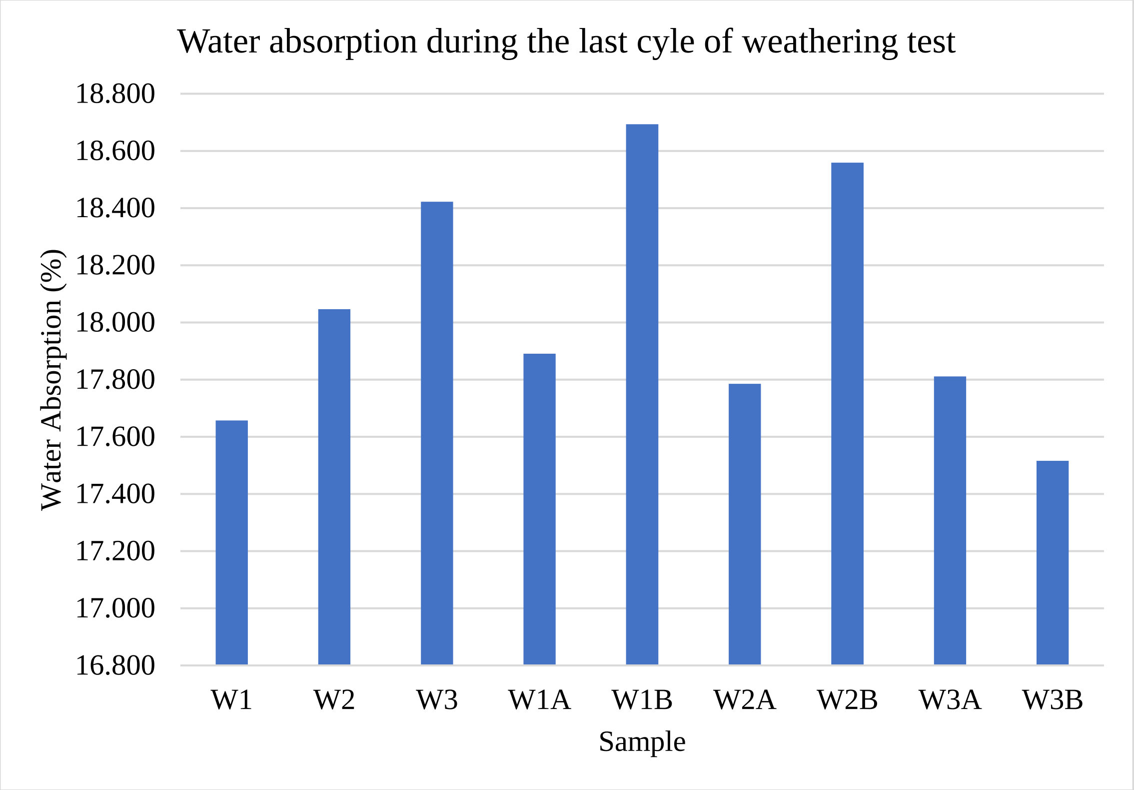


Figure 20 Water absorption during last cycle of weathering test

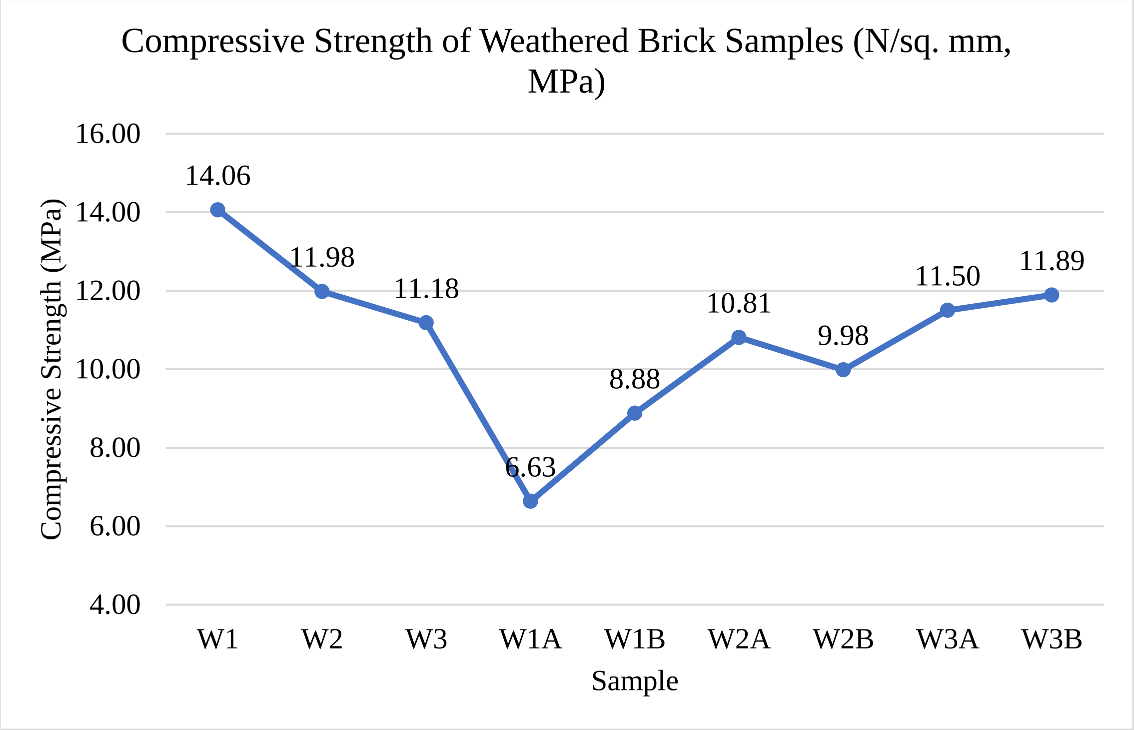


Figure 21 Compressive strength of weathered samples

The chart presented in Figure 21 provides a comprehensive overview of the compressive strength exhibited by all samples following twelve cycles of the weathering test. The calculated average compressive strength stood at 10.77 MPa, placing the CEBs within the classification of Class A as per the Standard Norms and Specifications for CSEB Blocks (Shrestha, 2012). It is noteworthy that each individual sample aligns with the Class A categorization even after enduring twelve cycles of the rigorous weathering test.

Upon closer examination, it becomes evident that the sample with the highest mass loss experienced the most significant negative impact on compressive strength. This observation underscores the direct correlation between extreme weathering, encountered under diverse climatic conditions, and the resultant reduction in the strength of the CEBs. The findings from this analysis contribute valuable insights into the material’s resilience and durability when subjected to prolonged exposure to challenging environmental factors. This understanding is pivotal for informing construction practices and ensuring the longevity and reliability of structures built with CEBs.

CHAPTER 5 CONCLUSIONS AND RECOMMENDATIONS

This research endeavored to systematically investigate the effects of prolonged immersion periods on the compressive strength and fracture characteristics of CEBs. The experimental study provided valuable insights into the structural performance of CEBs when subjected to extended moisture exposure, simulating real-world environmental conditions.

The results demonstrate that under immersion, the compressive strength of CEBs initially improved up to 16 days, followed by a gradual deterioration with increased immersion time. Both full-sized and half-bat CEB samples exhibited similar strength gain and loss patterns, affirming the comparable behavior of the material despite variations in size. While the initial strength enhancement can be attributed to cement hydration, the subsequent decline indicates potential deterioration of the soil binder matrix. Nevertheless, the peak compressive strength attained exceeded the minimum strength requirements specified in relevant standards.

Analysis of the failure patterns revealed typical axial splitting along the faces initially, transitioning to compound failures across the block length at prolonged immersion periods. This substantiates the weakening of internal structure over time when exposed to moisture. The findings demonstrate the necessity of providing adequate protection to CEB structures in wet climates to avoid strength reductions from weathering.

The results of accelerated weathering tests validated the durability of the CEBs, with limited mass loss and marginal increase in water absorption even after 12 wet-dry cycles. This performance surpasses minimum stipulated requirements, confirming the excellent durability characteristics of the tested CEBs.

Overall, the study successfully determined the relationship between moisture exposure, density, compressive strength, and fracture behavior of compressed earth blocks manufactured with stabilization. It provides a systematic framework for evaluating the long-term performance of CEBs, facilitating informed material selection and structural design. The research broadly contributes to the knowledge base on stabilized earthen construction, promoting its adoption in sustainable building practices.

To summarize, the key conclusions are:

- Prolonged moisture exposure causes initial improvement followed by gradual decline in CEB compressive strength. Adequate protection against weathering is recommended.
- Size variations do not significantly impact the strength response and fracture characteristics of CEBs under immersion.
- The manufactured CEBs demonstrate excellent durability under accelerated weathering, with minimal mass loss and water absorption.
- Relationships were established between water absorption and density, immersion period and strength, and fracture behavior, providing insights into long-term CEB performance.
- Outcomes validate the suitability of properly stabilized CEBs for durable, eco-friendly construction and advance earthen building knowledge.

The research provides a framework for evaluating stabilized earthen materials while also highlighting the need for developing suitable protection techniques and optimized manufacturing practices to harness the full potential of CEBs. Testing with diverse stabilization methods, soil types, and environmental conditions can build on these findings. It is hoped that the conclusions from this experimental study will promote the adoption of sustainable CEB construction, inspiring future work to fully characterize stabilized earth materials and transform earthen architecture in Nepal.

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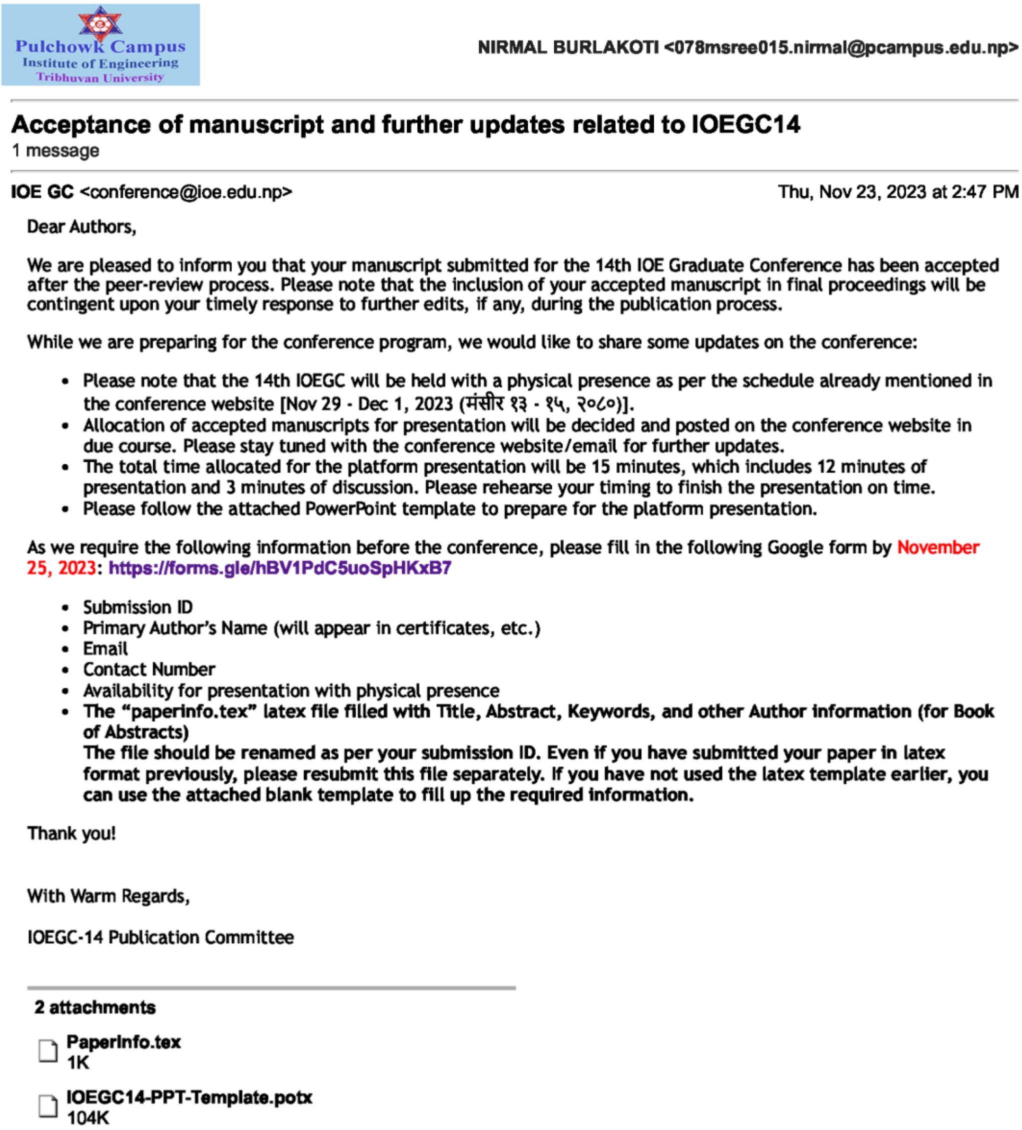

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Acceptance of manuscript and further updates related to IOEGC14

1 message

IOE GC <conference@ioe.edu.np> Thu, Nov 23, 2023 at 2:47 PM

Dear Authors,

We are pleased to inform you that your manuscript submitted for the 14th IOE Graduate Conference has been accepted after the peer-review process. Please note that the inclusion of your accepted manuscript in final proceedings will be contingent upon your timely response to further edits, if any, during the publication process.

While we are preparing for the conference program, we would like to share some updates on the conference:

- Please note that the 14th IOEGC will be held with a physical presence as per the schedule already mentioned in the conference website [Nov 29 - Dec 1, 2023 (मंसीर १३ - १५, २०८०)].
- Allocation of accepted manuscripts for presentation will be decided and posted on the conference website in due course. Please stay tuned with the conference website/email for further updates.
- The total time allocated for the platform presentation will be 15 minutes, which includes 12 minutes of presentation and 3 minutes of discussion. Please rehearse your timing to finish the presentation on time.
- Please follow the attached PowerPoint template to prepare for the platform presentation.

As we require the following information before the conference, please fill in the following Google form by November 25, 2023: https://forms.gle/hBV1PdC5uoSpHKxB7

- Submission ID
- Primary Author's Name (will appear in certificates, etc.)
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- Contact Number
- Availability for presentation with physical presence
- **The "paperinfo.tex" latex file filled with Title, Abstract, Keywords, and other Author information (for Book of Abstracts)**
  The file should be renamed as per your submission ID. Even if you have submitted your paper in latex format previously, please resubmit this file separately. If you have not used the latex template earlier, you can use the attached blank template to fill up the required information.

Thank you!

With Warm Regards,

IOEGC-14 Publication Committee

2 attachments

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APPENDIX A: EXPERIMENT DATA

Table 2 Water absorption test data

Sample No.	Length (cm)	Breadth (cm)	Height (cm)	Air Oven Dried Weight (kg)	24 hr Soaking Weight (kg)
1	22.8	10.9	5.3	2.454	2.626
2	23.0	10.9	5.6	2.534	2.856
3	22.7	10.9	5.6	2.502	2.762
4	22.6	10.9	5.6	2.517	2.746
5	22.9	11.0	5.7	2.750	2.932
6	22.7	11.0	5.6	2.648	2.830
7	22.8	10.9	5.7	2.648	2.858
8	22.8	10.9	5.6	2.543	2.848
9	22.7	11.0	5.5	2.445	2.770
10	22.8	10.9	5.7	2.575	2.878
1A	11.4	10.9	5.6	1.379	1.474
1B	11.1	11.0	5.6	1.322	1.426
2A	11.3	10.9	5.4	1.188	1.356
2B	11.4	11.0	5.4	1.190	1.354
3A	11.0	10.9	5.6	1.278	1.406
3B	11.3	10.9	5.6	1.294	1.432
4A	11.4	10.9	5.6	1.304	1.456
4B	11.1	11.0	5.6	1.285	1.406
5A	11.2	10.9	5.2	1.195	1.338
5B	11.2	11.0	5.3	1.210	1.338
6A	11.3	10.9	5.6	1.292	1.436
6B	11.3	10.8	5.5	1.293	1.426

Sample No.	Length (cm)	Breadth (cm)	Height (cm)	Air Oven Dried Weight (kg)	24 hr Soaking Weight (kg)
7A	11.2	10.8	5.5	1.256	1.384
7B	11.0	10.8	5.6	1.225	1.370
8A	11.1	10.9	5.5	1.294	1.384
8B	11.4	10.9	5.6	1.313	1.418
9A	11.1	10.9	5.5	1.289	1.412
9B	11.2	10.9	5.6	1.315	1.417
10A	11.2	10.9	5.5	1.317	1.410
10B	11.3	10.9	5.5	1.327	1.426

Table 3 Water absorption and compressive strength data

Sample No.	Area (sq. cm)	Volume (cu. cm)	Density (kg/cu. m)	24 hr Water Absorption (%)	Compressive Strength (N/sq. mm, MPa)
1	248.92	1310.96	1871.92	7.01	6.83
2	250.70	1395.56	1815.75	12.71	9.97
3	247.43	1377.36	1816.52	10.39	9.30
4	246.70	1373.32	1832.79	9.10	11.76
5	252.66	1440.18	1909.48	6.62	13.06
6	249.31	1404.44	1885.45	6.87	13.64
7	248.88	1410.34	1877.56	7.93	12.86
8	248.52	1383.43	1838.19	11.99	12.07
9	249.31	1362.89	1793.98	13.29	11.63
10	248.16	1406.22	1831.15	11.77	11.28
1A	124.28	695.94	1981.48	6.89	9.66
1B	121.36	679.64	1945.14	7.87	8.24

Sample No.	Area (sq. cm)	Volume (cu. cm)	Density (kg/cu. m)	24 hr Water Absorption (%)	Compressive Strength (N/sq. mm, MPa)
2A	123.17	661.01	1797.24	14.14	8.93
2B	124.65	673.13	1767.85	13.78	8.02
3A	120.26	673.47	1897.62	10.02	11.64
3B	122.79	691.74	1870.66	10.66	10.59
4A	125.00	695.86	1873.95	11.66	12.00
4B	121.73	681.71	1884.97	9.42	9.86
5A	122.08	634.82	1882.44	11.97	12.29
5B	122.46	644.96	1876.08	10.58	9.80
6A	122.43	685.61	1884.44	11.15	11.44
6B	122.42	677.37	1908.85	10.29	10.62
7A	120.97	669.38	1876.36	10.19	9.92
7B	118.79	661.28	1852.48	11.84	8.42
8A	120.98	661.37	1956.55	6.96	8.27
8B	123.88	689.60	1904.01	8.00	9.69
9A	120.63	667.47	1931.18	9.54	8.29
9B	122.44	685.68	1917.80	7.76	9.80
10A	121.72	673.50	1955.46	7.06	9.04
10B	123.17	677.44	1958.86	7.46	9.74

Table 4 Mass loss during weathering test cycles

Sample	W1	W2	W3	W1A	W1B	W2A	W2B	W3A	W3B
Cycle 1-2	-0.158	-0.155	-0.183	-0.01	-0.026	-0.031	-0.033	-0.051	-0.02
Cycle 2-3	0.064	0.09	0.121	0.011	0.029	0.025	0.037	0.049	0.019
Cycle 3-4	0.074	0.047	0.051	0	-0.002	0.007	-0.003	0.001	0.003

Sample	W1	W2	W3	W1A	W1B	W2A	W2B	W3A	W3B
Cycle 4-5	-0.036	-0.021	-0.036	-0.012	-0.007	-0.015	-0.004	-0.032	-0.027
Cycle 5-6	-0.098	-0.001	-0.063	-0.027	-0.024	-0.01	-0.011	0.025	-0.017
Cycle 6-7	0.131	0.03	0.098	0.047	0.038	0.029	0.021	0.008	0.045
Cycle 7-8	-0.046	-0.009	-0.084	-0.004	-0.023	-0.008	-0.01	-0.005	-0.011
Cycle 8-9	0.015	-0.065	0.083	0.013	0.025	-0.006	0.005	0.001	0.001
Cycle 9-10	-0.017	-0.102	-0.174	-0.018	-0.068	-0.006	-0.104	-0.07	-0.053
Cycle 10-11	0.015	0.17	0.173	0.023	0.07	0.002	0.094	0.07	0.055
Cycle 11-12	0.062	0.022	0.022	0.005	0.017	0.026	0.026	0.006	0.009
Cycle 1-12	0.006	0.006	0.008	0.028	0.029	0.013	0.018	0.002	0.004
Cycle 1-12 (%)	0.26%	0.26%	0.35%	2.57%	2.56%	1.08%	1.39%	0.19%	0.36%

Table 5 Water absorption during weathering test cycles

Sample	W1	W2	W3	W1A	W1B	W2A	W2B	W3A	W3B
Cycle 1	16.97	17.83	18.40	17.61	17.33	16.43	17.99	16.11	16.74
Cycle 2	10.66	11.06	9.73	16.55	14.95	14.16	14.98	12.47	15.22
Cycle 3	13.46	14.87	15.15	17.54	17.82	16.43	18.05	17.38	16.99
Cycle 4	16.40	17.27	17.80	17.45	17.52	16.78	17.85	17.39	17.22
Cycle 5	15.23	16.20	15.96	15.99	16.89	15.50	17.57	14.29	14.63
Cycle 6	10.60	16.07	12.82	12.77	14.04	14.56	16.35	16.64	12.79
Cycle 7	16.50	17.46	17.53	17.39	17.72	17.25	18.01	17.41	17.23
Cycle 8	14.23	16.67	13.40	16.59	15.10	16.31	16.95	16.77	16.09
Cycle 9	14.44	13.76	17.35	17.26	17.40	15.73	17.32	16.79	16.28
Cycle 10	13.80	13.25	14.67	14.77	16.48	14.84	17.18	16.64	15.55
Cycle 11	14.39	16.57	17.13	17.15	16.71	15.19	16.12	16.61	16.40
Cycle 12	17.66	18.05	18.42	17.89	18.69	17.79	18.56	17.81	17.52

Table 6 Compressive strength of weathered samples

Sample No.	Compressive Strength (N/sq. mm)
W1	14.06
W2	11.98
W3	11.18
W1A	6.63
W1B	8.88
W2A	10.81
W2B	9.98
W3A	11.50
W3B	11.89

APPENDIX B: EXPERIMENT PHOTOS

Figure 22 Soil mixture

Figure 23 Air oven

Figure 24 Clipper (Brick cutter)

Figure 25 Curing tank with controlled temperature

Nepal Bureau of Standards and Metrology
Scientific Metrology Laboratory
Calibrated for: Pulchowk Campus, Lalitpur
Certificate number: CCFM-196|288|1179
Instrument: Compressive Strength Testing Mach
Date of calibration: April 4, 2022
Recommended date for next calibration: April 3, 2023
Calibrated by:

Figure 26 Compressive strength testing machine

Figure 28 Preparation of specimen

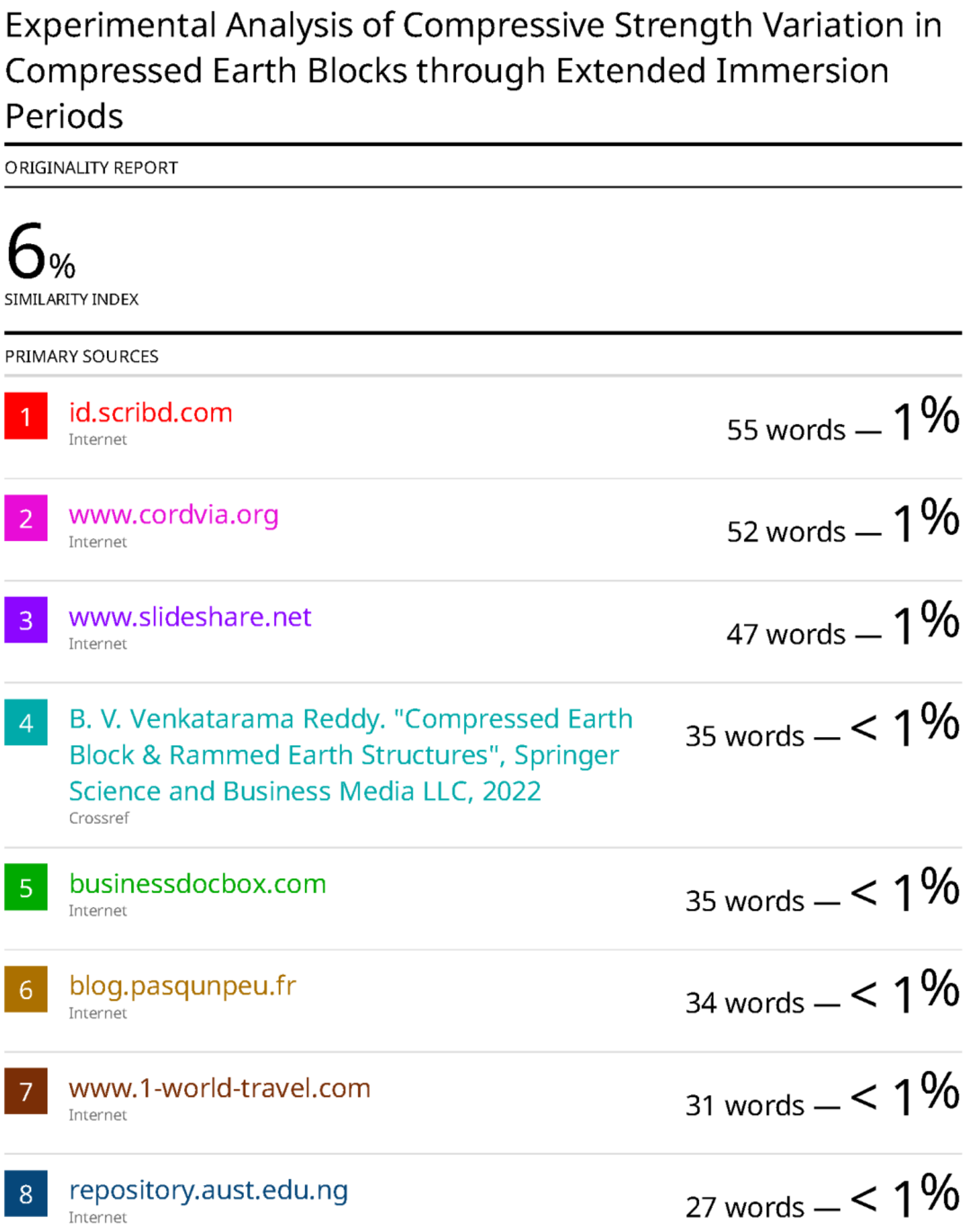
Figure 27 Compressive testing of brick sample

Figure 29 Weathering action

Figure 30 Failure of sample along center

Figure 31 Failure of sample along face

APPENDIX C: PLAGIARISM REPORT



Experimental Analysis of Compressive Strength Variation in Compressed Earth Blocks through Extended Immersion Periods

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APPENDIX D: RESEARCH PAPER

IOE Graduate Conference
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Comparison of Compressive Strength of Compressed Earth Blocks under Extended Immersion Periods

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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

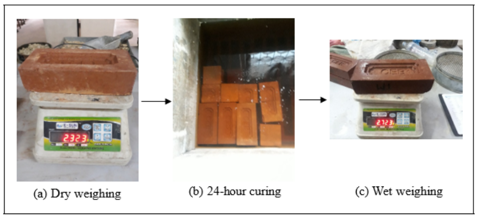
2.3 Physical Properties

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.

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

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



(a) Dry weighing (b) 24-hour curing (c) Wet weighing

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.

---

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

Figure 4: Compressive strength testing

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

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

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.

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

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.

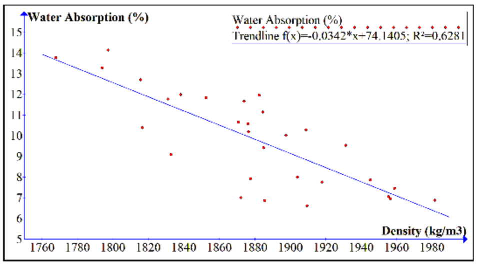


Figure 5: Density versus Water Absorption

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.

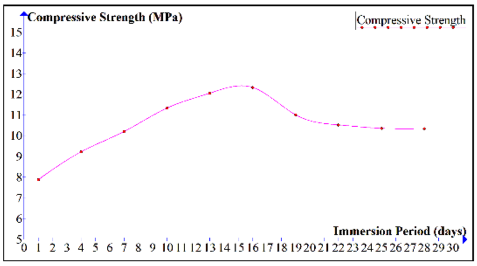


Figure 6: Wet compressive strength versus Immersion Periods

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.

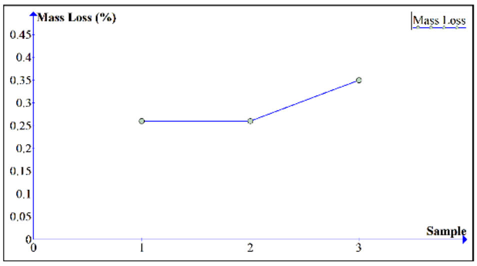


Figure 7: Mass loss in % of each sample

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.

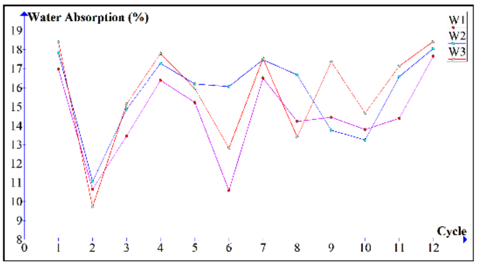


Figure 8: Water absorption in different cycles

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.

Acknowledgments

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