
AN INVESTIGATION INTO THE PROPERTIES OF COMPRESSED STABILIZED EARTH BRICKS WITH CEMENT FOR COST-EFFECTIVE SUSTAINABLE EARTH BUILDING MATERIAL

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ABSTRACT

New building masonry materials are being investigated as a result of Nigeria's lack of reasonably priced and accessible homes. Conventionally employed for mainstream masonry wall building, fired clay masonry bricks suffer from excessive energy consumption and carbon dioxide emissions, as well as other associated environmental issues brought on by the rising cost of energy. These issues might be resolved by using stabilized compressed earth bricks with Cement in masonry building. In this study, experimental testing on cement-containing compressed stabilized earth bricks (CSEBs) is reported, and the results are thoroughly discussed. The purpose of the tests was to compare the performance of CSEBs to that of traditional construction materials and assess the material's primary attributes, such as compressive strength, water permeability, durability, and dimensional stability. Compressed Stabilized Earth Brick (CSEB) offers the perspective of energy efficiency, cost reduction, and environmentally benign construction materials, contributing to sustainable development overall, in light of the increased awareness of sustainable building materials and environmental issues. When compared to other materials like concrete blocks or regular burnt brick, it came out that the qualities of CSEB could be easily compared.

Keywords: Compressive strength; absorption and permeability; Compressed Stabilized Earth Bricks.

1.0 Introduction

Various studies in developing nations have focused on exploring alternative materials for constructing affordable housing. Currently, the rate of construction in emerging nations is generally insufficient to meet even 10% of the annual net increase in population. This shortfall is partly due to the scarcity and high costs of traditional building materials. Efforts are being made to develop low-cost, durable, and energy-efficient building materials, enabling the construction of sustainable structures at a reasonable cost, especially as the housing shortage worsens (S. W. Baba *et al.*, 2013). Given the increasing global emphasis on reducing energy consumption, earth construction emerges as a particularly cost-effective and energy-efficient option. It possesses excellent thermal properties and requires low energy input for production, making it environmentally friendly and safe (Nagaraja A. *et al.*, 2018).

However, one of the most and often used building materials for homes is Compressed stabilize earth bricks, because of its many beneficial qualities, including its resilience to weathering, reasonable price, strong sound and heat insulation, appropriate fire protection, and appealing look (S. Deboucha, and R. Hashim 2011). This work proposes the use of cement to improve and develop bricks, which are made of earth stabilized with cement and compressed in a fabricated mold as a means to positively impact on the shelter conditions of poor countries of the developing world.

Compressed stabilized earthen brick when the earthen building material is stabilized with agents like cement in particular proportions and uses mechanical compaction to generate a compressed earthen unit of specific regular shape and dimension, it significantly eliminate the previous drawbacks, the soil can be stabilized with a chemical material like cement (Ali N *et al.* 2016). The shortcomings principally are low mechanical characteristics, unsatisfactory resistance to weathering and liability to volume change especially in the case of clay. These disadvantages can be improved to make the material compatible with desired application in construction by combined chemical and mechanical action technically known as stabilization (S. Krishnaiah, and P. S. Reddy, 2008; S. Deboucha, and R. Hashim, 2011; O. F. Job, 1998; E. E. J. Kamang, 1998)

1.1 Background of the Study

The global demand for affordable and sustainable housing continues to grow, particularly in developing countries where rapid population increases outpace the supply of adequate housing. Conventional building materials, such as concrete and fired bricks, have become increasingly expensive and scarce, creating barriers to addressing the housing deficit. This has spurred research into alternative construction materials that are cost-effective, environmentally sustainable, and locally available. Among these, compressed stabilized earth bricks (CSEBs) have garnered significant attention due to their potential to offer a sustainable solution to housing challenges.

Compressed stabilized earth bricks are produced by combining soil with stabilizing agents, such as cement, and compacting the mixture into uniform bricks using mechanical pressure. These bricks possess several advantageous properties, including high compressive strength, resistance to weathering, good thermal insulation, and low embodied energy compared to traditional building materials. Additionally, they can be fabricated using local resources, which reduces transportation costs and environmental impact, further enhancing their appeal in regions with limited access to industrial construction materials.

However, while CSEBs exhibit significant potential, certain limitations hinder their broader application in construction. The primary challenges include susceptibility to volume changes in clay-rich soils, inadequate mechanical properties, and poor resistance to prolonged weathering. Stabilization with cement has emerged as a promising technique to address these drawbacks. Cement improves the compressive strength, durability, and dimensional stability of CSEBs, making them suitable for various construction applications. Furthermore, cement-stabilized earth bricks align with the global push for energy-efficient and environmentally friendly construction methods, as they require minimal energy for production and exhibit excellent thermal performance, reducing the need for artificial cooling or heating in buildings.

This study investigates the properties of compressed stabilized earth bricks with cement, focusing on their potential as cost-effective and sustainable building materials. By examining their mechanical, thermal, and durability properties, this research aims to provide insights into optimizing their composition and manufacturing processes. The findings could have significant implications for the construction industry, particularly in developing regions, by promoting the adoption of sustainable practices that address housing needs while minimizing environmental impact.

1.2 Statement of the Problem

The construction industry in developing countries faces significant challenges in meeting the demand for affordable and sustainable housing. Traditional building materials, such as concrete and fired bricks, are becoming increasingly expensive and scarce, exacerbating the housing deficit. This situation leaves many low-income families unable to access safe and adequate shelter, perpetuating social and economic inequalities. Compressed stabilized earth bricks (CSEBs) have emerged as a potential solution to address these issues due to their cost-effectiveness, environmental sustainability, and use of locally available materials. However, despite their advantages, CSEBs suffer from critical limitations, including low mechanical strength, poor resistance to weathering, and susceptibility to volume changes, especially in clay-rich soils. These shortcomings restrict their widespread adoption in modern construction, particularly in regions with harsh environmental conditions.

Stabilizing CSEBs with cement has been proposed as a means to overcome these limitations. While research has demonstrated improvements in their properties, there is insufficient data on the optimal mix proportions, durability, and overall performance of cement-stabilized earth bricks in varying conditions. Additionally, questions remain about their cost-effectiveness and long-term sustainability compared to conventional building materials.

This study seeks to address these gaps by investigating the properties of compressed stabilized earth bricks with cement. The research aims to provide a deeper understanding of how cement stabilization influences the mechanical, thermal, and durability properties of CSEBs, with the ultimate goal of developing a cost-effective and sustainable alternative to traditional building materials.

1.3 Objectives of the Study

1.3.1 General Objective

To investigate the properties of compressed stabilized earth bricks (CSEBs) with cement as a sustainable and cost-effective building material

1.3.2 Specific Objectives

- I. To evaluate the compressive strength of cement-stabilized earth bricks to determine their structural viability.
- II. To examine the durability of CSEBs by assessing their resistance to weathering and other environmental factors.
- III. To analyze the water absorption and permeability characteristics of CSEBs to establish their suitability for various construction applications.
- IV. To propose applicable and user-friendly testing standards for evaluating the performance of CSEBs stabilized with lime.

1.4 Research Questions

What are the mechanical properties of Compressed Stabilized Earth Bricks (CSEBs) when stabilized with cement?

How does cement stabilization affect the compressive strength of CSEBs?

What is the water permeability of CSEBs, and how does cement content influence this property?

How durable are CSEBs under varying environmental conditions, such as exposure to moisture and temperature changes?

What are the dimensional stability characteristics of CSEBs under different climatic conditions?

How do CSEBs compare with conventional building materials (e.g., fired clay bricks, concrete) in terms of strength, durability, and cost-effectiveness?

What are the most suitable and practical testing methods for assessing the performance of CSEBs in developing regions?

1.5 Justification of the Study

This study is highly relevant to the field of sustainable construction, particularly in addressing the pressing need for affordable housing solutions in developing regions. The use of Compressed Stabilized Earth Bricks (CSEBs) presents a promising alternative to conventional building materials, offering numerous advantages such as cost-effectiveness, environmental sustainability, and low-energy production methods.

1.5.1 Relevance to Sustainable Construction

CSEBs are composed of locally available earth materials that are stabilized with cement, making them an eco-friendly option. By utilizing materials that are abundant and require minimal transportation, CSEBs significantly reduce the carbon footprint associated with construction. Furthermore, their excellent thermal properties contribute to energy-efficient buildings, reducing the need for artificial heating and cooling. The use of CSEBs aligns with

sustainable construction principles by minimizing waste and encouraging the reuse of natural resources, thus supporting long-term environmental sustainability.

1.5.2 Economic Benefits for Developing Regions

In developing countries, the high cost of traditional building materials such as fired clay bricks and concrete is a significant barrier to affordable housing. CSEBs offer an affordable alternative by utilizing locally sourced soil, reducing material and transportation costs. The cement stabilization improves the bricks' durability and strength, ensuring that they are viable for long-term use in construction. This cost-effective approach can make housing more accessible to low-income populations, contributing to the economic development of these regions. Additionally, the use of CSEBs can create local employment opportunities in the production and construction processes, further stimulating economic growth.

This study contributes to the body of knowledge by providing an in-depth analysis of the properties and potential of CSEBs, highlighting their suitability for widespread adoption in sustainable construction practices, particularly in developing regions.

2.0 Literature Review

2.1 Introduction

The construction industry continues to seek innovative and sustainable solutions to address the rising demand for affordable housing, particularly in developing countries. Among the various approaches explored, compressed stabilized earth bricks (CSEBs) have emerged as a promising alternative to traditional building materials. Their cost-effectiveness, use of locally available resources, and potential for environmental sustainability make them particularly appealing for low-income housing and infrastructure development.

The purpose of this chapter is to review the existing literature relevant to the properties and applications of CSEBs, with a particular focus on the role of cement stabilization in enhancing their performance. The chapter examines the fundamental properties of CSEBs, the impact of various factors on their performance, and the standards and testing methods used to evaluate their suitability for construction. Furthermore, the review highlights the advantages and limitations of CSEBs compared to conventional building materials and identifies gaps in the existing body of knowledge.

This literature review serves as a foundation for the study by contextualizing the research problem, summarizing current knowledge, and justifying the need for further investigation into the properties of cement-stabilized earth bricks for sustainable and cost-effective construction.

2.2 Overview of Compressed Stabilized Earth Bricks (CSEBs)

Compressed Stabilized Earth Bricks (CSEBs) are a form of construction material made by stabilizing soil with binding agents such as cement or lime and compressing the mixture into a uniform shape using mechanical pressure. These bricks represent an evolution of traditional earth construction methods, combining modern technology with the sustainable use of natural resources.

CSEBs offer several advantages, including cost-effectiveness, low environmental impact, and the ability to use locally available materials, reducing transportation costs and energy consumption. They are particularly valued in regions with limited access to conventional building materials, as they can be manufactured onsite with relatively simple tools and processes.

The stabilization process enhances the mechanical properties of earth bricks, improving their compressive strength, resistance to weathering, and durability. Cement, as a commonly used stabilizing agent, is particularly effective in addressing the inherent weaknesses of raw earth, such as its susceptibility to moisture and low tensile strength. The compression process ensures a consistent density, which contributes to the uniformity and quality of the bricks.

CSEBs have gained recognition for their excellent thermal insulation properties, which contribute to energy-efficient buildings by minimizing the need for artificial cooling or heating. These attributes, coupled with their aesthetic appeal and versatility, have positioned CSEBs as a viable solution for sustainable construction in both urban and rural settings.

2.3 Properties of Compressed Stabilized Earth Bricks (CSEBs)

Compressed Stabilized Earth Bricks (CSEBs) possess unique properties that make them suitable for sustainable construction. Their performance characteristics are influenced by factors such as soil composition, stabilizing agents, and compaction techniques. Key properties of CSEBs include:

2.3.1 Mechanical Properties

CSEBs are known for their compressive strength, which is significantly enhanced by stabilization with cement. This makes them structurally reliable for load-bearing applications in buildings.

2.3.2 Durability

Cement stabilization improves the resistance of CSEBs to weathering and erosion, increasing their lifespan, even under harsh environmental conditions.

2.3.3 Thermal Insulation

CSEBs exhibit excellent thermal properties, helping to regulate indoor temperatures and reduce reliance on artificial heating or cooling systems.

2.3.4 Water Resistance

Stabilized earth bricks demonstrate lower water absorption and improved resistance to moisture-related damage, making them suitable for various climates.

2.3.5 Eco-Friendliness

CSEBs require minimal energy for production and utilize locally available materials, reducing their environmental impact compared to conventional building materials.

2.4 Cement Stabilization in Earth Bricks

Cement stabilization is a widely used technique to enhance the properties of earth bricks by addressing their natural weaknesses, such as low strength and susceptibility to moisture. When added to soil in appropriate proportions, cement acts as a binding agent, improving the mechanical properties and durability of the bricks.

The addition of cement increases the compressive strength of earth bricks, making them suitable for load-bearing construction. It also reduces water absorption and enhances resistance to weathering, ensuring greater durability in various environmental conditions. Cement stabilization minimizes volume changes in clay-rich soils, reducing the risk of cracking and deformation.

This method is particularly advantageous in developing regions due to its simplicity and the widespread availability of cement. It enables the production of uniform, high-quality bricks that meet the demands of modern construction while maintaining the sustainability benefits of earth-based materials.

2.5 Factors Affecting the Performance of CSEBs

The performance of Compressed Stabilized Earth Bricks (CSEBs) depends on several factors that influence their strength, durability, and overall suitability for construction:

2.5.1 Soil Composition

The type and proportion of soil components, particularly clay and sand, significantly impact the brick's stability and mechanical properties. An optimal soil mix is crucial for achieving desirable results.

2.5.2 Stabilizing Agent

The type and amount of stabilizer, such as cement, determine the brick's strength and resistance to environmental factors. Higher cement content generally improves performance but increases costs.

2.5.3 Compaction Pressure

Adequate compaction during production ensures uniform density, enhancing the structural integrity and durability of the bricks.

2.5.4 Curing Conditions

Proper curing, including adequate moisture and time, is essential for the hydration of cement and the development of the brick's strength.

2.5.5 Environmental Factors

Exposure to moisture, temperature variations, and weather conditions can affect the long-term performance of CSEBs, making proper stabilization and sealing critical.

2.6 Standards and Testing Methods for CSEBs

The assessment of Compressed Stabilized Earth Bricks (CSEBs) requires established standards for evaluating key properties such as strength, durability, and water permeability. Internationally, several standards have been developed to guide the testing of earth-based materials, including the ASTM and ISO frameworks. These standards generally focus on compressive strength, moisture absorption, and resistance to weathering (Bush, 1984; Easton, 1996).

For strength testing, the compressive strength of CSEBs is typically evaluated by applying load until failure, while durability is assessed by subjecting the bricks to freeze-thaw cycles or prolonged moisture exposure. Water permeability tests are also essential, with methods such as the capillary rise test or water absorption test used to determine the material's resistance to moisture infiltration.

However, many of these standards may not be entirely suitable for developing regions, where soil types and climatic conditions often differ from those covered by international protocols. Local variations in materials, such as soil composition and cement content, can result in significantly different performance characteristics, making standardized testing less effective (Alagbe, 2010; Alitheia Capital, 2012).

Furthermore, there is a notable gap in the testing protocols for CSEBs, particularly regarding the long-term performance under different environmental conditions, such as varying humidity, temperature, and rainfall. Additionally, the lack of standardized procedures for field testing and the limited research on the effectiveness of cement stabilization across diverse soil types are areas that need further attention.

In summary, while existing standards for testing CSEBs provide a useful framework, there is a need to adapt and expand these protocols to better suit the diverse conditions found in developing regions. Addressing these gaps was crucial for optimizing the use of CSEBs in sustainable construction.

2.7 Comparative Analysis with Conventional Building Materials

Compressed Stabilized Earth Bricks (CSEBs) offer a cost-effective and sustainable alternative to conventional building materials such as concrete blocks, bricks, and cement. Unlike concrete, which requires high energy inputs and contributes significantly to carbon emissions, CSEBs are made from locally available soil and require less energy for production, making them an environmentally friendly choice (Bush, 1984; Easton, 1996).

In terms of strength, CSEBs, when stabilized with cement, can match or even exceed the performance of traditional clay bricks in certain applications. However, they generally have lower compressive strength compared to concrete blocks, making them more suitable for non-load bearing or low-rise structures (Adedeji et al., 2011). Additionally, CSEBs provide better thermal insulation than conventional materials, offering natural temperature regulation and reducing the need for air conditioning in hot climates (Alagbe, 2010).

While CSEBs are advantageous in terms of cost and sustainability, their primary limitation lies in their susceptibility to moisture damage and the need for proper stabilization techniques. Concrete and conventional brick materials often outperform CSEBs in moisture resistance and long-term durability without extensive treatment (Alitheia Capital, 2012).

Overall, CSEBs present a promising alternative to conventional building materials, particularly in areas with abundant soil resources and where sustainability is a priority. However, further improvements in stabilization and testing methods are needed to make them a more reliable choice for all construction applications.

2.7 Literature Review

Soil stabilization is a critical process aimed at improving the engineering properties of soil to make it more suitable for construction purposes. According to Krishnaiah and Reddy (2008), stabilization involves modifying the soil's attributes to enhance its performance, primarily in terms of strength, durability, and stability. The key factors influencing soil stabilization include compaction, cement content, mixing technique, and the type of soil being used, with soil composition being the most significant variable (Krishnaiah & Reddy, 2008).

One of the most common types of soil used in construction, especially in tropical regions, is lateritic soil. Comprising approximately 33% of the intertropical zone (Tardy, 1992), lateritic soils are abundant and widely used as raw materials for building materials and subsoil in road construction (Nzeukou Nzeugang et al., 2013; Tsozué et al., 2017; Kagonbé et al., 2020). These soils are particularly suitable for applications like adobe and bricks due to their rich iron and aluminum content, which provide good bonding properties when stabilized (Attah-Okine, 1995; Kassogue *et al.*, 2002). In the tropics, where the climate includes heavy rainfall during the wet season and a humid dry season, lateritic soils form as a result of intense weathering, which impacts their chemical composition and morphological characteristics (Holland, 1903).

However, in their natural state, laterite soils lack sufficient strength, dimensional stability, and durability for use in construction. To address these deficiencies, various stabilization techniques have been developed. Stabilization methods generally involve the incorporation of chemical or mechanical agents, such as cement, lime, or mechanical compaction, to enhance the soil's properties (Elahi *et al.*, 2021). Mechanical stabilization techniques focus on altering the soil's structure through compaction, which increases its density and reduces permeability, thereby improving its load-bearing capacity.

The addition of cement as a stabilizing agent significantly enhances the compressive strength, water resistance, and durability of earth-based materials like compressed stabilized earth bricks (CSEBs). Cement stabilization improves the soil's ability to withstand weathering and environmental changes, making it more suitable for use in construction in regions with variable climatic conditions. Moreover, proper stabilization helps prevent shrinkage and swelling, which are common issues with untreated soils, especially in clay-rich compositions.

Thus, the process of soil stabilization, particularly with cement, is fundamental in transforming locally available, naturally occurring materials into viable, durable construction products. This approach not only reduces the dependency on expensive traditional materials but also promotes sustainability by utilizing locally sourced, low-impact resources.

2.8 Review of Related Literature

The literature on Compressed Stabilized Earth Bricks (CSEBs) highlights the growing importance of sustainable and cost-effective housing solutions, particularly in developing countries where affordable construction materials are in high demand. Several studies have explored the feasibility, benefits, and challenges of using CSEBs, particularly when stabilized with cement.

Adam and Agib (2001) and Alagbe (2010) discuss the role of CSEBs in promoting low-cost housing, noting that the use of locally available materials, such as laterite soils, significantly reduces building costs. In Nigeria, for example, CSEBs are considered a viable solution for

addressing the country's housing deficit, particularly in rural areas and low-income urban settings (Adegbehingbe & Fadamiro, 2006; Daramola, 2006). The environmental benefits of using earth-based materials, combined with the durability and thermal efficiency of CSEBs, have been widely acknowledged in the literature (Bush, 1984; Easton, 1996). These properties make CSEBs an ideal material for sustainable construction in tropical climates, where insulation and moisture resistance are critical.

However, while the use of CSEBs offers promising solutions, there are notable challenges related to the performance of these bricks, especially regarding strength and durability. Adedeji et al. (2011) and Aluko (2002) emphasize that while cement stabilization improves the compressive strength and resistance to weathering, variations in soil composition and cement content can significantly affect the final product's quality. A lack of standardized testing methods for CSEBs further complicates the situation, as highlighted by Ademiluyi (2010), who stresses the need for well-defined criteria for evaluating the performance of these materials.

One major gap identified in the existing literature is the insufficient empirical research on the long-term durability of cement-stabilized earth bricks under different climatic conditions. Although some studies (such as those by Tardy, 1992; and Ajanlekoko, 2001) highlight the potential of CSEBs for sustainable housing, further investigation is needed to optimize the stabilization process and identify the most effective mix ratios for various environmental settings. Additionally, there is a call for developing universal standards and testing procedures for CSEBs, which would ensure their widespread adoption and improve their performance across different regions (Alitheia Capital, 2012; Dogan, 2009).

This review of related literature underscores the importance of continuing research into CSEBs, focusing on optimizing stabilization techniques, testing standards, and the integration of local materials to improve their application in low-cost housing projects globally.

3.0 Methodology

3.1 Introduction

This chapter outlines the methodology employed in the investigation of the properties of Compressed Stabilized Earth Bricks (CSEBs) with cement, with a focus on assessing their strength, longevity, water transmission characteristics, and developing suitable testing standards. This chapter presents the approach to data collection, the experimental procedures, and the methods used to analyze the performance of CSEBs in a controlled environment. It also outlines the steps to ensure the reliability and validity of the results.

3.2 Research Design

The research design for this study adopts an experimental and comparative approach, focusing on the systematic investigation of the properties of Compressed Stabilized Earth Bricks (CSEBs) with cement. The primary objective is to assess the strength, durability, water transmission characteristics, and the suitability of existing testing standards for CSEBs. The study involves both laboratory and field experiments to collect relevant data, followed by a comparative analysis with conventional building materials. The research is structured as follows:

3.2.1 Experimental Methodology:

The experimental design consists of controlled laboratory testing where CSEBs are manufactured using varying proportions of soil from (Makurdi) and cement. These bricks were subjected to different testing procedures to evaluate their compressive strength, durability (resistance to weathering and freeze-thaw cycles), and water permeability. The experimental procedure allows for precise control over variables, such as the soil-cement ratio and compaction process, ensuring consistent and replicable results.

3.2.2 Comparative Analysis:

In addition to testing CSEBs, the study compared their performance with conventional building materials, such as cement blocks and clay bricks. This comparison is based on key parameters such as cost-effectiveness, energy efficiency, strength, and durability. The comparative analysis was crucial in establishing the potential of CSEBs as an alternative to conventional materials, particularly in developing regions where construction costs are high.

3.2.3 Field Testing:

To assess the practical application and long-term performance of CSEBs, field tests were conducted in real-world construction environments. This will involve monitoring the performance of CSEBs in construction projects over time, paying attention to factors like moisture exposure, temperature fluctuations, and overall durability in actual use. Field testing will provide valuable insights into how CSEBs perform outside of laboratory conditions.

3.2.4 Data Collection and Analysis:

Data collection was systematic and include the measurement of compressive strength, permeability, durability, and other relevant properties. Statistical analysis was employed to analyze the data, comparing the results of different mixes of CSEBs and their performance against conventional building materials. This will help identify any significant differences and determine whether CSEBs meet the necessary standards for use in construction.

3.2.5 Development of Testing Standards:

Based on the findings from the laboratory and field tests, the study proposed suitable and user-friendly testing methods for CSEBs, taking into account the unique conditions of developing regions. The aim is to refine existing testing standards or propose new ones that can be easily implemented with available resources and infrastructure.

The research design ensures a comprehensive and practical evaluation of CSEBs, aiming to bridge the gap between laboratory performance and real-world application. By combining experimental testing, comparative analysis, and field observations, this study will provide critical insights into the viability of CSEBs as a sustainable building material.

3.3 Materials and Equipment

This section outlines the materials and equipment used in the study to investigate the properties of Compressed Stabilized Earth Bricks (CSEBs) with cement. The selection of materials and equipment is critical to ensuring accurate results and reproducibility of the experiments.

Materials:

Soil:

Locally sourced soil, primarily lateritic in nature, was used as the base material for the CSEBs. The soil was tested for its particle size distribution, plasticity, and compaction characteristics to ensure its suitability for stabilization. The selection of soil type is crucial since different soil compositions (e.g., clay, silt, and sand) influence the performance of the stabilized bricks.

Cement:

Ordinary Portland Cement (OPC) was used for stabilizing the soil. Various cement contents was tested, with the most commonly used ratio being between 5-10% of the soil weight. The cement will improve the compressive strength and durability of the CSEBs while also reducing their susceptibility to weathering.

Water:

Clean, potable water was used in the mixing process. The water content is an important factor in achieving proper hydration and ensuring the consistency of the soil-cement mix.

Additives

A small amount of lime was added as an additive to strengthen the bricks, enabling them to withstand extreme weather conditions that could adversely affect them if not used.

Equipment:

Molding Equipment:

A hydraulic compression machine was for molding the CSEBs. The mold was designed to produce bricks of uniform size and shape. The compaction force applied will vary depending on the soil type and required brick strength.

Testing Equipment:

Compressive Strength Testing Machine: This equipment was used to measure the compressive strength of the CSEBs according to standard testing procedures.

Water Permeability Apparatus: A capillary rise test setup or a water absorption test device was used to assess the water transmission characteristics of the bricks.

Durability Testing Setup: A weathering chamber or freeze-thaw cycles was used to simulate environmental conditions and evaluate the durability of the CSEBs under extreme conditions.

Soil Testing Kits:

These kits was used to determine the soil's properties, including grain size distribution, plasticity index, and compaction characteristics, ensuring the suitability of the soil for stabilization.

Mixing Tools:

Manual or mechanical mixing equipment was used to combine the soil, cement, and water to achieve a homogeneous mixture before compaction.

3.4 Preparation of CSEBs

The preparation of Compressed Stabilized Earth Bricks (CSEBs) involves several critical steps to ensure consistency and quality in the final product. The manufacturing of Compressed Stabilised Earth Blocks (CSEBs) includes combining soil, non-expansive clay, sand, and aggregates with a stabilising agent like Portland cement as shown in Table 3.1. Here is a detailed description of the process:

1. **Soil Preparation:** Soil is sourced and identified to meet the composition requirements (dry inorganic subsoil and non-expansive clay). The soil is screened and mixed with appropriate stabilizing materials (cement).
2. **Mixing:** The damp soil-cement mixture is prepared and thoroughly mixed. The moisture content is maintained within optimal limits to facilitate proper compression.
3. **Compression:** The mixture is loaded into a mold or press machine (either manually operated or automated). The press compresses the mixture under high pressure (ranging from 4-10 MPa) to form solid blocks.
4. **Curing:** The compressed blocks are placed in a cool and dry area where they are left to cure for up to 3 weeks. Curing ensures that the cement fully stabilises, improving the strength and durability of the blocks.
5. **Quality Testing:** Comprehensive tests, including compressive strength evaluations, ensure that the CSEBs meet construction standards.

Table 3.1: Composition of good soil for CSEB according to Auroville Earth Institute

Type of stabilization	Gravel (%)	Sand (%)	Silt (%)	Clay (%)	Requirements
Cement Stabilized block	15	50	20	15	When the soil is more sandy than clayey
Lime Stabilized block	15	30	20	35	When the soil is more clayey than sandy

3.4.1 Soil Selection and Preparation

Soil Collection: The soil, primarily lateritic in nature, is sourced from a local site. The suitability of the soil is confirmed through laboratory tests, such as grain size distribution, Atterberg limits, and compaction characteristics.

Soil Sieving and Mixing: The soil is sieved to remove large particles, stones, and other debris. This ensures a smooth texture and uniformity in the soil mixture. The sieved soil is then thoroughly mixed to achieve consistency before the addition of cement and water.

3.4.2 Cement Addition

Cement Proportions: The cement content is calculated based on varying percentages (typically 5%, 7.5%, and 10% by weight of the soil). This step is crucial as the amount of cement influences the compressive strength, durability, and overall quality of the CSEBs as shown in Table 3.2.

Mixing the Soil and Cement: The cement is uniformly mixed with the soil using manual or mechanical mixing techniques to ensure an even distribution. This is followed by the addition of water in controlled amounts to achieve the desired workability.

Table 3.2: Different percentages of cement used for stabilization

Cement %	Composition %		Water %
	Soil	Lime	
5	80	10	20
7	80	10	20
10	80	10	20

3.4.3 Molding of the Bricks

Mold Preparation: Molds of standard size (usually 300 mm × 150 mm × 100 mm) are prepared for brick formation. The molds are lightly oiled or greased to prevent sticking during demolding.

Compaction: The soil-cement mixture is then placed into the molds and compacted using a hydraulic press or manual compaction machine. The compaction force is applied in multiple layers to ensure uniform density and strength. The amount of pressure applied is determined based on the desired compressive strength and the soil-cement mixture's characteristics.

Curing: After molding, the CSEBs are removed from the molds and left to cure. Curing is carried out by storing the bricks in a shaded, moist environment for a minimum of seven days, which allows the cement to hydrate properly and ensures the formation of strong bonds between the soil particles.

3.4.4 Drying

Air Drying: After curing, the CSEBs are air-dried to allow excess moisture to evaporate. The drying process typically takes 2-3 weeks, depending on environmental conditions such as temperature and humidity.

3.4.5 Quality Control

During the preparation process, several quality control measures are taken to ensure the consistency and uniformity of the bricks. This includes regular checks on the mix ratio, compaction density, and curing conditions to ensure that the prepared CSEBs meet the required specifications.

3.5 Testing Procedures

Testing Compressed Stabilized Earth Bricks (CSEBs) is crucial to evaluate their strength, durability, water permeability, and other essential properties. This section outlines the key testing procedures used to assess the performance of CSEBs.

3.5.1 Compressive Strength Test

An unconfined compressive strength machine of capacity 26.7 kN was used to measure the compressive strength of the CSEBs according to ASTM D143 in the Geotechnical Laboratory of Civil Engineering Department of Joseph Saarwuan Tarka University, Makurdi.

The samples were placed between two 3 mm thick circular cast iron plates were used at the top and bottom to ensure uniform surface loading. To measure the block's axial strain, a strain gauge was used. The stress vs. strain curve for each block was prepared and from the curve maximum strength of the block and failure strain was determined.

3.5.2 Water Permeability Test

This was done to determine the ability of CSEBs to resist water absorption and transmission. The water absorption test involves immersing the brick in water for a specified period, typically 24 hours. The weight of the brick is measured before and after immersion, and the percentage increase in weight indicates the water absorption capacity. The permeability is assessed based on the rate of water absorption.

3.5.3 Durability and Weathering Test

This was necessary to evaluate the bricks' long-term performance under environmental stress. The durability of CSEBs is tested by subjecting them to freeze-thaw cycles or exposing them to accelerated weathering conditions (such as cyclic wetting and drying). The bricks are weighed and examined for any signs of cracking, erosion, or dimensional change after a set number of cycles.

3.5.4 Dimensional Stability Test

This was done to measure the dimensional stability of the CSEBs over time. The dimensions of the CSEBs (length, width, height) are measured before and after exposure to environmental factors such as moisture and temperature variations. Any changes in size are recorded to assess their stability.

3.5.5 Fire Resistance Test (if applicable)

This was done to assess the fire resistance of CSEBs. The bricks are subjected to a controlled fire source for a specified duration, and the extent of damage or structural changes are noted. The results indicate how well the CSEBs can resist fire and high temperatures.

3.5.6 Standard Compliance

This was done to ensure that the CSEBs meet established standards for building materials. The prepared CSEBs are tested according to national or international standards for building materials, such as ASTM or BS standards, ensuring the bricks comply with the requirements for strength, durability, and other properties.

3.6 Data Collection and Analysis

Data collection and analysis are essential for assessing the properties and performance of Compressed Stabilized Earth Bricks (CSEBs). In this study, the primary method of data collection was utilized, with the researcher gathering data directly for the first time, specifically tailored to meet the objectives of the research. Examples of this method include surveys, interviews, and experiments.

3.6.1 Data Collection

The Data was collected from laboratory tests, including compressive strength, water permeability, durability, and dimensional stability tests. The results from these tests were recorded for various CSEB samples made with different cement contents as shown in Table 3.1.

Environmental Conditions: During curing and drying, data were collected regarding temperature and humidity, as these factors affect the properties of CSEBs. Additionally, any variations in the soil composition used in the preparation was documented. The precise mix ratios of soil, cement, and water were documented for each batch to ensure consistency and repeatability of the experiments.

Table 3.3: Different percentages of water content used for stabilization

Cement %	Composition %		Water %
	Soil	Lime	
10	80	10	10
15	80	10	10
20	80	10	10
25	80	10	10

3.6.2 Data Analysis

Statistical Analysis: Descriptive statistics (mean, standard deviation, etc.) was used to summarize the test results for each property (e.g., compressive strength, water absorption).

Statistical tool such as Analysis of Variance (ANOVA) was employed to assess the influence of cement content on the performance of CSEBs.

Comparison Analysis: The properties of the CSEBs were compared across different cement contents and with traditional building materials. This comparison will highlight the effectiveness of cement stabilization in improving the properties of CSEBs.

Correlation Analysis: Correlation tests were conducted to identify relationships between the mix proportions, environmental conditions, and the properties of the CSEBs. For instance, the relationship between water content and compressive strength was explored.

Table 3.4: Different number of blows used for CSEB preparation

Cement %	Composition %			Water %
	Soil	Lime	Cement	
16	80	10	10	20
32	80	10	10	20
50	80	10	10	20
64	80	10	10	20

3.6.3 Presentation of Results

The results were presented in tables, charts, and graphs for clarity. These visual aids will help in interpreting trends and drawing meaningful conclusions about the effects of cement stabilization on the performance of CSEBs.

Data was presented for each test, including the control (without cement) and samples with varying cement percentages.

3.7 Suitability of Testing Methods

The selection of appropriate testing methods is essential for accurately assessing the properties of Compressed Stabilized Earth Bricks (CSEBs) and ensuring their suitability for construction applications. This section examines the suitability of the chosen testing methods in the context of the objectives of this study, particularly for use in developing regions.

3.7.1 Relevance to Local Conditions

The testing methods selected are appropriate for the materials commonly available in developing regions. Local soils, such as laterite, are frequently used for CSEBs, and the tests are designed to evaluate these specific materials under local environmental conditions. This ensures the relevance of the results to practical construction applications in these regions.

3.7.2 Feasibility and Cost-Effectiveness

The methods chosen are cost-effective and can be implemented using locally available resources. For example, the compressive strength test and water permeability test require

simple equipment such as a Universal Testing Machine (UTM) and water tanks, which are often available in local laboratories or can be easily set up.

The use of accessible materials, like standard molds and curing conditions, makes these tests suitable for regions with limited resources.

3.7.3 Accuracy and Reliability

The selected testing procedures, such as compressive strength and durability tests, are standardized and widely accepted in construction materials research. These methods provide reliable data on the strength, durability, and water resistance of the CSEBs, which are critical factors for ensuring the long-term performance of the bricks in real-world conditions.

Using multiple tests (e.g., compressive strength, water absorption, and weathering) allows for a comprehensive assessment of the CSEBs, ensuring that the results are robust and reliable.

3.7.4 Ease of Implementation

The testing methods are relatively easy to implement and do not require highly specialized knowledge or equipment. For instance, the water permeability test can be conducted with basic tools, and curing conditions can be controlled in simple settings. This makes the methods suitable for researchers and practitioners in developing regions where sophisticated testing laboratories may not be readily available.

3.7.5 Applicability to Standardization

The chosen testing methods align with existing standards for building materials, such as those from ASTM or ISO, making the results comparable to international benchmarks. This ensures that the findings can contribute to the broader body of knowledge and can be used for standardizing CSEBs in the construction industry.

3.7.6 Limitations

While the testing methods selected are generally suitable, they may not fully capture certain long-term environmental effects that could impact the performance of CSEBs, such as prolonged exposure to extreme weather conditions. Future studies could incorporate more advanced testing methods, such as accelerated aging or large-scale field tests, to better simulate real-life conditions.

4.0 Results

4.1 Introduction

This chapter presents the results of the experimental testing conducted on Compressed Stabilized Earth Bricks (CSEBs) that incorporate cement, followed by a detailed discussion of the findings. The tests were designed to evaluate the key properties of CSEBs, including compressive strength, water permeability, durability, and dimensional stability, while also comparing their performance to that of conventional building materials.

The chapter begins with an overview of the results for each property, then analyzes how the cement content and other factors influence the overall performance of the CSEBs. These

findings are discussed in the context of the study's objectives and are compared with existing literature to emphasize their potential for use in sustainable and affordable housing solutions.

4.2 Variation of Compressive Strength with Cement Content

In Fig. 4.7, the 7 days compressive strength of CSEB specimens prepared with 5%, 7% and 10% cement content has been plotted and in Fig. 4.8, the 28 days compressive strength of CSEB specimens prepared with 5%, 7% and 10% cement content has been plotted. The variation of 7 days and 28 days compressive strength of specimen prepared with 5%, 7% and 10% cement content has been presented.

From Fig. 4.8 it is seen that the 7 days compressive strength decreases from 0.39 MPa to 0.29 MPa with the increase of cement content from 5% to 7%. After that the compressive strength increases with the increase of cement content percentage. Also, it is seen that 28 days compressive strength decreases from 0.5 MPa to 0.3 MPa, which gradually increases to 2.62 MPa. But more than 10% cement content is not used because according to “Standard Norms and Specification for CSEB Blocks” (CSEB Green Buildings in Nepal, 2012) use of cement more than 10% is not cost effective. So, 10% cement content is the optimum cement content for CSEB specimen.

Table 4.1: Properties of CSEB

S/NO	PROPERTIES	VALUES
1	Dry compressive crushing strength (@ 30 days)	3-7 MPa
2	Wet compressive crushing strength (@ 30 days, after 24 hours immersion)	1.5-4 MPa
3	Tensile crushing strength, dry (on a core @ 30 days)	0.5-1 MPa
4	Bending crushing strength, dry (@ 30 days)	0.3-1 MPa
5	Shear crushing strength, dry (@ 30 days)	0.2-0.6 MPa
6	Apparent bulk density	1750-2000 kg/m ³
7	Total water absorption	8-15%
8	Coefficient of thermal expansion	0.010-0.015 mm/m°C
9	Shrinkage	0.2-1 mm/m
10	Permeability	1.10-5 mm/sec

4.3 Water Stabilization Results

Table 4.2: Different percentages of water content used for stabilization

Cement %	Composition %		Water %
	Soil	Lime	
10	80	10	10

15	80	10	10
20	80	10	10
25	80	10	10

4.4 Durability and Weathering Test Results

Presentation of results from the durability and weathering tests (e.g., freeze-thaw cycles or cyclic wetting and drying). Evaluation of the long-term performance and stability of CSEBs. Comparison with other building materials in terms of resistance to weathering and durability.

4.5 Dimensional Stability Results

Presentation of the results from dimensional stability tests. Analysis of how environmental conditions (temperature, moisture) affect the size and shape of CSEBs over time.

Discussion of the implications for the use of CSEBs in different climate zones.

4.6 Fire Resistance Test Results (if applicable)

Fire test was not done because of the lack of standard Laboratory to carry it out.

Table 4.3 Comparison of the Various Test Results

PROPERTIES	CSEB	FIRED CLAY BRICKS
Compressive strength	3-7 MP	10-140 Mpa
Tensile strength	0.5-1 MPa	Maximum 2.8 Mpa
Apparent bulk density	1750-2000 kg/m ³	1800-2200 kg/ m ³
Total water absorption	8-15% (Standard)	7-15% (Best quality)
Carbon emission during production	22 kg CO ₂ /tonne	200 kg CO ₂ /tonne
Manufacturing Cost	40 and 45% less than FCB	13,200 Tk/1000 unit

4.7 Statistical Analysis and Interpretation of Results

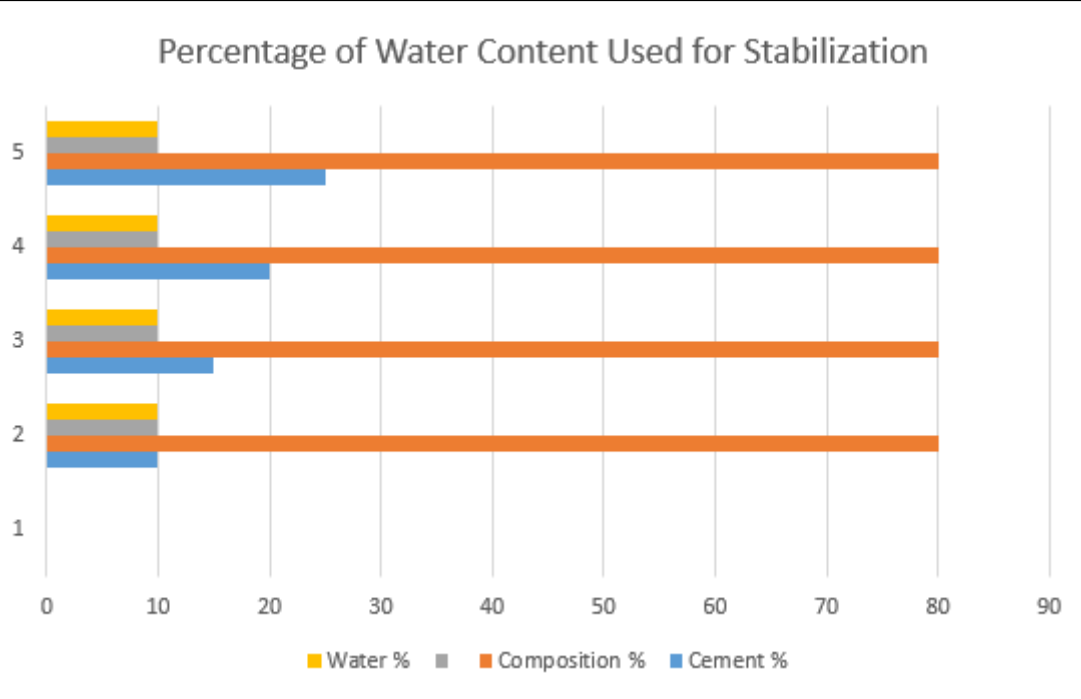


Figure 4.1 Percentage of Water Content Used For Stabilization

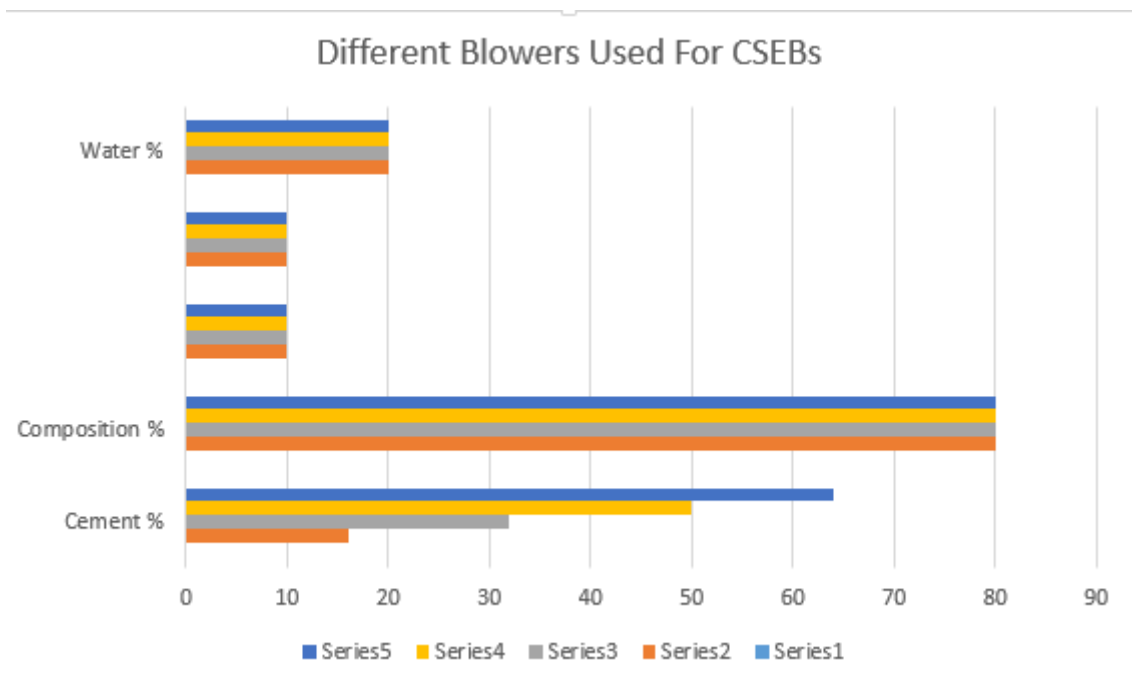


Figure 4.2 Chart of Different Blowers Used for CSEBs

4.8 Limitations of the Study

The water absorption capacity of the prepared CSEBs exceeded the standard threshold of 12%, influenced by the poor quality of lime and humid conditions, which may affect the blocks' long-term durability and performance under certain environmental conditions.

4.9 Summary of Key Findings

Laboratory test on soil was conducted to determine the soil properties. Compressive strength test on the prepared CSEBs was conducted to determine the compressive strength of prepared CSEBs. Compressive strength test was conducted on total 15 types CSEB specimens. The comparison of different combinations of CSEB specimens have been discussed with relevant graphs, charts and tables. Water absorption capacity of some prepared CSEB specimens was also determined after 24 hours immersion under water.

Finally, comparison of compressive strength and water absorption capacity of CSEB specimens have been presented with relevant figures. These can be summarized as follows:

- (i) Laboratory test results on the collected soil samples are compared and from that suitable, soil from the collected soil sample, for preparing CSEB are determined.
- (ii) Compressive test result conducted on 15 different types of CSEB specimens of different combination was compared. From the comparative study the optimum mixing water content, pressing and combination for preparing CSEBS are determined. From the compressive strength result, maximum compressive strength of CSEB specimen found was 2.63 MPa.
- (iii) Absorption test was also conducted on the prepared CSEB specimens. From the result obtained from absorption test it has been found that with the increase of Lime content water absorption capacity of CSEB specimen has increased.
- (iv) Images taken after Scanning Electron Microscopy investigations were compared with each other. It was found that size of the void decreases with increase of fly ash content. This shows Lime works well in establishing good bonding indicating an increase in strength.
- (v) Cost of production of each combination is determined. Cost of each type of block equivalent to brick size is also determined. Then it is compared with production cost of S-grade, A-grade and machine made brick and it has been found that production cost of Lime stabilized CSEB is less than these bricks.
- (vi) Moreover, the block samples exhibiting highest strength so far were replicated to form bricks using bigger mould following BSTI specifications and their compressive strength were observed and compared with curing period.

5.0 Conclusion

The conclusion chapter provides a summary of the study's findings, reflects on the research objectives, and outlines the contributions of the study to the field of sustainable construction. It also discusses the implications of the results and offers recommendations for future research and practical applications.

5.1 Summary of Key Findings

The main findings of this study are as follows:

- (i) Five river bed sand samples were collected and soil from Makurdi fulfilled the required criteria and was used as a raw material for the production of CSEBs.
- (ii) The compressive strength of the CSEBs varied between 0.28 MPa to 2.63 MPa. The maximum compressive strength 2.63 MPa was obtained using 10% Lime, 10% cement, 20 % water and 80 % sand.

(iii) The strength of the fly-ash and cement stabilized block was compared with various codes to check its performance and suitability as a construction material. According to the code IS :1725-1982 and New Mexico Earthen Building Code, these fly ash cement stabilized blocks exhibiting strength beyond 1.95 MPa fulfills the code requirement and holds the capacity to perform as a construction material in non-load bearing walls, rural houses ,one-story building, low rise buildings.

(iv) From the compressive strength test of unburnt bricks measuring 25 cm × 12cm × 7 cm, following BSTI specifications, it was seen that the highest strength i.e. 2.62 MPa was received after curing for 28 days. These bricks constituted the percentages of the CSEB exhibiting highest compressive strength of 2.63 MPa. The narrow differences between the compressive strength of the blocks and bricks received indicate the bricks can also be utilized as a construction material in non-load bearing walls.

(v) From the absorption capacity results, it has been found that the water absorption decreases with the increase of Lime content. This indicates there is sufficient strength to inhibit porosity which works well in exhibiting strength in the blocks In spite of the fact that the minimum water absorption capacity of CSEBs should be than 12%, the test results indicated the capacity exceeded 15 %.The poor quality of Lime and humid weather conditions might have contributed to an increment in absorption capacity.

5.2 Contributions to Knowledge

This study demonstrates that Makurdi soil is suitable for the production of compressed stabilized earth blocks (CSEB) and identifies an optimal mix that achieves a compressive strength of 2.63 MPa, meeting global standards for low-cost construction. It highlights the potential of unburnt bricks as a sustainable alternative material. Additionally, the findings emphasize the influence of lime quality and curing conditions on water absorption and the overall performance of the blocks.

5.3 Implications of the Study

CSEBs are ideal for low-cost housing in developing regions, offering affordable and eco-friendly construction options. They reduce energy usage in manufacturing, provide thermal insulation for energy-efficient buildings, and allow for faster construction with minimal disruptions. The use of manual or semi-automatic presses creates local employment opportunities.

CSEBs utilize local, eco-friendly materials, aligning with sustainable development goals. While not suitable for high-cost, high-performance construction due to average mechanical properties, they remain a viable, sustainable alternative for affordable housing.

5.4 Recommendations

The main objective of this research was to determine the strength characteristics of CSEB. Moreover, opportunities for future researchers are numerous. The following studies can be conducted in the future:

(i) In this research, the soils were collected from some specific sites only. Soils from other parts of Makurdi are not investigated for suitable soil for CSEB.

(ii) Because of use of poor quality of Lime, the targeted strength of Lime stabilized bricks that usually varies within 10-12 MPa could not be achieved.

(iii) Due to limitation of scope, analysis of dynamic property was not carried out. Dynamic test like Shaking Table test can be conducted.

(iv) In this study CSEBs are compacted by manual pressing. Compaction with mechanical pressing for example by using 'Auram Earth Block press' can be conducted.

(v) Because of the limitation of scope, analysis of lateral loading property of the Lime stabilized CSEB block was not carried out.

5.5 Limitations of the Study

We faced challenges in achieving fire resistance testing due to a lack of accessible laboratories in our area.

5.6 Directions for Future Research

The impact of fire on bricks needs to be investigated and improved to help builders understand how and when to effectively use bricks in construction. The findings in this area could also contribute to education and learning.

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