ENHANCING ADOBE BLOCKS TAILORED WITH JUTE-FIBER AND FLY-ASH

AN UNDERGRADUATE THESIS

BY

GOURAB BOSE DURJOY

Md. AHSANUL ALAM CHOWDHURY

SYED JIL ASIF ETHEMUD

DEPARTMENT OF CIVIL ENGINEERING
SYLHET ENGINEERING COLLEGE
SCHOOL OF APPLIED SCIENCE AND TECHNOLOGY
SHAHJALAL UNIVERSITY OF SCIENCE AND TECHNOLOGY

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CERTIFICATION

ENHANCING ADOBE BLOCKS TAILORED WITH JUTE-FIBER AND FLY-ASH

BY

GOUROB BOSE DURJOY (Registration No.: 2019333550)
Md. AHSANUL ALAM CHOWDHURY (Registration No.: 2019333557)
SYED JIL ASIF ETHEMUD (Registration No.: 2019333559)

Submitted in partial fulfillment of the requirements for the degree of Bachelor of Science in Civil Engineering, Sylhet Engineering College has been approved by the following supervisory committee members.

<u>SUPERVISOR</u>

Sibbir Ahmed
Assistant Professor & Head of Department
Department of Civil Engineering
Sylhet Engineering College
Sylhet, Bangladesh

<u>CO-SUPERVISOR</u>

Dr. MUSHTAQ AHMED
Professor
Department of Civil and Environmental Engineering
Shahjalal University of Science and Technology
Sylhet, Bangladesh

BOARD OF EXAMINERS

The thesis titled *"***ENHANCING ADOBE BLOCKS TAILORED WITH JUTE-FIBER AND FLY-ASH***"* was submitted by **Gourab Bose Durjoy, Reg. No. 2019333550, Md. Ahsanul Alam Chowdhury, Reg. No. 2019333557 and Syed Jil Asif Ethemud, Reg. No. 2019333559**; Session 2019-20, has been accepted as satisfactory in partial fulfillment of the requirement for the degree of Bachelor of Science in Civil Engineering on 22 July 2025.

Dr. Md. Jahir Bin Alam
Professor
Department of Civil and Environmental Engineering
Shahjalal University of Science and Technology
Sylhet, Bangladesh

Member (External)

DECLARATION

We hereby declare that all information in this document has been obtained and presented in accordance with academic rules and ethical conduct. We also declare that, as required by these rules and conduct, we have fully cited and referenced all material and results that are not original to this work.

GOURAB BOSE DURJOY

Reg. No.: 2019333550

Md. AHSANUL ALAM CHOWDHURY

Reg. No.2019333557

SYED JIL ASIF ETHEMUD

Reg No.: 2019333559

ABSTRACT

Adobe Blocks, a sustainable construction material, is gaining renewed attention due to its low embodied energy and carbon footprint. However, its limited strength properties pose challenges for structural applications. Work herein focuses on investigating the enhancement of traditional adobe blocks through the incorporation of fly ash and jute fiber, to improve compressive strength while maintaining environmental sustainability. To address this, four adobe mixes were prepared using Sylhet clay-rich soil with varying amounts of fly ash and jute fiber, leveraging their local availability in Bangladesh. Laboratory tests were conducted to evaluate compressive strength at 7- and 28-days following ASTM standards. Results showed that the combined inclusion of 1% fly ash and 1% jute fiber yielded the highest 28-day compressive strength of 2.73 MPa, marking a 56.8% improvement over the control mix (1.74 MPa). The observed strength gains are attributed to the pozzolanic reaction of fly ash and the fiber-bridging effect of jute, which together enhance bonding and crack resistance. The findings highlight that even low additive levels significantly improve performance and that the synergistic use of both additives is more effective than using either alone. This optimized mix offers a viable, eco-friendly alternative for low-rise construction, supporting broader efforts toward sustainable and locally sourced building materials.

Keywords: Adobe bricks, Sustainable construction materials, Jute fiber, Fly ash, Compressive strength, Earth-based building materials

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Gourab Bose Durjoy
Md. Ahsanul Alam Chowdhury
Syed Jil Asif Ethemud
Department of Civil Engineering
Sylhet Engineering College

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CHAPTER 1: INTRODUCTION

1.1 Background of the Study

Adobe, a traditional building material, is gaining renewed attention in sustainable architecture due to its eco-friendly properties. It requires minimal energy for production, is fully recyclable, and produces little waste (Illampas, Ioannou, and Charmpis 2009a). Adobe bricks offer durability, affordability, and excellent thermal mass performance, potentially lasting over 400 years with proper maintenance (Benghida2015).

The use of adobe as a construction material has long been valued for its numerous advantages, including durability, excellent thermal insulation properties, unique aesthetic appeal, and environmental benefits due to its low energy requirements in production (Illampas, Ioannou, and Charmpis 2009b). As a naturally sourced material, adobe is particularly relevant in promoting sustainable construction practices, especially in regions with abundant natural resources like soil, which is widely accessible in rural and arid areas globally (Kuyrukçu and Kuyrukçu 2015). Sustainable construction materials are gaining importance in addressing global environmental challenges faced by the construction industry. These materials offer alternatives to traditional options like concrete and steel, which have significant environmental drawbacks(Bahuguna2021).

Adobe construction has long been recognized for its cultural significance and sustainability in regions with earth-based building traditions. This vernacular architecture utilizes locally available materials, reducing costs and environmental impact while reflecting cultural practices (Filali and Ezzahir 2025).

The construction industry significantly contributes to global carbon emissions, with 39% of the total carbon footprint stemming from production and construction processes (Dighade et al. 2024). Recent studies have focused on reducing carbon footprints in construction through various strategies. These include using alternative additives in building materials, improving design, recycling construction waste, and increasing efficiencies of water technologies and building systems, which can reduce CO_2 emissions by up to 90% (Sizirici et al. 2021).

The global construction sector is under pressure to reduce its carbon footprint, driven by international commitments to combat climate change, such as the Paris Agreement (Karakosta and Papathanasiou 2025). Traditional materials like brick, cement, and steel are energy-intensive, emitting significant greenhouse gases during production and contributing to environmental degradation (Lokesh B J, Veena N Pavadeppagol, and Achappara Chaitra 2020; Wang 2025). In response, natural and locally sourced materials, such as adobe, are gaining traction for their ability to minimize embodied carbon and reliance on non-renewable resources (Kuyrukçu and Kuyrukçu 2015). By leveraging materials available in proximity to construction sites, builders can reduce transportation emissions and support local economies. Adobe, in particular, exemplifies this shift, offering a low-carbon alternative that aligns with sustainable development goals. This leads to an exploration of adobe's specific properties and its role in shaping environmentally conscious architecture (Benghida 2015).

Adobe's significance in construction extends beyond its environmental benefits to include its structural, thermal, and aesthetic properties (Illampas et al. 2009b). Adobe walls provide excellent thermal mass, regulating indoor temperatures and reducing energy consumption for heating and cooling (Heracleous et al. 2023)Structurally, adobe offers sufficient compressive strength for low-rise buildings, though its tensile and compressive strength is limited. Aesthetically, adobe's earthy textures and natural hues create visually appealing designs that blend seamlessly with natural surroundings, enhancing architectural authenticity. Its environmental benefits biodegradability, low embodied energy, and recyclability make it a standout choice for sustainable construction (Illampas et al. 2009b). However, the limitations of traditional adobe mixes necessitate innovation, prompting an examination of how conventional compositions can be improved.

To address the inherent limitations of traditional adobe mixes, particularly their constrained stability and compressive strength, this study investigates the integration of fly ash and jute fiber into adobe wall formulations, utilizing their abundant availability in Bangladesh to enhance structural performance. Fly ash, a byproduct of coal combustion in power plants, is readily available and improves adobe's compressive strength and durability by reducing porosity through its fine, pozzolanic particles, which foster a more cohesive matrix (Gangele, Rai, and Dubey 2025). The clay-rich soil of Sylhet, Bangladesh, characterized by high plasticity and strong binding properties, provides a locally sourced, sustainable base for adobe construction, ensuring structural stability while minimizing transportation-related emissions. Jute fiber, abundant due to Bangladesh's robust jute industry, serves as a natural reinforcement, enhancing tensile strength and crack resistance by interlocking with the soil matrix to improve overall resilience(Islam and Iwashita 2010). By combining fly ash, Sylhet's soil, and jute fiber, this research develops an optimized adobe mix that leverages local resources to enhance material properties, offering a sustainable, structurally robust solution for modern eco-friendly construction.

To achieve this, the study will measure the compressive strength of the composite through laboratory experiments, utilizing standardized testing protocols like ASTM C109 and the compressive strength of tailored adobe will be measured and how the different mix composition of adobe influences the compressive strength. The findings are expected to contribute to the broader adoption of environmentally sustainable building practices, particularly in regions where natural and industrial by-products are readily available, supporting affordable and eco-conscious construction solutions.

1.2 Objective of the Study

This study aims to develop an improved adobe mixture incorporating locally available clay-rich soil from Sylhet, coal-derived fly ash, and jute fiber to enhance the structural performance and sustainability of earthen construction in Bangladesh. The research focuses on optimizing material proportions to overcome the limitations of traditional adobe, particularly its variable compressive strength, and to establish a resilient, low-carbon building alternative.

Objective of this study is:

- To assess the compressive strength of tailored adobe compositions.
- To investigate the influence of additives on the strength of adobe block.

CHAPTER 2: LITERATURE REVIEW

2.1 Advancement of Adobe

A significant advancement has been noticed recently in research related to adobe construction. Numerous studies have been conducted to obtain best techniques for adobe mix.

2.1.1 Towards the development of performance-efficient compressed earth blocks from industrial and agro-industrial by-products.

(Valenzuela et al. 2024) explores the development of performance-efficient compressed earth blocks using industrial and agro-industrial byproducts as stabilizers and fiber reinforcement. This investigation evaluated the mechanical, thermal, and durability performance of compressed earth blocks in support of low carbon construction strategies. Stabilizers such as pozzolans, lime, fly ash, and cement were analyzed for their contribution to compressive strength and reduced permeability, whereas natural fibers like jute, rice husk and coconut were found to increase tensile strength and mitigate cracking. Among the various prediction and analysis tools, the authors highlight the Finite Element Method (FEM) as a valuable approach with strong potential for modeling the thermal, strength, and durability behavior of CEB units and walls. However, the paper remains largely general in its analysis of fiber and stabilizer types, without isolating or investigating the combined behavior of jute fibers and fly ash reinforced earth blocks.

2.1.2 Experimental evaluation of adobe mixtures reinforced with jute fibers.

(Araya-Letelier et al. 2021) approaches experimentally investigated the reinforcement of adobe mixtures (AMs) with varying lengths (7, 15, and 30 mm) and dosages (0.5% and 2.0% by weight) of jute fibers (JFs), to enhance the physical, mechanical, fracture, and durability properties of earthen construction materials. The study found that a higher fiber content (2.0%) slightly increased water absorption, which could affect long-term durability. The inclusion of jute fibers improved thermal insulation, reduced cracking, increased toughness, and enhanced resistance to erosion. Importantly, compressive and flexural strength stayed mostly the same, meaning structural strength was not compromised. The best results came from the mix using 2.0% jute fiber at 15 mm length, which increased flexural toughness by 297% and reduced cracking by 93%. However, the study does not incorporate any numerical modeling or simulation tools to predict or optimize the structural behavior of these composites.

2.1.3 Experimental Study on Compressed Earth Block using Fly-Ash Stabilizer.

(Raja Gurusamy R 2020)investigated the performance of compressed stabilized earth blocks (CSEBs) using fly ash as a stabilizer. The CSEBs were produced using a mix of 50% fine aggregate, 30% cement, 20% coarse aggregate, and varying proportions of fly ash (5%,10% and 15%). The mix containing 10% fly ash achieved the highest compressive strength of 1.24 MPa after 28 days of curing, an improvement over the control sample without fly ash, which reached only 1.07 MPa. The study also found that 15% fly ash led to the lowest water absorption rate at 11.17%, while the lowest abrasion loss (0.88%) occurred at 10% fly ash content, indicating improved surface durability. This confirms the beneficial role of fly ash in improving the strength and durability of earth blocks. However, the environmental impact is still a concern due to the high cement content (30%) in the mix design.

2.1.4 Engineering characteristics of compressed earth blocks stabilized with cement and fly ash.

(Elahi, Shahriar, and Islam 2021) examined the engineering performance of compressed stabilized earth blocks (CSEBs) using varying proportions of cement (0–

10%) and fly ash (0–30%) as alternatives to fired clay bricks. A total of 270 blocks and 192 cylindrical specimens were tested for compressive, flexural, tensile, and shear strength and durability. Fly ash significantly improved mechanical properties: compressive strength increased by up to 61%, flexural by 104%, and tensile by 54%, depending on the mix. The best results were achieved with 20% fly ash and 5–7% cement. Triaxial tests confirmed enhanced shear behavior, and Life Cycle Assessment (LCA) demonstrated lower environmental impact compared to fired bricks, despite slightly higher initial costs. However, the study does not explore agro-based reinforcements like jute fiber, nor does it incorporate finite element modeling, which could have helped predict stress distribution and long-term performance. Furthermore, reliance on cement reduces its
overall sustainability.

2.1.5 Characterization of jute fiber reinforced adobe brick and brick masonry.

(Unnikrishnan 2017) investigates the reinforcement of adobe (sun-dried) bricks using natural jute fibers, with the goal of improving mechanical properties while maintaining the material's sustainability. Adobe bricks were produced with varying jute fiber lengths (1 cm, 2 cm, and 3 cm) and contents (1% and 2% by weight). Experimental results showed that the optimal combination, which was 2 cm fiber length at 1% content, led to a 73% increase in compressive strength compared to unreinforced bricks. When applied to masonry prisms and mortar joints, jute reinforcement further improved structural performance, increasing compressive strength by 48% and shear bond strength by 79%. The study also reported a 10% reduction in brick weight, which could offer advantages in handling and structural load reduction. However, while the study confirms the strengthening potential of jute fibers in adobe masonry, it does not explore the use of fly ash or other pozzolanic stabilizers to further improve durability and resistance.

2.2 SUMMARY

The reviewed studies explore the enhancement of earthen construction materials using fly ash as a stabilizer and jute fiber as reinforcement. Fly ash consistently improves compressive strength, durability, and reduces water absorption, though high cement usage in some mixes raises sustainability concerns. Jute fibers effectively reduce cracking, enhance toughness, and improve thermal insulation without compromising strength. However, most studies treat these materials separately, lacking investigation into their combined effect.

CHAPTER 3: MATERIALS AND EXPERIMENTAL METHODS

3.1 Materials

The materials utilized in this study for the production of jute fiber-reinforced adobe bricks included soil with an appropriate composition of sand, clay, and silt as the primary matrix; jute fibers as the reinforcing agent; and water as the binding medium.

3.2 Soil

Sieve analysis was performed on the soil sample used for specimen preparation in accordance with the specified guidelines. The particle size distribution of the soil is presented in Figure 3.1.

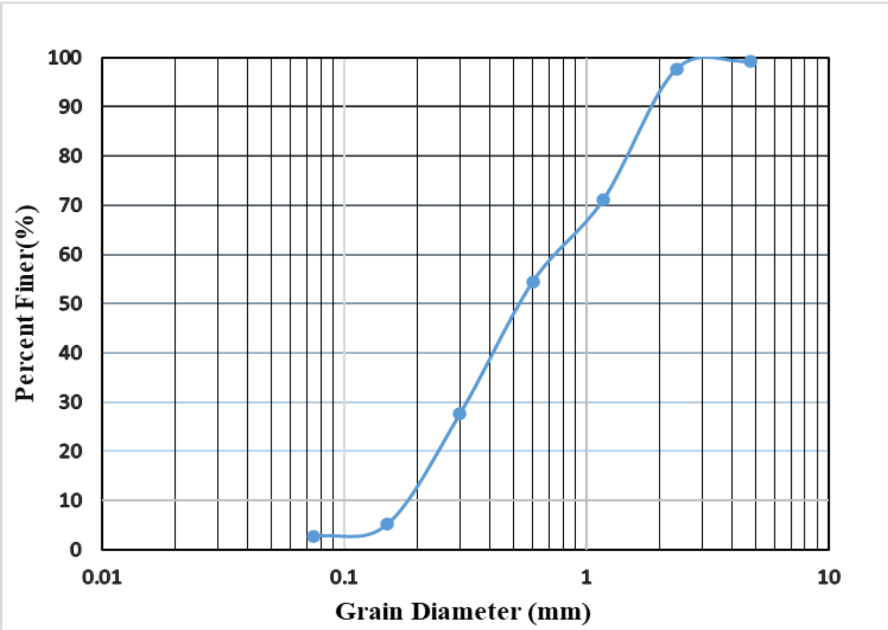

Figure 3.1 Particle size distribution of Soil

Additionally, Atterberg limits were determined, including the liquid limit, plastic limit and plasticity index, following standard procedures. The results of the soil properties are summarized in Table 3.1.

Table 3.1 Physical Properties of Soil

Liquid Limit	29.3%
Plastic Limit	17.6%
Plasticity Index	11.7%
Moisture Content	8.83%

3.3 Jute Fiber

Jute, a bast fiber from *Corchorus capsularis* of the Tiliaceae family shown in fig 3.2, is a fast-growing plant, reaching 12–15 feet in three months (Bangladesh Jute Corporation n.d.; Roy and Lutfar 2012). In Bangladesh, jute—termed the "golden fiber"—holds significant economic and cultural value, with the country being a leading global producer(Islam, 2012). Composed primarily of cellulose, hemicellulose, and lignin, along with minor protein and inorganic matter, Bangladeshi jute is inherently hydrophilic due to its hydroxyl and oxygen-containing groups (Ammayappan, Chakraborty, and Pan 2021)

Figure 3.2 Jute Fiber

These features enhance its performance in composite and geotechnical applications. In soil reinforcement, jute contributes to increased tensile and compressive strength. These properties collectively enhance the load-bearing capacity and structural stability of soils, making jute a sustainable and cost-effective natural reinforcement material in civil engineering applications.

3.4 Fly Ash

In Bangladesh, fly ash, a byproduct of coal-fired power plants as shown in figure 3.3, is gaining traction as a sustainable construction material, particularly in concrete production (Islam et al. 2023). Its pozzolanic properties, driven by its fineness and reactivity, enhance concrete's strength, durability, and workability when used as a partial cement replacement (Varma and Gadling 2016). By reducing cement production and diverting waste from landfills, fly ash utilization mitigates environmental impacts, offering a cost-effective solution for sustainable construction.

Figure 3.3 Fly Ash

3.5 Adobe Composite Sample Development Process

3.5.1 Soil Collection and Determination of Soil Property

Soil was collected from nearby locations of SEC and sieve the soil to remove large particles and stones to achieve a uniform grain size distribution. Preliminary

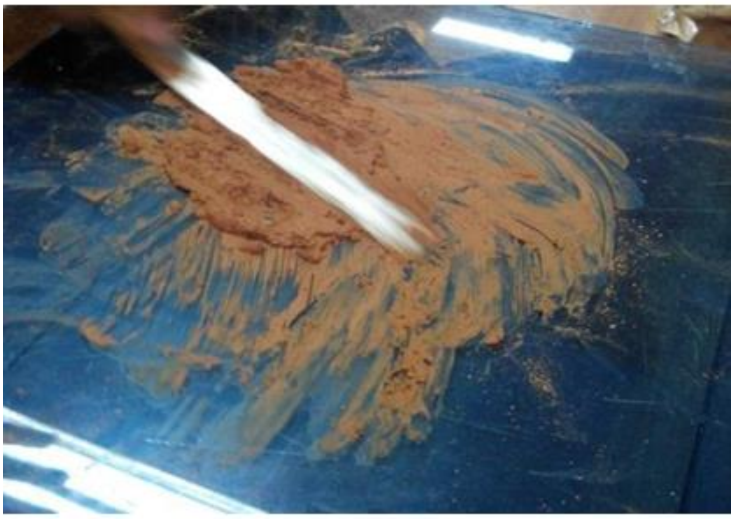

Figure 3.4 Liquid limit testing procedure

Figure 3.5 Plastic limit testing procedure

tests including liquid limit (LL), plastic limit (PL), moisture content (MC) and sieve analysis were conducted to determine the characteristics of soil sample as exhibited in figure 3.4, figure 3.5, figure 3.6 and figure 3.7 respectively.

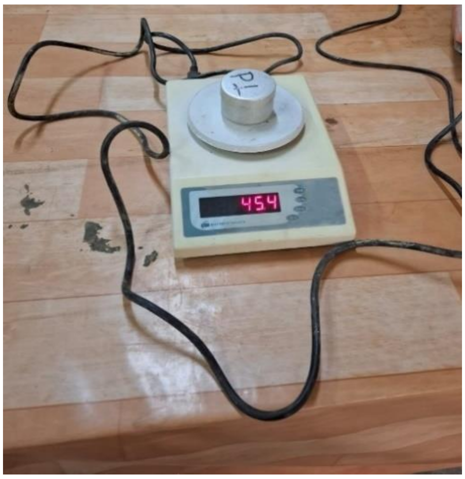

Figure 3.6 Determining moisture content

Figure 3.7 Performing sieve analysis for determining soil gradation

3.5.2 Preparation of Soil Mixes with Additives

Jute fiber was cut at a length of 2 cm as shown in figure 3.8 and fly ash was oven dried for 1 hour.

Figure 3.8 Processing of Jute Fiber

Adobe mixes were prepared using soil, fly ash, and jute fiber in four different combinations as detailed in Table 3.2, with water added gradually based on the MC and compaction was done rigorously as shown in figure 3.9. The mixtures were thoroughly blended to achieve consistency.

Figure 3.9 Compacting During Molding

3.5.3 Preparation of Soil Mixes with Additives

The selected mixture proportions were carefully chosen to optimize the performance of adobe bricks while maintaining workability during preparation. The fly ash content was limited to a maximum of 1% because adobe does not contain cement, and excessive fly ash can act as an inert filler rather than a pozzolanic binder. Studies have shown that high fly ash content in earthen materials can lead to reduced liquid limit, plastic index, and maximum dry density(Tang et al. 2023).

Jute fiber was also restricted to ≤1% by weight due to its water absorption capacity, and tendency to form clumps when used in excess. Several studies confirm that natural fibers in higher percentage often lead to increased porosity, decreased compaction, and poor mechanical performance(Unnikrishnan 2017; Zakaria et al. 2020).

Table 3.2 Details of Mixture Proportions for Adobe

Mix Nos.	Soil (%)	Fly-ash (%)	Jute fiber (%)
1	100	0	0
2	99	0.5	0.5
3	98	1	1
4	98.5	0.5	1

3.5.4 Molding and Curing of Adobe Samples

The mixtures were thoroughly blended to achieve consistency. This approach studied four combinations, 3 samples for each combination, for 7 and 28 days respectively.

Figure 3.10 Demolded Sample

Cylindrical molds (95 mm × 200 mm) were used to shape the specimens, which were demolded after 48 hours as presented in figure 3.10 and cured under sunlight for 7 and 28 days as shown in figure 3.11.

Figure 3.11 Curing under Sunlight

3.5.4 Mechanical Testing of Adobe Specimens

Compressive strength tests were performed by Universal Testing Machine (UTM) (Model No.: 6 Pillar, BE-UTM 1000, Balaji Enterprise, New Delhi.) at both curing intervals following ASTM standards as illustrated in figure 3.12. The mechanical test results were analyzed to identify the optimal soil-additive combination.

Figure 3.12 Testing Sample on UTM

3.5.5 Data Analysis and Strength Characterization

The mechanical test data was analyzed to determine the strength characteristics of each mixture and identified the most promising combinations of soil and additives.

CHAPTER 4: RESULTS AND DISCUSSION

4.1 Compressive Strength Analysis of Engineered Adobe Sample

The compressive strength of adobe blocks was assessed at both 7 and 28 days to evaluate the effect of incorporating fly ash and jute fiber as stabilizing additives. Four different mixes were tested, including a control mix (Mix 1) without any additives and three experimental mixes (Mixes 2-4) containing varying proportions of fly ash and jute fiber.

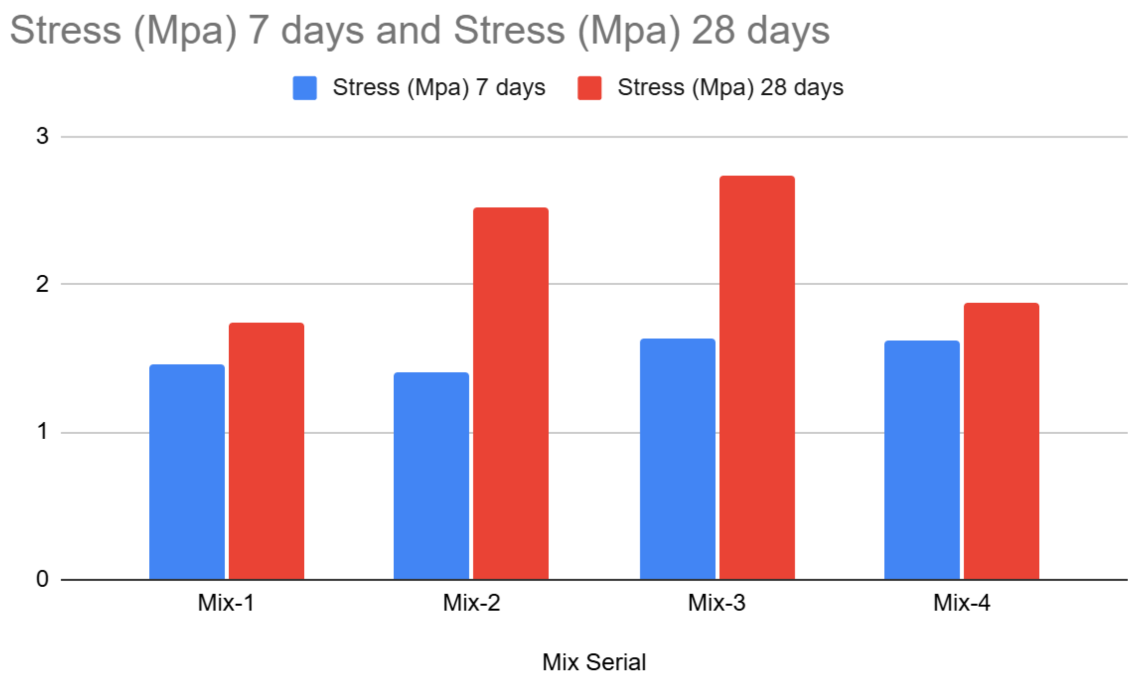

Figure 4.1 Comparison of 7- and 28-Days Compressive Strength

At 7 days, the compressive strength of all mixes ranged between 1.40 MPa and 1.64 MPa. The control mix (Mix 1) achieved a 7-day strength of 1.45 MPa, while the highest strength was recorded for Mix 3 (1% fly ash, 1% jute fiber) at 1.64 MPa, indicating an early improvement in bonding due to the synergistic effect of both additives. Mix 4, despite containing 1% jute fiber, showed a slightly lower strength of 1.63 MPa, possibly due to its reduced fly ash content (0.5%), which may have limited the pozzolanic reaction that contributes to early strength gain.

By 28 days, all modified mixes outperformed the control. Mix 3 again displayed the highest strength, reaching 2.73 MPa, a 56.7% improvement over the control mix's 1.74 MPa which is more than the existing adobe constructions in Aveiro district, Portugal (Silveira et al. 2012). Mix 2 (0.5% fly ash and jute fiber) followed closely with a strength of 2.53 MPa. These findings suggest that increasing the dosage of both additives positively influences the long-term strength of adobe blocks. However, Mix-4, which had a combination of 0.5% fly ash and 1% jute fiber, showed only a moderate strength of 1.88 MPa, further highlighting the importance of an optimal ratio between binder and reinforcement.

4.2 Discussion

The improvement in compressive strength with additive inclusion can be attributed to two primary mechanisms, the pozzolanic activity of fly ash contributing to cementitious bonding and jute fibers helping to hold the material together by bridging small cracks, which makes the blocks stronger and more resistant to breaking. This is consistent with previous studies where natural fibers such as jute was shown to enhance the post-cracking behavior. and ductility of earthen construction materials.

Table 4.1 Values of strength for adobes from constructions in different locations.

Location	Compressive strength (MPa)
Aveiro– Portugal (Silveira et al. 2012)	1.17
Mexico 24 (Gavrilovic et al. 1998)	1.18
Mexico25 (Meli 2005)	0.51-1.57
Italy 28 (Liberatore et al. 2006)	0.29-1.56
Sylhet, Bangladesh	2.73

Table 4.1 presents strength values reported by other authors for adobe samples from various countries, alongside the results obtained in this study. In most of the referenced studies, simple compression tests were performed on adobe bricks or half bricks, without mention of any correction for confinement effects. As a result, this comparison is not strictly rigorous and is intended only to offer a general indication of the quality of the adobes analyzed here, in relation to those used in other regions. The results show that the strength values obtained in this study is more than the range reported by other authors.

Overall, the results demonstrate that the combined use of fly ash and jute fiber can significantly improve the compressive performance of adobe blocks. The findings also underscore that a balanced proportion of both additives is crucial to achieving optimal mechanical properties.

CHAPTER 5: CONCLUSION

5.1 Conclusion

- Adobe blocks modified with fly ash and jute fiber exhibited improved compressive strength compared to the control mix with no additives.
- The highest 28-day compressive strength was recorded at 2.73 MPa for the mix containing 1% fly ash and 1% jute fiber (Mix 3), representing a 56.8% increase over the control sample (1.74 MPa).
- Even at lower additive levels (0.5% each of fly ash and jute), significant strength gains were observed, indicating that small quantities of additives can meaningfully improve performance.
- The results also showed that combined use of fly ash and jute fiber synergistically enhances strength more effectively than using one additive alone.
- Strength continued to develop from 7 to 28 days across all mixes, affirming the suitability of these engineered adobe blocks for construction use with progressive load-bearing capacity.

Based on the findings, the mix with 1% fly ash and 1% jute fiber is recommended for optimal compressive strength while maintaining eco-friendly material composition.

5.2 Limitations

Below resides the limitations present in this study.

1. Only compressive strength was tested. Other important properties like tensile strength, flexural strength, and impact resistance were not measured.
2. Durability tests such as water absorption, erosion resistance, and freeze-thaw

performance were not conducted.

3. The thermal insulation ability and embodied energy of the adobe blocks were not evaluated.
4. The study only covered short-term strength (7-day and 28-day). Long-term effects like shrinkage, cracking, and aging were not assessed.

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