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PRODUCTION OF AFFORDABLE, ECO-FRIENDLY AND LIGHTWEIGHT MUD BLOCK MADE FROM EARTHENWARE CLAY SOIL FOR MODULAR RURAL HOUSING

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Abstract: Mud blocks are affordable, eco-friendly, and widely available construction materials. In Ethiopia, many people, especially in rural areas, construct walls by hand-packing mud onto sparsely placed wooden frames using locally sourced soil, straw, and water in unmeasured quantities. This traditional method, though common, often results in weak wall constructions that fail under rain and wind due to poor strength and durability.

This research aims to address these challenges by enhancing the compressive strength of mud blocks made from locally available earthenware clay soil through the addition of cement, lime, and cereal straw ash. By experimenting with different additive ratios, the study seeks to identify the optimal mix for maximum strength. The findings will guide communities on how to produce durable mud blocks and promote their use in wall construction.

The study also aims to inspire the construction industry to adopt these cost-effective and locally available materials for scientific, sustainable building practices. By improving the strength and lifespan of mud walls, this approach could modernize traditional housing systems while reducing dependence on wood and concrete, ultimately saving costs and fostering more resilient homes.

Keywords: Compressive strength, mud block, earthenware clay soil, cereal straw ash.

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1. Introduction

Mud blocks, made primarily from earth, have been a cornerstone of construction for thousands of years. Even today, around 30% of the global population still resides in earthen homes, particularly in hot and dry regions such as parts of Africa and the Arabian Peninsula. These blocks are valued for their low cost, environmental benefits, and availability of local materials (1).

Traditionally, mud blocks are made by mixing earth and water into a thick paste, often with straw added to prevent cracking and increase durability. This mixture is then shaped into blocks using molds or by hand, a method passed down through generations. Builders discovered through trial and error that clay plays a crucial role in binding the blocks together, with research suggesting an optimal clay content of 10–22% (2).

Throughout history, various additives like plant fibers, animal hair, and even manure have been used to enhance the strength and stability of mud blocks. Today, modern composite mud blocks continue this tradition by combining soil with additives that improve specific properties, such as water resistance and thermal performance. In regions rich in silt and clay, mud blocks remain a practical and cost-effective option, although their full potential has yet to be thoroughly explored through scientific research (3).

In Ethiopia, traditional building practices are still common, particularly in rural areas. Nearly half of the population uses basic techniques, such as applying mud to wooden frames or forming sun-dried adobe blocks. These homes are typically constructed using unstandardized mixtures of soil, straw, and water, resulting in varying block quality. While these methods are affordable and widely accessible, the durability of these structures is often poor, leaving them susceptible to damage from heavy rain and strong winds (4).

This study seeks to improve the quality of Ethiopia's traditional housing by promoting the use of locally available, inexpensive materials like soil and cereal bran ash as alternatives to wood and concrete blocks. By developing a scientifically designed mixing process, the study aims to enhance the strength and longevity of mud blocks, offering a sustainable and affordable solution for rural communities (5).

Cereal bran, a common additive in Ethiopian mud blocks, is often added through trial and error. However, its exact effect on block strength remains unclear, contributing to premature structural failures. This research aims to establish standardized methods for evaluating and improving the performance of mud blocks, providing practical support for those facing challenges in home construction. The study focuses on extensive experimentation to develop inexpensive, environmentally friendly, and locally sourced wall materials, specifically mud blocks made from clay soil and various additives. The findings will encourage the adoption of low-cost, locally sourced mud blocks as alternatives to wood, bricks, and concrete in wall construction (6).

By enhancing the strength, durability, and water resistance of traditional mud walls, this research aims to modernize and improve conventional housing systems. Using mud blocks can reduce construction costs and speed up the building process, making it a viable option for low-income communities (7).

The study also explores how different compositions, mixing methods, and additives influence the strength and thermal

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conductivity of mud blocks. Common additives, such as silica (SiO_2), alumina (Al_2O_3), and iron oxide (Fe_2O_3), interact chemically at different temperatures to improve block properties. This study will provide valuable insights into the performance of clay-based mud blocks, offering laboratory-tested data for the construction industry, especially in urban settings. These findings will support future research and promote sustainable, cost-effective building practices (8).

Throughout history, building materials have played a crucial role in creating safe, climate-friendly shelters. Early humans used caves, trees, and simple materials like soil, stone, and wood for shelter. Mud and clay were among the first materials used because of their moldability and adhesive qualities when mixed with natural fibers. Additives like straw, grass, husks, and agricultural waste reinforced these materials, making them more durable against harsh weather conditions. Dung was often used as well, and wooden molds shaped adobe bricks (9) (2).

In addition to mud blocks, other ancient techniques such as rammed-earth walls and the use of logs, sticks, thatch, and stone were widely employed. In colder regions like the Arctic, the Inuit used ice blocks to build igloos, while ancient cyclopean architecture relied on massive stones stacked together. Many historical religious structures were also built using natural materials like stone, lime, and wood, reflecting their durability and availability.

Today, advancements in materials science have introduced modern composites like concrete, cement, and aerated concrete, along with plastics, which are lightweight, affordable, and easily molded. Glass has also become a prominent architectural feature, allowing for greater natural light in modern buildings. However, many rural and semi-urban areas still rely on traditional materials like mud bricks, which offer excellent thermal and acoustic properties and remain affordable and accessible (10) (2) (11).

Stabilized mud blocks, in particular, are energy-efficient and environmentally friendly. They present an excellent solution for rural and semi-urban construction. Their production provides opportunities for training young, unemployed individuals in simple construction techniques. By adopting this technology, communities can achieve durable, cost-effective housing while empowering local labor forces.

This manual aims to share knowledge about stabilized mud block technology and provide training to encourage its adoption. By equipping young people with these skills, the construction industry can address housing needs in rural and semi-urban areas in an effective and sustainable way.

2. Material and Methods

2.1. Materials

The materials used in this study to produce mud blocks were clay soil and sand as the main matrix and cement, lime, cereal straw fiber and cereal straw fiber ashes as additive materials to activate the reaction.

a) Clay Soil: Clay soils are old, tightly packed soils that formed and condensed over long periods of time. They're found all over the world, including in most parts of Ethiopia. One sure way to recognize clay soil is if water sits around after a rain, or if your soil is sticky. It is a natural material which was collected at a mountain named Key Gedel in south Wollo zone, Amhara region, Ethiopia.

Figure 1: Clay Soil

Figure 1 Alt Text: Photo showing earthenware clay soil used for the experiment.

b) Sand: Sand is a mixture of very small pieces of different rocks or minerals. It is the same minerals from which those pieces are broken, such as granite and feldspar. Sand is gritty to touch. It is a naturally occurring granular material composed of finely divided rock and mineral particles. Sand can be easily found at rivers and were collected from farmers and sand merchants.

c) Cement: Cement is a fine, soft powder used as a binder because it hardens after contact with water. It is produced from a mixture of limestone and clay that's charred and then ground up. Two types of cement (OPC and PPC) can be easily found in the market. Here OPC type cement was purchased from the market.

d) Lime: Lime is inorganic material composed primarily of calcium oxides and hydroxides, usually calcium oxide and/or calcium hydroxide. It is also the name for calcium oxide which occurs as a product of coal-seam fires and in altered limestone xenoliths in volcanic ejecta and it can be used for activation of the reaction. Lime can be easily found and was collected from the market.

e) Cereal straw: Cereal straw is the end waste material which is isolated from edible cereal. It was collected from merchants and farmers who lead their way of life in agriculture by producing cereals straws like teff.

Figure 2: Cereal straw fiber

Figure 2 Alt Text: Photo showing cereal straw fiber used for the experiment.

f) Cereal straw Ash: Cereal straw fibers were exposed to fire and were burnt and wait until the cereal straw fiber turned in to ashes. The ash was sieved through 425μm sieve to remove unburned particles and to get the final fine ash.

Figure 3: Cereal straw fiber ash

Figure 3 Alt Text: Photo showing cereal straw fiber burning and its ash used for the experiment.

g) **Water:** Water is a very necessary material to make mud block mixture and it should be used in pure form from tap water. Here water was used from tap water with variable amount for a suitable mud mixture.

2.2. Methods

2.2.1. Laboratory Tests (Before mud block sample preparation)

Before the production of mud block samples which are made from a mixture of earthenware clay soil, sand, cereal straw, cereal straw ash and water with the required amount, necessary tests were performed based on ASTM specification and the following tests and results were found.

a) Gradation Test

A sieve analysis was conducted to determine the particle size distribution of the soil. Representative samples, which had been oven-dried, were used for the test. The soil samples were passed through a 425µm sieve, and the fraction that passed through was air-dried. This material will be used for the production of mud blocks and for additional tests. The sieving process was carried out manually using a set of sieves and manual shakers.

Figure 4: Sieved clay soil sample

Figure 4 Alt Text: Photo showing sieved earthenware clay soil sample used for the experiment.

b) Atterberg Limit Test

This test measures the clay content of the soil in terms of liquid limit, plastic limit, and plasticity index to estimate the soil's plasticity, strength, and settlement characteristics. To determine the liquid limit, a 125g sample of soil, passing through a 425µm sieve, was mixed with water to form a thick, homogeneous paste. The paste was placed in the Casagrande apparatus cup, where a groove was created, and the number of blows required to close the gap was recorded. For the plastic limit determination, a 125g sample of soil, also passing through the 425µm sieve, was mixed with water until it became homogeneous and plastic enough to be shaped into a ball. The ball was then rolled on a glass plate until it cracked at approximately 3mm in diameter. The soil sample, now with a 3mm diameter, was placed in an oven at 105°C to determine the plastic limit.

Figure 5: Atterberg limit test

Figure 5 Alt Text: Photos showing test setup and procedure of Atterberg limit test for the soil sample.

Summary of the results obtained from laboratory experimental tests conducted on clay soil sample to determine its suitability as a construction material is shown below;

Table 1: Atterberg limit test result

	Properties	Value (%)
1	Colour	Red
2	Natural Moisture Content	19.5
3	Percentage passing sieve no 425µm	87.5
4	Liquid Limit	30.5
5	Plastic Limit	21.3
6	Plasticity index	9.2
7	Specific Gravity	2.81

Using the AASHTO Manual, Reapproved 1997, (Section D3282-93) method of soil classification, the soil samples fall into group A-2-4 (Silty or clayey gravel and sand), which is a suitable soil for mud block production.

2.2.2 Mud block sample preparation

After the soil samples were collected, the soil samples were air-dried for 14 days to allow partial elimination of natural water which may affect analysis, then sieved through 425µm sieve to obtain the final soil samples for the tests. The test conducted include natural moisture content, specific gravity, sieve analysis particle size distribution (PSD), liquid limit, plastic limit, plasticity index.

The required weights of mud block ingredients were prepared for each batch. The total weight of the sand and clay soil was always kept constant and equal to 2200gm for each batch. The amount of hay was kept constant in all the specimens and the cereal straw fiber weight was 10gm representing 0.5% of the total weight of the clay soil for one group batch and the other batch were considered without the addition of cereal straw fiber.

Figure 6: Weighing of materials

Figure 6 Alt Text: Photos showing the determination of sample weight for clay soil and additive materials.

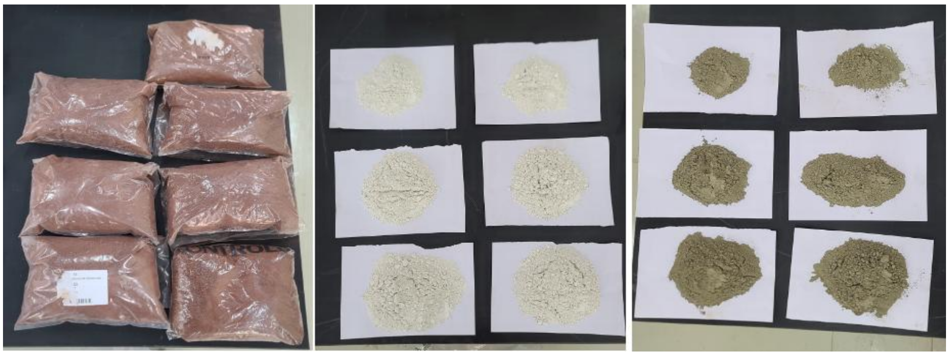

Figure 7: Materials getting ready to be mixed

Figure 7 Alt Text: Photos showing clay soil and additive materials getting ready to be mixed.

Depending up on the batch, first, clay soil, sand, cereal straw fiber and selected additives with known weight was mixed for few minutes, and then water was be added gradually until reaching a homogeneous paste. The mixing process was done manually.

Figure 8: Mud Mixture

Figure 8 Alt Text: Photos showing the mud mixture with and without cereal straw fiber

The mud mix was placed and compacted in plastic cylindrical molds in three layers. After casting the cubic samples, all top surfaces were given a smooth final finish by a straight edge. The plastic cylindrical mold has an internal diameter and height of 100×200mm respectively (as per ASTM standard). After casting the cylindrical samples, the mud block specimens were taken out of the molds and left to dry in the air.

Figure 9: Cylindrical mud block specimens

Figure 9 Alt Text: Photos showing the produced cylindrical mud block specimens

Enough representative samples were prepared as per the standard to represent each mix cases. Two mix cases were considered for the preparation of mud block samples;

1) Clay + Sand + Water + Cereal straw fiber + **Additives**
2) Clay + Sand + Water + **Additives**

Four additive cases were considered;

- No Additive
- Cement (6%, 8% and 10%)
- Lime (6%, 8% and 10%)
- Cereal Straw Fiber Ash (6%, 8% and 10%)

Batch Mix One: Mud block without cereal straw fiber

Table 2: Detail description for each mix cases without cereal straw fiber

Test No	Clay (gm)	Sand (gm)	Cement (gm)	Lime (gm)	Cereal straw fiber ash (gm)	No of samples
1	2000	200	-	-	-	3
2	2000	200	120	-	-	3
3	2000	200	160	-	-	3
4	2000	200	200	-	-	3
5	2000	200	-	120	-	3
6	2000	200	-	160	-	3
7	2000	200	-	200	-	3
8	2000	200	-	-	120	3
9	2000	200	-	-	160	3
10	2000	200	-	-	200	3

Batch Mix Two: Mud block with cereal straw fiber

Table 3: Detail description for each mix cases with cereal straw fiber

Test No	Clay (gm)	Sand (gm)	Cereal straw fiber (gm)	Cement (gm)	Lime (gm)	Cereal straw fiber ash (gm)	No of samples
1	2000	200	10	-	-	-	3
2	2000	200	10	120	-	-	3
3	2000	200	10	160	-	-	3
4	2000	200	10	200	-	-	3
5	2000	200	10	-	120	-	3
6	2000	200	10	-	160	-	3
7	2000	200	10	-	200	-	3
8	2000	200	10	-	-	120	3
9	2000	200	10	-	-	160	3
10	2000	200	10	-	-	200	3

2.2.3 Setup for Compressive Strength Test

The laboratory tests conducted in this study adhered to ASTM specifications and followed the appropriate procedures. The primary objective of the compressive strength test is to evaluate the performance and quality of materials used in construction projects. This test helps determine whether materials are suitable for specific applications, such as load-bearing structures, and ensures that they meet the required strength standards. It is essential for assessing the ability of concrete to withstand load and identifying the point at which it will fail.

The testing procedure focuses on investigating the strength characteristics of mud block samples. The laboratory equipment used for testing cylindrical mud block specimens was the UTEST machine. During the test, a single mud block specimen is placed between the jaws of a crushing machine, and pressure is applied until the block breaks. The ultimate pressure at which the mud block fails is then recorded.

The potential outcomes of this test include the maximum compressive strength, the load-bearing capacity, and graphs showing the load-time and stress-time relationships. The experimental measurements aimed to observe the progression of cracks as the load increased, the crack pattern prior to failure, and the ultimate capacity of the mud block samples.

Figure 10: Test setup

Figure 10 Alt Text: Photos showing the test setup for compressive strength machine

This test was conducted to gather data on the compressive strength of mud blocks, also referred to as crushing strength. A total of 20 mud block specimens, each with different ingredient proportions, were brought to the laboratory for testing. The compression strength of each specimen was tested individually. In total, 60 specimens across three trials were tested, and the average value of the three specimens was taken as the compressive or crushing strength of the mud blocks. The figure below illustrates the failure load for these specimens. As the load increased, cracks formed along the sides of the tested specimens. The width and length of the cracks gradually increased until the specimen eventually collapsed

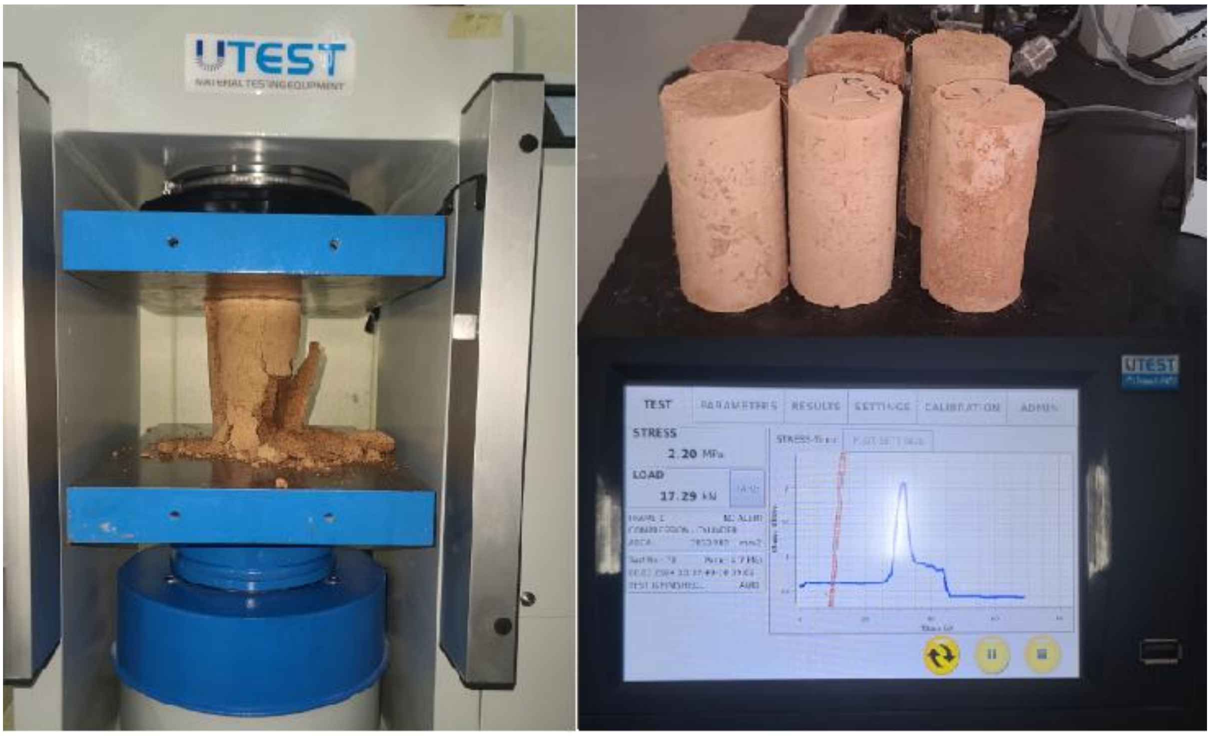

Figure 1: Testing mud blocks

Figure 11 Alt Text: Photos showing tested and failed cylindrical mud block specimens and the displayed test result of the compressive strength machine.

3. Result and Discussion

The results from all experiments are displayed in the form of tables and graphs. It consists of two parts; the first part discuss about the experimental result for mud block of cylindrical specimens made up of clay soil without cereal straw fiber and on the second part the experimental result for mud block of cylindrical specimens made up of clay soil with cereal straw fiber are discussed in detail. In both cases over sixty cylindrical mud block specimens were prepared and each specimens were tested to obtain the maximum load carrying capacity and the maximum compressive strength of the mud block. In this study additive materials of cement, lime and cereal straw fiber ash were considered and added in to the mud mix with variable percentage amount of 6%, 8% and 10% of the weight of clay soil. All test result that represent compressive strength and maximum load carrying capacity values origins from the experimental test.

3.1. Mud Mix without cereal straw fiber

The compressive strength of mud block was investigated in this section. Over thirty tests were carried out; it derives the maximum load bearing capacity and maximum compressive strength of the mud block. The basic content of the block samples were clay soil, sand, water and variable proportion of additives. Several additive materials have been added to the basic mud mixture to achieve maximum compression capacity. Cereal straw fiber materials in this case were not considered: but, cement, lime and cereal straw fiber ashes were considered as additives. The experimental results of the survey had given the following values;

Table 4: Experimental result of the mud block specimens without cereal straw fiber

No	Sample Description	Weight (Kg)	Maximum Load Carrying Capacity (KN)	Compressive Strength (MPa)
1	Clay + Sand	2.3	13.6	1.73
2	Clay + Sand + 6% Cement	2.31	16.21	2.06
3	Clay + Sand + 8% Cement	2.33	19.91	2.54
4	Clay + Sand + 10% Cement	2.36	23.43	2.98
5	Clay + Sand + 6% Lime	2.34	14.1	1.8
6	Clay + Sand + 8% Lime	2.32	14.8	1.89
7	Clay + Sand + 10% Lime	2.35	16.4	2.09
8	Clay + Sand + 6% CS Ash	2.29	13.8	1.76
9	Clay + Sand + 8% CS Ash	2.29	15.4	1.96
10	Clay + Sand + 10% CS Ash	2.27	18.2	2.32

The table shows the variation of maximum load carrying capacity and variation of compressive strength of mud blocks at variable additive materials with variable percentage. For better clarification the result is displayed in graph as follows:

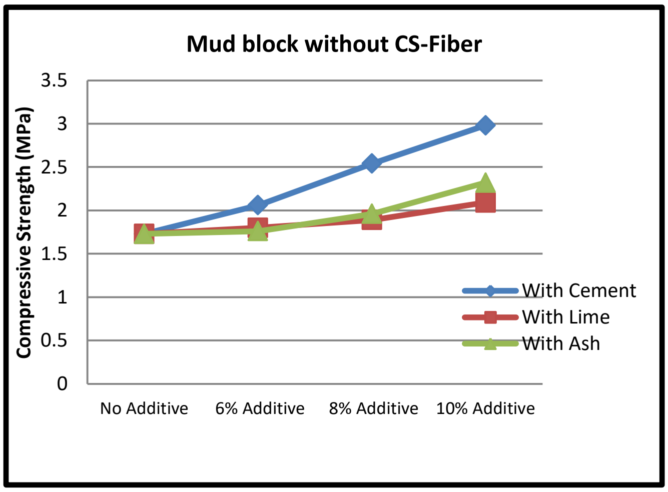

Figure 2: Compressive strength of mud block specimens without CSF

Figure 12 Alt Text: Graph showing the compressive strength of mud block specimens without cereal straw fiber for various additives.

In the graph cement used as an additive shows a great improvement on the compressive strength of mud block and as the percentage of cement increases then the compressive strength also greatly increases. In early additive percentage (6%) lime as an additive shows a little bit better increments in the compressive strength than CS-Fiber ash but afterward in additive percentages of 8% and 10% CS-Fiber ash was a better additive to obtain maximum compressive strength of mud blocks.

3.2 Mud Mix with cereal straw fiber

The compressive strength of mud block was investigated in this study. Over thirty tests were carried out for this mix case; it derives the maximum load bearing capacity of the mud block. The basic content of the block samples were clay soil, sand, cereal straw fiber, water and variable additives. Several additive materials have been added to the basic mud mixture to achieve maximum compression capacity. Cereal straw fiber materials in this case were considered: and cement, lime and cereal straw fiber ashes were considered as additives.

The table below shows the variation of maximum load carrying capacity and variation of compressive strength of mud blocks at variable additive materials with variable proportion.

The experimental results of the survey have given the following values;

Table 5: Experimental result of the mud block specimens with cereal straw fiber

No	Sample Description	Weight (Kg)	Maximum Load Carrying Capacity (KN)	Compressive Strength (MPa)
1	Clay + Sand + CS Fiber	2.27	14.87	1.9
2	Clay + Sand + CS Fiber + 6% Cement	2.24	17.28	2.2
3	Clay + Sand + CS Fiber + 8% Cement	2.31	20.87	2.66
4	Clay + Sand + CS Fiber + 10% Cement	2.32	20.32	2.59
5	Clay + Sand + CS Fiber + 6% Lime	2.31	16.2	2.06
6	Clay + Sand + CS Fiber + 8% Lime	2.31	18.3	2.33
7	Clay + Sand + CS Fiber + 10% Lime	2.27	19.8	2.52
8	Clay + Sand + CS Fiber + 6% CS Ash	2.26	15.1	1.92
9	Clay + Sand + CS Fiber + 8% CS Ash	2.27	19.1	2.43
10	Clay + Sand + CS Fiber + 10% CS Ash	2.25	19.6	2.5

For better clarification the result were displayed in graph as follows:

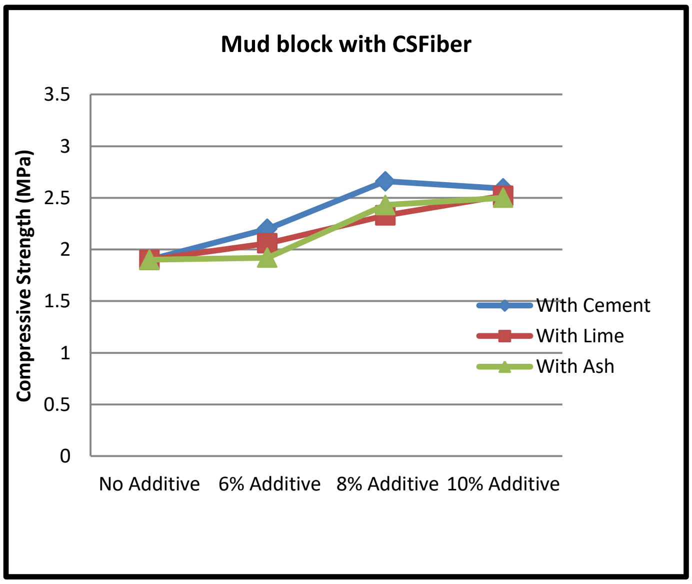

Figure 3: Compressive strength of mud block specimens with CSF

Figure 13 Alt Text: Graph showing the compressive strength of mud block specimens with cereal straw fiber for various additives.

In the graph in early additive percentage 6% and 8% cement used as an additive shows a great improvement on the compressive strength of mud block but at 10% of additive percentage the compressive strength of the mud block declines this implies that the optimum additive percentage of cement is around 8%. On the other hand lime and ash used as an additive shows a great increment on the compressive strength of mud block, this implies that lime and ash has a good bond with cereal straw fiber. The bond between lime or CS-Fiber ash with cereal straw fiber is good enough to increase the compressive strength of mud block.

3.3 Comparison of mud block with and without cereal straw fiber

The graphs below shows the variation of load carrying capacity of the mud block with and without cereal straw fiber for each additive cases and it helps us to understand the effect of cereal straw fiber on the load carrying capacity of mud block.

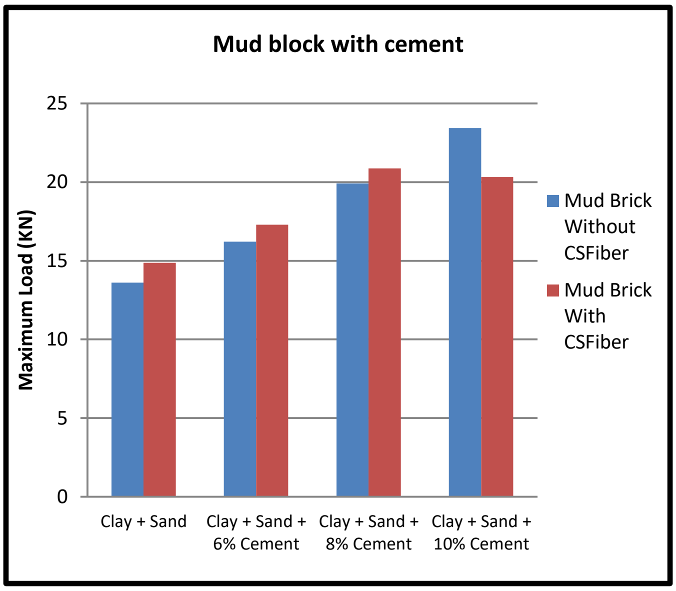

Figure 4: Maximum load of mud block specimens

Figure 14 Alt Text: Graph showing the maximum load carrying capacity of mud block specimens with and without cereal straw fiber for cement as an additive.

The graph shows the effect of increasing cement percentage on the load carrying capacity of the produced mud block. The result show that the load carrying capacity increases with an increase of cement percentage for mud block specimens produced without cereal straw fiber. At maximum cement percentage which is 10%, load carrying capacity of the mud block samples was 23.43KN. On the other hand mud block produced with cereal straw fiber shows an increase in load carrying capacity until cement percentage of 8%. Increasing cement percentage above 8% led to a decrease in the load carrying capacity of the mud blocks. At this optimum cement percentage, load carrying capacity of the mud block samples was 20.87KN.

Figure 15 Alt text: shows the effect of increasing lime percentage on the load carrying capacity of the produced mud block. The result show that the load carrying capacity increases with an increase of lime percentage for both mud blocks produced with and without cereal straw fiber. In this case adding cereal straw fiber on the mud mix shows a great increment on the load carrying capacity. At maximum lime percentage which is 10%, load carrying capacity of the mud block samples was 19.8KN.

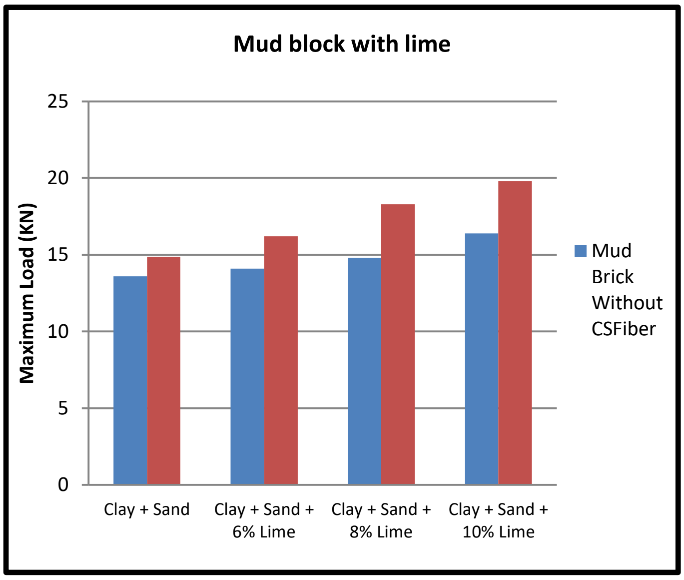

Figure 5: Maximum load of mud block specimens produced from lime

Figure 15 Alt Text: Graph showing the maximum load carrying capacity of mud block specimens with and without cereal straw fiber for lime as an additive.

The graph shows the effect of increasing CS-Fiber ash percentage on load carrying capacity of the produced mud block. The results show that in CS-Fiber ash percentage of 6% the maximum load does not show a significant increment but on CS-Fiber ash percentage of 8% and 10% the maximum load shows a great increment. In this case adding cereal straw fiber on the mud mix shows an increment on the load carrying capacity. At maximum CS-Fiber ash percentage which is 10%, load carrying capacity of the mud block samples was 19.6KN.

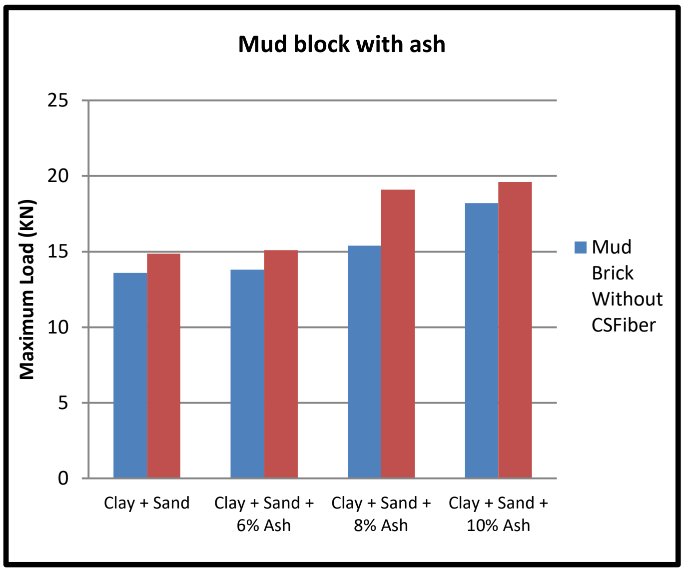

Figure 6: Maximum load of mud block specimens produced from CSF ash

Figure 16 Alt Text: Graph showing the maximum load carrying capacity of mud block specimens with and without cereal straw fiber for CSF ash as an additive.

The graphs below shows the variation of compressive strength of the mud block with and without cereal straw fiber for each additive cases and it helps us to understand the effect of cereal straw fiber on the compressive strength of mud block.

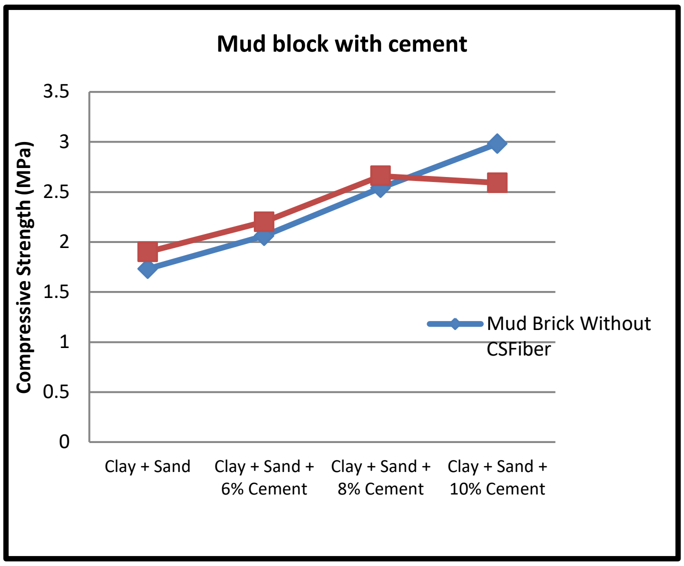

Figure 7: Compressive strength of mud block specimens produced from cement

Figure 17 Alt Text: Graph showing the compressive strength of mud block specimens with and without cereal straw fiber for cement as an additive.

The above graph shows variation on the compressive strength of mud block with and without cereal straw fiber for a variable percentage of cement additives. The result shows that the compressive strength increases with an increase of cement percentage for mud blocks produced with cereal straw fiber. A decline of compressive strength was observed for the mud blocks produced with cereal straw fiber for the maximum cement percentage. At maximum cement percentage, compressive strength of the mud block samples was 2.98MPa.

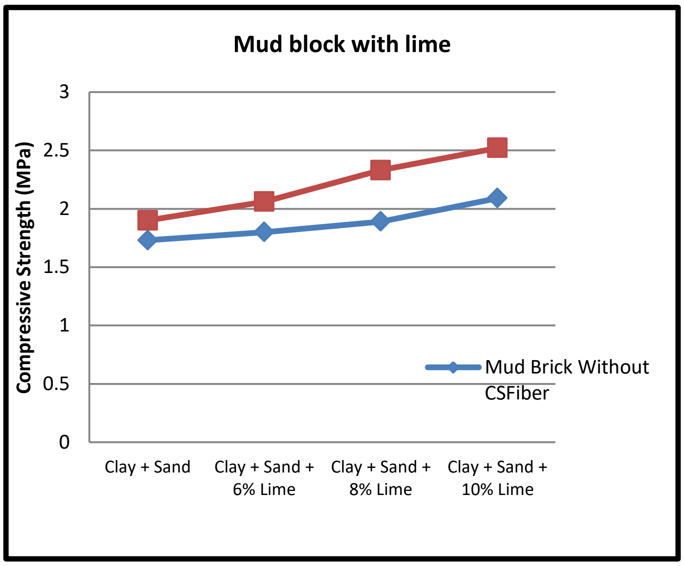

Figure 8: Compressive strength graph of mud block specimens produced from lime

Figure 18 Alt Text: Graph showing the compressive strength of mud block specimens with and without cereal straw fiber for lime as an additive.

The above graph shows variation on the compressive strength of mud block with and without cereal straw fiber for a variable percentage of lime additives. The result shows that the compressive strength increases with an increase of lime percentage for both mud blocks produced with and without cereal straw fiber. The gap of the two graph lines (red and blue) is visible; this means adding cereal straw fiber on the regular mud mix will have a significant increment on the compressive strength. At maximum lime percentage, compressive strength of the mud block samples was 2.52MPa.

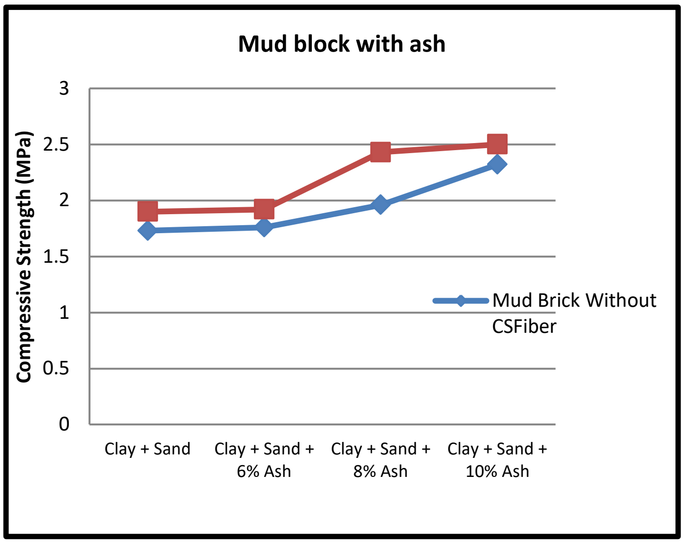

Figure 9: Compressive strength graph of mud block specimens produced from CSF ash

Figure 17 Alt Text: Graph showing the compressive strength of mud block specimens with and without cereal straw fiber for CSF ash as an additive.

The above graph shows variation on the compressive strength of the mud block with and without cereal straw fiber for a variable percentage of cereal straw fiber ash additives. The result shows that the compressive strength increases with an increase of CS-Fiber ash percentage for both mud blocks produced with and without cereal straw fiber. At the early stage of the graph, the graph lines seems like a straight line which implies that adding CS-Fiber ash with percentage of 6% does not affect the mud mixture very much. At CS-Fiber ash percentage of 8% and by adding cereal straw fiber on the mix the compressive strength increases from 1.96MPa to 2.43MPa this shows higher increment relative to the others. At maximum CS-Fiber ash percentage, compressive strength of the mud block samples was 2.5MPa.

Comparing Figure 19, Figure 20 and Figure 21: shows that whatever the mix is produced from and whether adding cereal straw fiber or not, mud blocks produced form cement additive has a better compressive strength. Furthermore addition of cereal straw fiber is more effective for the mud mix produced by lime additive than the others.

The compressive strength of the mud block samples produced with and without cereal straw fiber with the respective percentage increment of compressive strength was tabulated in the table below.

Table 6: Compressive strength and percentage increment of mud block specimens

Mud Mix Additives	Without Cereal Straw Fiber		With Cereal Straw Fiber	
	Compressive Strength (MPa)	% Increment	Compressive Strength (MPa)	% Increment
6% Cement	2.06	**19.19**	2.2	**16.2**
8% Cement	2.54	**46.4**	2.66	**40.35**
10% Cement	2.98	**72.28**	2.59	**36.65**
6% Lime	1.8	**3.68**	2.06	**8.94**
8% Lime	1.89	**8.82**	2.33	**23.06**
10% Lime	2.09	**20.6**	2.52	**33.15**
6% CS-Fiber Ash	1.76	**1.47**	1.92	**1.55**
8% CS-Fiber Ash	1.96	**13.24**	2.43	**28.45**
10% CS-Fiber Ash	2.32	**33.82**	2.5	**31.81**

The table shows that the maximum compressive strength is obtained from a mud mixture mixed with cement as additive with 10% amount; in this case the maximum compressive strength obtained was 2.98MPa. Here adding cement in to the common mud mixture with the maximum weight percentage increase the compressive strength by 72.28%. Adding lime as additive with weight percentage of 10% in the common mud mixture increase the compressive strength by more than 20.6% but the increment in the compressive strength with lime weight percentage of 6% is insignificant and increases the compressive strength by only 3.68%.

Adding cereal straw fiber ash as additive with weight percentage of 10% in the common mud mixture increase the compressive strength by more than 33.82% which is better than adding lime in the mix, but the increment in the compressive strength with cereal straw fiber ash of weight percentage of 6% is insignificant and increases the compressive strength by only 1.47%. The mud mixture produced from cereal straw fiber for additives cases of lime and cereal straw fiber ash, the compressive strength increase significantly this implies the bond between cereal straw fiber and the additives are good enough to improve the compressive strength.

4. Conclusion

This study examined the compressive strength of mud blocks, conducting over sixty tests to determine the optimal load-bearing capacity of the blocks produced. The basic components of the mud block samples included clay soil, sand, water, additives, and either the presence or absence of cereal straw fiber. Various additive materials cement, lime, and cereal straw fiber ash were incorporated into the mud mixture to maximize the compressive strength of the blocks.

The results indicated that increasing the cement content significantly enhanced the compressive strength of the mud blocks. For example, increasing cement content from 6% to 10% resulted in a 53.09% increase in compressive strength. The strength of the mud block was found to be more sensitive to variations in cement content than to the addition of cereal straw fiber. Therefore, increasing cement content appears to be a more effective way to boost compressive strength than adding cereal straw fiber.

Similarly, increasing lime content also improved the compressive strength of the mud blocks, although to a lesser extent. For instance, increasing lime content from 6% to 10% resulted in a 16.92% increase in compressive strength. While the addition of lime enhanced strength, it had a smaller effect compared to cement. Moreover, the amount of water in the clay-cement mixture must be carefully controlled; adequate moisture is required for cement hydration, but excess water can reduce strength and increase porosity.

The presence of cereal straw fiber had a notable impact on the mud block's compressive strength, particularly when combined with additives. For example, when lime content in the mud mix with cereal straw fiber was increased from 6% to 10%, the compressive strength increased by 24.21%. This was significantly higher than the 16.92% increase observed in mud blocks without cereal straw fiber. The same trend was observed with cereal straw fiber ash. Increasing the fiber ash content in the mud mix with cereal straw fiber from 6% to 8% resulted in a 26.9% increase in compressive strength, compared to only an 11.77% increase in blocks without fiber. Overall, adding cereal straw fiber to the mix greatly enhanced the compressive strength of the mud blocks.

From the experimental investigation, the following conclusions were drawn:

- Adding cement to the mud block mixture increased compressive strength, although higher cement content may not be cost-effective.
- The optimal cement percentage for mud blocks containing cereal straw fiber was found to be 8%. Higher cement content beyond this point led to a decrease in compressive strength.
- Cereal straw fiber had a significant positive impact on the compressive strength of mud blocks.
- For mud blocks containing cereal straw fiber, adding cement slightly improved strength up to a certain limit, beyond which the strength decreased.
- The addition of lime and cereal straw fiber ash increased the strength and load-bearing capacity of blocks made with cereal straw fiber.
- The most significant increase in compressive strength occurred when cement was used as an additive material.

Based on the experimental investigation, several key recommendations were made for the use and improvement of mud blocks in construction. It was suggested that further research is needed to study soil samples from different locations and understand the weathering effects on stabilized mud blocks. Given their affordability and availability, it is recommended that the Ethiopian government and development organizations consider using mud blocks for low-cost housing projects. To minimize weathering impacts, blocks with low water resistance should be used as partition walls. For external walls, protective measures should be taken against environmental effects. To scale up production and empower local communities, machine production of mud blocks is advised for better quality and efficiency, with training provided to local laborers to operate these machines, thus creating job opportunities. Additionally, a preliminary site assessment should be conducted before excavation work begins.

Data Availability Statement

The data sets generated and analyzed during the course of this study are not publicly available to ensure confidentiality and compliance with relevant ethical guidelines. However, the data can be made available upon reasonable request to the corresponding author. Such requests will be evaluated on a case-by-case basis, considering the purpose of the request and ensuring proper use in alignment with ethical and legal standards.

Declaration of Competing Interest

We have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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