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Stabilized Mud Block-Mix Optimization and Structural Testing

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Abstract: ***India is a rapidly developing nation, and its growth depends heavily on the availability of good-quality construction materials. To reduce the pressure on natural resources it has become essential to adopt alternative materials that are reusable, recyclable, cost-effective, and environmentally friendly. These alternatives should also offer good performance and low transportation costs. Cement production, in particular, has a significant environmental impact, contributing to issues such as ozone depletion, acid rain, and global warming. A major portion of pollution today comes from large-scale construction activities and industrial waste. One practical solution is to replace traditional burnt clay bricks with Compressed Stabilized Mud Blocks (CSMBs) made from locally available soil. Since these blocks do not require firing, they eliminate the carbon emissions associated with brick kilns, making them a sustainable masonry option. Cement can be partially or fully replaced with materials like hydrated lime, and fly ash. Considering that the production of one ton of cement releases nearly one ton of carbon dioxide, reducing cement usage can significantly lower environmental impact. By adopting these alternatives, we can move toward more sustainable, eco-friendly, and resource-efficient construction practices.***

Keywords: Natural resources, environmentally friendly, Fly ash, Hydrated lime, Eco-friendly materials, Sustainable construction.

1. Introduction

The construction sector is one of the biggest users of natural resources and energy in the world. It plays a large role in global carbon emissions. Traditional building materials like fired clay bricks need high-temperature kiln firing. This process uses a lot of fossil fuel energy and releases significant amounts of carbon dioxide (CO_2) into the atmosphere. With rapid urbanization and demand for housing and infrastructure growing, the environmental effects of conventional materials have raised major concerns for engineers, planners, and policymakers.

Earth has been used as a construction material for centuries because soil is widely available, construction is simple, and costs are low. However, traditional mud blocks without stabilization have poor strength, absorb a lot of water, and have limited durability. This limits their use mainly to temporary or non-load-bearing structures. Improvements in material engineering have led to stabilized mud blocks. These blocks combine soil with stabilizing agents like cement, lime, and byproducts such as fly ash to improve strength and durability.

Stabilized Mud Blocks (SMBs) do not require firing, which greatly reduces energy use and pollution. Using locally sourced soil cuts down transportation costs and supports sustainable building practices. Despite these benefits, the widespread use of SMBs is limited by differences in soil properties, the absence of standardized mix designs, and a lack of awareness about their structural performance. Thus, thorough experimental studies are necessary to determine reliable mix proportions and performance traits to build trust in SMB technology.

This study aims to tackle these issues through a systematic experimental investigation of stabilized mud blocks with different stabilizing agents, comparing their mechanical performance and durability.

2. Objectives of the Study

The research was undertaken with the following objectives:

1) To determine optimal mix proportions for strength and cost-effectiveness.
2) To investigate durability under weathering, moisture, or seismic conditions.
3) To compare SMB with conventional bricks in terms of strength, cost, and environmental impact.
4) To develop design guidelines for using SMB in sustainable construction.

3. Materials and Methodology

Materials

3.1 Red Soil

Locally available red soil was used as the primary material for block production. The soil exhibited moderate plasticity and contained a balanced proportion of sand, silt, and clay, making it suitable for stabilized block manufacturing.

Table 1: Properties of Red Soil

Property	Value
Specific Gravity	2.65
Plastic limit (%)	32.74
Moisture Content	12.23
Soil Classification	Poorly graded

Ordinary Portland Cement (OPC)

Ordinary Portland Cement (OPC 53 Grade) was used as a stabilizing agent to enhance early strength development.

Cement contributes to improved particle bonding and reduced water absorption due to hydration reactions.

Hydrated Lime

Hydrated lime was incorporated to promote long-term strength development and reduce shrinkage. Lime reacts slowly with soil minerals and fly ash, generating cementitious products that improve durability over time.

Fly Ash

Class F fly ash obtained from a thermal power plant was used as a supplementary stabilizer. Fly ash enhances workability and long-term performance while improving sustainability by recycling industrial waste.

Manufactured Sand (MSand)

Manufactured sand was used to improve particle gradation and block density, contributing to enhanced compressive strength.
Water

To guarantee consistent hydration responses, potable water devoid of contaminants was utilized for mixing and curing.

Properties of Flyash

- Fineness:
- Fly ash particles are very fine, often finer than cement
- Pozzolanic activity: Reacts with lime to form cementitious compounds.
- Low heat of hydration: Reduces temperature rise in concrete.
- Improves workability: Enhances flow and reduces water demand in concrete mixes.
- Sustainability: Utilizes industrial waste, reducing landfill needs.

Properties of Hydrated Lime:

- Alkaline nature: High pH, makes it useful for pH adjustment.
- Water retention: Absorbs water, useful in construction and agriculture.
- Reactivity: Reacts with acids and pozzolans (like fly ash) to form stable compounds.
- Antimicrobial: Has disinfectant properties.
- Uses: Soil stabilization, construction, water treatment, and more.

4. Experiments to Determine Properties of Sand

Determination of Water Content

12 ml of one clean container with lid (if fitted) being taken and its mass in grams, (g) numeral Container/article number (m1 with no. The article No:3m1). P.S.: Container with lid or bottle with stopper should be number equal and combined. A container is gripped into which a sample of wet soil is crumbled and deposited. In grams (m2), the container with lid is weighed. Lid is removed, and both are put in oven together. It is then dried continuously at 105±5 0 (or other temperatures- See, in some applications) according to an International standard for dry soil ASTM D 2216.A period of 16 to 24 hours is usually sufficient, but this varies with soil type. It will also vary if the oven contains a large number of samples or very wet samples. The soil is considered dry when the differences in successive weighing of the cooled soil at 4-hour intervals do not exceed 0.1% of the original mass.

Figure 1: Containers

$$w = \frac{m_2 - m_3}{m_3 - m_1} \times 100\%$$

Calculations:

Water content,

Observations

Table 2: Priliminary Analysis of water content test

S. No	Description	1	2	3
1	Container No	GT-99	B-2	GT-5
2	Weight of container in gms	13	12	10
3	Weight of container + wet soil in gms	79	67	69
4	Weight of container + dry soil in gms	74g	61g	69g
5	Weight of water in gms (4 – 5)	5	6	4
6	Weight of dry soil in gms (5 – 3)	61	49	55
7	Water content in %, w = 6 * 100 / 7	8.19	12.24	9.24

Result

Average water content of soil = 12.23%

Conclusion

The average water content of the soil is 12.23%, hence it is within the range (12-18%) so it is suitable for construction.

Specific gravity determination

Specific gravity of soil was conducted as per IS 2380part 3 section 1. It is determined by using pycnometer. Dry the pycnometer and weigh it with its cap (W1). Take about 200g to 300g of oven dried soil passing through 4.75mm sieve into the pycnometer and weigh again (W2). Add water to cover the soil and screw on the cap. Shake the pycnometer well and fill the pycnometer with water and weigh it (W3). Clean the pycnometer by washing thoroughly. Fill the cleaned pycnometer completely with water up to its top with cap screw on. Weight the pycnometer after drying it on the outside thoroughly (W4).
Specific Gravity, (GS) = (W2-W1)/ ((W2-W1) -(W3-W4)).

The apparatus used to determine the specific gravity of soil is given below in Fig. 2.

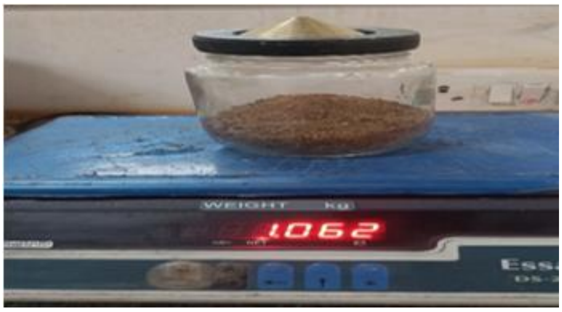


Figure 2: Pycnometer Bottle

$$G = \frac{(W_2 - W_1)G_T}{(W_4 - W_1) - (W_3 - W_2)}$$

Calculations:
The specific gravity, G is calculated from,

Observations:

Table 3: Preliminary Analysis of Specific Gravity test

S. No	Description	1	2	3
1	Weight of pycnometer W1 in gms	568g	568g	568g
2	Weight of pycnometer + Dry soil W2 in gms	1062g	1048g	1029g
3	Weight of pycnometer + Soil + Water W3 in gms	1755g	1781g	1773g
4	Weight of pycnometer + Water W4 in gms	1577	1577	1577
5	Temperature of Water T in °C	1	1	1
6	Specific gravity of soil solids G	1.56	1.73	1.73

Result:
Average specific gravity of the soil solids by pycnometer = 2.656.

Conclusion:
The average specific gravity of the given soil sample was determined to be 2.656.

According to the standard ranges (2.65–2.85), a result of 2.656 classifies this sample as a normal inorganic soil, likely consisting of quartz/sand or silty.

Grain size analysis
This test is done to determine the particle size distribution of soil as per IS 2720 (part 4) _ 1985. Take a representative oven dried sample of soil that weighs about 500g. (This is normally used for soil samples the greatest particle size of which is 4.75mm) Prepare a stack of sieves. Sieves having larger opening sizes are placed above the ones having smaller opening sizes. After the very last sieve a pan is placed under it to collect portion of soil passing through 75micron sieve. Here is a full set of sieves 4.75mm, 2mm, 1mm, 600micron, 300micron, 212micron, 150micron and 75micron. Make sure sieves are clean; if many soil particles are stuck in the openings try to poke them out using brush. Weigh all sieves and pan separately. Pour the soil into the stack of sieves from the top and place the cover, put the stack in the sieves shaker and fix the clamps, adjust the time on 10 to 15 minutes and get the shaker going. Stop the sieve shaker and measure the mass of each sieve plus retained soil. Coefficient of uniformity, Cu = D60/D10 Where, the apparatus used to conduct sieve analysis test is given below in Fig. 3.

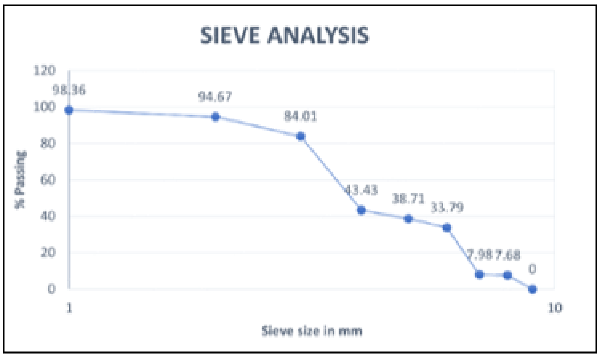


Figure 3: Sieve Shaker

Observations:

Table 4: Result of grain size analysis

S.No	IS Sieve No	Aperture Size in mm	Wt. of soil retained in gms	% wt. retained	Cumulative% wt. retained	% passing through
1	4.75mm	4.75	8	1.64	1.64	98.36
2	2.36mm	2.36	18	3.69	5.33	94.67
3	1.18mm	1.18	52	10.66	15.99	84.01
4	600 µ	0.60	198	40.58	56.57	43.43
5	425 µ	0.425	23	4.72	61.29	38.71
6	300 µ	0.30	24	4.92	66.21	33.79
7	150 µ	0.15	126	25.81	92.02	7.98
8	75 µ	0.075	21	4.30	96.32	7.68
9	PAN	PAN	18	3.68	100	0

Result:
Effective size of the particle D10 =0.15
Uniformity coefficient Cu = 5.86
Coefficient of curvature Cc =0.51

Conclusion:
The soil sample is classified as Poorly Graded (Gap-Graded). While Uniformity Coefficient (5.86) is quite high, the Coefficient of Curvature (0.51) falls significantly below the required range for a well-graded soil. This suggests that the soil has a "gap" in its grain size distribution meaning certain particle sizes are missing, or there is an overabundance of one specific size.

Figure 5: Seive Analysis

Atterberg's limit

Atterberg's limit is basic measure of the critical water content of a fine –grained soil: its plastic limit and liquid limit. The liquid limit (LL) is conceptually defined as the water content at which the behavior of a clayey soil changes from plastic to liquid. However, the transition from plastic to liquid behavior is gradual over a range of water content, and the shear strength of the soil is not actually zero at the liquid limit. The precise definition of the liquid limit is based on standard test procedures described below. The original liquid limit test of Atterberg involved mixing a pot of clay in a round –bottomed porcelain bowl of 10-12 cm diameter. A groove has to be cut through the pat of clay with a spatula, and the bowl is then struck many times against the palm of one hand. Soil is placed the metal cup portion of the device and a groove is made down its center with standardized tool of 2millimeter (0.079in) width. The cup is repeatedly dropped 10mm onto a hard rubber base at a rate of 120 blows per min, during which the groove closes cup gradually as the result of impact. The number of blows for the groove to close is recorded. The number of blows for the groove to close is recorded. The moisture content at which it takes 25 drops of the cup to cause the groove to close over a distance of 12.7 millimeters (0.50 in) is defined as the liquid limit. The test is normally run at several moisture content which requires 25 blows to close the groove is interpolated from the result. The apparatus used to determine the liquid limit of soil is given below in Fig. 4.

Figure 6: Casagrande Apparatus

Observations:

Table 5: Atterberg limit

S. No	Description	1	2	3
1	Container No.	B-1	7	224
2	Weight of container in gms	21	14	12
3	Weight of container + wet soil in gms	29	22	21
4	Weight of container + dry soil in gms	27	20	19
5	Weight of water in gms (3 – 4)	2	2	2
6	Weight of dry soil in gms (2 – 4)	6	6	7
7	Water content w in % = 5 * 100 / 6	33.33%	33.33%	28.57%

Result:

Plastic limit of the soil (PL) = 32.74%

Conclusion:

The plastic limit of the given soil sample was determined to be 32.74%.

This value represents the minimum water content ratio at which the soil transitions from a semi-solid to plastic state.

Physical Properties of Soil

Table 6: Physical properties of soil

Property	Typical Value
Color	Red to reddish-brown
Texture	Sandy loam to clay loam
Structure	Granular to crumb
Specific Gravity	2.65 – 2.75
Plastic Limit (PL)	32.74%

Chemical Properties of Soil

Table 7: Chemical properties of soil

Property	Typical Value
pH	5.5 – 6.8
Nitrogen (N)	0.05 – 0.1%
Potassium (K_2O)	0.2 – 0.6%
Iron Oxide Fe_2O_3	2 – 10%
Alumina Al_2O_3	15 – 25%

5. Experimental Methodology

Soil Selection and Preparation Setup Choosing the right soil is crucial for block quality. Collect soil samples that have a good mix of sand, silt, and clay. Remove impurities like stones, roots, and organic matter. Pulverize the soil to ensure a uniform particle size. Mixing with Stabilizers Earth has been used as a construction material for centuries of the blocks. Add cement, lime, or fly ash in the right amounts. Keep the moisture content appropriate during mixing. Make sure the soil, stabilizer, and water mix evenly. Compaction and Molding Compaction increases density and lowers voids. Place the prepared mixture into steel molds. Use manual or mechanical presses to compact it under high pressure. Carefully remove blocks to preserve their shape and edges. Curing Process Curing strengthens and increases the durability of the blocks. Keep the blocks moist for 7 to 28 days, depending on the type of stabilizer used. Protect them from direct sunlight and rain while curing. Ensure controlled conditions for consistent strength gain. Mechanical Testing checks block performance under different loads and conditions. Conduct compressive strength tests within the 2 to 7 MPa range. Measure water absorption and durability during wetting and drying cycles. Perform flexural strength and seismic resistance tests when needed. Performance Evaluation Compare stabilized mud blocks with traditional materials for practical use. Evaluate cost-effectiveness and environmental impact. Compare thermal insulation and energy efficiency. Document results for design guidelines and sustainable construction.

Mix Design and Proportioning

Table 8: Proportions used in mix design

Mix No	Hydrated Lime	Fly Ash	Cement (%)	Soil (%)	M Sand (%)	Mix Proposition (By Weight)
1	5% (450g)	5% (450g)	- (0g)	50% (4500g)	40% (3600g)	5% Hydrated lime + 5% Fly ash + 50% soil + 40% M-sand
2	5% (450g)	10% (900g)	- (0g)	50% (4500g)	35% (3150g)	5% Hydrated lime + 10% Fly ash + 50% soil + 35% M-sand
3	5% (450g)	15% (1350g)	- (0g)	50% (4500g)	30% (2700g)	5% Hydrated lime + 15% Fly ash + 50% soil + 30% M-sand
4	- (0g)	- (0g)	20% (1800g)	50% (4500g)	30% (2700g)	20% Cement + 50% soil + 30% M-sand

Sample Preparation Procedure
- Identify suitable soil with optimal clay, silt, and sand proportions.
- Pulverize and sieve the soil to remove debris and achieve desired consistency.
- Add cement, lime, fly ash, or other stabilizers in predetermined proportions and mix thoroughly
- Gradually add water to achieve optimal moisture content for molding.
- Press the mixture into block molds using manual or mechanical presses.

Curing Process
Allow blocks to cure under controlled conditions (e.g., shade, moisture)

Testing Program
- Conduct test (compressive strength, water absorption, etc.) to ensure blocks meet standards.

Compressive Strength Test
The compressive strength test for stabilized mud blocks is performed using a universal compression testing machine after curing (typically at 7 and 28 days). It measures the maximum load the block can withstand before failure, expressed in MPa, and is a key indicator of block quality and suitability for load-bearing construction.

Procedure:
- Place prepared blocks in compression testing machine.
- Align block to avoid eccentric loading.
- Apply load gradually at a uniform rate.
- Record the maximum load (P) at failure
- Note failure mode (cracking, crushing)
- Determine strength using load and block area.

Compressive Strength $(\sigma) = P / A$

Where:
P = Maximum load (N)
A = Loaded area (mm²)- Typical values: 2–5 MPa for stabilized mud blocks.
- Compare results at **7-day vs 2-day curing.**
- Ensure strength meets design requirements
- Compressive strength calculated.

Testing was performed at **7-day and 21-day curing periods**.

6. Results Analysis and Discussion

Water Absorption Testing

Table 9: Water Absorption Test of Stabilized Mud Block

S. No	Normal Brick	Dry Weight	Wet weight	Water Absorption For 24Hrs%
1	Sample A	9.090 Kg	9.910 Kg	8.2%
2	Sample B	8.810 Kg	9.940 Kg	11.3%

Testing Result

Table 10: 7 Days Test Results – Sample A vs Sample B

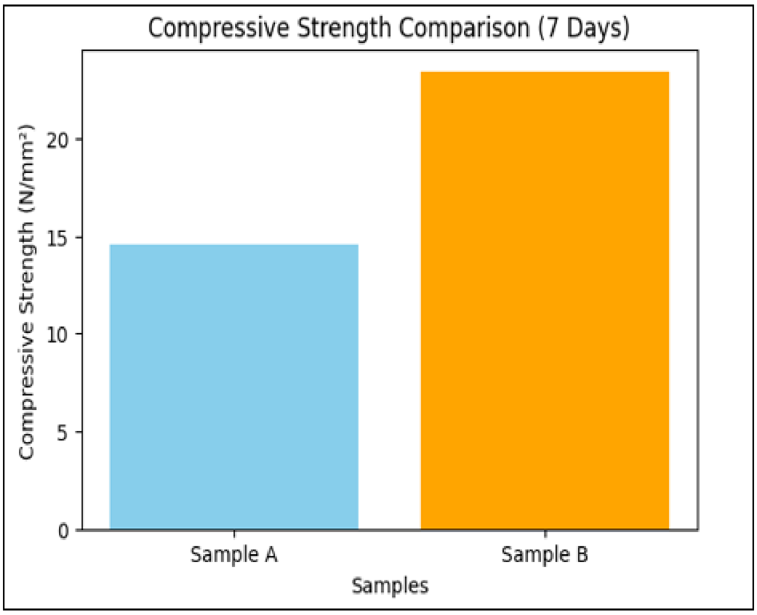
Parameters	Sample A	Sample B
Proportion	5% Hydrated lime + 15% Fly ash+ 50% soil + 30% M-sand	20%cement+ 30%MS and +50% Soil
Brick Weight	9.090 Kg	9.000Kg
Load KN	250 KN	400KN
Size (inch)	9” x 10” x6”	9” x 10” x6”
Compressive Strength For 7 Days (N/ mm²)	14.6 N/ mm²	23.4 N/ mm²

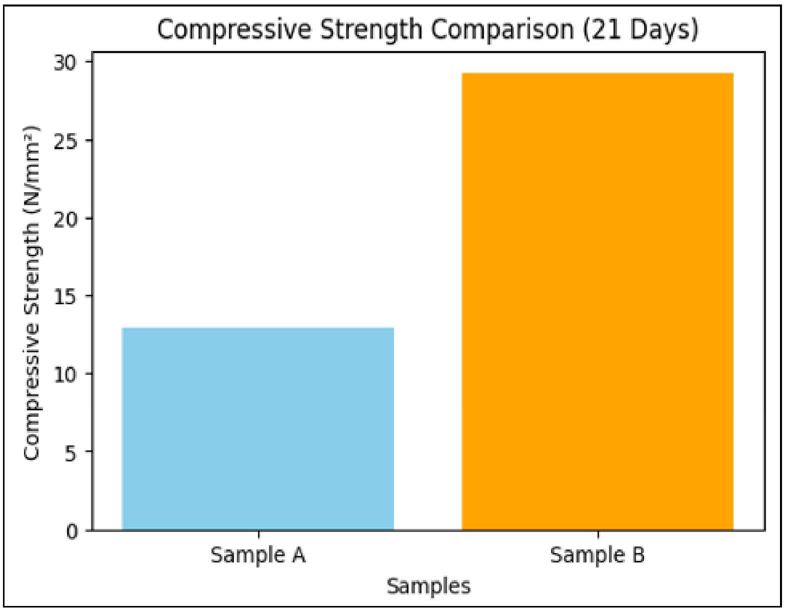
Table 11: 14 Days Test Results – Sample A vs Sample B

Parameters	Sample A	Sample B
Proportion	5% Hydrated lime + 15% Fly ash+ 50% soil + 30% M-sand	20%cement+ 30%MSand +50% Soil
Brick Weight	9.090 Kg	9.000Kg
Load KN	250 KN	400KN
Size (inch)	9” x 10” x6”	9” x 10” x6”
Compressive Strength For 7 Days (N/ mm²)	11.7 N/ mm²	26.3 N/ mm²

Table 12: 21 Days Test Results – Sample A vs Sample B

Parameters	Sample A	Sample B
Proportion	5% Hydrated lime + 15% Fly ash+ 50% soil + 30% M-sand	20%cement+ 30%MSand +50% Soil
Brick Weight	9.090 Kg	9.000Kg
Load KN	250 KN	400KN
Size (inch)	9” x 10” x6”	9” x 10” x6”
Compressive Strength For 7 Days (N/ mm²)	12.9N/ mm²	29.2 N/ mm²





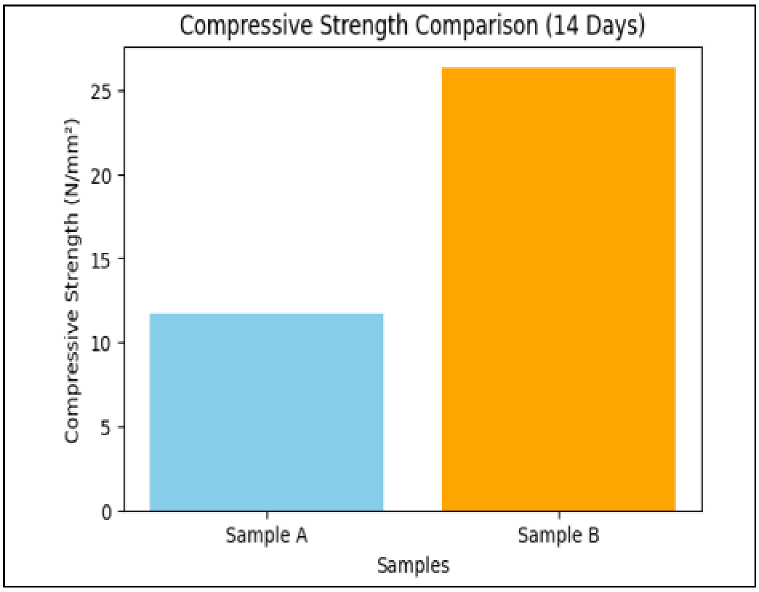


Figure 7: Graphical Representation of Compressive Strength Test Results of Sample A vs Sample B for 7,14 and 21 Days

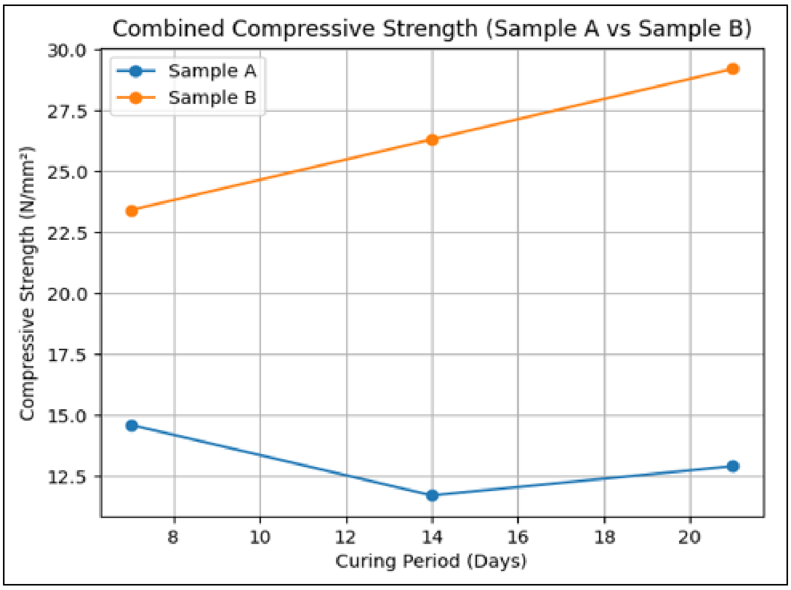


Figure 8: 7, 14 and 21 Days Test Results– Sample A vs Sample B

Graph Interpretation

The compressive strength results show a clear difference in behavior between Sample A and Sample B over the curing period of 7, 14, and 21 days. Sample A exhibits an inconsistent trend. Its strength drops from 14.6 N/mm² at 7 days to 11.7 N/mm² at 14 days, then rises slightly to 12.9 N/mm² at 21 days. This irregular behavior suggests slower or incomplete bonding because of the lime and fly ash stabilization, which needs more time for effective strength development. In contrast, Sample B shows a steady and continuous increase in compressive strength, rising from 23.4 N/mm² at 7 days to 29.2 N/mm² at 21 days. This consistent growth results from the presence of cement, which speeds up hydration and strengthens the bond between particles. Overall, Sample B demonstrates better strength performance at all curing stages and is more suitable for structural and load-bearing uses.

Overall Result Comparison

Comparison Table

Feature (Objective)	Normal BRICK	Stabilized Mud Block (SMB)
Strength (Strength Optimization)	Moderate compressive strength	Higher compressive strength due to cement/lime stabilization
Durability (Performance under Conditions)	Affected by moisture and weathering	More resistant to water, erosion, and environmental conditions
Cost Efficiency (Cost-effectiveness)	Higher production cost due to firing process	Lower cost using local soil and less energy
Environmental Impact (Sustainability)	High carbon emission due to kiln firing	Eco-friendly; uses natural materials and industrial waste (fly ash
Final Comparison	Less efficient overall	Superior in strength, durability, and sustainability

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7. Conclusion

The study confirms that Stabilized Mud Blocks (SMBs) are a sustainable and cost-effective alternative to traditional building materials. Soil testing showed that the selected red soil is suitable for SMB production. It has acceptable water content, specific gravity, and physical properties. Adding stabilizers like cement, lime, and fly ash improves the strength, durability, and water resistance of the blocks. Different mix proportions were tested to find the best balance between structural performance and cost.

Test results, including compressive strength and water absorption, show that well-designed and cured SMBs can meet construction needs. They also promote environmental sustainability by using local materials and industrial by-products like fly ash.

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