A Study on Polymeric Fibre Reinforced Stabilized Mud Blocks

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Abstract. It is a known fact that mud blocks casted out of black cotton soil have poor damage resistance due to clayey, brittle and weak nature of the black cotton soil. In order to improve the strength of the cotton soil based mud blocks, additives such as polypropylene filament, polypropylene flakes and poly styrene fibres have been used in addition to a natural binder namely Terminalia chebula. By varying the percentage of the additives and as also soil, sand and lime various fibre reinforced blocks are made. The as-prepared reinforced mud blocks on analysis were found to possess a maximum strength of 13.75MPa when polypropylene was added as a additive. The study revealed that the addition of polymeric additives with the use of Terminalia chebula resulted in reinforcement of the stabilised mud blocks with enhanced strength and durability.

Keywords: Artificial Fibres, Lime Stabilization, Terminalia chebula, Fibre Reinforcement, Compressed Stabilized Earth blocks, Stabilized Mud Blocks.

1. Introduction

Shelter for all is a major and important goal of all nations around the world. Despite best efforts, still India needs 27 million units of housing. There has been not only a huge cost escalation of materials but also a high demand of construction materials. Housing has gone out of the reach of middle class and economically weaker sections of the society. Still there is a need to provide housing to a large population in India. In the absence of appropriate strategies for the housing, the shortage is likely to shoot up to 38 million units in 2030. It was estimated that around 30% of world’s population are still having earthen structures. In view of the abundant availability, low cost and eco friendly nature, earth still used as extensively in building constructions. In fact, earthen masonry encourages the green building movement. Further it reduces the use of manufactured materials and consumes low energy. If the soil used for building constructions contains clay materials structural problems result. The advancements in the field of Material Science and Engineering have not developed earth as a good building material. Several researches have embarked on the use of stabilized mud blocks as building materials with improved strength and durability. There have been many attempts addressed such problems like low tensile strength, brittleness and deterioration on exposure to water [1-6]. The present study is on the production of mud blocks using black cotton soil with polymeric fibres as additives and Terminalia chebula as natural binder. The results of the study are presented in this communication.
2. Materials and Methods

2.1 Black Cotton Soil

The black cotton soil used for preparing mud blocks for this study is collected from Athoor block of Dindigul District Tamilnadu. The soil sample was collected about 2 m below the ground level. The physical properties are given in table 1, while the percentage chemical composition of the black cotton soil is given in table 2. Similarly the percentage of lime treated black cotton soil is given in the table 3.

2.2 Lime

The lime used for our study was obtained locally. The chemical composition of lime is given in table 4.

2.3 Terminalia chebula

Locally collected plants of *Terminalia chebula* were cut into small pieces and soaked in to water at a ratio of 1:15 with the solution brewing for nearly 24 hr prior to use [7]. The major phytoconstituents present in *Terminalia chebula* are hydrolysable tannins, poly phenols, gallic acid, chebulagic acid and chebulinic acid [8].

2.4 Sand

River sand passing through 2 mm IS sieve and retain over 425 micron sieve was used for this study. The specific gravity used was 2.67.

2.5 Fibre

In order to overcome the drawback of the lack of strength, polymeric fibres were added. To find out the effect of the morphology of the polymer on the strength and durability of the mud block, polypropylene flakes and polypropylene mono filaments were added. In order to study the effect of nature of the polymer over the properties of the mud blocks polystyrene fibres were also added and tested. These polymeric materials were obtained commercially from the vendors and used as such. The properties of fibres are given in the table 5.

3. Experimental Methods

Perusal of the properties of the black cotton soil shows that the plasticity index of the soil is fairly high. It is pertinent to observed that Walker, P.J., et.al (1995) had observed that soil with plasticity index higher than 25 needs only machine compaction. This higher plasticity index is due to higher clay percentage in the soil (table 1).

| Table 1. Properties of Black Cotton Soil |
|-----------------------------------------|
| Colour | Dark brown |
| Specific gravity | 02.03 |
| Silt (%) | 30.00 |
| Clay (%) | 70.00 |
| Swelling index (%) | 100.00 |
| Liquid limit (%) | 55.00 |
| Plastic limit (%) | 07.70 |
| Plasticity index | 47.30 |
| Dry density(g/cc) | 01.49 |
| Optimum moisture content (%) | 20.00 |
Table 2. % of Chemical Composition of Black Cotton Soil

| Chemical | SiO₂ | Al₂O₃ | Fe₂O₃ | CaO | MgO | P₂O₅ | K₂O | SO₃ |
|----------|------|-------|-------|-----|-----|------|-----|-----|
| %        | 62.4 | 16.1  | 11.6  | 5.1 | 1.7 | 0.4  | 1.8 | 0.5 |

Table 3. Properties of Lime Treated Soil

| Property                              | Value       |
|---------------------------------------|-------------|
| Optimum moisture content (%)          | 22.00       |
| Maximum dry density (g/cc)            | 0.55        |
| Liquid limit (%)                      | 46.20       |
| Plastic limit (%)                     | 10.50       |
| Plasticity index                      | 35.70       |

Table 4. Chemical Composition of Lime

| Elements | % Existing |
|----------|------------|
| O        | 28.92      |
| Ca       | 55.72      |
| C        | 10.24      |
| Si       | 02.76      |
| Mg       | 0.88       |

Table 5. Properties of The Fibres Used

| Material            | Polystyrene | Polypropylene |
|---------------------|-------------|---------------|
| Density (g/cm³)     | 1.34        | 0.91          |
| Tensile strength (MPa) | ≥15%       | ≥500          |
| Elongation rate     | Fine        | Fine          |
| Acid resistance     | Fine        | Fine          |
| Length of fiber(mm) | 10          | 10            |
| Diameter of fiber(µm) | 25-30      | 38            |
| Melting point (°C)  | 240-260     | 160-180       |
| Burning point (°C)  | >500        | >360          |
| Color               | White       | White         |
| Elongation rate     | ≥15%        | ≥15%          |

The percentage chemical composition of the soil reveals low calcium content and hence calls for lime supplementation in the mud block casting process. The treatment of lime to the black cotton soil has brought down the plasticity index from 47.3 to 35.7 (table 3). Both the polymeric materials used in this study are thermoplastics in nature and polystyrene has a greater tensile strength than polypropylene (table 5).

3.1. Mixing, Moulding and Curing

Various mixing procedures have been highlighted for casting and curing of the stabilized mud blocks [9 -11]. The black cotton soil was dried, the lumps were broken and the soil was sieved using 4.75 mm to remove organic matters and waste particles. The various mix proportions used for the making of stabilized mud blocks are shown in table 6.
Table 6. Mix Proportions Evolved in the Making of Polymeric Reinforced Mud Blocks

| Mix designation | Soil  | Sand | Lime | Polypropylene Flaked | Polypropylene Monofilament | Polystyrene |
|-----------------|-------|------|------|----------------------|---------------------------|-------------|
| S0              | 90.0  | 5    | 5    | -                    | -                         | -           |
| S1              | 89.9  | 5    | 5    | -                    | -                         | -           |
| S2              | 89.8  | 5    | 5    | 0.2                  | -                         | -           |
| S3              | 89.7  | 5    | 5    | 0.3                  | -                         | -           |
| S4              | 89.6  | 5    | 5    | 0.4                  | -                         | -           |
| S5              | 89.5  | 5    | 5    | 0.5                  | -                         | -           |
| S6              | 89.9  | 5    | 5    | -                    | 0.1                       | -           |
| S7              | 89.8  | 5    | 5    | -                    | 0.2                       | -           |
| S8              | 89.7  | 5    | 5    | -                    | 0.3                       | -           |
| S9              | 89.6  | 5    | 5    | -                    | 0.4                       | -           |
| S10             | 89.5  | 5    | 5    | -                    | 0.5                       | -           |
| S11             | 89.9  | 5    | 5    | -                    | -                         | 0.1         |
| S12             | 89.8  | 5    | 5    | -                    | -                         | 0.2         |
| S13             | 89.7  | 5    | 5    | -                    | -                         | 0.3         |
| S14             | 89.6  | 5    | 5    | -                    | -                         | 0.4         |
| S15             | 89.5  | 5    | 5    | -                    | -                         | 0.5         |

During this mixing, the fibres were added by hand in stages, to form a homogeneous soil matrix. Mixing was continued to ensure a uniform distribution of fibre throughout the soil matrix. The wet mixing was done by adding *Terminalia chebula* extract to soil-lime-fibre matrix. The percentage of *Terminalia chebula* extract was maintained as 20% common for all the mix proportions. The blocks were compacted immediately after the mixing and casted using Auroville Ramming Machine (AURAM). The constant moulding pressure of 15 MPa was given by a single acting ram of AURAM machine. The specification of the manual press was given in table 7. The blocks were then tested for compaction by pressing the penetrometer on the surface of the mud blocks. The depth of penetration indicated the quality of compaction. Adequate care was taken to see that the penetration was not more than 10%.

Table 7. Specifications of Manual Press Used

| Arm of lever | Dimension of blocks | Number of blocks | Applied Force | Compression Mode | Compression category |
|-------------|--------------------|-----------------|---------------|------------------|----------------------|
| 1800mm      | 240 X 240 X 100mm  | 1               | 15 MPa        | Static           | Low                  |

The blocks (S0 to S15) were kept under ambient curing for three days, and then the blocks were covered and cured by spraying water regularly for 28 days.

3.2 Testing

Initially the Unconfined Compressive Strength was found out and it was compared with the compressive strength of casted blocks tested at 7th, 14th, 21st and 28th day of curing in digital Compression Testing Machine of 3000 KN capacity. Also these mud blocks were subjected to water absorption and spray erosion tests after 28th day of curing to assess their performance in adverse weather conditions. The water absorption test was carried out based on IS: 3495 (Part II) 1976. The specimens were wetted for 24 hours and their weights are determined. The difference in weight of the
mud blocks before and after immersion was used for the calculation of water absorption. The test setup for the modified spray erosion is shown in figure 1. The obtained results were tabulated and discussed below.

Figure 1. Working setup for modified spray erosion test

4. Results and Discussion
4.1 Unconfined Compressive Strength (UCS)

The utility of any material for construction purpose depends on the compression strength. In this study, the mud blocks were prepared with polymeric adjuvant with a view to reinforce the mud blocks. The UCS test was carried out to determine the strength of cohesive or bonded soils in an inexpensive and practical manner without the need for applying a confining stress, while maintaining soil bonding or cementation prior to shearing [12]. The increase in the compressive strength by the addition of polymeric fibres can be attributed to the reinforcement action of the polymeric fibres. This result endorses the earlier view that addition of polymeric fibres reduces shrinkage cracking; improve tensile strength, durability and ductility [9]. From the results of the study (table 8) it is evident that the maximum strength could be obtained in the case of S5, S10 and S15 among the same polymeric constituents. The results also point out that the beyond 0.5%, the increase in compressive strength is not much significant.

Table 8. Unconfined Compressive Strength for All Mix

| % of Fibers | Compressive Stress MPa |
|-------------|------------------------|
|             | Polypropylene monofilament | Polypropylene flakes | Polystyrene |
| 0.1         | 0.299                   | 0.254                | 0.392       |
| 0.2         | 0.311                   | 0.278                | 0.414       |
| 0.3         | 0.383                   | 0.332                | 0.46        |
| 0.4         | 0.395                   | 0.395                | 0.483       |
| 0.5         | 0.422                   | 0.422                | 0.525       |

4.2 Compressive Strength Test

The compression strength was determined for all casted blocks (S0 to S15) at the 7th, 14th, 21st and 28th day of curing shown in the figure 2. The results show an apparent increase in the compression strength compared to the raw soil specimen. The matrix reinforced with the polymeric fibres at 0.5% recorded the highest compressive strength in the case of all three polymeric materials. The effect of fibre is so pronounced in polystyrene fibres. The highest compression strength of 13.75 MPa would be attained after 28 days of curing in the case of S15. Similar work was carried out by Hanifi Binici et.al and C.K.Subramania Prasad et. al [1, 6] by adopting plastic and natural fibres for the reinforcement of blocks with cement and lime as stabilizers. Comparison of results indicates that compressive strength registered an increase of nearly 2.5 times over the control. The higher strength attained in the present study may be due to the lime supplementation...
to the soil which resulted in good bondage between the soil particles with polymeric fibres acting as reinforcement materials [7].

![Figure 2. Compression strength of Mud Blocks at different mix proportions](image)

### 4.3 Water Absorption

The blocks were tested in accordance with the procedure laid down in IS:3495 (Part II) 1976, after immersion in cold water for 24 hours. As per code, the average water absorption shall not be more than 15% by its weight.

But in the case of S6 block, the water absorption was found to be nearly 29.2% which could be due to the poor compaction. Earlier workers have overcome this drawback by increasing the compaction pressure above 12.5 MPa and addition of sand was found to reduce the water absorption but did not affect the compression strength. But in the case of other samples, the water absorption was found to be much less. The addition of natural binder viz., *Terminalia chebula* could have reduced the voids, thus increasing the bonding between soil and sand which had resulted in less water absorption shown in figure 3 [14-17].

![Figure 3. Water Absorption of Stabilized Mud Blocks](image)

### 4.4 Spray Erosion

It is necessary to track the performance of the stabilized fibre reinforced mud blocks when it is exposed to adverse climatic conditions (rain, storm etc.) in the field in order to assess the durability such a study may not feasible option because of the large duration of time and hence a laboratory level test setup had been developed with reference to IS: 1725-1982 specifications [19 & 20]. Here the erosion test had been conducted to S5, S10 & S15 blocks which attained higher compressive strength in each kind of fibres used. The results of erosion test are given in the table 10. B.V.Venkataramareddy et.al [18] derived an equation for erosion rate is
\[ ER = \frac{d}{(Pr \times t)} \]  

Where,  
\begin{align*}  
D & = \text{avg. depth of the erosion} \\
Pr & = \text{precipitation rate} \\
t & = \text{duration of erosion in minutes} 
\end{align*}

From the results, it is evident that the rate of erosion is minimum for polystyrene fibre reinforced mud blocks.

**Table 9. Erosion Test Results of High Strength Mud Blocks**

| Mix Proportion | Time (minutes) | Depth of erosion in (mm) | Rate of Erosion in (mm/min) |
|----------------|----------------|--------------------------|----------------------------|
| \(S5\)         | 5              | 0                        | 0.062                      |
|                | 10             | 0                        |                            |
|                | 15             | 0                        |                            |
|                | 30             | 0.75                     |                            |
|                | 60             | 0.80                     |                            |
|                | 90             | 1.00                     |                            |
|                | 120            | 1.25                     |                            |
| \(S10\)        | 5              | 0                        | 0.059                      |
|                | 10             | 0                        |                            |
|                | 15             | 0.40                     |                            |
|                | 30             | 0.70                     |                            |
|                | 60             | 0.90                     |                            |
|                | 90             | 1                        |                            |
|                | 120            | 1.19                     |                            |
| \(S15\)        | 5              | 0                        | 0.049                      |
|                | 10             | 0                        |                            |
|                | 15             | 0.10                     |                            |
|                | 30             | 0.35                     |                            |
|                | 60             | 0.50                     |                            |
|                | 90             | 0.85                     |                            |
|                | 120            | 1.00                     |                            |

**Figure 4.** Spray Erosion pattern for High Strength Mud Blocks
The obtained values of the erosion are minimal and satisfies the IS codal recommendations which are shown in the figure 4. The erosion test reveals that with optimum stabilizer content of lime and *Terminalia chebula*, the fibres can be used without affecting the durability of the blocks [21]. The block possess minimal erosion rate and no extra care is needed to protect it [22]. The presence of *Terminalia chebula* extract acts as a natural water–proof coating on soil particles which may also be the reason for lower erosion since it acts as a barrier for the water entry.

![Figure 5.](image)

**Figure 5.** Comparison of Compressive strength, Spray Erosion and Water Absorption in various Stabilized Mud Blocks

Comparison of results obtained for various mud blocks casted with regard to such parameters like compression strength, water absorption and spray erosion clearly shows that there exists an inverse relationship between compression and spray erosion and water absorption.

4.5 Morphological Studies

Morphological studies were conducted for the samples which exhibited higher strength (S0, S5, S10 and S15) and the following inference could be arrived at.

![Figure 6.](image)

**Figure 6.** SEM Images of (a) S0, (b) S5, (c) S10 & (d) S15 samples

Figure 6 (a) shows that there was a tight packing and ingredients had bonded well. In fact there was less visible disintegration of soil particles. From the Figure 6 (b) it is evident that there was reinforcement of the polymeric fibres. There were also voids which could cause profound effect on the compression strength. The morphology stabilized mud blocks with 0.5% of polypropylene mono filament fibres S10 is shown in figure 6(c). The reinforcement of fibre was clearly visible between the soil particles and also voids. The voids may tend to discontinue soil particles that make the soil matrices weaker and eventually lead to high damage compared to S5 and S15. In the case of S15, (figure 6 (d)) there were no voids and surface morphology looked dense. The absence of voids and dense reinforcement in the case of polystyrene reinforced mud blocks could be the reason for
the better performance of the S15. Similar kind of study was carried out [23] using Sisal, a natural fibre and the results were correlated with strength, porosity and density. This study makes us to understand the changes in internal structure of mud blocks due to the compression stress, stabilizers and fibres.

5. Conclusion

The main drawback of the black cotton soil based mud blocks viz., the brittleness, lack of strength and poor damage resistance were overcome by indigenous use of polymeric fibres as a reinforcement materials and the natural binder viz., Terminalia chebula in the making of stabilized mud blocks. Of the three polymeric fibres used, polystyrene fibre reinforcement has yielded mud block with greater compression strength. At a concentration of 0.5% by weight of the dry soil, polystyrene could produce compression strength of 13.75 MPa. The aromatic nature of the polystyrene has resulted in the lowest water absorption of 4.1%. This could be attributed to the non-polar nature of the polymeric fibre combined with proper compaction which has resulted in the reinforcement in both horizontal and vertical directions holding the soil matrix. Further the spray erosion test indicated the attrition rate of only 1 mm in a maximum period of 2 hr. The surface morphological studies revealed the densely packed structure indicating the absence of voids and reinforcement of the polymeric fibres. Thus from the results of the study, it is certain that polymeric fibre reinforcement could increase the stability and enhance the durability of the black cotton soil based mud blocks. The results of the present study are bound to have impact on the use of stabilized mud blocks in the domain of cost effective building technology.

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