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Compressive Strength Characteristic of Environmentally Friendly Laterite Soil Blocks

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ABSTRACT

In order to minimize the environmental impacts caused by over exploitation of natural resources for the production of building material, the possibility of using blended soil blocks duly burnt for load-bearing walls has been assessed to alternate the fertile top soil of agricultural land. Since the vertical load carrying capacity primarily depends on the compressive strength, a comprehensive study was conducted for burnt soil blocks made with commonly available laterite and clay soil types in Tripura (India). The results indicate the possibility of using burnt soil blocks for single storey houses which may also be extended to two storey houses.

Keywords: *Blended brick, Fired lateritic soil brick, fertile top soil, compressive strength.*

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INTRODUCTION

Bricks are recognized as an important building material for construction of various civil engineering structures. The raw materials for the bricks constitutes clay, silt and sand in which total content of clay and silt may preferably be not less than 50 percent by weight[1]. Population explosion has increased the greater demand of this building material and thus more and more fertile top soil of the agricultural land has been excavated to meet this increasing demand. Hence reducing the productivity of the soil and leading to food crisis. The study has been initiated to investigate fully or partially replacement of fertile top soil of agricultural land by blending locally available laterite and clayey soil for manufacturing bricks and also assist in reducing transport costs, embodied energy and life cycle cost. In order to use this material for wider applications, it is necessary to develop strength characteristics of blended burnt bricks.

This paper describe the detailed research carried out on structural properties of burnt bricks using laterite and clay soil commonly available in areas with tropical climatic conditions.

OBJECTIVES

The research was carried out with the following objectives:

1. Selection of soil type.
2. Determination of physical properties of laterite and clay soil.
3. Manufacturing of bricks by mixing these soils in different proportions.
4. Determination of strength characteristics of burnt bricks mixed in different proportions for construction of load bearing building.

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METHODOLOGY

Selection and Determination of Physical Properties of Laterite and Clay Soil

The soil samples selected should preferably conform to the mechanical composition of Clay 20 to 30 percent by mass; Silt 20 to 35 percent by mass and Sand 35 to 50 percent by mass. The total content of clay and silt may preferably be not less than 50 percent by mass[1].

Laterite and clayey soil samples were collected from the site of National Institute of Technology Agartala (India). Table I shows the particle size distribution of soil type and the chemical compositions of the concerned soil are shown in table II. The samples were processed as per IS 2117-1991[1].

Table I Particle Size Distribution of Soil Type.

Soil type	Gravel % content	Sand % content	Silt % content	Clay % content	Water holding capacity (%)	p^H
Laterite	50	28	7	15	49.25	4.92
Clay soil	42	30	8	20	43.22	3.51

Table II Chemical Composition of the Laterite Soil.

Organic Carbon (%)	Calcium carbonate (ppm)	Phosphate (mg/100g of soil)	Potassium (ppm)	Sodium (ppm)	Calcium (ppm)
0.15- 0.329	0 - 2.35	6.64 – 15.6	1.87- 26.61	0.68 – 175.53	0 – 0.50

Manufacturing of Bricks by Blending these Soils in Different Proportions

The weathered clayey and laterite soil were dry mixed in varying proportions between 100% clay: 0% laterite soil and 0% laterite: 100% clay soil. The liquid limit, plastic limit, plasticity index and specific gravity were determined for each blend of soil as per IS 2720. (Part-III & V) The full range of modified soils used and their plasticity characteristic are outlined in Table III.

Table III Soil Properties.

Blend	% laterite soil	% clay soil	% Liquid limit	% Plastic limit	% Plasticity Index	Specific gravity
1	0	100	26.2	23	3.2	2.51
2	10	90	27.0	23	4.0	2.52
3	20	80	27.5	23	4.5	2.51
4	30	70	25.5	22	3.5	2.62
5	50	50	24.0	21	3.0	2.65
6	70	30	22.4	20	2.4	2.70
7	75	25	24.0	20	4.0	2.71
8	85	15	23.0	19	4.0	2.75
9	100	0	21.2	18	3.2	2.77

The bricks were manufactured as per the guidelines provided in IS 2117-1991.

Determination of Compressive Strength Characteristics of Brick

The compressive strength test was executed as per IS 3495 (part1)-1992. The specimen with flat faces horizontal, and mortar filled face facing upwards between two 3-ply plywood sheets each of 3 mm thickness were carefully centered between plates of the testing machine. Load was axially applied at a uniform rate of 14 N/mm^2 per minute till failure occurred and the maximum load at failure was noted. The load at failure is the maximum load at which the specimen fails to produce any further increase in the indicator reading on the testing machine. The compressive strength was calculated as Cs = P/A where: Cs = compressive strength of the specimen (MPa), P = Maximum load at failure (N), A= Average area of the bed faces (mm^2).For each lot, the minimum, the maximum, and the average compressive strength of five specimens were reported.

Water Absorption (After 24 h)

The test was done according to IS 3495 (part 2) 1992. The specimen was dried in a ventilated oven at a temperature of 105 to 115°C till it attains substantially constant mass and then cooled to a room temperature and its weight (M_1) was obtained. Dried specimen was immersed completely in clean water at a temperature of 27 ± 2°C for 24 hours. The specimen was then removed, wiped out any traces of water with a damp cloth, and weighed. The weighing was completed 3 minutes after the specimen has been removed from water (M_2).Water absorption, percent by mass, after 24-hour immersion in cold water is given by the following formula [2]:

$$\{(M_2 – M_1)/M_1\} \times 100 \qquad (1)$$

Efflorescence

The test was done according to IS 3495 (part 3) 1992. A shallow flat bottom dish made of glass of size 180mm × 180mm × 40 mm depth of square shaped containing sufficient distilled water to completely saturate the specimens was used. The end of the bricks was placed in the dish, the depth of immersion in water being 25 mm. The whole arrangement was placed in a warm 20 to 30°C well ventilated room until all the water in the dish is absorbed by the specimens and the surplus water evaporated. The dish containing the brick was covered with suitable glass cylinder so that excessive evaporation from the dish may not occur. When the water has been absorbed and bricks appear to be dry, a similar quantity of water in the dish was placed, and allowed to evaporate as before. The bricks for efflorescence were examined after the second evaporation and the results reported.

War page

The test was done according to the IS 3495 (part 4) 1992. A steel measuring wedge 60 mm in length, 15 mm in width and 15 mm in thickness at one end and tapered, starting at a line 15 mm from one end to zero thickness at the other end was used. The wedge graduated in 0.5 mm divisions and numbered to show the thickness of the wedge between the bases. A flat surface of steel not less than 300 mm × 300 mm in area and plane to 0.02 mm was used. Any dirt adhering to the surface of brick was removed before the test.

Density

The test was done according to the Indian Standard code [3].The brick was dried in a ventilated oven at a temperature of 105 to 115°C till it attains substantially constant mass. Then the brick was cooled to room temperature and its mass was obtained. Thereafter, the dimensions of the brick were measured accurately and the overall volume computed. The density was calculated as mass per unit volume.

Dimensional Test

The test was carried out according to the IS 1077-1992. Twenty (or more according to the size of stack) whole bricks were selected at random. All blisters, loose particles of clay and small projections were removed. They were arranged upon a level surface successively in contact with each other and in a straight line. The overall length of the assembled bricks was measured with a steel tape at one stretch.

RESULTS AND DISCUSSION

Characteristics of Sample of Lateritic and Clayey Soils of Nit Agartala

The textural composition of soils, such as % clay, % silt and % gravel was determined. Lateritic soil constitutes 50% gravel, 28% sand, 7% silt and 15% clay with water holding capacity and p^H value 49.25% and 4.92 respectively. The clayey soil sample constitutes 42% gravel, 30% sand, 8% silt, and 20% clay with water holding capacity 43.22%

and p^H value 3.51 respectively as shown in Table I.

Chemical analysis shows that lateritic soil mainly made up of organic carbon, calcium carbonate, phosphate, sodium and calcium. Table II gives details of the chemical composition of the soil type.

Atterberg's Limit of Blended Soil Samples

The samples dry mixed in varying proportions between 100% clay: 0% laterite soil and 0% laterite: 100% clay soil are outlined in Table III.The percent plastic limit and liquid limit decreases with the percent increase in laterite soil. There exist a poor correlation between percent laterite soil and percent plasticity index as shown in Figure 1. On the other hand a good correlation (R = 0.978) exist between specific gravity varying linearly with respect to every mixed proportion as shown in Figure 2. The relationship can be presented by the following regression equation:

$$S = -5E\text{-}06L^2 + 0.003L + 2.492 \qquad (2)$$

Where, S = specific gravity, L= percent laterite soil

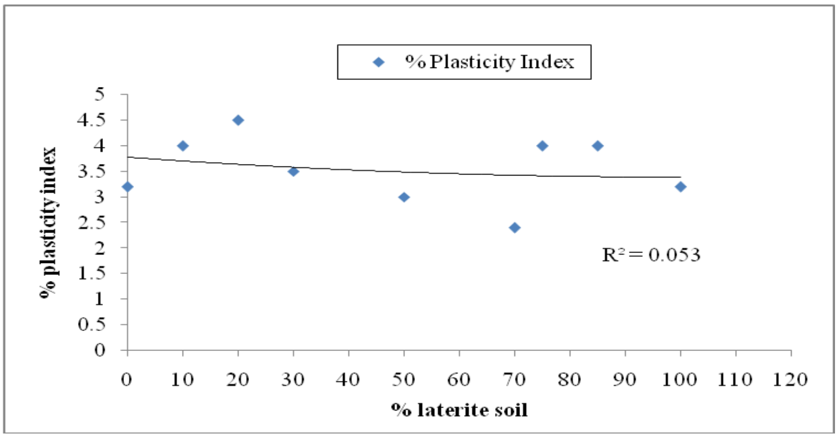

Fig. 1 Relationship between Percent Plasticity Index and Percent Laterite Soil.

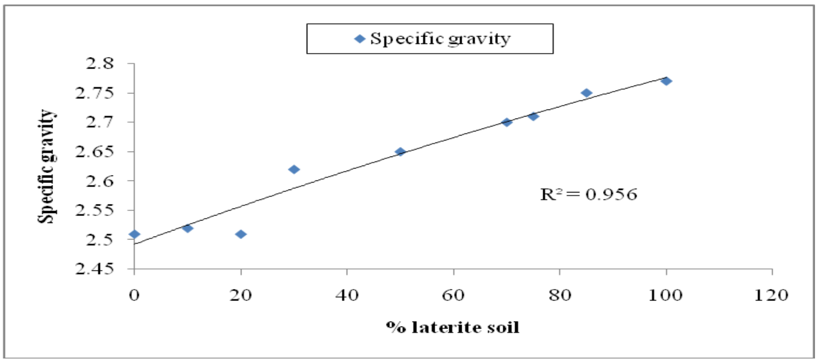

Fig. 2 Relationship between Specific Gravity and Percent Laterite Soil.

Characteristic of Compressive Strength and Density

Influence of laterite soil has a major impact in gaining the compressive strength and density of brick blocks. The average compressive strength as shown in Table IV and reported in Figure 3, linearly decreases with the increase in percent laterite soil in the mix. At 0% laterite soil (i.e., 100% clayey soil) the brick attains the maximum compressive strength of 7.1 MPa and at 100% a minimum of 5.1MPa, holding a strong coefficient of correlation (R^2 = 0.951). Similarly the average density of blocks decreases linearly with the percent increase in laterite soil in the mix with a strong coefficient correlation (R^2 = 0.976).The average density ranged from 1532 Kg/m^3 to 1812 Kg/m^3. The performance of the main characteristics of the lateritic soil bricks carried out in this study could be attributed mainly for the present of fine material used for preparation of specimens.

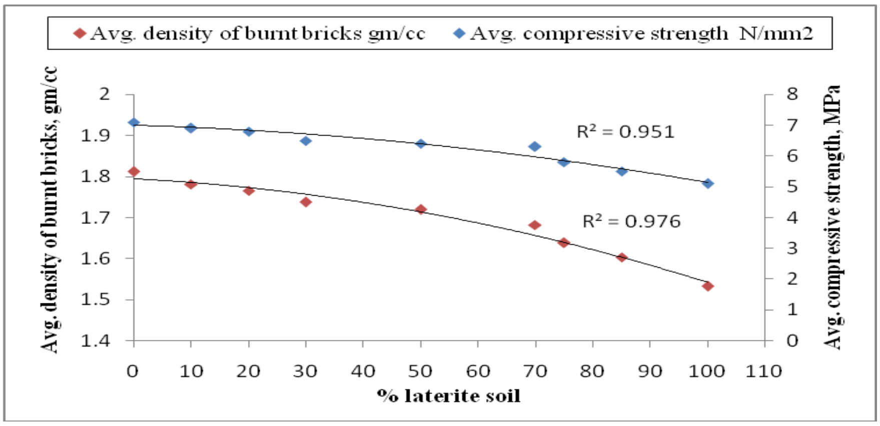

Fig. 3 Relationship between Avg. Compressive Strength and Avg. Density.

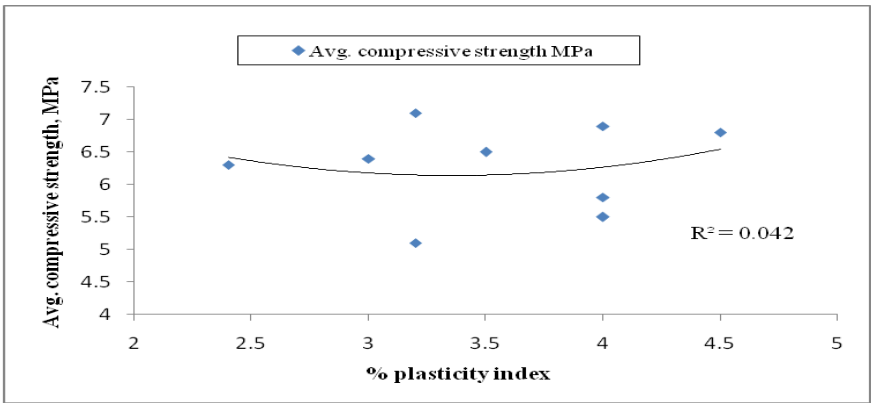

Fig. 4 Average Compressive Strength vs. Plasticity Index.

Figure 4 shows a poor correlation (R^2 = 0.042) between the plasticity index and average compressive strength of the brick blocks.

Table IV Summary of Brick Test Result.

Blend	% laterite soil	*Avg. compressive strength, N/mm^2	*Avg. density of burnt bricks, kg/m^3	*% water absorption
1	0	7.1	1812	18.50
2	10	6.9	1781	17.10
3	20	6.8	1765	16.65
4	30	6.5	1737	17.30
5	50	6.4	1719	16.58
6	70	6.3	1682	17.60
7	75	5.8	1638	15.70
8	85	5.5	1603	14.70
9	100	5.1	1532	15.40

* Average of 5 bricks of each mix.

Influence of Water Absorption on Density

The bricks, when tested in accordance with the procedure laid down in IS 3495 (Part- 2):1992 after immersion in cold water for 24 hours, water absorption was within 20 percent by weight up to class 12.5. Table IV and Figure 5 outlines that the percent water absorption has a varying effect with respect to block density (i.e., greater the density lesser is the percent water absorption).The blocks with average density of 1812 kg/m^3 and 7.1MPa average compressive strength absorbs minimum of 14.70% water and blocks with average density of 1603 kg/m^3 and 5.5MPa average compressive strength absorbs the maximum of 18.50% water. Thus, percent water absorption of brick blocks are influenced by its density. With the increasing density the water absorption decreases having a good coefficient of correlation (R^2 = 0.677). The average block density with respect to the percent water absorption can be represented by the following regression equation:

$$D= -6.641w^2+282.8w–1160 \qquad (3)$$

where,

D = avg. density of burnt brick in kg/m^3.

w = percent water absorption.

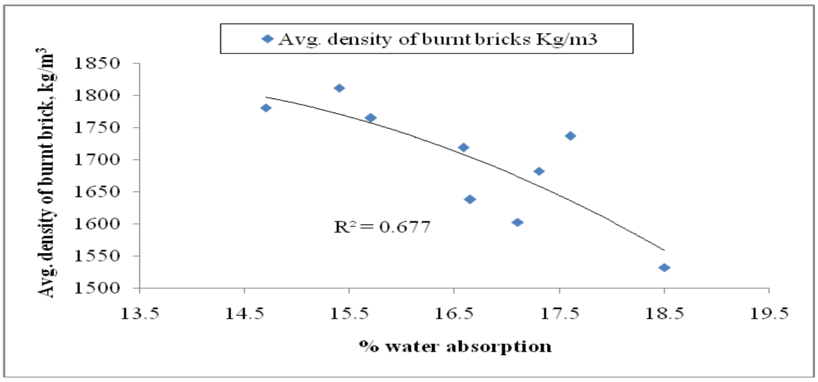

Fig. 5 Trend of Density of Burnt Bricks Vs Percentage of Tilla soil.

Influence of Density on Compressive Strength

Compressive strength of individual blocks consistently increases as dry density increases. Figure 6. illustrate the strong correlation (R^2 = 0.990) between average compressive strength and average density of brick block. In India block compressive strength is controlled through density prior to production the prototype blocks are determined in the laboratory. The average block density with respect to average density of blocks can be represented by the following regression equation:

$$C = 0.007D - 6.165 \quad (4)$$

Where,

C = avg. compressive strength MPa.

D = average density of brick blocks.

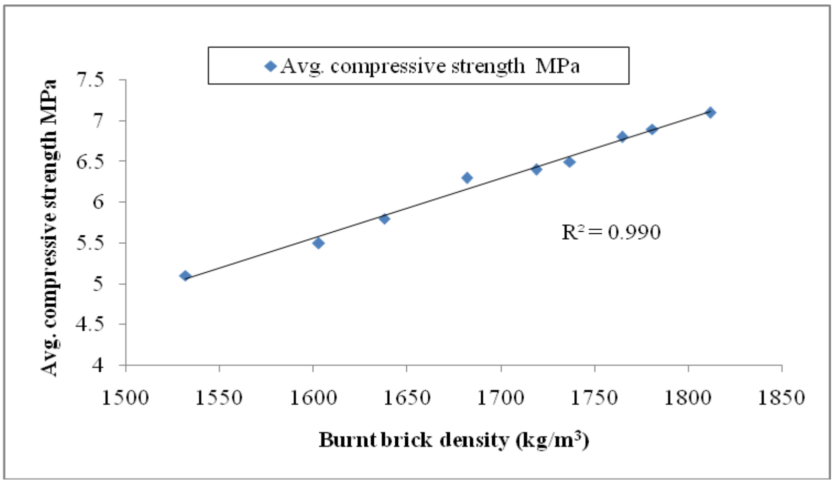

Fig. 6 Relationship between Avg. Compressive Strength and Density Of Brick Block.

Warpage, Efflorescence and Dimensional Test Result

Although the compressive strength is an indication of durability, the warpage, efflorescence and dimensional test carried out brought further information. Distortion or deformation of original shape of the clay body occurs during the manufacturing process. The warpage test resulted to negligible deformation. Moreover, the efflorescence test showed not more than 10 percent of the exposed area of the brick was covered with a thin deposit of salts. Thus satisfying IS 3495 (Part 3, 4): 1992.

For obtaining proper bond arrangement for the brickwork, the dimensional test was carried out. Table IV illustrates the dimensional test result. The brick blocks tested were within the standard range of length 3720 to 3880 mm; width 1760 to 1840 mm and height 1760 to 1840 mm satisfying Indian Standards [4].

Table V A Dimensional Analyses of Brick Blocks.

Blend	Dimensions (cm^3)	Length (mm)	Width (mm)	Height (mm)
1	19 x 9 x 9	3778	1790	1783
2	19 x 9 x 9	3788	1810	1815
3	19 x 9 x 9	3845	1806	1791
4	19 x 9 x 9	3792	1806	1787
5	19 x 9 x 9	3832	1798	1808
6	19 x 9 x 9	3874	1822	1847
7	19 x 9 x 9	3796	1780	1770
8	19 x 9 x 9	3820	1782	1822
9	19 x 9 x 9	3766	1802	1784

Feasibility Study of Wall Construction

One of the most important strength parameters needed for any load-bearing walling material is compressive strength. Compared with the results obtained in literature, we could find that:

- The Anifowose AYB [5] study carried on the stabilization of lateritic soil blocks with bentonite led to a compressive strength peaked at 8.244 MPa on firing at 800ºC with 6% of additive.
- The Solomon-Ayeh KA [6] study carried on the stabilization of laterite blocks with cement and lime led to 28-day compressive strengths for blocks ranging from 1.22 MPa (no stabilization) through 1.49 MPa (4% lime) to 4.44 MPa (8% cement)
- The Heathcote K [7] study carried on the stabilization of pressed earth blocks with cement led to 28-day compressive strength of 2.20 MPa with 5% of cement content.
- The Reddy et al [8] carried out a compressive study, which indicates the strength values in the range of 2.5–10MPa for individual blocks and 0.9–3.87MPa for masonry prism.
- Jayasinghe C. [9] showed with detailed studies in two storey load-bearing houses for small and carefully planned layouts, the maximum design strengths required can be maintained within 0.8 and 1.0 MPa when the ground floor wall widths are about 250 mm.
- The load is primarily from the self-weight of the walls and the portion of the roof supported in single storey construction. This stress is usually in the range of 0.1 MPa. This means that

characteristic wall strength required is about 0.5 MPa when a factor of safety of 1.4 (γ_f) is used for dead loads and 3.5 (γ_m) is used for material strength variations and workmanship factors as recommended in BS 5628: Part 1: 1992[10].

- Looking at the code requirements for stabilized earth blocks, the Australian code [11] specifies a minimum compressive strength of 2.0 MPa tested dry; the New Mexico building code [12] specifies that blocks have a minimum compressive strength of 2 MPa with one sample in five allowed to have a compressive strength less than 1.7 MPa; the UNESCO code [13] based on the work by Craterre requires a minimum dry compressive strength of 2.1 MPa; the British standard BS 5921: 1985 requires a minimum of crushing strength of 5 MPa for earth construction while the Indian Standards IS 1077–1986 and IS 1725–1982 specifies a minimum of 3.5 MPa for common burnt building bricks and a minimum of 2–3 MPa for soil-cement blocks used in General Building Construction respectively.

Compared with these code requirements, we could say that our results on compressive strength were by far higher than the minimum required.

CONCLUSION

The continuous use of natural resource based building materials has led to many environmental problems. Therefore, it is essential to develop alternative building materials that can give a comparable performance with respect to appearance, structural properties, and durability. This detailed study on the compressive strength of blended bricks with lateritic and clayey soils has indicated the following:

1. It is possible to use lateritic soils blended with clayey soil for the construction of masonry walls.
2. Since the failure of masonry walls is of compressive crushing nature, it is advisable to have an overall factor of safety of 5 or more.
3. Blended soil blocks duly burnt for load-bearing walls can alternate the fertile top soil of agricultural land, thus minimizing the environmental impact.

The research findings, makes it possible to use blended soil blocks duly burnt as a walling material with confidence for single storey houses using lateritic soil and clayey soil generally available in tropical climatic conditions. Furthermore, it can be a potential material for load-bearing walls of two storey houses under engineering supervision.

STM JOURNALS

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