Use of Cement Sand Admixtures to Produce High Strength Soil Bricks for Low Cost Housing Projects

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Abstract

Housing is universally accepted as a basic human need. Demand and cost of construction materials have drastically increased with the growth of population in Sri Lanka. In order to address this issue, attention has been focused on low-cost housing materials in this study. Accordingly, this research is focused on use of cement-sand admixtures to produce high strength soil bricks.

Lateritic soil and ordinary Portland cement were used for this study. Soil bricks were produced by increasing the cement compositions upto 5%, 10%, 15%, 20% of the total volume, and compacted to 33.33% and 44.44%, while applying 5kN force, and allowed for curing for 28 days. Average compressive strength of 5% cement soil bricks under above compaction ratios were 1.3MPa and 1.9MPa which is less than the standard limits of 2.8MPa stated in SLS 1382:2009, and it was 3.0MPa and 3.6MPa for 10% cement. However, the mixtures with 15% and 20% cement exceeded the required strength. The wet compressive strength of said brick was 2.6MPa and it was greater than the standard limits. The findings of this study confirmed that the decrease in particle size of the soil and the increase of compaction ratios increases the compressive strength of bricks. Therefore, a soil brick made with 10% cement, compressed to 33.33% is more appropriate for the low cost housing projects.

Keywords: Brick production, Compressive strength, Low cost bricks, Soil

1. Introduction

In recent years, the ownership of houses for the middle and low income families of the society has turned into a mirage as cost of building materials, construction costs and other factors has constantly increased putting the housing development at a very high price. In developed countries, accommodation and home ownership is easier as governments as well as financial institutions have planned effective housing policies and programs to aid the community in home ownership at affordable and reasonable price. In the developing world, especially in Sri Lanka, scarcity of living spaces for accommodation has always been an issue. The available housing stock is diminishing and reconstructing day by day as a result of the increase in the population and the high level of rural drift to urban areas.

In Sri Lanka, mainly fired or burnt clay bricks are used for building construction. Apart from that, cement blocks, sandcrete blocks etc. are also used. Local burnt clay bricks are produced by a cottage industry and have sustained unprecedented demand [1]. These are mainly used in the construction of non-load bearing walls or lightly loaded walls with the strength considered to be adequate even for carrying loads of two storey residential buildings [2].

The demand for housing facilities are increasing day by day and accordingly the demand for building materials also increase drastically.

Therefore, excessive usage or overexploitation of locally available building materials for construction purposes may result in heavy rates of deforestation, soil erosion, land degradation, increased river-water turbidity, lowered water tables and salinity intrusion in the lower reaches of rivers[3].

Considering the above facts, introduction of cost effective and environmentally friendly alternative building materials is of prime importance. At the same time, such alternative building materials should be sufficiently strong, durable and comply to national standard limits so that social acceptance would be at a considerably high level[4].

Therefore, to address the real issue, the scarcity of clay for brick making, the use of locally available sourced material, such as laterite soil, is a possible solution. Laterite is a red tropical soil that is rich in iron oxide and is usually derived from rock weathering under strongly oxidizing and leaching conditions[5]. As soil is abundantly available on sites, the cost of the brick making can be reduced.

In soil-brick making, the cement content used to stabilize the soil improves and increases the material strength and durability. The proper combination of cement, soil and sand optimizes strength of bricks. It is well known that the soils with higher proportion of sand in their composition, in most cases, will lead to greater soil-cement strength. The influence of other factors such as the limits of consistency, particle size distribution, and types of clay minerals should also be considered. A good homogenization of the mixture is critical. Only after homogenization, water is added in adequate amounts. Resistance to breakage increases proportionally to the cement content used. However, it should be limited to an ideal content that provides the brick or blocks the required strength without unnecessary increase in the cost of the final product [6].

The principles and advantages of interlocking soil bricks could be summarized as follows:

- As each brick has vertical holes (hollow,interlocking) two purposes are served. They are,
  - To reduce the weight of the block
  - To insert steel rods or bamboo in reinforcement and/or pour liquid grout into the holes which run through the full height of the wall thus increasing its stability further to insert electrical lines and water lines.
- Since the bricks can be laid dry, less or no mortar is required thus a significant amount of cement is saved.

- The bricks are shaped with projecting parts, which fix exactly into depressions in the blocks placed above, such that they are automatically aligned vertically and horizontally, thus brick laying is possible without special masonry skills.
- Speed of construction increases with the dry assembly of interlocking blocks which saves the construction time and thus the building costs are lower than for standard masonry construction.
- Interlocking blocks can be produced on a small scale on the building site (for self-help construction), or on a large scale in centralized production units.
- The structural stability and durability of interlocking block constructions can be far greater than for comparable timber constructions. Grout holes and channel blocks provide means to insert steel reinforcements in vulnerable parts of buildings for increased wind and earthquake resistance.
- The materials required (mainly soil) for block production and building construction are usually locally available in most regions.

2. Methodology

The research methodology consisted mainly of a literature survey and preliminary data analysis, field visits and sample collection, brick preparation, testing, results analysis, implementing conclusions and recommendations.

2.1 Preliminary Data Gathering and Analysis

Prior to starting field visits, sample collection and testing, preliminary data gathering and analysis were conducted using the available literature. Here, the available research data related to the use of cement sand admixtures in producing high strength soil bricks with low cost conducted in other countries, available technologies to produce bricks, tests that can be carried out to determine the physical properties of soil, advantages of producing interlocking soil bricks, market prices of available bricks, cost effective technologies that can be used etc. were evaluated.

2.2 Sample Collection

Considering the availability and accessibility of soil pits, a site which is authorized for soil excavation, located in Horawala area which is 1km away from the Pelawatta Junction on Matugama-Palwatte road in the Kaluthara district was selected. The samples were collected into sample bags, and brought to the laboratory for testing.

2.3 Preparation of Bricks

Initially, Sieve Analysis and Atterberg Limit tests using the Casagrande apparatus were performed, in order to determine the physical properties of the soil samples. Then, the soil was sieved by a mesh (aperture size: 10 squares for 1 inch). Next, the soil and cement with known proportion were thoroughly mixed while water spraying. [2 cups of cement + 18 cups of soil for preparation of 10% cement containing bricks (3 bricks can be prepared with this mixture)]. Then, the mixture was put into the brick mould and was compressed to the ratios of 1.6 and 1.8 separately by hydraulic jacks, applying a 5kN force. A compaction ratio of 1.6 was obtained by filling the soil upto 160mm in the mould and then compacting it upto 100mm. A compaction ratio of 1.8 was obtained by filling the soil upto 180mm in the mould, and then compacting it upto 100mm. Then, the bricks were let to cure by spraying water after covering with polythene sheet (Though the normal procedure of curing is soaking in water, we didn't do it because our bricks were made out of soil.). It was let to cure for 28 days. Then, the bricks were tested for compressive strength and the values were recorded. The above same procedure was repeated to prepare soil bricks with cement percentages of 5 %, 15% and 20%, and the average compressive strength of bricks of cement percentages of 5%, 10%, 15% and 20 % was calculated. The bricks were tested for water absorption by soaking the bricks in water for 24 hours and those bricks were also tested for compressive strength. Also bricks were prepared by varying the particle size distribution and tested for their compressive strength.

3. Results and Discussion

3.1 Results

Results obtained from physical tests performed are given in Tables 1-6.
Table 1 shows the sieve analysis test results of the representative sample which was brought fresh from the site. Table 2 and 3 shows the results of the sieve analysis test for two different particle size distributions obtained from the representative soil sample.

Table 1- Summary of sieve analysis test results for overall sample

Sieve size (mm)	Soil Retained (g)	Soil Retained (%)	Soil Passing (%)
4.750	9.5	1.9	98.1
2.000	92.5	18.5	79.6
0.850	167.5	33.5	46.1
0.430	99.5	19.9	26.2
0.250	50.0	10.0	16.2
0.075	60.5	12.1	4.1
Pan	20.5	4.1	0.0
Total	**500.0**	**100.0**	

Table 2- Summary of sieve analysis test results for sample 1

Sieve size (mm)	Soil retained (g)	Soil retained %	Soil Passing %
4.750	0.0	0.0	100.0
2.360	0.0	0.0	100.0
2.000	1.0	0.2	99.8
1.180	171.0	34.2	65.6
0.600	178.5	35.7	29.9
0.425	54.0	10.8	19.1
0.300	31.5	6.3	12.8
0.150	38.5	7.7	5.1
0.075	17.5	3.5	1.6
Pan	8.0	1.6	0.0
Total	**500.0**	**100.0**	

Table 3- Summary of sieve analysis test results for sample 2

Sieve size (mm)	Soil retained (g)	Soil retained %	Soil Passing %
4.750	0.0	0.0	100.0
2.360	0.0	0.0	100.0
2.000	0.0	0.0	100.0
1.180	62.0	12.4	87.6
0.600	207.0	41.4	46.2
0.425	77.5	15.5	30.7
0.300	46.5	9.3	21.4
0.150	66.5	13.3	8.1
0.075	28.5	5.7	2.4
Pan	12.0	2.4	0
Total	**500.0**	**100.0**	

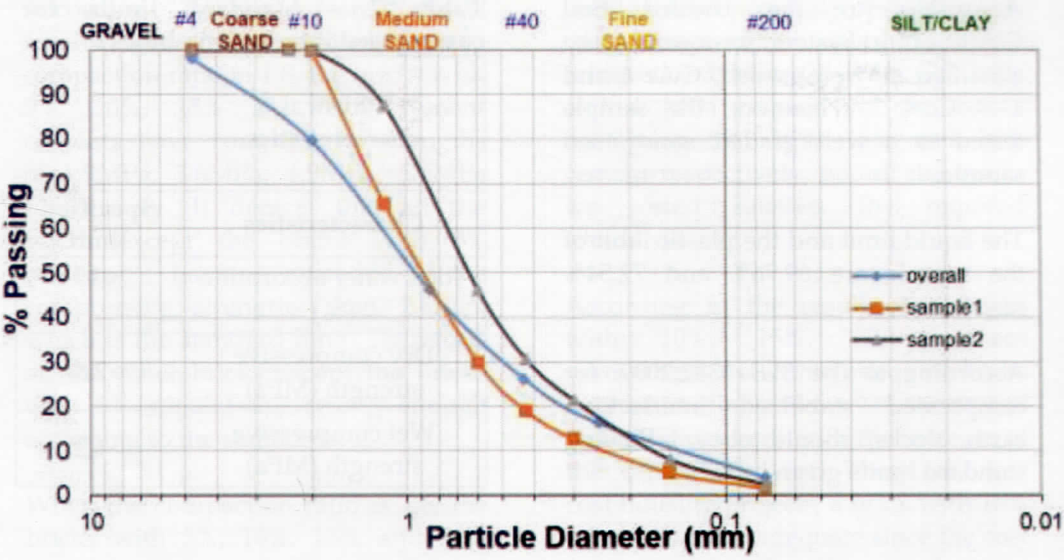

Figure 1 - Particle size distribution curves for overall sample, sample 1 and sample 2

Table 4 - Summary of average compressive strength test results of bricks

	Compressive Strength(MPa)			
Cement percentage (%)	5	10	15	20
Compaction force(50kN) (Compaction ratio 1.8)	1.9	3.6	4.9	5.5
Compaction force(40kN) (Compaction ratio 1.6)	1.3	3	3.6	4

Table 5 - Summary of water absorption test results of bricks

Cement percentage (%)	5	10	15	20
Water absorption (%)	15.3	12.2	9.2	8.7
Compressive strength (MPa)	1.3	2.6	3.7	4.0

Table 6 - Summary of compressive strength test results of bricks manufactured by sample 2

Cement percentage (%)	5	10
Compressive strength (MPa)	2.42	4.33

3.2 Discussion

According to the distribution curve for the overall sample shown in Figure 1, there is 1.9%, soil particles retaining on 4.75mm aperture size sieve. Therefore, there is 1.9% gravel present in the sample.

4.1% of particles are passing through the 0.075mm sieve which depicts that the percentage of silt/clay present in the sample is 4.1

Therefore, the percentage of sand in the sample is 94%.
Therefore, this is a sandy soil.
Coefficient of Uniformity (Cu) and the Coefficient of Curvature (Cc) are 8.67 and 1.28 respectively for this sample.

According to the Unified Soil Classification System, for a sand to be classified as well graded, $Cu \geq 6$ and $1 < Cc < 3$. Therefore, the sample tested is a well graded sandy soil sample.

The liquid limit and the plastic limit of the sample are 69.76% and 72.54% respectively.

According to the SLS 1382:2009, for compressed stabilized interlocking earth blocks, should obey following standard limits given in Table 7.

Table 7 - Standard limits for compressed interlocking blocks

Physical characteristics	
Characteristics	**Specified limit**
Total water absorption (%)	< 15
Dry compressive strength (MPa)	>2.8
Wet compressive strength (MPa)	>1.2

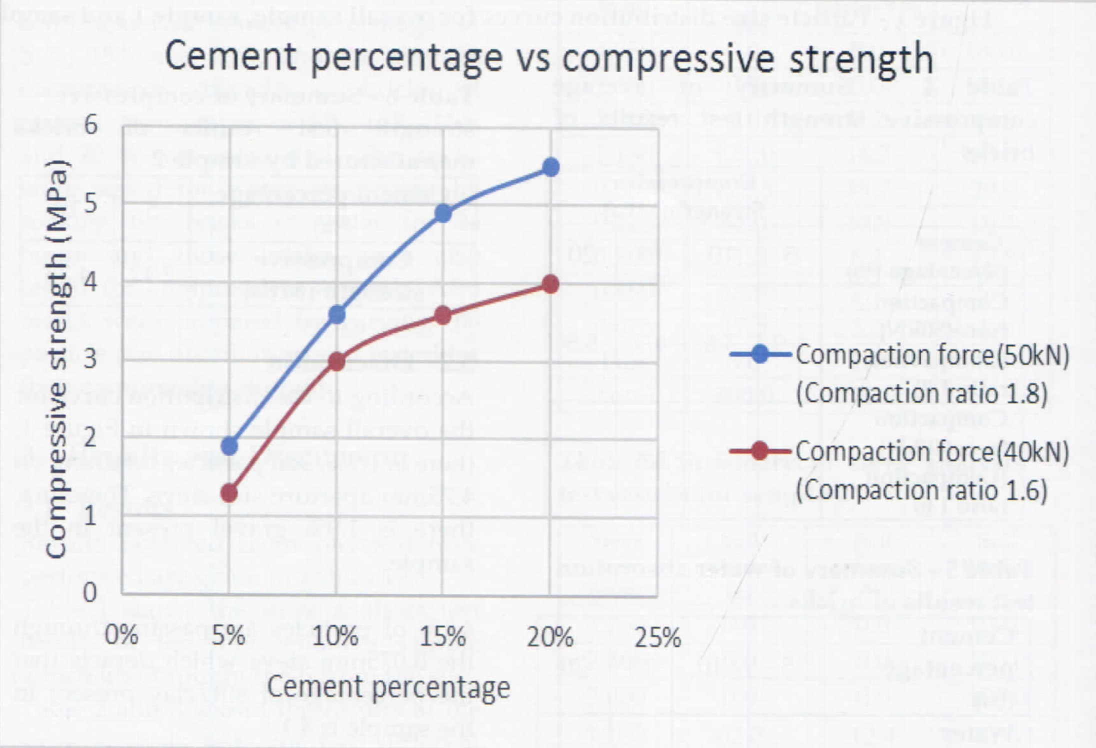

Figure 2 - Compressive strengths for compaction ratios of 1.6 and 1.8

According to the tested brick results(Figure 2), maintaining constant compaction ratio to 1.8, the bricks with 5%, 10%, 15% and 20% cement contents have compressive strengths of 1.9MPa, 3.6MPa, 4.9MPa, 5.5MPa respectively. It depicts that all the bricks except the bricks with 5% cement, have exceeded the compressive strengths than 2.8MPa which is the standard limit. Therefore, all the other bricks except the bricks with 5% cement are strong enough according to the standards.

When the compaction ratio is 1.6, the bricks with 5%, 10%, 15% and 20% cement contents have compressive strengths of 1.3MPa, 3MPa, 3.6MPa, 4MPa respectively. In that instance also only the bricks with 5% cement content have low strength than the specified limit (2.8MPa). Therefore, a brick with 5% cement content is not suitable for construction when the compaction ratio is 1.6. Bricks with cement percentage greater than 5% have achieved the specified limits so they are preferable for construction.

According to the water absorption test results of bricks with compaction ratio 1.8, the amount of water absorbed by bricks containing cement 5%, 10%, 15% and 20% are 15.3%, 12.2%, 9.2% and 8.7% respectively. According to SLS 1382 standards, the specified water absorption should be less than 15%. Therefore, standard limit is satisfied by 10%, 15% and 20% cement containing bricks. Also the water absorption decreases with the increase of cement content in the brick.

According to the limits specified in Sri Lankan Standards, wet compressive strength of soil bricks should be greater than 1.2MPa. After soaking bricks in water for 24 hours, the compressive strengths have achieved 1.3 MPa, 2.6 MPa, 3.7 MPa and 4 MPa respectively for bricks containing 5%, 10%, 15% and 20% cement respectively. So, all the bricks we tested satisfies the required standards.

According to the results, the bricks with 10%, 15%, 20% cement percentages are within adequate limits for constructions. However, the cost of the brick increases with the increase of the cement content. Therefore, low cost housing projects, a brick with 10% cement is more adequate since the cost for cement highly affects to the total cost.

In sample 2, where the grain sizes are less than that of sample 1, the compressive strength has increased than that of compressive strength values gained for sample 1. It depicts that by modifying the grain size distribution of soil the compressive strength can be increased.

Also the bricks are allowed to cure for 28 days, because bricks achieve higher strength when they are allowed to cure for 28 days than letting to cure less number of days.

Since these bricks are interlocking type they use less or no mortar for bonding. Also the laying of these bricks can be done faster than conventional bricks as these bricks interlock with each other. Laying of soil interlocking bricks can be done with less skilled labors. However, skilled labour is needed for the conventional brick works. The additional cost needed is only for finishing with varnish type sealing of outer surface to reduce water absorption. The cost for unit area with soil cement brick is less than the cost for unit area with conventional bricks for walls according to calculations. Therefore, this interlocking brick which was manufactured in this research study is more appropriate alternative solution for low cost housing projects.

These interlocking bricks are manufactured with soil which is abundantly available in many areas of the country and can be extracted from freely available suitable locations and even from soil excavated from land preparations for building construction. Therefore, environmental damage is less when compared to conventional bricks. Therefore, the soil brick manufacturing is an environmental friendly industry.

3.3 Cost Analysis

Table 8 - Summary of the cost for a wall construction for conventional bricks

	For 100ft^2 (Rs)	For One ft^2 (Rs)
Brick work in cement sand 1:5 in 4 1/2" thick walls in ground floor	31,141.25	**311.41**
9" thick brick wall cement sand 1:5 in ground floor	39,430.38	**394.30**

Table 9- Summary of the comparison of interlocking and conventional bricks.

	Unit Price (Rs)	Price of 1m^2 wall area (Rs)
***Building material cost**		
Brick Type 'A' solid cement block	66.00	891.00
Brick Type 'B' clay brick	26.00	1192.00
Brick Type 'C' compressed soil brick	20.00	800.00
***Bonding cost**		
Brick Type 'A' solid cement block (mortar+paste)		264.90
Brick Type 'B' clay brick (mortar+paste)		295.50
Brick Type 'C' compressed soil brick(interlocking+varnish)		50.00
***Labour cost**		
Brick Type 'A' solid cement block		710.16
Brick Type 'B' clay brick		710.16
Brick Type 'C' compressed soil brick		193.70

Dimensions of bricks indicated in Table 9

Brick Type 'A':390mm x 150mm x 190mm

Brick Type 'B':215.9mm x 101mm x 50mm

Brick Type 'C':250mm x 125mm x 100mm

5. Conclusions

- The representative soil sample used for this research was a well graded sandy soil sample.
- When considering the strength and cost effectiveness, bricks containing 10% cement is the most preferable one since the bricks containing 5% cement were unable to achieve the specified dry compressive strength with compaction ratios of 1.6 and 1.8.
- Bricks containing 10%, 15% and 20% of cement satisfy the specified percentage of water absorption by the brick.
- When considering the wet compressive strength, 10% cement containing bricks are more suitable.
- The compressive strength of the brick increases with the reduction of the particle size distribution of the soil sample used for brick manufacturing.
- The cost for unit area with soil cement brick is less than the cost for unit area with conventional bricks for walls according to calculations.
- Laying of soil interlocking bricks can be done with less skilled labours, while skilled labours for the conventional brick works. The additional cost needed only for finishing with varnish type sealing of outer surface to reduce water absorption.

6. Recommendations

- Compressive strength of soil cement bricks can be increased by increasing compaction ratio more than 1.8. However, optimum limit can be decided based on soil and cement prices.
- As strength of the bricks depends on the soil type and grain size distribution, it is recommended to modify the soil grain size distribution to optimum level by mixing different sizes of sieved soil grains.
- By applying high compression and using best soil mixture with modified grain size distribution can minimize cement content and thus the cost.
- Interlocking soil bricks can be recommended for all kinds of house construction projects as it gives standard strength with low cost, low skilled labour, low construction period and low environmental pollution.
- Durability of the brick depends on the type of sealing the bricks to avoid water intrusion, and therefore proper sealing is recommended.

Acknowledgements

The authors are grateful to the following personnel who helped us in various ways to complete this research project;
Dr.H.M.R. Premasiri, Head of the Department of Earth Resources Engineering and the final year research project coordinator, Dr. G.V.I. Samaradivakara, for their guidance and immense support.

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