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LOW CARBON STABILIZED EARTH BLOCK: A POTENTIAL ALTERNATIVE BUILDING BLOCK FOR SUSTAINABLE ENVIRONMENT

Mirza Md Rashiduzzaman[1], Fazle Zawad Akhond[2] and Md. Mominur Rahman[3,*]

[1]Nestlé Bangladesh Ltd, Sreepur, Rajendrapur Cantonment, Dhaka, Bangladesh.
[2]Gildan Shahriyar Fabrics Industries Ltd, Ashulia, Savar, Dhaka, Bangladesh.
[3]Department of Chemical Engineering, BUET, Dhaka-1000, Bangladesh.

[1]shafi1094@gmail.com, [2]fazlezawad@gmail.com, [3,*]mrrahman.rahman@gmail.com

Abstract*-Despite being a colossal source of Greenhouse Gas (GHG), fire-burnt clay molded brick remains the principal building material in Bangladesh. Accountability for the environmental degradation being the rationale for seeking alternatives, low carbon stabilized earth blocks were investigated as a primary approach towards the replacement of fire-burnt clay bricks. Various compositions of lime and cement were used in different soil types as stabilizers for earth block molding which was then compressed with hand press to furnish compaction and give a definite shape in solid form. After drying and curing those blocks were tested for strength. Although the tested strength of the blocks was not as rewarding as hoped, it yields fulfilling results regarding reduction of GHG emission, energy consumption and overall cost of production. Also this paper proposes some practical uses of these low strength blocks along with the proposition for further research to improve the strength of the block with a view to total replacement of fire-burnt brick for non-load bearing application in construction purpose.*

Keywords: Greenhouse gas, Fire-burnt brick, Stabilized Earth Block, Additives.

1. INTRODUCTION

Due to the unavailability of stone aggregate, brick has been the main building material for the country's construction industry for quite a long time. The rapid growth of population and concomitant high-speed urbanization has obligated the construction of vast number of brick buildings the outcome of which is a boom in the brick kilns number. From 1995 to 2005 the construction industry saw a 5.6% growth which went up to 8.1% to 8.9% in the following decade [1].

This sudden proliferation of brick kilns has resulted in an elevated concentration of Carbon Dioxide (CO_2) and Sulfur Dioxide(SO_2) in the air of Dhaka city especially during dry season. Fixed Chimney Kiln (FCK), the most popular type of kiln in Bangladesh, alone produces 50tonnes of CO_2 per 100,000 bricks production. The Bangladesh Country Environmental Analysis reports that poor air quality in Dhaka contributed to an estimated 3,500 premature deaths in 2002. Emissions from the kiln cluster north located at the north of Dhaka city are alone responsible for 750 premature deaths annually. Thus, northern cluster of FCKs are likely to contribute up to 20 percent of total premature deaths in Dhaka due to poor air quality.

Stabilized Earth Block(SEB) technology is an alternative to the conventional burnt brick technology and is relatively less expensive, uses local resources and consumes low energy with almost zero carbon emission at the production stage. However Stabilized earth block is a relatively new concept and needs systematic approach for ensuring the consistency of the method applied to manufacture such building block.

The percentage of sand and clay in soil type is an important factor that governs the selection of the type and amount required of the stabilizer for particular type of block production. Generally for more clayey soil lime ($CaCO_3$) is advised as stabilizer while cement is advised for more sandy soil [2]. Table 1 shows good soil composition for lime and cement stabilization and Table 2show suitability of stabilizers on a weight basis of the block.

Table 1: Soil composition for stabilizers

Soil Type / stabilizer	Gravel	Sand	Silt	Clay
Cement for more sandy soil	15%	50%	15%	20%
Lime stabilizer for more clayey soil	15%	30%	20%	35%

Table 2: Suitability of Stabilizers

Stabilizer	Suitability	Min^{m}	Avg	Maximum (economic)
Cement	Mostly sandy soil	3%	5%	7-8%
Lime	Mostly clayey soil	2%	6%	10%

Soil of Bangladesh is mainly divided into 3 broad categories. These are Floodplain soil, Hill soil & Terrace soil. Floodplain soil, which is the most abundant soil, has varied compositions of sand, silt and clay and constitutes about 79% of the total land [3].This type of soil is found everywhere. Hill soils are abundant in areas like Chittagong hill tracts, Banderban, Cox'sbazar, Feni, Comilla etc. This type of soil generally consists of equal portions of sand and clay. Hill soil type constitutes 12.7% of total land. Terrace soils are generally clayey and constitute 8.3% of total land. So before soil from any particular place is chosen its' ingredients has to be analyzed. Terrace soil is good for lime stabilization. Places among floodplains where there are more sand than clay, cement stabilization is the best way to go. Conversely lime stabilization is best for Terrace soil. For soils where essential amount of clay or sand is not present, more sand or clay can be introduced to alter the principal ingredient of the soil and choose stabilizer accordingly.

2. EXPERIMENTAL

Steps that followed during the experimental work on SEB were: suitable soil site selection, composition analysis, block making, drying and curing of the blocks, and measuring the strength of the blocks. Brief description of each step is given in the following sub-sections.

2.1Soil Site Selection

For this project soil samples were taken from two separate areas to ensure clear distinction in the properties of the both samples. Soil was taken from Lalbagh, Dhaka and from Munshiganj, Dhaka. Both areas are shown in the figure 1.

Figure 1: Soil Sample Locations

2.2 Composition Analysis

Selection of the suitable stabilizer is a critical part in making SEB which mostly depends on the type soil. Therefore, determination of the soil type is the foremost part of this experimental section. To find out whether the sample soil is clayey or sandy Sedimentation test was done. At first foreign objects (e.g. glass shards, stone) were gotten rid of. Two beakers were taken for each soil type and 50 grams of soil was put inside the beakers. It was then filled up to the 100 ml mark with water. Then the suspension of soil and water was stirred briskly with a stirrer to produce a homogeneous mixture. Next the suspensions were put into two measuring cylinders and were left to settle for more than 12 hours. Subsequently suspensions settled. As the area of the base of all the layers is same, volume of the layers are proportionate to their heights. Height of various layers e.g. Sand, clay, silt were measured and divided by the height of total suspension i.e. summation of heights of all layers to find out the percentage of any particular ingredient in the whole settled soil. The result then was compared to reveal the chief ingredient. The sedimentation test indicated that the soil from Lalbagh contains 70% clay, 25% silt and 5% sand and Soil from Munshiganj contains 75% sand, 15% silt and 10% clay.

2.3 Block Making

For block making the mould size was 5”×5”×4”. The size of the block was 5”×5”×3”. It was of a square shape. Soil sample was first broken down to small particles after removing foreign objects (glass shards, grass, stone etc.) and lime or cement was added according to the weight. 2 blocks with 5% and 8% (on weight basis of the block) lime stabilization was produced from the clayey soil. 3 blocks with 4%, 6% & 8% cement stabilization was produced with from the sandy soil. To extend the research, sand was added to clayey soil making sand the chief ingredient and 7 blocks were made out of this modified soil; 4 of them with cement stabilizer (4%, 6%, 8%, 10% cement) and 2 blocks with cement and lime mixture(6% cement- 3% lime and 6% cement-5% lime).From each type of soil one block was made having no stabilizer to get the reference strength values for each type of soil. In total 14 blocks were made.8-10% water was added to the mixed samples and mixed thoroughly. With more water the mould became too gooey and with less water it became too dry to form mould. The resultant mixture was then placed into a molding box and was subjected to uniform pressure and compacted to utmost level inside the molding box using a hand press. The handpress was connected to a hydraulic press.

2.4 Drying & Curing

Compressed block was then immediately removed from the molding box and was placed under the shade in ambient condition for drying and water splash was applied once every week for curing. After 30 days of drying and curing, blocks were tested for strength.

2.5 Strength Test

Sulfur coating was provided on the surface of each of the SEBs for smoothing the surface to provide uniform force distribution during strength measurement with Universal Testing Machine (UTM). Sulfur coated SEBs were then crushed inside the UTM and the strength of the respective block was measured. Figure 2 depicts the whole process.

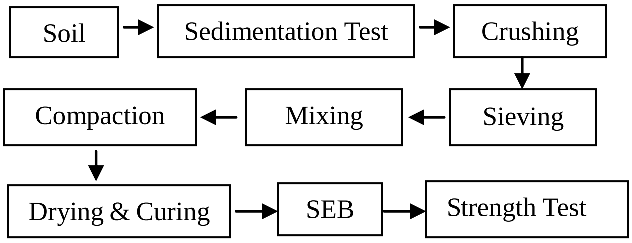

Figure 2: Process Block Diagram

3. RESULT AND DISCUSSIONS

3.1 Compressive Strength

Results obtained from the strength test of SEBs made of different soil types and stabilized with different stabilizers (cement, lime and mixture of cement and lime) are shown in figures 3 to 6. It was found that for clayey soil, compressive strengths of SEBs increased from 3.86 N/mm^2 to 4.21N/mm^2 for zero% to 5 % lime addition respectively and remained constant up to an overdose of lime of about 8% of the block weight (Figure 3). It seems that optimum economic lime requirement for this soil type is 5% which has the conformity with the reported average lime requirement for mostly clayey soil shown in Table 2.

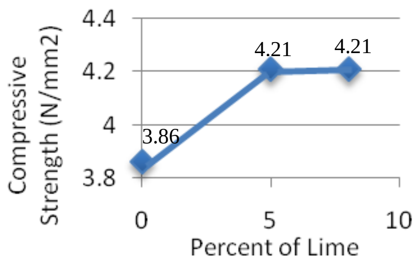

Figure 3: Strength result for clayey SEB with lime

An amazing feature was identified with the sandy soil when stabilized with cement (Figure 4). Addition of 4% cement as stabilizer actually had no effect on the compressive strength of SEB, since the compressive strength of the compressed earth block (CEB) without cement (3.65 N/mm2) was found to be the same for SEB with 4% cement as stabilizer. From this point onward, compressive strength of SEB increased with the increasing proportion of cement in soil which varied from 3.65 N/mm2 to 4.56 N/mm^2 for a variation of cement addition to the SEBs from 4% to 8% respectively. It is noteworthy that compressive strength of SEB made of sandy soil stabilized with cement increases with the increasing proportion of cement in the block. As literature reports the maximum economic ranges of cement percentage in SEB within 7-8% [4], mixing of cement stabilizer for this experiment was bracketed within the maximum range of 8%.

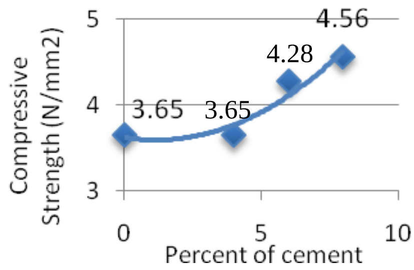

Figure 4: Strength result for sandy SEB with cement

It was found that the compressive strength of the altered soil block (clayey soil mixed with sand) without additives (Figure 5) was 3.65 N/mm^2 which was less than that of original clayey soil block (Figure 3) but very similar to that of sandy soil block (Figure 4) without additives. In the case of altered soil block (clayey soil turned into sandy soil), a remarkable increase in compressive strength with 4% cement additive was observed compared to originally sandy soil block with 4% cement additive. This can be attributed to the altered proportion of sand which was increased from 5% to 27%. As maximum strength of sandy soil block was found with 8% cement as stabilizer which is also the maxima of economic ranges for sandy soil [5], the next higher proportion of cement additive used for altered soil block was 8% which also showed a remarkable increase in strength of about 14% compared to originally sandy soil block with same proportion of cement additive. However, incremental increase in strength continued for altered soil block with 10% cement which was 6.3 N/mm^2 and found to 21% higher than that for 8% cement in altered soil block. The increasing rate of strength was found to be higher for higher proportion of cement stabilizer in altered soil block (Figure 5).

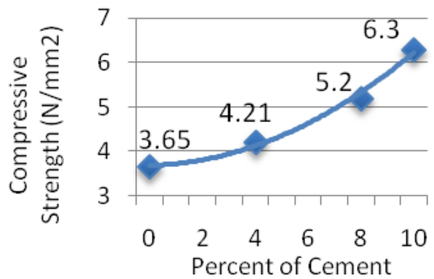

Figure 5: Strength result for altered SEB with cement

Figure 6 shows the strength behavior of altered soil block stabilized with mixed stabilizers (cement and lime) in different proportions.

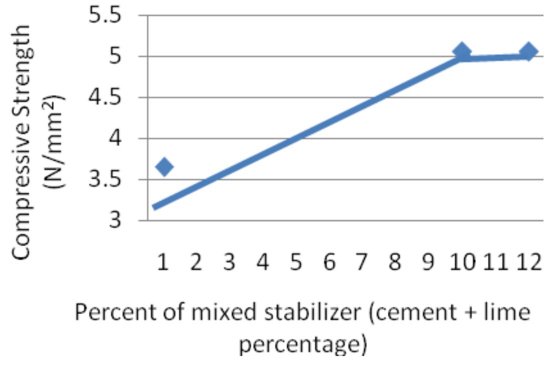

Figure 6: Strength result for SEB with mixed stabilizer

Altered soil block stabilized with mixed stabilizer (6% cement and 3% lime) showed a strength of about 5.05 N/mm2 which was eventually higher than that for clayey soil block stabilized with lime (Figure 3), originally sandy soil block stabilized with 6% cement (Figure 4) but almost similar for altered soil block stabilized with cement only (Figure 5). However, the strength of the altered soil block stabilized with mixed stabilizer (6% cement and 5% lime) remained unchanged compared to the prior composition in altered soil block. This peculiar behavior of mixed additive/stabilizer on the strength of the altered soil block can be attributed to the nature of altered soil. Literature advises to stabilize the sandy soil block with cement not with lime since lime has very little or no impact to enhance the strength of sandy soil block[6].

Since the altered soil was sandy in nature, lime had no effect on strength of these blocks. The strength of these altered soil blocks solely imparted by the addition of cement which was manifested with the strength of the altered soil blocks stabilized with different proportions of lime and fixed proportion of cement additives.

It is therefore clear that SEBs made of sandy soil and stabilized with cement show better compressive strength compared to the SEBs made of clayey soil and stabilized with lime. Also, SEBs made of altered version of clayey soil with sand show much better compressive strength when stabilized with cement. Therefore, it may be a better option always to stabilize soil block with cement even after the soil requires alteration of its nature by the addition of sand.

3.2 Embodied Energy Value (EEV) of SEB

Comparing the energy requirement of both blocks it is seen that the fired brick requires more energy than its counterpart. Fired brick requires 2.23 MJ energy per kg while earth block requires only 0.4201 MJ energy per kg [7]. The calculation is given elaborately below. And figure 7 depicts a visual comparison.

3.2.1 Calculation

For Fired brick: 20-24 Metric tons coal needed per 100000 bricks [8]. Using approximate density of calorific value of 32.5 MJ/kg coal. Net energy needed for a fire brick of weight 3.5 kg is7.800 MJ. Energy required per kg: 2.23 MJ

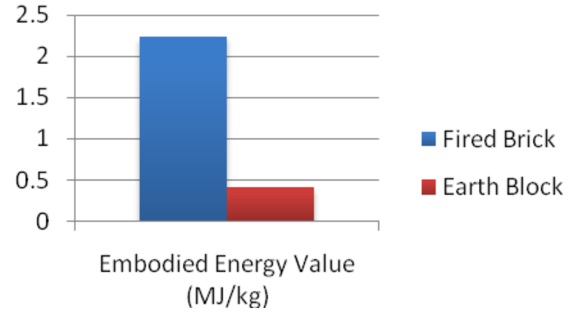

Figure 7: Embodied Energy Value Comparison

For the Earth Blocks:
10% cement earth block: (compressive strength 914 psi): For an earth block having 10%cement, the amount of cement needed is 0.16 kg. 4,982,000 Btu is needed to produce one metric ton of cement(not including the energy required for quarrying the raw materials) [7]. Net energy needed for an earth block of weight 2 kg with 10% cement is 0.841 MJ. Per kg energy required: 0.4201 MJ

3.3 Embodied Carbon Footprint of SEB

Comparing the CO_2 emission by both blocks in the production stage also gives a clear view of the superiority of earth block. Fired brick emits 0.143kg CO_2 per kg brick produced while earth block emits 0.043kg CO_2 per kg block produced [8]. The calculation is shown below and the graphical comparison is presented in the Figure 8 below.

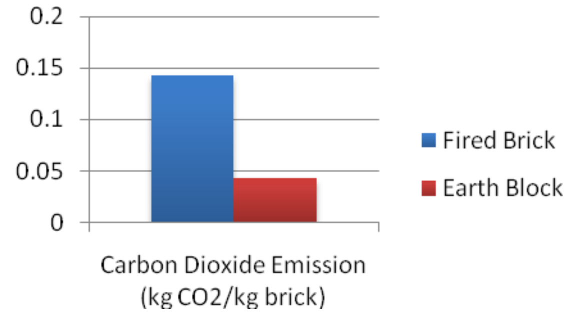

Figure 8: CO_2 Emission Comparison

3.3.1 Calculation:

CO_2 emissions is 0.544 metric ton of CO_2 per metric ton of cement and 0.785 metric tons of CO_2 per metric ton of lime produced. For Earth Block having 10% cement the CO_2 Emissions is 0.043 kg/kg of earth blocks. For Earth block having 6% cement and 3% lime CO_2 Emissions 0.044 kg/kg of earth blocks [7].

3.4 Production Cost of SEB

Contrasting the cost of production it can be seen that earth block excels in this sector too. While fired brick costs 1.93 BDT per kg [9], earth block costs 1.028 BDT per kg. The comparison is shown in the figure 9 below Only in the case of compressive strength earth block falls behind. While fired brick generally has a compressive strength of 20-40 N/mm^2 earth block has 3-6 N/mm^2.

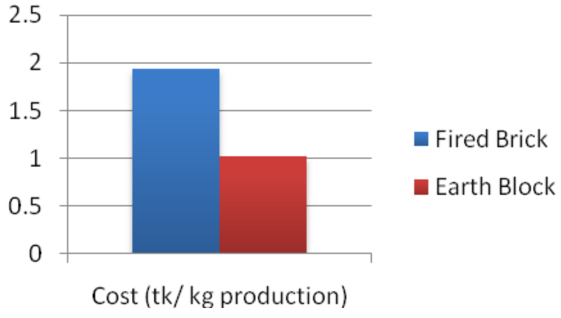

Figure 9: Cost Comparison

4. CONCLUSION

Compressed earth block has several advantages over fired brick. It is built from locally found soil. Raw materials are readily available. Also it has the advantage of soil regeneration capability within twenty years as it is made from the mixture of soil and additives and not burned. It also requires less embodied energy and carbon footprint and thereby it is an environment friendly option for construction purpose. It has the capacity of being the primary building material in the rural areas due to its low cost where one story buildings are abundant. The pronounced disadvantage of SEBs is its low compressive strength. According to Reinforced Cement Concrete (RCC) structure, partition wall and the outside wall of any building do not need to bear any significant load [10]. Therefore SEBs can be used on the partition walls inside a house and the outside walls as a non-load bearing unit. SEB technology is already being ventured in India, Brazil, China, Uganda, United Kingdom and numerous other countries. United Nations has been implementing a project named UN Habitat that is working to construct houses with earth blocks in Uganda[11]. A UK based company named Lime Technology is commercially producing Sumatec® Earth Blocks which has a compressive strength similar to that found in this project and are supposed to be used on the inner partition wall of a house.[12]However, this technology has started getting its recognition all over the world due to its low cost and environment friendly nature.

5. FURTHER RESEARCH

There are certain aspects that can be explored in an attempt to improve compressive strength of these blocks. In this project the amount of pressure applied to the blocks were not measured. Measuring the pressure could yield a significant relation between pressure and compaction of mold which in turn could have an effect on compressive strength.

Amount of water added to the mixture can be varied to find out how compressive strength alters with different proportion of water added.

In this project shrinkage test was not performed on the SEBs. Shrinkage test should be done in future projects as the blocks made in this project showed significant shrinking tendency.

Number of test blocks made should be increased and the range of percentage of additives should be expanded for a better understanding of the effect of additives on compressive strength. The effect of both lime and cement as additives should be investigated too.

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