American Chemical Science Journal
12(3): 1-10, 2016, Article no.ACSJ.23071
ISSN: 2249-0205

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Compressed Stabilized Earth Block: A Green Alternative for Non-load Bearing Building Block in Developing Countries like Bangladesh

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Authors' contributions

This work was carried out in collaboration between all authors. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/ACSJ/2016/23071
Editor(s):
(1) Georgiy B. Shul'pin, Semenov Institute of Chemical Physics, Russian Academy of Sciences, Moscow, Russia.
Reviewers:
(1) Nadezda Stevulova, Technical University of Kosice, Slovakia.
(2) Anonymous, University of Queretaro, Mexico.
(3) Ronaldo Goncalves Dos Santos, Centro Universitario da FEI, Brazil.
Complete Peer review History: http://sciencedomain.org/review-history/12992

Original Research Article

Received 12th November 2015
Accepted 5th January 2016
Published 16th January 2016

ABSTRACT

Fire-burnt clay molded brick remains the chief building material in Bangladesh although it is considered as a massive source of Greenhouse Gas (GHG). In this study compressed earth blocks stabilized with various additives were examined as an alternative to the fire burnt clay molded bricks with a view to a partial replacement of the same which is mainly responsible for its role in environmental degradation. Various compositions of lime and cement were used with different soil types as additives in earth block molding and then were pressed with a hand press to provide compaction and a definite shape in solid form. Drying and curing was done before the blocks were tested for strength. Although the strength yielded by the blocks was not comparable to that of fired clay brick, it produced rewarding results regarding the reduction of GHG emission, energy consumption and overall cost of production. Also this paper suggests some realistic uses of these low strength compressed stabilized earth blocks (CSEB) in real field. However, the results obtained from this study will aspire the future research to reach the target in replacing the fired brick to that

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amount which is now being used as non-load bearing building block in construction sector of Bangladesh.

Keywords: Greenhouse gas; fire-burnt brick; stabilized earth block; additives.

1. INTRODUCTION

Fire-burnt clay brick has been the main building material of construction industry in Bangladesh for quite a long time due to the unavailability of stone aggregate or other alternative building materials at comparable cost in the country [1]. The estimated number of brick kilns that operates countrywide is around 5020 of which 5000 kilns are coal fired and remaining 20 kilns are gas fired. About 17.2 billion unit fired bricks are produced each year from these kilns. Coal fired brick kilns use less valuable coal (3.5-4% sulfur content) mostly imported from India and indigenous firewood as fuel. It is estimated that 3.5 million tons of coal and 1.9 million tons of firewood are consumed in these coal fired brick kilns each year which produce about 9.8 million tons of CO_2 each year [2-4]. Among the brick making technologies available in Bangladesh, Fixed Chimney Kiln (FCK) is the most commonly technology implemented which accounts for more than 90% of the brick kilns in Bangladesh due to its low investment cost and ability to operate on low lands during dry season. FCK in Bangladesh alone occupies the lion share of brick production which accounts for more than 91% of total production in brick making sector [1] and consumes 1.9 MJ/kg-fired brick and produces 0.183 kg of CO_2 per kg of fired brick [1,2,5]. 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 enjoyed a 5.6% growth which went up to 8.1% to 8.9% in the following decade [6]. Rapid urbanization and infrastructure development inside and outside Dhaka Mega City favor to concentrate brick kilns, mostly FCK, at the northern outskirts of Dhaka City. The North Dhaka Brick Kiln Cluster consists of 530 closely spaced FCK, located in the Tangail, Gazipur and the Northern Upazilas of Dhaka district [2]. This rapid proliferation of FCK in North Cluster has resulted in an elevated concentration of CO_2, SO_2, and fine particulate matter ($PM_{2.5}$) in the air of Dhaka city especially during dry season. Source apportionment work for $PM_{2.5}$ shows that FCK in North Dhaka Cluster alone contributes 38% of $PM_{2.5}$ in the air of Dhaka city during 5-month dry season [1]. The Bangladesh Country Environmental Analysis reports that poor air quality in Dhaka contributed to an estimated 3,500 premature deaths annually. Emissions from the FCK at North Dhaka Cluster are alone responsible for 750 premature deaths annually which is equivalent to 20 percent of total premature deaths in Dhaka due to poor air quality [7]. Therefore, FCK at North Dhaka Cluster is considered to be the most polluting technology causing annual health damages of Dhaka city people estimated at about BDT 0.9 per brick production [1].

CSEB technology is an alternative to the conventional burnt brick technology and is relatively less expensive, uses local resources and consumes less energy with reduced carbon emission at the production stage. However, CSEB needs systematic approach for ensuring the consistency of the method applied to manufacture such building block. The percentage of sand and clay in soil is an important factor that governs the selection of the type and amount required of the stabilizer for particular type of CSEB production [8,9]. Generally for clayey soil (15% gravel, 30% sand, 20% silt and 35% clay) lime is advised as stabilizer whereas for sandy soil (15% gravel, 50% sand, 15% silt and 20% clay) cement is advised. Sandy soil requires a minimum of 3% cement stabilizer based on sand fraction of the soil. The average value of cement stabilizer is around 5% for most of the sandy soils. However, the economic maximum limit of cement stabilizer for sandy soil ranges from 7-8%. Contrarily, clayey soil requires a minimum of 2% lime stabilizer depending on the clay content of the soil. Average lime requirement for this type of soil is around 6% and the economic maximum limit is 10% [10].

Many research works have been carried out for soil stabilization with cement. Wang [11] stated that the cement contents may range from as low as 4% to a high of 16% by dry weight of soil. For construction in tropical countries, Garg [12] stated that the amount of cement added to soil that would give a compressive strength of 2.5 to 3.0 N/mm^2 should give satisfactory strength results. However, studies show that if the cement content is greater than 10%, CSEB production will be uneconomical. Contrarily, CSEB using less than 5% of cement binder is often too friable for easy handling [13]. Though cement is preferable for sandy soil stabilization, it can be added to stabilize any type of soil, except soils with organic content greater than 2% or sulphate content greater than 0.2% or having pH lower than 5.3 [11,12]. Sulfate content exceeding 0.2% have been known to weaken concrete [11,14]. Unconfined compressive strength is an indirect measure of soil stabilization. A minimum strength gain of 0.35 N/mm^2 of the lime stabilized soil over natural soil can be adequate to consider for stabilization, whereas a strength gain of 0.7 N/mm^2 for a soil-cement mixture over the natural soil can be considered adequate for cement stabilization [15]. Stabilization of soil by lime is achieved mainly through cation exchange, flocculation and agglomeration, and pozzolanic reaction. Cation exchange, flocculation and agglomeration reactions takes place rapidly and bring immediate changes in soil properties such as strength, plasticity and workability [16], whereas, pozzolanic reactions are time dependent. The cation exchange starts to take place between the monovalent metallic ions associated with the surface of the clay particles (Na^+, K^+ etc.) and that are surrounded by a diffuse hydrous double layer (H^+), which is modified by the ion exchange of calcium, because of which there is alteration in the density of the electrical charge around the clay particles, that leads to the flocculation and agglomeration of clay particles. This process mainly takes place within the lime fixation point and is mainly responsible for the modification of the engineering properties of clay soils treated with lime. In addition to cation exchange, pozzolanic reaction occurs between the silica and some alumina of the lattices of the clay minerals. During this process, the highly alkaline environment (pH 12.4) produced by the addition of lime causes silica and alumina to be dissolved out of the structure of the clay minerals and to combine with the calcium to produce new cementitious compounds: calcium silicate hydrates (CSH), calcium aluminate hydrates (CAH), and calcium alumino-silicate hydrates (CASH) which strengthen the soil with curing time [17-19]. The effectiveness of the treatment depends on the quality and quantity of lime as well as the chemical and mineralogical composition of the soil. The strength developed is obviously influenced by the quantity of cementitious gel produced and consequently by the amount of lime consumed [20]. Lime stabilization occurs at lime additions in excess of the lime fixation point. The initial consumption of lime gives an indication of the minimum quantity of lime that must be added to the soil in order to achieve a significant change in properties. This quantity must first satisfy the affinity of the soil for calcium and so it is not available for pozzolanic reactions. Bell [16,17] indicated that the optimum addition of lime needed for maximum modification of the soil is normally between 1% and 3% lime by weight, and further additions of lime do not induce changes in the plastic limit, but increase the strength. Cement can be added to lime-clayey soil mix to enhance stabilization process because the lime-clay ratio will be increased due to the existing of lime in cement and the present of lime attributed to the immediate reduction of plasticity. When lime-clayey soil is mixed with cement in presence of water, Calcium Silicate Hydrates (C-S-H) gel forms through hydration reaction [21]. This C-S-H gel has beneficial effect in clay material by reduction of deleterious heaving effects due to the rapid removal of alumina. The formation of ettringite contributes to the increase of porosity and decreases the free moisture content in soil pore. The C-S-H gel fills the void spaces and binds the soil particles together to imparting strength to the soil mixture [22].

Soil of Bangladesh is mainly divided into 3 broad categories. These are Floodplain soil, Hill soil and 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 in Bangladesh. Hill soils are abundant in areas like Chittagong hill tracts, Banderban, Coxs'bazar, Feni, Comilla etc. This type of soil generally consists of equal portions of sand and clay. Hill soil type constitutes around 13% of total land in Bangladesh. Terrace soils are generally clayey and constitute 8% of total land in Bangladesh [23].

There are 32 million general and institutional households in Bangladesh of which 26 million and 6 million households are in rural areas and urban areas respectively. With a population growth rate of 1.2%, each year Bangladesh needs new households to provide accommodation to these additional people [24]. To cater these households with building materials, several thousand of low tech brick making kilns, especially FCK, have been constructed in different zones of Bangladesh which are polluting ambient air, damaging crops production and human health enormously across the country. To address these issues and to provide better environment and social benefit, this research work aimed to develop low cost CSEB that will reduce emission and energy requirement and thus replace part of the traditional fired bricks which are mainly used as non-load bearing purpose in household construction sector in Bangladesh.

2. EXPERIMENTAL

Steps that followed during the experimental work on CSEB production were: suitable soil site selection, soil 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.

2.1 Soil Site Selection

Soil samples were taken from two separate locations to ensure clear distinction in the properties of the soil samples. Plenty of soil samples were taken from Lalbagh, Dhaka and Munshiganj, Dhaka. Soil sample locations are shown in the Fig. 1.

2.2 Soil Compositions

Selection of the suitable stabilizer is a critical part in making CSEB which mostly depends on the soil type. Therefore, determination of the soil compositions was the foremost part of this experimentation. Hydrometer method was used to determine whether the sample soils were clayey or sandy [25]. At first, foreign objects (e.g. glass shards, stone) were sorted out manually and then air dried. The air dried soil sample was ground manually with a ceramic mortar and pestle arrangement for homogenizing the soil sample. Thereafter, the ground soil was sieved with a 2 mm mesh screen. 50 g of each of the sieved soil samples was then dispersed in 1 L of water. The dispersion medium used was 40 g of Sodium Phosphite (Na_3PO_3) and 10 g of Sodium Carbonate (Na_2CO_3) in demineralized water. Amyl alcohol was used to disperse froth in determination of silt percentage. After suspending the soil, the hydrometer reading at 40 sec and at 2 hours was taken and correction factor was applied. Using the hydrometer readings, percentages of sand, silt, and clay was calculated.

2.3 Preparation of Earth Block

The foreign objects like glass shards, grass, stone etc were first sorted out from the air dried soil sample. Thereafter, the soil sample was crushed with a wooden pestle and sieved with 5 mm mesh screen. The sieved soil sample was then grounded with a wooden mallet against a rough concrete surface and sieved with a 2 mm mesh screen. Lime or cement binder was added to the finished soil sample on weight basis according to the soil type. Two blocks with 5% and 8% lime (on weight basis of the block) were prepared from the clayey soil

Fig. 1. Soil sample locations in Google Map

(soil sample from Lalbagh). Three blocks with 4%, 6% and 8% cement (on weight basis of the block) were prepared from the sandy soil (soil sample from Munshiganj). To extend the research work, clayey soil was mixed and modified with sand at a ratio of 70% : 30% respectively on weight basis and seven blocks were made out of this modified soil: Four of them with cement stabilizer (4%, 6%, 8%, 10% cement) and two blocks with mixed stabilizer (6% cement-3% lime and 6% cement-5% lime). From each type of soil one block was made without any stabilizer to get the reference strength values for each type of soil block. 8-10% water was added to the stabilizer-soil mix and mixed thoroughly. The resultant mixture was then placed into a moulding box and was subjected to uniform pressure and compacted under 4 N/mm^2 applied pressure inside the moulding box using a hydraulic hand press (Carver Laboratory Press, 14600-175).

2.4 Drying and Curing of Earth Block

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

2.5 Compressive Strength Test

Sulphur coating was provided on the surface of each of the CSEBs prepared for smoothing the surface to provide uniform force distribution during strength measurement with Universal Testing Machine (UTM: Tecnotest, MODENA-ITALY, KD 300/R). Sulphur coated CSEBs were then crushed with the UTM and the strength of the respective CSEB was measured.

2.6 Embodied Energy Value (EEV) of CSEB and Fired Brick

Embodied energy values of fired brick from FCK and CSEB were compared based on the following information: Energy requirement to produce 1 kg of ordinary fired brick in FCK was estimated based on coal consumption data and pertinent lower calorific value of coal, whereas the energy requirement for the production of 1 kg CSEB was estimated using energy consumption values of cement production and lime production. Energy consumption values for fired bricks, cement and lime were taken from the literature and corresponding embodied energy values of CSEB and fired bricks were then calculated and compared.

2.7 Embodied Carbon Footprint (ECF)

Embodied carbon footprints of CSEB and fired brick from FCK were calculated from the literature values of CO_2 emission data on cement and lime production and fired bricks production in FCK.

2.8 Production Cost

Specific cost (BDT/kg) of fired bricks in FCK was calculated on yearly basis production of fired bricks, per unit weight of fired bricks, yearly operational and maintenance cost (soil, land rent, labor, water, maintenance, staff salary, value added tax, coal consumption) and initial investment with a service life of 10 years having zero salvage value and a minimum attractive rate of return (MARR) of 10%. Yearly average production of the fired bricks from FCK was 3.5 million units each having an average final weight of 2.73 kg. Yearly operational and maintenance cost of FCK was calculated to be 22 million BDT with a capital investment of 6 million BDT. For various CSEB, assumed yearly production capacity was 80,000 units each having a final weight of 5 kg. Calculated yearly operating cost was around 0.6 million BDT for modified CSEB stabilized with 10% cement, 0.5 million BDT for modified CSEB stabilized with 6% cement and 3% lime, and around 0.2 million BDT for CSEB stabilized with 5% lime. In either cases, the initial capital investment is 0.01 million BDT. The MARR, useful life and salvage value for all three cases were same as those of FCK.

3. RESULTS AND DISCUSSION

3.1 Soil Compositions

The hydrometer test indicated that the soil sample from Lalbagh, Dhaka was too clayey and contained 70% clay, 25% silt and 5% sand whereas soil sample from Munshiganj, Dhaka was too sandy and contained 75% sand, 15% silt and 10% clay.

3.2 Compressive Strength

Results obtained from the strength test of CSEBs of different soil types stabilized with different stabilizers (cement, lime and mixture of cement and lime) are shown in Figs. 2 to 5. It was found that for clayey soil, compressive strength of

CSEBs increased from 3.86 N/mm^2 to 4.21 N/mm^2 for zero to 5 % lime respectively and remained constant up to a lime dosing of about 8% of the block weight (Fig. 2). Since strength gain of the prepared blocks with 5% and 8% lime over the reference block was found to be 0.35 N/mm^2, both the blocks were stabilized [15]. Compressive strengths after 30 days were found to be the same for both the stabilized blocks with 5 and 8% lime. Strength gain after lime fixation point is rather slower than within lime fixation point. This phenomenon is due to the pozzolanic effect which is time dependent and increases compressive strength in the long run.

An amazing feature was identified with the sandy soil when stabilized with cement (Fig. 3). Addition of 4% cement as stabilizer actually had no effect on the compressive strength of CSEB, since the compressive strength of the compressed earth block (CEB) without cement was found to be the same for CSEB with 4% cement. This was due to the fact that sandy CSEB with less than 5% cement binder actually shows no strength development [13]. From this point onward, compressive strength of sandy CSEB increased with the increasing proportion of cement which varied from 3.65 N/mm^2 to 4.56 N/mm^2 for a variation of cement addition from 4% to 8% respectively and accounted for 25% strength enhancement. However, strength gain of sandy CSEB with 6% cement over the reference sandy block without additive was found to be 0.63 N/mm^2 which revealed that sandy CSEB with 6% cement was not stabilized, whereas sandy CSEB with 8% cement was found to be stabilized with a strength gain of 0.91 N/mm^2 over the reference sandy block, since a strength gain of 0.7 N/mm^2 for a soil-cement mixture over the natural soil can be considered adequate for cement stabilization [15].

As the maximum economic ranges of cement percentage in sandy CSEB should be within 7-8% [10], mixing of cement stabilizer for this experiment was bracketed within the maximum range of 8%. The soil sample collected from Munshiganj was too sandy (75% of soil weight) and the compressive strength of these CSEBs increased with increasing proportion of cement addition due to good binding property of cement with sand.

It was found that the compressive strength of the modified soil block (clayey soil mixed with 30% sand) without additives (Fig. 4) was 3.65 N/mm^2 which was less than that of original clayey soil block (Fig. 2) but similar to that of sandy soil block (Fig. 3) without additives. This phenomenon might be due to cohesive property of clay in soil. In the case of modified CSEB, a remarkable increase in compressive strength (about 15%) with 4% cement was observed compared to originally sandy CSEB with 4% cement. This can be attributed to the altered soil nature due to the addition of 30% fresh sand to clayey soil on weight basis that led to an altered soil composition of 49% clay, 17.5% silt and 33.5% sand. As maximum strength of sandy CSEB was found with 8% cement which is also the maxima of economic ranges for sandy soil block stabilization [10], the next higher proportion of cement used for modified CSEB was 8% which also showed a remarkable increase in strength of about 14% compared to original sandy CSEB with same proportion of cement. However, incremental increase in strength continued for modified CSEB with 10% cement binder which was 6.3 N/mm^2 and found to be 21% higher than that for modified CSEB with 8% cement. The increasing rate of strength was found to be higher for higher proportion of cement stabilizer in modified CSEBs (Fig. 4). As previous study suggests CSEB production with more than 10% cement is uneconomical [13], further addition of cement binder beyond 10% was not examined in this study. However, modified soil block with 4% cement was found to be non-stabilized and modified soil blocks with 8 and 10% cement were found to be stabilized based on the strength gain [15]. Fig. 5 shows the strength behavior of modified CSEB stabilized with mixed stabilizers (cement and lime) in different proportions. Modified CSEB stabilized with mixed stabilizer (6% cement and 3% lime) showed a strength of about 5.05 N/mm^2 which was eventually higher than that for clayey CSEB stabilized with lime (Fig. 2), original sandy CSEB stabilized with 6% cement (Fig. 3) and modified CSEB stabilized with 6% cement (Fig. 4). However, the strength of the modified CSEB with mixed stabilizer (6% cement and 5% lime) remained unchanged compared to modified CSEB with (6% cement and 3% lime). This peculiar behaviour of mixed stabilizer on the strength of the modified CSEB can be attributed to the altered soil nature and pozzolanic effect of lime binder. Addition of excess amount of lime beyond lime fixation point does not increase the strength of the block immediately rather it increases the strength of the block in the long run even after several years. Therefore, the pozzolanic effect of lime beyond lime fixation point might be absent in those CSEBs within 30

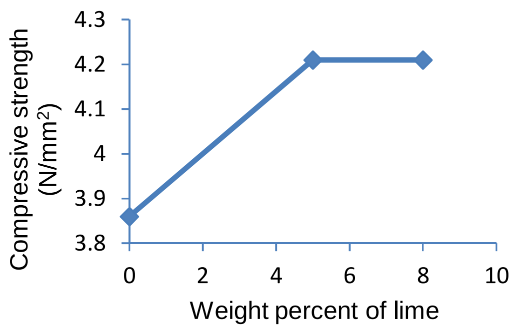

Fig. 2. Strength of clayey CSEB with lime

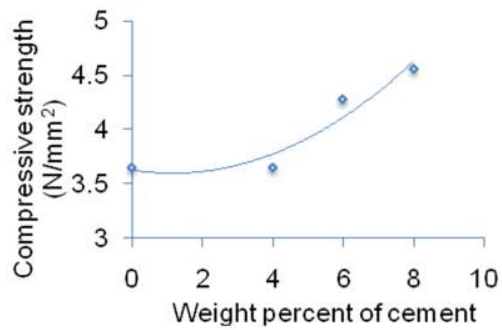

Fig. 3. Strength of sandy CSEB with cement

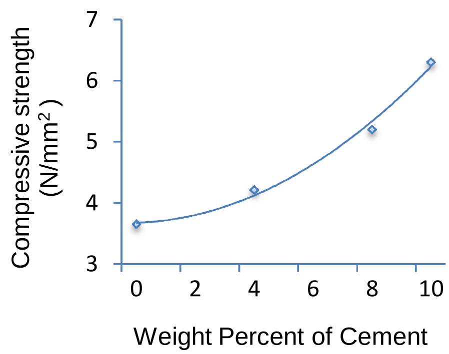

Fig. 4. Strength of modified CSEB with cement

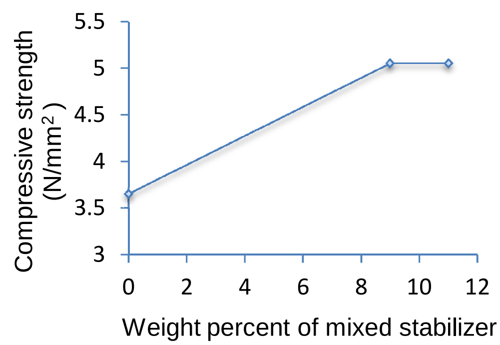

Fig. 5. Strength of modified CSEB with mixed stabilizer (cement and lime)

days period. The modified soil was still clayey even after modification with 30% sand. Clayey soil-lime mix with cement forms hydrates gel in presence of water which fills the void spaces created due to the flocculation and agglomeration effect of lime and binds the soil particles together thus imparting better strength to the soil mixture [25,26]. However, both the modified soil blocks with mixed stabilizers were found to be stabilized based on the strength gain over the reference modified soil block without stabilizer.

It is therefore clear that too much sandy or clayey soil requires addition of higher amount of stabilizers to get optimum strength of CSEB. Clay proportion in soil is a very important factor when stabilized with lime. If the clay content in soil sample is such that addition of too much lime is required to reach lime fixation limit, the clay content of the soil sample must be lowered by mixing with low clay content soil or other components of soil. Until the lime affinity of clay particles in soil is pacified, the pozzolanic effect of the lime binder will not be realized for higher strength of lime stabilized CSEB.

3.3 Embodied Energy Value (EEV) of CSEB

Fig. 6 depicts a visual comparison of energy requirement of various CSEBs produced in this study and country fired brick in FCK. Brick production from FCK requires energy at 1.90 MJ/kg [1,2,5]. Lime production requires energy at 3.75 MJ/kg [26], whereas cement production requires energy at 4.2 MJ/kg [27]. Therefore, energy requirement for production of modified CSEB with 10% cement was at 0.42 MJ/kg, clayey CSEB with 5% lime was at 0.1875 MJ/kg and modified CSEB with mixed stabilizer (6% cement and 3% lime) was at 0.3645 MJ/kg.

3.4 Embodied Carbon Footprint (ECF)

CO_2 emission for production of fired brick and various CSEBs was compared based on the following information: Estimated CO_2 emission from FCK was at 0.183 kg/kg-fired brick [1,2,5], whereas CO_2 emission for the production of CSEB was estimated using CO_2 emission values of cement production and lime production. Estimated CO_2 emission from lime production was at 1.075 kg/kg-lime [26], and for cement production it was at 0.8 kg/kg-cement [27]. Estimated CO_2 emissions were at 0.08 kg/kg-block of modified CSEB with 10% cement, 0.054 kg/kg-block of clayey CSEB with 5% lime and 0.08 kg/kg-block of modified CSEB with mixed stabilizer (6% cement and 3% lime). The graphical comparison is presented in the Fig. 7.

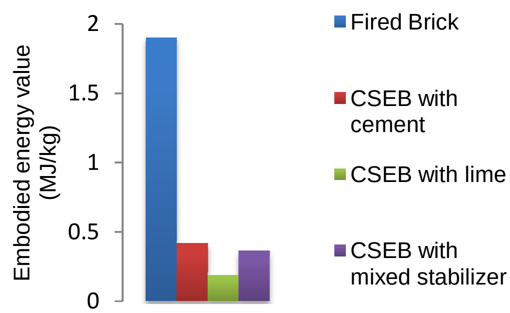

Fig. 6. Embodied energy value comparison

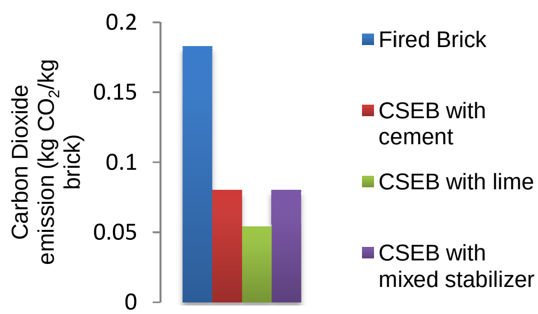

Fig. 7. CO_2 emission comparison of brick and CSEB

3.5 Production Cost

Cost for production of fired brick and various CSEBs was compared based on the following information: It was estimated that fired brick from FCK costs BDT 2.4 to produce 1 kg of ordinary fired brick, whereas cost for the production of per kg CSEB was estimated using cost of cement, lime, sand, soil, labour and machines. Cost comparison of different CSEBs and fired brick from FCK is shown in the Fig. 8. Current price of lime in Bangladesh is BDT 6/kg, cost of cement is BDT 9.2/kg, cost of raw soil is BDT 0.2/kg and cost of dry sand is BDT 0.66/kg. Labour and equipment cost is around 33% of the material cost per kg CSEB. Modified CSEB with 10% cement costs BDT 1.46 per kg block, clayey CSEB with 5% lime costs BDT 0.4 per kg block and modified CSEB with mixed stabilizer (6% cement and 3% lime) costs BDT 1.24 per kg block.

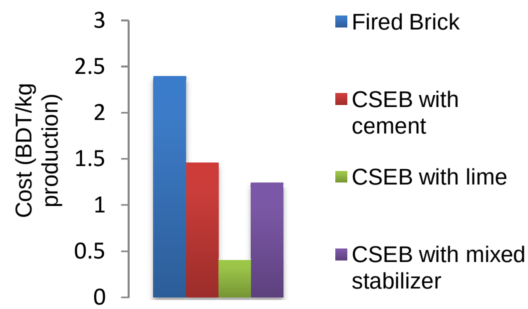

Fig. 8. Cost comparison of fired brick and CSEB

It is evident that CSEBs produced in this research work are inferior to the ordinary fired brick produced in FCK with respect to compressive strength since strength of the produced CSEBs varies from 3-6 N/mm^2, whereas strength requirement for common fired bricks as per BSTI (Bangladesh Standards and Testing Institute) standard is 17 N/mm^2 [28]. Some research institutes categorize the CSEB with a compressive strength range of 5-7 N/mm^2 as Type-A and 2-5 N/mm^2 as Type-B [10]. Therefore, all the clayey and sandy soil blocks prepared under this study with and without additives are of 'Type-B', whereas modified soil blocks with 8 and 10% cement and 9 and 11% mixed stabilizers are of 'Type-A'. Other modified soil blocks with and without stabilizers fall under 'Type-B' category. Among the CSEBs produced, modified CSEBs with 10% cement and mixed stabilizer (6% cement and 3% lime) are comparable and their respective strength classifies them as Class-A type CSEB. Though cost of modified CSEB with mixed stabilizer is 18% lower than the modified CSEB with 10% cement, strength of modified CSEB with 10% cement is 25% higher than modified CSEB with mixed stabilizer, whereas energy requirement for modified CSEB with mixed stabilizer is 15% lower than modified CSEB with 10% cement. Pollution load is same for both the modified CSEBs with 10% cement and 9% mixed stabilizer (6% cement and 3% lime). All these values are much lower for CSEBs compared to ordinary fired bricks from FCK. According to Reinforced Cement Concrete (RCC) structure, partition wall and the outside wall of any building do not need to bear any significant load [29]. Therefore, modified CSEBs with 10% cement and 9% mixed stabilizer (6% cement and 3%

lime) may be a potential option as a non-load bearing building block in construction sector of Bangladesh.

Only a 10% replacement of the fired bricks (around 1.5 billion bricks) produced in FCK countrywide with the modified CSEB type for non-load bearing construction purpose would save 6.50-6.75 PJ coal energy per year with a corresponding monetary value of 2.2-2.3 billion BDT considering coal price at BDT 8,500/ton coal and gross heating value of coal at 25 MJ/kg coal [2] and buyers in the consumer end would save annually 4-5 billion BDT in the country. Besides, it would be also possible to reduce CO_2 emission to environment by 450,000 tons per year. Considering the market price for carbon credit in brick making sector (USD 13.5/tCO_2) [5] in Bangladesh, it would be possible to earn an additional 474 million BDT (considering USD 1=BDT 78) per year. Therefore, country can save around USD 87 million and earn additionally USD 6 million each year.

4. CONCLUSION

It was evident that the soil samples collected for this study was far apart from the good soil compositions for cement or lime stabilization. Soil with too sandy or clayey in nature requires more stabilizers compared to modified soil compositions to attain the same compressive strength. Too clayey soil and sand modified clayey soil stabilized with lime show a constant compressive strength at and above lime fixation point based on 30 days dry compressive strength. It is expected that excess free lime beyond lime fixation point will increase the strength of clayey CSEB and sand modified clayey CSEB in the long run due to slow pozzollanic effect of lime. Compressive strength decreases with increasing proportion of sand in compressed clayey soil block without additive. Too sandy soil and sand modified clayey soil blocks stabilized with cement show good dry compressive strength compared to lime stabilized soil block based on 30 days dry compressive strength and it increases with the increasing proportion of cement in soil block. However, sand modified clayey soil shows better compressive strength compared to originally too sandy soil with same amount of cement. All CSEBs of 'Type-A' under this study posses good compressive strength and can be used in partition walls inside or outside house as a non-load bearing unit. CSEB technology is already being ventured in India, Brazil, China, Uganda, United Kingdom and numerous other countries. It is evident that CSEB requires less cost of production, embodied energy and carbon footprint and therefore it is an environment friendly option for construction purpose.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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Peer-review history:
The peer review history for this paper can be accessed here:
http://sciencedomain.org/review-history/12992