

Original research Articles

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

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 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 CO₂ each year [2,3,4]. 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 CO₂ 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

36 Tangail, Gazipur and the Northern Upazilas of Dhaka district [2]. This rapid proliferation of
37 FCK in North Cluster has resulted in an elevated concentration of CO₂, SO₂, and fine
38 particulate matter (PM_{2.5}) in the air of Dhaka city especially during dry season. Source
39 apportionment work for PM_{2.5} shows that FCK in North Dhaka Cluster alone contributes 38%
40 of PM_{2.5} in the air of Dhaka city during 5-month dry season [1]. The Bangladesh Country
41 Environmental Analysis reports that poor air quality in Dhaka contributed to an estimated
42 3,500 premature deaths annually. Emissions from the FCK at North Dhaka Cluster are alone
43 responsible for 750 premature deaths annually which is equivalent to 20 percent of total
44 premature deaths in Dhaka due to poor air quality [7]. Therefore, FCK at North Dhaka
45 Cluster is considered to be the most polluting technology causing annual health damages of
46 Dhaka city people estimated at about BDT 0.9 per brick production [1].

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

61 Many research works have been carried out for soil stabilization with cement. Wang [11]
62 stated that the cement contents may range from as low as 4% to a high of 16% by dry
63 weight of soil. For construction in tropical countries, Garg [12] stated that the amount of
64 cement added to soil that would give a compressive strength of 2.5 to 3.0 N/mm² should give
65 satisfactory strength results. However, studies show that if the cement content is greater
66 than 10%, CSEB production will be uneconomical. Contrarily, CSEB using less than 5% of
67 cement binder is often too friable for easy handling [13]. Though cement is preferable for
68 sandy soil stabilization, it can be added to stabilize any type of soil, except soils with organic
69 content greater than 2% or sulphate content greater than 0.2% or having pH lower than 5.3
70 [11,12]. Sulfate content exceeding 0.2% have been known to weaken concrete [11,14].
71 Unconfined compressive strength is an indirect measure of soil stabilization. A minimum
72 strength gain of 0.35 N/mm² of the lime stabilized soil over natural soil can be adequate to
73 consider for stabilization, whereas a strength gain of 0.7 N/mm² for a soil-cement mixture
74 over the natural soil can be considered adequate for cement stabilization [15]. Stabilization
75 of soil by lime is achieved mainly through cation exchange, flocculation and agglomeration,
76 and pozzolanic reaction. Cation exchange, flocculation and agglomeration reactions takes
77 place rapidly and bring immediate changes in soil properties such as strength, plasticity and
78 workability [16], whereas, pozzolanic reactions are time dependent. The cation exchange
79 starts to take place between the monovalent metallic ions associated with the surface of the
80 clay particles (Na⁺, K⁺ etc.) and that are surrounded by a diffuse hydrous double layer (H⁺),
81 which is modified by the ion exchange of calcium, because of which there is alteration in the
82 density of the electrical charge around the clay particles, that leads to the flocculation and
83 agglomeration of clay particles. This process mainly takes place within the lime fixation point
84 and is mainly responsible for the modification of the engineering properties of clay soils
85 treated with lime. In addition to cation exchange, pozzolanic reaction occurs between the
86 silica and some alumina of the lattices of the clay minerals. During this process, the highly

87 alkaline environment (pH 12.4) produced by the addition of lime causes silica and alumina to
88 be dissolved out of the structure of the clay minerals and to combine with the calcium to
89 produce new cementitious compounds: calcium silicate hydrates (CSH), calcium aluminate
90 hydrates (CAH), and calcium aluminosilicate hydrates (CASH) which strengthen the soil
91 with curing time [17, 18, 19]. The effectiveness of the treatment depends on the quality and
92 quantity of lime as well as the chemical and mineralogical composition of the soil. The
93 strength developed is obviously influenced by the quantity of cementitious gel produced and
94 consequently by the amount of lime consumed [20]. Lime stabilization occurs at lime
95 additions in excess of the lime fixation point. The initial consumption of lime gives an
96 indication of the minimum quantity of lime that must be added to the soil in order to achieve
97 a significant change in properties. This quantity must first satisfy the affinity of the soil for
98 calcium and so it is not available for pozzolanic reactions. Bell [16,17] indicated that the
99 optimum addition of lime needed for maximum modification of the soil is normally between
100 1% and 3% lime by weight, and further additions of lime do not induce changes in the plastic
101 limit, but increase the strength. Cement can be added to lime-clayey soil mix to enhance
102 stabilization process because the lime-clay ratio will be increased due to the existing of lime
103 in cement and the present of lime attributed to the immediate reduction of plasticity. When
104 lime-clayey soil is mixed with cement in presence of water, Calcium Silicate Hydrates (C-S-
105 H) gel forms through hydration reaction [21]. This C-S-H gel has beneficial effect in clay
106 material by reduction of deleterious heaving effects due to the rapid removal of alumina. The
107 formation of ettringite contributes to the increase of porosity and decreases the free moisture
108 content in soil pore. The C-S-H gel fills the void spaces and binds the soil particles together
109 to imparting strength to the soil mixture [22].

110 Soil of Bangladesh is mainly divided into 3 broad categories. These are Floodplain soil, Hill
111 soil and Terrace soil. Floodplain soil, which is the most abundant soil, has varied
112 compositions of sand, silt and clay and constitutes about 79% of the total land in
113 Bangladesh. Hill soils are abundant in areas like Chittagong hill tracts, Banderban,
114 Cox's bazar, Feni, Comilla etc. This type of soil generally consists of equal portions of sand
115 and clay. Hill soil type constitutes around 13% of total land in Bangladesh. Terrace soils are
116 generally clayey and constitute 8% of total land in Bangladesh [23].

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

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129 **2. EXPERIMENTAL**

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

135

136 **2.1 Soil Site Selection**

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

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2.2 Soil Compositions

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

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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 (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

174 (6% cement-3% lime and 6% cement-5% lime). From each type of soil one block was made
175 without any stabilizer to get the reference strength values for each type of soil block. 8-10%
176 water was added to the stabilizer-soil mix and mixed thoroughly. The resultant mixture was
177 then placed into a moulding box and was subjected to uniform pressure and compacted
178 under 4 N/mm² applied pressure inside the moulding box using a hydraulic hand press
179 (Carver Laboratory Press, 14600-175).

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181 **2.4 Drying and Curing of Earth Block**

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

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187 **2.5 Compressive Strength Test**

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

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194 **2.6 Embodied Energy Value (EEV) of CSEB and Fired Brick**

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

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204 **2.7 Embodied Carbon Footprint (ECF)**

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206 Embodied carbon footprints of CSEB and fired brick from FCK were calculated from the
207 literature values of CO₂ emission data on cement and lime production and fired bricks
208 production in FCK.

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210 **2.8 Production Cost**

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212 Specific cost (BDT/kg) of fired bricks in FCK was calculated on yearly basis production of
213 fired bricks, per unit weight of fired bricks, yearly operational and maintenance cost (soil,
214 land rent, labor, water, maintenance, staff salary, value added tax, coal consumption) and
215 initial investment with a service life of 10 years having zero salvage value and a minimum
216 attractive rate of return (MARR) of 10%. Yearly average production of the fired bricks from
217 FCK was 3.5 million units each having an average final weight of 2.73 kg. Yearly operational
218 and maintenance cost of FCK was calculated to be 22 million BDT with a capital investment
219 of 6 million BDT. For various CSEB, assumed yearly production capacity was 80,000 units
220 each having a final weight of 5 kg. Calculated yearly operating cost was around 0.6 million
221 BDT for modified CSEB stabilized with 10% cement, 0.5 million BDT for modified CSEB
222 stabilized with 6% cement and 3% lime, and around 0.2 million BDT for CSEB stabilized with
223 5% lime. In either cases, the initial capital investment is 0.01 million BDT. The MARR, useful
224 life and salvage value for all three cases were same as those of FCK.

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3. RESULTS AND DISCUSSION

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3.1 Soil Compositions

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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.

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3.2 Compressive Strength

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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 Figures 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.

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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].

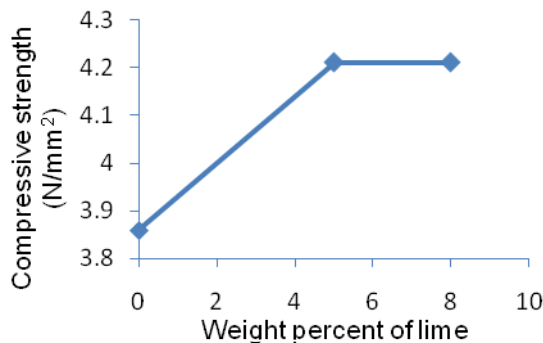


Fig. 2. Strength of clayey CSEB with lime

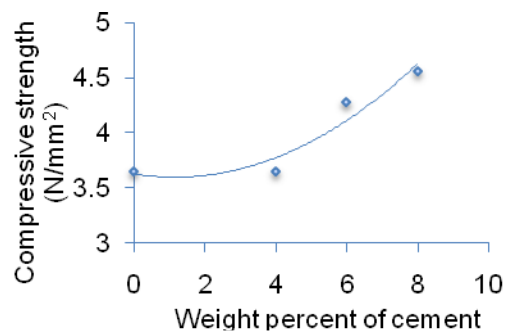


Fig. 3. Strength of sandy CSEB with cement

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268 As the maximum economic ranges of cement percentage in sandy CSEB should be within 7-
269 8% [10], mixing of cement stabilizer for this experiment was bracketed within the maximum
270 range of 8%. The soil sample collected from Munshiganj was too sandy (75% of soil weight)
271 and the compressive strength of these CSEBs increased with increasing proportion of
272 cement addition due to good binding property of cement with sand.

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274 It was found that the compressive strength of the modified soil block (clayey soil mixed with
275 30% sand) without additives (Fig. 4) was 3.65 N/mm^2 which was less than that of original
276 clayey soil block (Fig. 2) but similar to that of sandy soil block (Fig. 3) without additives. This
277 phenomenon might be due to cohesive property of clay in soil. In the case of modified
278 CSEB, a remarkable increase in compressive strength (about 15%) with 4% cement was
279 observed compared to originally sandy CSEB with 4% cement. This can be attributed to the
280 altered soil nature due to the addition of 30% fresh sand to clayey soil on weight basis that
281 led to an altered soil composition of 49% clay, 17.5% silt and 33.5% sand. As maximum
282 strength of sandy CSEB was found with 8% cement which is also the maxima of economic
283 ranges for sandy soil block stabilization [10], the next higher proportion of cement used for
284 modified CSEB was 8% which also showed a remarkable increase in strength of about 14%
285 compared to original sandy CSEB with same proportion of cement. However, incremental
286 increase in strength continued for modified CSEB with 10% cement binder which was 6.3
287 N/mm^2 and found to be 21% higher than that for modified CSEB with 8% cement. The
288 increasing rate of strength was found to be higher for higher proportion of cement stabilizer
289 in modified CSEBs (Fig. 4). As previous study suggests CSEB production with more than
290 10% cement is uneconomical [13], further addition of cement binder beyond 10% was not
291 examined in this study. However, modified soil block with 4% cement was found to be non-
292 stabilized and modified soil blocks with 8 and 10% cement were found to be stabilized based
293 on the strength gain [15]. Fig. 5 shows the strength behavior of modified CSEB stabilized
294 with mixed stabilizers (cement and lime) in different proportions. Modified CSEB stabilized
295 with mixed stabilizer (6% cement and 3% lime) showed a strength of about 5.05 N/mm^2
296 which was eventually higher than that for clayey CSEB stabilized with lime (Fig. 2), original
297 sandy CSEB stabilized with 6% cement (Fig. 3) and modified CSEB stabilized with 6%
298 cement (Fig. 4). However, the strength of the modified CSEB with mixed stabilizer (6%
299 cement and 5% lime) remained unchanged compared to modified CSEB with (6% cement
300 and 3% lime). This peculiar behaviour of mixed stabilizer on the strength of the modified
301 CSEB can be attributed to the altered soil nature and pozzolanic effect of lime binder.
302 Addition of excess amount of lime beyond lime fixation point does not increase the strength
303 of the block immediately rather it increases the strength of the block in the long run even
304 after several years. Therefore, the pozzolanic effect of lime beyond lime fixation point might
305 be absent in those CSEBs within 30 days period. The modified soil was still clayey even
306 after modification with 30% sand. Clayey soil-lime mix with cement forms hydrates gel in
307 presence of water which fills the void spaces created due to the flocculation and
308 agglomeration effect of lime and binds the soil particles together thus imparting better
309 strength to the soil mixture [25,26]. However, both the modified soil blocks with mixed
310 stabilizers were found to be stabilized based on the strength gain over the reference
311 modified soil block without stabilizer.

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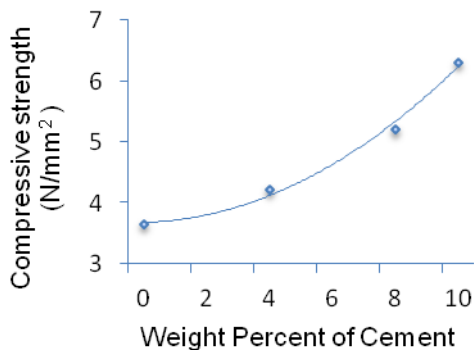


Fig. 4. Strength of modified CSEB with cement

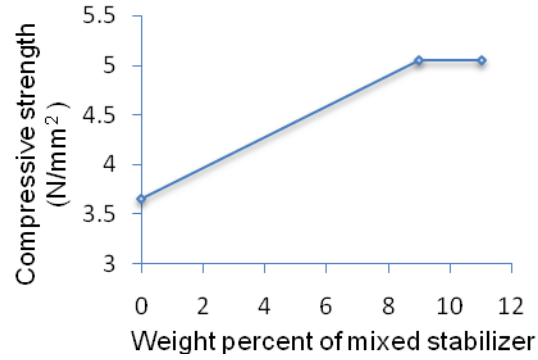


Fig. 5. Strength of modified CSEB with mixed stabilizer (cement and lime)

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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.

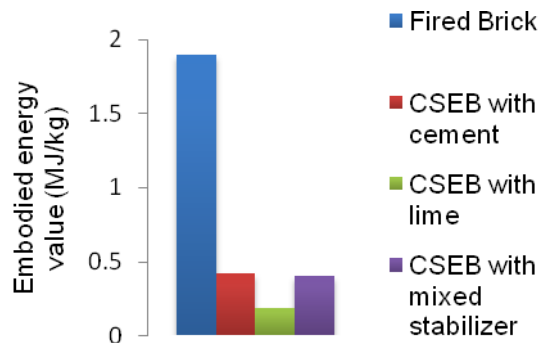


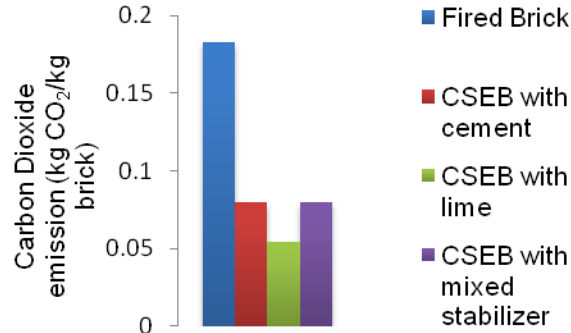
Fig. 6. Embodied energy value comparison

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3.4 Embodied Carbon Footprint (ECF)

CO₂ emission for production of fired brick and various CSEBs was compared based on the following information: Estimated CO₂ emission from FCK was at 0.183 kg/kg-fired brick [1,2,5], whereas CO₂ emission for the production of CSEB was estimated using CO₂ emission values of cement production and lime production. Estimated CO₂ emission from

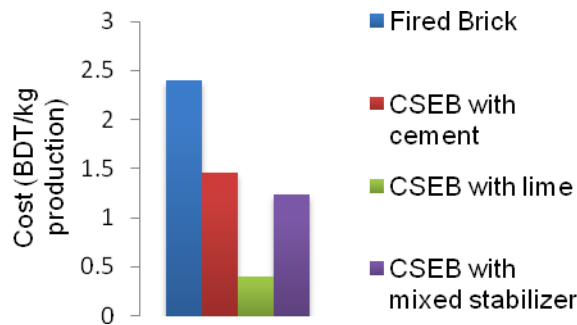
344 lime production was at 1.075 kg/kg-lime [26], and for cement production it was at 0.8 kg/kg-
 345 cement [27]. Estimated CO₂ emissions were at 0.08 kg/kg-block of modified CSEB with 10%
 346 cement, 0.054 kg/kg-block of clayey CSEB with 5% lime and 0.08 kg/kg-block of modified
 347 CSEB with mixed stabilizer (6% cement and 3% lime). The graphical comparison is
 348 presented in the Fig. 7.
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 351 **Fig. 7. CO₂ emission comparison of brick and CSEB**
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353 3.5 Production Cost

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 355 Cost for production of fired brick and various CSEBs was compared based on the following
 356 information: It was estimated that fired brick from FCK costs BDT 2.4 to produce 1 kg of
 357 ordinary fired brick, whereas cost for the production of per kg CSEB was estimated using
 358 cost of cement, lime, sand, soil, labour and machines. Cost comparison of different CSEBs
 359 and fired brick from FCK is shown in the Fig. 8. Current price of lime in Bangladesh is BDT
 360 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
 361 BDT 0.66/kg. Labour and equipment cost is around 33% of the material cost per kg CSEB.
 362 Modified CSEB with 10% cement costs BDT 1.46 per kg block, clayey CSEB with 5% lime
 363 costs BDT 0.4 per kg block and modified CSEB with mixed stabilizer (6% cement and 3%
 364 lime) costs BDT 1.24 per kg block.
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 367 **Fig. 8. Cost comparison of fired brick and CSEB**
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369 It is evident that CSEBs produced in this research work are inferior to the ordinary fired brick
 370 produced in FCK with respect to compressive strength since strength of the produced
 371 CSEBs varies from 3-6 N/mm², whereas strength requirement for common fired bricks as
 372 per BSTI (Bangladesh Standards and Testing Institute) standard is 17 N/mm² [28]. Some
 373 research institutes categorize the CSEB with a compressive strength range of 5-7 N/mm² as
 374 Type-A and 2-5 N/mm² as Type-B [10]. Therefore, all the clayey and sandy soil blocks
 375 prepared under this study with and without additives are of 'Type-B', whereas modified soil

376 blocks with 8 and 10% cement and 9 and 11% mixed stabilizers are of 'Type-A'. Other
377 modified soil blocks with and without stabilizers fall under 'Type-B' category. Among the
378 CSEBs produced, modified CSEBs with 10% cement and mixed stabilizer (6% cement and
379 3% lime) are comparable and their respective strength classifies them as Class-A type
380 CSEB. Though cost of modified CSEB with mixed stabilizer is 18% lower than the modified
381 CSEB with 10% cement, strength of modified CSEB with 10% cement is 25% higher than
382 modified CSEB with mixed stabilizer, whereas energy requirement for modified CSEB with
383 mixed stabilizer is 15% lower than modified CSEB with 10% cement. Pollution load is same
384 for both the modified CSEBs with 10% cement and 9% mixed stabilizer (6% cement and 3%
385 lime). All these values are much lower for CSEBs compared to ordinary fired bricks from
386 FCK. According to Reinforced Cement Concrete (RCC) structure, partition wall and the
387 outside wall of any building do not need to bear any significant load [29]. Therefore, modified
388 CSEBs with 10% cement and 9% mixed stabilizer (6% cement and 3% lime) may be a
389 potential option as a non-load bearing building block in construction sector of Bangladesh.

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391 Only a 10% replacement of the fired bricks (around 1.5 billion bricks) produced in FCK
392 countrywide with the modified CSEB type for non-load bearing construction purpose would
393 save 6.50-6.75 PJ coal energy per year with a corresponding monetary value of 2.2-2.3
394 billion BDT considering coal price at BDT 8,500/ton coal and gross heating value of coal at
395 25 MJ/kg coal [2] and buyers in the consumer end would save annually 4-5 billion BDT in the
396 country. Besides, it would be also possible to reduce CO₂ emission to environment by
397 450,000 tons per year. Considering the market price for carbon credit in brick making sector
398 (USD 13.5/tCO₂) [5] in Bangladesh, it would be possible to earn an additional 474 million
399 BDT (considering USD 1=BDT 78) per year. Therefore, country can save around USD 87
400 million and earn additionally USD 6 million each year.

401

402 **4. CONCLUSION**

403

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

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