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Role of lime with cement in long-term strength of Compressed Stabilized Earth Blocks

H.B. Nagaraj [a,*], M.V. Sravan [a], T.G. Arun [a], K.S. Jagadish [b]

[a] *Department of Civil Engineering, BMS College of Engineering, Bull Temple Road, Bangalore 560019, India*
[b] *Department of Civil Engineering, Indian Institute of Science, Bangalore 560012, India*

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Abstract

Compressed Stabilized Earth Blocks (CSEBs) are manufactured using stabilizers to provide adequate compressive strength and durability, so, as to make them suitable as building blocks. Though cement is a popular stabilizer used in manufacture of CSEBs, no study has been reported utilizing lime in combination of cement. This experimental study on CSEBs prepared using lime as a replacement to cement in certain proportions has clearly brought out the effectiveness of lime with cement in improving the long-term build-up of strength better than using cement alone. It was observed that blocks prepared with optimum quantity of lime along with cement has led to continuous buildup of strength even beyond 2 years, whereas blocks prepared with cement alone and lesser quantity of lime than optimum quantity have not gained much strength after 6 months from the time of preparation of the blocks. The research findings show a need to relook at the grading of ingredients and quantity of stabilizers for achieving good building blocks. This would be an added benefit not only in reducing the cost of the blocks, but also has serious implications in terms of the reduction of energy consumed in the manufacture of blocks when done in large scale.

Keywords: Stabilization; Lime; Compressive strength; Long-term strength; Sustainability

1. Introduction

From the civilizations of Mesopotamia dated 6000 years back the use of earth as a building material is very evident (Deboucha and Hashim, 2011). Earth, being available abundantly has invariably been the main construction material in providing housing systems. It offers a number of environmental benefits, including lower embodied energy levels; high thermal mass and maximizing the use of locally sourced materials (Walker, 2004). Considerable research has been undertaken in the modern times to make earth as a sustainable construction material. This has led to development of technology using earth in the form of rammed earth and unfired bricks popularly known as Compressed Stabilized Earth Blocks (CSEBs). The main advantage of manufacturing unfired bricks is that it requires lesser energy than fired bricks, and hence the release of carbon dioxide into the atmosphere is 80% less than fired bricks (Heath et al., 2009; Oti et al., 2009).

For six decades, extensive attempts have been made to make unfired stabilized bricks to be a reliable walling unit

* Corresponding author. Tel.: +91 9880 507 537.
E-mail addresses: hbnraj@gmail.com, drhbn.civ@bmsce.ac.in (H.B. Nagaraj).

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against the more expensive fired bricks and concrete blocks (Jagadish et al., 2008; Deboucha and Hashim, 2011). This is achieved by proper grading of the soil mix, proper compaction and stabilization using admixtures, which would ensure increased density, reduced water absorption, increased frost resistance and mainly increased wet compressive strength of masonry blocks. Compressive strength of the block has become a basic and universally acceptable unit of measurement to specify the quality of masonry units, as this is an indirect measure of durability of the blocks (Walker, 2004; Morel et al., 2007). Hence, durability aspects of cement stabilized earth blocks could be indirectly satisfied through the specification of wet compressive strength.

2. Role of stabilizers used in CSEBs

Stabilization is a process of mixing admixtures with soil to improve its volume stability, strength, permeability and durability (Bell, 1993). Stabilization is considered to be an important step in the manufacture of CSEBs, and is aimed at improving the performance of a soil as a construction material. Amongst the variety of soil stabilizers used, cement has been the most popular stabilizer in the manufacture of CSEBs. Attempts have been made by various researchers in the past to document the role of cement as a stabilizer in CSEBs (Spence, 1975; Venkatarama Reddy and Jagadish, 1989; Venkatarama Reddy, 1991; Houben and Guillaud, 1994; Walker and Stace, 1997; Kerali, 2001; Venkatarama Reddy and Walker, 2005). However, compared to cement, utilization of lime as a stabilizer in the preparation of CSEBs has not found popularity. Lime has been used in stabilizing clayey soils, and has been found to impart long-term strength gain as reported in the literature (Bell and Coulthard, 1990; Little, 1995; Mallela et al., 2004; Amu et al., 2011; Herrier et al., 2012). An outstanding testimonial of the durability of the lime-stabilized soils is the Friant-Kern irrigation canal in California as reported by Herrier et al. (2012).

In the recent past, attempts to independently utilize lime instead of cement in the preparation of CSEBs and compare their properties with those prepared with cement has been reported in the literature (Guettala et al., 2002; Raheem et al., 2010; Miqueleiz et al., 2012). Guettala et al. (2002) have tried to use various quantities of lime namely, 5%, 8% and 12% to improve the durability of the blocks. The evaluated dry strength of blocks reported by them is around 9.4, 14.2 and 16.2 MPa respectively for 5%, 8% and 12% of lime. Similarly, when tested under humid state, the strength of the blocks was found to be 4.4, 8.2 and 9.8 MPa respectively for 5%, 8% and 12% lime. From their study, it is clear that after an optimum value of lime content, any further increase in lime will not be so beneficial in the strength gain of the blocks. Raheem et al. (2010) have reported the 28 days wet compressive strength of compressed stabilized interlocking earth blocks prepared with lime and cement alone as stabilizers added in varying quantities from 5% to 25%, with an increment of 5%. For maximum amount of stabilizer content namely 25%, the strength gain of the blocks is found to be 3.2 MPa and 1.2 MPa for blocks prepared with cement and lime respectively. Very recently Miqueleiz et al. (2012) have reported the advantage of using lime towards the development of unfired clay bricks. From the results of tests conducted on cylindrical specimens of 65 mm diameter and 30 mm height prepared with use of 18% lime, they have found that, at the end of 90 days of ageing the maximum compressive strength of the cylindrical specimens was nearly 13 MPa, and the strength of cylindrical specimens prepared with 18% of cement were around 18 MPa. However, attempts to utilize lime in combination with cement as a stabilizer to achieve desirable properties of CSEBs have not been studied and reported. As lime is known to impart strength in the long term, its utilization in some proportion as a replacement to cement may be beneficial. This paper reports the attempts made to understand the role of lime in combination with cement as a stabilizer in improving the long-term properties of CSEBs, optimize the use of stabilizers and maximize the strength of the blocks. Any effort to optimize the quantity of stabilizers used in combination would help in reducing the cost of the blocks. This work is thus aimed at contributing towards improvising the existing technology of manufacture of unfired earth blocks. This would be a good contribution towards sustainable development.

3. Experimental programme

3.1. Materials

In the present study locally available red earth, sand, ordinary Portland cement and lime were used for preparation of CSEBs. It was ensured that the selected soil was air dried, pulverized to break the clods and sieved through 20 mm sieve. Ordinary Portland cement was used in the study conformed to requirements of Bureau of Indian Standard (IS: 8112, 1989); while lime conforming to technical guidance of Bureau of Indian Standard (IS: 712, 1984) was used. The selected soil was characterized for its physical properties namely, liquid limit, plastic limit, shrinkage limit, particle size distribution, sediment volume and specific gravity using the standard procedures as specified by Bureau of Indian Standards (BIS) (SP: 36-Part1, 1987) and the results are summarized in Table 1. Free Swell Ratio as defined by Prakash and Sridharan (2004) has been used as a simple method of identifying the presence of principal clay mineral in the soil. The same has been reported in Table 1.

Sand was tested for its specific gravity and particle size distribution and the results are reported in Table 1. The standard compaction test for the soil was done in Standard Proctor mould (BS: 1377-4, 1990) and the optimum values are reported in Table 1. The OPC cement was tested for its fineness, normal consistency, initial setting time and specific surface areas as per Bureau of Indian Standards.

Table 1
Properties of red earth and sand used in the present study.

Soil description	Gs	w_L	w_P	w_S	I_P	Grain size distribution				Sediment volume (cc)		Free Swell Ratio (FSR)[b]	Max. dry density, (g/cc)	Optimum moisture content, (%)
						Gravel (%)	Sand (%)	Silt (size) (%)	Clay (size) (%)	Water	Kerosene			
Red earth	2.65	48.1	25.5	14.2	22.6	0	35	35	30	13.0	13.0	1.0	1.83	12.0
Sand	2.62	NP[a]	NP	NP	NP	2	96	2	0	–	–	–	–	–

[a] NP: non-plastic.
[b] FSR: Free Swell Ratio, is defined as the ratio of equilibrium sediment volume of 10 g oven dried soil passing a 425 μm sieve in distilled water to that in carbon tetra chloride.

3.2. Proportioning of soil-admixture mix

Based on the extensive works carried out by various researchers, it has been shown that proper grading increases the density of the blocks, which in turn improves their compressive strength (Spence, 1975). As a guideline, the best possible combination of ingredients would be 70% of sand and gravel, and 10% to 20% clay for obtaining good wet compressive strength of blocks (Olivier and Mesbah, 1987; Houben and Guillaud, 1994;Venkatarama Reddy and Jagadish, 1995). In this present study, soil used is red earth, which has non-expansive clay mineral as inferred from FSR value being 1 indicating kaolinite as the dominant clay mineral. Hence, the sand content of the reconstituted soil was maintained around 75% and clay content less than 15% (refer Table 2). It has been reported in the literature that the optimum content of cement to get wet compressive strength of 3–5 MPa for compressed stabilized mud blocks made out of soils having kaolinite as the principal clay mineral proportion with about 70% sand and 20% fines [silt and clay] is 8% (Venkatarama Reddy and Jagadish, 1989; Venkatarama Reddy, 1991; Kerali, 2001). Therefore, in this study the stabilizer content was maintained at 8%. The main intention of this study was to use lime in combination with cement to evaluate its role in improving the performance of CSEBs. Eades and Grim (1960) and Bell (1996) have reported that the optimum amount of lime for maximum strength gain in stabilizing kaolinitic clays is found to be 4–6%. In order to estimate the optimum lime required for the varied proportions of soil mix, the authors carried out test to estimate the optimum lime required (ASTM D 6276, 1999). Based on the test results, it was found that 4% of lime showed an increase in pH above 12.4. To demonstrate the role of lime along with cement, three series of CSEBs, namely S1, S2 and S3 were prepared using different proportions of cement and lime as presented in Table 3.

Table 2
Proportions of constituents present in natural and modified soil used in the present study.

Constituent	Natural soil	Reconstituted soil
Sand	35.0	76.0
Silt	35.0	12.8
Clay	30.0	11.2

Table 3
Proportions of stabilizers used in the preparation of different series of CSEBs.

Series	Reconstituted soil, (%)	Cement, (%)	Lime, (%)
S1	92	8	0
S2	92	6	2
S3	92	4	4

3.3. Preparation of Compressed Stabilized Earth Blocks

The size of the blocks prepared using ASTRAM block making machine was 30.5 × 14.5 × 10.0 cm. The preparation process comprised of batching, mixing, placing the mix, compaction and ejection of the blocks. The density of the blocks was maintained at 2.05 Mg/m^3. The required quantities (mass basis) of the ingredients namely, soil, sand, and the stabilizers (lime and cement) as obtained from the calculations depending on the series were weighed and initially mixed in a dry condition. Based on initial trials, the optimum water content needed to mould the blocks and eject them successively as one unit was determined by mixing the dry mix of the ingredients with minimum water that is sufficient to obtain a good intact ball without sticking to the hand. For making soil blocks, the proportioned dry mix was spread on big tray, and the calculated quantity of water was sprinkled to the mix and thoroughly worked with hand to have uniform distribution of moisture (Plate 1). Wet mixing was undertaken for further 2–3 min after the addition of water. Care was taken to use hand gloves while remoulding the mix. Then the wet mix was transferred to the mould, placed in position on the ASTRAM machine (Plate 2). The wet mix was remoulded in the mould using a wooden mallet to give proper placement. The lid of the mould was closed and properly locked at the top. Using the toggle lever mechanism, the mix was pressed to give the designed compactive effort. The soil block was ejected from the mould by opening the top lid. The ejected block was weighed and serially labelled with date of preparation, date of testing and a suitable identification number (for the series adopted) for ease of future

Plate 1. View showing wet mixing of ingredients used for the preparation of the blocks.

Plate 2. Transferring of wet mix into the block making mould of ASTRAM press.

identification (Plate 3). All blocks were compacted within 15 min of wet mixing. It was ensured to cure the blocks in shade and also by keeping them moist for a minimum period of 28 days. Sufficient number of CSEBs were prepared for evaluating their engineering properties, namely, wet compressive strength and water absorption for various ageing periods, namely, 7, 15 days; 1, 2, 4, 6 months; 1, 2 and 5 years from the date of preparation.

3.4. Testing of Compressed Stabilized Earth Blocks

The CSEBs prepared as per the procedure described above were tested for their wet compressive strength and water absorption for different periods of ageing reckoned

Plate 3. View of CSEBs being numbered for future identification.

from the date of preparation as per the prescribed procedures of Bureau of Indian Standards. The test procedures adopted are presented below. The results in this study are an average of test conducted on six numbers of blocks at each period of ageing.

Wet compressive strength of the CSEBs was determined according to Bureau of Indian standards (IS: 3495-1, 1976). Each block was prepared by filling the frog marks on the faces by 1:1 cement mortar and was cured for a day (Plate 4). These blocks were later immersed in clean water for 2 days in advance before the date of testing corresponding to ageing selected in the study. Later, the blocks were removed from water, and the surfaces were wiped dry and tested for their compressive strength using Universal Testing Machine (UTM). The load was applied at the rate of 2 N/mm^2/min. Plywood sheet of 3 mm thick was placed on either faces of the block before the application of load.

Water absorption on CSEBs was done as per Bureau of Indian standards (IS: 1725, 1982). The blocks were dried completely in the oven and their mass was recorded accurately. The blocks were then immersed in water for 48 h. Later, the blocks were weighed again, and the increased mass was noted to determine their water absorption.

Plate 4. View showing frogs marks of CSEBs filled with 1:1 cement mortar.

4. Results and discussions

4.1. Wet compressive strength

Fig. 1 presents the plot of wet compressive strength of CSEBs for the three proportions (Table 3) versus curing periods of 7, 15 days; 1, 2, 4, 6 months; 1, 2 and 5 years. In general, there is an increase in wet compressive strength of blocks with ageing. Further, it can be observed that, the blocks prepared with cement alone (Series S-1) have shown to have marginally more wet compressive strength up to 18 weeks (4 months) of ageing compared to that of blocks prepared with lime and cement (Series S-2 and S-3). The relatively more strength of blocks prepared with cement alone at the initial stages of ageing may be due to quick hydration of cement, which helps formation of cementitious compounds in the blocks. For S-2 series CSEBs, in which 2% lime has been replaced for cement as a stabilizer, it has been observed that strength of these blocks are lower than for the S-1 series. This may be due to the reduction of cement in the blocks. Additionally, though lime is available in the mix, the quantity may not be sufficient to increase the pH of the system to release silica and make it available for producing cementitious gel needed for stabilizing the clay fraction. It has been reported by Bell (1996) that when lime is added to the clay soil, first it is adsorbed by the clay mineral until the affinity of the soil for lime is achieved. This quantity of lime is known as lime fixation and normally the amount is between 1% and 3% lime by weight of soil. Any amount of lime added in excess of the lime fixation contributes to the pozzolanic reaction and thereby create hydrated cementitious gel. This may be the probable reason for blocks of S-2 to have lower strength as compared to the blocks S1-series. With increased period of ageing, the blocks prepared with 4% lime and 4% cement (Series S-3) have shown to have strength values more than for cement alone (Series S-1) or with 6% cement and 2% lime (Series S-2). At 5 years of ageing, the CSEBs of S-3 series have attained a wet compressive strength of 7.2 MPa as compared to 4.9 and 4.3 MPa for S-1 and S-2 series respectively. This difference in the values of strength for the blocks of S-3 series with ageing may be due to availability of sufficient quantity of lime, which probably has led to an increase in the pH of the system sufficient enough to allow the silica and alumina in the clay to be dissolved and to combine with Ca^{++} to form calcium-alumino silicates (CAS), and that, this reaction would continue as long as $Ca(OH)_2$ exists in the mix and that there is available silica available for reaction (Eades and Grim, 1960; Diamond and Kinter, 1965; Compendium-8 1978; Little, 1995). In addition, calcium aluminate hydrate (CAH) and calcium silicate aluminate hydrate (CASH) may develop especially when kaolinitic clays are treated with lime (Bell, 1996). As a result, it has led to the formation of stable cementitious products due to the pozzolanic reactions and thereby binds the clay particles present in the matrix. In the opinion of some researchers this may take place over many months or years (Wild et al., 1998). Though the long-term improvement of strength of lime stabilized fine-grained soils has been reported in the literature (Mateos, 1964; Thompson, 1966; Winterkorn, 1986; Kerali, 2001; Al-kiki et al., 2011) its role in imparting long-term build-up of strength in CSEBs has not been reported as presented in this study. The optimum combination of cement and lime has been found to be mutually very beneficial in imparting strength to the blocks in a much better way, because the cement undergoes self-hydration in presence of water, producing hydration products that bind the sand particles. It is the binding of sand particles, and the products of the self-hydration of the cement that contribute to the early

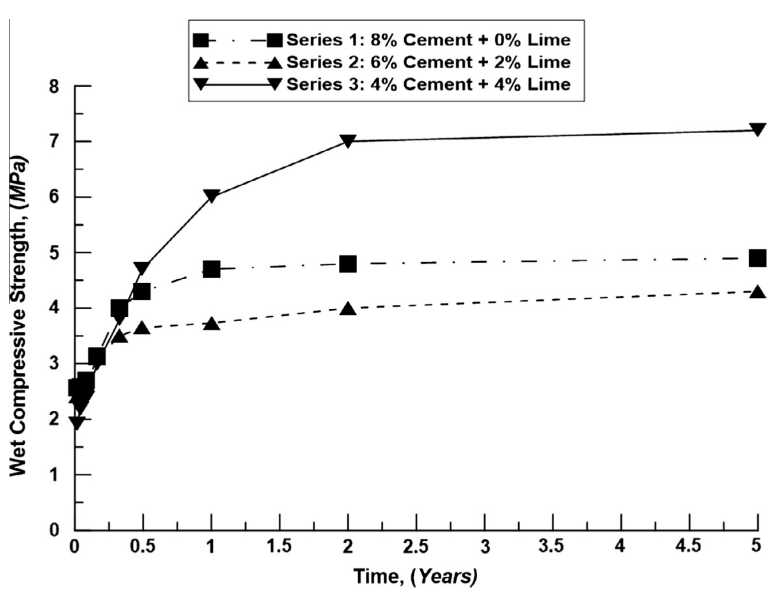

Figure 1. Wet compressive strength versus ageing for CSEBs prepared with different proportions of cement and lime.

strength of the blocks. In contrast, the pozzolanic reactions involving clay and lime are much slower, rather contributing more to the longer-term strength. Further, it is observed that blocks prepared with optimum quantity of lime has led to continuous build-up of strength of blocks even up to 2 years (S3 series), whereas the other series blocks prepared with cement alone (S-1 series) and less quantity of lime than the optimum quantity required (S-2 series) have not gained much strength after 6 months from the time of preparation of the blocks. Therefore, one can expect gain in strength of the blocks even up to 2 years after their preparation, provided they are prepared with the optimum quantity of lime. For a better understanding of the role of lime in combination of cement in the gain of strength of the blocks, the strength gained at different stages of ageing as compared with the final wet compressive strength of blocks prepared with cement alone has been presented in Table 4. It can be observed from the table that, though the strength gained by blocks prepared with cement alone is more up to 4 months compared to other two series, later the blocks prepared with optimum quantity of lime (S-3 series) have shown more build of strength. At 6 months of ageing, S-3 series blocks have attained strength comparable to 1-year strength of blocks prepared with cement alone (S-1 series). At the end of 5 years of ageing, S-3 series blocks have nearly 47% more strength as compared to blocks prepared with cement alone. However, S-2 series blocks prepared with less quantity of lime along with cement have shown to attain lesser strength than the other two series of blocks at any stage of ageing. Thus, this study not only brings out the role of lime in imparting long-term strength in the preparation of stabilized earth blocks, but also it brings out the fact that lime should be used in an optimum quantity along with cement in order to impart better strength to the blocks. Hence using a combination of cement and lime in an optimum combination would help in reducing the amount of stabilizer used in the preparation of the blocks. This would lead to the reduced cost of the blocks and also a better green rating.

4.2. Water absorption

Fig. 2 presents the water absorption of the CSEBs versus ageing for all the three series of blocks used in this study. It can be observed that water absorption initially remained around 14.0%, which is slightly less than the prescribed value of 15% for good quality bricks (IS: 1725, 1982). Later with time, blocks have shown a continuous reduction in the water absorption. By the end of 5 years of ageing, the value has reduced to as low as 7.0%. This observed reduction in the water absorption values of the blocks might be attributed to the micro-level changes tak-

Table 4
Strength gain for blocks of all series at different stages of ageing expressed as ratio of strength gain at any stage of ageing to the final wet compressive strength obtained for blocks prepared with cement alone (S1-series).

Duration	Days			Months			Years		
	7	15	28	2	4	6	1	2	5
Series – 1	52.2	52.7	55.1	63.9	81.6	87.8	95.9	98.0	100.0
Series – 2	49.2	50.1	53.4	63.2	71.4	74.5	76.1	81.6	87.8
Series – 3	39.2	44.7	48.6	61.2	77.6	95.9	122.4	142.9	146.9

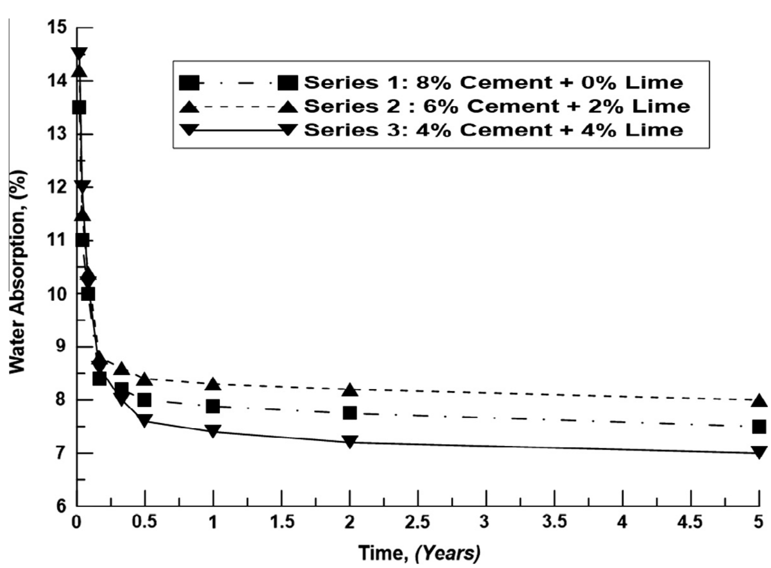

Figure 2. Water absorption versus ageing for CSEBs prepared with different proportions of cement and lime.

ing place due the interactions of admixtures with the soil and water to form cementitious products. As a result of the cementitious reactions, the interconnectivity between the voids may be getting reduced, and hence, reduction in water absorption of the CSEBs. The values of the water absorption for all the series are much lower than 15%, being around 7–8%. For S-3 blocks, the value is the lowest, being 7% indicating that more cementation is taking place in those blocks. This also complements the observed increased strength of the blocks of S-3 series compared to that of other blocks of the other two series.

5. Conclusions

From this experimental study on CSEBs prepared using lime as a replacement to cement in certain proportions has clearly brought out the effectiveness of lime with cement in improving the long-term build-up of strength better than using cement alone. Herein, the combination of cement and lime has been found to be mutually very beneficial in imparting strength to the blocks in a much better way, because cement has taken care of stabilizing the sand portion with hydration products obtained from cement and lime to stabilize clay fraction present in the mix. This would help in increasing the strength of the blocks, which would be a reflection on the durability and performance of buildings constructed using such CSEBs. The research findings show a need to relook at the grading of ingredients and quantity of stabilizers for achieving good building blocks. The use of lime would permit higher quantities of clay content than normally being used, thereby affecting the gradation and reduced dependence on natural sand, which is becoming scarce. Further, using stabilizers in combination would help in reducing their quantity in the preparation of blocks of comparable strength to that prepared with cement alone. This would be added benefit not only reducing the cost of the blocks, but also has serious implications in terms of the reduction of energy consumed in the manufacture of blocks when done in large scale. This would also help in a sustainable growth of the society by optimizing the resources used, reduction in energy consumed and lesser pollution of the environment.

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