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Stabilization of lateritic soil for masonry applications

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Abstract. Construction using local soil is encouraged globally to minimize environmental impacts and to promote sustainable construction. However, the reluctance in using soil for construction is mainly due to the lack of strength and durability. This study investigates the influence of Ordinary Portland Cement (OPC) as stabilization agent for masonry blocks using lateritic soil, being a predominant soil in South India. Lateritic soil collected from three different locations in Kozhikode district of Kerala, India was used for the study. Engineering properties of stabilized soil blocks made with varying quantities of cement (such as 2.5, 5, 7.5, 10 & 12.5 % by weight of soil) was determined using standard procedures. The results were compared with ordinary laterite blocks and un-stabilized laterite soil blocks. It was observed that the strength of lateritic soil stabilized blocks increases with the quantity of cement content. The dry density, compressive strength and flexural strength increase with cement content, whereas, water absorption decreases with cement content. Weathering resistance was also considerably enhanced with increase in cement content. Based on the performance comparison, the optimum quantity of cement for stabilization of lateritic soil in Kerala was observed as 8 % by weight of soil. Even though laterite blocks in natural form being the popular masonry material in northern Kerala for centuries, its compressive strength was found 30 % lesser than manufactured lateritic soil-cement blocks. This study reveals that the stabilization of lateritic soil using the optimum quantity of cement can replace conventional natural laterite blocks for economic, environmental friendly and sustainable construction initiatives.

1. Introduction

The Conventional masonry construction practices using materials like burnt clay bricks, cement blocks and sand-concrete blocks involve high energy for the raw material extraction and manufacturing, which is environmentally hazardous and uneconomical. The release of carbon dioxide and other pollutants during their life cycle contaminates the nature, flora, fauna, as well as humans [1]. The threat to sustainability due to over-exploitation of resources and the lack of naturally occurring materials encourages the need for sustainable, economical and easily accessible material for construction [2]. Construction using local soil can be a sustainable solution for these issues. Earth construction has been in practice since more than 9000 years [1]. Soil used for construction during the beginning was unstabilized, which over the course of time, became stabilized for more strength and durability. Numerous researches have been conducted on different soils and their stabilization techniques globally. The commonly used nomenclature like compressed earth block, pressed earth block, compressed stabilized earth block, soil cement block, stabilized soil bricks, etc., all refer to the same earth construction either using a stabilization agent or without it [3–6]. However, the major hindrance to the popularization of earth construction is their instability in presence of water, lack of strength and low durability [7, 8]. All stabilization techniques studied so far focused on these shortcomings of earth construction. Previous research studies have established cement and lime as efficient stabilization agents for most of the soils [9–12]. However, cement has been more efficient and popular than lime in terms of strength and durability [13]. The type of soil and the stabilization agent has a great influence on the performance of stabilized earth blocks [14–16].

Apart from moulding of soil and using for construction purposes, natural stones are also significantly used around the globe. One such natural stone that is extensively used in India [17] and African countries [18] is Natural Laterite Blocks (NLB). The properties of NLB are similar to that of lateritic soil[19]. Even though NLB

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is being used as popular masonry material for centuries, the supply of natural blocks is unable to meet the demand of the present construction industry. This paves the way for the stabilization and remoulding of lateritic soil as a replacement for natural laterite block, which has not been scientifically explored.

The aim of this study is to analyze the performance of blocks made using lateritic soil stabilized with cement and to compare the results with that of NLB. Lateritic soil collected from three different locations in Kozhikode district of Kerala, India were used for the study. Properties such as dry density, water absorption, compressive strength, flexural strength and weathering resistance of stabilized lateritic soil blocks made using varying proportions of cement were analyzed. The results were substantiated with scanning electron microscope images.

2. Methods

2.1. Materials

Lateritic soils were collected from three distinct locations in Kozhikode district, Kerala, India. The locations are namely Kunnamangalam, Kotooli and Atholi and are represented as lateritic soil 1 (LS1), lateritic soil 2 (LS2) and lateritic soil 3 (LS3) respectively. Three soils were used for the study to assess the variation in performance and to generalize the findings. Characterization of the collected lateritic soil samples were carried out in accordance with SP 36 (Part 1) – 1987 [20] of IS specification and are presented in Table 1. The chemical analysis of soil samples was carried out using X-ray fluorescence method using Bruker model S8 Tiger X-ray spectrometer and results are reported in Table 2. The major compounds identified in all samples include SiO_2, Al_2O_3 and Fe_2O_3. X-ray diffraction test was carried out using Rigaku Miniflex 600 diffractometer to identify the mineral presence in the lateritic soil samples. The minerals identified by X-ray diffraction is presented in Table 3. Kaolinite, was present in all the soil samples as the major component. Minerals identified in all three lateritic soil samples were similar and also confirms to previous studies on lateritic soils of Kerala [21]. The fraction of minerals in soil has a strong influence on the strength and durability characteristics of soil-cement blocks. Soils containing non-expansive clay minerals like kaolinite, are generally considered suitable for cement stabilization and soils with predominant expansive clay minerals are not proffered for cement stabilization [22].

The cement used for stabilization was Ordinary Portland Cement (OPC 53 grade) that complies with IS 12269 – 1987 [23]. The chemical and mineral composition of cement used is presented in Table 4. The mineral composition of OPC was calculated using the empirical formula of Bogue [24].

Table 1. Properties of lateritic soil samples.

Properties	Soil location		
	LS1	LS2	LS3
Optimum moisture content (%)	20	16	20.5
Maximum dry density (g/cm^3)	1.59	1.61	1.67
Liquid limit (%)	41.5	36	37.5
Plastic limit (%)	27.2	20.8	22.6
Plasticity index (%)	14.3	15.2	14.9
Particle size distribution			
Gravel + Sand (%)	53.0	58.3	64.5
Silt size (%)	36.1	32.3	21.2
Clay size (%)	10.9	9.4	14.3
Specific gravity	2.338	2.431	2.436
pH value	5.22	5.62	5.31

Table 2. Chemical composition of lateritic soil samples.

Compound	Composition (%)		
	LS1	LS2	LS3
SiO_2	55.68	57.45	53.71
Al_2O_3	23.18	18.26	20.43
Fe_2O_3	6.83	9.54	8.97
CaO	1.21	0.76	0.89
MgO	0.82	1.84	0.63
Na_2O	0.21	0.17	0.42
K_2O	0.65	2.85	2.21
TiO_2	0.96	0.79	1.08

Table 3. Mineral composition of lateritic soil samples.

Soil location	Minerals identified
LS1	Kaolinite, Quartz, Gibbsite, Feldspar, Goethite
LS2	Kaolinite, Quartz, Gibbsite, Feldspar, Mica, Goethite
LS3	Kaolinite, Quartz, Gibbsite, Feldspar, Mica, Goethite

Table 4. Composition of cement.

Chemical composition (%)									Mineral composition (%)			
SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	K_2O	Na_2O	Ignition loss	C_3S	C_2S	C_3A	C_4AF
21.43	4.97	3.87	63.86	1.05	1.47	0.51	0.19	1.05	58.13	17.60	6.62	11.78

2.2. Preparation

Stabilization of soil was done using different proportions of cement and soil. Blocks were casted, cured and tested for properties such as dry density, water absorption, compressive strength, flexural strength and weathering resistance. Three blocks of each mix proportion were tested to obtain the average value of the mentioned properties.

The soil collected from all three locations was initially spread out in thin layers for drying and then sieved through 4.75 mm sieve, as larger particles were unsuitable for block preparation [8]. Five different proportions of cement such as 2.5 %, 5 %, 7.5 %, 10 % and 12.5 % by weight of soil were used for the study. For block preparation, the required quantity of soil was weighed and taken from the prepared sieved soil and was mixed with cement at different predetermined proportions. Quantity of water taken for mixing was the sum of optimum moisture content mentioned in Table 1 for each soil and 30 % by weight of cement for its hydration. The measured quantity of water was then sprinkled over the soil-cement mixture and turned well multiple times to obtain a homogenous mixture. Blocks of size 305×143×100 mm were casted using a manual press using the soil-cement mixture and were cured by spraying water for 28 days and then stacked after labeling.

2.3. Testing

Dry density tests for the blocks were determined in accordance with IS 1725 – 2013 [25]. Oven-dried sample (at 105 °C) after attaining constant weight was weighed and all the dimensions were noted. Dry weight divided by the volume is the dry density.

Water absorption of the blocks were determined in accordance with IS 3495 (Part 2) [26]. Oven-dried sample was weighed and immersed in water for 24 hours and saturated weight was measured. The difference of saturated weight and dry weight represented as a percentage of dry weight is the water absorption.

Wet compressive strength of blocks were determined in accordance with IS 3495 (Part 1) [26]. Compressive strength was determined using an Universal Testing Machine of 1000 kN capacity. Saturated specimen was placed in the machine and load was applied at a rate of 14 N/mm^2/minute till failure. Peak load divided by the surface area is the compressive strength.

Flexural strength of blocks were determined in accordance with ASTM C293/C293M [27]. Center point loading method was done to obtain the value of modulus of rupture.

Weathering resistance of blocks were determined in accordance with IS 1725 – 2013 [25]. The block was dried in an oven at 65 °C till it achieved constant weight. The block was then immersed in water for 5 hours and subsequently dried in oven at 75 °C for 42 hours. All sides of the block were then scratched twice with wire brush at approximately 14.7 N force. This completes one cycle of test. Twelve cycles of the wire brush scratch procedure were performed on blocks to ascertain the weight loss.

Scanning electron microscope (SEM) images of blocks were taken using Hitachi SU660SEM to analyze the internal structure and effect of cement particles.

3. Results and Discussion

3.1. Dry density

Variation of dry density of blocks with cement content is shown in Fig. 1. It was observed that the density of blocks increases with cement content. The increase in dry density was about 17 % for LS1 for 12.5 % of cement by weight of soil, whereas LS2 and LS3 had an increase of about 4.5 % only. However, the general behavior of dry density with cement content was observed similar for all three soils. Also, similar results were observed in previous studies on soil stabilization with cement [13]. The reason for the increase in dry density may be due to the filling of all voids and pores by cement particles, which in turn increases the total solid mass. Also, the cement hydration products provide much stronger and closer bonding between soil particles. The dry density of blocks using LS1 was lower than LS2 and LS3. The reason for this may be due to the higher silt content of LS1 compared to the other two soils, as the unit weight of silt is lesser than sand and gravel.

3.2. Water absorption

Variation in water absorption of blocks with cement content is as shown in Fig. 2. It is observed that water absorption reduces with an increase in cement content. An average reduction of 19 %, 11 % and 9.5 % were observed for LS1, LS2 and LS3 respectively for 12.5 % cement content. The hydration products of two anhydrous calcium silicates (C_3S and C_2S) of cement forms two other compounds, calcium hydroxide (hydrated lime) and calcium silicate hydrate (CSH) [28]. The CSH gel occupies higher volume inside the soil-cement matrix than the C_3S and C_2S minerals [29]. Hence, the lesser the volume of voids, lesser will be the water absorption. It may also be noted that the water absorption is maximum for blocks of lowest dry density as the number of voids are relatively higher. In general, it was observed that the water absorption of blocks decreased with increase in dry density. Soil types LS2 and LS3 displayed lower water absorption than LS1 soil. The reason for this may be the presence of mica, for which the water absorption property is negligible and as such, the total absorption mass of LS2 and LS3 is reduced.

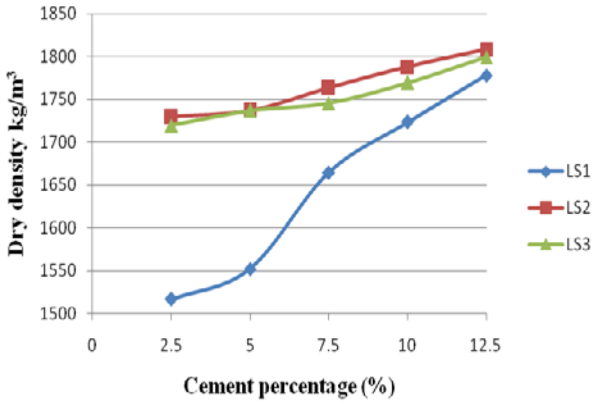

Figure 1. Variation of dry density with cement.

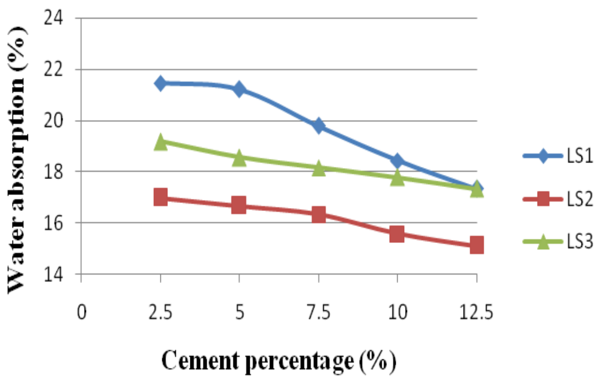

Figure 2. Variation of water absorption with cement.

3.3. Compressive strength

The results of compressive strength test are presented in Fig. 3. It is well evident that the compressive strength of blocks increases with an increase in cement content. It may also be noted that all three soils show almost similar variation with cement. The increase in compressive strength is more than double when cement content is increased from 2.5 to 5 % for all three soils. The strength had increased by more than five folds when the cement content was raised to 12.5 %. However, the minimum compressive strength specified for stabilized soil blocks in IS 1725-2013 is only 3.5 N/mm^2 which was achieved with around 8 % cement by weight of soil. The reason for the increase in compressive strength may be attributed to the binding action of cement that holds the soil particles together and the strong hydration products of cement (CSH and calcium hydroxide, as mentioned in section 3.2). The CSH and calcium hydroxide compounds are results of self-hydration of cement rather than reaction between cement and soil minerals as cement powder contains in itself everything it needs to hydrate [28]. The binding property of hydration products and the physical links between particles, helps the soil surface to distribute the load to the adjacent particle. Similar results were observed in previous studies on cement stabilized blocks [30], [31]. The compressive strength of blocks is dependent on cement as well as clay content [32]. As clay content increases, sand and gravel decrease and strength decreases. However, in this study, the clay content is similar for all three soils and there is no significant variation in compressive strength with different soil types at a constant cement content.

3.4. Flexural strength

The measure of flexural strength is represented in terms of modulus of rupture and the variation of the same with cement content is shown in Fig. 4. The modulus of rupture curve shows a steady increase with cement content for all three soils. The value increases by almost 50 % each time when the cement content is increased by 2.5 % from the previous cement content until 12.5 %. Maximum modulus of rupture was observed in blocks made using soil type LS1. Addition of cement enhances the flexural load carrying capacity of the blocks by improving the binding property of particles. The modulus of rupture displays a similar trend as compressive strength behavior with cement content.

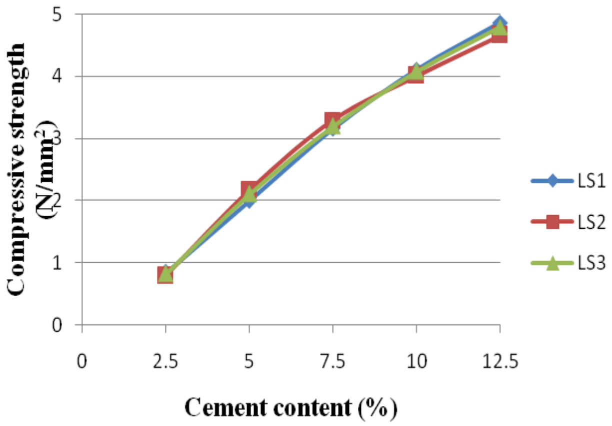

Figure 3. Variation of compressive strength with cement.

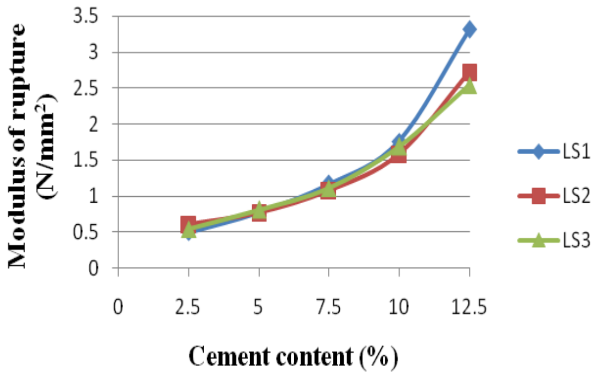

Figure 4. Variation of modulus of rupture with cement.

3.5. Weathering resistance

Weathering test results are displayed in Fig. 5. The results show a sudden drop (more than 60 %) in the weight loss when cement was increased from 2.5 % to 5 % for all soils. Weight loss is considered as the measure of durability. As weight loss decreases, more durable is the block. The reason for the increase in durability may be due to the action of hydration products of cement which holds the soil particles together and resist the wearing action on the surface by any foreign particles. Unstabilized soil particles are detrimental to the durability and hence the quantity of cement used for stabilization is important. Cement content above 5 % displayed a weight loss below 3 % for all soil types. It may also be noted that there is no significant increase in durability with cement content above 10 % as the weight loss is below 1 % for all soils. As in compressive strength property, the clay content of soil also influences the durability of the blocks. As clay content increases, it disrupts the bonding of soil and cement particles and thereby decreases the durability [32].

3.6. Comparison of strength with natural laterite block

The compressive strength result of lateritic soil-cement blocks (LSCB) with 8 % cement was compared with that of remoulded lateritic blocks (RLB) and natural lateritic block (NLB) and is shown in Fig. 6. RLB was prepared using soil obtained by crushing NLB and moulding it again using manual press without using any external stabilizing agents. It can be seen that the compressive strength of RLB is negligible compared to LSCB. This low strength may be attributable to the absence of a stabilizing agent. Without stabilizing agent, the moulded soil is highly unstable and weak in withstanding external stress. NLB, a popular masonry material in Kerala, has a strength of around 2.5 N/mm^2. However, the strength of NLB is almost 30 % lesser than that of LSCB with 8 % cement.

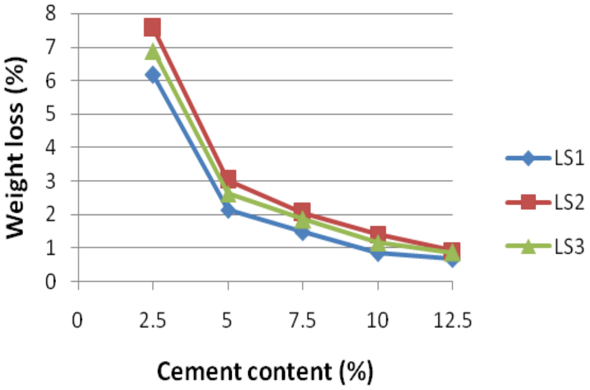

Figure 5. Variation of weight loss with cement.

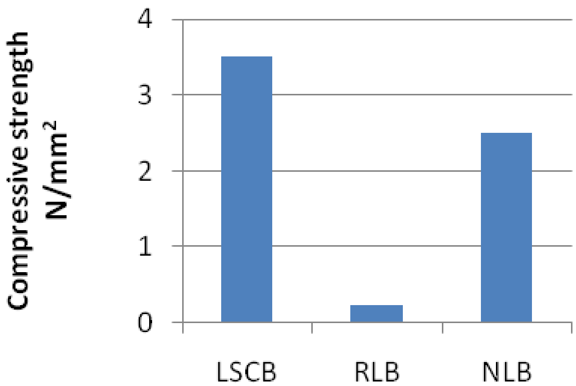

Figure 6. Comparison of compressive strength of LSCB, RLB and NLB.

3.7. Microstructure of blocks

The SEM images of blocks made using LS1 soil and different cement proportions are shown in Fig. 7. The SEM images of all three soil types were similar. It was observed that the number of pores and their sizes decreased with increase in cement content. Cement particles, which are smaller in size than soil, tend to occupy and fill the voids inside the soil matrix. Numerous pores were seen on the block surfaces with a minimum cement content of 2.5 %. However, blocks with 7.5 % and more cement appear to have a uniform surface with minimum number of pores and more binding between particles. The homogeneous structure seen in SEM images at higher cement contents indicates the stability and strength of the block. The images thus substantiate the results discussed in the above sections.

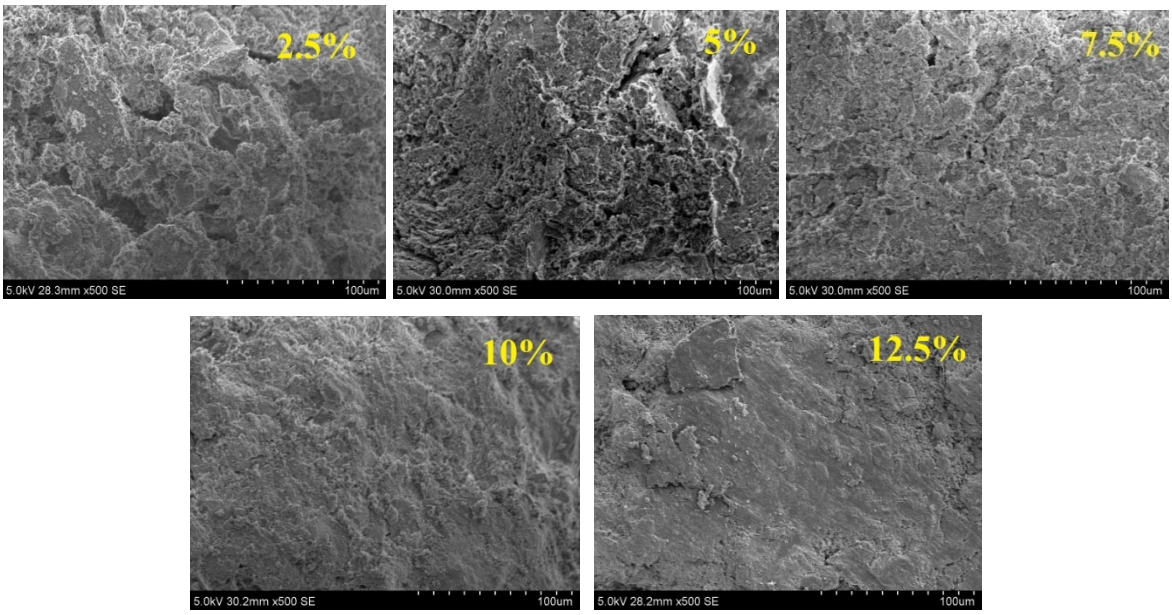

Figure 7. SEM images of lateritic soil-cement blocks with different cement contents.

4. Conclusion

The following conclusions can be drawn from the analysis on stabilization of lateritic soil using cement for masonry applications.

1. The major clay mineral observed in lateritic soil used for the study was kaolinite, which is non-expansive and as such, cement stabilization of lateritic soil was found effective in terms of enhancement in engineering properties of lateritic soil-cement blocks.

2. A significant reduction in water absorption was observed with increase in cement content. The average reduction in water absorption was observed as 11 % for 12.5 % cement content by weight of soil. Water absorption being a critical issue of soil blocks, can be resolved and brought under 18 % (limit specified in IS 1725 – 2013) with an addition of 8 % cement.

3. Mechanical properties such as compressive strength and flexural strength were enhanced manifold times with increase in cement content up to 12.5 %. However, over usage of cement is uneconomic and against sustainability concepts. The minimum compressive strength for soil blocks specified in IS 1725 – 2013 is 3.5 N/mm^{2,} which can be achieved with around 8 % cement.

4. The durability characteristics of blocks displayed significant improvement with increase in cement content. The maximum allowable limit of weight loss specified in IS 1725 – 2013 is 3 %. By addition of even 5 % cement, the weight loss was observed to be below 3 % and no significant weight loss was observed beyond 10 % cement.

5. Both strength and durability of stabilized soil blocks are enhanced by cement content and impaired by clay content. As far as lateritic soils used for the study are concerned, the clay content and other mineral contents are almost similar and the performance of stabilized soil depends on the variation in cement content.

6. Considering the critical aspects of soil blocks for masonry purposes, i.e., compressive strength, durability and water absorption, the optimum desirable results were observed with a cement content of 8 % by weight of soil for lateritic soils in Kerala.

It may be noted that the study was conducted exclusively for lateritic soils in Kozhikode district of Kerala. The performance of blocks may vary with the type of soil.

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