Magazine of Civil Engineering

ISSN 2712-8172

journal homepage: http://engstroy.spbstu.ru/

Research article

UDC 624.138

DOI: 10.34910/MCE.117.4

Effects of gradation and clay minerals on stabilized lateritic soil blocks

M.G. Sreekumar [1] ✉ ***, D.G. Nair*** [1] ***, K.S Jagadish*** [2]

[1] *Cochin University of Science and Technology, Kochi, Kerala, India*

[2] *Indian Institute of Science, Bengaluru, Karnataka, India*

✉ *sreekuair@cusat.ac.in*

Keywords: stabilized earthen block, clay mineral, soil gradation, lateritic soil, kaolinite, compressive strength

Abstract. Building blocks extracted from natural lateritic soil strata have wide popularity in masonry construction in the state of Kerala in India. However, extensive variations in strength and physical properties can be observed in these blocks even though they are collected from the same location. Stabilized soil blocks from this lateritic soil can be a sustainable solution for standardization. This research aims at optimizing the soil gradation and assessing the significance of clay minerals for the strength characteristics of stabilized earthen building blocks from lateritic soil. Lateritic soil samples from four different locations and depths were collected and tested for their characterization, as well as chemical and mineralogical investigations. The suitability of stabilizers such as cement, lime, and quarry waste was investigated and stabilized lateritic building blocks were manufactured in different particle combinations from each soil sample and tested to study the influences of gradation patterns on stabilization. The best combinations were further investigated for optimization studies. Combined effects of soil gradation, as well as the presence of chemical and mineral contents in the lateritic soil, were found to contribute toward strength gain. Results of the studies reveal the significance of silt content among the particles and the influence of kaolinite and hematite minerals in the soil samples on the strength gain of stabilized laterite blocks.

Citation: Sreekumar, M.G., Nair, D.G., Jagadish, K.S. Effects of gradation and clay minerals on stabilized lateritic soil blocks. Magazine of Civil Engineering. 2023. 117(1). Article no. 11704. DOI: 10.34910/MCE.117.4

1. *Introduction*

Tropical and sub-tropical countries are rich in lateritic soil deposits [1, 2]. The state of Kerala in India is covered with a laterite blanket of more than 60 % over various crystalline rocks [3, 4]. And the majority of this laterite deposit belongs to the category of moderate to weak laterization [5]. Building blocks extracted from this naturally available deposit are widely used in Kerala for masonry construction. But these laterite blocks are found highly varying in nature with respect to strength, durability, and physical characteristics [1, 4]. The availability of good quality cut laterite building blocks is further narrowed by the restriction imposed by Government on quarrying from greater depths. Stabilized building blocks made from abundantly available lateritic soil deposits can be suggested as a sustainable solution to overcome these issues of standardization and availability.

The lateritic soil is distinct from other soil types as it contains various chemicals and minerals. It is affluent in aluminium, iron, silica, and kaolinite clays and varies with mineral and chemical composition based on formation [6, 7]. Dense rainfall, warm temperature, and local topography influence the formation of a lateritic soil group. The existence of iron oxides influences the color of laterite soil and variation can be observed from light red to brown shades [8]. Rock weathering in tropical areas is very rigorous as seen in the fast disintegration of feldspars as well as ferromagnesian raw materials. Displacement of bases including Na_2O, K_2O, and MgO, silica, and the absorption of aluminium and iron oxides can also be noticed [9]. This procedure which includes leakage of silica and decomposition of iron and aluminium oxides is called laterization [10]. H.A. Narayanaswamy et al. observed a variation in the strength characteristics of lateritic rock with respect to location and strata along with a variation in dry and saturated environments. And they suggest climatic conditions in tropical countries and response to moisture owing to the porous nature of the material as the influential factors [11]. Similar observations were reported by Mc Farlane Mj and reported that the depth of induration of laterite profiles is due to water table fluctuations [12]. Mineralogy of the rocks and natural chemical stabilization (due to weathering) is responsible for the strength of these porous blocks. The induration of laterite is due to the development of constituent sesquioxides (Fe_2O_3 and Al_2O_3), precipitated, concentrated, and crystallized as a result of desiccation [13]. However, the significance of various chemicals and minerals present in the laterite soil towards strength gain of stabilized earthen blocks is yet to be studied.

As the characteristics of soil greatly vary according to particle sizes, a major challenge in the production of stabilized soil blocks is with respect to optimum soil grading limits influencing the strength and durability characteristics [14]. Hitherto, the documented research on compressed stabilized earth blocks indicates that all soils available in nature need improvements with respect to particle size proportions [15]. There are different recommendations for particle sizes that are suitable for earth construction. H. Danso conducted a review of different research on the suitability of particle size for adobe and reported desirable ranges for clay (0 % to 25 %), silt (0 % to 25 %), and sand (60 to 90 %) constituents [16]. Whereas the ranges suggested by L.P. Bengtsson and J.H. Whitaker are 20 % to 50 % for a combined proportion of clay-silt and 50 % to 80 % for sand particles [17]. But B.V. Venkatarama Reddy et al. restricted the upper range of clay as 14 % to16 % suitable for stabilized mud blocks [18, 19]. C.A. Oyelami and J.L. Van Rooy [20] reviewed earlier findings and reported wide ranges for different constituents from various research. According to their review, clay content of about 23 % was reported by H. Houben and H. Guillaud [21], a range of 6 % to 30 % by V. Rigassi [22] and 5 % to 40 % clay content 10 % to 30 % silt, and 25 % to 80 % sand and fine gravel by M.C.J. Delgado and I.C. Guerrero [23]. It is clear from the above discussion that there is still no agreement between the different recommendations rather than suggesting a wide range for each constituent.

The main objective of this study is for finding out the optimum soil gradation for the production of stabilized building blocks from lateritic soil and also for investigating the significance of clay minerals and chemicals towards strength gain. Soil samples collected from different locations and depths are investigated for verifying the results.

2. Methods

Lateritic soils from four different locations of Cochin (Kerala, India), within a radius of 20 Km were collected and subjected to characterization studies. Stabilized lateritic blocks were made out of these samples with different mix proportions for finding out the suitability of stabilizers and gradation patterns. Optimization studies were conducted to identify the optimum gradation with respect to strength characteristics. Chemical and mineralogical characteristics of soil samples were also evaluated to investigate the influences. Details of experimental programs are illustrated in the following sections.

2.1. Materials

Lateritic soil (source material), river sand and quarry waste (as stabilizers with respect to the gradation of the source material), cement, and lime (stabilizers) were used. The properties of the materials are detailed below.

2.1.1. Lateritic Soil

The soil samples used for this research are designated as S1, S2, S3, and S4 based on their locations. S1 sample was taken from Aluva (at an average depth of 3.50 m), S2 sample from Kakkanad (average depth of 1.50 m), S3, and S4 samples from different locations of Thrikkakkara from an average depth of 2.50 m and 4.50 m respectively. The samples were sieved through a 4.75 mm IS sieve and general properties were investigated (Table 1). The physical appearance of the soil samples is illustrated in Fig. 1.

Figure 1. Pictures of the soil samples.

Table 1. Properties of lateritic soil samples.

Properties	S1	S2	S3	S4
Colour	Blush red	Often red	Often red	Blush
Specific gravity	2.55	2.42	2.38	2.58
Liquid limit (%)	58	60	52	55
Plastic limit (%)	35	30	36	34
Shrinkage limit (%)	19.79	29	29	32
Plasticity Index (%)	23	30	17	21
pH value	4.73	4.49	4.55	4.22
Clay (%)	28	23	28	21
Silt (%)	18	15	16	20
Fine sand (%)	11	14	15	8
Medium sand (%)	23	32	24	34
Corse sand (%)	20	16	17	17
Dry density (gm/cc)	1.64	1.64	1.64	1.67
Optimum moisture content	21	21	22	20

2.1.2. Sand & quarry waste

Sand and quarry waste passing through a 2 mm IS sieve and retaining on 425 microns IS sieve were used for modifying the gradation of soil samples as stabilizers. Properties of sand and quarry dust are tabulated in Table 2.

Table 2. Properties of sand and quarry waste.

Properties	River Sand	Quarry Dust
Specific gravity	2.61	2.8
Bulk density (g/cc)	1.47	1.18
% bulking	44	66
Porosity	0.37	0.42
Voids ratio	0.25	0.56
% Gravel	2.4	0
% Sand	98.8	86
% Silt	1.2	14
Fineness Modulus	3.23	2.38
Grading zone	Zone 1	Zone 2

2.1.3. Cement and lime

Commercially available 53 grade ordinary Portland cement and locally available shell lime were used as stabilizers.

2.2. Experimental Program

The experimental program was conducted through two stages. Initially, to investigate the suitability of the stabilizers and further for assessing the influence of soil gradation on strength gain. The significance of various chemicals and minerals present in the laterite soil towards strength gain was also assessed.

3. Results and Discussion

3.1. Study on the suitability of stabilizers

The suitability of different stabilizers like sand, quarry waste, cement, and lime was investigated in this phase. Preliminary studies were conducted in S1 and S2 soil samples with cement and sand as stabilizers. Further, the studies were extended to S2, S3, and S4 samples with quarry dust and lime. Cement content was fixed as 8 % based on earlier studies [24–26]. Lime fixation studies were conducted based on previous researches and fixed the lime content [27, 28]. Mix designations and corresponding proportions of constituents with respect to different soil samples are shown in Table 3. Specified proportions of soil and stabilizers for each mix designation were taken and mixed thoroughly in a dry state to get a homogeneous mix. Optimum water content was determined and introduced to this mix, mixed well until a uniform consistency was obtained. The measured quantity of mix was then transferred to the mold of the manually operated block-making machine (ASTRAM) and compressed. The details of the block-making process are depicted in Fig. 2. The building blocks (190 mm × 110 mm × 100 mm) thus prepared were initially kept under a shade for 24 hours in a leveled platform and further subjected to 28 days of wet curing by covering with wet gunny bags. These building blocks after curing were subjected to different tests for density as per IS: 1725 -2013 [29], wet compressive strength as per IS: 3495 -Part I [30], and water absorption as IS: 3495 -Part II [31]. Results are presented in Table 4.

(a) Mixing (b) Filling the mould (c) Compacting

(d) Ejected blocks (e) Stabilized Lateritic soil blocks ready for curing

Figure 2. Manufacturing process of Stabilized Lateritic soil block specimens.

Table 3. Mix designations and proportion.

Sl No	Designation				Mix Proportion By Weight (%)				
	S1	S2	S3	S4	Soil	Sand	Quarry Dust	Cement	Lime
1	$S_{10}C_8$				90	10	–	8	–
2	$S_{20}C_8$				80	20	–	8	–
3	$S_{25}C_8$				75	25	–	8	–
4		A			100	–	–	8	
5		B	3X	4X	80	–	20	8	
6		RB			80	20		8	
7		C	3V	4V	75		25	8	
8		D	3Y	4Y	80		20	8	4
9		RD			80	20		8	4
10		E	3Z	4Z	75		25	8	4
11		RE			75	25		8	4

Preliminary studies conducted on the S1 sample gave satisfactory results for the stabilized lateritic block ($S_{25}C_8$, 3.60 N/mm^2) using cement and sand as stabilizers. Whereas, in the S2 soil sample, quarry dust is additionally required for better results (B, 2.14 N/mm^2). Improvement was further noticed on S2 blocks on lime stabilization (D, 3.16 N/mm^2). Results of S1 and S2 samples indicate the influence of gradation on the suitability of stabilizers. Studies were extended to S3 and S4 soil samples to verify this.

Fig. 3 shows the variation in compressive strength of stabilized lateritic blocks made from the selected soil samples with their mix combinations giving maximum strength. On comparing the suitability of cement to cement- lime combination for stabilization, blocks made from S2, S3, and S4 showed better results for the latter in line with the low pH value of the soil samples. The strength characteristics of blocks from all the soil combinations except S4 samples showed significant variations in introducing quarry dust/sand as stabilizers but did not show a unique behavior regarding the quantity of stabilizer (sand/ quarry dust). This further justifies the significance of soil gradation in block making. Studies were extended to evaluate this influence and for identifying the optimization of gradation.

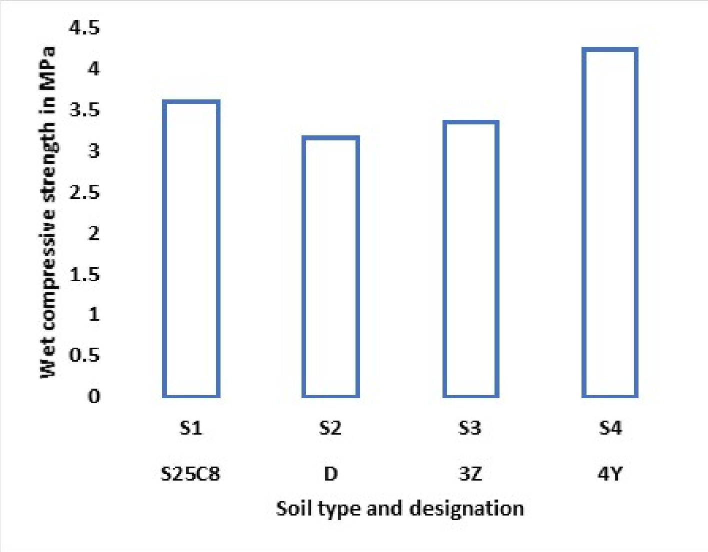


Figure 3. Selected mixes and Compressive strength of soil samples.

Table 4. Strength and durability properties of the stabilized lateritic blocks.

Sl No	Type of Soil	Designation	Test Results			
			Fresh Density (g/cc)	Dry Density (g/cc)	Wet Compressive Strength (MPa)	Water Absorption (%)
1	S1	$S_{10}C_8$	2.05	1.73	2.99	14.16
2	S1	$S_{20}C_8$	2.08	1.76	3.39	14.14
3	S1	$S_{25}C_8$	2.06	1.75	3.60	14.12
4	S2	A	1.94	1.67	1.72	14.72
5	S2	B	1.99	1.70	2.14	14.58
6	S2	RB	1.98	1.69	1.83	14.16
7	S2	C	1.98	1.69	1.94	14.63
8	S2	D	1.98	1.69	3.16	14.16
9	S2	RD	1.98	1.69	2.72	14.18
10	S2	E	1.98	1.69	2.98	14.16
11	S2	RE	1.98	1.69	2.57	14.15
12	S3	3X	2.01	1.70	2.16	14.18
13	S3	3Y	2.01	1.70	2.67	14.13
14	S3	3V	2.02	1.71	2.55	14.20
15	S3	3Z	2.03	1.72	3.35	14.14
16	S4	4X	2.00	1.70	4.10	14.12
17	S4	4Y	2.00	1.70	4.24	14.12
18	S4	4V	2.01	1.70	4.17	14.13
19	S4	4Z	2.00	1.70	4.22	14.12

3.2. Influence of soil gradation on strength gain

In this phase, quarry dust, cement (8 %), and lime (4 %) were selected as stabilizers based on the preliminary studies discussed above. Best mix combinations identified from each soil sample were selected and blocks were made and tested to confirm the results. In addition to this, one more combination was also tested in all samples by modifying the mix to restrict the clay content to the desired value of 15 % as reported by researchers [18, 19]. Since there were no considerable variations in the results of S4 samples, an additional mix was tested without adding quarry dust. The details of mix designations and gradation of soil samples before and after modification are tabulated in Table 5, and the results are presented in Table 6.

Table 5. Mix designation and gradation of soil samples for optimization study.

Sl No:	Soil Type	Soil gradation before modification			Designation	Mix Proportion By Weight (%)		Soil gradation after modification		
		Sand	Silt	clay		Soil	Quarry dust	Sand	Silt	clay
1	S1	54	18	28	S1A	75	25	62	17	21
2	S1	54	18	28	S2B	54	46	69	16	15
3	S2	61	16	23	S2A	80	20	66	16	18
4	S2	61	16	23	S2B	66	34	70	15	15
5	S3	56	16	28	S3A	75	25	64	15	21
6	S3	56	16	28	S3B	54	46	70	15	15
7	S4	59	20	21	S4A	80	20	64	19	17
8	S4	59	20	21	S4B	72	28	67	18	15
9	S4	59	20	21	S4V	100	0	59	20	21

Results of all the soil samples were reconfirming the results of the preliminary studies. Also, S1, S3, and S4 samples were found to comply with the basic strength requirements as per IS 1725-2013. Whereas S2 showed slightly low values compared to the standards. Water absorption of the blocks was found lower and complies with Indian standards. The suitability of quarry dust over river sand was verified in the S1 sample. Whereas, the S4 sample confirmed the appropriateness of virgin soil over stabilized soil with respect to gradation. At the same time, modified mixes stabilized by restricting the clay content proved inferior among the selected combination.

Table 6. Average measured strength and durability properties of soil samples.

Sl No:	Soil Type	Designation	Wet compressive strength (MPa)	Wet density	Dry density	Water absorption (%)
1	S1	S1A	3.98	2.02	1.72	14.12
2	S1	S1B	3.68	2.02	1.72	14.12
3	S2	S2A	3.13	2.02	1.72	14.14
4	S2	S2B	2.91	2.02	1.72	14.14
5	S3	S3A	3.50	2.02	1.72	14.15
6	S3	S3B	3.30	2.02	1.72	14.14
7	S4	S4A	4.47	2.01	1.72	14.14
8	S4	S4B	4.30	2.01	1.72	14.14
9	S4	S4V	4.68	1.99	1.70	14.18

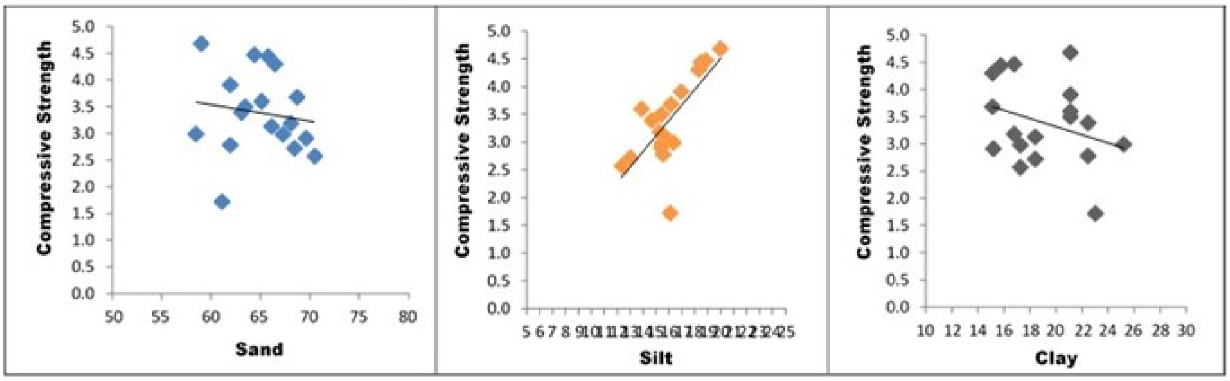
Table 7. Gradation of maximum strength gained lateritic soil sample after optimization.

Serial No	Soil Sample	Designation	Before modification				After modification			
			Sand	Silt	Sand + Silt	Clay	Sand	Silt	Sand + Silt	Clay
1	S1	S1A	54	18	72	28	62	17	79	21
2	S2	S2A	61	16	77	23	66	16	82	18
3	S3	S3A	56	16	72	28	64	15	79	21
4	S4	S4V	59	20	79	21	59	20	79	21

Table 7 shows the gradation of selected mix combinations before and after modifications based on the above results. On examining the gradation of the optimized soil samples before and after modification, a uniqueness in the pattern in line with the strength gain can be noticed. Optimized mixes of S1, S3, and S4 showed a clay content of 21 % and a combined sand-silt content of 79 % in their modified gradation. The presence of high silt content observed in the S4 sample (20 %) justifies the significance of silt in strength characteristics. Variations in the results of S3 confirm this observation.

3.2.1. Statistical Analysis

Results obtained from the studies were statistically analyzed by linear correlation to establish the relationships between various variables and to determine their rate of dependence on each other. Fig. 4 illustrates the correlation of particles with strength.



(a) Sand **(b) Silt** **(c) Clay**

Figure 4. Scatter plot showing the relationship between variables and Compressive Strength.

Fig. 4 (a) showed only a negligible influence of sand content in the compressive strength of the blocks by representing it almost as a horizontal line with minimal slope. Whereas 4(b) showed a positive influence and 4(c) negative influence in terms of the presence of silt and clay respectively. Table 8 shows the correlation between different constituents and compressive strength. A high significance of silt was evident from the analysis with a p-value less than 0.05. However, the correlations of sand and clay particles were found insignificant with higher p- values.

This statistical analysis establishes a positive correlation and significance of silt content and a slight negative correlation with respect to clay content. On analyzing the results of experimental studies, it can be seen that maximum strength was reported for the sample with the highest silt content in concurrence with the results of statistical analysis. At the same time, soil samples with the lowest silt content did not give a result as projected by the statistical analysis. Sand being a mandatory component of soil like clay and silt, its elimination cannot be possible from the soil sample. This justifies the influence of sand + silt content as verified by experimental research (79 %). The silt content of the S4 sample (20 %) can be recommended as the optimized value for comparing the silt contents of other samples with respect to the strength of the blocks. Low values of the clay contents of the modified gradation compared to the original gradation justified the results of the statistical analysis. However, the S2 sample with the lowest clay content among the samples was behaving inferior. This indicated the significance of an optimum clay content (21 %) as verified by the experimental research.

Table 8. Correlation analysis – influence of soil particles on compressive strength.

Variable	Mean	Standard deviation	r - value	p - value
Sand	64.96	3.546	-0.140	0.581
Silt	15.98	1.995	0.722	0.001
Clay	19.06	3.118	-0.303	0.221
Compressive Strength	3.386	0.772		

3.3. Influence of chemical and mineralogical fraction of clay on strength gain

Even though the modified soil samples (S1, S3, and S4) showed similarity in gradation patterns, variations can be observed in the compressive strengths of corresponding building blockings. S4, the soil sample taken from the deepest source showed maximum strength compared to other soil samples. Strengths of S1, S2, and S3 were also found to vary in the same order corresponding to the source depths. Variations in clay mineralogy of collected soil samples from different depths can be considered as the reason. The strength of S2 also supports these observations and points towards the influence of clay minerals along with gradation. As the presence of clay minerals varies in soil samples based on the depth of their source, the influence of clay minerals needs to be investigated.

Soil samples passing through a 75-micron sieve were subjected to energy dispersive X-ray spectrometry (EDAX) for identifying chemical composition and X-ray diffraction (XRD) for mineralogical analysis. Quantitative analyses were also carried out in both studies. The results of the EDAX analysis are presented in Table 9. Whereas Table 10 and Fig. 5–8 show the results of XRD analysis**.**

Table 9. Chemical composition and oxides of lateritic soil samples.

Soil Type	Al_2O_3	SiO_2	$Al_2O_3 + SiO_2$	K_2O	TiO_2	Fe_2O_3	MgO
S1	41.34	46.41	87.75	0.86	1.42	9.38	0.61
S2	35.22	41.57	76.79	0.51	2.17	20.35	0.18
S3	37.82	46.79	84.61	0.49	2.36	11.79	0.75
S4	40.92	48.34	89.26	0.70	1.89	8.15	

Chemical analysis of soil samples showed a similar variation in the total content of Al_2O_3 and SiO_2 as that of strength characteristics of the stabilized lateritic blocks made from the respective soil samples. At the same time, Fe_2O_3 values were found to vary in the reverse order justifying its negative influence.

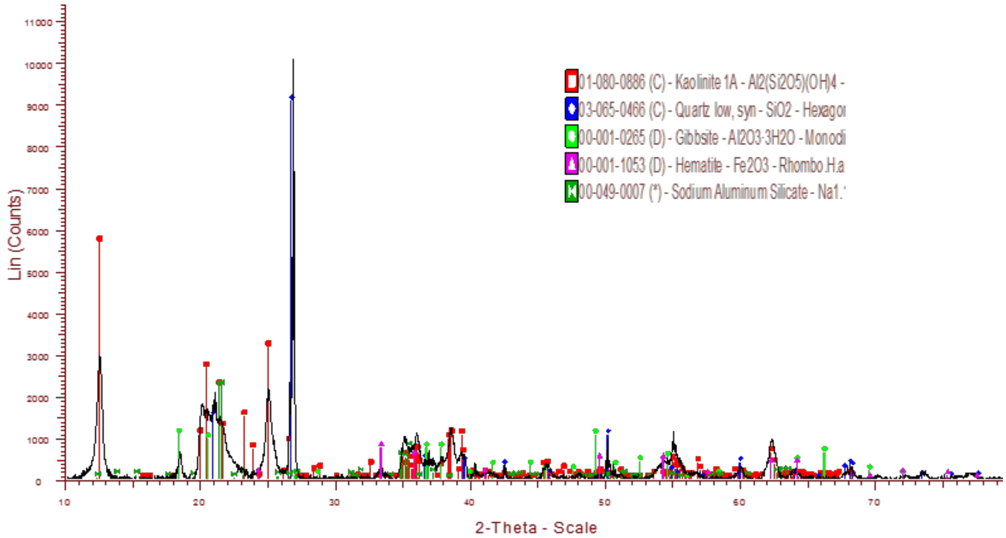


Figure 5. X-ray diffraction pattern of soil sample S1.

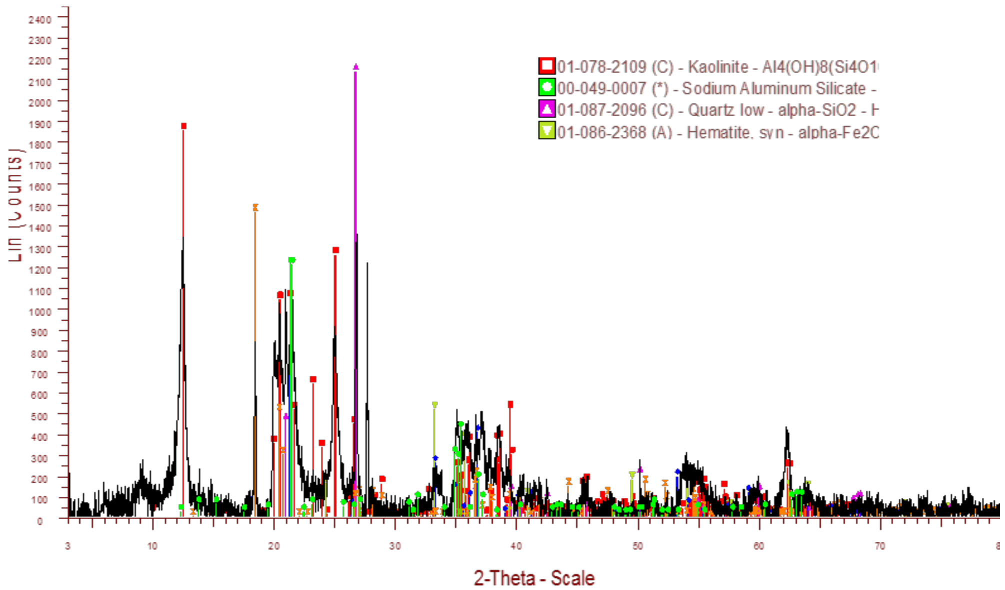


Figure 6. X-ray diffraction pattern of soil sample S2.

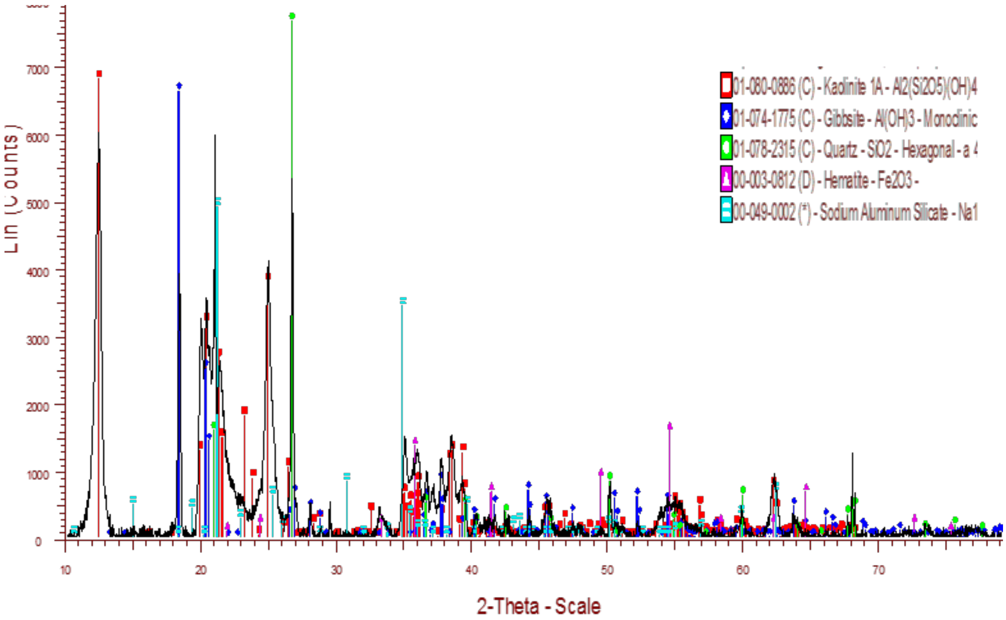


Figure 7. X-ray diffraction pattern of soil sample S3.

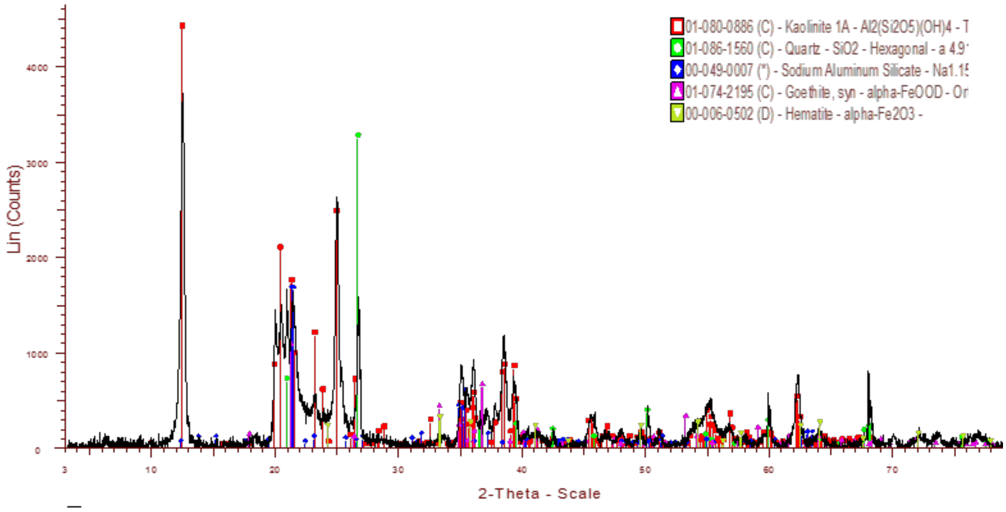


Figure 8. X-ray diffraction pattern of soil sample S4.

Table 10. Mineral composition of lateritic soil samples.

Soil Type	Kaolinite ($Al_2Si_2O_5(OH)_4$)	Quartz (SiO2)	Hematite (Fe_2O_3)	Sodium aluminium silicon oxide ($NaAlSi_3O_8$)	Gibbsite ($Al(OH)_3$)
S1	82.85	4.43			12.72
S2	69.917	1.919	5.920	16.571	5.672
S3	72.22	3.74	2.06	11.84	10.14
S4	83.967	2.429	1.524	10.090	1.991

Table 10 and XRD patterns of the soil samples (Fig. 5–8) shows the presence of kaolinite (Al_2 $Si_2O_5(OH)_4$), gibbsite ($Al(OH)_3$), sodium aluminium silicon oxide ($NaAlSi_3O_8$), quartz (SiO2) and hematite (Fe_2O_3) as the main minerals. Strength variation among the stabilized lateritic blocks was found to vary in the same order as that of kaolinite ($Al_2Si_2O_5(OH)_4$) content in the respective soil samples similar to the observations on chemical composition. It is generally agreed that in a wetted soil-cement mixture, cement hydrates and cementitious products such as calcium-silicate hydrate(CSH) and calcium aluminate hydrate (CAH) are formed apart from the release of a small percentage of calcium hydroxide (lime) [19]. Alumina dissolves in the high pH environment created by the presence of lime. The major part of this dissolved alumina reacts and forms CAH and CASH phases [32]. The presence of the hydroxides of silica and alumina was evident in the identified minerals of soil samples in different compositions. This also contributes to strength characteristics.

The presence of hematite (Fe_2O_3), as identified by XRD analysis was found to influence the strength in the reverse order. Soil samples collected from deep sources were having comparatively low iron content and showed more strength than that from lower depths with higher iron content. The colour of the soil samples were varying from bright red to pale red corresponding to the iron content.

Even though the presence of quartz is visible in all soil samples, the identified clay minerals contributed to the formation of cementitious phases, actively reacting with stabilizers (cement and lime) and thus resulting in strength gain.

4. Conclusion

Source materials for lateritic soil blocks comprise different particle fractions such as sand, silt, and clay. Each of these components has its role in strength development. This study established a positive correlation and significance of silt content with an optimum value of 20 %. However, a combined influence of sand and silt was found more significant than individual influences. The optimum clay content of 21 % was also verified through experimental research. Thus the recommended gradation for locally available lateritic soil can be suggested as sand – 59 %, silt – 20 %, and clay – 21 %**.** These results are thus helpful in standardizing the production of stabilized lateritic soil masonry blocks.

This investigation also verified the influence of source depths on the strength characteristic of stabilized lateritic blocks. Based on the depth of extraction, chemical and mineralogical compositions of the soil samples vary. Soil samples from deeper sources showed higher strength compared to those from lower depths due to a higher concentration of oxides of alumina, silica, and kaolinite minerals. Experimental studies also verified the combined effects of Al_2O_3 and SiO_2 in the development of cementitious properties and strength gain. The presence of kaolinite minerals had a positive influence and hematite was found to have a negative influence on the strength gain.

These investigations could thus establish a clear guideline for gradation and combined effects of chemical-mineralogical compositions of the source material in the strength gain of masonry blocks made from lateritic soil.

References

1. Maignien, R. Review of research on laterire. IV . France, Natural Resource Research, United Nation, 1966. 156 p.
2. Gidigasu, M.D. Laterite Soil Engineering: Pedogenesis and Engineering Principles. Amsterdam, Elsevier Scietific Publication Company, 1976. 554 p.
3. Narayanaswamy, Ghosh, S.K. Lateritisation of gabbro-granophyre rock units of the Ezhimala Complex of north Kerala, India. Chemical Geology. 1987. DOI: 10.1016/0009-2541(87)90130-6
4. Kasthurba, A.K., Santhanam, M., Mathews, M.S. Investigation of laterite stones for building purpose from Malabar region, Kerala state, SW India – Part 1 : Field studies and profile characterisation. 2007. 21. Pp. 73–82. DOI: 10.1016/j.conbuildmat.2005.07.006
5. Kasthurba, A.K., Santhanam, M., Achyuthan, H. Investigation of laterite stones for building purpose from Malabar region, Kerala, SW India – Chemical analysis and microstructure studies. 2008. 22. Pp. 2400–2408. DOI: 10.1016/j.conbuildmat.2006.12.003
6. Tardy, Y., Kobilsek, B., Paquet, H. Mineralogical composition and geographical distribution of African and Brazilian periatlantic laterites. The influence of continental drift and tropical paleoclimates during the past 150 million years and implications for India and Australia. Journal of African Earth Sciences. 1991. DOI: 10.1016/0899-5362(91)90077-C
7. Frank C. Townsend, M. Geotechnical Characteristics of Residual Soils. Journal of Geotechnical Engineering. 1985. 111 (1). Pp. 77–94. URL: https://doi.org/10.1061/(ASCE)0733-9410(1985)111:1(77)
8. Syafalni, Lim, H.K., Ismail, N., Abustan, I., Murshed, M.F., Ahmad, A. Treatment of landfill leachate by using lateritic soil as a natural coagulant. Journal of Environmental Management. 2012. DOI: 10.1016/j.jenvman.2012.08.001
9. Mitchell, James Kenneth, K.S. Fundamentals of soil behavior. 3rd ed. New York, John Wiley and Sons, 2005. 577 p.
10. Gidigasu, M.D. Mode of formation and geotechnical characteristics of laterite materials of Ghana in relation to soil forming factors. Engineering Geology. 1972. DOI: 10.1016/0013-7952(72)90034-8
11. Narayanaswamy, A.H., Mcgregor, F., Millogo, Y., Fabbri, A. Physical, Mechanical and Hygrothermal Properties of Lateritic Building Stones (LBS) from Burkina Faso. 2016. (November 2017). DOI: 10.1016/j.conbuildmat.2016.08.082
12. McFarlane, M.J. Laterite and landscape. London, Academic Press, 1976.
13. Varghes, T., Byju, G. Laterite soils – their distribution, characteristics and management. Technical Monograph No. 1. Thiruvanathapuram, India, 1993. 116 p.
14. Venkatarama Reddy, B.V., Latha, M.S. Influence of soil grading on the characteristics of cement stabilised soil compacts. Materials and Structures/Materiaux et Constructions. 2014. 47 (10). Pp. 1633–1645. DOI: 10.1617/s11527-013-0142-1
15. Nagaraj, H.B., Rajesh, A., Sravan, M.V. Influence of soil gradation, proportion and combination of admixtures on the properties and durability of CSEBs. Construction and Building Materials. 2016. 110. DOI: 10.1016/j.conbuildmat.2016.02.023
16. Danso, H. Suitability of Soil for Earth Construction as Building Material. 2018. (December). DOI: 10.31031/ACET.2018.02.000540
17. Bengtsson, L.P., Whitaker, J.H. Farm structures in tropical climates. Rome, Italy, FAO/SIDA COOPERATIVE PROGRAMME, 1988.
18. Venkatarama Reddy, B.V. Stabilised soil blocks for structural masonry in earth construction. Modern Earth Buildings Materials, Engineering, Constructions and Applications. Woodhead Publishing, 2012. Pp. 324–363.
19. Reddy, B.V.V., Latha, M.S. Applied Clay Science Retrieving clay minerals from stabilised soil compacts. Applied Clay Science. 2014. 101. Pp. 362–368. DOI: 10.1016/j.clay.2014.08.027. URL: http://dx.doi.org/10.1016/j.clay.2014.08.027

20. Oyelami, C.A., Van Rooy, J.L. Geotechnical characterisation of lateritic soils from south-western Nigeria as materials for cost-effective and energy-efficient building bricks. Environmental Earth Sciences. 2016. DOI: 10.1007/s12665-016-6274-1
21. Houben, H., Guillaud, H. Earth construction: a comprehensive guide 1994.
22. Rigassi, V. Compressed earth blocks : Manual of production. I1985. ISBN: 3528020792.
23. Delgado, M.C.J., Guerrero, I.C. Earth building in Spain. Construction and Building Materials. 2006. 20 (9). Pp. 679–690. DOI: 10.1016/j.conbuildmat.2005.02.006
24. Reddy, B.V.V., Gupta, A. Strength and elastic properties of stabilized mud block masonry using cement-soil mortars. Journal of Materials in Civil Engineering. 2006. 18 (3). Pp. 472–476. DOI: 10.1061/(ASCE)0899-1561(2006)18:3(472)
25. Sreekumar, M.G., Nair, D.G. Stabilized lateritic blocks reinforced with fibrous coir wastes Methodology of Research. International Journal of Sustainable Construction Engineering & Technology. 2013. 4 (2). Pp. 23–32.
26. Sreekumar, M G, D.G.N. Mechanical Properties of Stabilized Lateritic Soil Blocks with Fibrous Waste Additives. International Journal of Sciences: Basic and Applied Research (IJSBAR. 2018. 8 (12). Pp. 336–350.
27. Eades, J.L., Grim, R.E. A Quick Test to Determine Lime Requirements For Lime Stabilization 1960.
28. Ciancio, D., Beckett, C.T.S., Carraro, J.A.H. Optimum lime content identification for lime-stabilised rammed earth. Construction and Building Materials. 2014. DOI: 10.1016/j.conbuildmat.2013.11.077
29. Bureau of Indian standards. IS 1725 : 2013 (Reaffirmed Year : 2019) Stabilized Soil Blocks used in General Building Construction – Specification. New Delhi, Bureau of Indian standards, 2013.
30. Bureau of Indian standards. Determination of compressive strength. IS: 3495 (Part 1): 2019 Methods of test of burnt clay building bricks. New Delhi, Bureau of Indian standards, 2019.
31. Bureau of Indian standards. Burnt Clay Building Bricks — Methods of Tests Part 2 Determination of Water Absorption (Fourth Revision). IS 3495 : Part 2 : 2019. New Delhi, Bureau of Indian standards, 2019.
32. Billong, N., Melo, U.C., Louvet, F., Njopwouo, D. Properties of compressed lateritic soil stabilized with a burnt clay-lime binder: Effect of mixture components. Construction and Building Materials. 2009. DOI: 10.1016/j.conbuildmat.2008.09.017

Information about authors:

***Moothattu Govindan Nair Sreekumar**,*
ORCID: https://orcid.org/0000-0002-0324-222X
E-mail: sreekuair@cusat.ac.in

***Deepa G. Nair**, PhD*
ORCID: https://orcid.org/0000-0003-1644-6317
E-mail: deepagnair@cusat.ac.in

***Kaup S. Jagadish**, PhD*
E-mail: ksjagadish@gmail.com

Received 02.05.2021. Approved after reviewing 12.07.2022. Accepted 13.07.2022.