Study on Performance of Expansive Soil Using Agro Waste as a Sustainable Stabilizer

S. Vismaya, K. Divya Krishnan, and P. T. Ravichandran

Abstract For a safe construction of diminutive and edifice structures in soil, the foundation soil should be keenly observed and improved before the construction activities. To improve the soil characteristics, replacing the traditional methods of soil stabilization can be done by utilizing the agriculture wastes as one of the best cost-effective and sustainable method. For this study, agriculture waste wheat husk ash (WHA) of different percentages (3, 6, 9 and 12%) were mixed to the problematic soil at varying curing periods (3, 7, 14 and 28 days) and tests like standard proctor compaction, unconfined compressive strength and free swell index test were done in order to know the optimum percentage of additive to develop the improved characteristics of the soil. According to the test results, wheat husk ash of 9% showed an enhancement of 150% in strength at 28 days of curing, indicating it as the optimum dosage and there is a volume reduction in soil by 50% with the addition of WHA compared with untreated soil. Wheat husk waste which is one of the agricultural wastes produced abundantly causing waste disposal problem and threat to the surroundings can be utilized in soils for strength enhancement which leads to a sustainable eco-friendlier environment by reducing the environmental impacts.

Keywords Stabilization · Wheat husk ash · Soil · Unconfined compressive strength · Compaction

1 Introduction

Foundation is the portion of a building that should be strong enough to transmit load efficiently to the soil which is available beneath it. The quality of soil has larger impact on the structures to be constructed. Expansive soil is a kind of problematic soil which shows undesirable properties making it a weak soil because of the volumetric change behavior. Excessive swelling and shrinking of the clay soil are seen

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whenever soil is in contact with the moisture leading to failure of the structures, thus indicating that the bearing ability of the soil is not enough to support loads. In order to improve the soil properties and to rectify the problem of swelling and shrinking, ground improvement techniques are required. Soil stabilization is one among that will enhance and modify the soil properties by improving strength and reducing the swell-shrink properties. Mechanical stabilization is one of the technique available which depends on particle gradation, aggregate as well as plasticity characteristics, making this method suitable in construction of embankments of railways, roads, etc. The other technique is chemical stabilization which has many advantages which includes uniformity in quality and performance, this will reduce the volume increase. The chemical stabilization includes alteration of soil performance using lime, Portland cement, fly ash, sodium chloride, calcium chloride, or materials such as bitumen.

The traditional method of lime stabilization is done by many methods which include usage of high calcium quick lime, hydrated high calcium lime, dolomite lime, normal hydrated as well as pressure hydrated dolomite lime. Researchers like Pongsivasathit and Sreekrishnavilasam [1, 2] studied how traditional stabilizers like cement, cement kiln dust improved the mechanical strength and Saride [3] initiated to understand the behavioral mechanisms of lime and cement stabilized in eight different organic soils. Authors like Vakili et al. [4] combined cement with sodium silicate, GGBFS and performed tests to increase shear strength, whereas the study [5] investigated on effects of nanoparticles on consistency, compaction, hydraulic conductivity and compressive strength of cement-treated residual soil on improving pozzolanic reaction. Some of the main advantages of chemical stabilization are that the setting and curing time are controllable. But researchers are searching for alternate admixtures because of the cost and environment concerns. There are many kinds of wastes such as industrial wastes, agricultural wastes, domestic wastes and mineral wastes. There is an ongoing trend in utilization of waste materials and locally available materials in soil stabilization for a sustainable eco-friendly environment.

Industrialization has led to production of huge number of waste generation which is useless materials generated during manufacturing process in mills, factories and industries. Researchers like Gidley and Sack [6] used many methods to utilize industrial wastes in the construction which improved soil strength. The wastes include fly ash, bottom ash, red mud, copper slag ash, waste paper sludge, etc. These wastes come in large quantities and their problem of disposal is a main problem. Adding industrial wastes like beverage can of aluminum affected significantly the compaction, strength as well as swell properties of the clay [7]. Incorporating industrial wastes like high-density polyethylene (HDPE) and glass to the soil is found satisfactory to be used as stabilizer in subgrade modification for road structure by resolving disposal issues by promoting sustainability in highway construction [8]. Divya Krishnan K studied strength characteristics of two different expansive clayey soils using phospho gypsum in varying percentages at different curing periods. The outcomes show that addition of certain percentage of phospho gypsum showed optimum dosage in both the soils by exhibited maximum compressive strength [9]. The studies are done by tests performed on strength behavior of black cotton soil using coal bottom ash

(CBA). CBA as a cementitious material, enhanced the strength of the soil and also reduced swelling and shrinkage property. Coal bottom ash was added at 0, 10, 20, 30 and 40% as an additive and conducted various tests such as UCS, CBR, MDD and OMC. It was observed that the optimum condition is reached by 30% addition of coal bottom ash.

At present, the method of soil stabilization is also slowly taken up by the use of various agricultural wastes. Research on combining those wastes with chemical additive showed an increase in rate of stabilization. As E. A. Basha who studied in using rice husk ash as a stabilizer combining with cement said, agriculture wastes from rice, wheat, sunflower and tobacco plants have silica in cuticle parts. Plants get enough minerals during their growth from Earth and it is also available in large quantity, so that it can be utilized to bring down construction cost, specifically in the rural regions of developing countries [10]. Agricultural wastes which are produced in 350 million tons in India are a result of agricultural operations from fields, poultry and farm wastes. Utilization of agricultural wastes will reduce many problems associated with it, such as waste disposal, land availability making it a very cost-effective method and by reducing carbon footprints caused by chemicals usage present in traditional stabilizers. Apart from rice husk ash, researchers used two types of fly ash in soft soil stabilization. The optimum content of the high calcium fly ash along with the effect of palm oil fuel ash resulted in pozzolanic reaction and altering the engineering properties of the soil [11]. In an economic point of view, the improved characteristics of soil using the combination of wheat husk ash and coir fibre increases the California Bearing Ratio which indicates the enhancement in the strength characteristics of soil [12]. With increased olive waste production in Jordan [13] burned olive waste and used as a soil stabilizer to reduce the problem. Based on the effects of various wastes in soil as a stabilizer, the wheat husk ash (WHA) is used in this study as an additive to enhance the soil characteristics in a cost-effective approach and to reduce waste disposal problems.

2 Materials and Methodology

2.1 Soil

Expansive soil of 1 m depth is considered for this study which is collected from Taramani area, Chennai and the quantity of soil required is sun-dried and pulverized and used for further experimental work. In order to get the swell and strength characteristics, basic tests like Atterberg's limit, compaction and unconfined compressive strength tests were done in accordance with IS standards [14–18]. Table 1 gives the geotechnical properties of the soil. From the test results, the plasticity index of 31.37% and the other test results indicate that the soil is classified under high compressible-high plasticity clays according to unified soil and Indian Standard Classification system. Light compaction [19] is done in untreated soil and an optimum moisture

Table 1 Basic properties of expansive clay

Free swell index (%)	Specific gravity	Atterberg's limit			Plasticity index (%)	Soil classification	Unconfined compressive strength (UCS) (kPa)
		Liquid limit (%)	Plastic limit (%)	Shrinkage limit (%)			
85	2.51	55.6	24.23	10.4	31.37	CH	125.20

content of 22% and a maximum dry density of 14.90 kN/m^3 is obtained indicating it as a weak soil.

2.2 Wheat Husk Ash (WHA)

Wheat husk, which is an agricultural waste produced in abundant quantity and locally available, is taken and burnt in a temperature of 600 °*C* and is passed through 425-micron sieve which is taken for the study. The ash produced by this process is a silicious material which will help in pozzolanic reaction to take place along with the soil and moisture content. Elemental composition of WHA includes silicon of 60.44%. Here, the investigation is done according to the strength and swell characteristics and the chemical characteristics impart the alteration in the soil. The chemical composition for wheat husk ash includes 85% of SiO_2, 2.51% of CaO and 24.23% of MgO. As per Lin et al., by mixing additives pozzolanic reactions will be quicker if calcium is more [20]. The additive silica is of sufficient amount and available for the reaction to take place producing cementitious compound like silicate hydrate or calcium silicate [21].

3 Sample Preparation and Tests

For the present study, experiments are carried out with adding different percentages of WHA to the soil (3–12%). After the basic tests, in order to obtain the strength value, compaction characteristics of the soil–binders' mixtures, moisture density relations are found out that is using light compaction. In accordance with IS: 1970 (Part 10) (1973), unconfined compressive strength (UCS) was tested for untreated soil as well as soil-additive mixtures of different percentages (3, 6, 9 and 12%) was done [20]. For the UCS tests, samples of 38 mm and 76 mm in diameter and length, respectively, are made according to the optimum conditions. The wet sample obtained by mixing the soil with dry WHA of varying percentage with optimum water content is placed in cylindrical mold and compacted from both the ends. The extruded sample is kept for curing (3, 7, 14 and 28 days). Microstructural analysis is done in order to know the microstructural characteristics of the specimen after oven drying of soil with and without the additive.

4 Results and Discussion

4.1 Effect of Additive in Strength Characteristics of the Soil

In this study, unconfined compressive strength tests were done to analyze the strength characteristics of various combination of soil-additive mix. Strength development is studied at varying curing periods of 3, 7, 14 as well as 28 days. Figures 1 and 2 show the typical stress–strain behavior of the treated soil with varying percentages of additive at 7 and 28 days period of curing.

From the graphs, it was observed that strength develops with number of days of curing. Treating soil with 9% WHA showed optimum value indicating the maximum

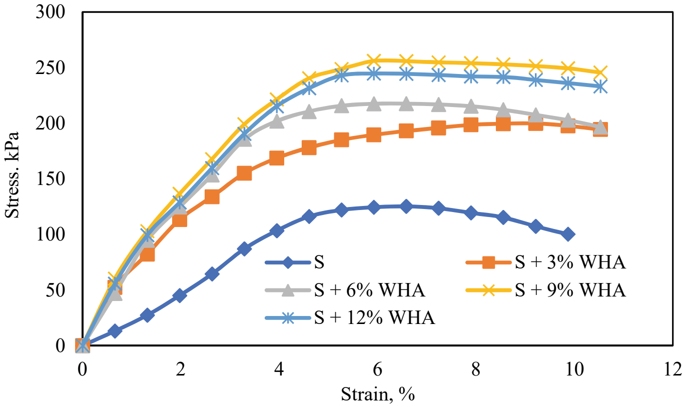


Fig. 1 Stress–strain variation of stabilized soil with WHA at 7 days curing period

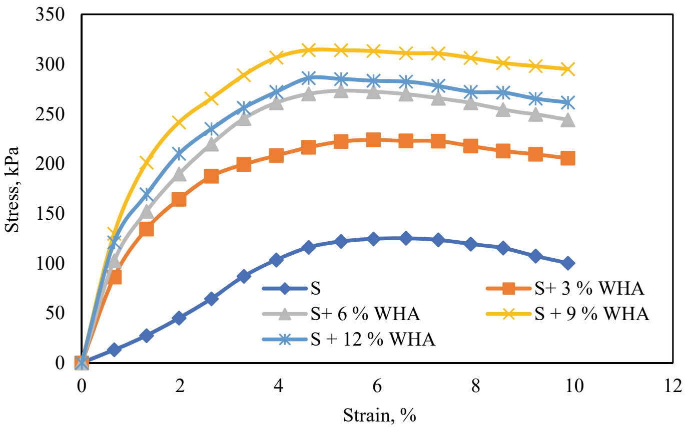


Fig. 2 Stress–strain variation of stabilized soil with WHA at 28 days curing period

Table 2 UCS values of unstabilized and stabilized soil with WHA

Soil + WHA%	Curing period (days)			
	Unconfined compressive strength (UCS), kPa			
	3	7	14	28
SS + 3%	155.60	199.78	214.66	223.98
SS + 6%	180.56	217.57	247.94	273.35
SS + 9%	192.96	255.98	294.66	314.14
SS + 12%	177.09	244.65	276.44	285.92

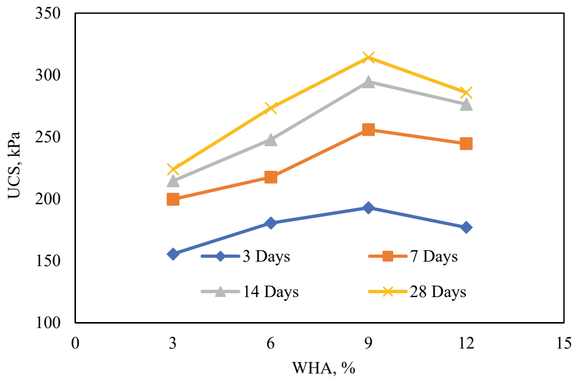


Fig. 3 Effect of UCS value of soil with varying percentage of WHA

strength. After 14 days and 28 days of curing, strength development to a value of 294.66 and 314.14 kPa, respectively, is observed and then reduces thereafter with increase in additive percentage and the same was observed in other curing days. The stress was increased and reached peak at lesser strain in case of WHA-treated sample compared with untreated sample. Table 2 and Fig. 3 show the results and the variation of effects of UCS with varying percentages of WHA by treating the soil. Here the strength of same percentage is always proportional to curing days [22].

Calcium-silicate, calcium-aluminate and calcium-aluminum-silicate hydrates are the compounds which are cementitious, resulting in strength in the sample. As it is a time depending process, it increases with curing days. However, the value decreases after addition of additive after 9%, because in stabilized soil with the extra additive content, there is no pozzolanic reactions to take place with the binder content and they remain as unbonded reducing the overall strength [23].

4.2 *Effect of Additive in Swell Characteristics of the Soil*

Sample for free swell tests is prepared from the tested UCS samples and Table 3 gives the tested results of free swell index of untreated and treated soil with varying

Table 3 FSI values of unstabilized and stabilized soil with WHA

Soil + WHA%	Curing period (days)			
	FSI, %			
	3	7	14	28
SS + 3%	70	65	60	55
SS + 6%	60	55	55	50
SS + 9%	60	55	50	45
SS + 12%	55	50	50	45

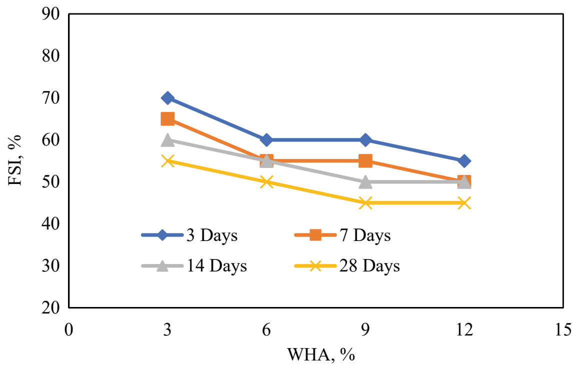


Fig. 4 Variation of FSI values with different percentages of WHA

percentage of WHA at different curing periods. Increasing the additive proportion of WHA in untreated soil results in the decrease of the swell value. At 28 days, the FSI value got reduced to 45% from 85% of the soil by increasing the WHA content. It was a conclusion that the chemical composition of stabilizer will give an evidence of the effectiveness in stabilization in expansive soil [24]. The calcium ions reduce the intensity of swelling potential of clay having Smectite and Illite clay minerals. Thus, expansive nature of a soil can be determined using free swell index test to know the swelling potential.

Figure 4 gives the variation of FSI with WHA at varying curing periods, indicating the volume change by lowering the swelling character of the expansive soil. The soil is made less expansive irrespective of the percentage addition of wheat husk ash.

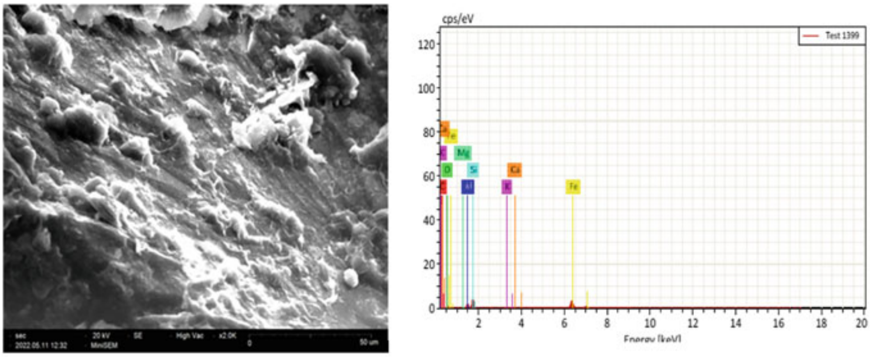
4.3 Microstructural Analysis of the Soil

The strength and swell characteristics show that WHA is suitable for soil stabilization. Based upon the test results, the values are compared in order for detailed observation with the help of SEM and EDS analysis. Figure 5 shows the SEM image and EDS spectra of untreated soil, WHA and soil treated with 9% WHA at 14 days curing period. From the figure, it is evident that there is alteration in soil structure giving a compact and dense structure of uniform matrix by number of curing days [25]. The void spaces in untreated soil are more when compared with treated sample because of the chemical reactions taking place with curing days [26]. The elemental composition is easily analyzed with the help of EDS and it was seen that elements, like silica, calcium and aluminum are increased with WHA when compared with untreated soil.

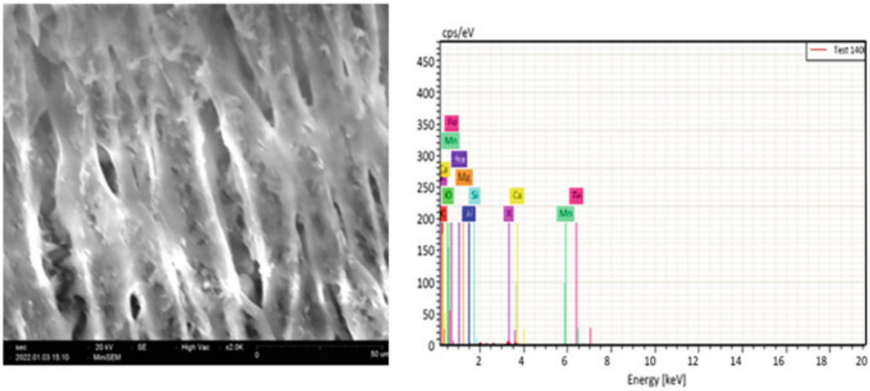
5 Conclusion

From the study of soil modified with WHA in order to observe the strength and swell characteristics enhancement, following conclusions are observed:

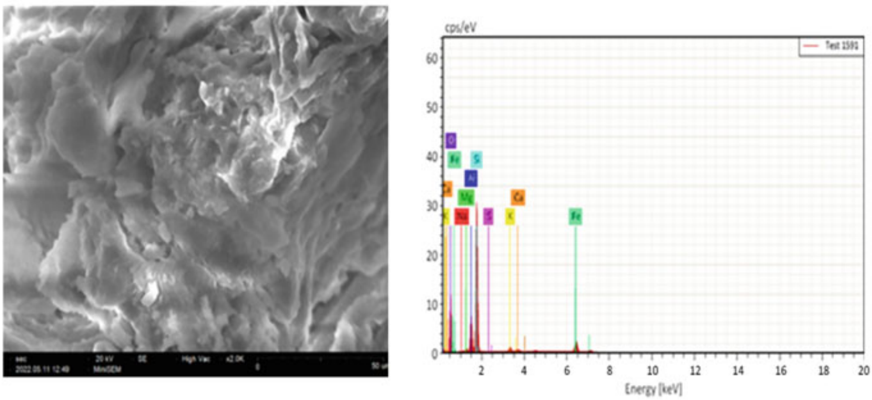
- The unconfined compressive strength was improved with the addition of stabilizer with longer curing days. The soil showed maximum strength of 314.14 kPa in 28 days curing period, resulting in an effective stabilization at the optimum content of 9% of WHA. The strength was enhanced by 150% when bonded with the additive comparing it with the untreated soil, having less unconfined compressive strength of 125.20 kPa.
- The volume change behavior of getting less swell potential is observed with the addition of additive. Thus, swelling behavior problem was reduced by improving the strength characteristics and FSI value of 45% was obtained for soil with 9% WHA from the untreated soil FSI of 85%.
- SEM images confirm that there is formation of calcium hydroxide, silicon hydroxide and C–S–H reactions imparting the strength in the expansive soil.
- Thus, by utilizing WHA as a sustainable stabilizer can save significant amounts of costs and it was considered as an eco-friendlier stabilizer to improve the strength and swell characteristics.



(a) Untreated Soil



(b) Wheat Husk Ash



(c) Soil treated with 9 % WHA

Fig. 5 SEM micrograph and EDS spectra of untreated, WHA and treated sample at 14 days curing

References

1. Pongsivasathit S, Horpibulsuk S, Piyaphipat S (2019) Assessment of mechanical properties of cement stabilized soils. Case Stud Constr Mater 11:1–15
2. Sreekrishnavilasam A, Rahardja S, Kmetz R, Santagata M (2007) Soil treatment using fresh and landfilled cement kiln dust. Constr Build Mater 21(2):318–327
3. Saride S, Puppala AJ, Chikyala SR (2013) Swell-shrink and strength behaviors of lime and cement stabilized expansive organic clays. Appl Clay Sci 85(1):39–45
4. Vakili MV, Chegenizadeh A, Nikraz H, Keramatikerman M (2018) Investigation on shear strength of stabilised clay using cement, sodium silicate and slag. Appl Clay Sci: 124–125:243–251
5. Bahmani SH, Huat BBK, Asadi A, Farzadnia N (2014) Stabilization of residual soil using SiO_2 nanoparticles and cement. Constr Build Mater 64:350–359
6. Gidley James S, Sack WA (1984) Environmental aspects of waste utilization in construction. J Environ Eng 110(6):1117–1133
7. Canakci H, Celik F, Bizne MOA, Bizne MOA (2016) Stabilization of clay with using waste beverage can. Procedia Eng 161:595–599
8. Fauzi A, Mohd W, Wan N, Rahman A, Jauhari Z (2013) Utilization waste material as stabilizer on Kuantan clayey soil stabilization. Procedia Eng 53:42–47
9. Divya Krishnan K, Ravichandran PT (2020) Investigation on industrial waste material for stabilizing the expansive soil. IOP Conf Ser Mater Sci Eng 912:062062
10. Basha EA, Hashim R, Mahmud HB, Muntohar AS (2005) Stabilization of residual soil with rice husk ash and cement. Constr Build Mater 19:448–453
11. Jafer H, Atherton W, Sadique M, Ruddock F, Loffill E (2018) Stabilisation of soft soil using binary blending of high calcium fly ash and palm oil fuel ash. Appl Clay Sci 152:323–332
12. Ahmed, Sharma A (2019) Use of coir fiber and wheat husk ash to improve the characteristics of clayey soil. Int J Eng Trends Technol 67(10):85–89
13. Attom MF, Al-sharif MM (1998) Soil stabilization with burned olive waste. Appl Clay Sci 13:219–230
14. IS 2720 Part XL (2002) Methods of tests for soil determination of free swell index of soils. Bureau of Indian Standards, New Delhi
15. IS 2720 Part III (1987) Methods of tests for soil determination of specific gravity. Bureau of Indian Standards, New Delhi
16. IS 2720 Part V (1985) Methods of tests for soil determination of Atterberg's limits. Bureau of Indian Standards, New Delhi
17. IS 2720 Part VI (1972) Methods of tests for soil determination of shrinkage factors. Bureau of Indian Standards, New Delhi
18. IS 2720 Part VII (1980) Methods of tests for soil determination of water content dry density relation using light compaction. Bureau of Indian Standards, New Delhi
19. Locat J, Berube MA, Choquet M (1990) Laboratory investigations on the lime stabilization of sensitive clays: shear strength development. Can Geotech J 27(3):294–304
20. Sharman AK, Sivapullaiah PV (2016) Ground granulated blast furnace slag amended fly ash as an expansive soil stabilizer. Soils Found 56(2):205–212
21. IS 2720 Part X (1973) Methods of tests for soil determination of unconfined compressive strength. Bureau of Indian Standards, New Delhi
22. Horpibulsukn S, Phetchuay C, Chinkulkijniwat A, Cholaphatsorn A (2013) Strength development in silty clay stabilized with calcium carbide residue and fly ash. Soils Found 53(4):477–486
23. Kate JM (2005) Strength and volume change behavior of expansive soils treated with fly ash. American Society of Civil Engineers geo-frontiers congress—innovations in grouting and soil improvement, 1–15
24. Al-Rawas AA, Taha R, Nelson JD, Al-Shab TB, Al-Siyabi H (2002) A comparative evaluation of various additives used in the stabilization of expansive soils. Geotech Testing J 25(2):199–209

25. Jha K, Sivapullaiah P (2015) Mechanism of improvement in the strength and volume change behavior of lime stabilized soil. Eng Geol 198:53–64
26. Al-Mukhtar M, Khattab S, Alcover J-F (2012) Microstructure and geotechnical properties of lime-treated expansive clayey soil. Eng Geol 139–140:17–27