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ORIGINAL PAPER

Use of Natural Pozzolana and Lime for Stabilization of Cohesive Soils

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Abstract The present study investigates the use of natural pozzolana combined with lime for ground improvement applications. Laboratory tests were undertaken to study the effect of natural pozzolana, lime or a combination of both on the physical and the mechanical characteristics of cohesive soils. Natural pozzolana, lime and natural pozzolana-lime were added to two cohesive soils at ranges of 0–20 and 0–8%, respectively. Consistency, compaction, undrained traxial shear and unconfined compressive strength tests were performed on untreated and treated soil samples to assess the physical and mechanical characteristics of the soil. Treated samples were cured for 1, 7, 28 and 90 days. The results show that the cohesive soils can be successfully stabilized by combining natural pozzolana and lime.

Keywords Lime · Natural pozzolan · Cohesive soil · Stabilization · Compaction · Strength · Curing

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1 Introduction

The reduction of available land resources and the increased cost associated with the use of high quality materials have led to a large need for using local soils in geotechnical construction. Many sites around big cities such as Algiers present poor engineering properties and land for construction projects is scarce. Hence, sites with poor soils have to be used. Poor engineering properties of some of these soils create difficulties during construction and hence the need to stabilize these soils to improve their properties.

More civil engineering structures are also built on soft soils, leading necessarily to the development of various ground improvement techniques such as soil stabilization. Soil stabilization is a technique introduced many years ago with the main purpose to improve the physical and chemical characteristics of soils and render the soils capable of meeting the requirements of specific engineering projects (Kolias et al. 2005). Several additives, such as cement, lime and mineral additives such as fly ash, silica fume, rice husk ash…, have been used for stabilisation of soft soils (Al-Rawas and Goosen 2006).

Lime as an additive is most commonly used to stabilise fine soils due to its effectiveness and economic usage. As an additive, lime improves significantly the engineering properties of soft soils. Lime stabilisation is achieved through cations exchange, flocculation agglomeration, lime carbonation and pozzolanic reaction. Cations exchange and flocculation agglomeration reactions take place rapidly bringing immediate changes in soil properties, whereas pozzolanic reactions are time dependent. These pozzolanic reactions involve interactions between soil silica and/or alumina and lime to form various types of cementation products thus enhancing the strength.

The studies reported in the literature show that the addition of lime increased the optimum moisture content and strength, and reduce the plasticity index and maximum dry density of the soil (Guney et al. 2007).

Several investigators (Al-Rawas et al. 2005; Goswami and Singh 2005; Rahman 1986; Muntohar and Hantoro 2000; Attoh-Okine 1995; Nalbantoglu 2006; Lasledj and Al-Mukhtar 2008; Osula 1996; Ola 1977; Bagherpour and Choobbasti 2003; Kavak and Akyarli 2007; Manasseh and Olufemi 2008; Bell 1996; Okagbue and Yakubu 2000; Ansary et al. 2006) found that in most cases the effect of lime on the plasticity of clay soils is more or less instantaneous.

The works reported by several researchers (Ola 1977; Rahman 1986; George et al. 1992; Bell 1996; Gay and Schad 2000; Hossain et al. 2007) indicate that soils treated with lime experienced notable increases in optimum moisture content while undergoing a decrease in maximum dry density. In addition, some investigators (Lin et al. 2007; Chen and Lin 2009) postulated that failure behaviours similar to brittle materials were observed in shear failure mode for soil specimens stabilized with lime. Moreover, some researchers (Ola 1977; Rahman 1986; Attoh-Okine 1995; Hossain et al. 2007; Manasseh and Olufemi 2008) found that the strength behaviour of soils was greatly improved after lime treatment.

In recent years, industrial by-products have been added and mixed with soft soils to improve their engineering properties. The improved characteristics of soft soils, resulting from the utilization of cementing additives like fly ash, rice husk ash and silica fume, bring about environmental and economic benefits. The effectiveness of these by-products for stabilization of soils has been investigated. The addition of such materials reduced the plasticity index (Parsons and Kneebone 2005; Goswami and Singh 2005; Kolias et al. 2005; Nalbantoglu 2004; Basha et al. 2003; Basha et al. 2005; Rahman 1986; Muntohar and Hantoro 2000). In term of compaction, several researchers (Senol et al. 2006; Kolias et al. 2005; Sezer et al. 2006; Prabakar et al. 2004; Basha et al. 2003; Muntohar and Hantoro 2000; Kalkan 2009; Basha et al. 2005; Rahman 1986) observed that soils treated with cementing additives show an increase in optimum moisture content and a decrease in maximum dry density. Furthermore, the studies (Sezer et al. 2006; Kolias et al. 2005; Senol et al. 2006; Basha et al. 2005) indicate that the strength of soils can be improved by addition of such cementing additives.

On the other hand, cementing additives react with the lime more effectively than alone. The efficiency of lime stabilization may be greatly increased. Some investigators (Goswami and Singh 2005; Muntohar and Hantoro 2000; Bagherpour and Choobbasti 2003) found that workability and strength behaviour of soft soils were greatly improved after a combined treatment.

Hossain et al. (2007) utilized volcanic ash (VA) from natural resources of Papua New Guinea. Several tests of compaction and unconfined compressive strength have been conducted for studying the influence of volcanic ash, finely ground natural lime, cement and a combination of ash, cement and lime. In term of compaction, the results showed that maximum dry density decreased and optimum moisture content increased as VA content increased for both soils tested. The combination of VA, lime and cement exhibited the same behaviour. On the other hand, the compressive strength increased with the increase in curing time and VA content for both soils tested. For example, with a 20% volcanic ash content they observed an increase of 31 and 19 times compared with both tested untreated soils respectively after 91 days of curing. In mixed mode of stabilization, stabilizer combinations (VA, lime and cement) with higher dosages produced higher compressive strength. For example, with the combination of 10%VA + 4%L that both tested soils represented an increase of 10–21 times respectively compared with untreated soils. But, apart from the study of Hossain et al. (2007), the effect of the combination of natural pozzolana (volcanic rock) and lime on soil stabilization is not well documented in the literature.

Natural pozzolana is found abundantly in extensive areas of Beni-Saf quarry in the West of Algeria (Ghrici et al. 2007). The use of natural pozzolana in association with lime for the stabilization of cohesive soils needs to be investigated. As the soil is a good source of alumina, the effects of lime treatment can be enhanced to a great extent if the apparent shortage of silica can be adequately supplemented by the addition of natural pozzolana, which is high in reactive silica content. However, the literature indicates only very few investigations on soils stabilization in Algeria.

This paper presents the results of the effect of lime, natural pozzolana and their combination on Atterberg limits, compaction characteristics, undrained triaxial shear behaviour and unconfined compressive strength of two Algerian cohesive soils classified as CH and CL according to the unified soil classification system (USCS).

2 Experimental Investigation

2.1 Materials Used

2.1.1 Soils

The soils used in this study were obtained from a site situated near Chlef town West of Algeria. These clays were encountered at a depth of about 4–5 m. Laboratory tests were carried out to classify each type of soil. The engineering properties of clayey soils are presented in Table 1.

2.1.2 Natural Pozzolana

The natural pozzolana (NP) used in this investigation was collected from a quarry at Beni-Saf region in the West of Algeria. The NP was ground in a laboratory mill to a specific surface area of 420 m^2/kg. The chemical composition of NP is presented in Table 2.

2.1.3 Lime

The lime (L) used was a commercially available lime typically used for construction purposes. The chemical and physical properties of lime are presented in Table 3.

2.2 Laboratory Tests

A series of laboratory tests consisting of Atterberg limits, compaction, shear strength and unconfined compressive strength were conducted on the two selected clayey soils. Extensive combinations of natural pozzolana and lime were used for stabilization of the two soils. The percentages of NP were 0, 10, and 20%, while the percentages of the lime were 0, 4, and 8%. A total of 18 combinations based on soil 1 and soil 2 with single and mixed modes of stabilizers were studied (Table 4).

2.2.1 Atterberg Limits Tests

Plastic (PL), liquid (LL) limit and plasticity index (PI) were obtained following the method given in the ASTM D4318 (2000). Variations in the plasticity index of untreated clayey soils before and after admixtures added were then studied. The air dried soils (passing the N° 40 sieve) were initially mixed

Table 1 Physical characteristics of the soils

Basic characteristics	Soil 1	Soil 2
Color	Grey	Red
Depth (m)	4	5
Natural water content (%)	32.87	13.77
Specific gravity	2.71	2.84
Passing 80 μm sieve (%)	85.0	97.5
Liquid limit (%)	84.8	47.79
Plastic limit (%)	32.78	23.23
Plasticity index (%)	52.02	24.56
Classification (USCS)	CH	CL
Optimum water content (%)	28.3	15.3
Maximum dry density (kN/m^3)	13.8	16.9
Unconfined compressive strength (kPa)	55.6	222.5

Table 2 Chemical composition of natural pozzolana

Chemical composition	Natural pozzolana (%)
SiO_2	46.4
Al_2O_3	17.5
Fe_2O_3	9.69
CaO	9.90
MgO	2.42
CaO free	–
SO_3	0.83
Na_2O	3.30
K_2O	1.51
TiO_2	2.10
P_2O_3	0.80
Loss of ignition	5.34

Table 3 Physical and chemical properties of lime

Chemical name	Lime
Physical appearance	Dry white powder
CaO	>83.3
MgO	<0.5
Fe_2O_3	<2
Al_2O_3	<1.5
SiO_2	<2.5
SO_3	<0.5
Na_2O	0.4–0.5
CO_2	<5
$CaCO_3$	<10
Specific gravity	2
Over 90 μm (%)	<10
Over 630 μm (%)	0
Insoluble material (%)	<1
Bulk density (g/l)	600–900

Table 4 Stabilizer combination scheme for stabilized soils

Designation	Sample mixture (%)		
	Soil	NP	L
P0L0	100	0	0
P0L4	96	0	4
P0L8	92	0	8
P10L0	90	10	0
P10L4	86	10	4
P10L8	82	10	8
P20L0	80	20	0
P20L4	76	20	4
P20L8	72	20	8

with the predetermined quantity of natural pozzolana, lime or a combination of both in a dry state. Distilled water was added to the soil mixture. To let the water permeate through the soil mixture, the paste was allowed to stand in an airtight container for about 24 h prior to testing. After this tempering, the paste was remixed with each stabilizer thoroughly for at least 15 min before performing the first test. The plastic limit tests were performed on material prepared for the liquid limit test. The plastic limit was determined as the average of the two water contents and rounded to the nearest whole number. Both liquid and plastic limit tests were conducted at room temperature.

2.2.2 Compaction Tests

The method given in the ASTM D698 (2000) was applied to determine the maximum dry density (MDD) and the optimum moisture content (OMC) of the soils. The soil mixtures, with and without additives, were thoroughly mixed for 1 h prior to compaction. The first series of compaction tests were aimed at determining the compaction properties of the non treated soils. Secondly, tests were carried out to determine the proctor compaction properties of the treated soils with varying amounts of natural pozzolana and lime.

2.2.3 Shear Strength Tests

Triaxial compression tests according to ASTM D2850 (2003) were conducted on treated and untreated samples compacted at maximum dry density and optimum moisture content. In order to avoid excessive moisture loss, the specimens were wrapped up with a plastic film after removing from moulds. They were kept in the laboratory at a temperature of 25°C and a relative humidity of 50%. The unsaturated, unconsolidated undrained (UU) tests performed in the triaxial compression tests were conducted with confining pressure of 25 and 50 kPa.

2.2.4 Unconfined Compressive Strength Tests

Unconfined compressive strength tests on compacted specimens were conducted according to the ASTM D2166 (2000). Specimens were cured in plastic bag to prevent moisture change. Tests were performed at different curing ages (1, 7, 28 and 90 days). For each type of mixtures, the unconfined compressive strength value was obtained as the average of two unconfined compressive strength tests.

3 Results and Discussion

Table 5 presents the results of physical and mechanical properties of all stabilized soil mixtures with various stabilizer combinations.

3.1 Atterberg Limits

The plasticity index (PI) variation for both untreated and treated soils are presented in Fig. 1. The decrease

Table 5 Summary of physical and mechanical properties of stabilized soil mixtures

Specimen	Atterberg's limits		Compaction				Unconfined compressive strength (MPa)							
	Grey soil	Red soil	Grey soil		Red soil		Grey soil (days)				Red soil (days)			
	PI (%)	PI (%)	OMC (%)	MDD (kN/m^3)	OMC (%)	MDD (kN/m^3)	1	7	28	90	1	7	28	90
P0L0	52.02	24.56	28.3	13.8	15.3	16.9	0.06	0.06	0.06	0.09	0.22	0.22	0.22	0.28
P0L4	21.47	22.63	30.4	13.2	17.8	16.4	0.27	0.57	1.03	1.95	0.33	0.48	0.69	2.11
P0L8	19.92	19.68	31.1	12.9	17.4	16.2	0.28	0.52	1.05	3.04	0.40	0.46	0.72	1.80
P10L0	52.99	17.41	27.6	14.0	14.3	17.1	0.05	0.07	0.08	0.13	0.25	0.25	0.27	0.37
P10L4	19.76	17.76	26.8	13.3	16.6	16.5	0.43	1.00	1.88	3.18	0.66	1.16	2.05	3.90
P10L8	19.25	20.64	29.8	13.3	17.7	16.1	0.35	0.88	1.74	4.69	0.66	1.10	2.00	4.75
P20L0	46.03	17.39	25.8	14.3	13.8	17.1	0.07	0.10	0.10	0.19	0.25	0.26	0.28	0.48
P20L4	20.15	18.03	29.0	13.6	18.7	16.4	0.41	1.11	1.66	2.45	0.87	1.63	2.89	4.70
P20L8	20.23	20.31	28.2	13.6	18.2	16.0	0.46	1.42	2.62	5.38	0.83	1.68	2.78	5.97

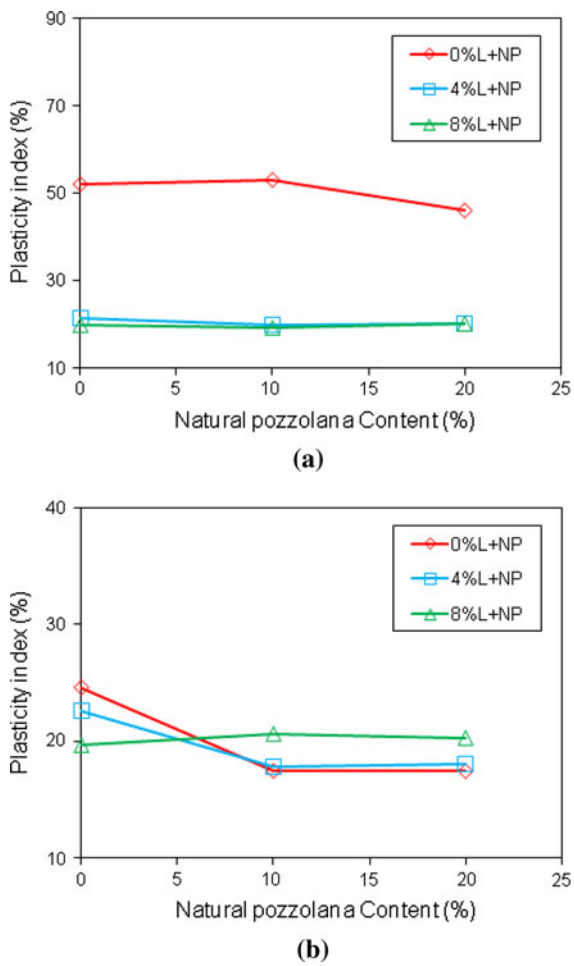

Fig. 1 Effect of stabilizers on plasticity index. **a** Grey soil. **b** Red soil

in plasticity index indicates an improvement in the workability of the soil. The grey soil showed an immediate decrease in plasticity index upon the addition of lime. It is obvious that an addition of 4% of lime was sufficient to enhance the workability of the soil by reducing the plasticity index from 52 to 21.5%. Increasing the lime content beyond 4% had a marginal effect on reducing the plasticity index. For the same class soil, Nalbantoglu (2006) observed that the plasticity index decreased from 45.6 to 13.5% for the addition of 7% lime.

For the red soil, the plasticity index decreased from 24.6 to 22.6% for an addition of 4% of lime. Beyond this value, the plasticity index decreased again from 24.6 to 19.7%, for 8% of lime addition. For the same class soil, Okagbue and Yakubu (2000) observed that the plasticity index decreased from 19.9 to 14.4% for 10% limestone addition. Similar behaviour was found by several researchers (Attoh-Okine 1995; Bagherpour and Choobbasti 2003; Ansary et al. 2006).

The addition of natural pozolana alone to both grey and red soils enhances their workability as a result of a reduction on the plasticity of these soils. A reduction of the plasticity index respectively from 52 to 46% and from 24.6 to 18% for the grey and the red soil is observed. A similar trend was observed by Parsons and Kneebone (2005) and Rahman (1986) when they used fly ash and rice husk ash respectively.

The combination of natural pozzolana and lime exhibited a marginal effect on reducing the plasticity index compared to the use of the lime alone for the grey soil. For red soil, the combination of 4%L + NP shows a similar decrease in plasticity index as that of natural pozzolana alone. However, with high lime contents in the combination, the plasticity index increases compared to natural pozzolana alone.

The consistency limits test results were plotted on the Casagrande plasticity chart in order to determine the soil classification according to the unified soil classification system (USCS) (Fig. 2). It is clearly seen from Fig. 2 that for the grey soil classified as CH class clay, falls in the class of MH soil after addition of a proportion of lime/or lime and natural pozzolana except for the natural pozzolana alone.

Similar trend was observed for the red soil classified as CL class, as it passes from CL class clay to MH class soil after stabilization with addition of either lime alone or lime combined with natural pozzolana. The addition of natural pozzolana alone results in a soil classified within the range falling between a CL class and an ML class.

The modification of the plasticity characteristics of the grey and red soils caused by the addition of natural pozzolana and lime is likely to render these soils satisfactory for most construction operations even under severe environmental conditions such as rain.

3.2 Compaction Characteristics

The compaction test was used to determine the effect of stabilizers on maximum dry density (MDD) and optimum moisture content (OMC). Fig. 3 shows the effect of the addition of natural pozzolana (NP), lime

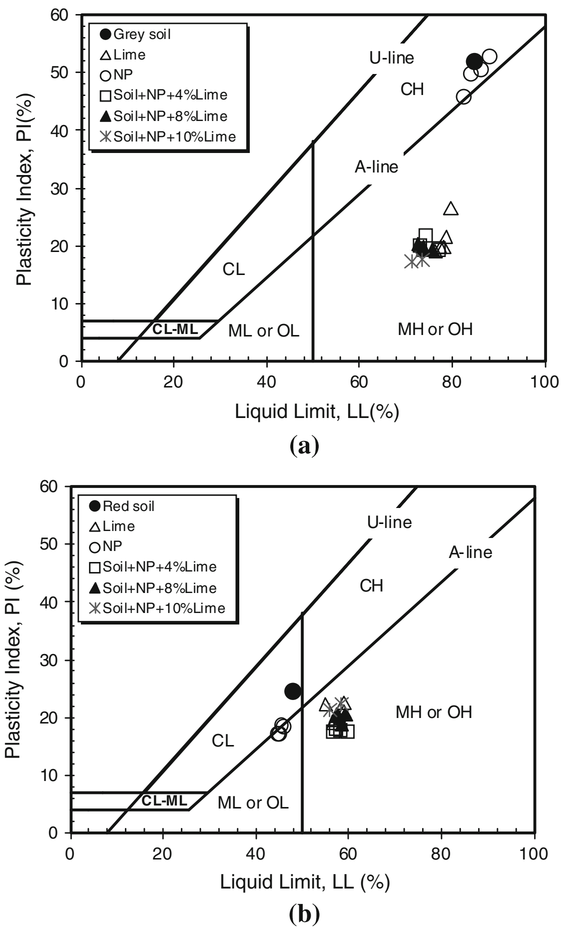

Fig. 2 Location of untreated and treated cohesive soils in a plasticity chart. a Grey soil. b Red soil

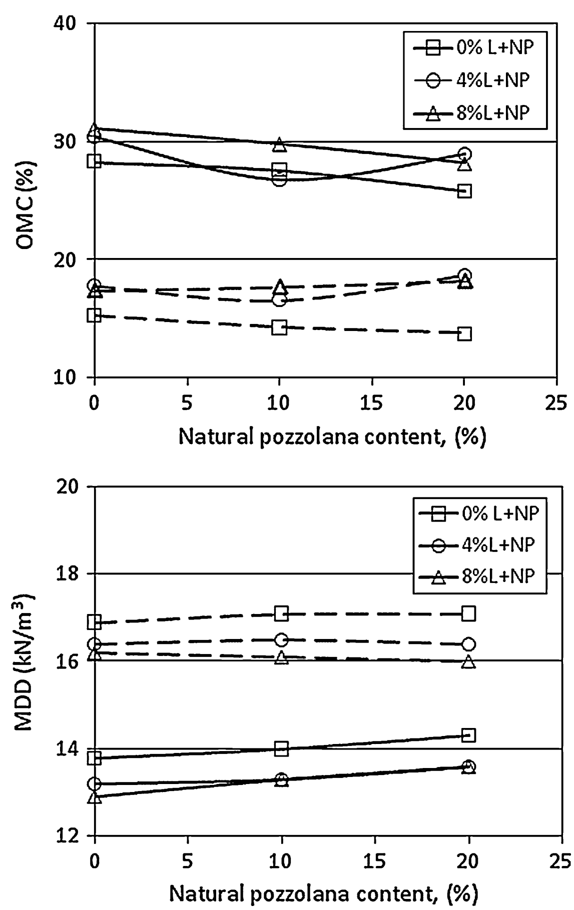

Fig. 3 Variation of compaction characteristics of stabilized soils: *Full line* grey soil and *dashed line* red soil

(L) and their combinations on the compaction characteristics of the grey and red soils tested.

It can be clearly seen that adding lime increases the OMC and decreases the amount of the MDD with increasing lime content. Similar behaviour was also observed in the literature in the case of lime stabilized clayey soils (Ola 1977; Rahman 1986; George et al. 1992; Bell 1996; Gay and Schad 2000; Hossain et al. 2007; Kavak and Akyarli 2007; Manasseh and Olufemi 2008). The explanation of this behaviour is probably a consequence of the following reasons: (1) the lime causes aggregation of the particles to occupy larger spaces and hence alters the effective grading of the soils, (2) the specific gravity of lime generally is lower than the specific gravity of soils tested, (3) the pozzolanic reaction between the clay present in the soils and the lime is responsible for the increase in OMC.

Variations in OMC and MDD with increasing natural pozzolana contents for grey and red soils are also presented in Fig. 3. The OMC decreases and the MDD increases as natural pozzolana content increases from 0 to 20%. The increase in dry density is an indicator of soil properties improvement. A similar trend has been observed by Hossain et al. (2007) using volcanic ash from natural resources when varying the proportion from 0 to 20%.

The decrease in OMC observed in this study, apparently results from the lower affinity of natural pozzolana for water. In addition, the increase in MDD is attributed to the relatively higher specific gravity of the natural pozzolana. The addition of a combination of natural pozzolana and lime to the grey soil decreases the OMC and increases the MDD. However, for the red soil, the combination of natural pozzolana and lime increases the OMC and reduces the MDD particularly at 20%NP content. Several researchers (Ola 1977; Rahman 1986; Basha et al. 2005) revealed that the change in dry density occurs because of both particles size and specific gravity of the soil and the stabilizer used.

3.3 Shear Strength

The effects of natural pozzolana, lime and their combinations on the stress–strain relationships of the grey and red soils at the confining pressure of 25 and 50 kPa are shown in Figs. 4 and 5 respectively.

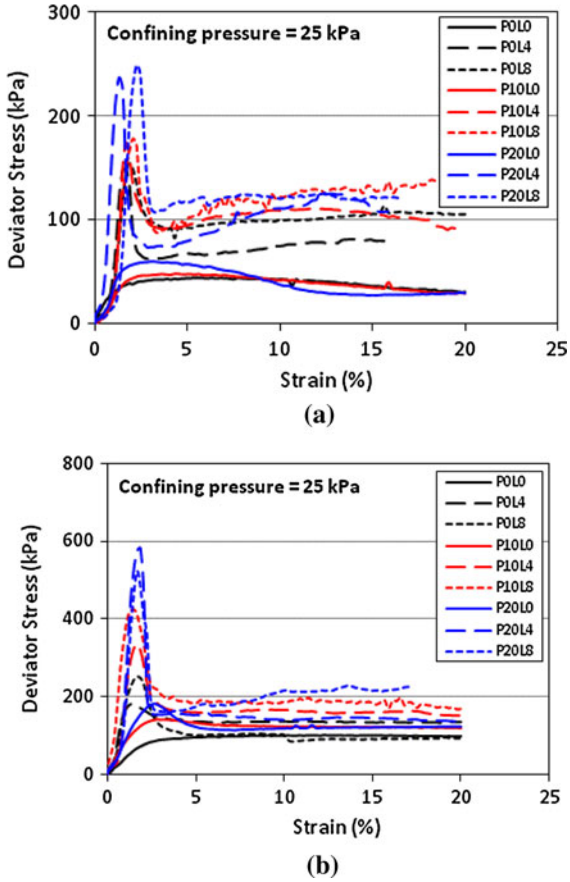

Fig. 4 Stress-Strain relationships of UUU tests for the untreated soil specimens with different proportions of stabilizers when effective confining pressure was designed at 25 kPa. **a** Grey soil. **b** Red soil

As shown in Fig. 4, when stress reaches its maximum for untreated grey and red soils, the strain is about 9 and 12%, respectively. However, peak shear stresses and failure behaviours similar to brittle materials were observed in the shear failure mode for specimens of both soils stabilized with lime or with combinations of natural pozzolana-lime. Similar failure mode was observed by other researchers (Lin et al. 2007; Chen and Lin 2009). Moreover, the curves shapes for specimens stabilised with natural pozzolana alone are nearly similar to those of untreated samples for both soils. In addition, a marginal effect on shear stresses was observed for the soil specimens stabilized with natural pozzolana. The maximum shear stress is given by samples stabilized with a combination of both natural pozzolana and lime.

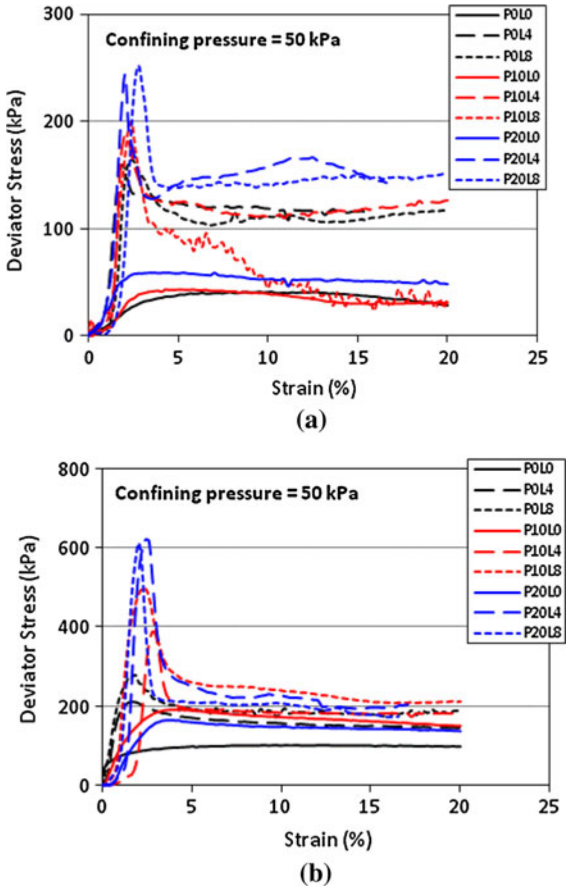

Fig. 5 Stress-Strain relationships of UUU tests for the untreated soil specimens with different proportions of stabilizers when effective confining pressure was designed at 50 kPa. **a** Grey soil. **b** Red soil

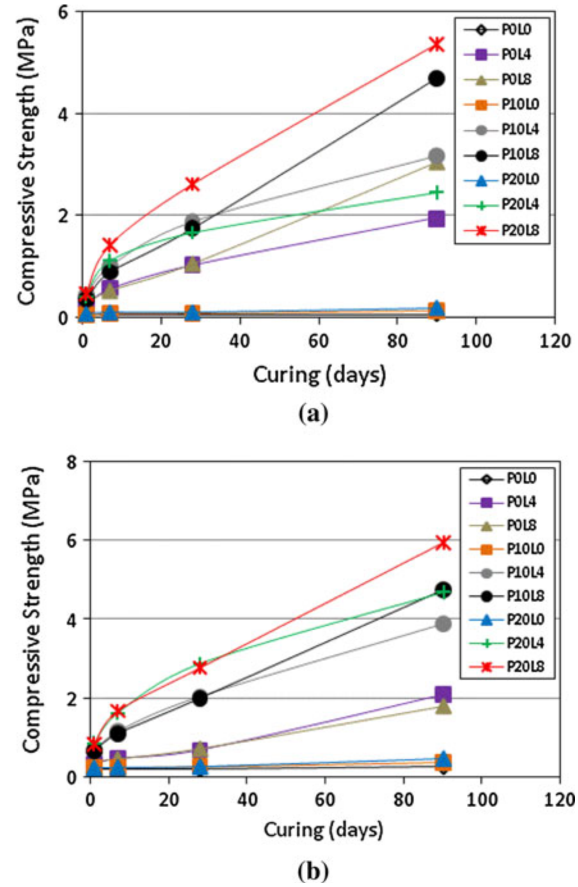

Fig. 6 Influence of stabilizers on unconfined compressive strength. **a** Grey soil. **b** Red soil

Similar stress–strain relationships at the confining pressure of 50 kPa are illustrated in Fig. 5. The maximum shear stress is given by both samples of soils stabilized with lime alone and combined with natural pozzolana. Moreover, red soil specimens exhibited a significant increase in shear stress compared to grey soil specimens. Maximum shear strengths are observed for clayey soils stabilized with a combination of natural pozzolana-lime compared to those stabilized with lime or natural pozzolana alone.

3.4 Unconfined Compressive Strength

The trend of changes in unconfined compressive strength (UCS) with various percentages of stabilizers for grey and red soils is presented in Fig. 6.

It can be seen from Fig. 6 that the addition of lime increases the compressive strength of stabilized soil specimens. The compressive strength increases with the increase in lime content from 0 to 8% for both grey and red soils. This increase is in agreement with earlier findings (Ola 1977; Rahman 1986; Attoh-Okine 1995; Hossain et al. 2007; Lin et al. 2007; Manasseh and Olufemi 2008). This is attributed to soil lime reaction, which results in the formation of cementitious compounds that binds soil particles together. In general, compressive strength increases with increasing curing age. The grey soil gave higher compressive strength than red soil. For example, with 8% lime content, grey soil developed an unconfined compressive strength of 3 MPa after 90 days of curing which represented an increase of 33 times compared to untreated soil. For red soil and for the same lime content and curing, the soil developed an unconfined compressive strength of 1.8 MPa which represented an increase of 6.3 times compared to untreated soil.

In contrast, the addition of natural pozzolana slightly increases the strength for both grey and red soils. For example, with a 20% NP content both grey and red soils show a marginal increase of 2 times compared with the untreated soil after 90 days of curing. However, Hossain et al. (2007) observed, after 91 days of curing of two untreated soils (S1 and S2), an increase of 31 and 19 times, respectively when 20% volcanic ash was used.

Stabilizer combinations with higher contents produced higher compressive strength. It can be seen that at 90 days and with a combination of 10%NP + 4%L for grey and red soils represented an increase of 34 and 14 times respectively compared with both untreated soils. Hossain et al. (2007) observed that the combination of 10%VA + 4%L for both S1 and S2 soils represented an increase of 21 and 10 times respectively compared with both untreated soils. Also, it can be noted that at 90 days, the combination NP + 8%L produced higher compressive strength for both grey and red soils. For example, with the combination of 20%NP + 8%L, grey soil developed an unconfined compressive strength of 5.4 MPa after 90 days of curing which represented an increase of 1.8 times compared with 8% lime alone and 58 times compared with untreated soil. For red soil and the same combination and curing age, the soil developed an unconfined compressive strength of 6 MPa which represented an increase of 3.3 times compared with 8% lime alone and 21 times compared with untreated soil.

Finally, for both soils, compressive strength increases with increasing curing time and stabilizers content. The natural pozzolana- lime combinations produced higher strength than stabilization with lime alone or natural pozzolana alone. Therefore, natural pozzolana cannot be used solely for soil stabilization. However, lime stabilized soils can be intensified by adding between 10 and 20% of natural pozzolana. The better performance of natural pozzolana-lime combination stabilized soil can be attributed to the pozzolanic properties of the mixture and to the utilization of readily available silica and alumina from natural pozzolana by the calcium from the lime to form cementitious compounds which binds the soil particles together. Since lime is more costly than natural pozzolana, the use of a combination of both lime and natural pozzolana will result in lower construction cost. For example, if stabilisation with 4% of cement for a high moisture content soil is replaced with a mixture of lime (4%) and natural pozzolana (20%), and assuming an average price for one ton of Portland cement, lime and natural pozzolana of 80 €, 50 € and 5€ respectively, the cost reduction on materials could be about 20%.

4 Conclusions

This study presents the effect of natural pozzolana, lime and their combinations on Atterberg limits, compaction, shear strength and unconfined compressive strength of cohesive soils. On the basis of the test results, the following conclusions can be drawn:

- The plasticity index decreased with increasing lime contents. Moreover, when both natural pozzolana and lime were added to the cohesive soils, an appreciable change of the plasticity behaviour was observed. However, the addition of natural pozzolana has a minor effect on the plasticity index of the grey soil. Both grey and red soils tend to change according to the unified soil classification system. The use of lime alone and the combination of natural pozzolana-lime, transformed grey soil (CH) and red soil (CL) into MH class soils.
- The maximum dry density of lime stabilized soils decrease with increasing lime content, in contrast with natural pozzolana stabilized soils. The combination lime-natural pozzolana increases the maximum dry density for grey soil and decreases that of red soil. On the other hand, the optimum moisture content of lime stabilized soils increased with the increase in lime content, in contrast with natural pozzolana stabilized soils. The combination lime-natural pozzolana decreased the optimum moisture content for the grey soil and increased that of the red soil.
- The failure modes were similar to that of brittle materials for both soils stabilized with lime or with a combination of natural pozzolana-lime. Furthermore, maximum shear strengths were observed for samples stabilized with a combination of natural pozzolana-lime compared to those stabilized with lime or natural pozzolana alone.

- The addition of lime improved the unconfined compressive strength. The improvement is more significant with increasing curing time. The combination natural pozzolana-lime can substantially improve the unconfined compressive strength.
- Combining two local materials (natural pozzolana and lime) can effectively improve the properties of cohesive soils and help in increasing land availability for construction projects.
- For future research it is recommended to test the influence of the addition of lime and natural pozzolana in cohesive soils, making more combinations on the quantities of the additives.

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