


Stabilization of Gypsum Clay Soil by Adding Lime

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Abstract

Often, the temperature and water variation exist in semi-arid areas of a clayey soil leads to vertical and horizontal settlements, cracks in the soil and in general disorder to the building installed on this soil. The objective of this work is to stabilize the local gypsum clay soil, which poses problems at the level of self-construction built on it. Chemical soil stabilization can improve soil properties. In fact, adding natural lime to these clays can provide an ideal solution for stabilizing them through interesting modifications to their geotechnical properties throw the experimental tests on both unstabilized and stabilized soil samples by adding lime in quantities of 2, 4, and 6%, in percentages by the soil's weight, prepared at room temperature, The unconfined compressive strength (UCS) at different curing ages is measured, The results obtained provide a significant increase in compressive strength and modulus of Elasticity which allow better qualities and improve strength parameters throughout any phase of earthwork construction design that leads to strengthening subgrades, reducing the thickness, and, as a result, low construction costs. The results of the study show that (1) for the best utilization effect, the optimum percentage of lime is 6%; (2) the UCS is 3.23 times of the pure soil after curing of 28 days under the optimum percentage of lime; (3) the curing age has a significant effect on strength; (4) the main reason for the strength increase of the modified soil is that the crystal produced by the pozzolanic activity fills the pores of the soil. The ideal percentage is 6% lime treatment with a resistance of 2.3 MPa and 135.60 MPa the value of elasticity modulus at 28 days.

Keywords: Gypsum Clay; Stabilization; Lime; Compression; Strength; Modulus of Elasticity.

1. Introduction

Dispersed soils are materials whose physical and mechanical properties change over time. Therefore, we can also name the soft soils (silt, clay, and marl) that can create stresses under buildings, causing settlement, swelling, and slippage during their lives [1]. Thanks to innovative technologies, it is now possible to build on all types of soils. Soil stabilization by incorporating mineral additives is a well-known technique in recent years, and extensive studies have been conducted on the impairment of soil stability using various additives, such as lime and cement [2, 3].

In practice, many stabilization processes are available; we are interested in the most widespread stabilization by the addition of lime [4]. This stabilization is a common applied method among the others due its effective and economic usage. Lime, as an additive, brings several beneficial changes to the engineering properties of soil. The stabilization by lime is achieved through cation exchange, flocculation agglomeration, lime carbonation, and pozzolanic reactions. Cation exchange and flocculation agglomeration reactions take place rapidly and bring 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. This use explains that these techniques offer the maximum benefit, especially in terms of cost price, significant reduction in transportation costs and the facility of execution and also the costs of the projects realization and of course infects the environment to ensure optimum.

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These additions are made to clay soils to improve their geotechnical properties (physical and mechanical), and this process is interesting for reducing soil plasticity and increasing its resistance [5-7]. Several studies reported in the literature showed that the addition of lime increased the optimum moisture content and strength and reduced the plasticity index and maximum dry density of clay soils [5, 8-12]. This gave efficiency and durability to the structures. What is proven by the results obtained by Bahar et al. (2004) and Ouhadi et al. (2014) indicate that the short- and long-term unconfined compressive strength of soft clay increases with increasing lime content and treatment period [13-16].

Due to the instability of the soil in the region in the presence of disturbing elements (gypsum) which negatively affect the solidity, durability of the facilities and even the additional cost of their construction; we want through this study recommend the possibility of making the ground object of study stable by the chemical way (the addition of lime and cement). The carried out study aims at determining the mechanical parameters of this local gypsum clay soil treated with a lime addition with different percentages 2%, 4% and 6%. These treated samples are stored at room temperature. In order to help us choose the optimal dose from the point of view of mechanical resistance. The influence of lime addition treatment on its mechanical properties is then analyzed.

2. Description of the Soils Studied

The soil subject of this study is clay samples from a popular area called "*Lahdab*". The latter is located on the territory of the city of Bechar, located in the southwest of Algeria. The site is bounded on the north by the First Barga, on the south by Tigheleine Valley, on the east by the brick factory, and on the west by the crossroads (Figure 1). Their meteorology is characterized by weak precipitations and important temperature variations between winter and summer (cold and wet winters von hot and dry summers). Their geology comprises clayey formations characterized by a high variation of volume when the conditions of their equilibrium are modified (natural climatic phenomena due to prolonged dryness, intense human activity by modification of the ground water level because of excessive pumping, configuration of constructions in their environment). At dry state, the expansive soils are very difficult to compact since their consistency varies from hard to very hard. At wet state, they are very sticking. However, their employment can possibly be decided based on specific treatment with lime and/or hydraulic binders.

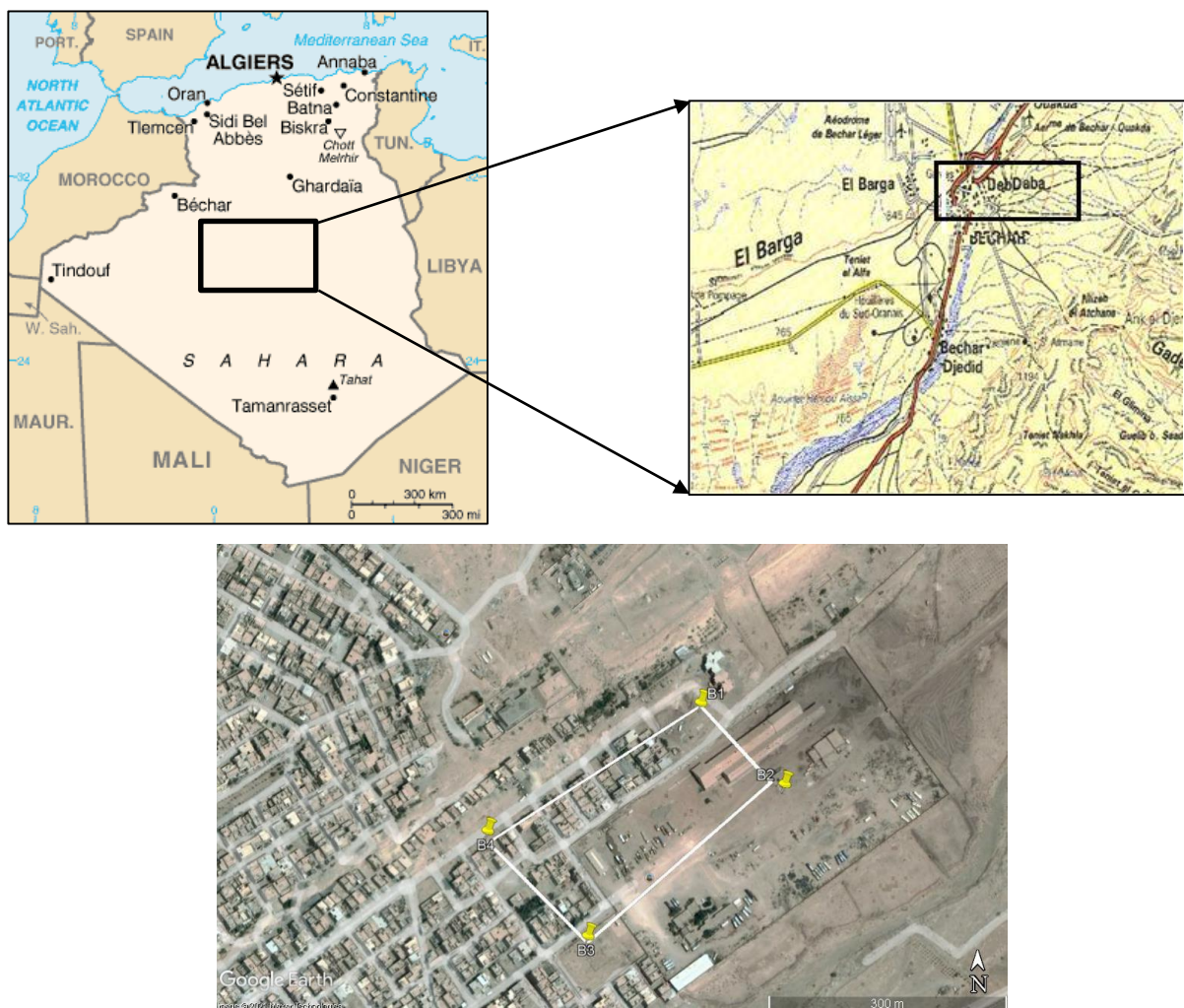


Figure 1. Location of study site

It is noted on this site, that many of the self-construction will be exposed to the slight to high cracks observed on the facades and inside the structures (Figure 2).



Figure 2. Interior and exterior building wall degradation illustration

2.1. Soil Identifications

It is essential to carry out the physicochemical and mechanical identification of the soil in order to identify the problems encountered at the level of the structures. Table 1 summarizes the results of all soil experiments.

Table 1. Results of the physicochemical properties of the soil studied

Parameters	Symbols	Soil
Depth	(m)	2
Dry density	ρ_d (kN/m ³)	1.86
The optimum water content	W _{opm} (%)	8
Percentage of passing % < 80 μ	% < 80 μ	70%
Percentage of passing % < 2 μ	% < 2 μ	64%
Liquidity limit	w _l (%)	58.50%.
Plastic limit	w _p (%)	29%
Plasticity index	I _p (%)	29.5%
The activity	A _c	0.46
The value of blue V _b	V _b (cm ³)	2.67
Total specific surface	S.S.T (m ² /g)	56
Silicate	SiO ₂	54.02
Alumina	Al ₂ O ₃	15.59
Ferrite	Fe ₂ O ₃	5.40
Calcium carbonate	CaCO ₃	13.89
Magnesia	MgO	1.86
Sulphate	SO ₃	0.15
Chloride	Cl ⁻	0.028
Potassium oxide	K ₂ O	2.31
Sodium oxide	Na ₂ O	0.05

Physical and chemical identification tests show that the soil is inorganic fatty clay of high plasticity with little calcium carbonate.

2.2. Lime

The quicklime used is and manufactured by the SAIDA factory, the chemical composition of the product is mentioned in Table 2.

Table 2. Results of the chemical composition of Quicklime

Basic Characteristic	Lime technical sheet
Physical appearance	Dry white powder
Humidity	>5
Fe ₂ O ₃	< 2
Al ₂ O ₃	< 1.5
MgO	< 0.5
SiO ₂	< 2.5
SO ₃	< 0.5
Na ₂ O + K ₂ O	< 2.5
SiO ₂	< 0.47 to 0.5
CO ₂	< 5
CaCO ₃	< 10
Insoluble in HCl	< 1
Density	600 to 900 g/l
Specific weight	20 gr/cm ³

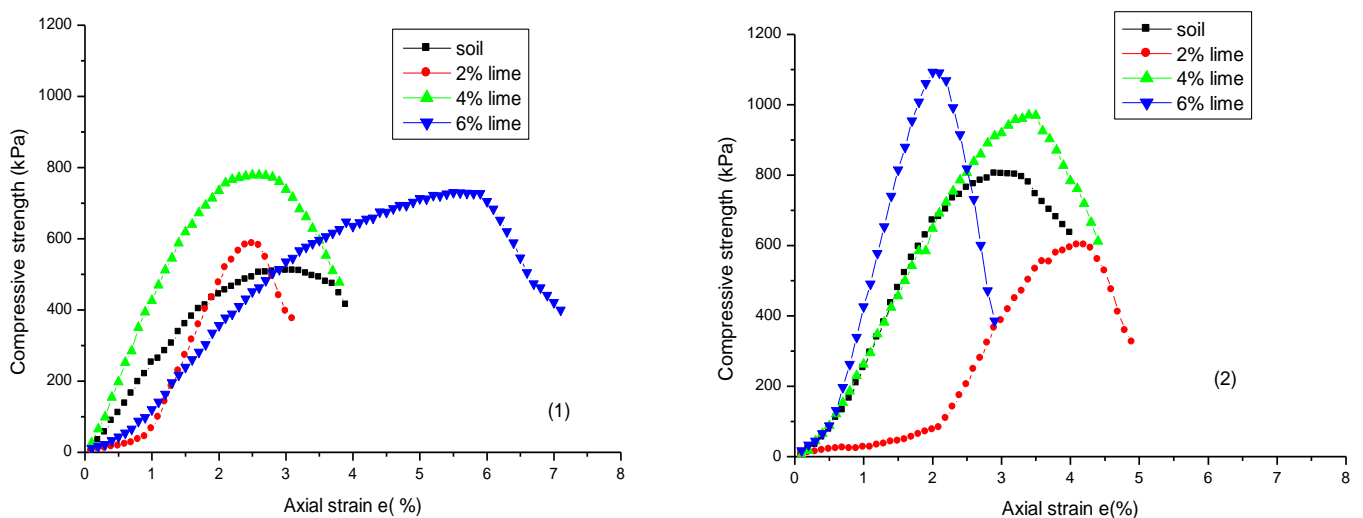
3. Experimental Procedures

The treatment procedure includes the drying of samples at 60°C in the oven for 24 hours, homogenization, the addition of lime in steps of 2% (2, 4, and 6%) and compaction according to the normal Proctor test [17].

3.1. Unconfined Compressive Strength Test (UCS Test)

The unconfined compressive strength is a critical evaluation index of the curing / stabilization technology treatment effect [18].

Unconfined compression strength (UCS Test) data of the soil samples was determined in OMC-MDD condition following the standards of ASTM D2166-00 [19]. The blended soil samples were prepared by using cylindrical moulds having dimensions of 5 × 10 cm. Compaction of the soil was carried out in three equalized layers at the optimum water content and at the maximum dry density deduced from the normal Proctor test [17]. After remolding, the specimens are stored in plastic bags for 24 hours to prevent the specimens from drying out and kept at 20°C. The specimens were tested for UCS. During the testing procedure, the specimens were charged with a rating of 1 mm/min till collapsed. In addition, the samples are made for different periods (1, 2.7, 14, and 28 days). Compressive strength values are illustrated in Figure 3.



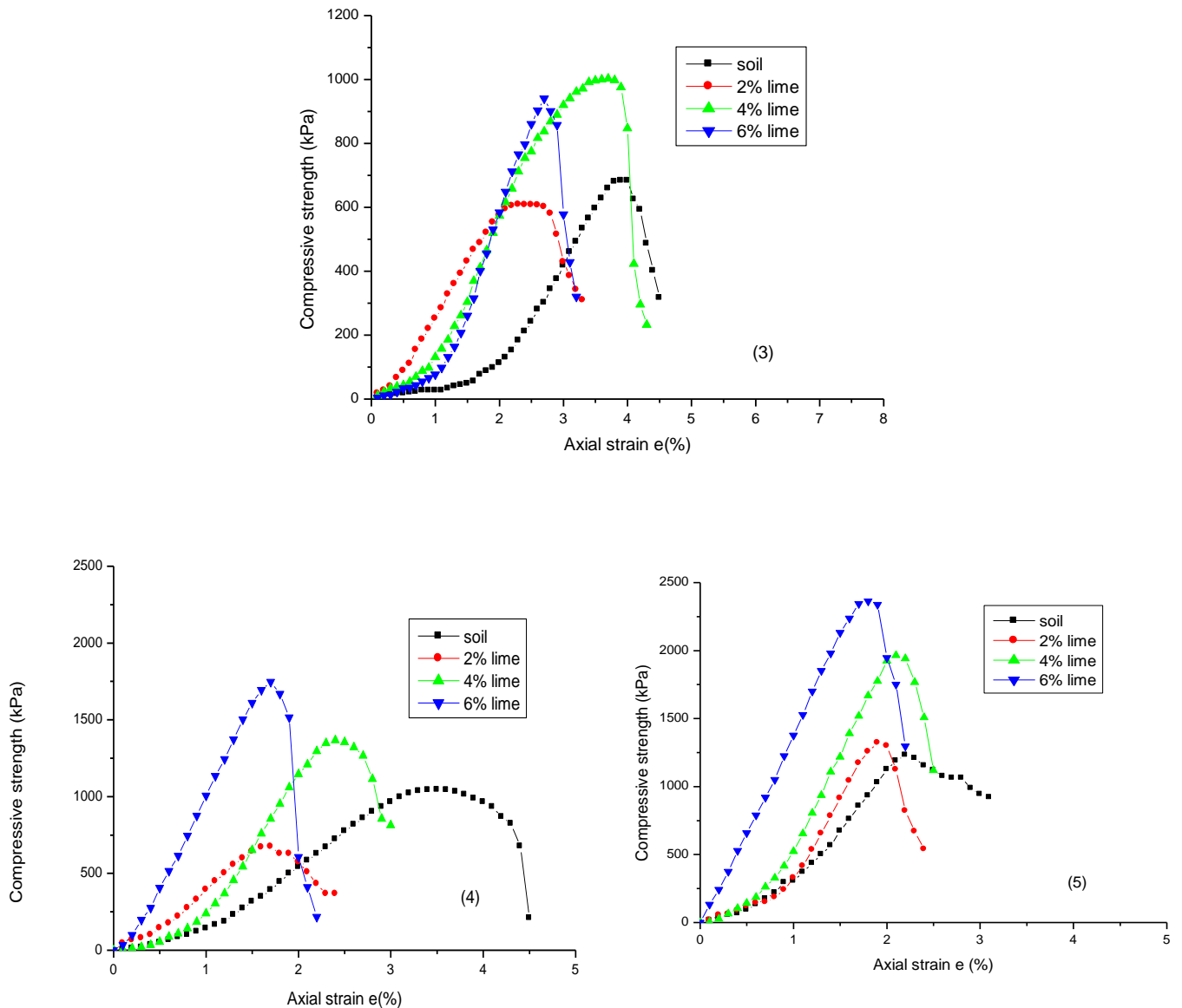


Figure 3. Correlation of compressive strength versus strain for soil blended with lime at various fractions and different curing periods: (1) 1 day, (2) 2 days, (3) 7 days, (4) 14 days, (5) 28 days

4. Results and Discussions

4.1. UCS of Soil under the Influence of Lime (2%, 4% and 6%)

According to the geotechnical test method standard, the maximum axial stress is taken as the unconfined compressive strength without side limitation. If the maximum axial stress is not apparent, the corresponding stress of the axial strain of 15% is taken as the unconfined compressive strength. The unconfined compression strength selected the lime dosage of 0, 2, 4, and 6% and explored the unconfined compression strength of the same-dosage curing agent at the curing age of 1, 2, 7, 14, and 28 days. The unconfined compression strength of different curing ages obtained by the test is shown in Figure 3.

The strength-strain relationship of various mixes is depicted in Figures 3, it is noticed that the peak strength of the soil blended with lime was increased first and then decreases while increasing the content of lime and curing age and ultimately, the ductility of the soil is enhanced. As can be seen, the UCS increased and reached its maximum resistance with the addition of lime of up to 6% and the curing age is 28 days. The unconfined compressive strength obtained increases proportionally with the lime dosage and the curing period, namely that the treated soil samples develop improved resistance values compared to that of the untreated soil (Figure 4) [10, 20, 21]. This increase is in agreement with the earlier findings [22-24] found that the strength behavior of soils was greatly improved after lime treatment.

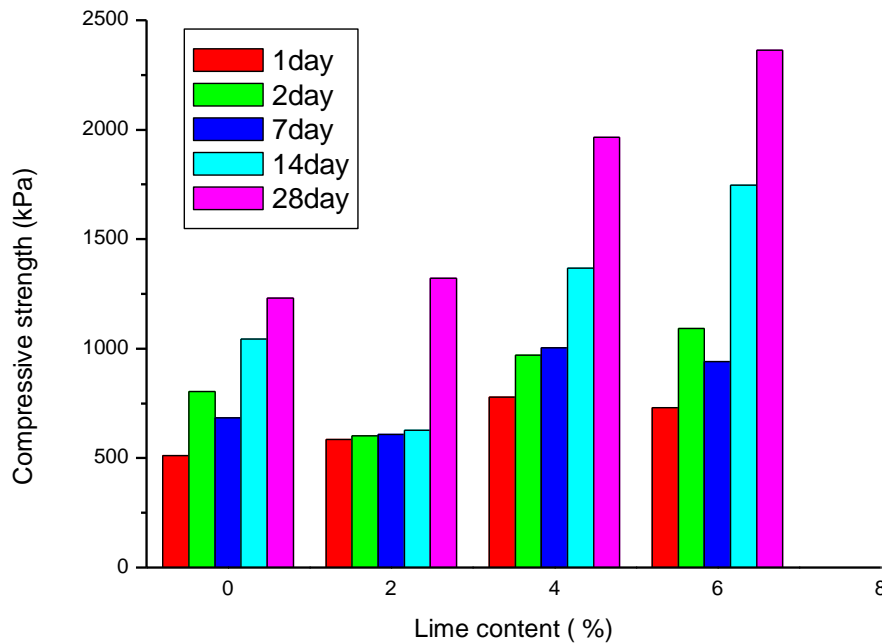


Figure 4. Results of compressive strength development with increasing cure time

The validation of the research results is the subject of a comparison with those mentioned by other predecessors, the compressive strength found is in almost typical relationships depending on the type of soil treated [25-27]. The resistance used in the laboratory for scales is that at 28 days R_{c28} [28]. According to Bruce [26], it ranges between 0.2 MPa and 2 MPa for cohesive soils and between 0.5 and 5 MPa for granular soils (depending on the dose used). Values reported by Topolnicki [27] 0.5 to 2.5 MPa in clay are comparable to these. Resistance up to 28 days at 6% lime, we obtained 2.36 MPa which is included in this range.

The increased development of the resistance of the stabilized soil observed in particular the first 7 days of curing (exchange of cations and flocculation/agglomeration) which make the soil more granular and friable [29, 30], then it increases at a constant rate more or less for about 4 weeks. This supports the idea that cementing products due to the pozzolanic reaction between lime and clay soil particles are formed once the flocculation process is completed [31].

For the 4% and 6% percentages of lime, the increase in the compressive strength is attributed to the reaction of the lime with the particles of the clay soil, which results in the formation of cementing agents (CSH and CAH) thus binding the soil particles together [2]. However, at 2% lime has a harmful effect on the resistance, a decrease in the resistance compared to the untreated soil for the duration of maturation 1, 2, 7, and 14 days seems that this percentage is insufficient to react the cementing agents. According to Holtz (1969) the addition of 3% to 5% lime per dry weight of soil is recommended to achieve considerable changes [32].

The soil treated with 6% lime develops a compressive strength of around 2.3 MPa, attesting to a double increase at 28 days compared to that of the untreated soil. The treatment of soils by adding hydraulic binder results in a material whose strength and rigidity increases but whose deformation at break decreases compared to virgin soil [33]. The observation is that the deformability is inversely proportional to time i.e. 5.5% to 1.8% at 1 day and 28 days respectively.

4.2. Effects of Soil Treatment with Lime on the Modulus of Elasticity (ME)

Modulus of elasticity (ME) follows the line of greatest slope of the stress-strain curve, representing the maximum modulus E_{max} . Tests carried out by HOLM (1979) [34], have shown that the stabilization of soils with lime increases the value of the modulus of elasticity (ME), according to FG BELL [10, 21] which is confirmed by the results found after treatment (Figure 5).

Solanki et al. (2009) showed the variation of modulus of elasticity (ME) and unconfined compressive strength (UCS) values with lime content. It is evident that there is a significant increase in ME and UCS with increasing lime content [35].

Each modulus of elasticity (ME) value in the bar graph depicted in Figure 5 is the average value of three (ME) tests and the maximum variation between these three tests was found to be 10%. (ME) increased from the reference value of 52.48 MPa to 64.6 MPa in 7 D, 106 MPa at 14 D and finally reached 135.6 MPa at 28 days curing time. The soil shows brittle behavior with lime in the long-term, the ME is 2.58 times of the pure soil after curing of 28 days under the optimum percentage of lime 6%. The elastic modulus values are calculated and presented in the Figures 5 and 6.

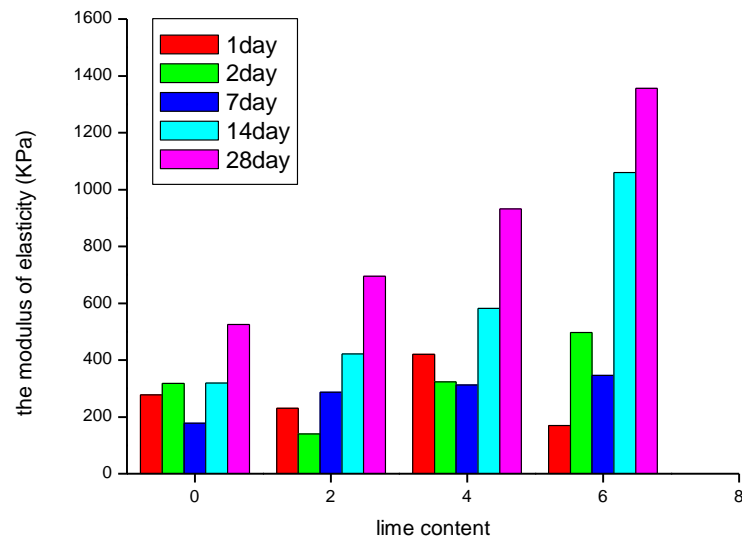


Figure 5. Development of modulus of elasticity with increasing cure period

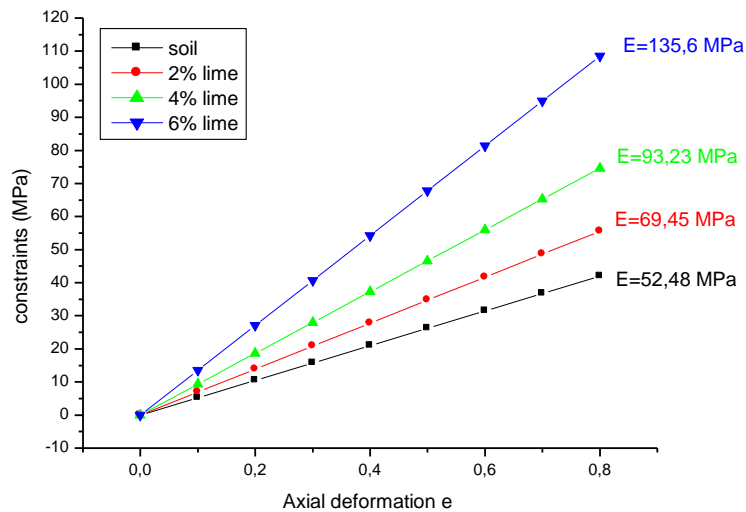


Figure 6. Development of the modulus of elasticity with the addition of lime to soil stabilized at 28 days of hardening

The increase in UCS values is in the range of 3, 23 times the original strength but the increase in elastic moduli is approximately 2, 58 times compared to untreated soil after the fourth week of treatment. Moreover, the dispersion of resistance values is remarkable for the elastic modulus corresponding to large compressive strength (Figure 7). From 4% and 6% lime addition to the clayey soil, it was very clearly and very dispersive.

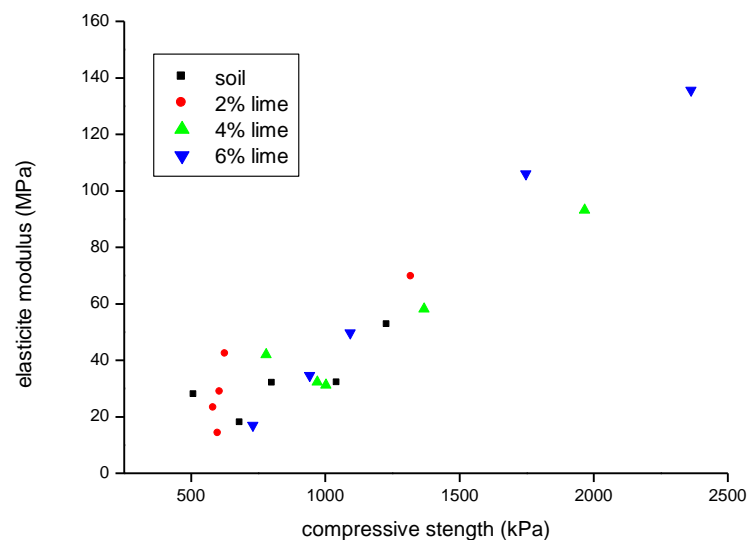


Figure 7. Relationship between elastic modulus of treated and untreated clay soil and its compressive strength

On the other hand, with the optics the results obtained, the rigidity of the material seems to evolve in an almost linear way with the compressive strength (R_c) up to a certain value where this one remains almost constant and that the maximum is reached for a 6% lime treatment (Figure 6) which was mentioned by Ganne et al. and Jegandan et al. in the results of tests on treated soils ranging from clay to sand [33]. The deformation modulus E_{50} (corresponds to 50% of the maximum applied load). Since we have R_{c28} is 2.36 MPa equivalent to 6% lime, the E_{50} is around 295.34 MPa ($55R_c < E_{50} < 160R_c$ for $R_c < 2.5$ MPa) which is mentioned by Jegandan et al. (2010) [33].

5. Conclusions

Clay soils are often dangerous and especially containing gypsum in the presence of water, and stabilization by adding minerals is a technique for improving problem soils. The objective of this study is to analyze the effect of the addition of lime on the geotechnical properties of clay soil with high plasticity. The tests most commonly carried out in road geotechnics are those of compaction and unconfined compressive strength.

In light of the results found, the increase in unconfined compressive strength based on the percentage of lime addition and the increase in the hardening period consist of short- and long-term reactions. Regarding the UCS, the soil was incorporated with lime up to 2, 4, and 6% and the curing age was significantly enhanced. However, the strength behavior of the soil blended with 6% lime give better performance. The addition of lime to the soil enhanced the stiffness and brittleness response of the soil having strain at failure. The lime fixation point occurs at 4% lime addition, where the behaviour of the soil changes from soft to stiff. The unconfined compressive strength of soil can be increased by nearly three times with the addition of 6% lime after a curing time of 28 days. In addition, a remarkable improvement in both moduli of elasticity can be achieved by the addition of lime, depending on the curing time.

The modulus of elasticity ME is 2.58 times of the pure soil after curing of 28 days under the optimum percentage of lime 6%. The curing age has a significant effect on strength. The soil sample has a certain strength at 7 days of curing, and the strength increase is basically completed after 14 days. The main reason for the increased strength of the modified soil is that the crystal fills the pores of the soil so that the soil particles are connected together. On the other hand, the addition of lime has a certain filling effect because of its smaller particle size, which plays a certain role in the solidification and rigidity of soil. The presence of lime in the samples increased the pH value of the soil and provided the conditions for long-term pozzolanic reactions.

In some types of soils, stabilization (only) does not achieve the required criteria, and the soil may lose its resistance at high dosages. Researchers found that variations in compaction energy had a major effect on both swell potential and swelling pressure. Basack et al. (2021) [36] researched the impact of various compaction energies on compaction parameters, UCS, CBR, and soil swell%. When compaction energy went up, MDD increased, OMC decreased, UCS increased, and CBR increased. As a result, increasing compaction energy can be an effective method for stabilizing tested soil up to a certain level.

6. Declarations

6.1. Author Contributions

I.S., A.E.B., and T.R. contributed to the design and implementation of the research, to the analysis of the results and to the writing of the manuscript. All authors have read and agreed to the published version of the manuscript.

6.2. Data Availability Statement

The data presented in this study are available on request from the corresponding author.

6.3. Funding

The authors received no financial support for the research, authorship, and/or publication of this article.

6.4. Conflicts of Interest

The authors declare no conflict of interest.

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