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Unconfined Compressive Strength Characteristics of Lime Treated Clay

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Abstract.

Stabilisation of clay by mixing with lime is the most frequently used method of ground improvement today. The overall objective of the study presented in this paper was to investigate the effect of hydrated lime on the unconfined compressive strength of lime stabilised clays. In order to illustrate such effect, a number of unconfined compression tests were carried out; all the stabilized specimens were tested using unconfined compression apparatus. The unconfined compressive strength (UCS) of treated clay experienced an increase with lime addition. Two variables influencing the amount of strength developed were studied, these variables included water content and curing time. Curing time contributed to an increase in the UCS that is approximately twice of the strength of unestablished clay.

Key words: Lime: Compression tests; Soil stabilization; unconfined compressive strength.

1. INTRODUCTION

The addition of hydrated lime is an attractive technique when the project requires improvement of the local soil. Lime stabilization finds an application, for instance, in slope protection of earth dams, in the construction of pavement base layers and as a support layer for shallow foundations.

As supported by findings from previous studies, soil strength is improved by lime treatment, but the strength improvement levels found to be affected by several factors. Researchers have investigated different variables influencing the levels of improvement. Some variables that affect the strength of lime-clay mixtures are: soil properties, lime properties, curing time and temperature and water content.

For the lime stabilisation to be successful, the clay content should not be less than 20%. Further, increasing organic content has been reported to have a detrimental influence on the strength of the treated clay by retarding the hydration process. [1] reported that the structure and composition of calcium silicate hydrate, which ponds clay particles, can be changed due to the organic matter. In addition, the water required for hydration may be limited because 10 or more times of the dry weight of the organic matter is held in water. Regarding soil type, the work carried out by [2] demonstrated that the soil type can affect the strength development of lime treated soil. It was found that Kaolinitic clays give the highest strengths comparing with montmorillonite.

In terms of lime properties, [3] stated that hydrated lime is less effective stabiliser than quick lime. This is in agreement with [4] findings who reported the results of tests conducted on three different soils treated with lime. The results indicated that quicklime proved more effective than hydrated lime in improving strength, due to more calcium hydroxide potential.

Moreover, lime form is influential factor in increasing or decreasing the strength. For instance, adding quick lime in slurry form is more effective than adding as a powder where in the first form it can produce a higher strength than the last one. This is supported by [5] study which showed that the quick lime slurries provide higher strength as well as small amount of lime is used.

With regard to curing, Curing is important for lime treated clays because the reactions between lime and clay particles are time and temperature dependent. [6] examined the effect of curing time on the strength development of lime treated soil. The results showed that, soil stabilisation was effective in increasing the strength at any curing time. Further evidence in support of the effect of the time and temperature is offered by studies conducted by [3] and [7]. Based on their observations, as curing time increases the strength of soil-lime mixtures increases and this can be accelerated by increasing curing temperatures to give higher strengths.

The water content of the clay is also a significant property controlling the strength of the lime stabilised clays. [3] stated that the strength remains low with high water contents. There is far less agreement, however, on the effect of water content on the strength. [8] concluded that significant strength increase could be obtained, even at water content more than the liquid limit, if enough lime and time are available.

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In general, according to [7], the strength increases rapidly during the first 7 days, and then increases more slowly at a fairly constant rate. However, it is noticed that, in the literature regarding the strength improvement of lime treated clays, the increase in strength, with respect to curing time, is not linear with lime content as in [3] study. While in the research of [9] and [10] it is found that the unconfined compressive strength increases approximately linearly, considering the dry unit weight, as lime content increases.

2. EXPERIMENTAL PROGRAM

In order to study the unconfined compressive strength characteristics of lime treated clay, both untreated and treated kaolin were subjected to similar laboratory tests. The experimental program was carried out in three parts. First, the geotechnical properties of the soil. Next, the minimum amount of lime required for full stabilization, based on the modified initial consumption of lime was established. A number of unconfined compression tests were then carried out as discussed below.

2.1 Test Materials

The soil tested in this study is commercial kaolin clay. It was mixed with 5% lime (determined based on Initial Consumption of Lime). A fine ground hydrated lime (calcium hydroxide – $\text{Ca}[\text{OH}]_2$) was used.

2.2 Specimen Preparation

The clay samples were firstly dried at 60°C before mixing. To prepare the lime-clay mixtures, the required amounts of dry kaolin were mixed with 5% of hydrated lime by weight of kaolin in the dry state until an even distribution of lime in mixture was obtained. The dry lime-clay mixtures were then mixed with distilled water.

2.3 Methods

Index Properties

The procedures described in [11] were used to determine the index properties of the untreated kaolin.

Initial Consumption of Lime (ICL)

The pH test is the preferred method for identifying the lime content required to obtain a long-term pozzolanic reaction. In order to determine the minimum lime content required, the method developed by [12] was used.

Proctor's Compaction Test

The optimum moisture content (OMC) and the maximum dry density (MDD) of the clay were obtained using the Standard Proctor compaction test carried out according to [11]. The test was performed by the compaction of the clay into a mould that is filled at a fixed moisture content in three, approximately, equal layers of clay. The compaction is achieved by a standard number of blows (27 blows) from a hand rammer of 2.5 kg dropping from a height of 300 mm.

Unconfined Compression Strength Test

The unconfined compression test was used to evaluate the laboratory strength of the studied soil according to [11]. In this test, samples of kaolin and lime treated kaolin were compacted by hand in three layers in cylindrical mould. All specimens were taken out from the moulds, of 38 mm in diameter and 76 mm in height, and cured for 7, 14 and 28 days in plastic bags for curing process. After reaching the specified curing time, the cylindrical specimens were subjected to a gradually increased axial compression load until failure occurs. The specimens tested at an axial strain rate of 1% per minute.

3. DISCUSSION OF TEST RESULTS

3.1 Index Properties

The index properties of the untreated kaolin are summarised in Table 1.

Table 1: Basic properties of untreated kaolin

Property	Value
Specific Gravity	2.61
Liquid Limit, %	65.9
Plastic Limit, %	33.3
Plasticity Index, %	32.6
Maximum Dry Density, kg/m ³	1422
Optimum Moisture Content, %	29.9
Unconfined Compressive Strength, kPa	183
pH	5.43

3.2 Initial Consumption of Lime (ICL)

The plot of pH values corrected at 25^oC versus lime content are presented in Fig. 1. It can be seen that, the initial lime content needed for the lime treatment of clay is 2%. Therefore, this percentage of hydrated lime could be used. However, according to [13], for optimum improvement of the soil strength the optimum lime content for kaolin is in the range of 4% to

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6%. Therefore, in the current study, 5% of hydrated lime by weight was chosen for the stabilization.

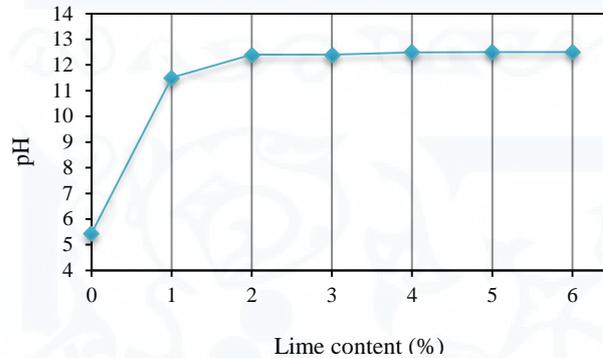


Fig. 1: Determination of the initial consumption of lime

3.3 Compaction Characteristics

Fig. 2 illustrates the moisture-density relationship of kaolin with 0% and 5% lime. As shown, the addition of lime tends to increase the optimum moisture content (OMC) and reduce the maximum dry density (MDD). For the same compaction effort, the optimum moisture content of the untreated clay changed from 29.9% to 33.3% when 5% lime was added to the clay. The maximum density decreased from 1422 kg/m^3 to 1382 kg/m^3 . This change is considered as an indication of the improvement of the compaction characteristics of the lime stabilised clay. This is consistent with the study conducted by [6]. The reduction in the dry density occurs because the agglomerated and flocculated particles of soil occupy larger spaces and the reason for increasing OMC is that, the lime requires more water for the pozzolanic reactions. [14] referred the decrease in density to the difference in the specific gravity of the clay and hydrated lime..

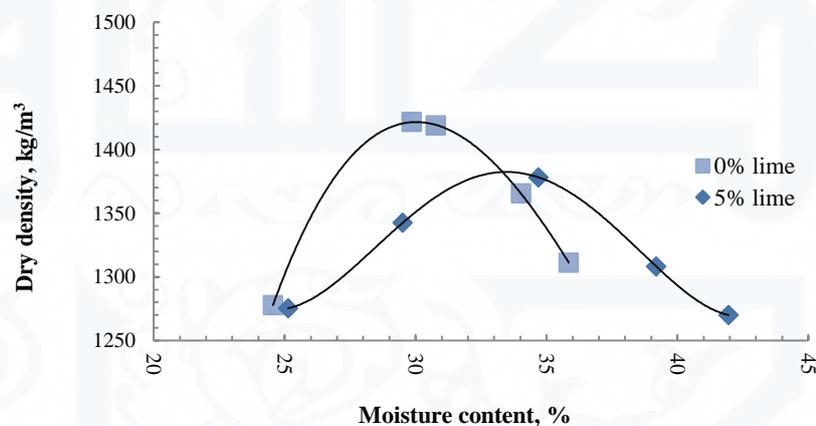


Fig. 2: Influence of lime on compaction characteristics of clay

3.3 Unconfined Compressive Strength

Fig. 3 shows the stress-strain behaviour of untreated kaolin and kaolin treated with 5% lime and compacted at OMC. As can be seen, the untreated clay failed at the UCS of 183 kPa, whereas treated clay at different curing time failed at higher values of the UCS.

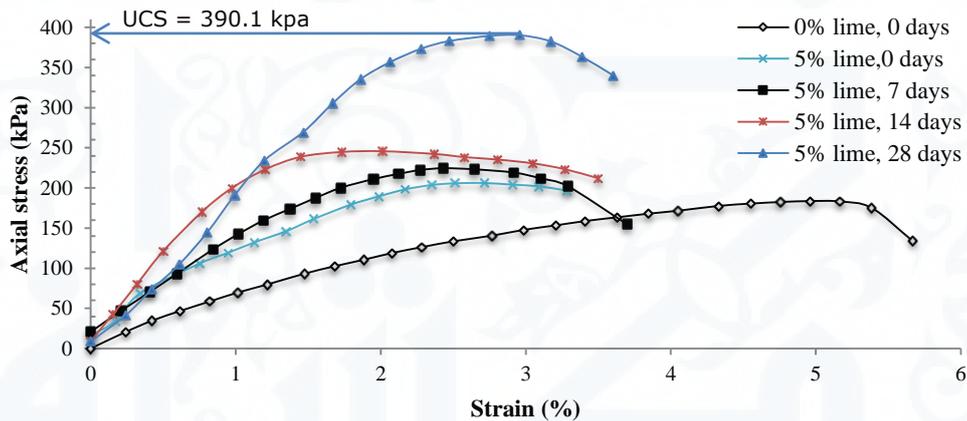


Fig. 3: Unconfined compression test curves

Fig. 4 presents the relationship between the UCS and the curing time. As can be seen, the lime-treated soil exhibited a trend of increasing UCS with increasing curing time. For example, the UCS increased about twice of the original strength after 28 days curing. The summary of the UCS values is given in Table 2.

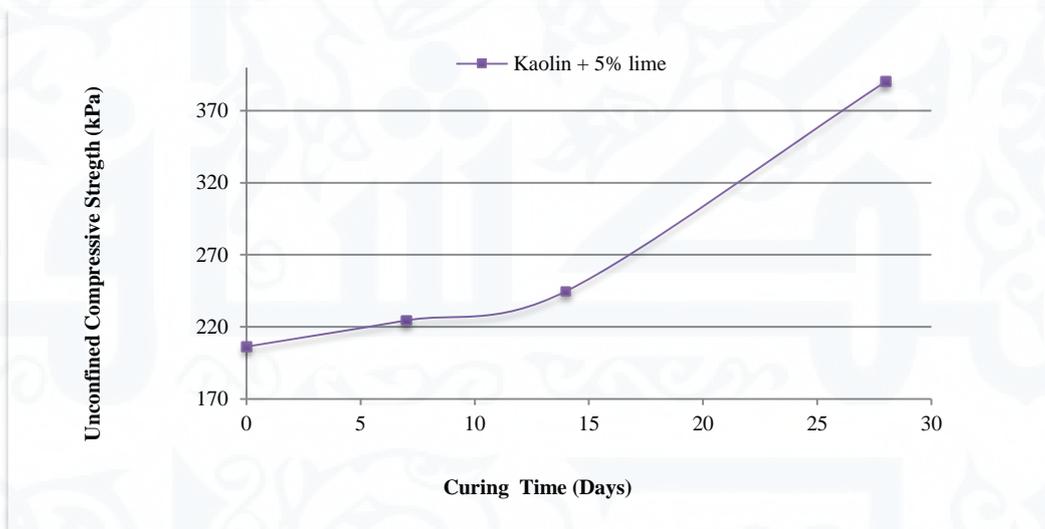


Fig.4: Influence of curing time on UCS of treated kaolin

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Table 2: Summary of the unconfined compressive strengths

Description	Curing period (days)	UCS (kPa)
Kaolin	0	183
	0	206.2
Kaolin + 5% lime	7	224.39
	14	244.67
	14	244.67
	28	390.1

Fig. 5 presents the results of the UCS tests in terms of water content. The lime stabilised specimens at curing periods of 14 and 28 days achieved maximum strengths at optimum moisture content (OMC=33.3%) whereas for the wet side (WMC = 37.5%) and the dry side (DMC = 29.9%) of the OMC the UCS decreased for the same periods, even though they were still higher than the UCS of the untreated clay. The stabilised clay cured for 14 days experienced an increase from 189 kPa to 205.2 kPa on WMC, while at 28 days of curing the increase was from 252.25 kPa to 344.6 kPa on DMC. In other words, higher or lower than OMC water content decreases the UCS values compared to UCS at OMC. Similarly, [12] stated that the strength remains low with high water contents. The UCS decreases with the increasing water content because high water content prevents lime-clay contact; therefore, the bonding material created by the reaction between lime and clay particles is limited. This is on contrary to the principles of the reaction required in lime stabilisation, where the chemical reaction needs more water to produce the pozzolanic materials.

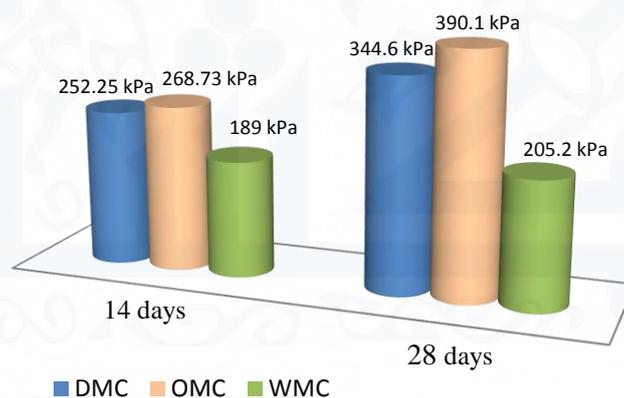


Fig. 5: Influence of water content on UCS of treated kaolin clay

4. Conclusion and Recommendations

The unconfined compressive strength of lime treated samples increased with increasing the curing period particularly after 28 days curing while it decreased with increasing water content. The added lime led to increase of around twice of the strength of the untreated clay. Contrary to curing time, water content, lower or higher than the OMC, decreased the strength of clay. These strength measurements correlate well with the laboratory data obtained by other researchers.

From the results obtained in this study, it can be concluded that the hydrated lime effectively improve the strength and compaction properties of kaolin clay.

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