Influence of grain size distribution on engineering properties of soils treated with hydrated lime

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Recived 24 Feb 2007 Revised 19 Nov 2007

Abstract

This paper describes the results of a study which was primarily directed to the determination of geotechnical properties of fine and coarse grain soils stabilized by lime obtained from Taleghan, northwest of Tehran to assess its suitability as construction material. Soils were treated with lime mixtures in various portions between 3 to 9 percents by weight. The samples were cured for different periods of time up to 90 days under 30°c and 60 percent relative humidity. The geotechnical properties were investigated by: (a) compaction characteristics, (b) compression tests and (c) direct shear tests. The results indicated soils maximum dry densities decreased while the optimum water contents increased. The compressive and shear strength of admixtures depicted an increasing trend. It was observed that addition of 6 percent of lime caused a significant increase in strength properties of CL and SC grain soils. However, the SC soil yielded the best results.

Keywords: Hydrated Lime, Compressive test, Direct Shear Test, Clayey Soil, Curing period.

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Introduction

When geotechnical engineers are faced with clayey soils, the engineering properties of those soils may need to be improved to make them suitable for construction. Lime has been used extensively to improve the shear strength of fine and coarse grained soils [1]. The low strength of soil is generally associated with increase in moisture content. The addition of lime changes the soil behavior so that it reacts like a granular mass, the particles of which are strongly bounded by pozzolanic cementitious compounds formed by reactions with soil-silica and lime in the presence of water. The cemented soil particles then resist internal swelling pressure of the clay. With formation of these compounds, strength increases with an increase in curing periods [2, 3, 4, 5]. Many factors such as soil type, type and amount of lime added, curing period, moisture content and method of compaction influence the final strength [2].

For any given soil, there is an optimum lime content beyond which the strength gain may be marginal or may slightly decrease due to increase of water content. Strength characteristics including compressive strength and direct shear test were studied and recommended values of lime content for specific condition are presented in this paper to enhance the engineering properties of fine and coarse grain clayey soils. This may be advantageous for construction work in civil engineering field.

Experimental program

Literature review revealed that soil- lime system has a complex behavior and most of present knowledge is empirical in nature. Therefore, laboratory study is a suitable way to evaluate engineering properties of raw materials and mixes to study the effect of the variables that might affect strength and other engineering properties of mixes. In order to achieve the objectives of this study, experimental program according to Fig.1 was adopted. Some details concerning the program are as follows:

Materials and methods

a- soils

Soils used in this investigation were obtained from Talegan, Northwest of Tehran. The soils were collected by open excavation from depth of 1m below ground level. The soils were dried, passed through standard sieve sizes and classified under SC and CL according to unified classification. Fig.2 depicts grain size distribution of the soils. The properties of fine portion of soils are given in Table 1.

Table 1: Properties of fine fraction of clayey sand (Percent)

Sio_2	51.72
Al_2O_3	12.7
Fe_2O_3	7.6
Cao	12.6
Mgo	1.4
Cl^-	0.05
Liquid Limit	29
Plastic Limit	17
Plasticity Index	12

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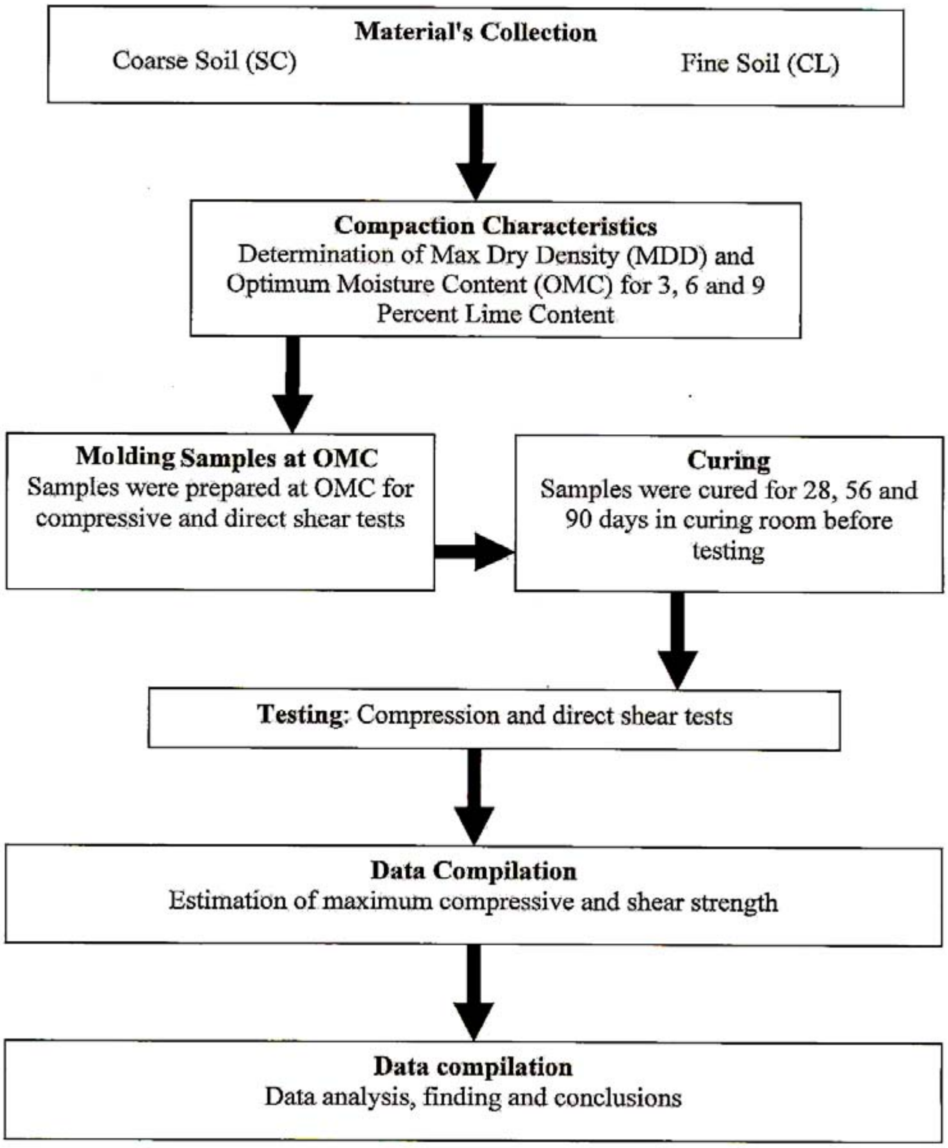

Fig 1: program of the work

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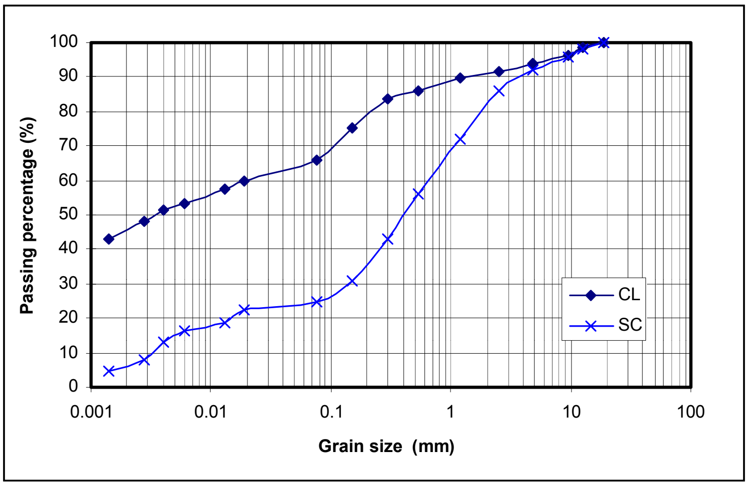

Fig 2: Grain size distribution of the soils

b- Lime

There are many types of lime available in the market. Despite the fact that quick lime is more effective as a stabilizer compared to hydrated lime [4], the later was used because it is more convenient to handle. The hydrated lime produced in Hamadan plant of Hamadan province, with 98 percent finer than sieve No. 200 was used in this investigation. The properties of lime are presented in Table 2.

Table 2: Chemical analysis of hydrated lime (Percent)

Sio_2	1.65
Al_2O_3	0.34
Fe_2O_3	0.07
Cao	72.97
Mgo	0.31

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c- moisture- density relationships

Tests were conducted according to ASTM D 1557 [6] to establish the dry density and moisture content relationship for all mixtures studied. The lime was added in every case as a percentage of total dry weight of the mixture. Potable water was used in the study. The materials were mixed thoroughly for five minutes to ensure complete homogeneity. From these tests, the optimum moisture content and maximum dry density for each combination were obtained.

Strength evaluation of various mixes

Lime- soil mixture can be evaluated in the laboratory using different methods. The compaction, compressive and direct shear tests were used for evaluation in this study. Specimens for compressive and direct shear tests were prepared by mixing thoroughly and were compacted in 10*10*10 cm and 10*10*5 cm moulds at optimum water content observed earlier.

After preparation of 135 specimens, they were placed in curing room under 30°C temperature and 60 percent relative humidity content and divided into three sets. Each set was allowed to cure under laboratory conditions for durations of 28, 56 and 90 days.

Compaction characteristics

Relationship between molding moisture content and dry density was studied by varying water content in the range of 8 to 20%

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depending on the fine/ lime content. Results of the compaction tests of lime treated CL and SC soils mixtures are presented in Fig. 3. The figure shows the compaction curves for both soils untreated and treated with 3%, 6% and 9% hydrated lime. The results indicated that the optimum water content increase with increasing lime and fine soil contents. The maximum dry density tends to decrease with increasing lime content.

It is observed that fine grain soil has a higher water content and lower density compare to the coarse grain soil. This can be attributed to the increase in fine materials, more water absorption and lower specific gravity of fine grain soil.

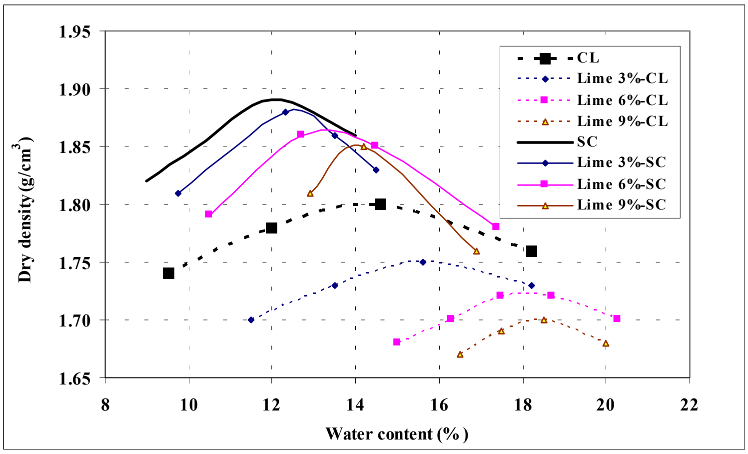

Fig 3: Relationship between maximum dry density and optimum water contents for all mixes

Compressive Tests

A conventional compressive testing system was used to carry out the tests on 54 cured samples containing 3, 6 and 9 percent hydrated lime according to BS 1881 [7]. The cured sets of 28, 56 and 90 days durations were tested in compression apparatus at a speed rate of 1 mm/min. As expected, results revealed that compressive strength of lime mixtures is dependent on the lime content added, soil type, and curing lime. The effects of these variables on compressive strength are discussed below. The average compressive values of three sets have been presented in Figs. 4 and 5 for the soils under study.

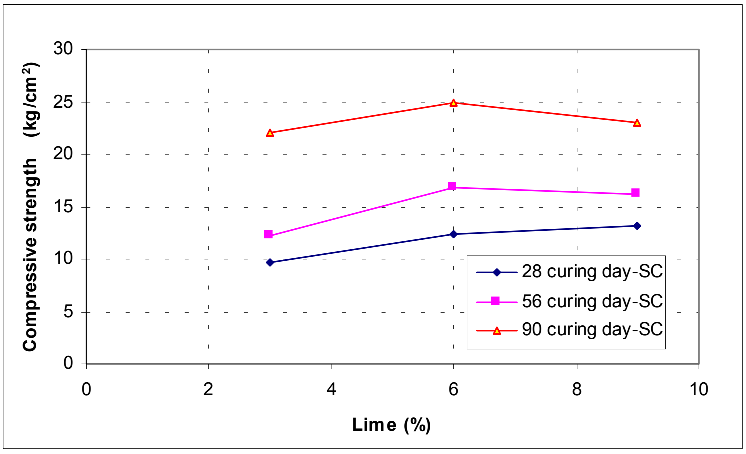

Fig.4: Effect of hydrated lime on compressive strength of SC soil

Effect of lime content

The behavior of fine and coarse soil stabilized with lime had been studied by many researchers with different objectives [8, 9, 10]. Fig. 4

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indicates the effect of lime content on the compressive strength of coarse grain mixes cured for 90 days. As can be seen from the figure, there is substantial increase in compressive strength with increase in lime content. This trend continues up to six percent lime content is reached. Then the increase in strength becomes insignificant with increasing lime until a content of nine percent. The reason behind such behavior may be attributed to the degree to which the soil- lime pozzolanic reaction had proceeded. Because the fine content of the SC is limited to 25% of the mixture, adding lime will cause cat ion exchange and flocculation- agglomerations with soil particles and results in increase of strength [11, 12]. Such reaction will continue until reaching the optimum value, which is about six percent in our study, after this stage any more lime content might be considered as redundant and will cause less reaction and therefore, marginal strength will be gained.

Fig.5 indicates that there is a substantial increase in the compressive strength with increase of lime content of soil samples (CL). This trend continues up to 6 percent lime content.

Comparison of Figs. 4 and 5 indicates that increase in strength of SC soil is higher than that of CL soil. This may be attributed to the lower water content, higher density and internal friction angle of SC soil granules. Moreover, it may be concluded that 25 percent fine is sufficient source of silica and alumina to achieve optimum strength value in our study.

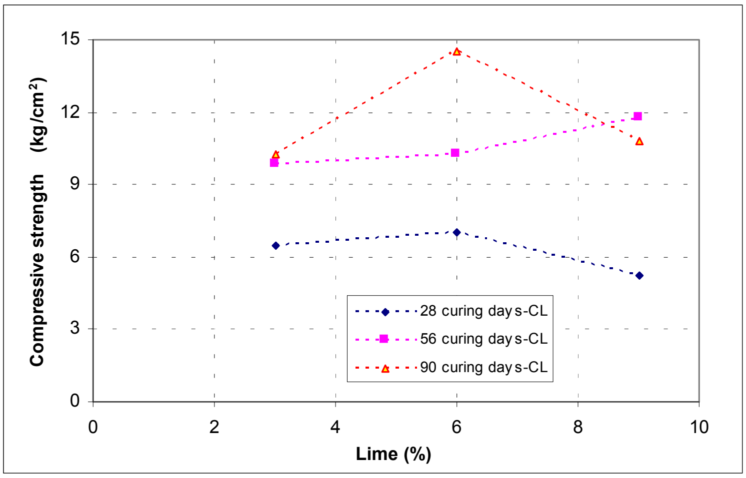

Fig.5: Effect of hydrated lime on compressive strength of CL soil

Effect of curing period

Lime reacts with soil very slowly and may take years to complete. The effect of curing period on the compressive strength was investigated at three periods of 28, 56 and 90 days. Fig. 6 indicates that the strength of mixtures is time dependent and strength is gained gradually due to the formation of cementation agent which is produced due to the reactions of lime with fine soil particles. This agent crystallizes slowly into interlocking matrix and increase the sample strength. Longer curing period allows longer time for lime to react and form a strong skeleton structure throughout the material, binding the coarse grains together. For short curing times the reaction of lime does not reach its advanced stages and this results in remaining of some of the molding water between the coarse grains which loosen the mixture [13]. For longer curing period, more efficient lime reaction takes place and may utilize all the water within the mixture. The same trend is also observed in fine grain soil (Fig. 7). Figs. 6 and 7 shows the effect of curing time for fine and coarse grain soil mixed with different percent age of lime content. They indicate that the strength gain of CL soil with 6 percent lime and 90 days curing period is about 14 kg/cm^2 which are proximately 60 percent less than SC soil.

Direct Shear Test

A conventional direct shear testing system was used to carry out tests on 81 cured samples containing 3, 6 and 9 percent hydrated lime under normal load of 0.8, 1.6 and 2.4 kg/cm2. The cured sets of 28, 56 and 90 days durations were tested in direct shear test apparatus at a speed of 0.2 mm/min. The average friction angle and cohesion values are used to minimize experimental errors for evaluation of engineering properties of CL and SC soils.

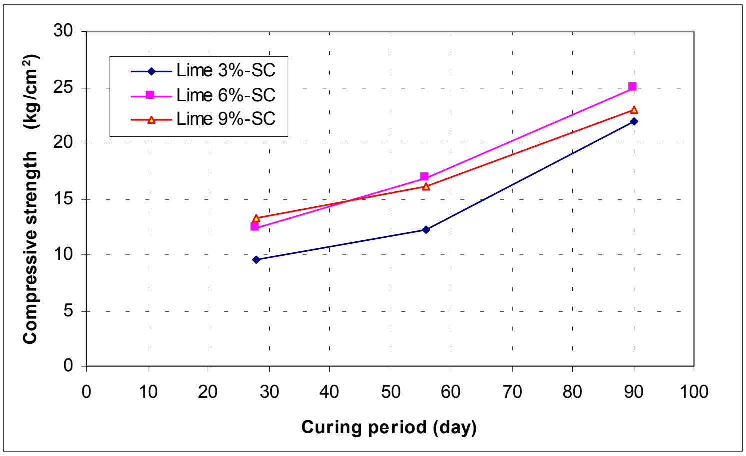

Fig 6: Effect of curing period on compressive strength of SC soil

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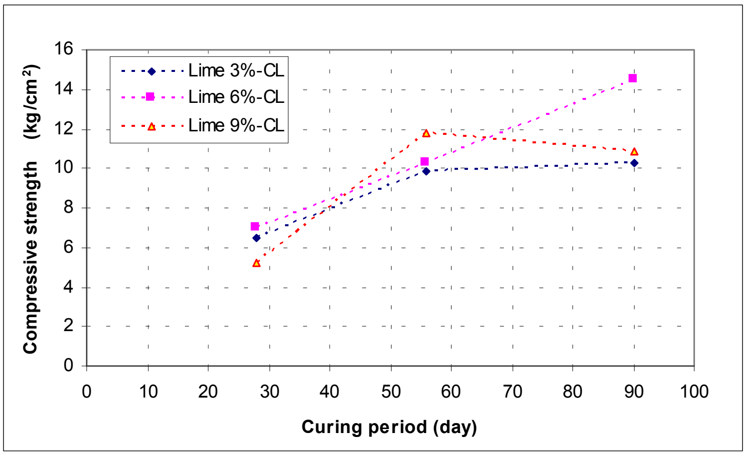

Fig.7: Effect of curing period on compressive strength of CL soil

Effect of lime content

Figs. 8 and 9 indicate the effect of lime content on friction angle of CL and SC soils cured for 90 days. As can be seen from Fig. 8, there is substantial increase in friction angle of CL soil with increase in lime content. This trend continuous up to 6 percent lime content is reached. Then the increase becomes insignificant with increase of lime content. This behavior can be attributed to the degree of soil- lime pozzolanic reaction which is called cementation. Fig. 9 indicates nearly descending trend with increase in lime content. This may be attributed to the effect of cementation in long term period. However, 6 percent yields the best result.

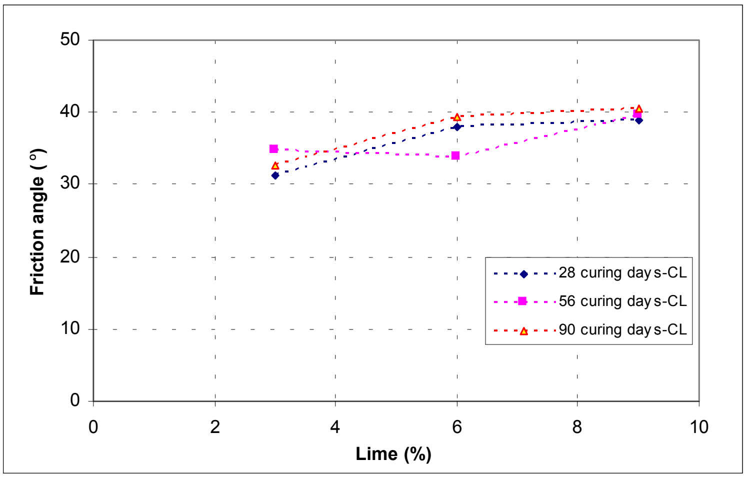

Fig.8: Effect of hydrated lime on friction angle of CL soil

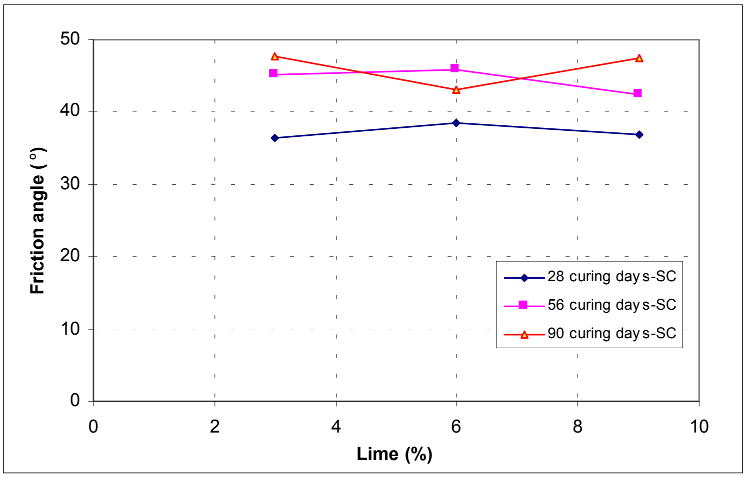

Fig.9: Effect of hydrated lime on friction angle of SC soil

Figs. 10 and 11 indicate the effect of lime content on cohesion of soil classified as CL and SC. The trend indicates that optimum strength value is reached at 6 percent lime content.

Comparison of figures depicts that soil classified under SC yielded a higher strength values under similar condition. This may be attributed to the lower water content, higher density and roughness of coarse soil granules.

Effect of curing period

Figs. 12 to 15 indicate the effect of curing period on friction angle and cohesion of SC and CL soils cured for 90 days. As can be seen from fig. 12, there are an ascending trend in cohesion and friction angle of SC mixes for curing period of up to 56 days. After that this trend is not observed and in fact a descending trend is observed at 6

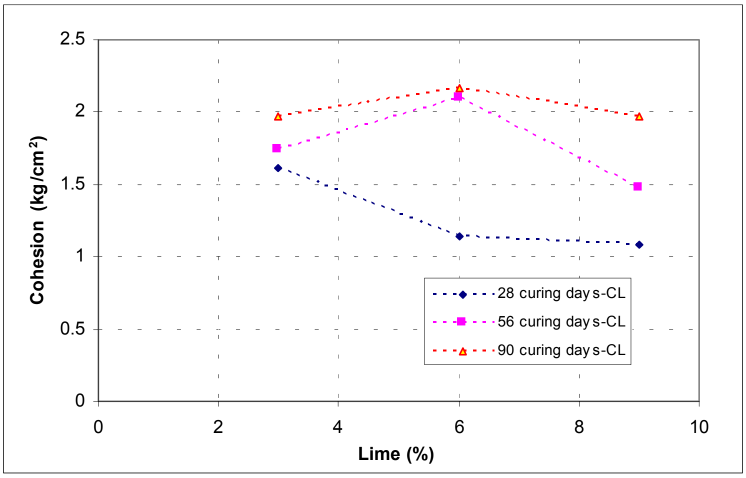

Fig.10: Effect of hydrated lime on cohesion of CL soil

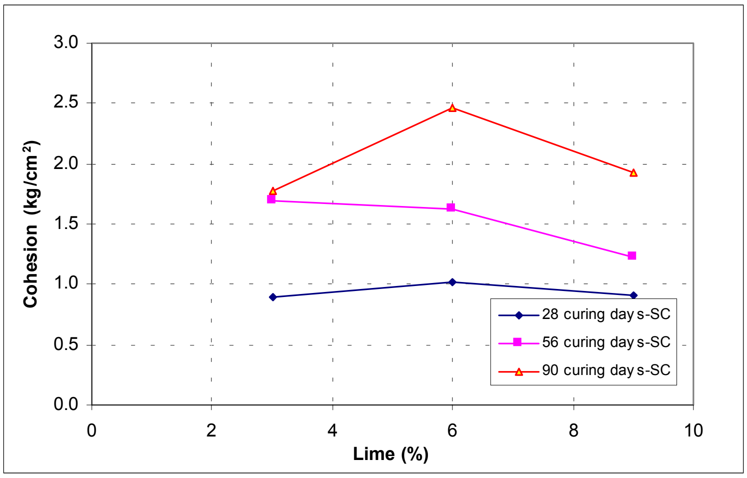

Fig.11: Effect of hydrated lime on cohesion of SC soil

percent lime content. This may be attributed to the effect of cohesion increase in long period (Fig. 13).

The addition of lime to clayey sand changes the fabric of clay particles from dispersed to flocculated [8]. This is reflected in increase of friction angle (Fig.12). With short curing period, the flocculated particles are cemented by pozzolanic reaction compounds. With longer curing, the increase in strength is only through an increase in cohesion (Fig.13). Thus, it is clear that flocculation of particles increase value of friction angle, whereas cementation of particles increases the value of cohesion. The same trend is nearly observed with CL soil (Figs. 14, 15).

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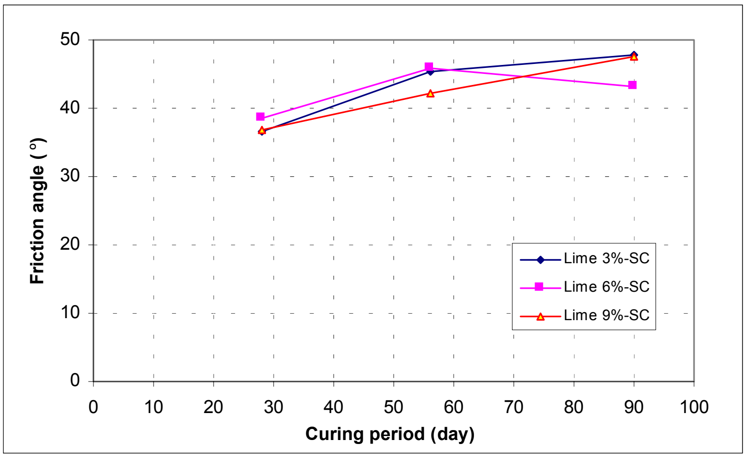

Fig.12: Effect of curing period on friction angle of lime treated SC soil

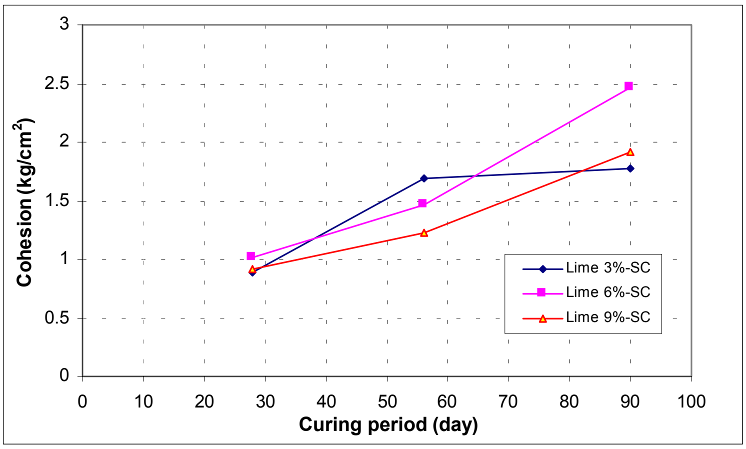

Fig.13: Effect of curing period on cohesion of lime treated SC soil

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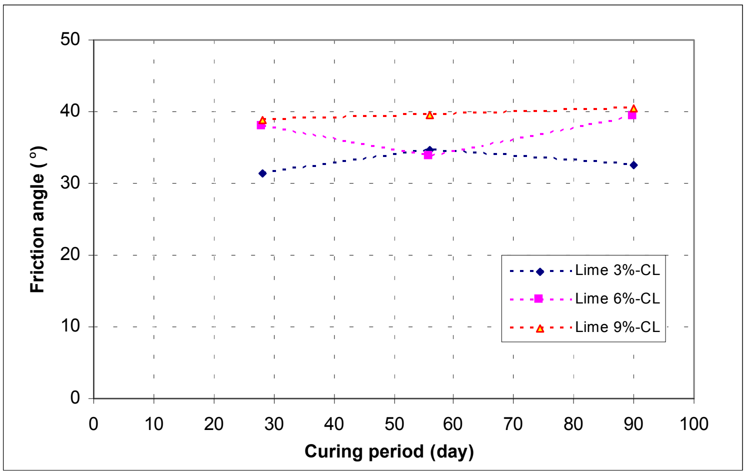

Fig.14: Effect of curing period on friction angle of lime treated CL soil

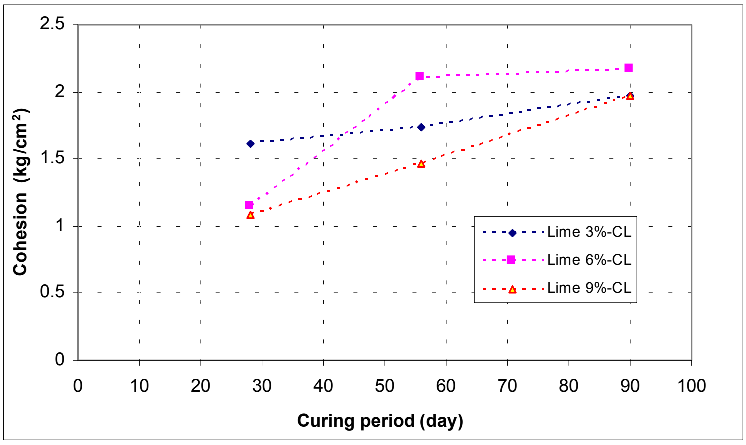

Fig.15: Effect of curing period on cohesion angle of lime treated CL soil

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Conclusion

Shear strength of chemically stabilized soil is affected by a number of various factors. Based on results of different tests conducted on treated samples of fine (CL) and coarse soils (SC), the following conclusions may be drawn:

1. Strength parameters obtained from tests on treated samples indicate that addition of lime mixtures has beneficial effect on strength of soils under study.
2. Gain in strength of mixtures is time dependent: short curing period cause the flocculation of fine particles, whereas long curing period cause cementation of fine particles.
3. The coarse soil with suitable mixtures of fine and lime may be compacted to achieve fairly high dry unit weight as compare to fine soil.
4. Coarse soil containing 25 percent fine grains used in combination with 6 percent of lime was observed to give remarkable improvement in strength properties as compare to fine grain soil.

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