Lime-treatment of sand improved by bentonite addition

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ABSTRACT

Lime treatment is an efficient way to stabilize soils. Its efficiency lies in the low quantity of lime addition and the ecological advantage related to the use of the soil already in place without requiring soil replacement. Lime mostly reacts with the clay and silt fraction of the soil while it does not stabilize a pure sand for which cement treatment is often more adapted. However, the carbon equivalent of cement is higher and stabilization requires more quantity of cement than lime. It is believed that a very low clay content can be enough to drastically increase the properties of a sandy soil by lime treatment. Hence, adding a low quantity of clayey materials in addition to lime can make sand stabilization possible. In this context, this paper present the results of an experimental program carried out on different sand-bentonite mixtures treated with lime and then compacted under the optimum Proctor conditions. Lime-treated soils have been compressed under uniaxial conditions at different curing times. The results show that the unconfined compressive strength (UCS) of lime-treated soils is considerably increased because of a low content of bentonite added in a pure sand. Also, beyond a given bentonite content, the soil strength starts decreasing when bentonite is further added. This study shows that an optimum value of bentonite content that induces a maximum compressive strength can be obtained. However this optimum value of bentonite content seems to depend on the considered curing time

Keywords: Lime, Stabilization, Bentonite, Mixture

1 INTRODUCTION

Clay soils can be stabilized by the addition of small percentages, by weight, of lime. Its efficiency lies in the low quantity of lime addition and the related ecological advantage because it uses the soil already in place without requiring soil replacement. Lime treatment has its effect on soil at two different levels. First, lime reacts quickly with clay by modifying its structure. It allows the clay minerals to merge and form bigger aggregates (Little, 1995). The second effect is soil stabilization. Long term pozzolanic reactions take place after soil modification (Eades, 1962). CSH and CAH formations from pozzolanic reactions improve the soil mechanical properties. In clayey soils treated with lime, the reaction takes place between the calcium of the lime and the silicates and aluminates of the clay minerals. However, the reaction is slow because it requires the dissolution of clay minerals into silicium and aluminium ions. The dissolution is possible only at high alkaline solutions (pH > 10) (Keller, 1964). Research on soil stabilization was active during the last decades. (Estéoule and Perret, 1979) and (De Bel, 2008) observed an increase on the unconfined compressive strength (UCS) in phases as a function of time. Many important parameters influence soil stabilization, such as water content and dry density of soil (Locat et. al., 1990). Also, higher temperatures increase the speed of the reaction (Estéoule and Perret, 1979), (De Bel, 2008). Conversely organic matter decreases the efficiency of lime

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(Locat et. al., 1990). In addition, the clay mineral type is an important parameter of soil stabilization (Bell, 1996). Montmorillonite, for example, has a better efficiency for lime adsorption than kaolinite. Consequently, CEC value is an important factor to be considered. On the other hand, a major advantage of lime is that its production, compared to cement production, releases less carbon dioxide. Consequently, it becomes more ecologically-efficient to use lime for soil stabilization if time is not an important factor. However, sandy soils cannot be treated in the same way. These are usually treated with cement (NRS, 1969).

The idea of the present study is to make lime stabilization possible with sand by adding clay minerals. This paper contributes to the understanding of the effect of a small amount of bentonite on the efficiency of sandy soils treated with lime. In the present work, different proportions of sand-bentonite mixtures have been studied. Therefore, two series of tests have been carried out. The first series consist of investigating the properties of sand-bentonite mixtures at high bentonite content (HBC). Three different compositions have been chosen for unconfined compression tests: 30%, 45% and 60% bentonite mixed with 70%, 55% and 40% sand respectively. A second series of tests have been carried out at lower bentonite contents (LBC): 5%, 10%, 15% and 20% in weight of bentonite and respectively 95%, 90%, 85%, 80% in weight of sand.

2 METHODOLOGY

2.1 Soil materials

The sand used in the experience is homometric with a D50 of 260µm (i.e. the particles have all more or less the same size). The reason for taking homometric sand is to have the simplest sand possible and the easiest to consider in subsequent theoretical and numerical modeling. It corresponds to the skeleton of the mixture. The second part of the mixture is bentonite. This part stands for the clayey cohesive matrix that reacts with lime. Bentonite is taken because of its high reactivity with lime (principally montmorillonite), its cheapness and its availability in the market. Since sodium bentonite is known to have a very high swelling index, calcium bentonite is thus chosen to avoid any excessive swelling upon wetting (7ml/2g). It has 65% of fine particles (< 2µm), 28% silt (2µm < D < 67µm) and 7% sand (> 67µm).

2.2 Proctor Compaction (ASTM D-3668)

In order match in situ field conditions, tested samples should be prepared at 98.5% of the Normal Proctor Optimum (OPN) density. Consequently, a preliminary step before sample preparation is the determination of the Optimum Proctor Curve. The soil is mixed by hand with a precise lime quantity. The lime quantity has been calculated according to the Eades & Grim procedure (ASTM D-6276) (Eades and Grim, 1966). It has been decided to add 1% lime for the LBC soils; 2% for the HBC soils and 3% for the pure bentonite. Distilled water is poured at different moisture contents. Finally, the wet soil is put in a plastic bag to mellow for 24 hours at 20°C. After 24h, compaction takes place. The results give the Normal Proctor Optimum density and the Optimum moisture content to use for the samples preparation.

2.3 Unconfined compression test (ASTM D-5102)

Unconfined compression test allows measuring both compression resistance and stiffness of the mixtures. Five samples of each composition and for each curing time have been prepared at 98.5% OPN according to the same procedure as Proctor. Their dimensions are of 70mm length and 36mm diameter. In order to avoid any exchange with the outside, the sample is protected by a plastic film, an aluminum film and a layer of paraffin. The samples are then put at 20°C and stay for curing.

Afterward, unconfined compression tests are performed to determine the force displacement curve and obtain the UCS.

3 RESULTS

3.1 Proctor Optima

Based on (Kenney et. al., 1992), (Ferber, 2005), the studied mixtures of sand and bentonite have all a maximum optimum dry density at a known composition which is higher than the optimum dry density of sand and bentonite taken separately. Proctor tests for our compositions have also been carried out to point out this property for the lime treated mixtures. Results in Figure 1 shows that there exists a mixture with the highest Normal Proctor Optimum: the mixture with 10% bentonite. It reaches a density of 17.3kN/m³. Dry density reached from Proctor compaction of pure sand is of course higher than in the case of pure bentonite. However, the addition of a small amount of bentonite in pure sand enhances the obtained optimum dry density, because fine particles fill the macro voids between sand particles.

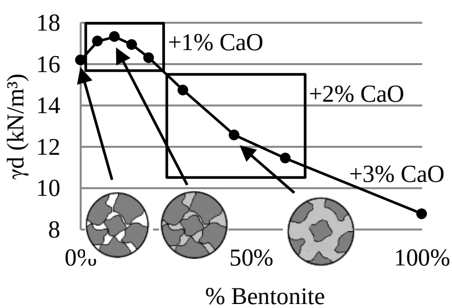

Figure 1. Normal Proctor Optimum of mixtures in function of their bentonite content

However, if too much bentonite is added, clay starts to separate the sand particles from each other which progressively reduces the resulting dry density (cf. Figure 1). For similar sand-bentonite mixtures, (Kenney et. al., 1992), (Sivapullaiah et. al., 1998) and (Ferber, 2005) obtained a maximum dry density at around 20% of bentonite. In our case, the optimal bentonite content seems a bit lower. It may be explained by the fact that the soil is treated. So the treated clay aggregates fill more rapidly the voids hence they are larger.

3.2 Unconfined compression tests for high bentonite content mixtures

The UCS of HBC mixtures all treated with 2% of lime has been evaluated at different curing times: 7, 14, 28, 56 days. An untreated mixture (referred as curing time 0) has also been tested for each composition. Figure 2 shows the UCS for HBC mixtures, in function of the curing time. The symbols show the exact value of each sample and the lines represent their mean value for each curing time. As expected, UCS increases with time. More striking is the fact that the mixture at 30% bentonite is more resistant than the others. After 56 days, its UCS is 350% higher.

3.3 Unconfined compression tests for low bentonite content mixtures

Mixtures at LBC are also investigated. Fig. 3 shows the evolution of the UCS of LBC. The composition with the highest UCS depends on the curing time. At the beginning (i.e. 7 to 14 days), the mixture with 20% of bentonite gives the best UCS but at 28 and 56 days, the mixture at 15% has the maximum value. Finally, after 112 days, the mixture of 10% overtakes all the previous mixtures and has the maximum UCS. All the LBC mixtures have been treated equally at 1% of lime as specified in the Eades & Grim test. As time goes by, the optimal composition goes further and further on the lower bentonite content mixtures. Figure 4 shows another view of this phenomenon. The optimum mixture at 7 days is at 20% but at 56 days, the optimum at 1% lime is at 15%. After 7 days (short period of curing time), both 1% lime and 2% lime curves are linked to one curve. Thus, at short time period, the UCS values for all 6 mixtures follow one curve because the lime content added has been calculated following the Eades & Grim procedure which is consequently sufficient to stabilize the soil at short term. However, at longer curing times, a discontinuity is observed between the curves at 1% and 2% of lime, which could indicate that the Eades & Grim procedure does not necessarily give the best results for soil stabilization.

3.4 Lime consumption

A complementary test, the Leduc Method (Perret, 1979), has also been carried out. The goal is to determine the lime consumption of the samples in function of curing time. The Fig. 5 shows the amount of lime still left in the soil samples in function of curing time. The HBC mixtures have a higher value of lime availability because they have been treated with 2% lime as opposed to the LBC mixtures treated at 1% lime. These results show two different conclusions.

First, in each two series (HBC & LBC), the lime consumption of the highest bentonite content decreases more rapidly than the two others. The mixture at 60% bentonite has reacted more quickly with lime than the mixture at 45% and 30%. For the LBC the results show the same property. The mixture at 20% bentonite consumes the lime faster than the mixtures at 15% and 10%. The lime reacts faster in an environment containing more bentonite.

Second, for LBC, the UCS of the mixture at 10% continues to increase at long curing time whereas the other mixtures reach a constant value (Fig. 3). This is consistent with the lime consumption (Fig. 5). The decrease of lime content is important for the 10% bentonite mixture between 28 and 112 days. On the other hand, for the two other mixtures, the lime consumption seems to have stabilized after 56 days. The quantity of lime has thus not been sufficient for mixtures at 15% and 20% bentonite. Both UCS stabilization for mixtures at 15% and 20% of bentonite after 56 days and UCS increase at HBC at 56 days show that if the 15% and 20% bentonite mixtures have been treated with more lime, their UCS would be increased.

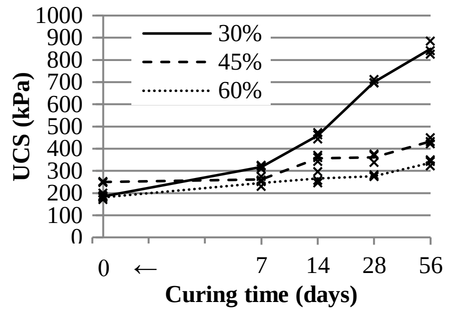

Figure 2. Compression resistance of the mixtures at 30%, 45% and 60% cured with 2% lime

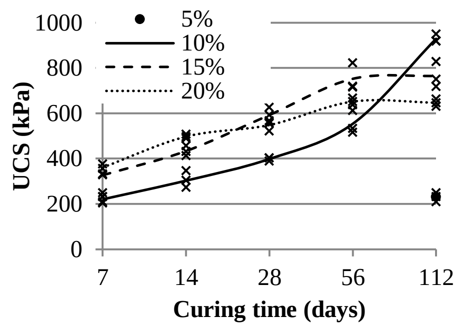

Figure 3. Compression resistance of the mixtures at 5%, 10%, 15% and 20% cured with 1% lime

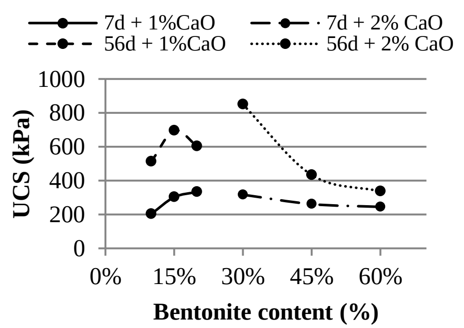

Figure 4. UCS in function of the bentonite content for two curing times

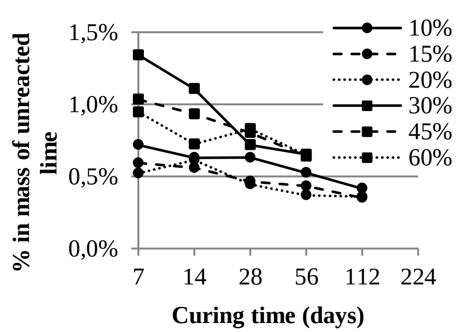

Figure 5. Lime consumption of all the mixtures in function of curing time

3.5 *Temperature effect*

Unconfined compression tests for lower bentonite contents (such as 5%, 10%, 15% and 20% bentonite) show interesting results of optimum displacement in terms of bentonite contents as a function of the curing time. However, to have a more rapid and quicker result, and also to investigate temperature effects, unconfined compression tests have also been carried out for low bentonite contents at 50°C for 7 days and 14 days curing time as shown in Figure 6.

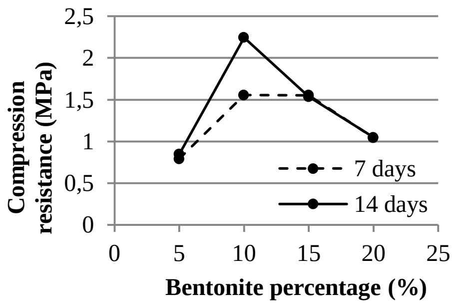

Figure 6. UCS of low bentonite mixtures at 50°C

Apart from the one at 10% bentonite, the mixtures treated at 50°C have already reached their maximal compression resistance after 7 days. At 14 days curing time, the compression resistance for these mixtures still stays the same. However, the mixture at 10% bentonite still evolves after 7 days. Consequently, for the mixtures at 15% and 20% bentonite, all the lime reacted with the soil before 7 days. On the other hand, in the mixture at 10% bentonite, the lime still has an ongoing reaction. Finally, Figure 6 shows a maximum value of compression resistance after 14 days at 50°C for the mixture at 10% bentonite. Further studies and investigations are being done to examine curing time periods at high temperatures shorter than 7 days. One of the advantages with high temperature is that the results come much quicker than the tests done in common room temperature curing times but the results should be taken with extreme caution if comparison has to be done with soil treatment at 20°C since reaction types may change between such different temperatures. ASTM 5102 indeed notes that temperatures higher than 49°C should normally be avoided and the use of a curing temperature of 40°C does not cause any significant additional pozzolanic reactions. Consequently, in order to obtain quicker results, accelerated curing times at a temperature of 38°C recommended in (Mooney and Toohey, 2010) can be considered.

4 DISCUSSION & FURTHER STUDY

Reaction between lime and bentonite depends on both quantities in the mixture. If too few quantity of lime is added the reaction prematurely stops. For example, the reaction of 1% lime with 20% bentonite and 80% sand gives a final UCS of approx. 600kPa but a treatment with 2% lime on the 30% bentonite – 70% sand mixture presents an UCS of 850kPa after 56 days and continues to higher values. This leads us to ask which optimal quantity of lime is then needed to fully react with the bentonite in the mixture. This answer needs to first measure the maximum UCS value that can reach the lime treated mixture at "infinite time". The idea is then to use accelerated curing times at 38°C so the maximum value is reached much faster the treatment at 20°C.

5 CONCLUSION

Sand takes an important part in the process of soil stabilization even if it does not directly react with lime. A soil having an important part of clay does not necessarily behave better than a more sandy soil when treated with lime. This interesting phenomenon gives us a reason to investigate further in detail the interaction between lime treatment and sand. This paper shows that lime treated bentonite behaves like a binder between sand particles. In the first step, three compositions have been studied showing that the one with the lowest bentonite content is the most resistant. This observation led us to investigate lower bentonite contents to find at which mixture composition this UCS is optimal. The results show that the optimal mixture is not the same in function of curing time. At shorter curing times, the mixture at 20% bentonite has the highest UCS, but as curing gets longer, the optimum appears for lower bentonite contents until it arrives at 10% bentonite after 112 days. There are two reasons for this to happen. First, it appeared that the mixture with the highest bentonite content reacts the most rapidly. And second, the amount of lime added in the soil has been taken as the same for the LBC mixtures and is insufficient for an optimal UCS increase in the case of higher bentonite contents. The evolution of this UCS increase is consequently stabilized too prematurely for mixtures at 15% and 20% bentonite. The next step of this research is to calculate the maximum UCS at “infinite” curing time (when no reactives are anymore present). For this, accelerated curing times at the temperature of 38°C are being taken into account.

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