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Evaluation of mechanical properties of cement treated soils with different plasticity

Évaluation des propriétés mécaniques des sols traités au ciment avec une plasticité différente

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ABSTRACT: This study examines the compression and strength properties of cement treated clays with various plasticity index. Clay samples with different plasticity were obtained by mixing kaolin and montmorillonite at different ratios. Clay blends were treated with cement in percentages of 3, 6 and 9 % in terms of the dry mass of clay blends and the amount of water content for each clay blend was set to the optimum water content. Besides, a group of cement free specimens were prepared for comparison reasons. All specimens were cured for 7, 28 and 90 days in a humidity-controlled room at a constant temperature. After curing, specimens were subjected to unconfined compression, ultrasonic pulse velocity tests.

RÉSUMÉ: Cette étude examine les propriétés de résistance des argiles traitées au ciment présentant différents indices de plasticité. Des échantillons d'argile de plasticité différente ont été obtenus en mélangeant du kaolin et de la montmorillonite à différents rapports. Les mélanges d'argile ont été traités avec du ciment en pourcentages de 3, 6 et 9% en termes de masse sèche des mélanges d'argile et la quantité d'eau contenue pour chaque mélange d'argile a été réglée à la teneur optimale en eau. En outre, un groupe de spécimens sans ciment a été préparé à des fins de comparaison. Tous les échantillons ont été durcis pendant 7, 28 et 90 jours dans une pièce à humidité contrôlée à une température constante. Après durcissement, les échantillons ont été soumis à des tests de compression non confinée et de vitesse de propagation des ultrasons.

Keywords: cement-treated clay; plasticity; unconfined compressive strength

1 INTRODUCTION

The engineering properties of cement treated soil are investigated extensively in literature. The main mechanism of cement-soil is explained by Schaefer et. al (1997). The mechanism consists of four different steps; hydration of the binder (cement, lime etc.), ion exchange, formation of cement hydration products and formation of pozzolanic recycling products (Kitazume and Terashi, 2013).

Cement treated soils can be evaluated by means of soil plasticity, compressibility, strength, volume change, deformation, permeability and freezing resistance properties. Mixing process, cement content, compaction technique and curing conditions can change the mechanical properties of cement treated soils. Besides these parameters, the most important factors affecting the mechanical properties of cement treated soil are the physico-chemical properties such as grain diameter, water content, Atterberg limits, type of clay minerals, cation exchange capacity, amount of soluble silica and alumina, organic matter content, pore water pH of soil (Porbaha et al., 2000). In the past years, chemical and mechanical properties of cement treated soils were extensively investigated by Chew et al. (2004), Horpibulsuk et al. (2011, 2012), Lorenzo and Bergado (2004), Sariosseiri and Muhunthan (2009), Verastegui Flores et al. (2009) and Gajewska et al. (2017).

Ahnberg et al. (1995) examined the changes on the strength of different soils treated with lime and cement. According to the results of their experiments, it was observed that the greatest strength increment occured in clayey silt and sensitive clays as a result of stabilization. Lorenzo and Bergado (2006) studied the effect of high water content on strength of clays and they observed the maximum strength in specimens with water content equal to liquid limit value.

Verastegui Flores et al. (2009) used a non-destructive testing method to observe the strength of cement-treated clay as a function of time. It was found that small-strain shear modulus (G_0) and strength of cement treated specimens increased logarithmically with time. Also, the functions obtained from their experiments were in agreement with data on other cement-treated studies published before.

In this study, the strength properties of clays with different plasticity and different mineral composition were investigated.

2 MATERIALS AND METHODS

2.1 Materials

Two types of commercially processed clay (kaolin and calcium montmorillonite) were used in this study. In order to obtain clay blends having a different plasticity, kaolin and montmorillonite were mixed in certain proportions (0, 10, 20, 30 and 40 % replacement level by weight of kaolin with montmorillonite). Index properties, optimum moisture content of kaolin, montmorillonite and clay blends were obtained in accordance with ASTM D 4318-10, ASTM D689 standards, respectively. Physical properties of kaolin and montmorillonite are shown in Table 1, index properties of clay blends are also presented in Table 2. Pozzolanic cement was used to observe the strength properties of clays having different plasticity. Physico-chemical properties of cement are given in Table 3. Montmorillonite clay contains 85% of montmorillonite and 10% of quartz and 5% of Ca-feldspar

Table 1. Index properties of kaolin and montmorillonite

Value (%)	Kaolin	Montmorillonite
Liquid limit	52	191
Plastic limit	30	76
Plasticity index	22	115
Optimum water content	33	45

Table 2. Index properties of clay blends

	Liquid Limit, w_L (%)	**Plastic Limit, w_P (%)**	**Plasticity Index, I_P (%)**	**Optimum water content, (%)**
10% montmorillonite	63	35	28	35
20% montmorillonite	72	38	34	38
30% montmorillonite	75	39	36	39
40% montmorillonite	98	44	54	42

Table 3. Chemical properties of cement

Component	**Cement (%)**
SiO_2	25.02
Al_2O_3	7.57
Fe_2O_3	3.69
CaO	53.27
MgO	1.33
Na_2O	0.72
K_2O	0.96
SO_3	3.37
Loss on ignition	3.56
Specific surface -Blaine (cm^2/g)	3700
Specific gravity –density (kg/m^3)	2.91

2.2 Specimen preparation

Specimens were treated with cement at three dosage levels (3, 6 and 9%) by dry weight of clay. The amount of water content in the specimens was set to their optimum water content obtained from untreated clay blends.

Firstly, kaolin and the necessary amount of cemnet that equals the 10, 20, 30 and 40% replacement level of montmorillonite were mixed in dry form by using a mixer. Then, the required amount of cement (3, 6 and 9% by dry weight of clay blends) was added until a homogenous clay blend-cement mix was obtained. After preparing the cement-clay mixtures, water equal to the optimum water content of clay blend was poured into the mixer. After 2 minutes mixing process, mixture was moved directly to the cylindrical molds with a diameter of 50 mm and a height of 100 mm and compacted by using standard proctor energy. In order to apply the standard proctor energy to the cylindrical molds, a special hammer (approximately 1/2 scale of the standard proctor hammer) was used. Preparation of mixture and compaction processes were completed in less than 30 minutes to avoid settling.

All specimens were covered with stretch wrap plastic foil to prevent moisture loss and were allowed to cure in a curing room (at 25 °C temperature and 97% relative humidity) for 7, 28 and 90 days.

2.3 Unconfined compression strength and ultrasonic pulse velocity tests

Unconfined compression tests were performed in accordance with the ASTM D 2166 test standard, at a constant speed of 1.42 mm/s until a maximum 20% of strain was achieved or specimen failure occurred. At least three specimens were prepared and subjected to unconfined compression test to provide repeatability.

Ultrasonic pulse velocity (UPV) test is a non-destructive test method that measures the velocity of compression stress waves. The velocity of these compression stress waves travelling in a solid material is affected by the density and stiffness of the material. If a material having large air voids would be subjected to upv test, pulse transmissibility and velocity of pulse would be very low.

Ultrasonic pulse velocity device consist of three elements as a wave generator, transducers and an oscilloscope unit. Transducers are connected to the device and one is used for wave transmitter, the other one is used as a wave recorder. The device is calibrated before measurement process and ultrasound gel is applied surface of the transducers in order to allow conductivity. After the travelling compression waves reached the wave recorder from the wave transmitter, the travelling time was measured in order to calculate pulse velocity by using the following equation:

$$V=L/t \quad (1)$$

Where; V, L and t define pulse velocity (m/sec), path length (m) and travel time (sec), respectively. Figure 1 shows a scheme of Ultrasonic pulse device used in this study.

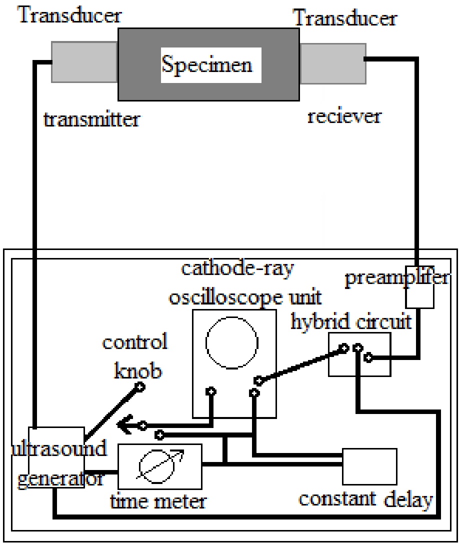


Figure 1. Scheme of ultrasonic pulse device

3 RESULTS AND DISCUSSION

3.1 Undrained shear strength of cement treated clays

The effect of the plasticity properties on the strength of cement-treated clays was evaluated in unconfined compression tests.

Stress-strain curves of untreated kaolin and kaolin-montmorillonite blends are shown in Figure 2. Also, as it can be seen in Table 2, the replacement of montmorillonite causes an increase in plasticity as expected, a distinct decrease of the strength of the clayey soils was observed with increasing montmorillonite content and plasticity. This effect was more clear in clay blend containing 40 % montmorillonite. As it is known, montmorillonite generally shows low strength based on its high plasticity (Tiwari and Ajmera, 2011). The authors stated that, even small proportions of montmorillonite increased the plasticity and reduced the shear strength of soils.

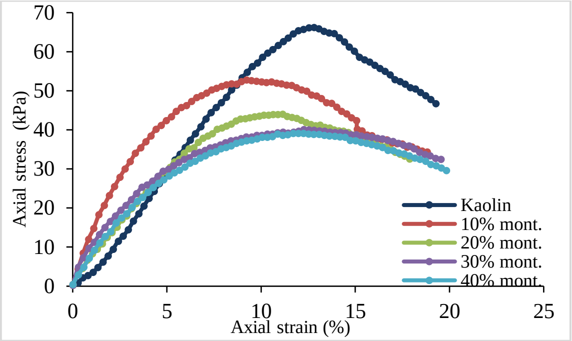
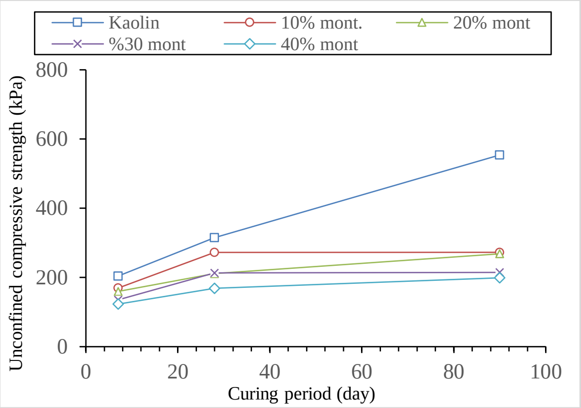


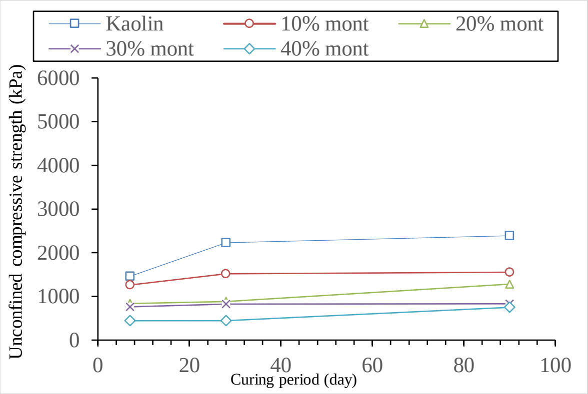
Figure 2. Stress and strain curves of untreated clays with different plasticity

Irrespective of montmorillonite replacement level and curing period, addition of cement causes remarkable increase in unconfined compressive strength (UCS) values (Fig 3). Strength increase is due to hydration of cement and pozzolanic reactions in specimens. In the first 7 days strength increase is provided by hydration of cement however, it should be noted that, after 7 day the pozzolanic reactions cause further strength increase.

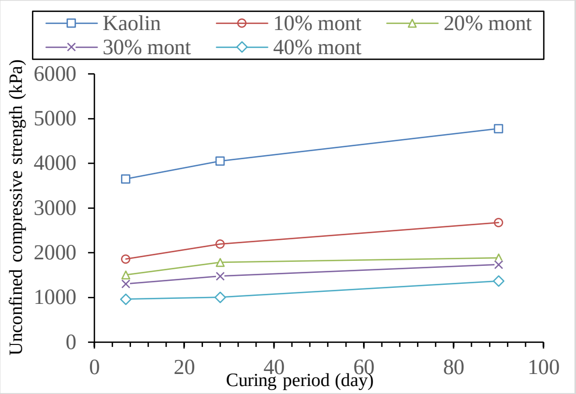
Strength gain generally is proportional with cement content during the first 7 days as a result of hydration reaction. In the case of pozzolanic reactions, different mechanisms are involved. Pozzolanic reaction is the most effective in kaolin-cement mix. Furthermore, Ca^{+2} ions released by cement during pozzolanic reaction interact with kaolin. Therefore, the long-term increase in strength in specimens containing kaolin is much greater than montmorillonite-containing specimens.



(a)



(b)

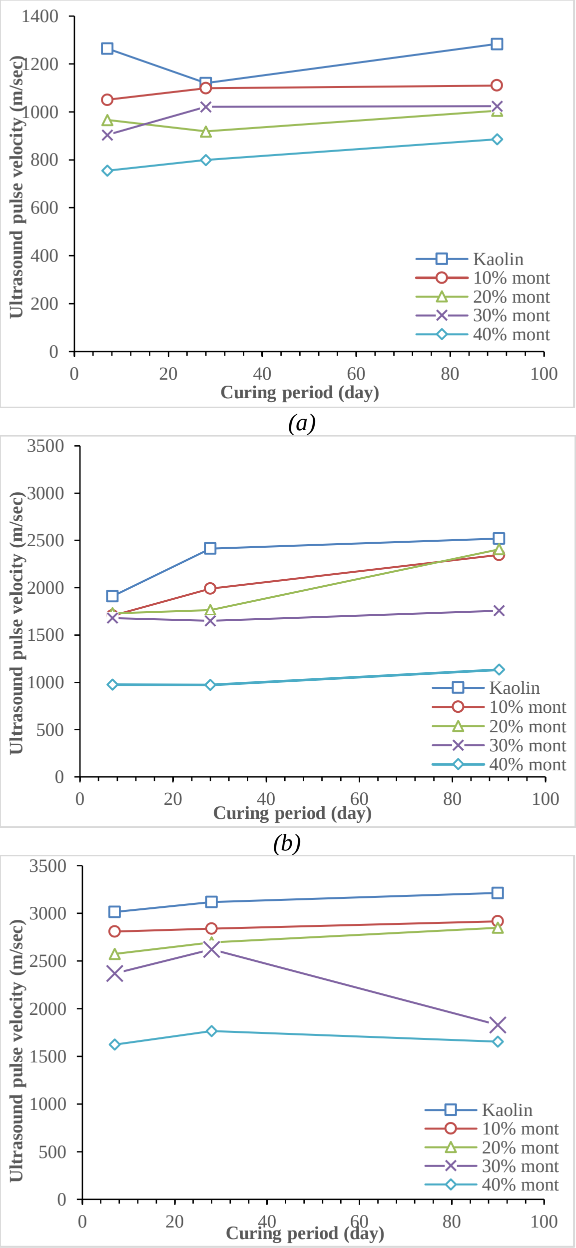


(c)

Figure 3. Unconfined compressive strength values of specimens containing (a) 3% cement (b) 6% cement (c) 9% cement against curing time

3.2 Ultrasonic pulse velocity of cement treated clays

As it can be seen from Fig 4, the ultrasonic pulse velocity increased with increasing cement content and decreasing montmorillonite replacement level. The ultrasonic pulse velocity value can be explained by the cementitious products from the hydration-pozzolanic reactions, volume of voids and microcracks in the transition zone of the stabilized specimens. The structures of the stabilized specimens are constituted by compaction process. After curing time, the cementitious products formed and these cementitious products increased the ultrasonic pulse conductivity by filling the gaps of the samples and by an increase of the compression modulus. Therefore, it can be concluded that ultrasonic pulse velocity rate is higher in the more rigid and high strength specimens. According to Fig 4, the effects of Montmorillonite on the results are limited for 20 and 30 percentages and that also the influence of the curing time for this cement percentage is not significant.



(a)

(b)

(c)

Figure 4. Ultrasonic pulse velocity values of specimens containing (a) 3% cement (b) 6% cement (c) 9% cement against curing time

Moreover, a correlation between the unconfined compressive strength, ultrasonic pulse velocity is presented in Figure 5. The correlation may provide a non-destructive approach for the observation of strength of cement treated clays. Fig 5 implies that the accuracy of correlation decreases for very high unconfined compressive strength values. This behaviour may be a result of increasing unconfined compression strength due to more bonding when more cement is added. However, the compression modulus does not change anymore after sufficient cement amount.

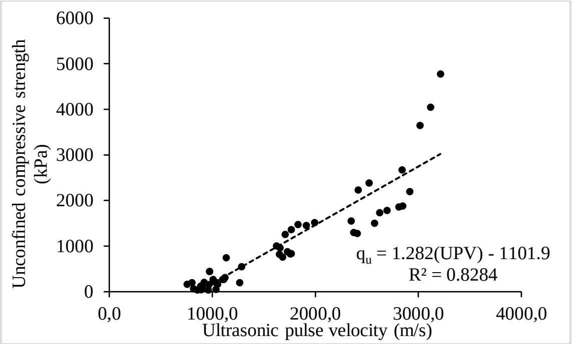


Figure 5. UPV and UCS relationships obtained by linear curve fitting

4 CONCLUSIONS

In this study, the effect of plasticity, cement content and curing period on cement treated clays are investigated by unconfined compression tests and ultrasonic pulse velocity measurements. Major outcomes of the study can be summarized as follows:

Higher compressive strength of the specimens is obtained by increasing cement content and curing time. However, unconfined compressive strength decreases with the increase of the plasticity, in other words, the montmorillonite content. Ultrasonic pulse velocity is affected by curing time, montmorillonite replacement level and cement content as well as the unconfined compressive strength. The highest UPV value is obtained in the specimen having highest strength consequently the specimen that the pores were mostly filled with cementitious products. Finally, reasonable correlation between UPV and unconfined compressive strength was obtained.

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