Procedia Engineering
Volume 143, 2016, Pages 187–195
Advances in Transportation Geotechnics 3 . The 3rd International Conference on Transportation Geotechnics (ICTG 2016)

Silty Sand Stabilized with Different Binders

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Abstract
The paper presents results of unconfined compression strength and seismic wave measurements during curing on a silty sand stabilized with three type of binders: geopolymers, lime and a mixture of lime and fly ash. Unconfined compression tests and indirect tensile tests were performed after 63 days of curing, and seismic wave measurements with ultrasonic transducers were measured during the curing period. The tests results show that specimens stabilized with geopolymer give much higher strength and stiffness results than the other binders. The specimens prepared with soil-lime-fly ash mixtures show a just slight increase in strength comparing to soil-lime specimens, conversely to what has been reported by other authors.

Keywords: Geopolymer; fly ash; lime; seismic wave velocities; unconfined compression strength

1 Introduction

Artificially cemented soils have been used as very convenient materials for transportation infrastructures, such as subgrades in roads or railways (Viana da Fonseca A. , Rios, Amaral, & Panico, 2013) (Viana da Fonseca, Amaral, Panico, & Rios, 2014). One of the major advantages is that in situ soils can be used, avoiding economic and environmental costs related with collection, transport and disposal. In general, ordinary Portland cement is used although its production is responsible for releasing a significant amount of carbon dioxide to the atmosphere. The total CO_2 production derived from the cement industry is estimated to represent between 5 to 8% of the global carbon dioxide emissions (Scrivener & Kirkpatrick, 2008). This has led to the development of new binders such as geopolymers made by the alkaline activation of fly ash. On the other hand, some authors (Narendra, Sivapullaiah, & Ramesh, 2003) (Consoli, Dalla-Rosa, & Saldanha, Variables Governing Strength of Compacted Soil-Fly Ash-Lime Mixtures, 2011) (Consoli, Dalla-Rosa, & Saldanha, 2011) have shown that adding a mixture of low calcium fly ash and lime to the soil provides much high strength improvement than using

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Selection and peer-review under responsibility of the Scientific Programme Committee of ICTG 2016

doi:10.1016/j.proeng.2016.06.024

lime alone. This is very interesting because the production of lime also generates carbon emissions and therefore, the possibility to reduce the lime content while increasing strength is much more sustainable.

2 Background

Geopolymers as described by (Davidovits, 1991) result from the reaction between aluminosilicate materials (like fly ash) and alkaline solutions such as sodium or potassium silicates and hydroxides. To improve the conditions for the alkaline activation, the original raw material source of the aluminosilicate material should be subjected to a preliminary thermal treatment that transforms its structure from crystalline to amorphous creating an environment where chemical combinations are easier. For that reason, raw materials with a natural or artificial thermal history, such as fly ash, blast-furnace slag, Portland cement residues, pozzolanic wastes, or metakaolin, are more suitable for alkaline activation than noncalcined materials (e.g., clay or feldspars). The conceptual model used to describe the reaction mechanism can be summarized in the following sequence: dissolution, precipitation/gelation, and crystallization/hardening (Duxson, et al., 2007). In the precipitation/gelation stage, also named as polymerization, the smaller molecules agglutinate to form larger molecules that precipitate in the form of short-range ordered aluminosilicate gel, a three-dimensional structure where Si occurs in a variety of environments. This three-dimensional network continues to grow and the gel evolves from an Al structure to a Si structure while the mechanical strength notably increases. The application of geopolymers for soil improvement start from the same hypothesis used for Portland cement, that is, the soil does not participate in the chemical reaction, but the created binder bonds the soil particles.

These geopolymeric reactions made by low calcium fly ash are quite different from the pozolanic reactions that support the hardening of soil-lime mixtures. In lime mixtures the soil takes part in those reactions and therefore the type of soil has a major influence on the treatment success. Clayey soils are often treated with lime, since cation exchange and flocculation reduces their water content and plasticity index. Clay is also better for the pozzolannic reaction because it provides silica and alumina ions for the formation of calcium hydrate aluminosilicates similar to the products generated by the curing process of Portland cement.

3 Experimental Program

3.1 Materials

The soil involved in this research program is classified as silty sand according to the Unified Classification System (ASTM, D 2487 Standard Practice for Classification of Soils for Engineering Purposes (Unified Soil Classification System), 2000). It results from the weathering of Porto granite, a rather abundant rock in the north and central regions of Portugal. The particle size distribution plotted in Figure 1 shows evidence of a very well graded soil containing about 30% fines from which only 8% is clay (mainly kaolinite). The Atterberg limits gave values of w_L =34% and w_P =31% thus IP=3, which makes this soil non plastic. The specific gravity of the solids was determined as 2.72. The effective diameter, D_{50}, is 0.25 mm, with uniformity and curvature coefficients of 113 and 2.7 respectively (Viana da Fonseca, Rios, & Amaral, Structural Anisotropy by static compaction, 2013).