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Stabilisation of clayey and marly soils using industrial wastes: pH and laser granulometry indicators

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ABSTRACT

The use of non-conventional additives in soil stabilisation has increased significantly in recent years. Nevertheless, the effectiveness of alternative additives, which can be determined by the impact promoted on the pH of the soils, could be limited due to insufficient time for the pozzolanic reaction (associated with a quick decrease of pH). Thereby, this paper focuses on the study of the efficacy of using different dosages of innovative industrial wastes in both clayey and marly soils. The additives studied were dolomitic lime (from residual quarry sludges), biomass fly ash, steel slag (from Electric Arc Furnace), and conventional lime which was used as a control. The effectiveness of these additives was evaluated by measuring the evolution of pH, carbonate content and particle size at 0, 7, 14 and 28 days. Results showed that residual dolomitic lime can be as effective as commercial lime in soil stabilisation, while the biomass ash used in this work was found to be the least effective additive. All additives used in this study led to greater changes in soil properties for clayey samples.

1. Introduction

Soil stabilisation is a technique commonly used in civil engineering to improve poor engineering properties (such as high plasticity, low permeability, and low mechanical strength) of soils, which make them unsuitable for use as building materials. The addition of conventional additives such as lime or cement to the soil is frequently used in soil stabilisation to improve its performance.

The hydration process promoted by the use of these stabilisation agents produces a cation exchange and the flocculation of the soil particles. As a result of the agglomeration of particles, a soil with coarser particle size distribution, lower plasticity and higher permeability is obtained (Kinuthia et al., 1999; Lin et al., 2007). Besides, the presence of OH^- ions causes an increase in pH values, enabling the development of a pozzolanic reaction. In this reaction, the Si and Al present within the mineral structure of the soil (or added by the stabilisation agents) are combined with the available Ca^{2+} from the additives, resulting in cementitious compounds, such as Calcium Silicate Hydrates (CSH) and Calcium Aluminate Hydrates (CAH) (Yong and Ouhadi, 2007; Chen and Lin, 2009). The formation of these compounds improves the resistance properties of the soils.

In addition to these traditional additives, certain authors (Dermatas and Meng, 2003; Misra et al., 2005) have analysed the incorporation of non-conventional agents in soil stabilisation, in an attempt to improve the geotechnical characteristics of soils while reducing environmental and economic costs. In this context, the use of industrial by-products and waste materials which otherwise must be disposed of has been found to be especially beneficial. Thereby, some authors (Basha et al., 2005; Hossain and Mol, 2011; Xeidakis, 1996) have proved that the use of wastes such as volcanic fly ash, Mg-hydroxide and rice husk ash could be appropriated for clayey soil stabilisation. However, in marly soil stabilisation the effectiveness of these alternative additives could be limited due to a quick decrease of pH values, which detains the pozzolanic reaction (Chen and Lin, 2009; Aiban, 1994; Al-Amoudi et al., 2010) and therefore the improvement of soil characteristics. Thus, the efficacy of these alternative agents in relation with the specific type of soil should be studied before their general use is proposed.

In this sense, this paper aims to study the potential effectiveness of using several industrial by-products in the stabilisation of both clayey and marly soils, carrying out an analysis of the viability of using these materials as stabiliser agents. For this purpose, the evolution of pH values and carbonates content was measured for different treated soils as control parameters for the pozzolanic reactions and changes in the soils properties. These parameters were analysed since they have been proved to have a remarkable influence on the evolution of soils properties Ramesh et al. (2012). In addition, the changes in the particle size of the soils were tested to prove the effectiveness of the alternative stabiliser to change the behaviour of soils. In this study, the non-conventional additives were 5% and 10% of biomass fly ash, steel slag (from Electric Arc Furnace) and dolomitic lime. Furthermore, soil

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Table 1
Natural soil properties, referred to dry weight.

Properties	Marl	Clay
Physical properties		
Liquid limit	58%	69%
Plastic limit	30%	28%
Plasticity index	28%	41%
Maximum dry density	1.6 g/cm^3	1.2 g/cm^3
Optimum water content	19%	40%
Swelling	0.88%	4.59%
Chemical properties		
Carbonates	38.2%	17.9%
Sulfates	1.64%	0.38%

stabilisation by using conventional hydrated lime was carried out as a control. The curing times used in this work were 7, 28 and 42 days, trying to analyse the evolution of soil properties.

2. Methodology

2.1. Materials

2.1.1. Soils

In this study, the soils used were a sample of natural marl from the region of Jaén and clayey soil from the area of Granada, both located in Southern Spain. Table 1 shows the main properties of the soils used in this work. In both cases, soils were classified as Clay with High plasticity (CH), according to the Unified Soil Classification System (USCS). In addition, Figs. 1 and 2 show the X-Ray Diffraction (XRD) analysis carried out for a more accurate characterisation. Mineral compositions of both soils were similar: calcite, dolomite, quartz, illite, palygorskite and smectite clay minerals (montmorillonite-beidellite). These clay minerals whose peaks are around 7° 2θ angles contribute to produce a high plasticity and swelling-shrinking properties in the soils (Table 1).

2.1.2. Additives

The additives tested in this work were hydrated lime, dolomitic lime, biomass fly ash and steel slag. Lime was used as a control since it is commonly used in soil stabilisation and it has been proved to be an effective agent (Al-Mukhtar et al., 2012; Obuzorm et al., 2012). This stabiliser was a commercial lime called CL-90-Q, according to the Spanish Standard UNE-EN 459-1 AENOR, Asociación Española de Normalización y Certificación (2011). Table 2 shows the chemical composition of this additive (as well as the rest of the additives used in this work), which was obtained by X-ray fluorescence (XRF).

Dolomitic lime used in this research was made from residual sludges in a quarry (dedicated to the production and extraction of dolomites and dolomitic marbles, which are abundant in the natural location of the tested soils) from the nature stone cutting. Thus, the use of this additive, mainly composed of CaO, MgO, CaCO3, MgCO3 could lead to the reduction of economic costs in soil stabilisation along with an improvement in the waste management system.

Another additive used in this study was biomass fly ash, which is a by-product formed during the incineration of olive waste to produce electricity, and thereby this additive is mainly composed of quartz, sylvite, alkali sulfate, calcite, dolomite, hematite, and, also, some silicates (Mg_2SiO_4) and aluminates ($Ca_2Al_2SiO_7$). The deviation of the baseline from the background is typical of amorphous materials. This material was tested because it is abundant in Southeastern Spain. Also, the use of biomass fly ash, in soil stabilisation would allow for the reduction of waste material formed in the production of energy by incineration of biomass, leading to a double environmental benefit.

Steel slag is an industrial by-product obtained from Electric Arc Furnace. The production of this waste has increased in the last decades as a consequence of the great industrial growth, reaching 400 million tonnes of iron and steel slag per year, according to Worldsteel Association, 2015. In this way, the application of steel ash in soil stabilisation could reduce an abundant waste. The chemical composition of this additive is shown in Table 2, and its predominant XRD pattern shows that the slag is a crystalline heterogeneous material whose main components are iron oxides, calcium (magnesium) compounds (hydroxide, oxide, silicates, and carbonate), elemental iron, and quartz.

2.2. Preparation of treated soils

The samples were prepared by mixing 5% and 10% (by total dry weight of the soil) of each additive with the different soils (marl and clay) in 1 min. Then, distilled water was added (by using an amount of water corresponding to the liquid limit of each soil, Table 1, which allows the hydration of the samples) to produce the reaction between the additives and the soil by mixing in 3 min. The maximum particle size of the soil samples was fixed in 2.0 mm since it was considered appropriate to facilitate its hydration and reaction with the additives, this size being obtained by crushing (without breaking the particles, only disaggregating the material) and sieving the original soils. The samples of soils treated with the different additives were stored in a curing room at controlled temperature of 20 ± 1 °C and 95% of relative humidity (Falciglia et al., 2014) during 7, 28, and 42 days. After the established curing times, the samples were air dried before testing them. Thus, it was possible to analyse the influence of curing time, additive dosage, and the evolution of the properties of the treated soils, by using 3 specimens per each additive (lime, dolomitic lime, biomass fly ash and steel slag), each percentage (5% and 10%) and each time (7, 28 and 42 days). This makes a number of 72 specimens per type of soil, plus other 3

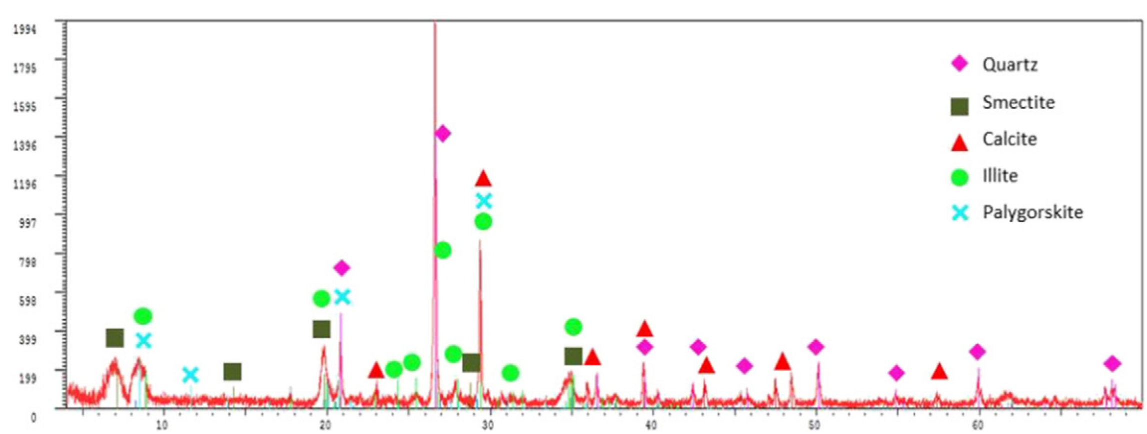

Fig. 1. XRD results for the clayey soil.