Applied Clay Science 108 (2015) 61–69

Contents lists available at ScienceDirect

Applied Clay Science

journal homepage: www.elsevier.com/locate/clay

Research paper

Stabilization treatment of a dispersive clayey soil using granulated blast furnace slag and basic oxygen furnace slag

A.R. Goodarzi *, M. Salimi

[a] Faculty of Engineering, Hamedan Branch, Islamic Azad University, Hamedan, Iran

ARTICLE INFO

Article history:
Received 18 October 2014
Received in revised form 19 February 2015
Accepted 20 February 2015
Available online 6 March 2015

Keywords:
Dispersive clay
Furnace slags
Flocculation
Pozzolanic reactions
Soil stabilization

ABSTRACT

Dispersive clays may pose considerable distress if not adequately taken care of. On the other hand, the treatment of problematic soils with waste materials has been recently proved to be a useful option from economic and environmental view point. Hence, in this research, the potential use and effectiveness of dispersive soil stabilization using two types of industrial by-product, including granulated blast furnace slag (GBFS) and basic oxygen furnace slag (BOFS) were investigated. The slags were separately added (ranging from 2.5 to 30%) to a laboratory dispersed sample and a set of experiments were performed to study the physicochemical, mechanical and microstructural changes of the stabilized soil. The results indicate that the soil dispersion can be eliminated upon adding 10% BOFS. This is attributed to the exchange of interlayer sodium ions on the clay surfaces by multivalent cations from the agent. Besides, an increase in the ion concentration of soil-additive mixtures induces a more depression of the diffuse double layer that decreases the soil dispersivity potential. With increasing the curing time, an improvement in the strength of composite samples is observed. The formation of cementitious compounds due to the pozzolanic reactions is responsible for such a treatment, as confirmed by the XRD analyses and SEM micrographs. It appears that the GBFS has a lower activity as compared to BOFS, therefore causes less influence on the soil engineering parameters and a higher percentage (20–25%) of GBFS is required to govern soil dispersion. Overall, utilization of the studied slags particularly of BOFS is very effective to overcome the problems associated with dispersive soils.

1. Introduction

Dispersive clayey soils are one of the most common problematic soils that have a wide geographical distribution and exist in several countries such as Australia, Greece, Iran, South Africa, and the United States (Gutierrez et al., 2003; Ouhadi and Goodarzi, 2006; Fernando, 2010; Abbasi and Nazifi, 2013). The soil dispersibility happens when the attractive forces (Van der Waals attraction) among the clay particles become less than the interparticle force of repulsion, resulting in weakening of the soil structure, so that the particles repel each other and go into suspension when the soil mass is even in contact with still water (Bauder et al., 2008; Zorluer et al., 2010). The soil dispersion is a complicated physicochemical phenomenon which is affected by the clay mineralogy and pore size distribution. It also depends on the chemistry of the pore and eroding fluids, since this can change the diffuse double layer (DDL) geometry and electrical charge of the clay particles that may affect the soil particle arrangement (Yildiz et al., 1999). The previous studies indicated that the presence of active clay minerals, such as montmorillonite, low electrolyte concentration, and exchangeable sodium ions contribute to dispersive behavior in soils, whereas ordinary erosion-resistant clays have a preponderance of Ca^{2+}, Mg^{2+}, and K^{+} cations (Abend and Lagaly, 2000; Baik et al., 2007). Dispersive clays are generally very stiff in dry state; however, they can be pulverized and become structurally unstable when subjected to water. This may pose considerable distress and severe damages to geotechnical structures that come into contact with dispersive soils or constructed out of them (Gutierrez et al., 2003). For example, the erosion due to soil dispersion can cause the formation of piping processes which have contributed to the failure of 37% of earth dams in different parts of the world. Such a condition may also negatively affect the self-sealing capacity of the landfill clay liners and lead to decreasing the safety performance of geoenvironmental projects (Baik and Lee, 2010).

A simple way to prevent the problems encountered in dispersive soils is to replace them with suitable materials (Ouhadi and Goodarzi, 2006). This method may have some limitations within an economic range; while, in many cases chemical modification procedures have been adopted to overcome deficiencies in the performance of problematic soils (Manso et al., 2013; Saride et al., 2013; Aldaood et al., 2014). Chemical stabilization is usually done by using additives such as lime, gypsum, and cement. However, in recent years, some disadvantages and the increased cost associated with the use of the traditional stabilizers are leading researchers to replace them with new alternative soil modifiers like industrial waste materials, either for

---

* Corresponding author. Tel.: +98 9163620733; fax: +98 8134494127.
E-mail address: amir_r_goodarzi@yahoo.co.uk (A.R. Goodarzi).

http://dx.doi.org/10.1016/j.clay.2015.02.024
0169-1317/

economic consideration, resource and environmental conservation or enhancement of soil engineering characteristics (Cokca et al., 2009; Abdi, 2011; Harichane et al., 2012). Granulated blast furnace slag (GBFS) and basic oxygen furnace slag (BOFS) are two types of by-products resulting from the manufacture of iron that are produced in large amounts throughout the world (Zhang et al., 2011). As a result of growing environmental awareness, they are highly regarded as a recycled material that can reduce impacts on the environment due to their resource-conservation and energy-saving effects. Utilization of GBFS and BOFS as supplementary cementitious materials in concrete technology is most well-known (Zhang et al., 2011; Kim and Lee, 2012). BOFS is also now used in different civil engineering fields in asphaltic mixes, road-base layers, and the context of embankment construction projects (Poh et al., 2006). Al-Rawas (2002) reported that the formation of aggregations resulted in the reduction of the swelling characteristics of expansive Al-Khod (in northern Oman) soil treated with GBFS. The other studies confirmed the positive effects of GBFS on the volume change behavior, strength and durability of clays (Cokca et al., 2009; Obuzor et al., 2011); however, based on the literature review, its application for dispersive soil treatment has not been accurately investigated. In addition, there is a lack of detailed studies on different aspects of BOFS for modification of clayey soils. Thus, the present research was conducted to address the potential use and effectiveness of GBFS and BOFS to enhance the stability of a dispersive soil. For this propose a set of macro and micro level tests including Atterberg limits, cation exchange capacity (CEC), double hydrometer, sedimentation, unconfined compression strength, pH value, EC measurement, XRD and SEM were performed to investigate the mechanisms of soil and additives interactions.

2. Materials and methods

2.1. Materials and sample preparation

The problems associated with dispersive soils have generally occurred in clays that contain predominantly expansive lattice type minerals such as montmorillonite (Abbasi and Nazifi, 2013). Besides, smectite clay (rich in montmorillonite) is utilized in many geotechnical and geo-environmental projects (Goodarzi and Akbari, 2014). Thus, in this research, smectite was used to prepare the potentially dispersive soil. The mineral identification with X-ray analysis and the chemical tests show that the used smectite contains high amount of montmorillonite and its main exchangeable cation is sodium. Therefore, it can be considered as a Na-dominant-montmorillonite which has a high tendency to dispesivity. An artificial dispersive soil sample was prepared by adding different concentrations of $NaNO_3$ solutions to the smectite at laboratory condition by an earlier described procedure of Ouhadi and Goodarzi (2006). For this purpose, the following manner was used: I) the presence of exchangeable sodium ions generally contributes toward dispersive behavior in soils. Therefore, a liter of soil-electrolyte mixture with a ratio of 1:50 was prepared by mixing smectite and a specific concentration of $NaNO_3$. Because the soil dispersion is usually occurred in low ionic concentration, the range of $NaNO_3$ was varied within 0.001 to 0.25 Normal. II) The soil-electrolyte mixtures were kept for 96 h and shake for 24 h to achieve equilibrium. III) The dispersivity of each prepared mixture was quantified employing the double hydrometer test ASTM D-4221. For this, the standard hydrometer tests were first performed to obtain the particle size distribution of samples. The non-standard tests were then run on those samples with no chemical dispersant (sodium hexa-metaphosphate) and no mechanical agitation of the solution. The dispersion of mixed samples was identified as the ratio of 5 μm particles from the parallel test to the same sized particles in the standard hydrometer test. If the ratio is greater than 50%, the soil is classified as dispersive; if it is between 30% and 50%, the soil is moderately dispersive; and if it is less than 30%, the soil is considered non-dispersive. Therefore, this ratio was considered to obtain the required concentration of $NaNO_3$ to cause the maximum dispersivity in the soil samples. Finally, the prepared dispersive smectite sample with the highest percentage of dispersion was selected in the rest of the research. The engineering properties of laboratory dispersed soil sample were then measured according to ASTM methods (ASTM, 2006). Its geoenvironmental characteristics were also determined using the procedures described in the EPA manual (EPA, 1983). The engineering and geoenvironmental characteristics of the soil sample are given in Table 1.

GBFS and BOFS produced in Iran Ferroalloys Industries Co. were selected as admixtures to improve the soil engineering properties. Their chemical compositions were determined using the XRF analysis and are given in Table 2. As it can be seen, the used by-products have a significant amount of multivalent cations that can easily exchange the cations having lower valance on the clay surfaces. The additives were separately added in amounts ranging from 2.5, 5, 10, 15, 20, and 30% in dry mass to the dispersed soil sample. Prior to mixing, all the constituents were oven dried and passed through a No. 200 (0.075 mm) sieve. The mixtures were blended with the needed amount of water for each test. They were then placed in air-tight plastic bags and cured in a warm humid chamber at temperature 22 ± 1 °C and with a relative humidity of 85%. At the end of each curing period (i.e. 1, 3, 7, and 28 days), the experiments were performed to investigate the effects of GBFS and BOFS on the dispersivity and engineering properties of the soil sample.

2.2. Macro and micro level tests

To determine dispersibility of soil different chemical and physical measurement techniques are commonly used such as pinhole test, double hydrometer test and crumb test. These tests may yield different results for the same soil samples; hence, more than one test should be used to identify dispersibility of natural soils. However, as the pinhole and crumb tests are qualitative tests, they may not be useful to monitor the quantitative impact of different percentages of additives on the soil dispersion. Besides, the aim here was not to define the exact dispersibility of unknown soil samples but to assess how the chemical stabilizers affect the behavior of soil dispersion when compared with untreated sample. Additionally, since the condition of soil suspension for performing double hydrometer test is almost similar to that employed in the sedimentation, EC, pH, XRD, and SEM tests used in this study, it would be possible to compare the physicochemical interactions and microstructural changes of treated specimens in conjunction with the dispersivity potential variations which are calculated by the double hydrometer test. Therefore, in this study, the dispersivity potential of samples was evaluated by the application of double hydrometer test. To evaluate the impact of GBFS and BOFS on the dispersivity behavior, a series of double hydrometer tests were performed on the artificially prepared dispersive samples. For this purpose, several similar suspensions of the soil-electrolyte mixtures in a ratio of

Table 1
Engineering and geo-environmental properties of dispersed smectite sample.

Characteristics	Quantity measured
Mineral composition in decreasing amount	Montmorillonite, quartz, calcite
Soil-pH	10.01
EC, mS/cm	2.70
SSA, m^2/g	463
CEC, cmol/kg	85.4
Clay fraction, %	82
Specific gravity, G_S	2.82
Liquid limit (LL), %	393.7
Plasticity index (PI), %	350.5
Soil classification	CH
Maximum dry density, gr/cm^3	1.21
Optimum moisture content, %	45.5
Unconfined compression strength[a], MPa	0.54

[a] The soil sample was mixed with the optimum moisture content and compacted at the maximum dry density.