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Research paper

Clay stabilization using coal waste and lime — Technical and environmental impacts

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ABSTRACT

This study evaluates the technical and environmental effects of coal waste materials on the stabilization of a medium plastic clay. The coal waste was used in its natural state and after igniting at 750 °C to produce the coal waste ash. In addition, hydrated lime powder was applied as a traditional stabilizer. Atterberg limits, California bearing ratio (CBR) in dry and saturated condition along with swelling and unconfined compressive strength tests were carried out. Soil structural changes during the curing period were analyzed using the X-ray diffraction and scanning electron microscope (SEM) tests. About the environmental issue, toxicity characteristic leaching procedure (TCLP) test was carried out to analyze the leachate obtained from different studied samples for heavy metal concentrations. Based on the CBR and compressive strength tests, the addition of coal waste powder and its ash to some extent enhanced the soil bearing capacity. However, the combination of these additives with lime resulted in considerably higher compressive strength and CBR especially in saturated condition. The results of X-ray diffraction and SEM analyses indicated substantial changes in the soil structure after adding the additives. The initial structure of the soil was porous and flaky which transformed to a solid and coherent structure after treating with the combination of coal waste and lime. Concentration of heavy metals in stabilized samples containing the coal waste and its ash was less than the regulatory levels determined for hazardous materials and properly satisfied the minimum requirements.

1. Introduction

Soil stabilization is one of the conventional methods used to improve the quality of road subgrade and pavement layers. This method enables enhancing the existing material properties at the project site and reaching the needed specifications. Besides, improving the quality of pavement and filling layers would reduce the total thickness of pavement and leading to a reduction in administrative costs. According to literature in the past hundred years, several additives were used as stabilizing agents. Some of these stabilizer additives consist of various types of cements, lime, pozzolanic additives and bitumen. Aside from the aforementioned materials which are considered as common soil stabilizers, in recent years, most researchers are taking greater interests on application of waste materials. In addition to land occupation, the waste depot produced from various manufacturing industries causes many environmental problems as well (Lee et al., 2011; Jafari and Esna-ashari, 2012; Fauzi et al., 2013; Ahmed, 2015). Some of the waste materials which have been taken into consideration included blast furnace slag, cement kiln dust, rice husk ash, coal ash, recycled polymer additives, recycled glass and combination of waste materials with conventional stabilizers such as cement and lime (Lee at al., 2011). In addition to modifying the behavioral characteristics of existing soil, reduction of the environmental problems resulting from the waste disposing was one of the main goals of these studies (Ansari Mahabadi et al., 2007).

Several researchers have reported on the formulation of new soil stabilizers by replacing the conventional additives with industrial waste products. During a research study, a combination of blast furnace slag and lime was applied to stabilize a low bearing capacity clay. As reported, the application of such material increased the compressive strength and the soil bearing capacity, especially during the flood condition (Obuzor et al., 2012). Other research studies have introduced the pozzolanic by-products such as the rice husk ash (RHA), cement kiln dust (CKD) and cement dust as effective stabilizer agents especially for clayey soils (Sreekrishnavilasam et al., 2007; Seco et al., 2011; Oza and Gundaliya, 2013).

In recent years, soil reinforcement with discrete fibers has been developed as another soil improving method. Jafari and Esna-ashari (2012) investigated the combination effects of tire cord waste products and lime on the mechanical characteristics of clayey soil subjected to freezing and thawing cycles. The results indicated that the compressive strength and stress–strain behavior of soil depended on both the

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stabilization and reinforcement effects of lime and fiber, respectively. Based on the obtained results, the inclusion of fiber somewhat caused flexible behavior and compensated for weakness of stabilization (Jafari and Esna-ashari, 2012).

Coal is one of the most abundant resources used to produce energy. Every year almost 5.5 billion tons of coal is produced worldwide and about half of the coal obtained from mines is buried as waste material (Doulati Ardejani et al., 2010; Garcia et al., 2012). One of the most beneficial ways to avoid the environmental problems arising from disposal of the waste materials is to consume them in construction industry such as in pavement construction layers.

Several studies have been conducted about the application of coal and particularly its ash in civil engineering projects (Mfinanga and Kamuhabwa, 2008). According to literature (Kinuthia and Nidzam, 2009; Obozor et al., 2012; Lu et al., 2014; Shibi and Kamei, 2014) the addition of coal ash to stabilized soil containing conventional stabilizers such as cement and lime increased the material strength and improved its durability against moisture and freeze–thaw conditioning. During a research study, coal waste was used as a part of embankment layer materials. Herein waste material and siliceous additives were implemented to stabilize the coal materials (Kinuthia and Nidzam, 2009). According to the attained results, the strength of the applied material was proper after 7, 28 and 90 days of curing periods (Kinuthia and Nidzam, 2009).

In most studies coal ash has been used as a supplementary additive. Due to high pozzolanic components and low free lime this additive shows the behavior of type F or type N fly ashes. The specifications of these types of fly ashes have been presented in ASTM C618 (ASTM, 2012). Shibi and Kamei (2014) assessed the effect of freeze–thaw cycles on the strength and physical properties of cement stabilized soil containing recycled bassanite and coal ash. Bassanite is a by-product derived from gypsum waste. Results showed that the addition of bassanite and coal ash combination improved the strength and durability, whereas the addition of coal ash alone had a negative effect on the strength characteristics of stabilized soil. The improvement was mainly related to the formation of ettringite as a result of reaction between the calcium oxide and aluminum oxide of coal ash and the calcium sulfate of the bassanite (Shibi and Kamei, 2014).

A comparative study was performed to assess the effects of the RHA and coal ash on the behavior characteristics of an expansive clay. For this purpose RHA and coal ash were added to the clayey soil at four levels of 0, 2, 4 and 6% by weight and cured for 180 days. Results indicated that the RHA increased the macroaggregates with a diameter larger than 0.25 mm and reduced microaggregates with a diameter less than 0.25 mm, whereas the coal ash did not significantly affect the formation of macroaggregates. Finally it was presumed that the RHA and coal ash are proper soil amendment agents for the improvement of the expansive clayey soils (Lu et al., 2014).

Apart from the technical and mechanical properties, presence of pollutants in soil or stabilizer material can bring about several risks to the surrounding environment, particularly contamination of underground water resources. For instance, excessive heavy metal concentration in the soil or stabilizer material certainly increases the risk of respiratory and cancer diseases by contaminating the underground water resources. The water penetrated to the road pavement and subgrade layers could directly seep to underground water resources. Thus, the amount of pollutant in the stabilized soil, especially the leachate removed from these layers was analyzed in many studies.

Industrial by-products such as fly ashes, red mud, biosolids, dolomitic residues and berringite, have been shown to contribute to metal immobilization (Mench et al., 2000; Garrido et al., 2005; kumpiene et al., 2007). Coal and biofuel combustion fly ashes are alkaline materials with high absorptive capacity. During a research the effects of the coal ash and peat combination on the mechanical properties of a copper and lead contaminated soil was evaluated. According to results, after the soil stabilizing process the rate of copper and lead leakage reduced as much as 98 and 100%, respectively (Kumpiene et al., 2007). The obtained results confirmed that the stabilization method was a promising technique for in situ remediation of copper and lead (Kumpiene et al., 2007).

Every year a significant amount of coal waste are gathered from the coal washing plants in Iran. For example, many dumps containing huge amounts of waste exist around the area of Alborz Markazi coal washing plant located in the northern part of Iran. During a day more than 250 tons of coal waste is produced in this plant (Shahhoseiny et al., 2013). One of the solutions for the environmental issue is the use of these coal wastes in various industries such as highway construction. The main objective of this study was to investigate the feasibility of using this material for subgrade soil stabilization and comparing it with lime as a common stabilizer.

2. Materials

In this section the technical characteristics of the studied soil and stabilizing additives used in this research are presented and analyzed.

2.1. Clay (CL)

In this research, the clay samples were provided from the suburbs of the Taleghan city, Iran. The soil gradation was determined using the hydrometer test according to ASTM D422 (ASTM, 2007). Fig. 1 compares between the gradation of the studied soil and additive materials.

Atterberg limits tests were performed using ASTM D4318 test method (ASTM, 2003). Based on the results, the liquid and plastic limits of soil were equal to 47 and 21%, respectively. According to the Unified classification as standardized in ASTM D2487 (ASTM, 2011) this soil was classified as CL. Compaction test was performed using the modified proctor method according to ASTM D1557 (ASTM, 2012). Based on the obtained results the optimum moisture content and the maximum dry density of studied soil were equal to 18% and 1.67 g/cm^3, respectively. In addition the specific gravity of the soil which was determined using ASTM D854 (ASTM, 2014), was equal to 2.57.

The chemical composition of clay was determined using X-ray fluorescence spectroscopy (XRF) method according to ASTM E 1621 (ASTM E1621–13, 2010). Table 1 presents the results of XRF test. Given this table, the main chemical compositions of studied clay consisted of SiO_2, Al_2O_3, Fe_2O_3 and CaO. The presence of the pozzolanic compositions (i.e. SiO_2 and Al_2O_3) along with the calcium oxide in the soil would play an important role in the formation of the cementitious compounds in combination with the examined stabilizers.

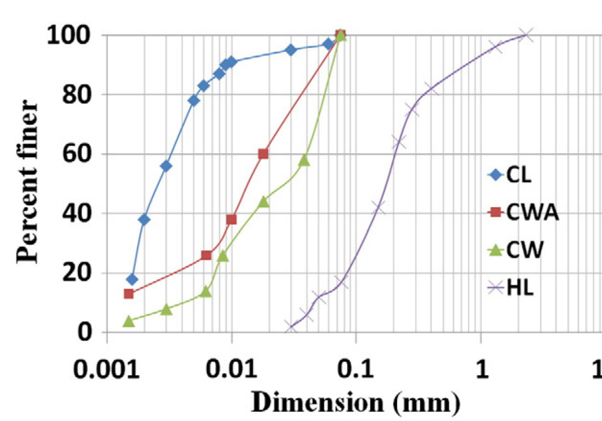

Fig. 1. Gradation of studied clay in comparison with additives.