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Ground granulated blast furnace slag amended fly ash as an expansive soil stabilizer

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Abstract

The potential of using a binder for stabilization of expansive soils that consists of a mixture of fly ash and ground granulated blast furnace slag (GGBS) is evaluated in this study. The joint use of these two materials to form a binder provides new opportunities to enhance pozzolanic activities that may reduce the swell potential and increase the unconfined compressive strength of expansive clays. The influence of different percentages of binder on the Atterberg limits, compaction characteristics and unconfined compressive strength of an artificially-mixed soil were examined. The addition of binder was shown to bring about a significant improvement in these soil properties. It was found that the liquid limit and plasticity index of the expansive soil decreased considerably with the addition of binder, while the strength improved. Adding a small amount of lime (one percent) further improved the soil properties by enhancing the pozzolanic reactivity of the binder. Based on the results of the unconfined compressive strength tests, the addition of 20% binder is recommended as optimum content. In addition, the mineralogical and morphological studies of soil specimen stabilized with optimum binder content suggested the formation of hydrated particles and cementitious compounds as a result of the reaction between the clay and the binder. Test results indicate that the use of GGBS mixed fly ash as binder to stabilize expansive is well suited for sustainable construction besides economic benefits.

Jel classifications: D00; D10

Keywords: Fly ash; GGBS; Stabilizing agent; Index properties; Unconfined compressive strength; XRD; SEM

1. Introduction

Expansive soils are known worldwide for their volume change behaviour due to variation in the water content. Expansive soils contain clayey minerals such as montmorillonite, which increase in volume during wetting and decrease in volume during drying. This change in volume can exert sufficient stress on a building, sidewalks, driveways, basement floors, pipelines and even foundations to cause damage. Expansive soils are clayey soils with large specific surface area and high cation exchange capacity (Nalbantoğlu, 2004; Nalbantoglu and Gucbilmez, 2001). Since expansive soils are found worldwide, the challenge to civil engineers is one felt around the globe. If not adequately treated, expansive soils may act as a natural hazard resulting in severe damage to structures (Al-Rawas et al., 2002). To date, distress problems related to this type of soil have resulted in the loss of billions of dollars in repairs and rehabilitation (Nelson and Miller, 1992). Expansive soils are found worldwide, mainly in the arid and semi-arid regions (Mishra et al., 2008) such as Australia,

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Canada, China, India, South Africa, and the United States. In India, expansive soils are popularly known as Black cotton soils, and cover nearly 20% of the total land area (Shelke and Murty, 2010).

Lime and cement are well known additives for the stabilization of expansive soils (Al-Mukhtar et al., 2010; Bell, 1996; Prusinski and Bhattacharja, 1999; Yong and Ouhadi, 2007). These additives are produced from industrial processes and are associated with the emission of greenhouse gases such as carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O). Industrial by-product materials such as fly ash (Cokca, 2001; Ferguson, 1993; Phani Kumar and Sharma, 2004), blast furnace slag (Cokca et al., 2009; Higgins, 2005), cement kiln dust (Miller and Azad, 2000; Zaman et al., 1992), limestone dust (Brooks et al., 2010) as additives are becoming more popular due to their relatively low cost. Additionally, CO_2 emissions can be reduced significantly by the increased use of such supplementary cementing materials currently wasted in lagoons and landfill sites. The most important feature in the stabilization of clayey soils is the ability of stabilizer to provide a sufficient amount of calcium (Wang, 2002). Industrial waste, such as fly ash and blast furnace slag can be used as stabilizing agents because they are siliceous and calcareous materials.

The purpose of this study is to investigate the joint activation of fly ash and ground granulated blast furnace slag (GGBS) in the stabilization of expansive soils. In India, the two types of industrial waste produced in the greatest volumes are fly ash and granulated blast furnace slag, with an annual production of 170 and 15 million tonnes, respectively (Chatterjee, 2011; Singh et al., 2008). The majority of fly ash is utilized in the cement industry, for construction of roads and embankments, and for manufacturing of bricks, while GGBS is mainly used as partial replacement of cement in concrete. These industrial by-products have also great potential to be used as stabilizing agents. However, the utilization rate is as low as 58% for fly ash and 55% for blast furnace slag (CEA, 2014; Singh et al., 2008). The main reason for their underutilization is the lack of pozzolanic reactivity. Indian fly ash, which is obtained by burning bituminous coal has a low lime content of less than 10% (Sunku, 2006). Hence, a chemical activator such as lime or cement is added to improve its pozzolanic reactivity. On the other hand, GGBS (obtained after granulated slag is ground into fine powder) is a latent hydraulic cement (rich in lime content) which only needs to be activated (Bijen, 1996).

There is a wide variation in the chemical properties of fly ash and GGBS. Fly ash is low in calcium oxide content but rich in silica and alumina while GGBS is relatively high in calcium oxide. The combination of these two materials can be more beneficial when used as a stabilizing agent than using them individually. Each can provide sufficient lime or silica to support pozzolanic reaction, thereby requiring lower amounts of chemical activators. Studies relating to the alkali activation of slag/fly ash mixtures in blended cements and concretes have been carried out by few researchers (Bijen and Waltje, 1989; Puertas et al., 2000; Shi and Day, 1999). However, no studies on the joint activation of fly ash and GGBS as stabilizing agents for expansive soils have been published to date.

In recent years, a number of stabilizers from various industries have been developed for the purpose of soil stabilization. Stabilizers can be amended with activators like lime or cement to enhance their cementitious and pozzolanic properties. Wild et al. (1998) improved the unconfined compressive strength of sulphate containing soils by stabilizing them with lime and GGBS. A study by Kolias et al. (2005) showed the technical benefits of using a combination of fly ash and cement as stabilizing agents. An experimental study carried out by Degirmenci et al. (2007) demonstrated the possibility of using a mix of phosphogypsum, cement and fly ash for soil stabilization. Lin et al. (2007) used different percentages of sludge ash and hydrated lime mixtures to stabilize soft soils. The laboratory test results indicated that strength of the soils with additives increased significantly, while the swelling behaviour reduced considerably. In a study on granular soils, freezing–thawing durability of the samples was found to improve when stabilized with mixtures of silica fume-lime and fly ash-lime (Yarbaşı et al., 2007). Samaras et al. (2008) performed experiments to show how fly ash and lime could be used as a stabilizing agent for sewage sludge. Chen and Lin (2009) improved the basic properties of a subgrade soil by using a mix of cement and incinerated sewage sludge. In a study on stabilization of expansive soil, Al-Rawas (2002) showed that additives such as copper slag containing higher amounts of Na^{+} but lower amount of Ca^{2+} and CaO were less effective than GBFS, which had low amounts of Na^{+} but relatively higher amount of CaO. Calcium ions help in reducing the intensity of swell potential of the soil containing smectite and illite clay minerals by forming aggregations of different sizes. He concluded that the chemical composition of stabilizing agents provides a good indication about their effectiveness in soil stabilization and should essentially be determined.

An attempt has been made in this study is to utilize mixture of fly ash and GGBS as binder to stabilize expansive soil. Since both the materials require alkali activation, addition of small amount of lime in the binder is also considered. The influence of the binder on Atterberg limits, compaction characteristics and unconfined compressive strength of the expansive soil have been taken into account for evaluating performance.

2. Materials and methodology

2.1. Materials

This investigation was carried out on an artificially-mixed soil containing 80% Black Cotton (BC) soil and 20% commercial sodium bentonite (by dry weight).The mixed soil was selected to represent high swelling soil since bentonite clay is widely known for its high swelling characteristics. This was done to observe the effectiveness of the binder on the properties of a relatively higher swelling soil. The BC soil used in this study was procured from the Belgaum district of Karnataka state, India. The commercial sodium bentonite used in this study was obtained from the Kolar district of Karnataka state, India. Both the BC soil and commercial sodium bentonite were air-dried and pulverized to pass an IS (Indian Standards) 425 μm sieve prior to use. The artificially-mixed soil was prepared by mixing oven dried BC soil and bentonite with the