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Research paper

Swelling and geo-environmental properties of bentonite treated with recycled bassanite

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ABSTRACT

This paper describes an investigation of the use of recycled bassanite, which is derived from plasterboard waste, as an additive material to mitigate the swelling potential of bentonite considering its environmental impact. Recycled bassanite was mixed with furnace cement and with lime at 2:1 ratios, and then the admixture was mixed with the tested bentonite at four different content ratios. The effects of adding bassanite admixture on the swelling properties, mechanical properties, environmental properties, microstructure, and mineralogical composition of the tested bentonite were investigated. The test results indicated that recycled bassanite has the potential for use as a stabiliser to mitigate swelling in expansive clay. Increasing the admixture content reduced the potential for swelling, the plasticity, the montmorillonite intensity, the percentage of sodium ions and the cation exchange capacity of the bentonite. The compressive strength, unit weight and percentage of calcium ions were increased for all admixture contents used. The different bassanite–cement/lime admixture contents resulted in approximately the same reduction in the swelling potential of the tested bentonite. The bassanite–cement/lime admixture had much more pronounced effects on the swelling and mechanical properties of the bentonite than bassanite alone. The bentonite treated with 6% admixture content exhibited the greatest reduction in swelling potential; hence, this admixture content ratio is considered optimal for stabilising bentonite and mitigating its swelling. The measurements of hydrogen sulphide gas, fluorine solubility and pH of the treated bentonite were found to be within the acceptable limits, indicating that bassanite–cement/lime admixtures used did not have any negative environmental effects. However, bassanite is not recommended for use alone as an amendment for expansive clay because it releases fluorine at amounts that may exceed the allowable limit in some cases.

1. Introduction

Bentonite is an expansive clay, which can be problematic as a foundation soil due to its susceptibility to swelling in wet conditions. Swelling in bentonite soil is related to an imbalance in electrical charges and cation exchange capacity produced by sodium-based montmorillonite (Ameta et al., 2007). To reduce the potential for swelling in bentonite, it is necessary to balance the electrical charges in the soil structure and minimise the ion exchange capacity. This can be accomplished through the replacement of sodium ions in bentonite by inorganic compounds such as calcium. This approach has been applied in a wide range of studies to reduce the swelling potential of expansive clay soils and achieve acceptable stability (Al-Mukhtar et al., 2012; Eisazadesh et al., 2012; Al-Mukhtar et al., 2010; Ahmed, 2009; Yilmaz and Civelekoglu, 2009; Buhler and Cerato, 2007; Al-Rawas et al., 2005; Ameta et al., 2007; Tonoz et al., 2004; Basma and Tuncer, 1991; Cokca, 2001). The stability of expansive soil is especially important for lightweight structures such as small buildings, temporary roads and embankments. Construction of lightweight structures over expansive soil poses many challenges due to upward pressure on foundations that causes cracks and other architectural damages. Several methods can be used in order to mitigate the soil swelling potential. The most appropriate mitigation method depends on the type and purpose of the structure and the depth of the active zone (i.e. the swelling soil). The use of lime, cement, fly ash, and other chemicals as additives to mitigate the potential for swelling of expansive clay soil has been studied extensively (Akcanca and Aytekin, 2012; Al-Mukhtar et al., 2012; Al-Mukhtar et al., 2010; Bin-Shafique et al., 2010; Ahmed, 2009; Buhler and Cerato, 2007; Guney et al., 2007; Al-Rawas et al., 2005; Tonozet al., 2004; Cokca, 2001; Mathew and Narasimha, 1997; Bell, 1996; Basma and Tuncer, 1991). The use of gypsum as a stabiliser for expansive soil has been limited (Yilmaz and Civelekoglu, 2009; Ameta et al., 2007) and has not received much attention in the literature, even though gypsum is rich in calcium, which can replace sodium ions in bentonite. In addition, the few studies that have addressed the application of pure gypsum as a stabilising material for expansive clay soils did not consider all relevant

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aspects, particularly the environmental impact. Furthermore, to the best of the authors' knowledge, the use of recycled gypsum/bassanite produced from gypsum waste, rather than pure gypsum, has not been reported in the literature. Yilmaz and Civelekoglu (2009) investigated the use of different quantities of pure gypsum in the treatment of expansive soil and reported that gypsum had the potential to be used as a stabilising agent for expansive clay soil. Ameta et al. (2007) studied the use of a lime–gypsum mixture to reduce the potential for swelling of expansive clay soil from economic point of view and obtained promising results. In both studies, only pure new gypsum was used as a stabiliser to mitigate swelling potential, and the environmental impact of its use was not considered.

In order to address the ever-increasing demands to reduce the construction cost and associated environmental impact as well as declining natural recourses, significant emphasis is placed recently on using recycled and waste materials in the construction industry. Waste gypsum plasterboard is produced in large quantities throughout the world because gypsum is used in many applications in the construction industry, including: plasterboard, drywall, wallboard, and decoration. The disposal of gypsum waste in landfill sites pauses a serious problem because it emits hydrogen sulphide gas and fluorine in excess of permitted limits when exposed to water (Kamei and Horai, 2009; Ahmed et al., 2011a; Kamei et al., 2015). Consequently, gypsum waste must be sent to controlled landfill sites, which increases the cost of its disposal.

The use of recycled bassanite, produced from gypsum waste plasterboard by heating, to improve the strength of weak soils has recently been explored (Ahmed, 2015; Kamei et al., 2013a,b; Ahmed et al., 2011a,b; Kamei et al., 2007) as a way to reduce the quantity of gypsum waste, reduce the cost of gypsum disposal in landfills, protect the environment and reduce the cost of earthwork projects. To the best of the authors' knowledge, the use of recycled bassanite as a stabiliser for expansive clay soil has not been reported in the literature.

Calcium is the main component of bassanite, present as $CaSO_4 \cdot 0.5H_2O$. This gives rise to the idea of using recycled bassanite as an additive to reduce the swelling potential of expansive soils. In addition, the positive results obtained by employing pure gypsum to reduce swelling clay reported by Yilmaz and Civelekoglu (2009) and Ameta et al. (2007) provide further motivation for exploring this application. Therefore, the feasibility of using recycled bassanite, produced from plasterboard waste, to mitigate the swelling potential of bentonite clay soil is investigated in this study, taking environmental impacts into consideration. Moreover, the effect of the type of binding agent (cement or lime) used to prevent the dissolution of the bassanite was investigated, based on the swelling potential mitigation, strength and environmental properties of the tested soil. The emission of hydrogen sulphide, the release of fluorine and the pH level were the environmental properties measured in this study. Various tests were conducted to measure the swelling and mechanical properties and the microstructural and mineralogical composition of the tested bentonite including: free swell percentage, Atterberg limits, plasticity index, cation exchange capacity, unconfined compressive strength, and unit weight. In addition, Scanning electron microscope (SEM), X-ray diffraction (XRD) and X-ray fluorescence (XRF) tests were conducted to characterise the mineral composition and microstructure of the treated bentonite.

2. Materials and methods

2.1. Materials used

The four types of materials used in this research were bentonite, recycled bassanite, furnace cement and lime. XRD diffractograms showed that the bentonite used contained montmorillonite, crystal quartz silicon dioxide, heulandite, and calcite, as shown in Fig. 1. The chemical composition, and mechanical and index properties of the bentonite used are presented in Tables 1 and 2, respectively. The moisture–density relationship for the bentonite was determined using standard compaction testing in accordance with ASTM Standard D698-12e2 (ASTM, 2012) and is presented in Fig. 2. The recycled bassanite ($CaSO_4 \cdot 0.5H_2O$) used in this research was produced from waste plasterboard ($CaSO_4 \cdot 2H_2O$) by heating. Details of the recycled bassanite production process have been presented previously (Kamei et al., 2007; Ahmed et al., 2011b). The cement used in this research was blast furnace slag cement, produced mainly from the by-products of Portland cement and iron. The chemical composition of the cement used is also presented in Table 1. The lime used in this research was a commercial lime and its chemical composition is presented in Table 1. Lime and cement were used as binding agents in this study not only to mitigate the potential for swelling but also to prevent the dissolution of the bassanite and thereby ensure the long-term strength of the soil and improve its environmental properties (Kamei and Horai, 2009; Ahmed et al., 2011b).

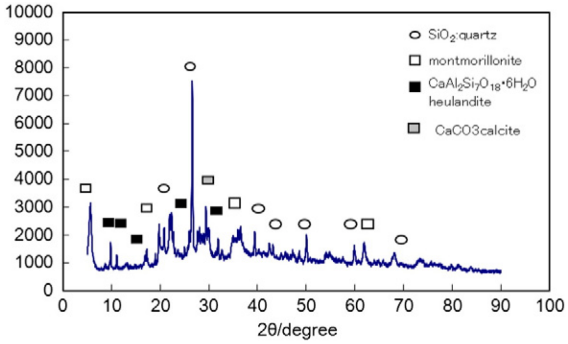

Fig. 1. XRD pattern for the bentonite.

2.2. Sample preparation method

The recycled bassanite was mixed with lime and with cement at ratios of 2:1. This ratio was selected based on previous research results (Ahmed and Issa, 2014) that showed this ratio to be necessary to provide long-term strength. Also, Ameta et al. (2007) reported that the best performance of gypsum–lime admixtures used to mitigate the potential for swelling of expansive clay soil was obtained at a mixing ratio of 2:1. The admixtures produced are referred to here as bassanite–cement (B–C), bassanite–lime (B–L), and bassanite only (B). Four different admixture contents, 3, 6, 9 and 12%, based on the dry soil weight, were tested. The admixtures were mixed with the tested bentonite to assess the feasibility of using recycled bassanite as a stabiliser to mitigate the swelling potential of bentonite. The recycled bassanite was first mixed with lime or cement in a dry state, and the required content of each admixture was mixed with the tested bentonite in a dry state.

Table 1
Chemical compositions of the bentonite, cement and lime.

Chemical composition	Content, %		
	Bentonite	Cement	Lime
SiO_2	61.97	26.30	1.01
Al_2O_3	15.20	8.70	0.20
Fe_2O_3	2.65	1.90	0.05
CaO	3.30	54.10	91.11
MgO	2.25	3.70	3.49
SO_3	–	2.00	0.03
Na_2O	3.37	0.26	–
K_2O	1.19	0.42	–
TiO_2	0.20	0.69	–
P_2O_5	0.09	0.08	–
MnO	0.07	0.28	–
Cl	–	0.007	–
R_2O, (%)	–	0.54	–
Ignition loss	9.71	0.80	–
Insoluble residue	–	0.20	–