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Research paper

Effect of lime and fly ash on swelling percentage and Atterberg limits of sulfate-bearing clay

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ABSTRACT

Lime and fly ash are admixtures used to reduce the swelling of clay. The current study added 3%, 5%, and 7% (wt) of lime to sulfate-bearing clay and found that chemical reactions between the lime and sulfate-bearing clay led to ettringite formation as the lime content increased. This mineral shows good potential for water absorption, which increased the swelling percentage and pressure and the plastic properties of the clay. It was shown that lime is incapable of improving the swelling properties of sulfate-bearing clays. Next, 3%, 5%, and 7% (wt) of fly ash was added to the clay. Fly ash suppressed swelling and decreased the plasticity index of the clay. The optimum content of 3% (wt) fly ash improved the swelling properties of the sulfate-bearing clay. The fly ash was then added to 5% lime-stabilized sulfate-bearing clay. The results showed that the fly ash compensated for the negative effects of the lime, reducing the swelling percentage and pressure and the plasticity index of the lime-stabilized sulfate-bearing clay.

1. Introduction

Clay that shows changes in volume with variation in the moisture content is referred to as expansive clay (Nelson and Miller, 1992). A change in volume can cause cracking and damage to structures built upon expansive clay with the accompanying financial loss (Wayne, 1984; Avsar et al., 2009). Clays, especially those classified as CL and CH, are expansive (Komin and Ogata, 1996; Khattab et al., 2007) and experience softening and a decrease in strength when saturated (Ghose and Subbarao, 2007). It is common to use admixtures such as lime, cement, fly ash, and a combination of lime and fly ash, lime and silica fume, and lime and blast furnace slag to stabilize expansive clay (Mutaz and Dafalla, 2014; Zaimoglu et al., 2015). To treat clay, these admixtures create reactions that produce a cation exchange effect and pozzolanic reactions (Al-Mukhtar et al., 2012). Cation exchange quickly stabilizes the clay and improves its plastic and compaction properties (Leroueil and Bihan, 1996).

Lime increases the calcium and magnesium ions which substitute for sodium and potassium ions in the clay. Because the latter have little dependence on water, they improve clay properties and decrease swelling (Abdi and Wild, 1993; Kumar et al., 2007). The plastic limit of clay increases as well, but the liquid limit will either increase or decrease (Saride et al., 2013; Bell, 1996; Wild et al., 1996; Guney et al., 2007; Al-Rawas et al., 2005; Bozbey and Garaisayev, 2010). The reaction of lime with clay depends on the temperature of the environment. Heat production caused by quicklime can facilitate the reactions.

Quicklime can cause variation of the Atterberg limits (Oates, 1998). Pozzolanic reactions result in formation of calcium silicate hydrate (CSH), calcium aluminate hydrate (CAH), and calcium alumino silicate hydrate (CASH) gels (Mitchell, 1986; Croft, 1964). When dissolved in the silicate and alumina of clay, carbo-alumia hydrate may form depending on the existing CO_2 content (George et al., 1992). The pozzolanic reaction decreases the liquid limit, plasticity index, and swelling of clay (Khemissa and Mahamedi, 2014; Goodarzi and Salimi, 2015; Kinuthia et al., 1999; Grimshaw, 1971). The modification of performance, strength, and formability of the clay are other effects of this reaction (Rajasekaran, 2005).

The pozzolanic reaction of the fly ash decreases the plastic and swelling properties of the clay (Seco et al., 2011; Buhler and Cerato, 1999; Sharma et al., 2012; Ji-ru and Xing, 2002; Kolay and Ramesh, 2015). The presence of metallic sulfate in the clay, underground water, or the penetration of sulfate through the sulfate-bearing water can results in various clay reactions, especially cation exchange and pozzolanic reactions (Sherwood, 1962). These change the lime-clay reactions in lime-stabilized clay and causes swelling and loss of strength (Abu Seif, 2015; Ouhadi and Yong, 2008; Kinuthia and Wild, 2001; Celik and Nalbantoglu, 2013; Wild et al., 1999; Manso et al., 2013). The destructive effects of the sulfate in the lime stabilized clays has been discussed by many researchers, and in some projects the swelling value of up to 30 cm has been reported (Ouhadi and Yong, 2008). The engineering properties of the lime stabilized clay are crucially related

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Table 1
Physical properties and mineralogical composition of clay.

Properties	Measured value	XRD analysis results
Liquid limit (%)	120	Illite (I)–Montmorillonite (M): (40%)
Plastic limit (%)	35.9	Quartz (Q): (37%)
Plasticity index	84.1	Gypsum (G): (4%)
Special gravity	2.64	Calcite (C): (8%)
Maximum dry density (g/cm^3)	1.41	Orthoclase (O): (2%)
Optimum moisture content (%)	29	Jarosite (J) (6%)
Natural moisture content (%)	5.81	
Color	Milky	
Unified soil classification standard	CH (79% clay size, 21% silt size)	

Table 2
Physical properties of the lime and fly ash used in study.

Physical properties	Lime	Fly ash
Color	Milky white	Bright grey
Specific gravity	2.37	2.3
Moisture content (%)	1	0.5
Minimum density (kN/m^3)	5.5	–
% Sand size	13	3
% Silt size	76	76
% Clay size	11	21

to the presence of sulfate (Wild et al., 1999). Actually, the simultaneous presence of clay, lime and plaster causes that the calcium silicate and calcium aluminate not to be formed, but to form ettringite (Yazici, 2004). Ettringite formation in lime stabilized sulfate bearing clay has been discussed in previous studied carried out by other researchers (e.g., Celik and Nalbantoglu, 2013, Manso et al., 2013, and Wiliam et al., 1999).

Abu Seif (2015) has investigated the effect of alive lime on the swelling potential of the expansive clays and demonstrated that if there is sulfate in the reaction environment, addition of lime >3% will increase the percentage and pressure of swelling due to the formation of expansive minerals like ettringite. Wild et al. (1999) carried out a test about the effect of the sulfate on clays on lime stabilized clays and showed that if the sulfate exceeds 1.8%, ettringite forms and therefore the swelling increases.

The current study investigated the effect of fly ash admixture on sulfate-bearing clay stabilized with lime and without lime. Sulfate-bearing clay was first stabilized using different amounts of lime to investigate the effect of lime on swelling and the Atterberg limits. Next, the effect of the addition of fly ash on clay and lime-stabilized clay was investigated.

2. Materials and methods

2.1. Clay and admixtures

The clay used in this study was sulfate-bearing illite-montmorillonite. The physical properties and XRD analysis results are presented in Table 1. The clay diffraction pattern is shown in Fig. 1.

Lime and fly ash were used to treat the clay. The lime was industrial hydrated lime (calcium hydroxide) and the fly ash was F class. The physical properties of the lime and fly ash are provided in Table 2.

Distilled water was used throughout the study. Table 3 shows the results of chemical analysis of the clay and the admixtures. As shown, the clay was illite-montmorillonite that have been detected that are as mixed-layers with a high liquid limit containing 2.45% total SO_3.

2.2. Sample preparation

The method proposed by Mohamed (2013) was followed for sample preparation. Initially, all materials were dried thoroughly and then sieved through a #40 sieve. Table 4 shows the results for the three sample groups sulfate. Group 1 comprised sulfate-bearing clay samples with lime contents of 0%, 3%, 5%, or 7% (wt). This group was produced to investigate the effects of lime on the swelling and plastic properties of the samples (samples 7L, 5L, and 3L in Table 4). Group 2 comprised sulfate-bearing clay samples with 3%, 5%, and 7% (wt) fly ash. The samples in this group were produced to investigate the effect of fly ash on the swelling and plastic properties of sulfate-bearing clay (samples 5F, 3F, and 7F in Table 4). Group 3 comprised sulfate-bearing clay stabilized with 5% lime to which was added 3%, 5%, or 7% (wt) fly ash. These samples were produced to investigate the swelling and plastic properties of fly ash on the 5% lime-stabilized sulfate-bearing clay (samples 5L7F, 5L5F, and 5L3F in Table 4). The lime and fly ash contents used as admixtures are approximately those used in previous studies (Al-Rawas et al. (2005) for lime and Seco et al. (2011) and Zha et al. (2008) for fly ash). Al-Rawas et al. (2005) considered 3, 6, and 9% of lime admixture to modify the swelling properties of the clay. Also, Zha et al. (2008) considered a value of 5% and Seco et al. (2011), as well, considered 3, 6, 9, 12, 15% fly ash in their studies.

2.3. Laboratory tests

Testing to determine the Atterberg limits and swelling was carried out on all samples according to ASTM D4318, 2010 and ASTM D4546, 2008 standards, respectively. Samples preparation for swelling test similar to previous researches (Al-Rawas et al., 2005; Maaitah, 2012; Aldaood et al., 2014a; Aldaood et al., 2014b; Zha et al., 2008; Al-Mukhtar et al., 2012; Cokca et al., 2009; Abu Seif, 2015; Urena et al., 2013; Kilic et al., 2015) was conducted. Initially optimum moisture content (%ω_{opt}) and maximum dry density (γ_d) based on compaction test

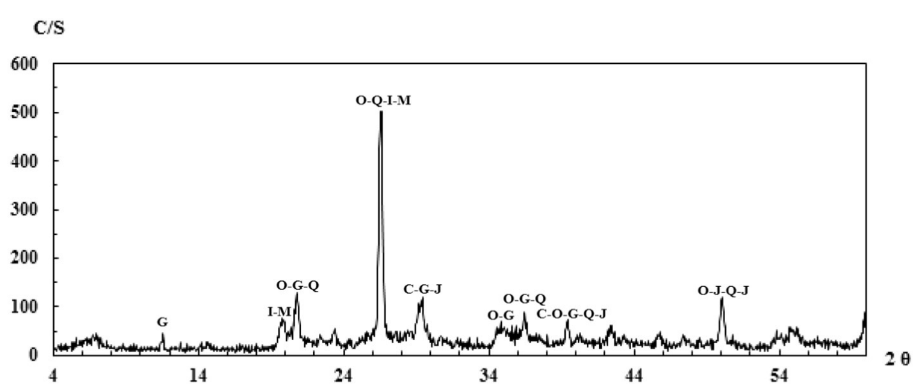

Fig. 1. The clay diffraction pattern.

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