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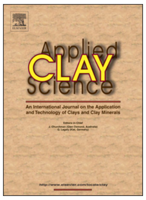

Research paper

A study on desiccation cracking behavior of polyester fiber-reinforced expansive clay

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ABSTRACT

Expansive clays swell in presence of the water and shrink in its absence, thereby producing desiccation cracks which significantly alter its mechanical and hydraulic performance. In this study, the improvement in the crack resistance of locally available expansive clay by polyester fiber reinforcement was investigated. Laboratory tests were conducted to quantitatively evaluate the effect of fiber content and fiber length on desiccation cracking of fiber reinforced clay. The alkaline stability of the polyester fibers was tested by exposing the fibers to harsh alkaline environment and was found to be suitable for the soil under consideration in barrier systems. A digital image acquisition system was employed to capture the evolution and propagation of cracks in the soil specimen subjected to desiccation. The results demonstrate a significant influence of fiber reinforcement on the cracking behavior of expansive clay at the onset of desiccation. The average crack opening width, the spacing of cracks and the average cell area were measured and compared with those of unreinforced specimen. In fiber reinforced clay, a noticeable reduction in the total cracked area, which is due to the presence of fibers, has been observed. The crack intensity factor (ratio of the area of the cracks to the total specimen area), the average width, the spacing of cracks and the cell area decreased with fiber inclusion, thereby increasing the relative integrity of the specimen relatively. The average shrinkage strain for unreinforced and fiber-reinforced soil specimen was also determined. Fiber reinforcement was found to be effective in restraining desiccation cracking except when longer fibers were used.

1. Introduction

Expansive clay is abundant over a 0.3 million m^2 area in India, and covers central India and the Deccan Plateau. These are derived from the basaltic traps, the ferruginous gneisses, and the schists of central and south-central India. The substantial presence of the montmorillonite mineral imparts high shrink-swell potentials (Chen, 1988). Clay-rich soils having low hydraulic conductivity are used in waste containment systems like landfill liners and covers. Since expansive clays have a high clay content and low hydraulic conductivity (in the order of 1×10^{-9} m/s) they can potentially be used as an impervious barrier material in landfill lining systems. However, due to their shrink-swell nature, they have a tendency of severe desiccation cracking leading to distress in impervious barriers of landfill lining systems.

Desiccation cracking alters the long-term sealing effect of impervious barrier layers in landfill lining systems to generate leachate, which may eventually contaminate the soil and groundwater (Miller et al., 1998; Witt and Zeh, 2005). Albrecht and Benson (2001) showed that the hydraulic conductivity of the clay layer increases as much as by an order of three due to cracking, because the cracks act as drainage paths for water infiltration. Various methods such as surface moisture barriers (Albright et al., 2004) and chemical stabilization have been attempted by several researchers in the past to mitigate desiccation cracking of clay barriers. Chemical stabilization of the soil by using additives such as lime, cement and sand reduced the shrinkage potential of the soil significantly (Leung and Vipulanandan, 1995; Omidi et al., 1996). The shrinkage behavior reduced in these cases, but in some cases, an increase in hydraulic conductivity of soil was observed due to aggregation of clay particles. Other methods of reducing desiccation cracking involve compaction control, surcharge loading and thermal methods (Nelson and Miller, 1992; Steinberg, 1998).

Several researchers have shown that the inclusion of natural or synthetic fibers in soil increases its bearing capacity and shear strength. Original use of the fiber reinforcement involved the natural use of plant roots or the use of available fibers such as sisal, straw, coconut fiber, coir and the like in order to increase the shear strength and stability of slopes (Gray, 1978; Wu et al., 1988). The main advantage of discrete reinforcement of soil with fibers over conventional geosynthetic

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sheet reinforcement is the absence of a single potential plane of failure (Maher and Gray, 1990). Fiber reinforcement helps in preventing tensile crack formation, and in reducing the swelling potential, the liquefaction potential, the thermal conductivity and the brittle behavior of the material (Hejazi et al., 2012; Viswanadham et al., 2010). Viswanadham et al. (2009) studied the effect of discrete geofiber reinforcement on the improvement in the swelling behavior of a locally available expansive soil. It was found that the swelling potential and swelling pressure significantly reduced due to the presence of the fibers. Viswanadham et al. (2011) and Divya et al. (2014) reported a significant increase in delay in cracking of fiber reinforced soil with an increase in fiber content due to the ductile behavior.

Al-Wahab and El-Kedrah (1995) reported a reduction of 25%–45% in desiccation crack index (ratio of area of cracks to the total surface area) due to fiber reinforcement of compacted clay. The amount of shrink-swell was reduced by 30%–35%. Ziegler et al. (1998); Miller and Rifai (2004) and Harianto et al. (2008) also observed that fiber inclusion reduces the desiccation cracking of the soil, along with an improvement in the mechanical performance of the soil.

Recently, Phanikumar and Shankar (2016) investigated the hydraulic conductivity of fly-ash stabilized expansive clay as a liner material, and reported that the hydraulic conductivity decreased with increase in fly ash content for different permeating fluids. Sabat and Nayak (2015) found out that 25% fly ash-calcium carbide residue is optimum for expansive clay to be used as a liner material. However, much less attention has been paid to modification of expansive clay with fiber reinforcement for application as a clay barrier. In addition, the past work did not pay sufficient attention to the distribution of fibers within the clay mass. Even distribution of fibers within the clay mass is paramount in attaining effective fiber reinforcement for improvement in desirable engineering properties of soil. Hence, the primary objective of this work is to assess the potential of polyester fibers in restraining desiccation cracking of expansive soils. Secondly, the study aims at evaluating the effect of fiber content and fiber length on the distribution of fibers in soil mass during mixing, and its effect on desiccation cracking.

2. Materials and methods

2.1. Expansive clay

The expansive clay was collected from a construction site at a depth of about 1.5 m below the typical root zone, near the city of Nanded in Maharashtra, India. The clay was characterized for its physical, mineralogical, chemical and geotechnical properties, as discussed below.

2.1.1. Physical properties

The physical properties of the clay are reported in Table 1. The specific gravity, G_s, of the clay was determined using Helium Gas Pycnometer (Pycnomatic ATC), according to ASTM D 5550 (2006) because it is considered to give reliable and accurate results for expansive clays (Uday and Singh, 2013). The particle size distribution of the soil is presented in Fig. 1. Various percentage fractions such as gravel (>4.75–< 19 mm), sand (>0.075–<2 mm), silt (>0.002–<0.075 mm) and clay (<0.002 mm) were determined according to ASTM D 422-63 (1994). The Atterberg limits were determined according to ASTM D 4318-93 (1994) and ASTM D 427-93 (1994) and the soil was classified as Clay of High Plasticity, CH, according to the Unified Soil Classification System (USCS).

Table 1
Physical properties of soil used in the study.

Soil properties	Value
Specific gravity	2.58
Size fraction	
Gravel (%)	1
Sand (%)	5
Silty (%)	34
Clay (%)	60
Atterberg limits	
Liquid limit (%)	87
Plastic limit (%)	38
Shrinkage limit (%)	20
Free swell index (%)	120
Soil classification	CH

Note: CH, high plasticity clay; According to USCS (Unified Soil Classification System).

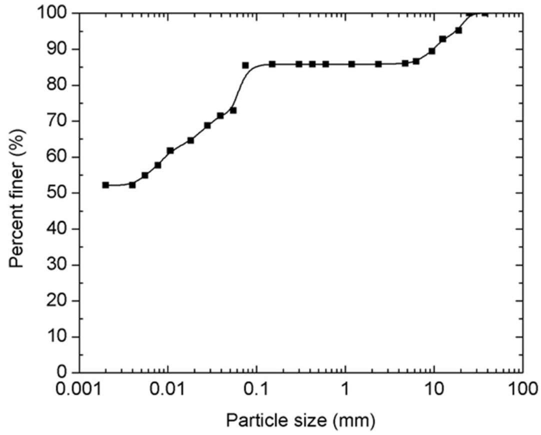

Fig. 1. Particle size distribution of soil used in the study.

2.1.2. Mineralogical properties

X-ray diffraction (XRD) spectra yielded the mineralogical composition, which is reported in Table 2. The presence of the mineral montmorillonite (49.3%) signifies the expansive nature of the soil under consideration (Viswanadham et al., 2009).

2.1.3. Chemical properties

The chemical composition of the clay was determined by X-ray fluorescence (XRF) and is reported in Table 2.

2.2. Polyester fibers

The polyester fibers that had a special trilobal cross section with an effective diameter of 40 μm were used as shown in Fig. 2a. The amount of adhesion force and fiber sliding resistance between the fiber and the soil is proportional to the contact surface area and the fiber surface roughness (Tagnit-Hamou et al., 2005; Frost and Han, 1999). The irregular trilobal shape offers better surface roughness than the conventional circular cross section.

The mechanical properties of a single filament of polyester fiber (M/s. Pragati Enterprise, India) was determined according to ASTM D 1577-07 (2012) and ASTM D 3822 (2014) by using specialized single fiber tensile test equipment (Textechno Fafegraph ME, Germany) at the Bombay Textile Research Association (BTRA), Mumbai, India, as reported in Table 3. The breaking force-strain curve of a single fiber filament is presented in Fig. 2b. Three consecutive tensile tests were performed on single fiber filament extracted from the polyester fiber yarn. The linear

Table 2
Mineralogical and chemical composition of soil used in the study.

Mineralogical composition (%)	Montmorillonite	Anorthite	Calcite	Quartz	Magnetite
	49.3	41	5	4.3	0.4
Chemical composition (%)	SiO_2	Al_2O_3		CaO	MgO
	47.3	12.5		6.3	8.3

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