Geotextiles and Geomembranes 46 (2018) 646–655

Contents lists available at ScienceDirect

Geotextiles and Geomembranes

journal homepage: www.elsevier.com/locate/geotexmem

Stabilization of soft clay using short fibers and poly vinyl alcohol

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ARTICLE INFO

Keywords:
Geosynthetics
Fiber reinforcement
Chemical stabilization
Expansive clay
Polymer
UCS

ABSTRACT

In this study, the effect of the combined addition of fibers and a nontraditional polymer on the mechanical behavior of a clay was investigated. Poly vinyl alcohol, PVA, used as a solution with concentrations of 0.1%, 0.3%, 0.5%, 1.0% and 1.5% and 1,2,3,4 Butane Tetra Carboxylic Acid, BTCA was added as a crosslinking agent at concentration rates of 0.1%, 0.3% and 0.5%, respectively. Short polypropylene fibers were added to the clay at proportionate quantities of 0.25% and 0.50% of the dry weight of the soil. Clay samples were prepared for unconfined compressive strength (UCS) tests at two different initial void ratio values, denoting relatively stiff and markedly soft states. UCS tests were conducted on both 1-day and 14-day cured samples. The results confirmed significant UCS improvements with combined fiber reinforcement and PVA-BTCA stabilization when samples were cured for 14 days. It was also observed that fiber reinforcement outperformed PVA-BTCA stabilization for clays with the lower initial void ratio. PVA-BTCA stabilization was however found to be superior to fiber reinforcement in clays with a relatively higher initial void ratio. The effect of fiber reinforcement and PVA-BTCA stabilization on the stability of soils subjected to excessive wetting was also evaluated using soaking tests. Stabilization with PVA and BTCA was found to enhance the stability of soaked samples significantly. The results of soaking tests proved that BTCA made PVA-stabilized samples more durable when exposed to soaking.

1. Introduction

The design and construction of roads and other geostructures, often require incorporating poor quality soil materials with low bearing capacity and high moisture susceptibility into the construction. The Australian railway network is mainly responsible for transporting bulk commodities and freight to and from ports around the nation as well as conveying passengers along major corridors. Some of the railway networks in Australia traverse coastal areas including soft clays with very low bearing capacity and excessive settlement characteristics, which are prone to flooding. This may affect the overlying rail tracks, leading to a possible derailment. The geoengineering solutions for counteracting the adverse effects of soft and problematic soils in construction, such as pavement subgrades, include attempting to dewater and compact the subgrade soil (Pujades et al., 2014; Koerner et al., 2016; Estabragh et al., 2018), stabilization with chemical binders such as lime, cement, polymers and geopolymers (Mirzababaei et al., 2009; Sauceda et al., 2014; Puppala, 2016; Kua et al., 2017; Hoy et al., 2017), reinforcement with geosynthetics and short fibers (Viswanadham et al., 2009; Saad et al., 2012; Jamsawang et al., 2015; Mirzababaei et al., 2017a, 2017b; 2018; Soltani et al., 2018a), or other available amendment alternatives based on the project condition.

Chemical stabilization incorporates the use of chemical binders for improving the shear strength, compressibility, permeability and durability of weak soils, especially soils subjected to harsh environmental impacts (Harichane et al., 2011; Correia et al., 2015; Mohammadinia et al., 2017). Traditional chemical binders include lime, cement, fly–ash, and bituminous materials. The chemical stabilization technique often requires a curing period to enhance the strength improvement process. Research into the use of traditional binders and their stabilization mechanisms has been well documented in the literature (Sherwood, 1993; Celauro et al., 2012; Nagaraj et al., 2014; Soltani et al., 2017a). Lime has been found to successfully modify fine-grained soils by reducing the plasticity and increasing the workability and strength (Little, 1995). The strength gain mechanism in lime–stabilized soils involves an immediate change in the soil texture (i.e. flocculation),

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https://doi.org/10.1016/j.geotexmem.2018.05.001
Received 2 November 2017; Received in revised form 13 April 2018; Accepted 30 May 2018

and long-term pozzolanic and carbonation reactions (Lin et al., 2007). The addition of cement to fine-grained soils also contributes to the pozzolanic reaction, resulting in a strength gain. Unlike lime stabilization, stabilization with cement is quicker and independent from the soil type (EuroSoilStab, 2002; Yong and Ouhadi, 2007).

Non–traditional binders, on the other hand, have become increasingly available for soil improvement projects. A number of non–traditional binders have been developed for soil stabilization applications, which include polymer-based additives, sulphonated oils, lignin derivatives, enzymes, resins, silicates, and calcium/sodium chloride geopolymers (Santoni et al., 2002; Alazigha et al., 2016; Kua et al., 2017; Hoy et al., 2017; Soltani et al., 2017b; Latifi et al., 2018). Although the performance of traditional binders in combination with other reinforcing agents, such as fibers has been well demonstrated in geotechnical engineering applications (Cai et al., 2006; Estabragh et al., 2012; Anggraini et al., 2015; Kumar and Gupta, 2016; Festugato et al., 2017), limited research has been undertaken to evaluate the effect of non–traditional binders such as polymers and their combination with reinforcing elements such as fibers on the mechanical behavior of soft clays (Masoumi et al., 2013; Ayeldeen and Kitazume, 2017; Soltani et al., 2018b). There are many commercially available chemical binders that have been proved to be effective for soil stabilization and dust control purposes. However, such products often lack documentation of measured engineering properties, and more importantly, the manufacturers merely detail the involved stabilization mechanisms (Onyejekwe and Ghataora, 2015).

Polymers with hydrocarbon chains act as potential particle binders by entwining within the soil particles and thus stabilizing the weak soil into a relatively firm mass (Brown et al., 2004). Mirzababaei et al. (2009) reported a significant reduction in the swelling pressure of highly expansive clays stabilized with poly (methyl methacrylate) and poly (vinyl acetate), owing to the formation of aggregated clay particles.

Poly vinyl alcohol (PVA) is recognized as an eco–friendly, odorless, water-soluble, non–ionic and hydrophilic polymer with an excellent film forming potential, which can potentially be used to aggregate clay particles (Carr and Greenland, 1975). PVA is the only water-soluble biodegradable polymer with carbon atom chains that can be degraded in the environment by microorganisms and is capable of establishing hydrogen bonds with water. Some major applications of PVA include paint industry, paper coating, adhesives, water-soluble packaging films for detergents and short fiber production for soil and concrete reinforcement (Ojeda, 2013). PVA has also been reported as a well-accepted safe component for humans and environment in the pharmaceutical, cosmetic, food industry, and agricultural products (Luadthong et al., 2008).

As a non–toxic polymer with high flexibility and tensile strength (in dry form), PVA is an uncharged molecule which can simply diffuse into the soil pores (Greenland, 1963). Therefore, once PVA has entered the pore–spaces of the host soil, it can stabilize the soil by filling the pores and entwining within soil particles. PVA has also been reported to improve the chemical resistance of the concrete against environmental impacts such as corrosion (Viswanath and Thachil, 2007). The PVA–cement gel can effectively fill the pores in the concrete, preventing absorption of water, and thus improving the flexural strength of the concrete (Allahverdi et al., 2010; Yaowarat et al., 2017).

Soil aggregates coated with a PVA film are still vulnerable to an increase in the moisture content of the soil in that, aggregates may tend to disperse upon an exposure to the excessive free water within soil pores due to environmental impacts such as excessive rainfall. Çay et al. (2014) suggested using a crosslinking technique such as freezing/thawing, methanol treatment, chemical crosslinking, or irradiation to ensure the stability of PVA film against excessive moisture contents. 1,2,3,4–butane tetra carboxylic acid (BTCA) has been reported for crosslinking PVA to form three–dimensional hydrophilic hydrogel structures, capable of absorbing large amounts of water. The results of their research indicated that crosslinking with BTCA improved the water stability of PVA membranes and made the PVA membranes water resistant.

Mirzababaei et al. (2017a) originally investigated the effect of fiber reinforcement using short fibers on the shear strength of soft to stiff clays. It was concluded from this earlier study that short fibers did not perform well in soft clays with a high initial void ratio. Therefore, in this study, it was decided to combine the fibers with a non-traditional additive to enhance the improving effect of fibers for increasing the strength of soft clays with a high initial void ratio/moisture content. Therefore, this research on the stabilizing soft clay with PVA and studying the combined effects of PVA and short propylene fibers on the soft clay's mechanical response is novel. In this study, to investigate the combined effects of fibers and polymers on the mechanical behavior of stiff and soft clays, a series of unconfined compressive strength (UCS) tests were carried out on fiber–reinforced and polymer–stabilized clay samples compacted to relatively low (i.e. stiff clay) and high (i.e. soft clay) initial void ratio values. In order to study the behavior of stabilized samples subjected to extended curing times, a number of samples were also cured for 14 days and further were subjected to UCS tests. To investigate the durability of the stabilized samples subjected to excessive wetting, stabilized/reinforced samples with optimum PVA and/or BTCA concentrations and fiber were also subjected to soaking tests.

2. Materials

The soil used in this study was collected from Sarina Township located in Central Queensland, Australia. The soil is classified as a clay with high plasticity (CH) in accordance with the Unified Soil Classification System (USCS). The activity ratio and the specific gravity of the soil were measured as 0.50 and 2.71, respectively. The grain–size distribution of the soil indicated a 93.30% clay fraction (< 2 μm). The consistency limits included a liquid limit of 74% and a plastic limit of 27%. Mechanical properties of the soil, determined as per relevant Australian standards, are provided in Table 1. Short monofilament propylene fibers with a length of 19 mm and a thickness of 32 μm, supplied by Texo (www.Texo.net.au), were used as the reinforcements. PVA and BTCA in dry form, supplied by Sigma–Aldrich (www.SigmaAldrich.com), were used as the chemical binders. Basic properties of the fibers and the chemical binders used in this study are summarized in Table 2.

3. Experimental program

Modified Proctor compaction tests were carried out on unreinforced and 0.50% fiber–reinforced soils, and the results are provided in Fig. 1. The highest fiber content used in this study, i.e., 0.50%, did not

Table 1
Mechanical properties of the soil.

USCS soil classification		CH
Specific gravity, G_s		2.71
Activity		0.50
Grain size analysis	Sand (%)	3.60
	Silt (%)	3.10
	Clay (%)	93.30
Atterberg limits	Liquid limit, *LL* (%)	74.00
	Plastic limit, *PL* (%)	27.00
	Plasticity index, *PI* (%)	47.00
Compaction characteristics	Maximum dry unit weight, γ_{dmax} (kN/m^3)	16.20
	Optimum moisture content, ω_{opt}(%)	16.80
Swelling properties at γ_{dmax} and ω_{opt}	Swelling pressure (kPa)	218.50