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Technical note

Hydro-mechanical behavior of a lateritic fiber-soil composite as a waste containment liner

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ABSTRACT

In waste disposal landfill projects, the hydraulic conductivity of the barriers is a major consideration. The use of fibers mixed with backfill may improve the overall performance of the barriers. Fiber-soil composites show a more resistant and ductile behavior than the soil alone. The presence of fibers may reduce cracking problems related to shrinkage or traction in liners or covers. In this study, laboratory tests were performed to evaluate the use of fiber-soil composites as a containing barrier. Hydraulic conductivity and diametral-compression tests were carried out on PET fiber reinforced and unreinforced compacted soil specimens. The tests were conducted under confinement conditions similar to those found in the field. Diametral-compression tests were used to induce cracks in the specimens. Hydraulic conductivity was measured at different stages during the diametral loading. In the tests performed under low confinement pressure (10 kPa), the crack openings led to a significant increase in hydraulic conductivity. The results showed that the addition of fibers increases the tensile strength of the soil-fiber mass and delays the opening of cracks. Moreover, in the tests under high confinement pressure (100 kPa), a decrease in hydraulic conductivity occurred at all stages of the diametral load application.

1. Introduction

In waste disposal landfills, covers and bottom liners are used to limit the escape of gases and liquids into the environment. These barriers are, in general, constructed using fine-grained soil (usually clays). The primary consideration in a hydraulic barrier is hydraulic conductivity. Generally, plastic soils exhibit lower hydraulic conductivity, but may be influenced by water content and temperature variations, which may cause contraction and the formation of cracks (Andersland and Al-Moussawi, 1987; Rayhani et al., 2008). Tensile cracks can also occur due to differential stresses or differential settlements experienced by the hydraulic barrier. The existence of cracks, due to either shrinkage or traction, can significantly increase the hydraulic conductivity of a clay barrier.

There have been proposals for the use of additives to increase the mechanical strength and prevent cracking of hydraulic barriers (e.g. Miller and Rifai, 2004; Ribeiro and Lollo, 2002; Hamidi and Hooresfand, 2013). The inclusion of additives, such as cement and lime, on the volumetric retraction and hydraulic conductivity of clay soils has been evaluated. Such stabilization has been shown to be effective in the reduction of soil shrinkage, but it may not significantly increase resistance to cracking. However, these stabilization processes also reduce soil plasticity, thereby increasing the potential for cracking under shear or tensile strains, leading to an increase in hydraulic conductivity that can compromise performance.

The use of natural fibers as reinforcement has previously been evaluated (Maher and Ho, 1994; Qiang et al., 2014). Moreover, the employment of synthetic fibers has been evaluated by a number of researchers. Examples include studies on polypropylene fibers (Maher and Ho, 1994; Al-Wahab and El-Kedrah, 1995; Kaniraj and Havanagi, 2001; Tang et al., 2007; Consoli et al., 2007, 2012; Correia et al., 2015; Festugato et al., 2017; Madhusudhan et al., 2017), polyester fibers (Kumar et al., 2005) and, rubber fibers (Ozkul and Baykal, 2007). The use of polyethylene terephthalate (PET) fibers is of particular interest because PET is widely used for the manufacture of bottles and packaging for a number of products (Sax, 2010).

Unconfined compression and diametral-compression tests are usually performed to evaluate the mechanical contribution of fibers to composite behavior (e.g. Maher and Ho, 1994; Consoli et al., 2007; Festugato et al., 2017). Studies using fibers have shown improvement in the mechanical behavior of the fiber-soil composites, especially with regard to peak strength, irrespective of the type of fiber used as reinforcement. Some variations in the rupture mechanisms have also been observed, ranging from brittle to ductile behavior. The behavior of fiber-soil composites is closely related to the type, content, length and diameter of the fiber reinforcement, the type and content of the additive

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Table 1
Soil physical properties.

Specific gravity of solids, G_s		2.66
Grain sizes	% < 2 µm	22
	% < 20 µm	44
	% < 2 mm	100
Liquid limit w_L (%)		49.5
Plastic limit w_P (%)		23.0
Skempton's activity ($A = (w_L - w_P)/\% < 2$ µm)		1.2

Table 2
Physical and chemical properties of the soil.

Chemical composition (%)	Al_2O_3	30.50
	Fe_2O_3	14.06
	K_2O	0.13
	Na_2O	0.35
	SiO_2	54.95
pH	H_2O	4.72
	KCl 1N	3.95
Exchange complex ($cmol_c$/kg)	Ca^{2+}	0.1
	Mg^{2+}	
	K^+	0
	Na^+	0
	Al^{3+}	1.1
	H^+	1.2
Soluble metals ($cmol_c$/kg)	K^+	0.01
	Na^+	0.01

Table 3
Main properties of PET fibers.

Title (dtex)/Thickness (µm)	8/27
Length (mm)	10
Relative density	1.39
Tenacity (g/dtex)	2.8
Resistance to ultimate traction (MPa)	385
Elongation in the crack (%)	48.2

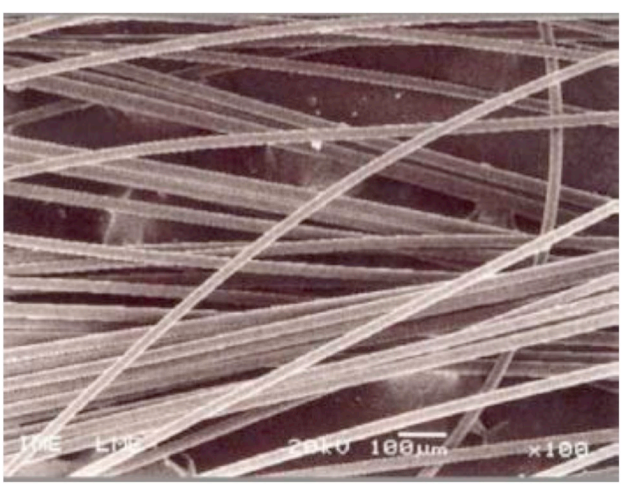

Fig. 1. Image of the fibers obtained by scanning electron microscope.

in the case of artificially cemented soils, as well as the soil properties. Laboratory tests have been performed in order to determine the effect of fiber reinforcement on desiccation cracking in compacted clay samples and the impact of fiber on the hydraulic conductivity of the fiber-soil composite (e.g. Miller and Rifai, 2004). Moreover, theoretical studies have demonstrated the significant benefit of fiber inclusion on crack reduction (Michalowski and Zhao, 1996; Rifai and Miller, 2009; Zornberg, 2002). These studies reflect that the mechanical behavior of fiber-soil composites has been studied extensively.

This paper presents the results of a laboratory study of the use of

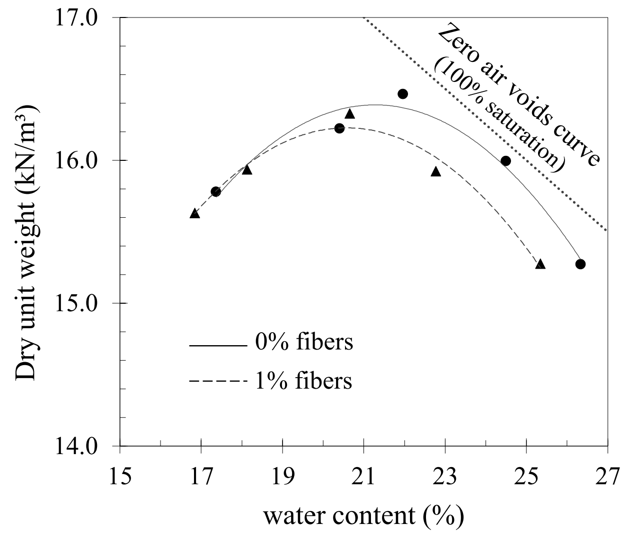

Fig. 2. Standard Proctor Compaction tests for fiber contents of 0% and 1%.

Table 4
Maximum dry unit weights and optimum water contents of the composites.

Percentage of fibers (%)	0	1
Maximum dry unit weight (kN/m^3)	16.4	16.3
Optimum water content (%)	21.2	20.7

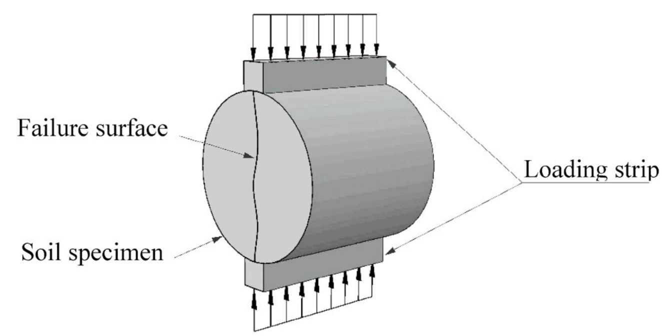

Fig. 3. Schematic representation of a diametral-compression test (DNER-ME 138, 1994).

short, recycled PET fibers mixed with soil as an effective containing barrier. Under well-controlled laboratory conditions, the potential benefit of the presence of fibers in reducing cracking of a compacted lateritic soil was evaluated. Cracking of the specimens was performed by diametral-compression tests using a specially assembled triaxial cell. Hydraulic conductivity tests were conducted, before and at various stages during the diametral loading, under different confinements in order to represent typical field conditions.

2. Soil and fiber properties

Hydraulic conductivity is the most important characteristic of a compacted soil used as a hydraulic barrier. Therefore, for good design of a fiber-soil composite considered for use as barriers, the optimum fiber content for effective reduction of cracking should be determined. The fiber-soil composite should also present good workability.

Table 1 shows the physical characteristics of the soil used in this study. The soil is clayey sand, a typical lateritic residual soil from the state of Rio de Janeiro. In tropical regions, lateritic soil occurs over broad areas. Lateritic soil deposits may reach thicknesses of several meters and are often used for embankments and hydraulic barriers,