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Shear strength behavior of geotextile/geomembrane interfaces

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ABSTRACT

This paper aims to study the shear interaction mechanism of one of the critical geosynthetic interfaces, the geotextile/geomembrane, typically used for lined containment facilities such as landfills. A large direct shear machine is used to carry out 90 geosynthetic interface tests. The test results show a strain softening behavior with a very small dilatancy (<0.5 mm) and nonlinear failure envelopes at a normal stress range of 25–450 kPa. The influences of the micro-level structure of these geosynthetics on the macro-level interface shear behavior are discussed in detail. This study has generated several practical recommendations to help professionals to choose what materials are more adequate. From the three geotextiles tested, the thermally bonded monofilament exhibits the best interface shear strength under high normal stress. For low normal stress, however, needle-punched monofilaments are recommended. For the regular textured geomembranes tested, the space between the asperities is an important factor. The closer these asperities are, the better the result achieves. For the irregular textured geomembranes tested, the nonwoven geotextiles made of monofilaments produce the largest interface shear strength.

1. Introduction

The main functions of a municipal solid waste (MSW) landfill are to permit the maximum accumulation of waste in the smallest possible space and to isolate the waste from the natural surroundings. Besides, a MSW has to maintain security and provide a future usage after its closure. Landfill liner and cover systems are mainly formed by geosynthetic protection layers, which interact on geosynthetic/geosynthetic and geosynthetic/soil interfaces.

An important subject with respect to the landfill stability is the interface shear strength, which has been investigated thoroughly in the last decade (e.g. Fox and Kim, 2008; McCartney et al., 2009; Palmeira, 2009; Eid, 2011; Fox and Ross, 2011; Brachman and Sabir, 2013; Thielmann et al., 2013).

The geotextile/geomembrane interfaces can be used for both liner and cover systems of the landfills. Geomembranes are typically used as a hydraulic barrier and geotextiles protect it from damages that may occur in some situations, such as high normal stresses and angular soil particles. Geotextile/geomembrane interfaces have previously been studied by Giroud et al. (1990), Koutsourais et al. (1991), Giroud and Darrasse (1993), Gilbert and Byrne (1996), Stark et al. (1996), Jones and Dixon (1998), Wasti and Özdüzgün (2001), Hebeler et al. (2005), Bergado et al. (2006) and Pitanga et al. (2009).

The objective of this paper is to study the interface shear behavior of the geotextile/geomembrane, providing a deeper understanding of how the structure of these geosynthetics at a micro-level influences the interface shear behavior at a macro-level. The interface shear behavior is studied by means of the direct shear tests on 18 different interfaces using 8 different geosynthetic materials. The guidelines of ASTM D5321 (2014) are followed during the direct shear test on different types of geosynthetic interfaces. The means to grip the different geosynthetics and the suitable test parameters (shear displacement rate, consolidation time, hydration time) are established based on the studies from Stark and Poeppel (1994), Stark et al. (1996), Fox et al. (1997, 1998), Gilbert et al. (1997), Jones and Dixon (1998), Eid et al. (1999), Triplett and Fox (2001), Zornberg et al. (2005), Sharma et al. (2007) and McCartney et al. (2009). The following relationships are analyzed in this study: interface shear strength vs. shear displacement, shear displacement vs. normal displacement, and interface shear strength vs. normal stress.

This paper provides a useful and practical application for both researches and practitioners who use these materials in the field, helping them to make a decision about what geosynthetic material could work better in a particular loading condition.

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2. Experimental work

2.1. Materials

The characteristics of geosynthetics used for the direct shear tests are listed in Table 1 and described as follows:

(1) Three nonwoven geotextiles: GT1 (500 g/m^2) is made of needle-punched monofilaments; GT2 (500 g/m^2) is made of needle-punched staple fibers; and GT3 (335 g/m^2) is made of thermally bonded monofilaments.
(2) Five geomembranes of 1.5 mm thickness: GMs has smooth surfaces; GMr1 and GMr4 have irregular heavy textured surfaces smaller than 1 mm; GMr2s1 and GMr3 show regular, evenly spread asperities greater than 1 mm; GMr2s2 exhibits regular spread asperities smaller than 1 mm.

Table 2 summarizes the geotextile/geomembrane interfaces tested as well as the testing conditions.

2.2. Testing equipment

The tests on geosynthetics are carried out with a large direct shear machine, whose shear box is 300 mm long and 300 mm wide and therefore fulfills the minimum requirements. The tests are performed at a constant shear displacement rate and fixed normal stress. The shear box is divided into a moving lower part and a static upper part. The geotextile is fastened to the lower box, while the geomembrane is fastened to the upper box. The following gripping systems are used for the different types of geosynthetics:

(1) Geotextiles are gripped with a double-side adhesive tape. This system works well for the range of normal stresses tested.
(2) Based on the studies of Fox et al. (1997, 1998), a particularly textured plate is designed for gripping the drainage geocomposites, the geomembranes and the geosynthetic clay liner (GCL). The dimensions of this plate are 300 mm × 285 mm × 10 mm. The plate has 210 drainage holes of 2 mm diameter and 1680 pyramids of 1 mm height, which protrudes from the topside, as shown in Fig. 1a. The bottom side has channels to allow for water flow, as shown in Fig. 1b. This plate is screwed onto a metal support that is placed into the direct shear box. The topside is in contact with the geosynthetic and the bottom side is in contact with the metal support.

2.3. Test procedure

The shear test is carried out according to ASTM D5321 (2014). The geotextile/geomembrane interfaces are tested under wet conditions with the following parameters:

(1) Hydration time is 24 h for the geotextiles and the geomembranes were not hydrated. The geotextile samples are submerged into tap water inside a humidity chamber (temperature of 21 °C, humidity of 96%).
(2) Consolidation time inside the machine is 10 min.
(3) Constant shear rate is 5 mm/min. Stark et al. (1996) and Triplett and Fox (2001) found out that the shear rate does not significantly affect the peak and post-peak strengths.

The normal stress is applied to the loading platen above the upper metal support. After 10 min of consolidation, the lower shear box moves in parallel direction to the shear force at a constant shear rate. The maximum shear displacement is 50 mm. The shear displacement, shear force and vertical displacement are recorded during the test. The shear force is measured using a suitable dynamometric ring. Two linear variable differential transformers (LVDTs) are used to measure the shear and vertical displacements.

3. Constitutive model on geosynthetic interfaces

All interfaces tested exhibit frictional behavior, which is modeled by Mohr–Coulomb's equation $\tau = c_a + \sigma_n \tan\delta$, where τ and σ_n are the interface shear strength and normal stress acting on the failure plane, respectively; c_a is the adhesion; and δ is the interface friction angle. Linear regression of the plot of τ vs. σ_n is used to identify the best-fit shear strength parameters. The shear strength of most interfaces tested in this study presents important friction angles and negligible adhesion.

4. Direct shear test results

As mentioned above, the geotextile/geomembrane interfaces are tested under wet conditions (Table 2). However, the water content does not affect significantly the interface shear strength, as shown in Fig. 2 as well as proven by Mitchell and Mitchell (1992) and Bergado et al. (2006). The range of normal stresses applied is 25–450 kPa. The peak interface shear strength is usually reached at shear displacement of 4–10 mm and the post-peak strength is obtained at shear displacement around 50 mm.

Table 1
Type of geosynthetics.

Geosynthetic	Label	Type	Raw material/Type of fiber	Manufacturing process	Mass/area (g m^{-2})	Density (g m^{-3})	Thickness (mm)[a]
Geotextiles	GT1	NW	PP/monofilament	Needle-punched	500		4 ± 0.2
	GT2	NW	PP/staple fibers	Needle-punched	500		5 ± 0.6
	GT3	NW	70% PP + 30% PE/monofilament	Thermally bonded	335		2 ± 0.2
Geomembranes	GMr1	Textured (∼0.5 mm)[b]	HDPE	Coextrusion nitrogen gas		≥0.94	1.5
	GMr2	Textured (s1: ∼1.2; s2: ∼0.8)[c]	HDPE	Calendared structured		≥0.94	1.5
	GMr3	Textured (∼1.3)[b]	HDPE	Structured same resin as base		0.94	1.5
	GMr4	Textured (∼0.25)[b]	HDPE	Coextrusion nitrogen gas		≥0.93	1.4
	GMs	Smooth	HDPE	Flat sheet extrusion		0.94	1.5

Note: NW = Nonwoven geotextile; PP = Polypropylene; PE = Polyethylene; HDPE = High density polyethylene.
[a] Thickness at 2 kPa for geotextiles, at 20 kPa for geomembranes.
[b] Average asperity height (mm).
[c] Average asperity height of GMr2, which presents two different textured sides: s1 = side 1 and s2 = side 2.