Soil-geosynthetic interface strength on smooth and texturized geomembranes under different test conditions

Résistance au cisaillement des interfaces entre sols et membranes géo-synthétiques lisses ou rugueuses sous différentes conditions

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ABSTRACT: Potential ground contamination from landfills justifies the use of sub-systems such as soil and geosynthetic layers as barriers at the landfill bottom and slopes. In configurations of barrier systems, geomembranes have often been used. For this type of application, the mechanisms of interaction between soil and geomembrane must be properly understood and failures along soil-geomembrane interfaces in slopes have been observed. This paper presents experimental results of shear strength mobilization along soil-geomembrane interfaces for different types of geomembranes and degrees of saturation of the underlying soils. Direct shear and ramp tests were used in this study. The results showed a little or no increase on values of interface friction angles with increasing degree of saturation of the soil. The highest values for interface shear strength were obtained for the texturized HDPE geomembrane.

RÉSUMÉ: Le potentiel de contamination des décharges sanitaires justifie l´utilisation de techniques d'imperméabilisation sur les fonds et les talus latéraux, tels que des couches de sols et des membranes géo-synthétiques. Pour ces systèmes d'imperméabilisation, on a souvent eut recours à des géo-membranes comme matériau imperméabilisant de protection. Pour ce type d'application, les mécanismes d´interaction entre le sol et la géo-membrane sont encore peu connus, la rupture le long de ces interfaces a été observée sur des talus par des phénomènes de glissement du sol sous la géo-membrane. Cet article présente des résultats expérimentaux de mobilisation de la résistance au cisaillement pour des interfaces sol/géo-membrane, pour différents types de géo-membranes et différents degrés de saturation des sols. Ces résultats montrent une augmentation légère voire nulle des valeurs d'angle de frottement des interfaces avec l´augmentation du degré de saturation des sols. Les valeurs de résistance au cisaillement les plus élevées ont été obtenues pour des géo-membranes en polyéthylène haute densité (PEHD) présentant une texture.

KEYWORDS: Interface strengh, geosynthetics, landfill, geomembranes.

1 INTRODUCTION

Geomembranes are often used as landfills barriers aiming at avoiding contamination of underneath soils or ground water. Some projects using these systems have a soil layer above the synthetic materials. Sometimes this soil layer is executed with sand for leachate drainage. Interaction between soil-geomembrane in landfills slopes still need a better understanding. Improper evaluation of soil-geosynthetic interation parameters for this kind of construction has yielded to slope failures along that interface (Dwyer *et al.* 2002, Gross *et al.* 2002, Palmeira 2009, for instance).

Shear strength interfaces studies of different kinds of materials can be found in the literature (Fleming *et al.* 2006 and Khoury *et al.* 2011, for instance). An increasing number of studies on soil-geosynthetic interface strength has been observed due to the risk of failures along these interfaces.

Failures due to soil sliding on a geomembrane in slopes under low stress levels can be more accurately modelled using ramp tests (inclined plane tests). Conventional direct shear tests sometimes is a adopted for this type of study, but some studies have demonstrated that for low values of normal stresses (typical in barrier systems of landfills), this kind of test may overestimate interface shear strength interface parameters (Girard et al. 1990, Giroud et al. 1990 and Gourc et al. 1996, for instance).

Some aspects related to soil-geosynthetic interface strength still need to be properly understood. With this regard, it might could be expected that soil moisture content may influence the interface strength parameters. Soil moisture content can increase due to saturation by leachate or due to infiltration of rain water.

This paper presents and discusses results from ramp and conventional direct shear tests on differents kinds of soil-geomembrane interfaces with varying soil degree of saturation.

1.1 *Parameters and interface shear strength*

Nowadays there are some studies about interface shear strength parameters using ramp tests, with several of them having addressed the use of GCL´s as lining materials. Briançon *et al.* (2002) verified that for six types of interfaces between geosynthetics and geocomposites, the effect of increasing GLC bentonite moisture content can reduce friction angles between 20 and 40%. Viana (2007) evaluated interface shear strength between soil and GCLs and found reductions of up to 43.5% on the interface friction angle.

Mello (2001) highlights the importance of studies on the influence of unsaturated soil conditions on displacements stabilization and mobilized loads in the geosynthetic layer with time. According to the author even after 120 hours using the same inclination, it was not observed reduction of the adhesion component or system failure. Besides, during this time the displacements of the sample and the transferred loads to the geosynthetic remained the same value.

Interface parameters between soils and geosynthetics are usually evaluated using Mohr-Coulomb failure criteria (Lima Júnior 2000, Mello 2001, Aguiar 2003 and Viana 2007 - see Eq. 1):

$$\tau = \alpha + \sigma.\tan\delta \qquad (1)$$

Where:
α = Adesion;
σ = Normal stress;
δ = Interface friction angle.

2 MATERIALS AND METHODOLOGY

Works in the literature have shown that conventional direct shear tests under low normal stresses levels can overestimate the values of interface friction angle (Girard *et al.* 1994, Izgin and Wasti 1998, Koutsourais *et al.* 1998, Lopes 2001, Rebelo 2003). Because of this limitation ramp tests have been increasingly used. ISO 12957-2 (2005) normalizes the execution of this type of test.

In this work ramp and conventional direct shear tests for interface shear strength evaluation were carried out varying the soil degree of saturation between 5.5 and 66%.

The soil used in the tests had 12% of fines. Table 1 shows soil proprieties.

Table 1. Soil proprieties.

Propieties	Value
γ_s (kN/m^3)	2,63
γ_d (kN/m^3)	14,14
e_{max}	1,05
e_{min}	0,67
Relative Density (%)	50

The soil retention curve was estimated using Arya and Paris' model (1981), and is presented in Figure 1. PVC and HDPE (smooth and texturized) geomembranes were tested (See Table 2).

Table 2. Proprieties of geomembranes.

Propriety	PVC	Smooth HDPE	Textured HDPE
Thickness (mm)	1.0	1.0	1.0
Mass per unit area (g/m^2)	1.2-1.35	0.947	0.946
Maximum force at Failure (kN/m)	14	35.5	33

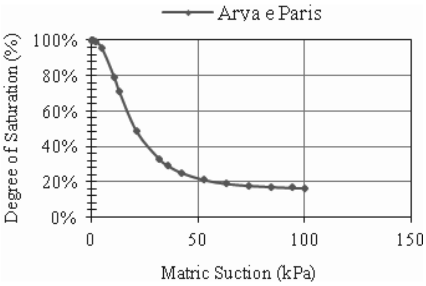


Figure 1. Estimated retention curve obtained from Arya and Paris (1981).

Seventy five ramp tests were performed where the following parameters were evaluated: interface friction angle (ϕ_{sg}); maximum relative soil displacements immediately before failure ($\delta_{máx}$) and mobilized tensile load in the geomembrane (F). In addition, 50 conventional direct shear tests were also carried out with the same soil and PVC and HDPE geomembranes.

The dimensions of the specimens and normal stresses in the ramp tests were equal to 51 cm x 51 cm and 1.2 kPa, 3.2 kPa and 7.2 kPa, respectively. These values were based on others studies and they aimed at simulating low confining pressures when only a thin cover soil (or drainage layer) is on the geomembrane in a slope of a waste disposal area.

(a) (b)

Figure 2. (a) Ramp test and (b) Conventional direct shear test.

Double layers of lubricated plastic films were used underneath the geomembrane specimen to reduce friction between the geomembrane and the ramp smooth metallic surface. This procedure was adopted to maximize the mobilization of tensile force in the geomembrane. The top extremity of the geomembrane specimen was fixed to the ramp structure by a clamping system connected to a load cell. This allowed the measurement of mobilized tensile forces in the geomembrane during the test. Figure 2 (a) presents a general view of one of the ramp tests performed.

For the conventional direct shear tests, the specimens had a plan area of 100 cm^2 (10 cm x 10 cm, Fig. 2b) and higher confining pressures were used, with values equal to 25 kPa, 55 kPa and 150 kPa.

3 RESULTS OBTAINED

3.1 *Interface friction angle*

Table 1 and Figure 3 present values of interface friction angles obtained from ramp and conventional direct shear tests for the range of degree of saturation tested. Mean and standard deviation values are also presented in Table 1.

The interface friction angles obtained were rather insensitive to changes in the soil saturation degree (S_r) for the interfaces tested. The variations of results can be considered to be within the expected scatter of results in this type of test. The standard deviation varied between 1.5^o and 3^o with large variations having occurred for the direct shear tests. The highest interface friction angle in the test with the texturized HDPE geomembrane was obtained for the highest value of degree of saturation. However, it was noticed that for higher values of S_r a certain amount of soil intruded between the soil box and the ramp, influencing the results to some extent. The same can be noticed for the test with the smooth PVC geomembrane.

A progressive failure mechanism was observed in the tests with the PVC geomembrane because of the extensible nature of this geomembrane. Figure 4 shows a view of the anchored extremity of the geomembrane specimen in one of the tests with the PVC geomembrane, where it can be seen that a greater amount of soil adhered to the geomembrane for the lower value of degree of saturation, probably due to the greater soil-geomembrane adhesion under low moisture content. The results of interface friction angle obtained in the on the smooth HDPE geomembrane were smaller than those obtained for the texturized geomembrane, as expected, and also insensitive to the variation of soil degree of saturation.

Table 1. Interface Friction angles obtained in ramp and direct shear tests.

S_r (%)	$\phi_{S\text{-}PVC\,S}$ (°)		$\phi_{S\text{-}HDPE\,S}$ (°)		$\phi_{S\text{-}HDPE\,T}$ (°)
	RT	DS	RT	DS	RT
5.5	29	30	26	27	32
10.8	30	30	28	29	33
15.7	30	31	27	27	34
20.3	30	32	29	32	30
26.3	31	33	29	31	36
45.1	31	33	30	31	37
58.4	30	33	27	29	36
66	34	39	27	31	39
Average (°)	30.6	32.6	27.9	29.6	34.6
Median (°)	30.5	33.0	29.0	33.0	33.0
Variance (°)	2.3	8.3	1.8	3.7	8.6
Standard Deviation (°)	1.5	2.9	1.4	1.9	2.9
Coefficient of variation (%)	4.9	8.8	4.9	6.5	8.4

DS: Direct shear tests
RT: Ramp tests
PVC S – Smooth PVC geomembrane
HDPE S – Smooth HDPE geomembrane
HDPE T – Texturised HDPE geomembrane
S_r – soil degree of saturation

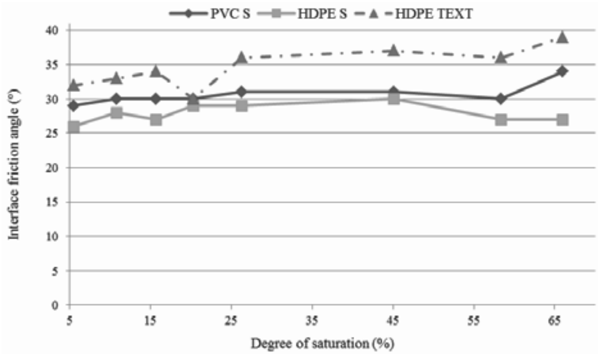
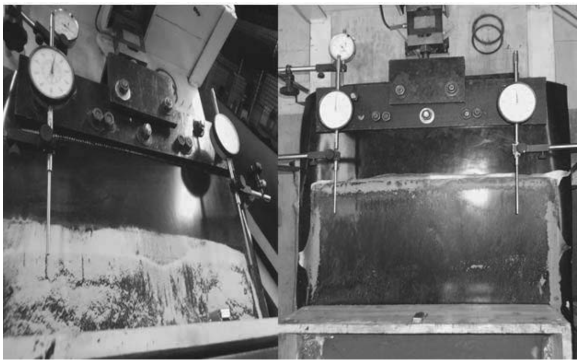


Figure 3. Interface friction angle (ϕ_{sg}) *versus* degree of saturation.

The higher values of interface friction angle were obtained in the tests on the texturized HDPE geomembrane. Figure 5 shows images of tests on the texturized HDPE geomembrane for different values of soil degree of saturation. Greater amount of soil adhered to the geomembrane for the lower value of degree of saturation as also observe in the test with the smooth PVC geomembrane.



(a) (b)

Figure 4. Tests on smooth PVC geomembrane: (a) degree of saturation of 5.5% and (b) degree of saturation of 66%.

(a) (b)

Figure 5. Tests on texturized HDPE geomembrane: (a) degree of saturation of 5.5% and (b) degree of saturation of 66%.

3.2 *Additional parameters to interface shear strength*

Table 2 sumarizes results of maximum box displacements (δ_{max}) immediately before interface failure as well as mobilized tensile forces (F) in the geomembrane. Some increase on δ_{max} with soil degree of saturation can be noted for the tests with the PVC geomembrane.

Table 2. Maximum box displacements and mobilised force in the geomembranes obtained in ramp tests.

S_r (%)	**PVC L**		**PEAD L**		**PEAD T**	
	δh_{max} (mm)	**F (kN/m)**	**δh_{max} (mm)**	**F (kN/m)**	**δh_{max} (mm)**	**F (kN/m)**
5.5	39.2	0.61	70	1	70.3	1
10.8	43.7	0.6	68.6	0.9	67.5	1
15.7	51.7	0.6	71.5	0.8	72	1.3
20.3	51.2	0.7	82.4	1.1	74.4	1
26.3	54.58	0.52	67.66	0.8	73	1.2
45.1	49.7	0.5	73.7	0.8	69.6	1.3
58.4	45	2	71.54	1.2	47.5	1.5
66	43.9	0.9	73.36	0.8	69.2	1.1
Average	47.4	0.8	72.3	0.9	67.9	1.2
Median	52.89	0.61	75.0	1.0	73.7	1.1
Variance	27.0	0.2	21.0	0.0	73.1	0.0
Standard Deviation	5.2	0.5	4.6	0.2	8.6	0.2
Coefficient of variation (%)	11.0	62.1	6.3	17.1	12.6	15.6

For the HDPE geomembranes δ_{max} was rather insensitive to the variation of degree of saturation. The mobilized tensile force in the geomembrane was also insensitive to the variation of soil degree of saturation, with some higher values for some tests, but without allowing a conclusion on the influence of moisture content on the value obtained (probably a result of test scatter).

The highest values of F were obtained in the tests with the texturized HDPE geomembrane, whereas the lowest ones were obtained in the tests with the smooth PVC geomembrane. The smallest values of δ_{max} were also obtained in the tests with the smooth PVC geomembrane.

4 CONCLUSIONS

This paper presented results of ramp and direct shear tests on different geomembrane products in contact with a sandy soil. The degree of saturation of the soil was varied during the test to assess possible influence of this parameter on the adherence between soil and geomembrane. The results obtained showed that the interface friction angle between soil and geomembranes was insensitive to the variation of soil degree of saturation for the conditions employed in the test programme. A progressive interface failure mechanism was observed in the tests with PVC geomembranes due to the more extensible nature of this type of geomembrane.

The largest values of interface friction angles were obtained in the tests with the texturized HDPE geomembrane, whereas similar lower values were obtained in the tests with the smooth PVC and HDPE geomembranes. As a consequence of higher adherence with soil, the largest mobilized tensile forces were obtained in the tests with the texturized HDPE geomembrane.

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