Assessment of the interface shear strength between HDPE geomembrane and tropical soil by the direct shear test

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ABSTRACT: Liners are important impermeable constituents of sanitary landfill to contain the transport of pollutants to the unsaturated zone. The system can be made of different kind, being the compacted soil and geosynthetics widely used. Thus, knowing the interface shear strength of those materials is important to avoid rupturing the system. The purpose of this paper is to compare the shear strength in the geomembrane-soil interfaces by the direct shear test. Assays were performed under the saturated condition (water and leachate). The used soil is a colluvial, lateritic, tropical silty sand-clay, typical of the city of Campinas, in Brazil. In this work, high density polyethylene (HDPE) 2,00mm geomembrane, smooth and two texturized – with different roughness level - were used. It was found that the shear strength is directly influenced by the roughness of the geomembrane, showed higher friction angle in the textured geomembrane. The direct shear test, performed with soil contaminated by leachate showed smaller friction angle than uncontaminated soil.

Keywords: Geomembrane, Interface shear strength, Friction Angle, Sanitary Landfill, Leachate.

1 INTRODUCTION

Municipal waste landfills are engineering works are planned for the disposal of solid and semi-solid waste produced by human activities, which must be discarded because they have no economic value or are useless to people. Landfills should be designed to confine these materials to avoid contact with natural resources (Bacas et al 2016).

The landfill liner and cover are usually composed by the union of compacted clay and geosynthetic products, such as: geomembrane and geotextile, for barrier and drainage function. The interaction of these materials is important to determine the stability of the landfill (Vangla & Gali 2016). These barriers, when placed in slopes, may generate unstable situations due to a low soil-geosynthetic interface shear strength. The failure of Kettleman Hills Class 1 hazardous landfill is one of the most studied cases (Souza et al. 2016).

Several properties of geosynthetics are determined in their manufacturing process, but interface shear strength is not one of them. Direct shear, inclined plane or ring-shear are specific laboratory tests used to obtain this parameter (Punetha et al. 2017). In the case of direct shear, the size of the box should be considered. The use of the smaller shear box, 100 x 100mm, is sufficient for soil-geomembrane studies, although ASTM D5322 recommends the use of the 300x300 box in all situations (Koerner 2012).

In recent years, several interface shear strength studies, with different materials, conditions and equipment, have been performed (e.g Wasti & Özdüzgun 2001, Fleming et al. 2006, Adamska 2006, Rebelo & Vilar 2006, Sharma et al. 2007, Bacas et al. 2015, Vangla & Gali, 2016, Souza et al. 2016, and Punetha et al. 2017).

The purpose of this study is to verify the variation of the shear strength Soil – HDPE Geomembrane interface in the saturated conditions, with water and leachate, to observe if the contaminant reduces this parameter and that can put the landfill stability in risk.

2 MATERIAL USED

The leachate and the soil were supplied by the University of Campinas (UNICAMP), due to the facilities of obtaining samples and its easy localization. The leachate was collected in a landfill lysimeter located on the FEC - Faculty of Civil Engineering, Architecture and Urbanism at UNICAMP. Table 1 presents the leachate characterization.

Table 1. Leachate characterization.

pH	-	7,02
Chemical Oxygen Demand - COD	mg/L	524
Biochemical Oxygen Demand - BOD	mg/L	26
Total Suspense Solids	mg/L	9,07
Fixed Suspended Solids	mg/L	1,87
Volatile Suspended Solids	mg/L	7,20
Alkalinity	mg/L	3175
Conductivity	mS/cm	4,69
Total Kjeldahl Nitrogen (TKN)	mg/L	716
Ammoniacal Nitrogen (N-NH3)	mg/L	481

The soil samples used in this study were collected at 1.00-1.50m depth on the Experimental Field of Soil Mechanics and Foundations (EFSMF) of the FEC. The EFSMF's profile presents up to 6.5 m a layer made of a thick colluvial and lateritic soil. X-ray diffraction tests indicated the presence of minerals such as kaolinite, gibbsite, hematite, goethite and quartz (Miguel & Bonder 2012). The figure 01 shows a natural sample of this soil.

Figure 1. Natural Soil Sample

Three high density polyethylene geomembranes of 2,00mm thickness were used in the present study. The GM1 has a smooth surface and the GM2 and GM3 are textured geomembranes. The GM2 shows an irregular textured surface greater than 0,40mm, while the GM3 has regular asperities greater than 0,7mm.

The figure 2 shows the GM1, GM2 and GM3 and their properties are summarized in the table 2.

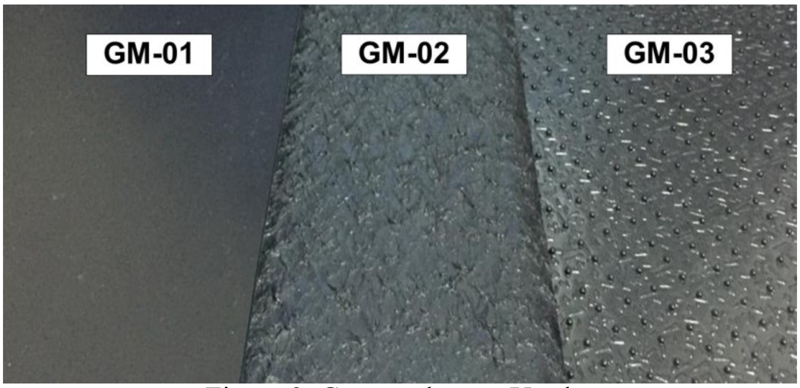


Figure 2. Geomembranes Used.

Table 2. Properties of Smooth and Textured Geomembranes.

Properties	Unit	GM1	GM2	GM3
Type	-	Smooth	Textured	Textured
Manufacturing process	-	Blown Sheet	Blown Sheet	Flat Sheet
Texturing	-	-	Coextrusion – Nitrogen Gas	Structuring
Thickness	mm	2,13	2,10	2,19
Density	g/cm³	0,946	0,945	0,947
Asperity Height	mm	-	0,43	0,71
Break Strength	kN/m	66,35	44,84	50,9
Yield Strength	kN/m	42,25	43,25	43,2
Break Elongation	%	780	480,7	533,5
Yield Elongation	%	19	15,26	21
Tear Resistance	N	325	351,4	355
Puncture Resistance	N	810	839,1	838
Carbon Black Content	%	2,80	2,30	2,56
Oxidative Induction Time (OIT)	Minutes	207	201	195

3 METODOLOGY

The procedures of the ASTM (1998a, 1998b, 1998c and 2012) were adopted to obtain the soil physical properties, as: natural unit weight (ρ), particle unit weight (ρs), field moisture content (w), void ratio (e), porosity (n), degree of saturation (S), Atterberg Limits, particle-size Distribution Curve and Standard proctor test curve. The particle-size distribution curves were obtained with and without the use of dispersant.

Soil samples were compacted on Normal Proctor Energy with 2% under their optimum moisture contents. Later, they were molded according to the dimensions of the equipment. In order to protect the equipment, the tests were not performed under flooded conditions, neither with water nor with leachate. In this way, the samples had to be saturated outside the equipment, which took one week for water and two weeks for the leachate. The figure 03(a) shows the molds used, the figure 03(b) shows the molding process and the figure 03(c) shows the molded samples

demonstrates a sketch of the saturation process.

The small direct shear box (100x100mm) were used in this study, which is divided in two halves. The lower shear box is movable and the upper is fixed. The geomembrane samples were cut in the exact dimensions of the rigid walls of the equipment and positioned immobile between the two halves. Normal loads were applied by placing dead weights on a hanger, and they were, approximately, 55, 110 and 165 kPa. The displacement rate used for all the test was about 0.7mm/min, and the horizontal displacement was monitored every half millimeter. The test was stopped at 20mm. The saturated and compacted soil samples was carefully placed in the upper box frame and covered by the load head.

The figures 4 shows the equipment and the scheme of the test.

Figure 3(a). The molds (100x100mm). (b) The molding process. (c)The molded samples

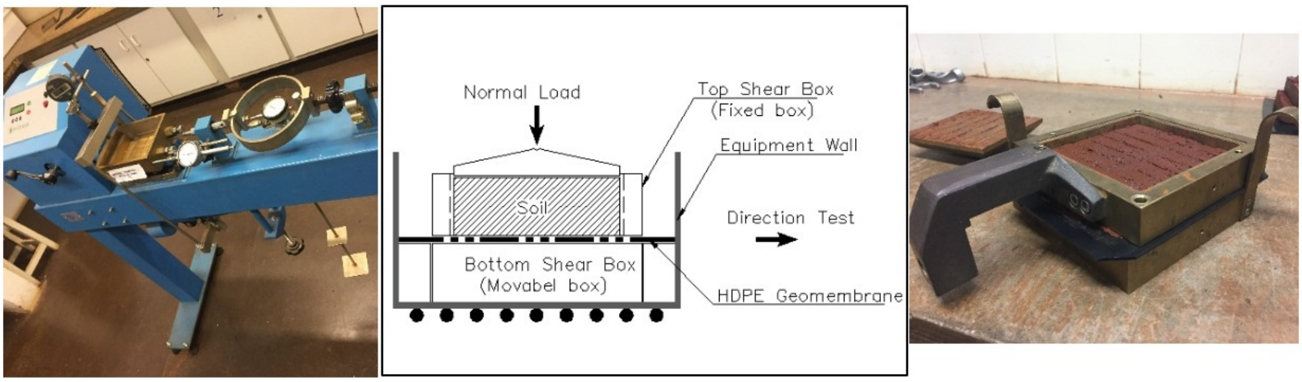


Figure 4(a). Direct shear equipment. (b) Scheme of direct shear test. (c) Geomembrane positioned between the boxes

4 RESULT AND DISCUSSION

4.1 *Geotechnical characteristics*

The table 3 summaries all the soil physical indexes, and the figures 05(a) and 05(b) show the particle-size distribution curve and the standard proctor test curve.

Table 3. Geotechnical parameters.

Natural unit weight - (ρ)	g/cc	1,431
Particle unit weight - (ρs)	g/cc	3,031
Field moisture content - w	%	28,67
Void ratio - e	-	1,724
Porosity - n	-	0,63
Degree of Saturation - S	%	50,34
Liquid Limit - LL	%	44,9
Plastic Limit - PL	%	33,1
Plasticity Index - PI	%	11,8
SUCS Classification	-	CL-ML

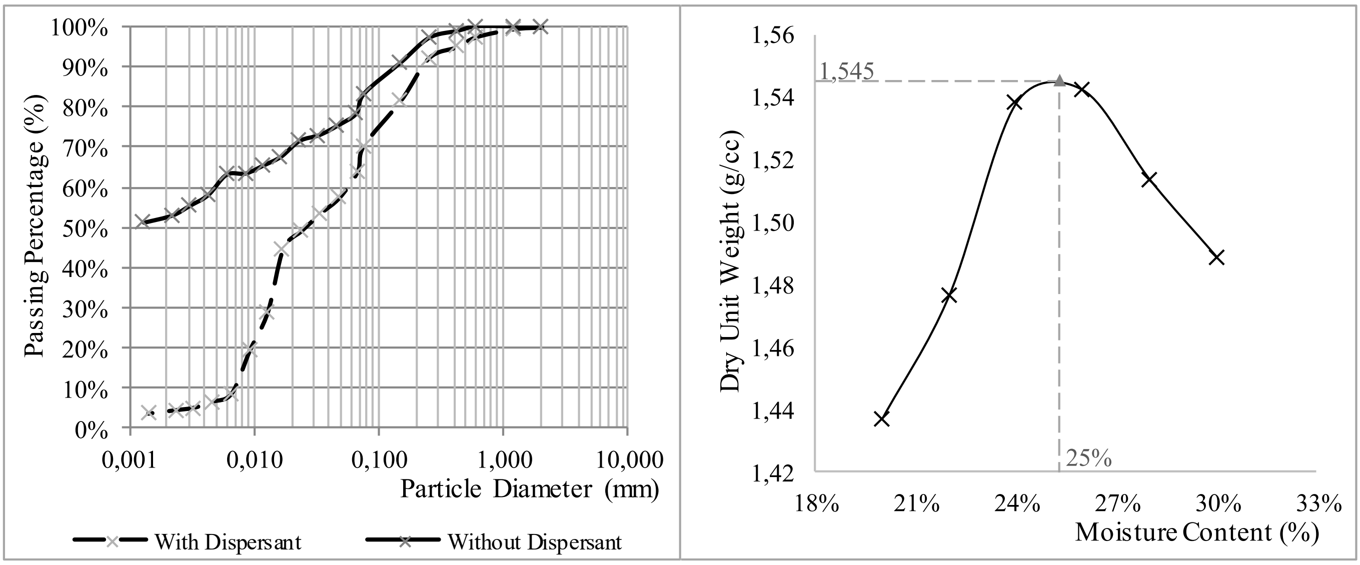


Figure 5(a). Particle-size distribution curve. (b) Standard proctor test curve.

It is possible to observe a great difference between the particle size curves with and without dispersant. Clay particles form microaggregates structures through the physicochemical attractions, as result of large leaching processes. The use of the dispersant breaks the microaggregates, without it, the agglomerated particles can be considered as particles of silt or fine sand. The soil is classified as sandy silt when the dispersant is not used, and as sandy-silt clay with using dispersant.

The soil presents a high particle unit weight, which indicates the possible presence of oxides and hydroxides of iron, those are typical cementing agents of lateritic soils. Furthermore, the soil also has a void ratio higher than one, which is a peculiarity of tropical lateritic soils.

4.2 *Shear strength of soil-geomembrane interface*

Figures 06a, 07a and 08a show the typical shear strength soil-geomembrane versus horizontal displacement curves, for the soils saturated with water.

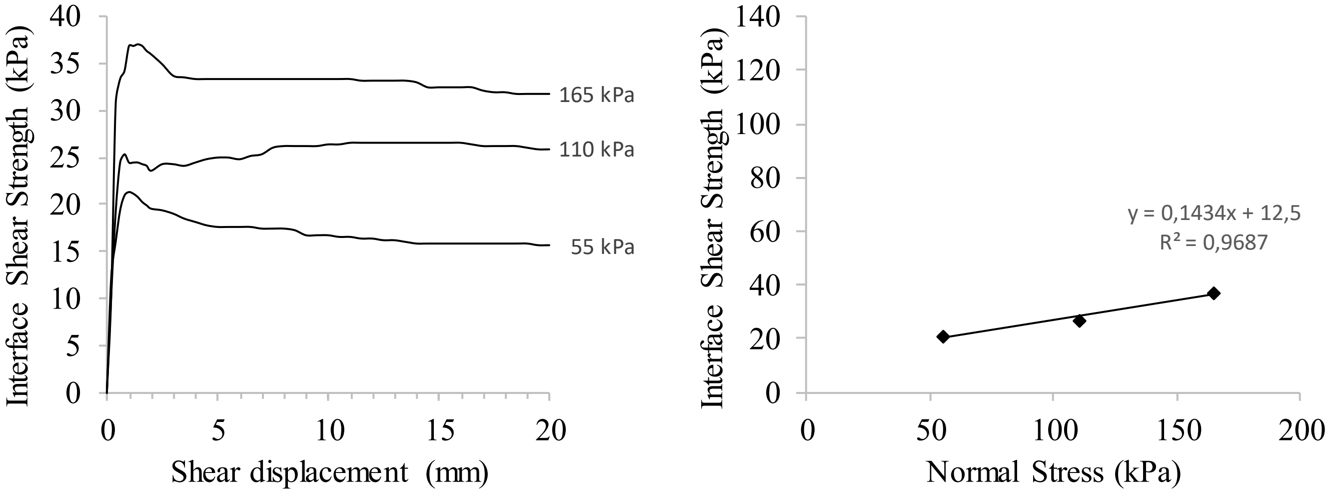


Figure 6. (a)Shear Strength vs. horizontal displacement and (b) interface shear strength envelopes for GM1-Soil Saturated with Water

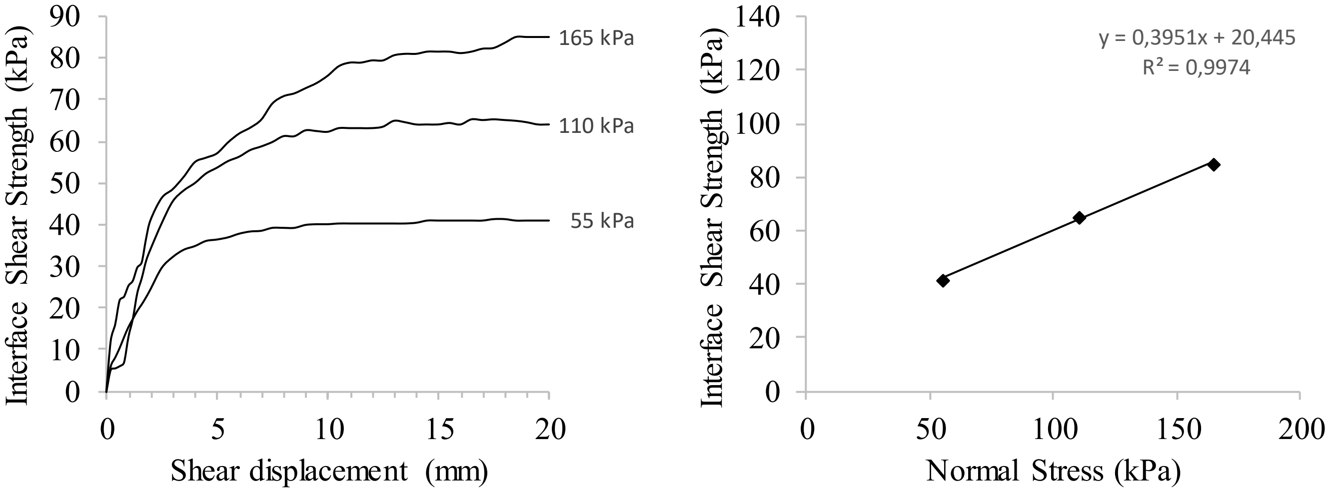


Figure 7. (a)Shear Strength vs. horizontal displacement and (b) interface shear strength envelopes for GM2-Soil Saturated with Water

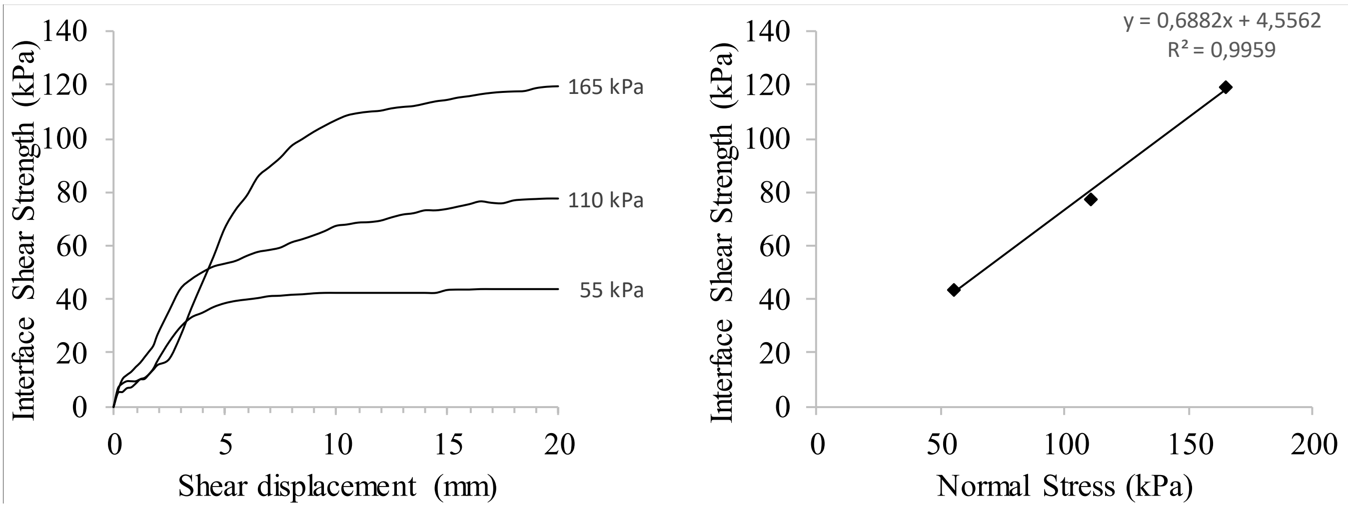


Figure 8. (a)Shear Strength vs. horizontal displacement and (b) interface shear strength envelopes for GM3-Soil Saturated with Water

Figures 09a, 10a and 11a show the typical shear strength soil-geomembrane versus horizontal displacement curves, for the soils saturated with leachate.

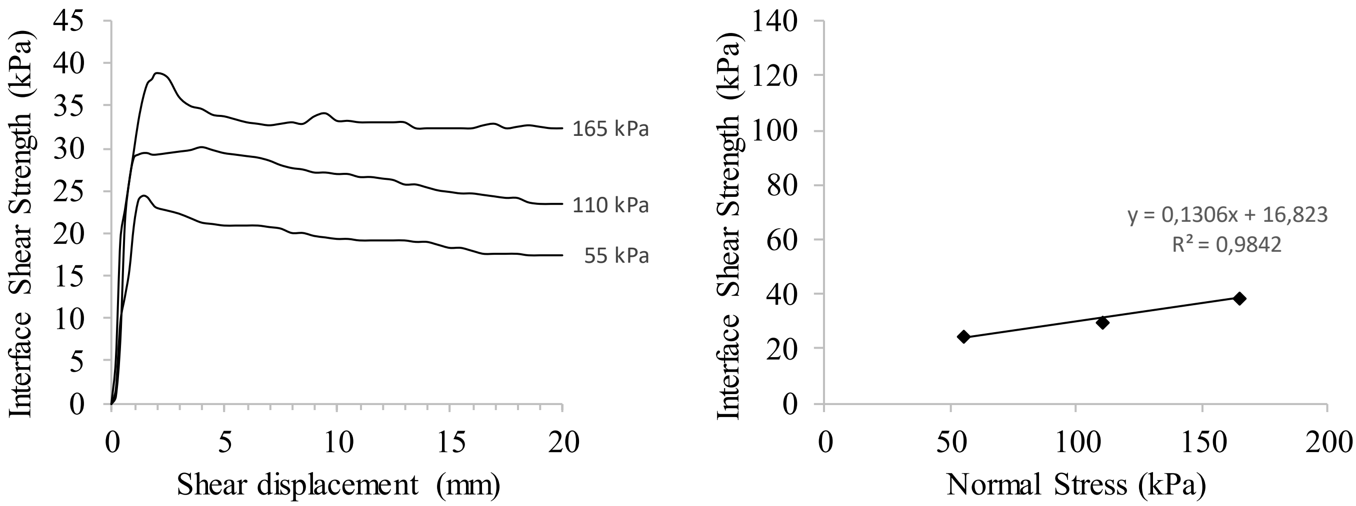


Figure 9. (a)Shear Strength vs. horizontal displacement and (b) interface shear strength envelopes for GM1-Soil Saturated with Leachate

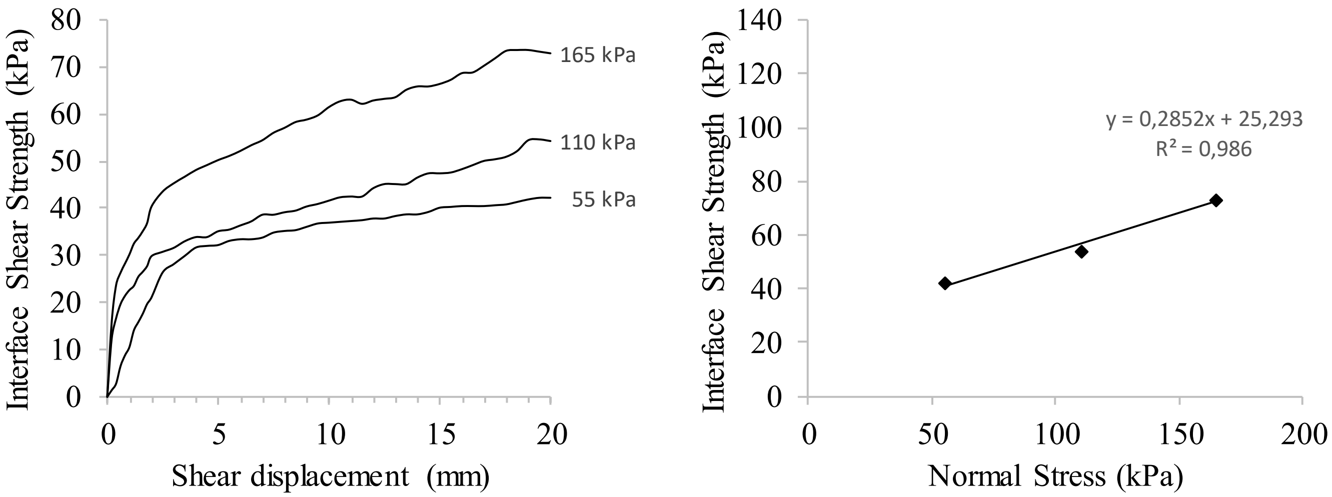
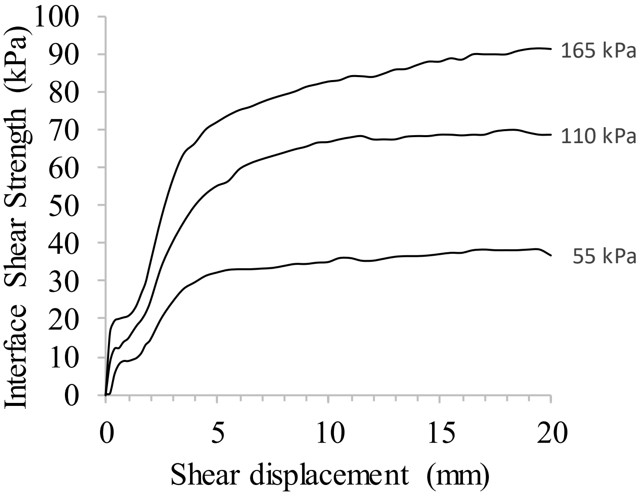


Figure 10. (a)Shear Strength vs. horizontal displacement and (b) interface shear strength envelopes for GM2-Soil Saturated with Leachate



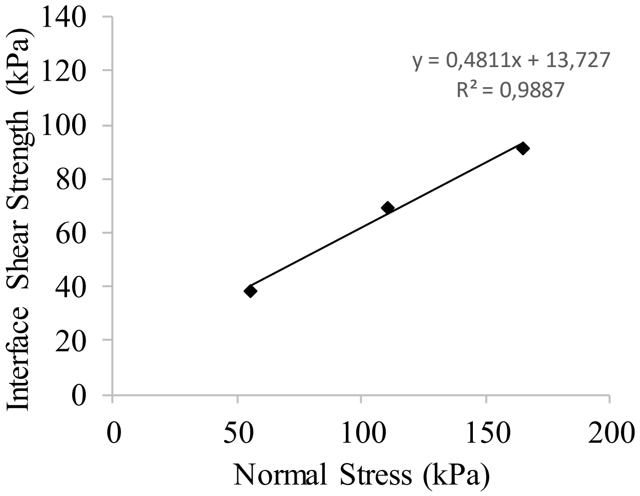


Figure 11. (a)Shear Strength vs. horizontal displacement and (b) interface shear strength envelopes for GM3-Soil Saturated with Leachate

The GM-1 geomembrane, which has a smooth surface, reaches the peak interface shear strength with displacement up to 2mm, after this point, the shear strength begins to decrease. In the case of soil samples saturated with water, the shear strength decreases until reaching the residual strength. However, with contaminated soil samples, the interface shear strength continues to decrease until the end of the test.

The shear strength is mobilized with larger displacement than the smooth geomembranes and no peak shear strength were observed in the shear strength versus displacement curve for geomembrane with textured surface. Residual strengths are obtained with displacements greater than 5mm, and in some cases the shear strength continues to increase until the end of the test.

Based on the Mohr-Coulomb theory, it was possible to obtain the interface shear strength envelope from the interface shear strength vs displacement curves. They were obtained by fitting linear regression lines. For all test, the R^2 was higher than 0,95. The figures 06b, 07b and 08b show the typical interface shear strength envelopes for geomembrane-soil interface under saturated conditions with water. And the figures 09b, 10b and 11b show the same, but saturated conditions with leachate.

The interface friction angle and adhesion, for each test, were obtained from the linear regression lines, their values are shown in table 4.

Table 4. Properties of Smooth and Textured Geomembranes.

Geomembrane	Type	Fluid	Adhesion	Interface Friction Angle
GM 1 – Soil	Smooth	Water	12,50	8,20
GM 1 – Soil	Smooth	Leachate	16,82	7,40
GM 2 – Soil	Textured	Water	20,45	21,6
GM 2 – Soil	Textured	Leachate	25,29	15,9
GM 3 – Soil	Textured	Water	4,57	34,5
GM 3 – Soil	Textured	Leachate	13,73	25,7

The interface friction angle increases with textured surfaces, as well as the type of texture. GM-2 and GM-3 are textured geomembranes, but with different kinds of texture as shown in figure 02. The interface friction angle is about 60% higher in the GM-3 than the GM-2 for both case.

The interface friction angle is also affected by the leachate, for all the cases it decreases. For smooth geomembranes, the decrease is not so significant, but it is in textured geomembranes. The contaminant reduces the interface friction angle about 26% for both cases. However, the adhesion in all the cases increases with the leachate.

5 CONCLUSION

Based on the result of this study, the following conclusions were drawn:

I. The interface shear strength depends directly on the type of surface of the material (smooth or textured), the type of soil, the normal load and the liquid used for saturation.

II. The interface shear strength in textured geomembranes are developed with larger displacement, for this reason, it is not possible to detect the peak shear strength. However, in the smooth geomembrane, although it does not have a high shear strength, it is possible to detect the peak and residual shear.

III. Friction angle is influenced mainly by the presence of the roughness in the geomembrane, in this way the interface friction angle is higher in the textured geomembranes.

IV. Friction angle is also affected by the type of texture. The textured geomembranes manufactured by the flat die process, which has a regular texture and a controlled roughness height, shows a higher friction angle than the geomembrane textured by the coextrusion process.

V. The leachate does not affect the interface friction angle for smooth geomembranes. For textured geomembranes, the leachate decreases the value of the friction angle. However, the adhesion in all cases increases.

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