STUDY OF FRICTIONAL BEHAVIOUR OF GEOSYNTHETICS USED FOR MUNICIPAL SOLID WASTE LANDFILLS

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Abstract: The study of friction of the geosynthetics used for municipal solid waste landfills both basal-liner and capping systems is a very important issue. Safe disposal and storage of the waste requires the design, construction and filling of repositories underlain by multi-layer liner systems. These lining systems typically contain a large number of material interfaces (geosynthetics/geosynthetics or geosynthetics/soil), many of which have low shear strengths. This introduces potential failure surfaces along the side slopes and base of the fill mass. The failure of the landfill can induce contamination in the groundwater, soil and atmosphere.

The knowledge of shear strength parameters of contacts between geosynthetics (geotextiles, geogrids, geomembranes) and soils is needed for safer design of landfills. For this reason the company CESPA proposed investigation of the shear strength parameters to University of Cantabria.

For last three years, a research project about this subject has been undertaken by the Geotechnical Group in the University of Cantabria. In this research, a methodology for direct shear tests between two geosynthetics and/or a soil and a geosynthetic achieving the friction parameters of these interfaces has been developed. A large number of tests have been done on different types of contacts. Some of them show particular features, concerning non-linearity of failure envelope, different failure modes, etc.

Keywords: geosynthetic, direct shear test, landfill, design method.

INTRODUCTION

Environment management of the world is important to guarantee the share and working capital at long term. One of most important aspect to manage is the solid waste production. The waste production is more and more due to economic growth and consumption patterns. And the waste processing alternatives worry about environmental impacts and health of the people. To decide where it can place the incinerators is a controversial issue for a lot of countries. The landfill alternatives have problems like room lack and the concern by the soil and the air contamination. This way, two important aims exist in landfills design, on the one hand increase the landfill capacity, on the other its safety. Respect to the first point, increasing the landfill capacity, increasing both its storage height and its width. It is fundamental issue owing to room lack. The landfills are near to cities and villages, where is produced the majority of waste, involving some risks. Respect to the second point, increasing the landfills safety face to slipping of waste mass and associated structures due to improvement of their capacity. It is fundamental issue to avert any health and environment risk. Both points have in common the necessity of study of shear resistance parameters of geosynthetics used in municipal solid waste landfills, aim of this paper.

Figure 1 shows a sketch of a basic transversal section of a modern landfill, where it can see the different types of geosynthetics and their functions.

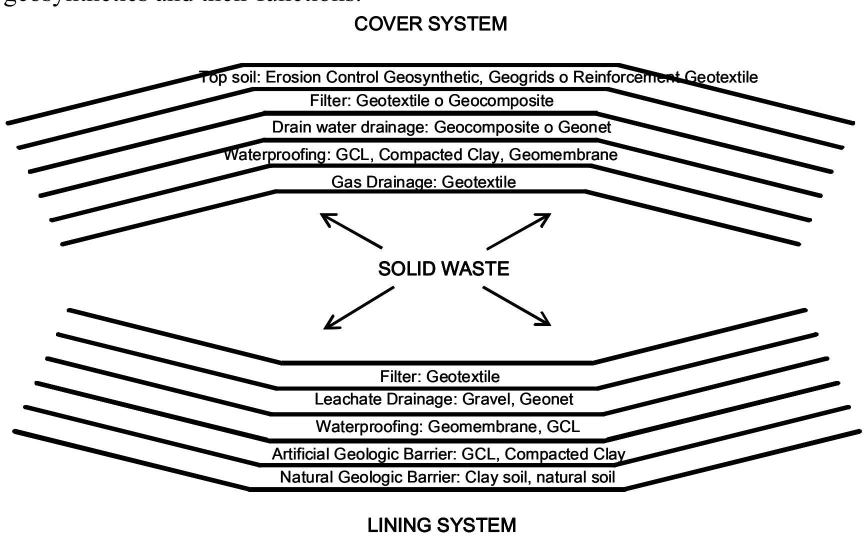

Figure 1. Sketch of a basic section landfill

The main geosynthetics used for landfills are geotextile, geogrids, geonets, geomembrane, geosynthetic clay liner, geocomposite and erosion control geosynthetics.

REVIEW OF PREVIUS WORK

In this research is used the direct shear test to carry on test between two geosynthetics and between one soil and one geosynthetic. It was made the decision of use this type test after study the different standards, ASTM D 5321-02, ISO 12957-1:2005, ISO 12957-2:2005, and the different researches made for different authors: Koerner (1994), Mitchell *et al.* (1990), Stark and Poeppel (1994), Fox *et al.* (1997), Russell *et al.* (1998), Wasti and Özdüzgün (2001), Zornberg *et al.* (2005), Hebeler *et al.* (2005). The main conclusions drew of this study were:

- Most of authors used direct shear test modifying the conventional direct shear machine for soils.
- Advantage of the direct shear test: simple carrying out and capacity to test a lot interfaces soil/ge0synthetic and geosynthetic/geosynthetic in a short time
- Most of authors used large size sample, it was larger or equal than 300 mm x 300 mm, to represent better the material and to reduce boundary effects.
- Both standards, ASTM D 5321-02 and ISO 12957-1:2005, and mentioned researches agree with basic properties of the support to fix the geosynthetics: horizontal, rigid, rough and porous.
- The direct shear box can be a conventional direct shear box or pull out box, both methods give similar results
- The main disadvantaged of the direct shear test is the limited horizontal displacement, obtaining more residual shear stress than residual shear stress obtained with torsional ring shear test.
- The torsional ring shear test is an alternative to direct shear test. The torsional ring gets less residual shear stress than direct shear box but the ring has some objections: sample size is very small and the shear direction continuously changes. This situation does not model field conditions.
- Another alternative is the tilting plane test. This test is suitable for less normal stress than 50 kPa, it gets less shear resistance parameters than direct shear test, but it is not possible to test high normal stresses.
- Both standards ASTM D 5321-02 and ISO 12957-1:2005 allow to user design direct shear machines and geosynthetics fix systems, carrying out the minimum characteristics demanded by these standards.
- The standard ASTM D 5321-02 offers more alternatives to make different tests than ISO 12957-1.

These conclusions, the differences between standards and between researches named above, it was made the decision of use the direct shear test with conventional shear box size of 300 mm x 300 mm, so-called Large Digital Shear Box made in Great British, and following the standard ASTM D 5321-02.

ORIGINAL TESTING EQUIPMENT

The direct shear machine, Large Digital Shear Box, is a standing apparatus that measures 2.4 m long, 0.55 m wide and 1.35 m high (see Figure 2). The dimensions of shear box are 300 mm long by 300 mm wide. These values are enough to minimize boundary effects, allowing the failure surface to form anywhere within the specimen during testing. At the firs time this apparatus was design to test soil and/or gravel but to get to test geosynthetics it was added geosynthetic fix system (see Figure 3), this device measures 298 mm long, 298 mm wide and 30 mm thick with adjustable high, and it has a gag in one side to fix the geosynthetic. This element is placed inside bottom shear box.

The main functions of direct shear machine are:

- Horizontal force system to get constant horizontal displacement rate
- Normal force system to get the normal stress
- Implementation to measure shear force, horizontal and displacement during the test. These values give enough information about shear resistances parameters of the materials testing.

The technical specifications for the large digital shear machine are summarized in Table 1.

Table 1. Technical specifications for the direct shear machine

Feature	Specification
Specimen area (plan view)	300 mm x 300 mm
Allowed introduce specimen area	150 mm x 150 mm 225 mm x 225 mm
Maximum specimen thickness	200 mm
Maximum normal force	100 kN
Maximum horizontal force	100 kN
Maximum horizontal displacement	60 mm
Range of horizontal displacement	0 to 10 mm/min
Weight	930 kp

Figure 2. Large direct shear machine

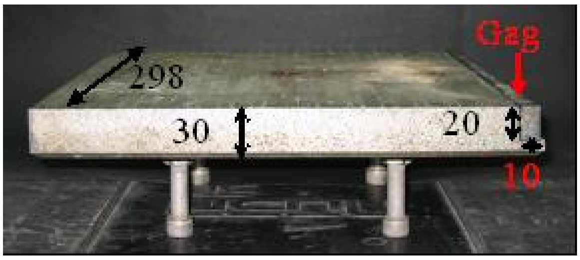

Figure 3. Bottom steel support to fix geosynthetics. Size 298x 298x30 mm

This original testing equipment was used to carry out the first tests between two geosynthetics, following steps of the standard ASTM D 5321-02. Using the different geosynthetics fix systems described in this standard and ISO 12957-1:2005. Entailing the next limitations and objections:

- ASTM D 5321-02 shows that to fix the geosynthetics it can use soil or rough rigid support. But if this method is used at apply shear force the geosynthetic in contact with the soil was slipped, creased and folded (see Figure 4)
- ISO 12957-1: 2005 shows that it can use sand paper to fix the geosynthetic to bottom rigid support. This method does not work for more normal stress than 100 kPa, due to sand paper slides with regard to rigid support. (see Figure 5)
- Both standards show use soil like fix and support system for geosynthetics, but this method requires long and working procedure and spent a lot of time
- The researches mentioned before show different fix systems depending on the type of geosynthetic.

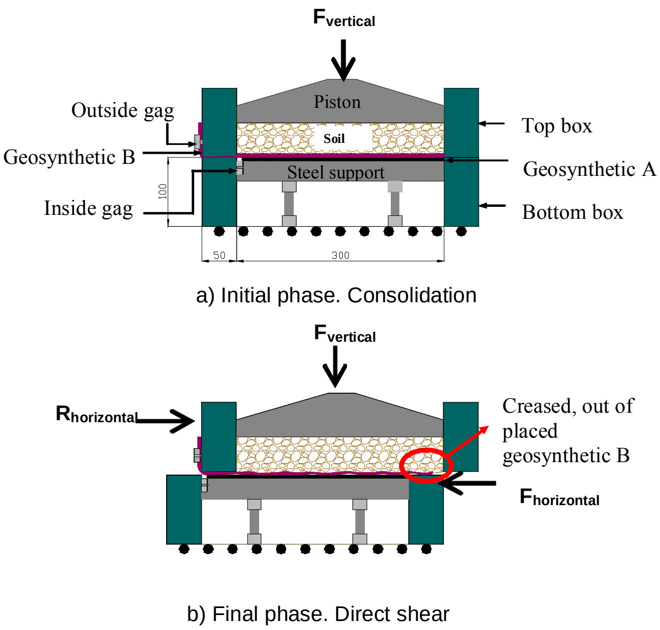

Figure 4. Sketch original direct shear test

Figure 5. Geosynthetics fix system suggested by standard ISO 12957-1: 2005. Bottom steel support 300x300 mm

MODIFICATIONS TESTING EQUIPMENT

To overcome the limitations and objections described above it was made new geosynthetic fix system up, that shows the next advantages:

- Same fix system for several types of geosynthetics
- Quickly and simple placing and taking to pieces
- It avoids geosynthetic slides, creases and folds with regard to rigid support
- It does not cause damages to geosynthetics
- This method replaces to soil like support system therefore less time for carrying out test.

The new geosynthetic system consists in a steel piece that has the next characteristics:

- Rough face avoids the slide of the geosynthetic for all test stress range
- Rough face does not have to make any damages at materials
- Allow fluid flow through piece to drain and to moisten at geosynthetic.

Figure 6 shows the plan of the new piece (patented application register number ES200800483). It is a rectangular steel plate, 299 mm x 284 mm x 10 mm; it has 210 drainage holes and 1680 pyramids 1 mm high, which protrude from top face. The bottom face has 16 canals to allow water flow. This piece is screwed on to steel support that it is placed into the direct shear box, the way it is shown in Figure 7.

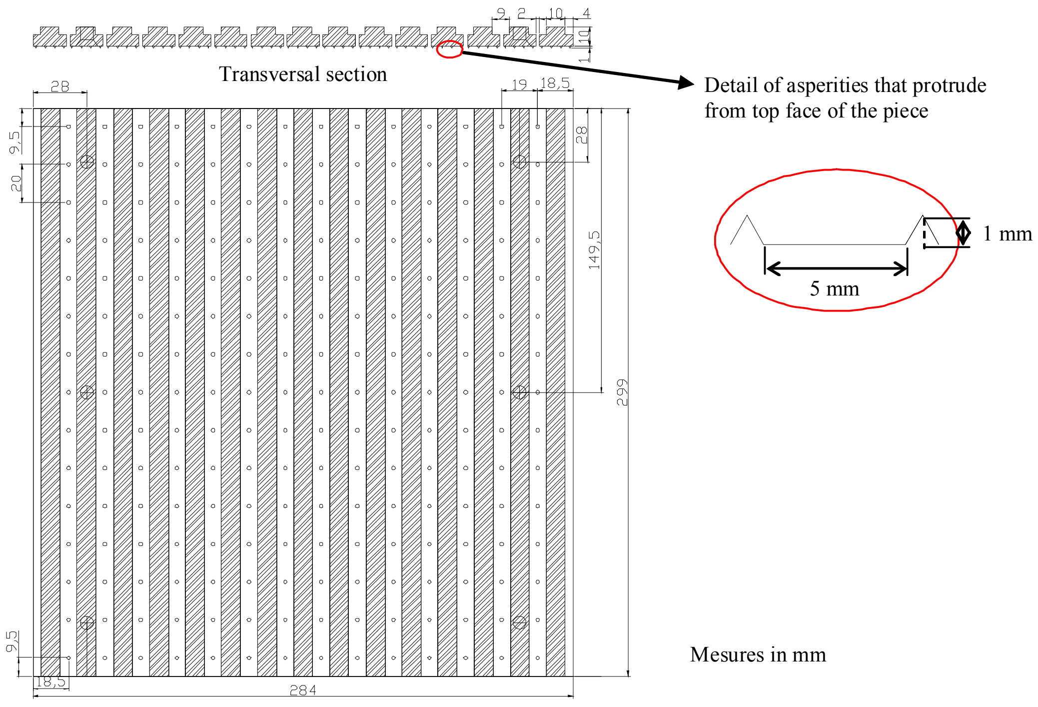

Figure 5. Plan of texture plate

LABORATORY TESTING PROGRAM

Materials

In this paper are presented four interfaces testing, which can be use in side slope of the lining system for solid waste landfills: GC/GCL, Soil/GM, GCL/GM

- GM: HDPE texture geomembrane, thickness 1.5 mm

- Soil: sandy clay, LL=45%, IP=21.3%, Modified Proctor (γ_{max}=19 kN/m^3, W_{opt}=12%)
- GCL: Geosynthetic Clay Liner (mass/area 5000g/m^2) with reinforce fibers and granular bentonite is held between a woven and a non-woven geotextiles. Testing non-woven face.
- GC: Drainage geocomposite (950 g/m^2) consist of one geonet between two non woven geotextiles

All interfaces were tested with the geosynthetics placed the machine direction parallel to the shearing plane.

Procedures

The direct shear apparatus has moving container, lower shear box, and another stationary, upper box. The moving of the travelling container is only in a direction parallel to that of applied shear force. To apply the normal stress is used a rigid load plate. The shear force is measure using a dynamometric ring. Two linear variable differential transformers (LVDT) are used to measure horizontal and vertical displacement of the specimen during the consolidation and shear phase. The conditions and velocities of the different tests are showed in Figure 7. This sketch presents values of hydration time, consolidation time and horizontal displacement rate, depending on type of interface and test conditions: dry or wet. These values are the results of study and check different researches, Fox *et al.* (1998), Gilbert *et al.* (1996), Gilbert *et al.* (1997), Eid *et al.* (1999), Nye and Fox (2007), Pasqualini *et al.* (2002), Stark and Poeppel (1994), Sharma *et al.* (2007), Triplett and Fox (2001), Zornberg *et al.* (2005) and checking the new contributions. The data of direct shear test of this study is shown in the Table 2.

Table 2. Summary of conditions test

Interface	Size sample (mm)	Range normal stress (kPa)	Condition	thydra. (h)	tconsol. (min)	Shear rate (mm/min)
GC/GCL	300x282	100-500	dry	0/0	10	5
GCL/GM	300x282	100-500	wet	48/0	1440	0.055
Soil/GM	200x200	100-500	dry	0/0	10	1

The normal stress represents the normal load applied to the base lining system in Spain. The shearing was carried out up to a horizontal displacement of 50 mm was achieved. The situation of the geosynthetics inside the machine is showed in Figure 7, just as necessary devices. The test procedures were carried out in compliance with ASTM D5321-02. The readings during shearing were taken automatically by a computerized data logging system.

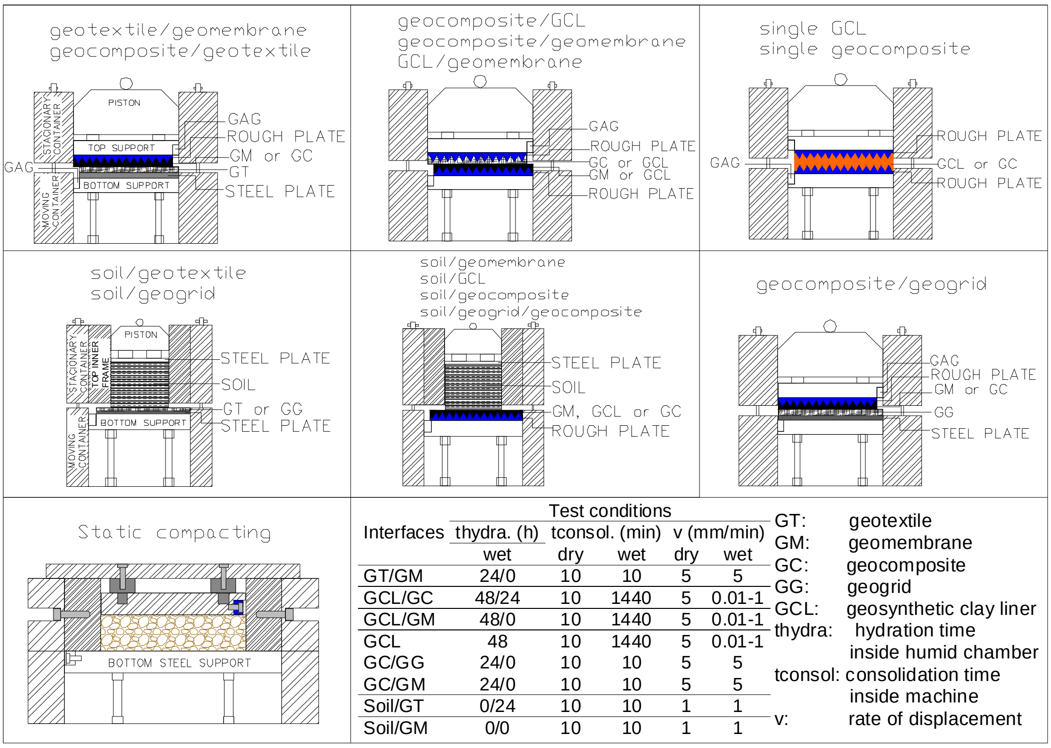

Figure 7. Summary of large direct shear methodology for geosynthetics

ANALYSIS OF RESULTS

Direct shear test on drainage geocomposite/GCL

The shear stress versus horizontal displacement curves are illustrates in Figure 8. The peak shear stresses were mobilized at displacements of 7.5 mm and 10 mm. The peak and residual friction angles and adhesion were 26º, -21 kPa and 18º, -2 kPa respectively as depicted in Figures 11 and 12. These values were obtained from lineal adjusted type Mohr Coulomb, $\tau = ca + \sigma \tan\phi$, where τ is the shear strength, ca is the adhesion, σ is the normal stress and ϕ is the friction angle. The shear resistance parameters, ca and ϕ, are only useful for the range of normal stress tested. The adhesion is an adjustment parameter without physical explanation. In all test the failure plane is between the geocomposite and GCL.

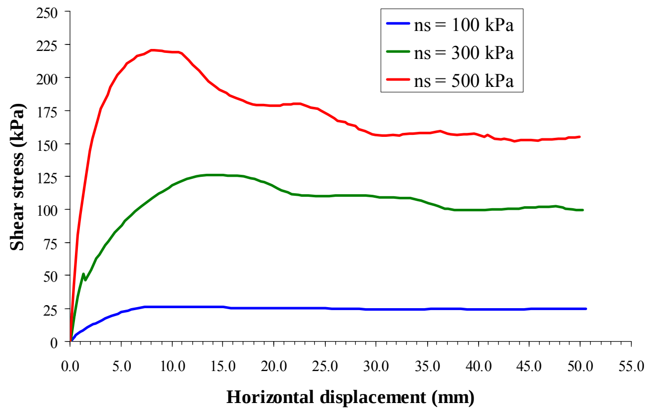

Figure 8. Shear stress-displacement curves for interface GC/GCL

Direct shear test on GCL/geomembrane

The shear resistances parameters obtained from lineal adjustment were: peak friction angle and adhesion, 4º and 39 kPa, residual adhesion, 9 kPa as showed in Figures 11 and 12. The peak shear stresses were mobilized at displacements of 6 mm and 7 mm, after that the curve falls quickly to reach the residual value. It can see in Figure 9. All test showed failure plane inside GCL, between woven geotextile and bentonite layer.

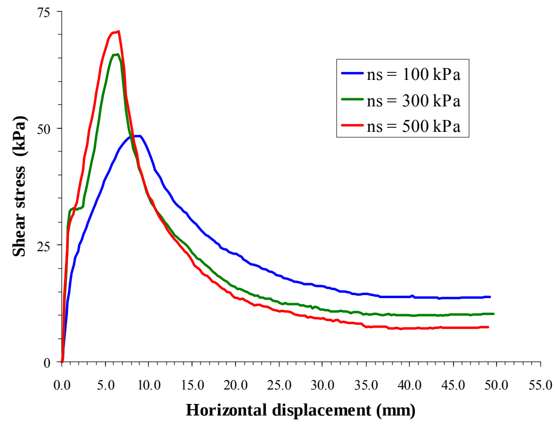

Figure 9. Shear stress-displacement curves for interface GCL/GM

Direct shear test on soil/geomembrane

Figure 10 presents shear stress versus horizontal displacement curves. These curves show strain softening behaviour. First shear stress reaches the peak and next the curve falls up to residual value. The peak shear stresses were mobilized at displacements of 6 mm and 7.5 mm. The peak and residual friction angles and adhesion were 34º, -41 kPa and 23º, -28 kPa respectively as depicted in Figures 11 and 12. These results have negative adhesion like test between drainage geocomposite and GCL presented before. After testing, the samples were checked. The bigger asperities of geomembrane were oriented in direction and opposite way of shear direction, some of them flattened due to during the shear the asperity run into gravels. It was observed rest of soil between asperities like Figure 13 shows it.

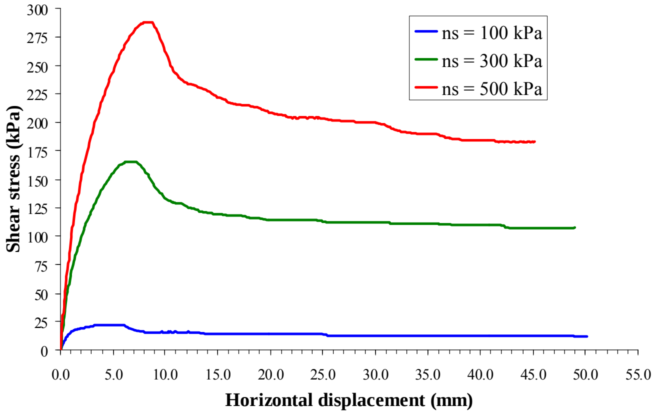

Figure 10. Shear stress-displacement curves for interface soil/GM

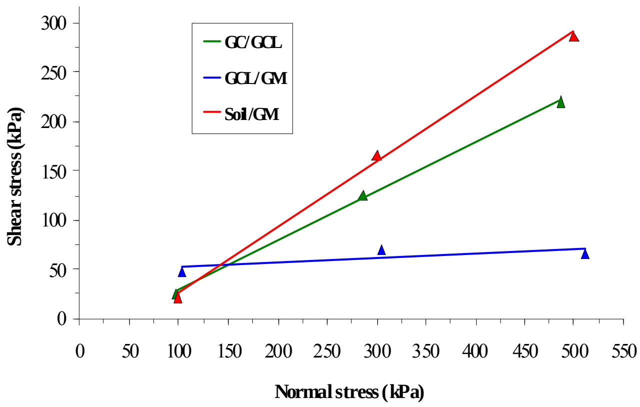

Figure 11. Peak failure envelopes

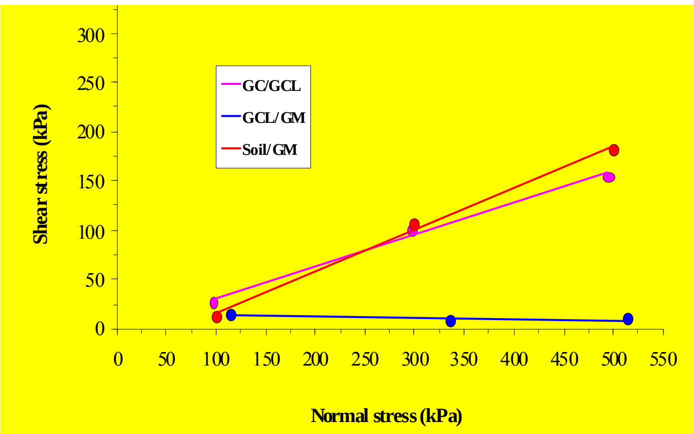

Figure 12. Residual failure envelopes

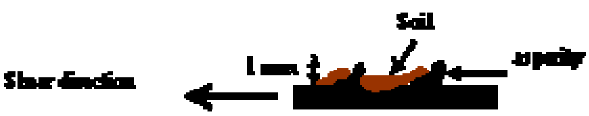

Figure 13. Contact between soil and textured geomembrane

CONCLUSIONS

The following conclusions are reached based on design of the gripping surface to fix geosynthetics in the large direct shear test, between two geosynthetics, and between a soil and a geosynthetic. Just as different tests results using the gripping surface and specific methodology.

- The invented steel textured plate fixes well GCL, geomembrane and geocomposite up to 500 kPa of normal stress.

- The specific methodology means can carry out test with identical procedures to compare results.
- The specific methodology means reasonable time spent on carry out test, and it is possible represent a suitable field conditions.
- The size of samples 300 mm x 300 mm is good to represent non uniform material.
- The results of test have sense with mechanical and physical behaviour of interfaces testing. This way interface GCL/geomembrane in wet conditions the weak plane is inside the GCL due to low shear resistance of the wet bentonite. The interface drainage geocomposite/GCL testing in dry conditions, the failure plane was between non-woven geotextile belong to geocomposite and non-woven geotextile belong to GCL, due to the bentonite of the GCL becomes very rigid by increase of normal stress.
- The failure envelopes show the weak interface is GCL/geomembrane in wet conditions.
- Finally, comment in the geosynthetic world has a great necessity to create communal methodology, using the same devices and machine, to carry out large direct shear tests geosynthetic/geosynthetic and soil/geosynthetic to check results and to make comparisons between different geosynthetics materials.

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