Evaluation of GCL internal shear strength in inclined plane tests

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ABSTRACT
The stability of barriers composed of geomembranes and/or geosynthetic clay liners (GCLs) depends on the interface and/or internal shear resistances of the materials involved in the project. The internal resistance of stitch-bonded and needle-punched GCLs depends on the resistance of the core material (bentonite) and on the technique used to attach each geotextile layer of the GCL. When using a GCL in a slope, the evaluation of its internal shear strength is of fundamental importance for stability analysis. This paper presents results of inclined plane tests on specimens (50cm x 60cm) of stitch-bonded and needle-punched GCLs under dry and hydrated conditions subjected to confining stresses varying from 2.5kPa to 10kPa. The results obtained enhance the importance of the mechanical strength of the filaments used in the manufacturing of the GCL as well as the internal shear strength of GCLs for the analysis of slopes where these products are used, especially under hydrated conditions.

1. INTRODUCTION

GCLs must present adequate strength and durability when subjected to chemical, biological, physical, and mechanical degradation mechanisms to function properly as barriers. The barrier function in slopes of waste disposal areas can be jeopardized when external and internal stability requirements are not met. GCLs that are installed in those situations must present minimum internal shear resistance in order to guarantee that failure will not occur. The inadequate functioning arising from internal rupture will damage the lining system, leading to cover soil sliding and damage to the environment. Therefore, quantifying GCLs internal shear strength parameters is of utmost importance for the evaluation of the stability of slopes incorporating these products.

Soil-geosynthetic interface shear strength can be evaluated by pull-out, direct shear or inclined plane tests (Briançon 2002, Ling et al. 2002, Bergado et al. 2006, Viana and Palmeira 2008). In slopes of landfills, the internal shear strength of GCLs may be mobilised under low confining stresses (typically below 20kPa), which favours the use of the inclined plane test, because this type of test provides more reliable results under low stress levels (Girard et al. 1990, Giroud et al. 1990, Gourc et al. 1996, Izgin and Wasti 1998, Palmeira et al. 2002, Palmeira 2008, Viana and Palmeira 2008)

GCLs may suffer internal failure if the manufacturing process used to fix each of its components is not strong enough for the shear stresses developed during GCL installation, liner construction and service life of the disposal area. The low shear strength of bentonite, particularly when hydrated, favours the development of internal failure, hence the need for the determination of interface and internal shear strength parameters for these products for design purposes. The internal shear strength of the GCL depends on its manufacturing characteristics and core material (bentonite) properties, and values of internal strength can vary significantly depending on the type of equipment and testing conditions used.

The internal shear strength of a GCL will be a combination of the shear strength of the core material and the tensile strength of the filaments used to fix the geotextile covers. Failure of each of these components of the product is reached at very different magnitudes of shear displacement. Direct shear tests have shown that the ratio between residual and peak internal shear strengths of GCLs varies significantly, depending on type of material tested, hydration conditions and shear displacement necessary to characterise failure. In general, the ratio between residual and peak shear strength is greater for stitched GCLs (Gilbert et al. 1996, Chiu and Fox 2004, Fox et al. 1998). Fuller (1995) observed lower internal shear strengths of needle-punched GCLs in comparison to stitched GCLs. The use of mixtures of bentonite and granular materials has been suggested as a measure to increase the internal shear strength of GCLs (Fox et al.1998, Thiel et al. 2001, Schmitt et al. 1997, Fox and Stark 2004, Viana and Palmeira 2008).

This paper presents an experimental study on the internal strength of GCLs under dry and hydrated conditions using the inclined plane test with emphasis on the influence of the product structure and manufacturing process.

2. EQUIPMENT AND MATERIALS USED IN THE TESTS

A large inclined plane test equipment was used to perform the tests reported in this paper. A general view of the equipment is shown in Figure 1. When a cover soil is present, various sizes of boxes to confine this soil can be used. In the present study a box with internal dimensions of 0.6m x 0.5m was used for the evaluation of the internal strength of the GCLs. The geosynthetics to be tested can be clamped to the plane anchorage system (at the plane extremity) and up to three geosynthetic layers can be tested simultaneously. The clamps used to fix the geosynthetic layers are connected to load cells to measure the tensile load mobilised at the geosynthetic end during the test. The anchorage of the geosynthetic extremity to the plane simulates more accurately the conditions found in the field for linings in slopes in the region close to the slope crest. In the tests reported in this paper only the extremity of the bottom geotextile layer of the GCL was clamped. The roughness conditions of the surface of the inclined plane can be varied for research purposes. In the present study a low friction boundary along that plane was achieved with the use of double layers of plastic film and oil. Weights can be used to provide surcharge on the system, increasing the stress level on the interfaces. The loading plate used to apply the normal stress was installed directly on the GCL specimen. Displacement transducers measured the relative displacements between the GCL top and bottom geotextile layers with respect to the plane surface. During the test the inclination of the plane with the horizontal was continuously increased up to the slide along the weakest interface. Tests were performed under initial normal stresses (plane at the horizontal position) varying between 2.5kPa and 10kPa.

Figure 1. Inclined plane test device used in the tests.

Two types of GCL were tested in the research program. The first one, code GCL A, consists of a sodium bentonite with a top nonwoven geotextile cover layer and a bottom woven geotextile cover layer, needle-punched, with mass per unit area equal to 5kg/m^2. The second GCL, code GCL B, has top and bottom cover layers consisting of woven geotextiles, stitched, with sodium bentonite and a mass per unit area of 4.5kg/m^2. The tests were performed on dry GCL specimens and on hydrated specimens after a period of

24h submersion in water. The GCL specimens were hydrated already installed in the plane, prior to the increase of plane inclination with the horizontal direction. Figures 2(a) and (b) presents views of the GCLs tested.

(a) GCL A

(b) GCL B

Figure 2. Views of the GCLs tested.

3. RESULTS AND DISCUSSIONS

Figure 3 shows the failure envelopes obtained from inclined plane tests on specimens of GCLs A and B under dry and hydrated conditions. This figure shows that, in general, the cohesion intercept was negligible and the friction angle was approximately 47^o for both GCLs under dry conditions. This high value of friction angle is due to the contribution of the filaments of the needle-punching or stitching processes used in the manufacture of these products. After hydration, the internal shear strength of GCL A was significantly reduced, yielding to a friction angle of 11.5^o. It was observed that the expansion of the bentonite of GCL A caused a marked reduction on the strength of the filaments (needle-punched) of this product, which yielded to lower internal shear strength after hydration, as will be commented later in this paper. That was not the case for GCL B, for which the shear strength envelope was nearly the same under dry or hydrated conditions, due to the low contribution from the bentonite in comparison to that of the filaments, as shown in Figure 3.

The variations of mobilised tensile forces in the bottom geotextile layers with plane inclination for tests on the GCLs under dry and hydrated conditions and under different initial normal stresses are depicted in Figures 4(a) and (b). Figure 4(a) shows that, due to the smaller internal shear strength of GCL A, the mobilisation of tensile force in its bottom geotextile layer starts at earlier stages of the tests for the hydrated specimens, in comparison to what is observed for the dry specimens. The greater internal strength of GCL B provided by its stronger stitching network results in little influence of the bentonite shear strength to the overall mobilization of tensile force in the bottom geotextile with plane inclination.

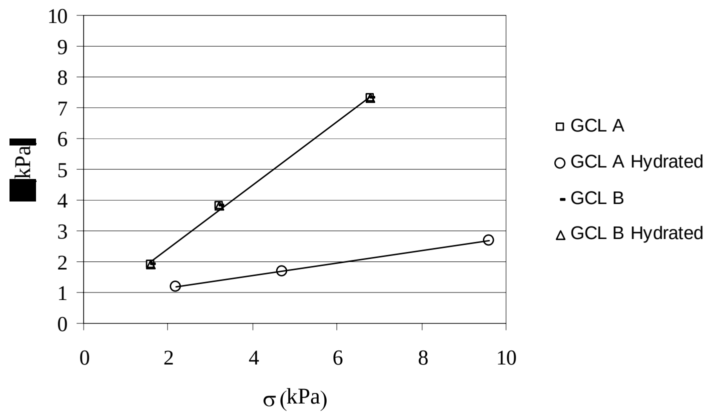
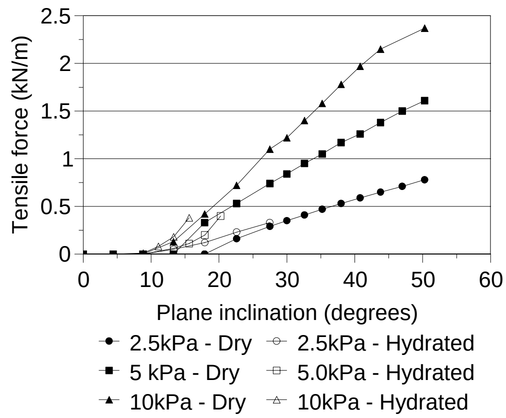
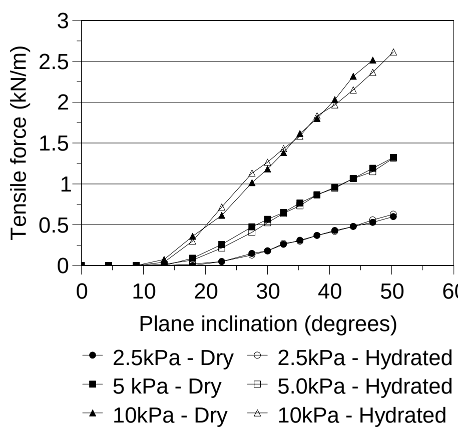


Figure 3. Failure envelopes.



(a) GCL A



(b) GCL B

Figure 4. Tensile force in the bottom geotextile layer versus plane inclination.

Figure 5 shows the variation of the tensile force mobilised in the anchored bottom geotextile layer of the GCL versus the relative displacement between top and bottom geotextile layers. This figure shows that for the situations were internal failure did not occur, the relative displacements between top and bottom geotextiles reached values up to 9mm. For the specimen of hydrated GCL A, internal failure was reached, with final relative displacements over 100mm. The mobilised tensile force in the bottom geotextile varied between 0.62kN/m and 2.52kN/m depending on the GCL and normal stress considered. Table 1 summarises the results of final plane inclination and relative displacements obtained in tests on specimens of GCLs A and B under dry and hydrated conditions.

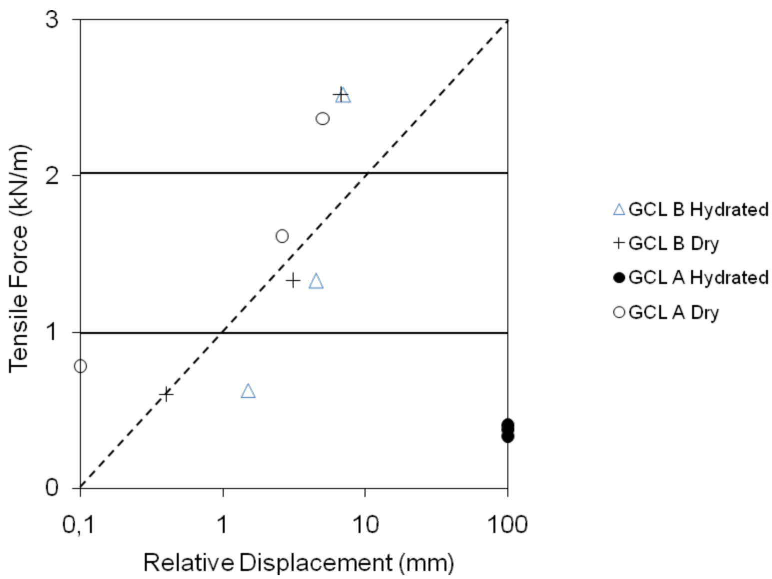


Figure 5. Tensile force in the bottom geotextile layer versus relative displacement.

Table 1. Results of final relative displacements.

σ (kPa)	GCL A				GCL B			
	Dry		Hydrated		Dry		Hydrated	
	δ (mm)[1]	i (^{0})[2]	δ (mm)	i (^{0})	δ (mm)	i (^{0})	δ (mm)	i (^{0})
2.5	0	50.3	100	27.5	0.4	50.3	1.5	50.3
5	2.6	50.3	100	20.3	3.1	50.3	5.2	50.3
10	5.1	50.3	100	15.6	6.79	50.3	7.0	50.3

Notes: ([1]) Relative displacement at the end of the test; ([2]) i = Plane inclination at the end of the test; ([3]) σ = initial normal stress on the GCL.

The internal shear strength of the GCL is highly dependent on the tensile strength of the filaments used in needle-punching or stitching processes, strength at the connections between filaments and geotextile covers and quantity and spatial distribution of the filaments. Therefore, the filaments can have a marked effect on the shear strength and on the shear stiffness of the GCL. However, the tests carried out in this study showed that tensile or connection failure of the filaments may occur during the expansion of the bentonite caused by hydration. This may yield to a significant reduction on the internal shear strength of the GCL, which may compromise the stability of the lining system in a slope, if this aspect is not properly considered in the design. Figure 6 shows an enlarged view of a filament that failed during hydration of GCL A. This failure mechanism can be minimized or avoided under high stress levels, because under such conditions the expansion of the bentonite during hydration will be inhibited to some extent.

Therefore, the critical conditions will take place under low stress levels and in this case the inclined plane test on hydrated GCLs can provide important data on the internal strength of the GCL.

Figure 6. Enlarged view of GCL A after hydration: Failed filament

4. CONCLUSIONS

This paper presented results of inclined plane tests on two GCLs under dry and hydrated conditions. Under dry conditions the friction angle was quite high for both GCLs and the cohesive intercept was negligible. However, hydration caused a significant reduction on the internal shear strength of GCL A (needle-punched). After hydration, the friction angle of GCLA was reduced to 11.5^o. It was identified that this reduction was caused by tensile failure of the filaments or failure at the connections between these filaments and the geotextile covers during hydration. On the other hand, hydration had very little effect on the internal shear strength of GCL B (stitched) due to the strong network of filaments crossing this GCL resulting from the stitching manufacturing process. As a consequence, the shear strength of the bentonite core of GCL B had negligible influence on its overall internal shear strength.

Tensile forces in the anchored bottom geotextile layer of GCL A were mobilised at earlier stages of tests on hydrated specimens, in comparison to what was observed in tests on dry specimens. Hydration had little effect on the mobilised tensile forces in the bottom geotextile layer of GCL B.

The results obtained highlight the importance of the strength of the filaments used in GCL manufacturing for the internal strength of these products. As observed for GCL A, the filaments may fail during expansion of the bentonite and this must be identified and its consequences evaluated for design purposes. In this context, the inclined plane test is a useful tool for the determination of internal shear strength of GCLs under low stress levels.

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