Some aspects concerning the laboratory evaluation of geosynthetic interface friction

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ABSTRACT: The use of drainage geocomposites (GCD) coupled with other geosynthetics, has become a common practice in landfill covering and lining systems. The global stability of these systems is closely related to the interface shear strength, which, in turn, is affect by many parameters and testing conditions. Therefore, the evaluation of the interface friction angle is a key issue for the liners design and performance. One of the laboratory methods used to investigate the geosynthetic interface shear strength is the inclined plane device, very suited for tests at low pressure. The paper deals with the results of an inclined plane test program carried on for two different types of interfaces: GCD - GCL (geosynthetic clay liner) and GCD - GMB (geomembrane). The effects of the dry and the wet conditions, together to the progressive damage induced by relative displacement, were investigated. Finally, some considerations regarding the time of loading were also highlighted.

Keywords: *inclined plane test, drainage geocomposite, geosynthetic clay liner, geomembrane, dry and wet conditions*

1 INTRODUCTION

Several typologies of geosynthetics are currently available to accomplish specific functions, such as filtration, drainage, waterproofing, separation, reinforcement and erosion control. Moreover, in civil engineering applications, different geosynthetics are often coupled in multi-layer systems, thus generating interfaces between polymeric materials and between geosynthetics and soil. These discontinuities may be a crucial point in the design of earth works, since sliding may occur as consequence of an improper assessment of the interface shear strength (Blight 2007, Palmeira 2009, Eid 2011).

The measurement of geosynthetic static interface shear strength may be carried out in laboratory by means of various devices. The direct shear test is widely used at medium-high contact stress (Gilbert et al. 1996, Triplett & Fox 2001, Zornberg et al. 2005, Fox et al. 2006, Fox & Ross, 2011). One limit of this device is the difficult to study the interface strength reduction at large displacements, because the maximum allowable device displacement (generally about 100 mm) should not be sufficient: to increase the relative displacement, many one-directional loadings or cycles of reversed displacements may be performed on the same specimen.

The low normal stress condition may be more properly studied by means of the inclined plane apparatus (Reyes Ramìrez & Gourc 2003, Gourc & Reyes Ramìrez 2004, Wu et al. 2008, Briançon et al., 2011, Carbone et al. 2015), which gives more conservative results, with respect to the direct shear test, in determining the geosynthetic interfaces strength at normal stress lower than 20 kPa (Wasti & Özdüzgün 2001, Ferreira et al. 2016). For this reason this kind of test is suitable especially for the design of landfill covers and, in Europe, it is subjected to a specific standardization (EN ISO 12957-2 2005).

Among the main types of tests available for the study of interface friction, the pull-out test can still be mentioned (Moraci & Cardile 2012, Moraci et al. 2014). It allows measuring the overall strength resulting from the soil-geosynthetics interface friction mobilized on both the upper and the lower sides. From this point of view, it enables designing the anchorage zone of liners or reinforcements, in which the interface strength is influenced by two or even three-dimensional interaction effects.

The paper summarizes the results of inclined plane tests carried out on different interfaces widely used in landfill cover lining systems: GCD (drainage geocomposite) – GCL (geosynthetic clay liner) and GCD – GMB (geomembrane). The aim of the work is of extending the database on interface strength, also in the perspective of a possible review of the European standardization. To this purpose, the interface strength was studied in wet and dry conditions, also including the effect of a progressive damage induced by relative displacement.

2 THE TEST PROCEDURE

The research on geosynthetic interfaces friction was carried out by means of an inclined plane device, available at the geotechnical laboratory of the University of Padua (ICEA Department). It consists of a tilting plane, above which a steel block, free to slide along the plane, can be placed. The first geosynthetic, involved in the interface, is fixed to the inclined plane while the second one is bound to the bottom of the sliding block. The inclined plane has a length of 1.10 m and width of 0.25 m while the block has a length of 0.42 m and a width of 0.22 m. The inclination of the plane can be varied between 0° and about 45°. In order to ensure a straight sliding, the block is constrained by lateral guides, without introducing significant additional friction forces (Fig. 1).

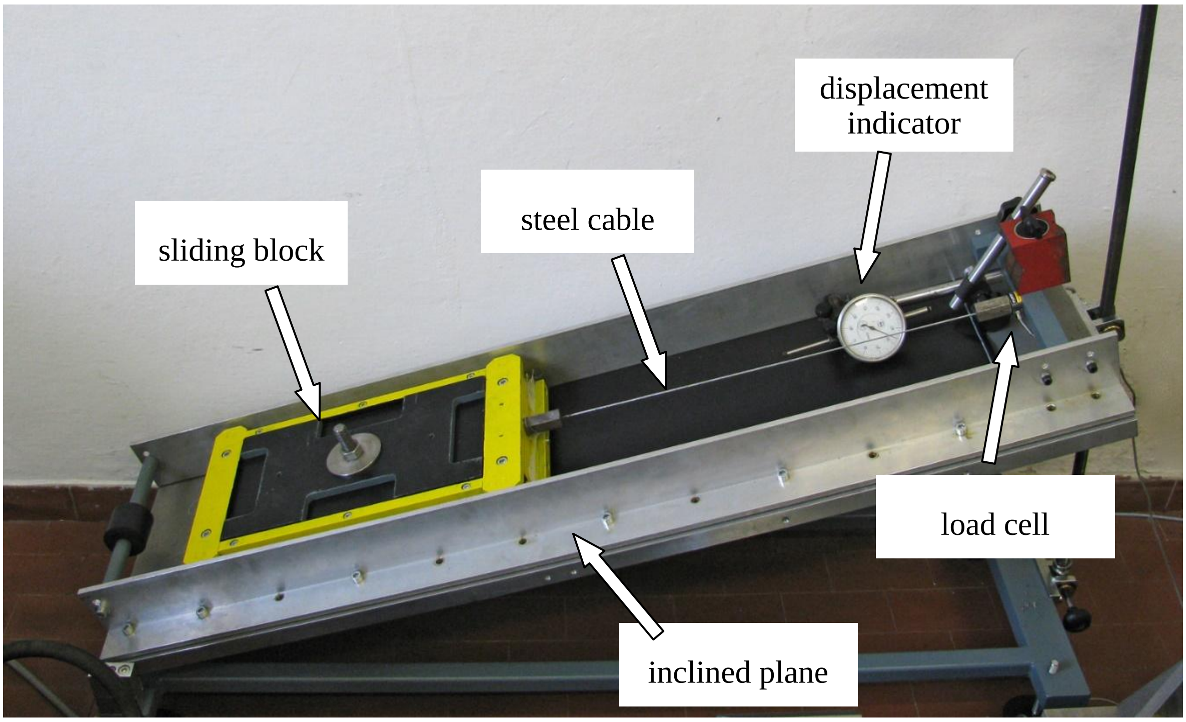

Figure 1. Inclined plane device available at the geotechnical laboratory of the ICEA Department of the University of Padua.

The test procedure allowed to measure the friction angle according to three modes, as described below. At the start of the test, the plane is horizontal; gradually, the inclination of the plane is increased at a constant rate, of about 3°/min, according with the indications of the EN ISO 12957-2 (2005). The tilting angle (β_0) at which the block starts to slide corresponds to the "first movement" angle of friction (φ_0). In static condition, the first movement friction angle equals the tilting angle reached by the plane:

$$\tan \varphi_0 = \tan \beta_0 \tag{1}$$

The measurement of this angle is not always easy. The various interfaces may exhibit very different behaviors: in some cases the sliding starts as soon as the angle β_0 is reached, with a clearly accelerated motion (“sudden sliding” behavior), so that the initial time of the motion can be easily identified. Conversely, for other interfaces, the measurement of the φ_0 angle may be more difficult because the motion evolves very slowly (“gradual sliding” behavior), becoming almost imperceptible. In other cases small movements may occur, but they are not related to an incipient contact slip (“jerky sliding” behaviour) (Gourc and Reyes Ramìrez, 2004).

To overcome the difficulties in detecting β_0 angle, it was adopted, in this work, the convention of detecting the interface strength φ_0 for a relative displacement of 1mm.

Once the first displacement has occurred, a second parameter may be evaluated according to EN ISO 12957-2 (2005). While the plane inclination continues to increase at a constant rate of 3°/min, the plane inclination, $\beta_{50\ mm}$, at which the block reaches a cumulated displacement of 50 mm is detected. The standard friction angle, φ_{stand}, can be obtained from the following expression:

$$\tan\varphi_{stand} = \tan\beta_{50\ mm} \tag{2}$$

It should be noted that the value of 50 mm of displacement, as defined by the European Standard, is merely conventional: the same Eq. (2) comes from the static equilibrium, while the block is in a kinematic condition, with velocity and acceleration not always negligible.

During the test another strength parameter may be evaluated by using the "force procedure" (Briançon et al., 2011): at the end of the sliding the block is retained by a steel cable, parallel to the plane. The force in the cable (*F*) is measured by means of a load cell, while the plane inclination goes on, always with a constant velocity of 3°/min. From static equilibrium, a new parameter, in the following called limit friction angle (φ_{lim}), can be defined according to the following expression:

$$\tan\varphi_{lim} = \tan\beta - \frac{F(\beta)}{W\cos\beta} \tag{3}$$

where *W* is the weight of the block. Even if the plane inclination (β) changes, the force increases in such a way that φ_{lim} remains almost constant.

For a virgin specimen, firstly φ_0 and φ_{stand} were measured; subsequently, φ_{lim} was measured after a displacement of about 300 mm. In order to investigate the damage due to relative displacement, the test was repeated various times on the same specimen, by allowing the block to slide again from the starting position thus obtaining friction parameters related to the amount of the cumulated relative displacement. Almost 5 or 6 cycles were performed for each specimen and, in order to outline a range of variability of the parameters, three different specimens for each interface were tested.

All the experiments were carried out at a vertical stress of 5 kPa and at a laboratory temperature of about 20° C. For comparative purposes, dry and wet conditions were investigated: the wet tests were carried out by immersing the specimens in water and testing them after dripping. For the GCL the immersion phase lasted 15 hours without the application of a confining vertical stress.

3 STUDIED INTERFACES

A first interface considered in this study is the contact between a drainage geocomposite (GCD_1) and a geosynthetic clay liner (GCL): the first geosynthetic is the one fixed to the plane while the second is the one linked to the sliding block.

The GCD_1 is a drainage geocomposite formed by a draining body enclosed between two nonwoven geotextiles: it has a thickness of 7.2 mm under a pressure of 2 kPa and a mass per unit area of 740 g/m^2. GCL is formed by two different geotextiles, one woven and one nonwoven, including a bentonite layer; the overall thickness is of 6 mm and the mass per unit area is of 4300 g/m^2. Both faces of geosynthetic, of woven and of nonwoven, were tested in contact with the GCD_1.

The last interface was between a smooth HDPE geomembrane (GMB), with a thickness of 2 mm and a mass per unit area of 2000 g/m^2, and a second drainage geocomposite (GCD_2). GCD_2 is very similar to GCD_1, the only difference being the thickness of 6.1 mm under a pressure of 2 kPa and the mass per unit area of 670 g/m^2.

4 TEST RESULTS: COMPARISON OF MEASURES

In the following, a comparison of the results obtained during the inclined plane tests, according to the various definitions, is presented. The test results for the GCD_1/GCL interface, in dry and wet conditions, are shown in Fig. 2 in terms of evolution of interface friction angles versus cumulated displacement. In this case the side of the GCL in contact with the GCD_1 is that of woven geotextile.

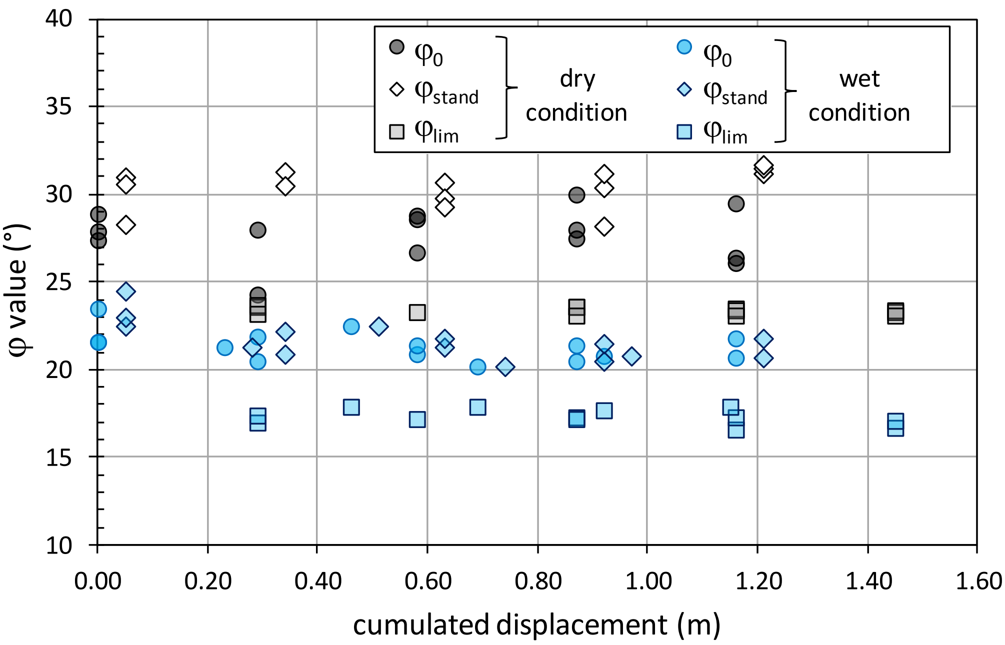

Figure 2. Interface friction angles versus cumulated displacement, for the GCD_1/GCL_{woven} interface, in dry and wet conditions.

All the friction parameters show a visible reduction passing from dry to wet condition, from about 5°-6°, for φ_0 and φ_{lim}, until 7°-10° for φ_{stand}. The data dispersion is more pronounced for φ_0 in dry condition (about 5°) and minimum for φ_{lim}, in both dry and wet conditions; in this latter case the dispersion not exceeds 1°. All the three parameters of friction show a low dependence from cumulated displacements, so indicating a low sensitivity of the interface to damaging.

Moreover it is interesting to observe that the interface behavior changes passing from dry to wet condition: in dry condition it is of the "gradual sliding" type, whereas it becomes of "sudden sliding" type in wet condition.

It is important to highlight that for a "gradual sliding" behavior φ_{stand} is always appreciably greater than φ_0, while in the case of "sudden sliding" the two angles are quite coincident. Furthermore, φ_{lim} is always lower than the other two parameters (φ_0 and φ_{stand}): the difference between φ_{stand} and φ_{lim} is of about 7° in dry condition and of about 4° in wet condition.

The results related to the contact of the GCD_1 with the other side of the GCL, the nonwoven face, are shown in Fig. 3, limited to the dry condition. Also in this case the behavior is of "gradual sliding" type, so that φ_{stand} is always greater than φ_0, but with differences decreasing as damaging increases. However, both φ_0 and φ_{stand} increase, up to 4°, with the increase of the cumulated displacement. The parameter φ_{lim} is always the lowest and it remains almost constant at the variation of the cumulated displacement. Lastly, by comparing Fig. 2 and Fig. 3, it can see that passing from the contact with the woven side of the GCL to that nonwoven, the mobilized friction values are comparable.

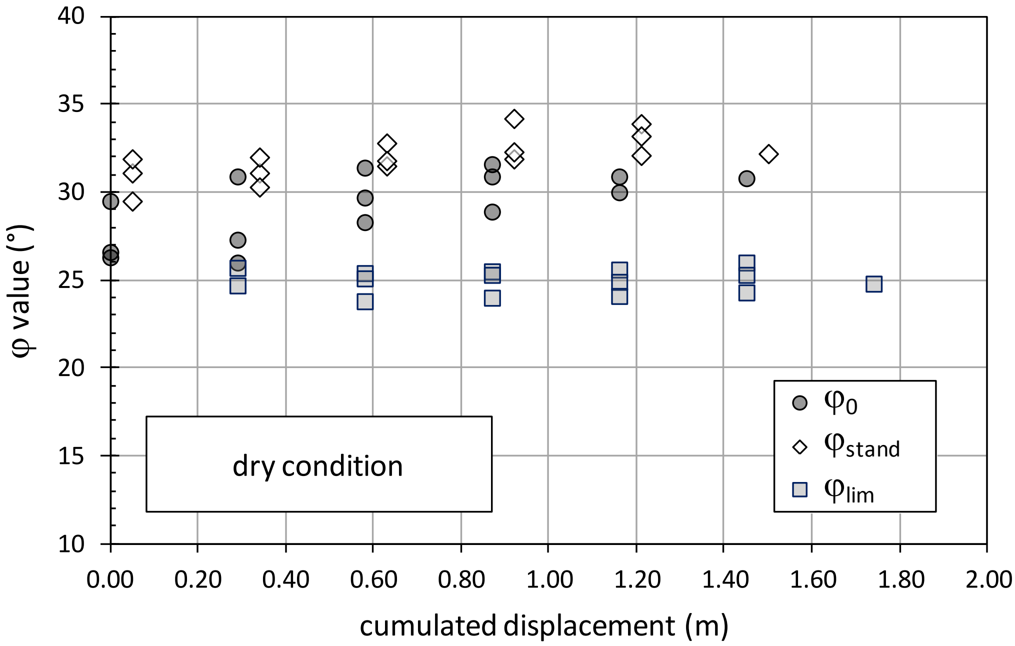

Figure 3. Interface friction angles versus cumulated displacement, for the $GCD_1/GCL_{nonwoven}$ interface, in dry condition.

The results related to a different interface, the contact between the smooth GMB and the GCD_2, are shown in Fig. 4, for both the dry and the wet conditions, in terms of evolution of interface friction angles versus cumulated displacement. Also this interface shows a reduction of all the friction parameters passing from dry to wet condition: the difference is of 3°- 4° for φ_0 and φ_{lim}, and of about 5° for φ_{stand}.

As it is logical to expect, considering the smooth surface finishing of the GMB, all the three parameters of friction do not show a relevant dependence from cumulated displacements, so indicating a low sensitivity of the interface to damaging.

Also for this interface the behavior changes, passing from "gradual sliding" in dry condition to "sudden sliding" in wet condition.

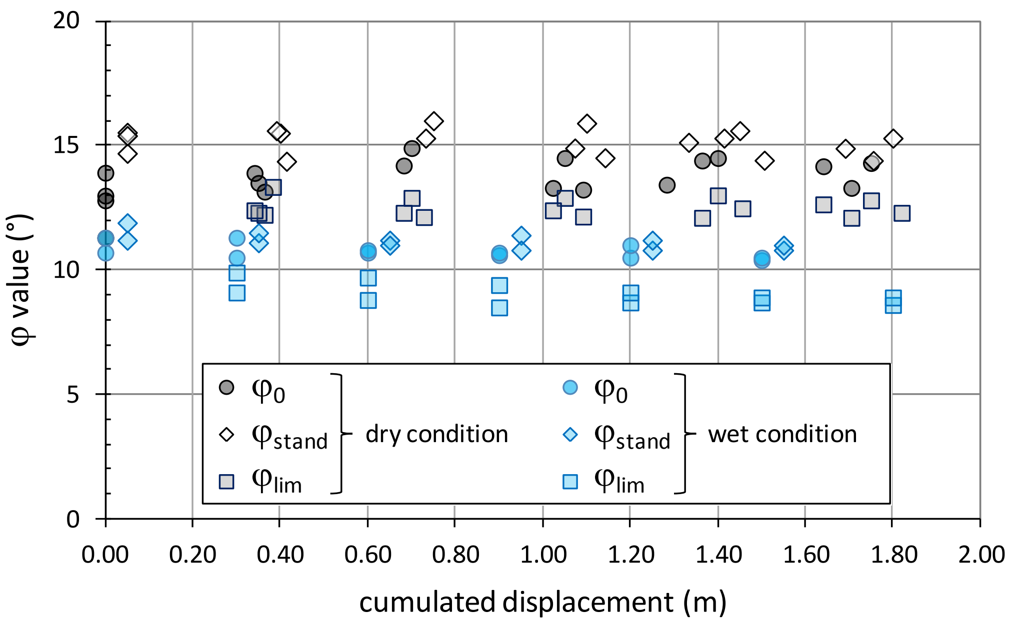

Figure 4. Interface friction angles versus cumulated displacement, for the GMB/GCD_2 interface, in dry and wet conditions.

5 SOME CONSIDERATIONS CONCERNING THE TIME EFFECT

As illustrated by the above results and those already published (Pavanello & Carrubba 2016), the "Force procedure" seems to provide the more conservative friction values respect to φ_0 and of φ_{stand}. Introduced by Briançon et al. (2011), this procedure is based on the static interface friction evaluation after that relative sliding has occurred, thus removing any adhesion forces.

An interesting issue, related to this method, is the effect of time, i.e. the effect of the rotation speed of the plane, on the measured value of friction. Briançon et al. (2011) indicate that the measure of φ_{lim} is not significantly dependent on the inclination rate of the plane. To this regard, the same authors report the comparison between tests conducted on two different interfaces, the first between a smooth ethylene/propylene/diene geomembrane and a non-woven heated geotextile, and the second between a smooth HDPE geomembrane and the same geotextile, with rotation speed of the inclined plane dβ/dt selected in the range between 1.3°/min and 3.2°/min. The authors conclude that for both interfaces and for both types of sliding, sudden or gradual, the plane inclination rate had no significant influence on the value of the limit friction angle.

However, as noticed for example by Müller et al. (2004), the available interface fiction may change in time in relation to the viscous-elastic behavior of polymeric materials, as well as with environmental factors like temperature or ageing.

Although these results refer to the long-term behavior, the dependence of friction on time and on loading speed is not negligible. In order to investigate this aspect, further tests were conducted with a different methodology. In the first phase, during the rising of the plane, the block was retained; subsequently, once the desired inclination, greater than the angle of first displacement β_0, was reached, the block was allowed to slide up to tighten the cable. At this stage the force in the cable was monitored over the time at constant plane inclination. As can be seen, the test procedure is quite similar to that of the "force procedure" with the only difference that the plane inclination does not vary over time but is kept constant; in order to better highlight the variations of mobilized friction over time. A typical result is shown in Fig. 5, for the case of GMB-GCD_2 interface, in dry conditions, in terms of retaining force in the time. In the same Fig. 5 the variation of the mobilized interface friction in time, as deducted by Eq. (3), is highlighted. The test confirms that interface friction between polymeric materials is not a constant but it depends on the elapsed time: the force increases according to a logarithmic law, and the mobilized friction decreases in a similar way. The friction value, after four days, lowered of about 2° respect to the initial value and it is also lower than the limit friction angle, which, for this interface, was found equal on average to 12.5°.

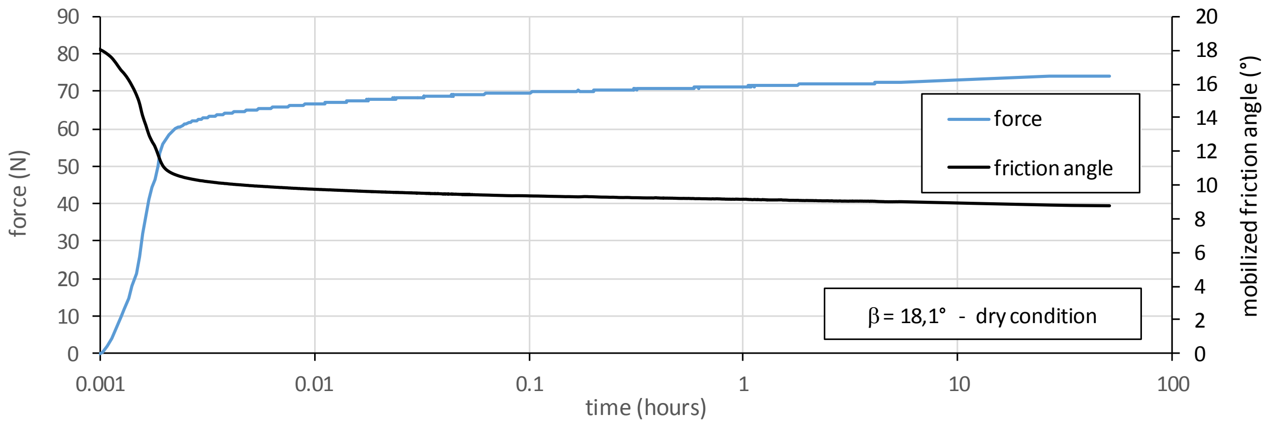

Figure 5. Force in the cable and mobilized interface friction angle versus time in dry condition (GMB/GCD_2 interface).

A similar behavior was observed, on the same GMB-GCD interface, in wet conditions (Fig. 6): also in this case, after four days, the mobilized interface friction decreased in time of about 2° respect to the initial value and it is lower than the limit friction angle, which, for wet condition, was equal on average to 9.2°.

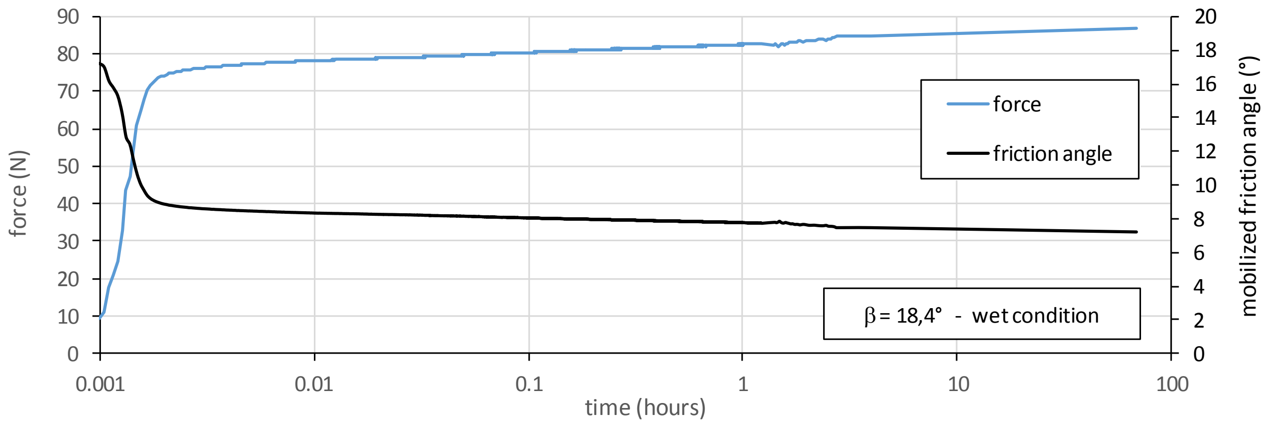

Figure 6. Force in the cable and mobilized interface friction angle versus time in wet condition (GMB/GCD_2 interface).

These results clearly show how the interface friction can depend on the time and it may be even lower than that coming from the force procedure, which is the more conservative method of evaluation of the interface friction by means of an inclined plane.

Starting from this consideration, it seems correct to believe that also the inclination speed of the plane may have an effect on the measured friction angle during the "force procedure", even if the continuous variation of the loading may partially conceal the viscous effects.

To investigate this possibility, the authors have carried various "force procedure" tests, on the same GMB/GCD_2 interface, at various inclination rate of the plane, from 1°/min up to 7.5°/min. The results of these tests seems to indicate that the variation of the limit friction angle value, due to variation of rotating speed, may be of the same order of the data dispersion and therefore the effect of the rotation speed on the limit friction angle is negligible.

6 CONCLUSIONS

The inclined plane tests carried out for various geosynthetic interfaces, in dry and wet conditions, have highlighted some aspects resumed in the following.

First of all, the standard angle of friction, as defined by EN ISO 12957-2 (2005), gives the less conservative parameter (values of φ_{stand} higher than φ_0) when the sliding mode is of the gradual type. Otherwise, when the sliding mode is of the sudden type, standard and first movement angles of friction are almost coincident. The presence of water at the interface is able to reduce the mobilized interface friction: for example, for the GCD_1/GCL_{woven} interface, the reduction of friction from dry to wet conditions, is of about 5°- 6°, for φ_0 and φ_{lim}, and of about 7°-10° for φ_{stand}.

The tested interfaces are not much sensitive to damaging caused by progressive displacements with the only exception of the contact between nonwoven face of the GCL and the nonwoven geotextile of the GCD_1.

The limit angle of friction φ_{lim} is rather stable, because it does not depend on the cumulated displacements; moreover, it provide the more conservative friction values and it shows the lower dispersion of data respect to the mean value. The difference between standard and limit angle of friction may be significant; it may range between 4° and 9° in relation to the analysed interface.

The results of constant loading test (fixed inclination) clearly show how the mobilized interface friction can depend on the loading time and they seem to indicate that the interface friction may be even lower than the limit friction angle.

Concluding, the limit friction angle can be considered a lower bound value of the interface friction range outlined by all the various testing procedures; however, long time of loading may reduce the margin of safety due to geosynthetic viscous effects. At this regard, further studies are needed to verify the long-term behavior under constant loading.

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