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Sand-Nonwoven geotextile interfaces shear strength by direct shear and simple shear tests

Castorina Silva Vieira [*1], Maria de Lurdes Lopes [1a] and Laura Caldeira [2b]

[1] *Department of Civil Engineering, Faculty of Engineering, University of Porto, R. Dr. Roberto Frias, 4200 465 Porto, Portugal*
[2] *National Laboratory of Civil Engineering, Av. do Brasil, 1700-066 Lisbon, Portugal*

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Abstract. Soil-reinforcement interaction mechanism is an important issue in the design of geosynthetic reinforced soil structures. This mechanism depends on the soil properties, reinforcement characteristics and interaction between these two elements (soil and reinforcement). In this work the shear strength of sand/geotextile interfaces were characterized through direct and simple shear tests. The direct shear tests were performed on a conventional direct shear device and on a large scale direct shear apparatus. Unreinforced sand and one layer reinforced sand specimens were characterized trough simple shear tests. The interfaces shear strength achieved with the large scale direct shear device were slightly larger than those obtained with the conventional direct shear apparatus. Notwithstanding the differences between the shear strength characterization through simple shear and direct shear tests, it was concluded that the shear strength of one layer reinforced sand is similar to the sand/geotextile interface direct shear strength.

Keywords: soil reinforcement; soil/geosynthetic interfaces; direct shear tests; simple shear tests

1. Introduction

Soil-reinforcement interaction mechanism has an utmost importance in the design of geosynthetic reinforced soil structures. This mechanism depends on the soil properties, reinforcement characteristics and elements (soil and reinforcement) interaction. The accurate identification of the interaction mechanism and the choice of the most suitable test for its characterization are important factors. For instance, in a reinforced soil embankment, the soil-geosynthetic interaction can be best characterized by laboratory pullout tests in the upper zone of the retained reinforced soil mass, where the reinforcement is pulled out, and the interaction between the two materials is better characterized trough direct shear tests near the base of the slope, where soil sliding is expected.

Several experimental studies have been conducted to investigate the shear behaviour of soil-geosynthetic interfaces through large scale direct shear tests (Vieira *et al*. 2013, Liu *et al*. 2009, Hsieh and Hsieh 2003, Lee and Manjunath 2000). Small direct shear devices has also been

*Corresponding author, Assistant Professor, E-mail: cvieira@fe.up.pt
[a] Professor, E-mail: lcosta@fe.up.pt
[b] Principal Research Officer, E-mail: laurac@lnec.pt

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used to characterize soil/geotextile interfaces (Hatami and Esmaili 2015, Esmaili *et al*. 2014, Deb and Konai 2014, Khoury *et al*. 2011, Anubhav and Basudhar 2010). The use of the simple shear device to characterize interfaces behaviour is very scarce and is limited mainly to sand-steel interfaces (Uesugi and Kishida 1986, Evgin and Fakharian 1998, Oumarou and Evgin 2005).

The simple shear test was developed to simulate the conditions in a thin shear zone separating two masses that slide with respect to each other. A condition approached in some landslides that occur along planar surfaces (Terzaghi *et al*. 1996). The simple shear test apparatus differs from the conventional direct shear devices since tilting elements delimit the vertical boundaries of the specimens, allowing a more uniform deformation of the soil and the rotation of principal stresses. Besides the failure planes are not imposed. This paper presents results from simple shear tests carried out to characterize the behaviour of a dry sand reinforced with one geocomposite reinforcement layer. In this situation a weak plane inside the reinforced sand may be created at the sand-geotextile interface.

The conventional direct shear device used to characterize soil shear strength can only accommodate small size specimens, which imposes serious limitations in terms of reproducing real conditions. Based on this evidence and following the European and North American Standards for determining the friction characteristics of soil/geosynthetic interfaces (EN ISO 12957-1 2005, ASTM D 5321-02 2002), a large scale direct shear test device was designed and built at University of Porto (Vieira *et al*. 2013).

Conventional shear boxes could be used to characterize soil/geosynthetic interfaces if it can be shown that the data generated using smaller devices do not reveal scale or edge effects when compared to the minimum size devices recommended by the standards (Anubhav and Basudhar 2010). The scale effect of the direct shear box on sand-geotextile interfaces shear strength will be analysed in this work.

The knowledge of soil/geosynthetic interface properties is essential for accurate design and suitable modelling of geosynthetic reinforced structures. Results of direct shear tests were used by Zarnani *et al*. (2011) to estimate the plane strain soil parameters required to simulate the dynamic response of two instrumented reduced-scale model reinforced soil walls. Vieira *et al*. (2011) also used results from direct shear tests to model the behaviour of a geogrid reinforced steep slope constructed in the North of Portugal.

Bearing in mind the importance of the knowledge of soil/geosynthetic interfaces behaviour, the laboratory study herein presented was prepared and carried out. With the results reported in this paper is intended, on one hand, to show the influence of the test device used to characterize the interface shear strength and, on the other hand, to increase the available experimental data that could be used in the design and analysis of geosynthetic reinforced structures.

2. Materials and testing program

In the laboratory study herein presented the interfaces between a silica sand (99.5% of silicon dioxide) and three geocomposites used frequently as reinforcement (high strength geotextiles) were characterized through direct and simple shear tests. The direct shear tests were performed on a conventional direct shear device and on a large scale direct shear apparatus. Unreinforced sand and one layer reinforced sand specimens were characterized trough simple shear tests.

According to the Unified Soil Classification System, the sand is classified as SP - poorly graded sand and it was referred as SP45. Fig. 1 shows the grain size distribution of this sand. The

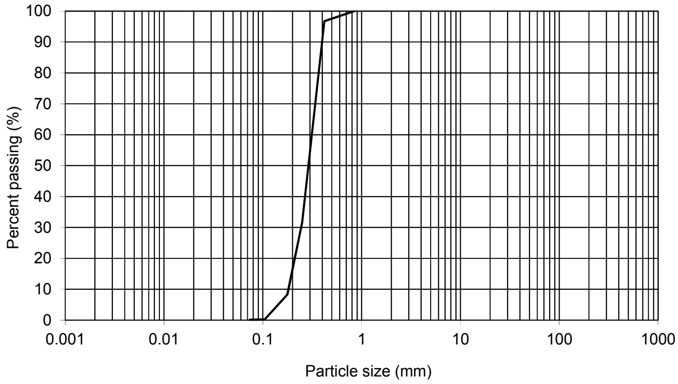
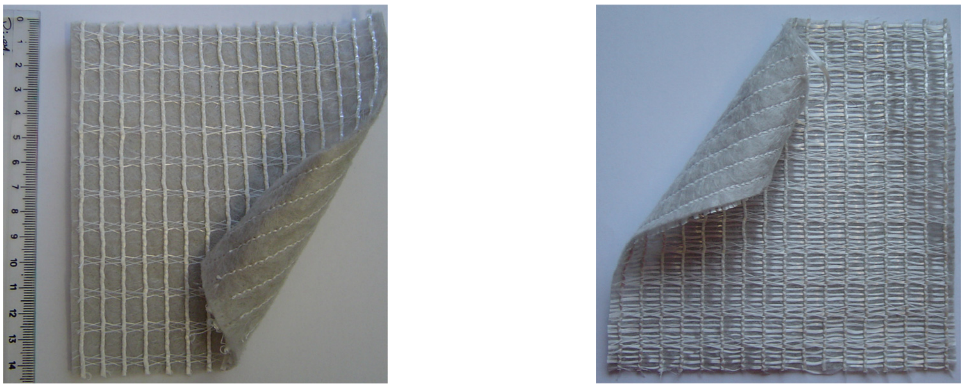


Fig. 1 Grain size distribution of the SP45 sand



(a) (b)

Fig. 2 Visual appearance of the geocomposites: (a) geocomposite with uniaxial reinforcement, GC100; (b) geocomposite with biaxial reinforcement, GC50-50

Table 1 Main properties of the geosynthetics used in the laboratory study*

Geocomposite reinforcement	GC50	GC100	GC50-50
Raw materials	PP continuous filament nonwoven / PET yarns		
Orientation of reinforcement	monodirectional	monodirectional	bidirectional
Mass per unit area (g/m^2)	310	370	370
Thickness (mm)	2.1	2.4	2.6
Water flow rate normal to the plane (mm/s)	65	65	50
Tensile strength (Machine Direction) (kN/m)	63	115	63
Elongation at break (%)	13	13	13

* Values provided by the manufacturer

sand has mean diameter of 0.29 mm, uniformity coefficient of 1.7 and coefficient of curvature equal to 1.0. All the tests were performed at the sand air-dried water content and with relative density (I_D) of 70%.

The geosynthetics used in this study are high strength composite geotextiles, consisting of polypropylene (PP) continuous filament needlepunched nonwoven and high strength polyester (PET) yarns. Two geotextiles reinforced by polyester yarns in one direction (uniaxial reinforcement) with nominal strength of 50 kN/m and 100 kN/m and one geotextile reinforced in both directions (biaxial reinforcement) with nominal strength in the machine and cross directions of 50 kN/m were chosen. Fig. 2(a) shows one of the geocomposites with uniaxial reinforcement (referred as GC100) and Fig. 2(c) exhibits the geocomposite with biaxial reinforcement (referred as GC50-50). The main properties of these geocomposites are summarized in Table 1.

The geocomposites used in this study combine the functions of reinforcement and drainage, being suitable for short and long term soil reinforcement applications such as base reinforcement, subgrade stabilisation, railway foundations, reinforced steep slopes and retaining walls. They were selected based on the evidence that they are materials frequently used as reinforcement and simultaneously their physical characteristics allow being tested in small scale devices.

In the scope of research on soil-geosynthetic interface characterization, a laboratory prototype of a large scale direct shear test device, able to perform monotonic and cyclic direct shear tests, was designed and built at University of Porto (Vieira 2008). The development of this prototype was based on the European (EN ISO 12957-1 2005) and North American (ASTM D 5321-02 2002) standards.

The developed large scale direct shear device is based on a hydraulic actuation with closed loop command computer control. The apparatus consists of the shear box, a support structure, five hydraulic actuators and respective fluid power unit, an electrical cabinet, internal and external transducers and a computer (Fig. 3).

The shear box comprises an upper box, fixed in the horizontal directions, with dimensions of 300 mm × 600 mm in plant and 150 mm in height, and a lower box, with dimensions of 340 mm × 800 mm in plan and 100 mm in height, rigidly fixed to a mobile platform running on low friction linear guides. A rigid base or a rigid ring can be inserted in the lower box. As indicated by the European standard (EN ISO 12957-1 2005), the apparatus is able to perform constant area direct shear tests (if the rigid base is placed inside the lower box – Fig. 3), or reducing area direct shear

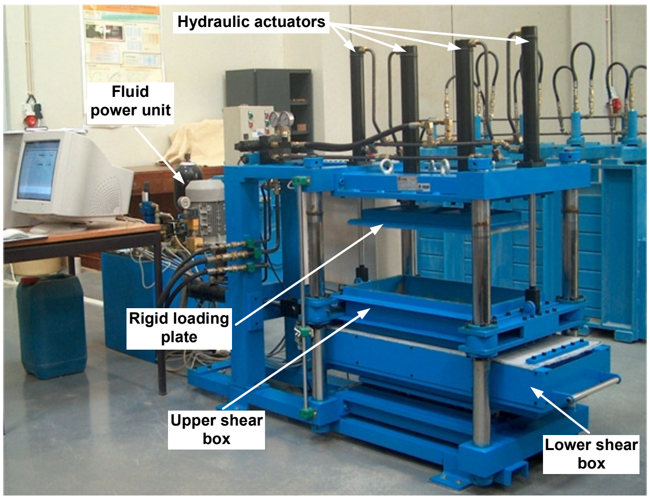


Fig. 3 Overview of the large scale direct shear test device

tests, if the rigid ring is put inside the lower box. More details regarding this device can be found in Vieira *et al*. (2013).

The direct shear tests included in this study were performed with the rigid base placed on the lower shear box (constant contact area tests). To prevent relative displacements between the specimen and the rigid support, an aluminium oxide abrasive sheet (P80 type) was glued to the rigid support. The geosynthetic specimens were connected to the lower box, outside of the shear area, by rigid bars with several screws located at each edge of the box (Fig. 3). The sand was placed inside the upper shear box, at its air-dried water content, with relative density (I_D) of 70%. It was compacted in two thick layers with 25 mm height to the target unit weight (controlled by the weight and volume of the sand).

The tests were conducted with a constant displacement rate of 1 mm/min at normal stresses of 50, 100 and 150 kPa. Prior to shearing, the normal stress was applied to the specimens for one hour. After this period, the settlement of the soil under the pre-established normal stress has stabilised in all the specimens.

A conventional direct shear device was also used to characterize the direct shear behaviour of the sand and sand/geotextile interfaces. The shear boxes have dimensions in plant of 60 mm × 60 mm and 20 mm in height.

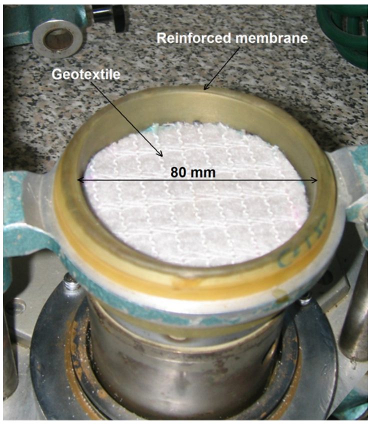
Some changes in the lower shear box were needed to allow the characterization of sand/geotextile interfaces. A rigid base was built to allow the fixing of the geotextile in the lower shear box (Fig. 4). The rigid base is provided with a rectangular ring that fixes the geotextile and prevents relative movements (Fig. 4(a)).

The length of the shear box of the conventional device is 10 times lower than the length of the large scale device so the tests were conducted with a constant displacement rate of 0.1mm/min (also 10 times lower that the displacement rate adopted in the large scale tests). The direct shear tests were also carried out at normal stresses of 50 kPa, 100 kPa and 150 kPa.

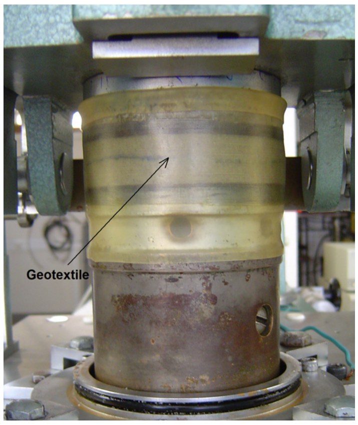
To characterize the shear behaviour of geotextile reinforced sand specimens, as well as, unreinforced sand specimens, a linear simple shear device Norwegian Geotechnical Institute type, model Geonor h12, was used. The specimens are cylindrical, with an initial height of 16 mm and a diameter of about 80 mm, enclosed in a wire reinforced rubber membrane. In the tests of reinforced sand specimens, the thickness of geosynthetic was deducted from the height of specimen to determine the amount of sand corresponding to the desired relative density (I_D = 70%). The sand

(a) (b)

Fig. 4 Rigid base adjustable to the lower shear box of the conventional direct shear device: (a) rigid base outside the lower shear box; (b) rigid base placed inside the lower shear box



(a)



(b)

Fig. 5 Preparation of the geosynthetic reinforced sand specimen for simple shear tests: (a) geotextile placed over the first layer of sand; (b) specimen prepared to be tested

was deposited in two layers, being the geotextile placed between them (Fig. 5(a)). Rigid metal plates are placed at the bottom and top of the specimen. Fig. 5 illustrates two stages of geotextile reinforced sand specimen preparation.

During the consolidation of the specimens the settlements were recorded to allow the correction of the height. The simple shear tests were carried out with strain rate of 0.1 mm/min until the failure of the specimen at normal stresses of 50, 100, 150 and 300 kPa.

The testing program presented in this paper comprises 12 large scale direct shear tests (sand and sand/geotextile interfaces), 12 direct shear tests performed with the conventional direct shear device and 16 simple shear tests carried out on reinforced and unreinforced sand specimens.

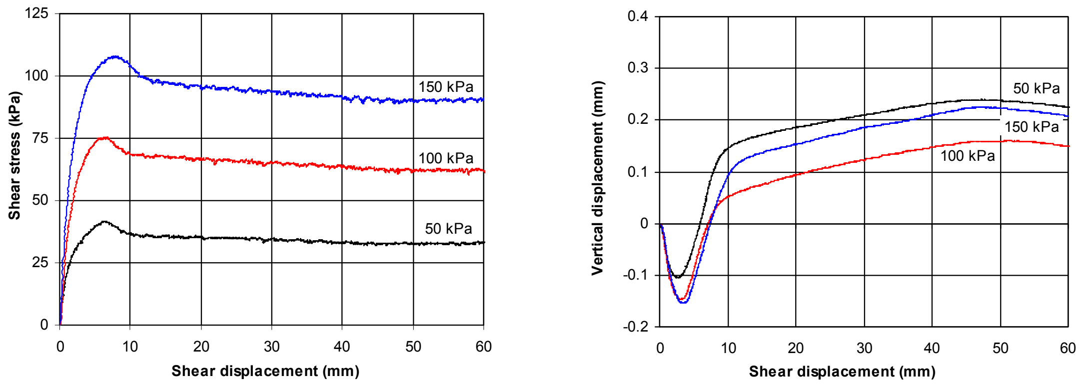
3. Results and discussion

3.1 Sand/geotextile interfaces characterization through direct shear tests

3.1.1 Results of large scale direct shear tests

The evolution of the shear stress and the vertical displacement of the rigid plate centre, as function of the shear displacement, relating to direct shear tests carried out to characterize the interface between the sand SP45 and the geotextile GC100 is shown in Fig. 6. The shear stress-shear displacement curves, plotted in Fig. 4(a), show a well-defined peak shear strength. As expected, initially, the sand exhibited a contraction followed by a dilating phase (Fig. 4(b)). For the intermediate normal stress (100 kPa), the interface shear stress behaviour was consistent with the tests carried out at the lowest and highest normal stresses. Nevertheless, its vertical displacement evolution presented a contractile behaviour, similar to the one observed at the highest normal stress (150 kPa), but a dilating phase less expressive than the one observed in the other tests.

Fig. 7 presents the peak and the large displacement shear strengths for confining pressures of 50, 100 and 150 kPa, as well as, the corresponding linear best fits. It should be noted that the coefficients of determination, R^2, also included in Fig. 7, are very close to the unit which proves the suitability of the linear fits to the values recorded in the laboratory tests.



(a) (b)

Fig. 6 Results of large scale direct shear tests for SP45/GC100 interface characterization:
(a) shear stress-shear displacement; (b) vertical displacement (settlement)-shear displacement

Following Coulomb failure criterion, the interface SP45/GC100 presented an apparent adhesion $c_{a,p}$ = 9.0 kPa and a peak friction angle δ_p = 33.5°. The large displacement strength can be defined by an apparent adhesion $c_{a,cv}$ = 4.2 kPa and friction angle δ_{cv} = 29.9°. The failure envelopes evidenced an apparent adhesion for this sand/geotextile interface probably due to the nonlinearity of the relationship between the shear strength and the normal stress at lower confining pressures. The apparent adhesion has been also reported by other authors for sand/geosynthetic interfaces (Liu *et al*. 2009, Ling *et al*. 2002, Cazzuffi *et al*. 1993).

The coefficient of interaction or friction ratio, f_g, is defined as the ratio of the maximum shear stress in a soil/geosynthetic direct shear test, $\tau_{\text{soil/geo}}^{\max}(\sigma)$, to the maximum shear stress in a direct shear test on soil, $\tau_{\text{soil}}^{\max}(\sigma)$, under the same normal stress σ

$$f_g = \frac{\tau_{\text{soil/geo}}^{\max}(\sigma)}{\tau_{\text{soil}}^{\max}(\sigma)} = \frac{c_a + \sigma \tan\delta}{c + \sigma \tan\phi} \tag{1}$$

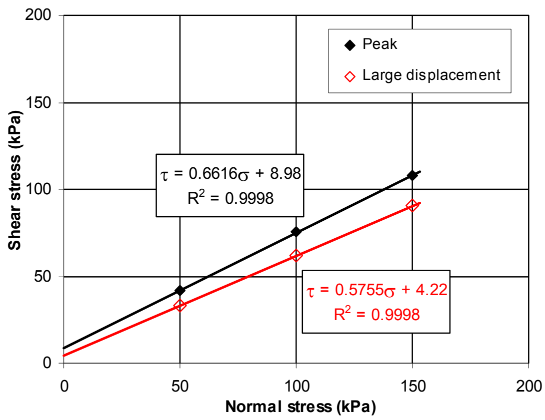


Fig. 7 Peak and large displacement shear strengths for SP45/GC100 interface

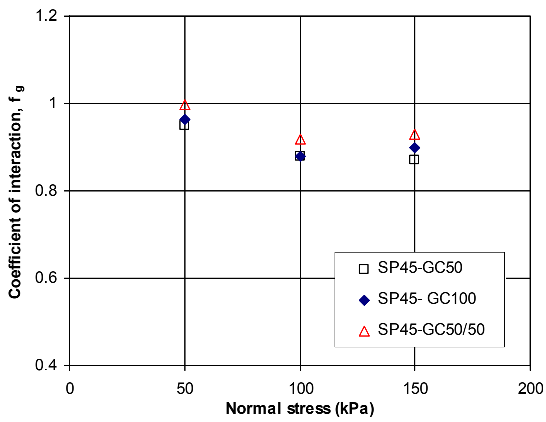


Fig. 8 Coefficient of interaction against normal stress for distinct interfaces (obtained with large scale device)

Fig. 8 presents the coefficients of interaction for the three interfaces under analysis, as a function of the normal stress. As shown previously for the interface SP45/GC100 (Fig. 7), the results of direct shear tests have evidenced apparent adhesion, so the coefficient of interaction, determined by Eq. (1), depends on the normal stress

Regardless the interfaces, the greatest coefficients of interaction were achieved for the lowest value of the confining pressure (50 kPa). The coefficients of interaction are almost independent of the normal stress value for greater values (100 kPa and 150 kPa). Fig. 8 also evidences that the interface SP45/GC50-50 has the highest shear strength. This conclusion can be justified by the greatest surface roughness of this geotextile, resulting from the existence of PET filaments in both directions (Fig. 2(b)).

For the interfaces under analysis, the coefficients of interaction (also called interface shear strength coefficient or interface efficiency) are in the range 0.87-1.0. These values are consistent with those reported by other researchers for sand/geotextiles interfaces. Hsieh *et al*. (2011) reported a peak friction efficiency of 0.92 for a quartz sand/PP geotextile interface, while Silvano and Lopes (2005) found coefficients of interaction ranging from 0.73 to 0.84 for a loose coarse sand/nonwoven geotextile interface. Liu *et al*. (2009) reported interface shear strength coefficients ranging from 0.71 to 0.78 for a sand/geotextile interface.

3.1.2 Results of direct shear tests performed with the conventional device

The evolution of the shear stresses and the vertical displacements of the rigid plate centre, as function of the shear displacement, for the direct shear tests carried out to characterize the interface between the sand SP45 and the geotextile GC50 is illustrated in Fig. 9. On the contrary of the curves presented in Fig. 6(a), the shear stress-shear displacement curves for the direct shear tests carried out with the conventional device did not evidence any peak of strength. The contractile behaviour of the sand, exhibited in Fig. 9(b), was the expected. The comparison of the curves presented in Fig. 9 with those achieved with the large scale device will be presented in the sequence.

Fig. 10 presents the maximum shear strengths and the large displacement shear strengths for confining pressures of 50, 100 and 150 kPa, as well as, the corresponding linear best fits for the interface SP45/geotextile GC50. Considering that the shear stress-shear displacement curves did

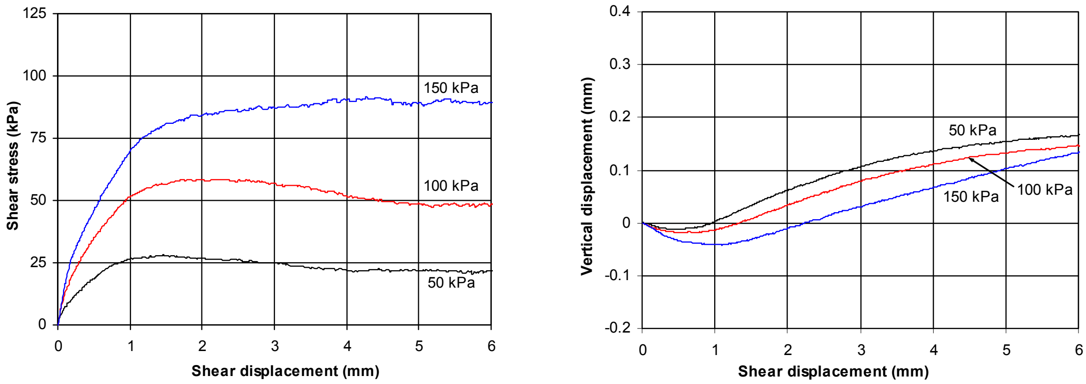


Fig. 9 Characterization of SP45/GC50 interface with the conventional direct shear device: (a) shear stress-shear displacement; (b) vertical displacement-shear displacement

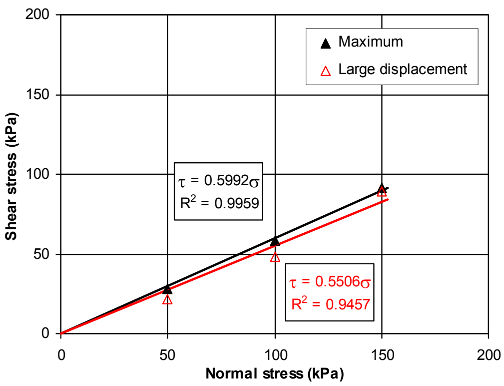


Fig. 10 Failure envelopes for SP45/GC50 interface achieved with the conventional device

not evidence a well defined peak of strength (Fig. 9(a)), the maximum values of the interface shear strength, plotted in Fig. 10, are close to the values reached at large displacements.

The coefficients of determination, R^2, particularly for the maximum shear strength, are very close to the unit which proves the adequacy of the linear fits to the values recorded in the laboratory tests.

The coefficients of interaction for the three interfaces under analysis, as a function of the normal stress, are plotted in Fig. 11. On the contrary of the results achieved with the large scale device, the lowest coefficients of interaction were reached for the lowest value of the confining pressure (50 kPa). As concluded for the results obtained with the large scale device, the interface SP45/GC50-50 has exhibited the highest coefficients of interaction, with the exception of the results for 50 kPa. This exception has resulted from the low interface shear strength obtained on the test performed with confining pressures of 50 kPa (see Figs. 12(c) and 13(c)).

The coefficients of interaction achieved with the conventional device, for the interfaces under analysis, are in the range 0.63-0.92, slightly lower than those reached with the large scale device (0.87 - 1.0).

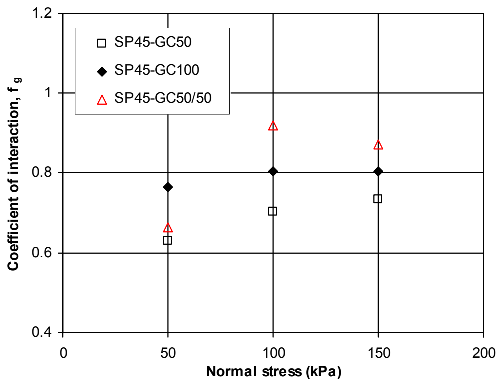


Fig. 11 Coefficient of interaction against normal stress for distinct interfaces (obtained with conventional device)

3.1.3 Comparison of the direct shear tests results

Regarding the influence on test results of the dimensions of the shear boxes (scale effects), contradictory opinions can be found in the literature. Palmeira (1988) stated that the scale effects do not affect the peak value of the friction angle obtained from direct shear tests, while Hsieh and Hsieh (2003) found that, in general, the shear strengths obtained in shear boxes with large dimensions are greater than those reached with smaller shear boxes.

Fig. 12 compares the evolution of the shear stress with the shear displacement normalized by the length of the shear box, Δ_{shear}/L, obtained with the large scale and the conventional direct shear devices for the three interfaces under analysis. As mentioned, the shear stress-shear displacement curves, obtained in the large scale direct shear tests, tend to exhibit a peak of strength, not evident in the results achieved with the conventional apparatus.

In general (with some exceptions), the maximum shear strengths reached with two devices are relatively close however they were achieved for lower values of the normalized shear displacement in the large scale device. When the conventional device was used, the maximum shear stresses under normal stress of 50 kPa tended to be lower than those achieved with the large scale apparatus (Figs. 12(a) and 12(c)).

The failure envelopes for the direct shear tests performed with the conventional device (60 mm × 60 mm) and the large scale device (300 mm × 600 mm) are compared in Fig. 13.

The shear strength parameters obtained by the direct shear tests carried out with the two devices are summarized in Table 2. Table 2 also included the values achieved for the sand friction angle.

Table 2 Summary of direct shear tests results

	Large scale device		Conventional device	
	Friction angle, δ_p (º)	Apparent adhesion, c_a (kPa)	Friction angle, δ_p (º)	Apparent adhesion, c_a (kPa)
Sand SP45	39.4	-	38.5	-
SP45/GC50	32.3	10.6	30.9	-
SP45/GC100	33.5	9.0	33.8	-
SP45/GC50-50	34.3	9.8	36.0	-

The failure envelopes for sand/geotextile interfaces characterized with the large scale apparatus have evidenced an apparent adhesion (see Fig. 13 and Table 2). As mentioned previously, this apparent adhesion, also reported by other authors for sand/geosynthetic interfaces (Liu *et al*. 2009, Ling *et al*. 2002, Cazzuffi *et al*. 1993), is probably due to the nonlinearity of the relationship between the shear strength and the normal stress at lower confining stresses. The direct shear tests performed with the small device have not revealed this apparent adhesion.

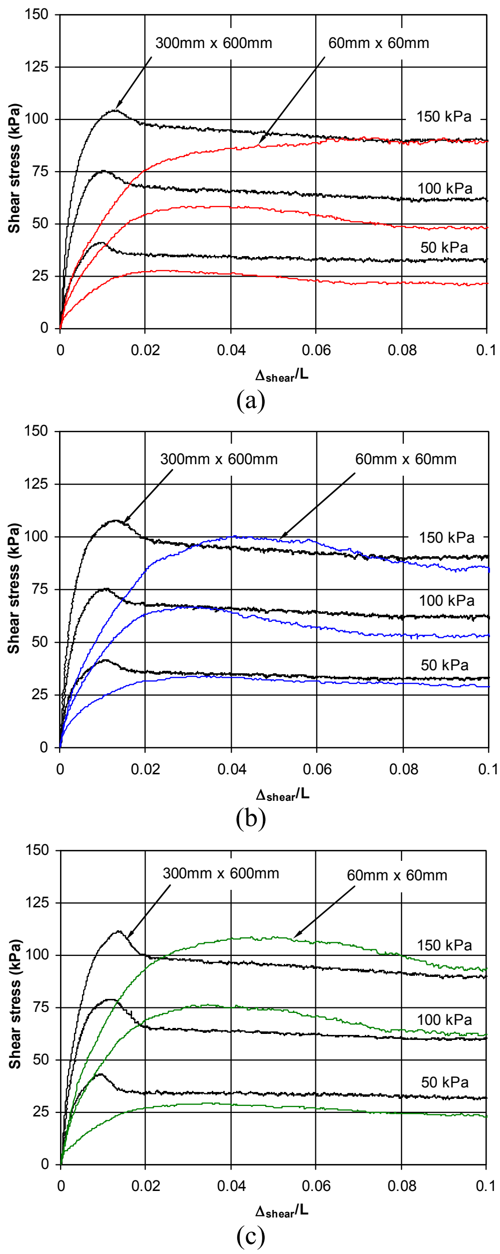
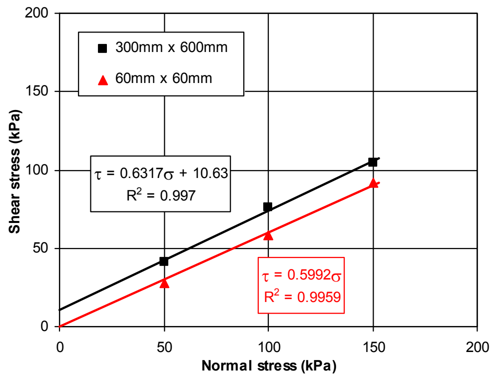
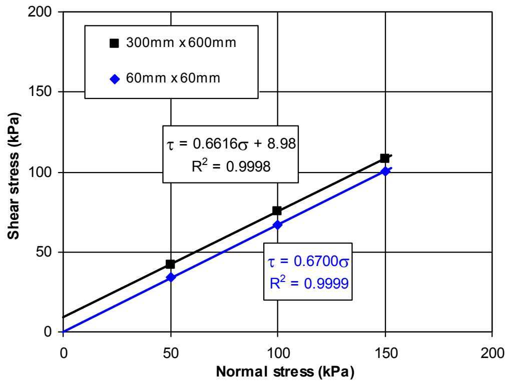


Fig. 12 Comparison of shear stress- normalized shear displacement curves achieved with two devices, for: (a) SP45-GC50 interface; (b) SP45-GC100 interface; (c) SP45-GC50/50 interface



(a)



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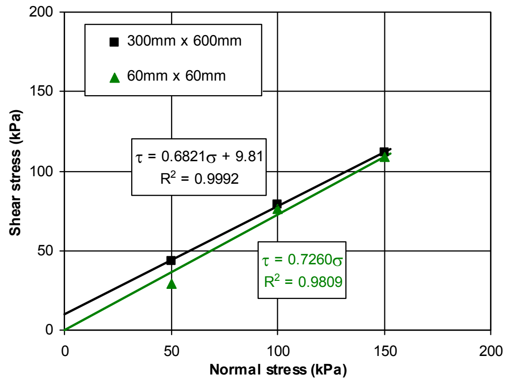
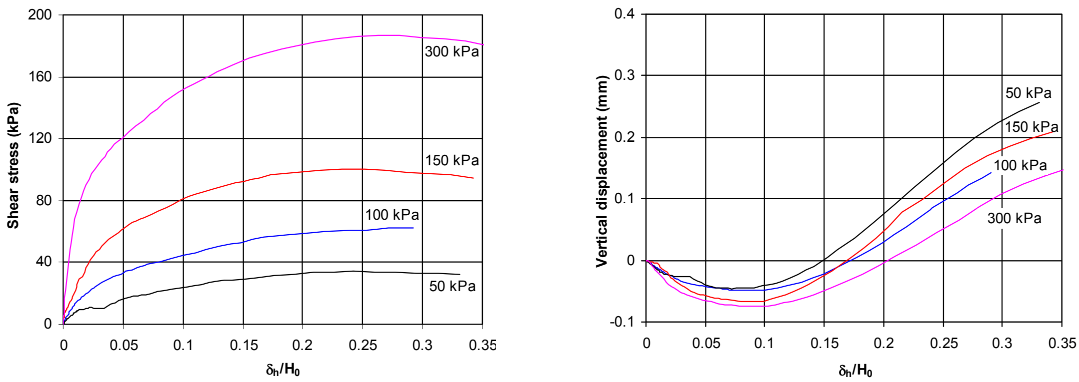


(c)

Fig. 13 Comparison of the failure envelopes, obtained with two devices, for: (a) SP45-GC50 interface; (b) SP45-GC100 interface; (c) SP45-GC50/50 interface

For the three interfaces analysed, the shear strength was higher when it has been evaluated with the large scale apparatus (Fig. 13). It should be noted that, when analysing the scale effects on the direct shear behaviour of soil/geosynthetic interfaces, the results cannot be compared only by the peak values of the interface friction angle. Table 2 shows that the interface friction angles achieved with the small device were higher for SP45/GC100 and SP45/GC50-50 interfaces but, since



(a) (b)

Fig. 14 Simple shear tests results for sand SP45 reinforced with GC50: (a) shear stress-shear strain (δ_h/H_0) behaviour; (b) evolution of vertical displacements during shear (δ_h = horizontal shear displacement; H_0 = initial height of the sample)

apparent adhesion has been recorded with the large scale device, it does not mean higher interface shear strength.

3.2 Characterization of unreinforced and reinforced sand by simple shear tests

Fig. 14 illustrates the shear stress versus shear strain behaviour, as well as, the vertical displacement during shear for sand specimens reinforced with geotextile GC50. The shear stress-shear strain curves for the one layer reinforced sand specimens did not evidence any peak of strength.

The contractile behaviour of the reinforced sand specimens is illustrated in Fig. 14(b). The analysis of Fig. 14(b) shows that the test with normal stress equal to 100 kPa has presented a contractile behaviour similar to the one observed for the lowest normal stress (50 kPa) but a dilating phase less expressive than the one observed in the other tests.

The maximum shear stresses, for distinct values of the normal stress, reached during shear of unreinforced sand specimens and sand specimens reinforced with geotextile GC50 are compared in Fig. 15. The corresponding linear best fits, which represent the failure envelopes, were also included in Fig. 15. The failure envelopes have evidenced an apparent cohesion even for the unreinforced sand, possibly due to the nonlinearity of the relationship between the shear strength and the normal stress at lower confining stresses.

Unexpectedly, the shear strength of the reinforced sand specimens was lower than the shear strength of the unreinforced sand specimens, which proves the existence of a weak failure plane (the interface).

The presence of the geotextile led to a looser layer of sand over the reinforcement, as a result of the damping caused by its presence during the deposition process of the sand. The existence of this looser layer of sand creates a thin shear zone separating two masses of sand and justifies the lower shear strength of the reinforced sand specimens.

Fig. 16 confirms the hypothesis above-mentioned. When a reinforcement layer is placed within the specimen, greater settlements (negative values of the vertical displacements) were recorded and the dilatant phase had less significance. To simplify the figure, it was decided to present only

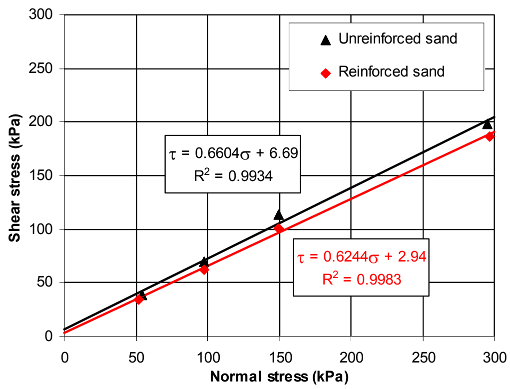


Fig. 15 Comparison of the failure envelopes for unreinforced and reinforced sand specimens (with GC50)

the vertical displacements related to the tests performed with the highest and lowest value of the normal stress.

Fig. 17 presents the ratios of maximum shear stresses reached on reinforced sand, τ_{reinf}, to the maximum shear stresses on unreinforced sand, $\tau_{unreinf}$, as a function of the normal stress, for the three geotextiles under analysis. The ratios $\tau_{reinf}/\tau_{unreinf}$ are in the range 0.82-0.96 and have assumed similar values to those of the coefficients of interaction achieved with large scale direct shear tests (Fig. 8).

The results illustrated in Fig. 17 do not provide evidence of any specific tendency related to the variation of the ratio $\tau_{reinf}/\tau_{unreinf}$ with the normal stress or with the geotextile tensile strength.

The shear strength parameters achieved with the simple shear device for the unreinforced sand and for the sand reinforced with distinct geocomposites are summarized in Table 3. The friction angle for the reinforced sand is almost independent of the geotextile used to reinforce the sand. The characteristics of the surface (Fig. 2), the thickness and the mass per unit area (Table 1) do not seem to have influence in the shear behaviour of the reinforced sand.

The comparison of the shear strength parameters obtained with the three devices will be presented in the next section.

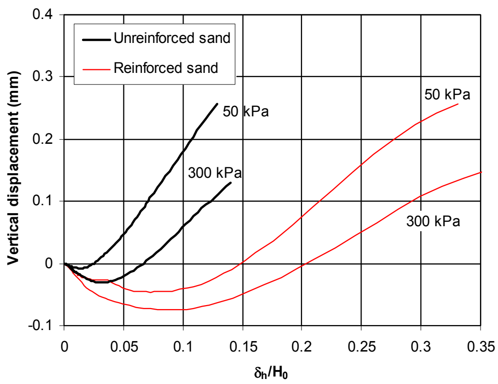


Fig. 16 Comparison of vertical displacements during simple shear tests for unreinforced and reinforced sand specimens (with GC50)

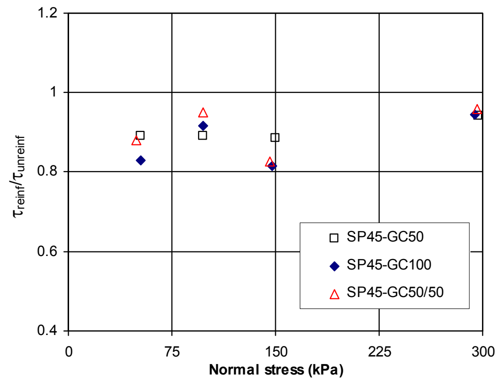


Fig. 17 Ratio of maximum shear stress on reinforced sand to the maximum shear stress on unreinforced sand

Table 3 Summary of shear strength parameters obtained with simple shear tests

	Friction angle, ϕ (º)	Apparent cohesion, c_a (kPa)
Unreinforced sand	33.4/34.7*	6.7/-
Sand reinforced with GC50	32.0	2.9
Sand reinforced with GC100	32.5	-
Sand reinforced with GC50-50	32.3	3.1

* Imposing null cohesion

3.3 Comparison of simple shear and direct shear tests results

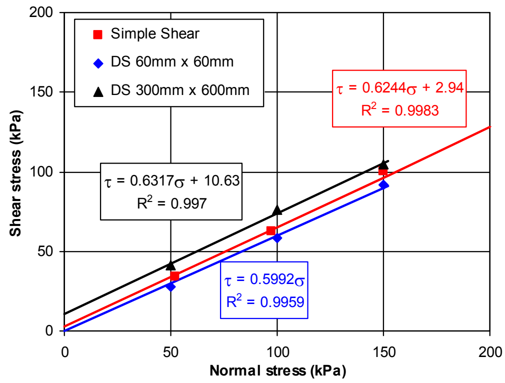
Fig. 18 compares the failure envelopes obtained with simple shear tests for reinforced sand specimens and the failure envelopes achieved in the direct shear tests (DS) performed to characterize the interfaces between the sand and the geotextiles with the conventional device (60 mm × 60 mm) and with the large scale apparatus (300 mm × 600 mm).

While the direct shear tests characterize the interface between two materials (sand and geotextile) imposing a shear displacement at the interface level, the simple shear tests analyze the behaviour of a non-homogeneous material (reinforced sand), where the geotextile placed between the two layers of sand generates a thin shear zone. Despite this difference, the analysis of Fig. 18 and the comparison of Tables 2 and 3 show that, the shear strength of the reinforced sand specimens approaches the shear strength of the sand/geotextile interfaces.

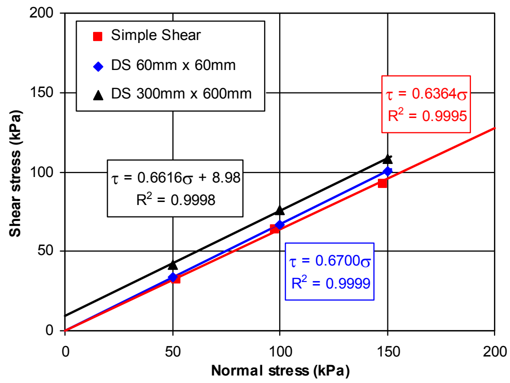
The shear strength reached with the large scale direct shear device is higher than that achieved with the other devices. With the exception of the results achieved for the geotextile with biaxial reinforcement (Fig. 18(c)), the failure envelopes are nearly parallel. This exception is due to the lower interface shear strength obtained for the interface SP45/GC50-50 characterized with the conventional direct shear device under normal stress of 50 kPa.

4. Conclusions

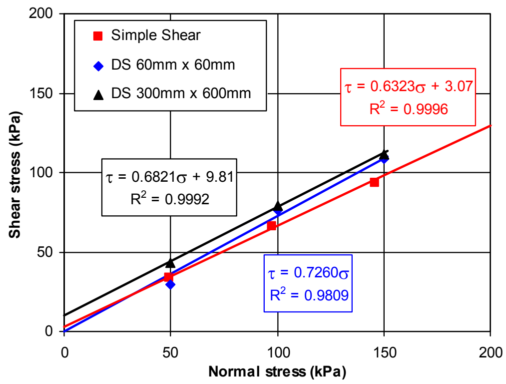
The shear strength of interfaces between a siliceous sand and three geocomposites used as reinforcement (high strength geotextiles) were characterized through direct and simple shear tests.



(a)



(b)



(c)

Fig. 18 Comparison of the failure envelopes achieved with the direct shear tests (DS) and simple shear tests for: (a) SP45-GC50 interface; (b) SP45-GC100 interface; (c) SP45-GC50/50 interface

Even knowing that the conventional direct shear can only accommodate small size specimens, which could impose serious limitations in terms of reproducing real conditions, the direct shear tests were performed on a conventional direct shear device and on a large scale direct shear apparatus. Unreinforced sand and one layer reinforced sand specimens were characterized trough simple shear tests.

Based on the analysis and interpretation of the results of direct shear tests, the following conclusions can be drawn:

- the coefficients of interaction for sand/geotextile interfaces depend on the confining pressure; the minimum value achieved for the geotextiles under analysis was 0.63 (slightly lower than 2/3 commonly recommended);
- the shear strength of soil-geosynthetic interfaces reached with the large scale device was slightly higher than that obtained with the conventional direct shear apparatus. Notice, however, that the large scale direct shear device should represent more accurately the real behaviour of the interface so its use would be preferable.

Although the characterization reached by the simple shear tests is distinct from that of the direct shear tests (the failure plane is not imposed), it can be stated that the shear strength of the anisotropic material (sand and geotextile) approaches the shear strength of the interface between the two materials.

The results presented in this paper allow us to conclude that, for this type of geosynthetics, in the absence of the large scale apparatus recommended for determining the friction characteristics of soil/geosynthetic interfaces, small scale devices could be used with appropriate adjustments.

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