Direct Shear Testing of Sand – Geotextile Interfaces

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Abstract. The effect of shear box size, geotextile type and properties and sand grain shape and size on the sand – geotextile interaction was investigated experimentally by conducting interface tests with conventional and large-scale direct shear equipment. Four clean uniform sands, one with subangular grains and three with rounded grains of different sizes were tested in dry and dense condition. Seven non-woven polypropylene geotextiles of various types and properties and seven woven geotextiles with or without apertures were used in the tests. The large-scale direct shear tests were conducted according to ASTM Standard D5321, using a 300 mm square shear box. The tests with the conventional 100 mm square shear box were performed using the same normal stresses and comparable shearing rate with the large-scale tests. The interface friction coefficient values obtained from the tests with the conventional and the large-scale shear box are in good agreement. Therefore, the 100 mm shear box is satisfactory for testing materials like those used in the present investigation. The values of friction coefficient, $tan\delta$, at the sand – geotextile interface are affected by the geotextile type and range from 71% to 104% with respect to the internal friction coefficients, $tan\varphi$, of sands. Although the interface friction coefficient values are larger in the sand with subangular grains, the efficiency ($tan\delta/tan\varphi$ ratio) values for the sand with subangular grains are lower in comparison with the sand with rounded grains of equal size. For interfaces between sands of different grain sizes and geotextiles without apertures, the obtained efficiency values generally increase with decreasing sand grain size.

1 Introduction

Design procedures for reinforced sand structures require quantification of the interaction behavior at the sand – reinforcement interface. This is accomplished by conducting large-scale laboratory direct shear and pull-out tests and is expressed in terms of an apparent friction angle, δ, or an interface friction coefficient, $tan\delta$. The abovementioned experimental procedures are rather costly because they require the use of specially designed and constructed large-size direct shear or pull-out boxes and specialized personnel. More specifically, both ASTM D5321 (2006) and EN ISO 12957-1 (2005) direct shear tests call for a square shear box of 300 mm in size. While such a large shear box is appropriate for geonets, geogrids, many geocomposites, and large particle-sized soils, Koerner (2005) considers it to be excessive for geotextiles (and certainly for geomembranes) against sands, silts and clays. Conventional geotechnical engineering laboratory shear boxes (e.g., 100 mm), are felt to be satisfactory for

geotextile testing (Koerner 2005). It is, therefore, of merit to verify the suitability of interface direct shear tests with 100 mm shear box, by comparing their results obtained for geotextiles manufactured with different processes and having different properties with those of standardized tests with 300 mm shear box.

The interaction behavior at sand – geotextile interfaces has been investigated extensively by conducting direct shear tests and it was found that it depends on the surface characteristics, the type, the strength and the stiffness of the geosynthetic (Williams and Houlihan 1987, Koutsourais et al. 1998). On the other hand, the results of direct shear tests on interfaces between dense Ottawa 20–30 sand and a non-woven needle-punched geotextile of four different densities indicated that the apparent friction angle is independent of the geotextile density (Athanasopoulos et al. 2002). Also, the friction coefficient for rounded sand – woven geotextile interfaces is lower than the one obtained for angular sand – woven geotextile interfaces (Anubhav and Basudhar 2013), but the apparent friction angle can decrease with increasing (Formazin and Batereau 1985) or decreasing (Choudhary and Krishna 2016) sand grain size. The aforementioned observations show that the effect of geotextile type and properties and sand grain shape and size on the sand – geotextile interaction needs further documentation. Toward these ends, 93 direct shear tests with conventional and large-scale equipment were performed on 22 interfaces between sands differing in grain shape or grain size and various woven and non-woven geotextiles, and the results obtained are reported herein.

2   Materials

The direct shear tests were conducted using four clean, uniform sands in dry and dense condition. From the properties of sands presented in Table 1, it can be seen that three of them (designated as R 20–30, R 30–40 and R 40–100) are standard Ottawa quartz sands with rounded grains of different sizes, since their grain sizes are limited between ASTM sieve sizes Nos. 20 and 30, 30 and 40, and 40 and 100, respectively. As shown in Fig. 1, the fourth sand (designated as S 20–30) has subangular grains of the same sizes with R 20–30 sand and was tested in order to investigate the effect of grain shape on sand – geotextile interaction. The values of angle of internal friction, φ, of the sands in dry and dense condition, were determined by conducting triaxial compression tests and are also shown in Table 1. These φ values are used for normalizing the obtained values of the interface friction angle, δ.

Table 1. Sand properties

Sand	Grain shape	Grain sizes (mm)			Void ratios		Shear strength	
		D_{max}	D_{50}	D_{min}	e_{max}	e_{min}	φ (°)	D_r (%)
S 20–30	Subangular	0.85	0.71	0.60	0.96	0.62	47.0	83
R 20–30	Rounded	0.85	0.71	0.60	0.77	0.46	36.0	82
R 30–40	Rounded	0.60	0.51	0.43	0.85	0.52	35.0	92
R 40–100	Rounded	0.43	0.25	0.15	0.79	0.52	37.0	90

S 20-30 (Subangular) Sand   **R 20-30 (Rounded) Sand**
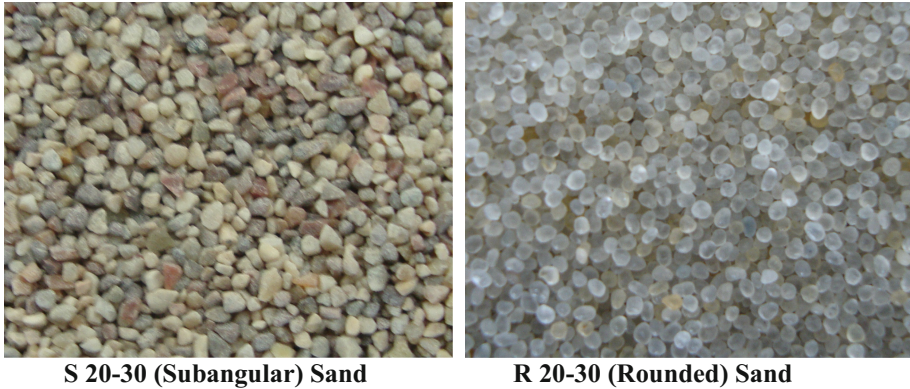
Fig. 1. Enlarged views of sands used in study

Seven non-woven polypropylene geotextiles and seven woven geotextiles with or without apertures, provided by eight different manufacturers, were tested during this investigation. The geotextiles were selected in order to cover a wide range of types of the commercially available products and pertinent properties of them, according to the manufacturers, are presented in Table 2. More specifically, two needle-punched with

Table 2. Geotextile properties

Geotextile	Thickness (mm)	Mass per unit area (g/m^2)	Apparent opening size (μm)	Tensile test results	
				Max. tensile load (kN/m)	Extension at max. load (%)
TS 50 (NW)	1.90	200	110	15.0/15.0 *	75/35 *
B 200 (NW)	2.70	201	100	10.6/12.9 *	88/90 *
F 400 (NW)	1.80	275	75	16.5/17.5 *	52/55 *
SF 40 (NW)	0.45	136	120	8.5	60
SF 56 (NW)	0.54	190	80	12.8	65
SF 77 (NW)	0.65	260	60	20.0	70
SF 111 (NW)	0.85	375	55	29.0	70
TP 240 (W)	1.17	240	200	50.0/50.0 *	15/13 *
TP 310 (W)	1.01	310	105	66.0/66.0 *	14/10 *
TP 400 (W)	1.15	400	94	86.0/86.0 *	20/14 *
SG 80/80 (W)	1.35	360	255	82.0/86.0 *	20/11 *
HS 400/50 (W)	1.10	700	—	400.0/50.0 *	<10/<20 *
H 50.145 (W)	1.15	225	—	32.0/32.0 *	15/18 *
N 66447 (W)	0.90	194	1256	44.4/39.6 *	27/22 *

(NW): Non-woven, (W): Woven
*Machine direction/Cross machine direction

comparable properties (POLYFELT TS 50 and BONDEX 200), one needle-punched with thermally treated surfaces (FIBERTEX F 400) and four thermally bonded fabrics with different properties (TYPAR SF 40, SF 56, SF 77 and SF 111), constitute the group of the selected non-woven geotextiles. These materials are designated as TS 50, B 200, F 400, SF 40, SF 56, SF 77 and SF 111, respectively. The set of woven geotextiles consists of three polypropylene with different properties (THRACE PLASTICS 240, 310 and 400), one standard grade polypropylene (BONAR SG 80/80), one high strength polyester/polyamide (HUESKER Stabilenka 400/50), as well as two materials with apertures of different size, one polyester with PVC coating and aperture size, A, equal to 1.20 mm (HUESKER HaTe 50.145) and one polyethylene with aperture size, A, equal to 0.77 mm (NICOLON 66447). The woven geotextiles are designated as TP 240, TP 310, TP 400, SG 80/80, HS 400/50, H 50.145 and N 66447, respectively. Enlarged images of all geotextile types used in the present study are shown in Fig. 2.
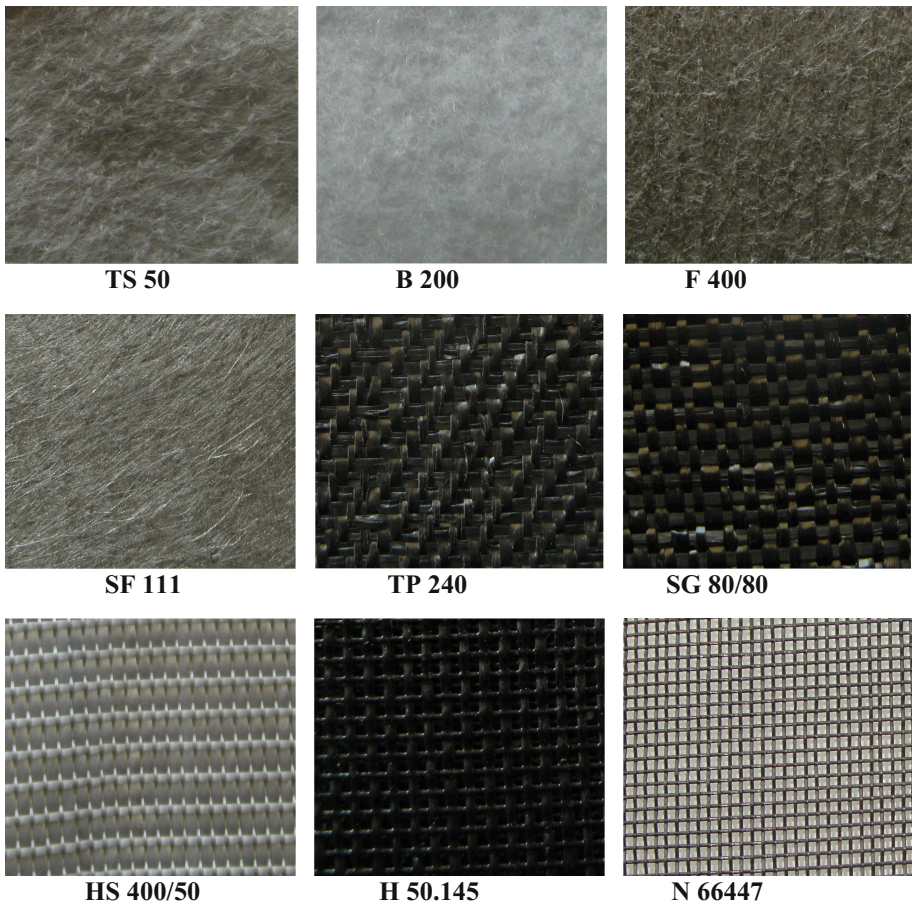

TS 50	B 200	F 400
SF 111	TP 240	SG 80/80
HS 400/50	H 50.145	N 66447

Fig. 2. Enlarged views of geotextiles used in study

3   Experimental Procedures

Conventional and large-scale direct shear equipment was utilized to conduct the tests on sand – geotextile interfaces in order to evaluate the interface friction coefficient, $tan\delta$. The direct shear tests with the large shear box were performed on interfaces between dry, dense R 20–30 sand and selected non-woven and woven geotextiles of various types, with the purpose of investigating the effect of shear box size on the sand – geotextile interaction.

The large-scale tests were conducted using a direct shear apparatus of controlled displacement with a 300 mm square shear box. A cross section of the square shear box is shown in Fig. 3a. The normal load, with maximum value of 100 kN, is applied hydraulically to the top plate whereas the horizontal displacement of adjustable rate is applied through electric motors to the lower part of the shear box. The upper part of the shear box is held in place by the reaction of the load ring. A system described in detail by Athanasopoulos et al. (2002), which was designed and fabricated in order to make the shear box capable of accommodating interface shear testing, was used in the tests. For sand – geotextile interface testing, the proper parts of the system were placed and assembled in the lower part of the shear box in the order indicated in Fig. 3b. The geotextile sheet was placed and clamped on the rough interface plate and dry sand was placed and compacted in layers in the upper part of the shear box. The sand was compacted using a hand operated tamper and care was taken in order to produce sand layers with constant density. The relative density of the sand in these tests ranged from 83% to 93%. The reported difference between the angles of internal friction, φ, of loose ($D_r = 46\%$) and dense ($D_r = 80\%$) sand is 6.5^o (Gourc et al. 1996). The increase of sand relative density from an average value of 51% (loose condition) to an average value of 93% (dense condition) caused an increase of the friction angle, δ, by 6–7° in sand – non-woven geotextile interfaces (Miyamori et al. 1986, Gourc et al. 1996) and by 5–10° in sand – woven geotextile interfaces (Makiuchi and Miyamori 1988). However, negligible differences in the friction angles φ and δ were obtained by Lee and Manjunath (2000) for an increase of sand relative density from 50% to 80%. From all these data it can be concluded that the range of sand relative density in the present
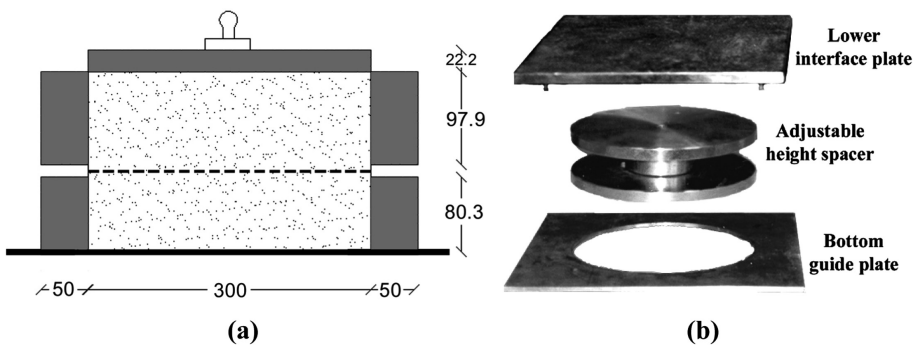

Fig. 3. Large (300 mm) shear box, (a) dimensions, (b) system for sand – geotextile interface testing

study does not have a substantial effect on the results since it is not expected to cause variations in the friction angles φ and δ larger than 1°. The large-scale tests were conducted according to ASTM Standard D 5321 (2006), with normal stresses, σ_n, equal to 100, 200 and 400 kPa, at a constant rate of shearing equal to 1 mm/min and were completed at a horizontal displacement of 30 mm.

All the other tests were conducted using a conventional direct shear apparatus of controlled displacement with a 100 mm square shear box. The specimen configuration used in these tests, is shown schematically in Fig. 4a and is depicted in Fig. 4b. The dry sand was placed and compacted in the lower part of the shear box. The sands were compacted using a hand operated tamper and care was taken in order to produce sand layers with constant density. The geotextile sheet was placed and fixed on the rough surface of a wooden block and, then, the block with the geotextile sheet was placed in the upper part of the shear box in contact with the sand. Taking into consideration that evidence of negative influence on the test results was not found in the literature for this test setup and that it is also suggested by Koerner (2005), it is intuitively believed that placing the sand and the geotextile in the lower and the upper parts of the shear box, respectively, is practically the same as the customary test setup used in the large-scale tests. Since geotextiles of different thickness and compressibility were tested in this study, it was very complicated to adjust the height effectively with the wooden block in the lower part of the shear box so as the sand – geotextile interface to coincide with the shearing plane. This adjustment was accurately made in the large-scale tests with the "adjustable height spacer" included in the system of Fig. 3b. Thus, the specimen configuration of Fig. 4 was preferred in the conventional tests for simplicity reasons. All conventional tests were conducted at a relative density of the sands between 87% and 97%, with normal stresses, σ_n, equal to 100, 200 and 400 kPa, at a constant rate of shearing equal to 0.25 mm/min and were completed after failure at the sand – geotextile interface (peak value of shear force). The chosen rate of shearing is equal to 0.25%/min with reference to the dimension of the shear box in the shearing direction and is comparable to the equivalent shearing rate of 0.33%/min used in the large-scale tests. A number of conventional tests were repeated for the verification of data resulting in differences between shear stress values at failure ranging from 1.1% to 10.6%. Consequently, the repeatability of the tests is considered satisfactory.
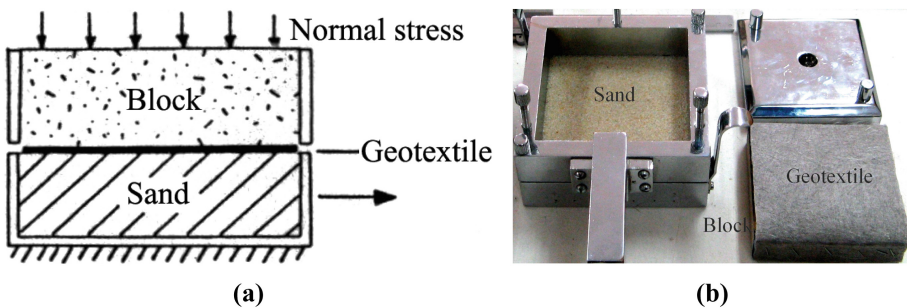

Fig. 4. Specimen configuration for sand – geotextile interface testing with the 100 mm shear box

4   Results and Discussion

Typical "shear stress – horizontal displacement" curves obtained from large-scale and conventional direct shear tests, conducted on various sand – geotextile interfaces, are shown in Fig. 5. All these curves present a peak indicating failure at the sand – geotextile interface. The typical "vertical displacement – horizontal displacement" curves presented in Fig. 6, show an initial decrease and a subsequent increase of the specimen height as shearing progresses. Although the measured values are low, these observations signify compression and expansion at the sand – geotextile interface, respectively. The shear and normal stress values at failure were used to plot the "shear stress – normal stress" diagrams, in order to evaluate the interface shearing resistance between the geotextiles and the sands. As it is typically shown in Fig. 7, the interaction behavior can be described by a linear Mohr – Coulomb failure envelope presenting adhesion values equal to zero. From the slope of the failure envelopes resulted from
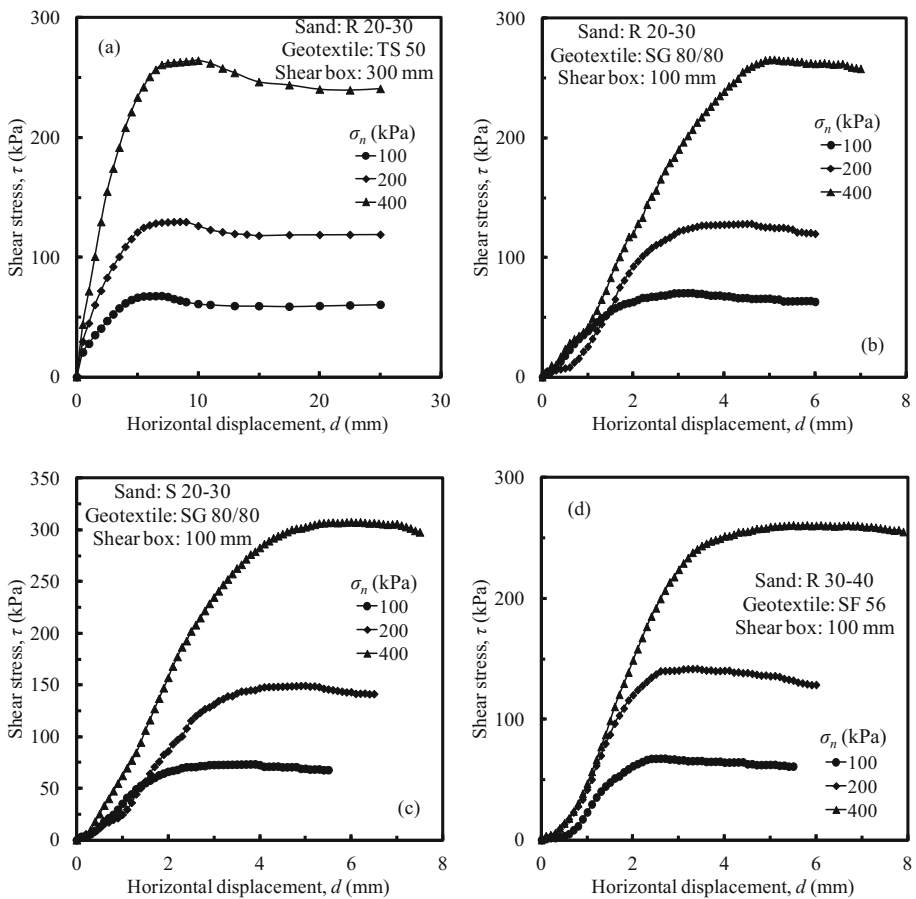

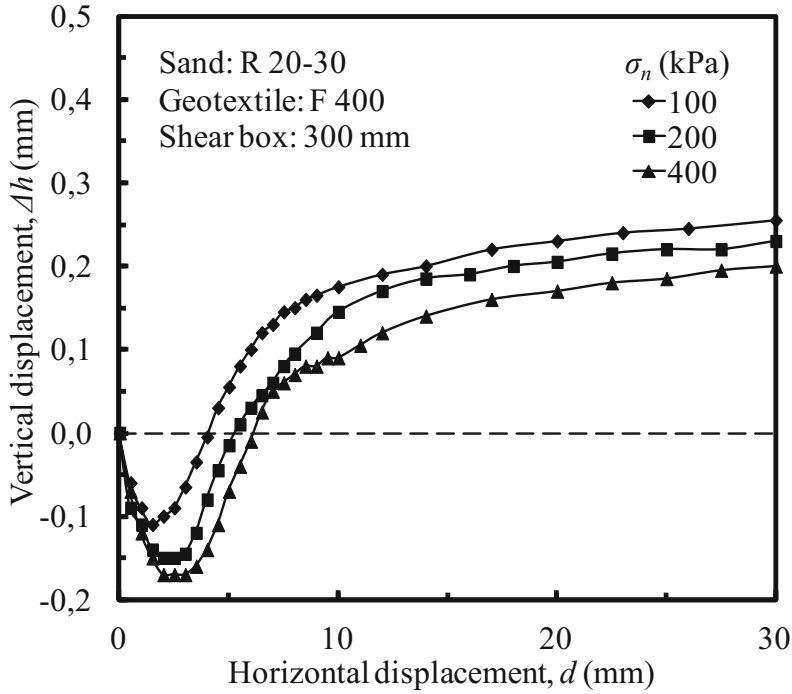**Fig. 5.**   Typical shear stress – horizontal displacement curves

Fig. 6. Typical vertical displacement – horizontal displacement curves
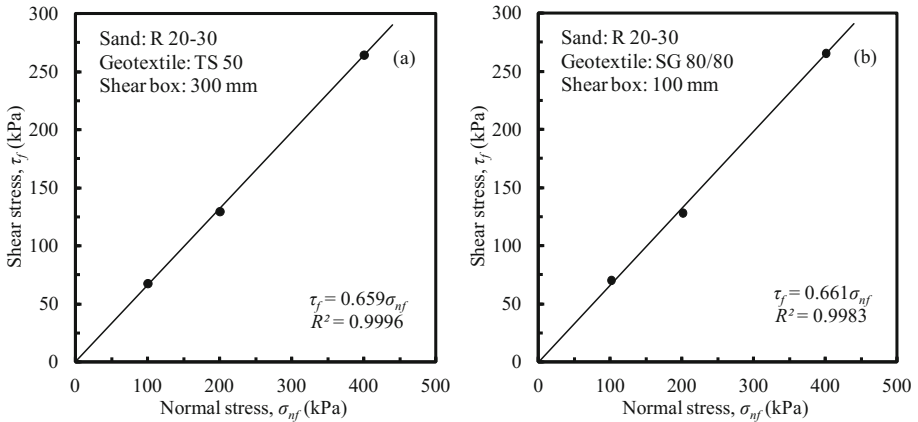

Fig. 7. Typical failure envelopes for sand – geotextile interfaces

interface direct shear tests, the constant (independent from the interfacial normal stress) values of interface friction coefficient, $tan\delta$, were estimated and are presented in the following sections. The interface friction coefficient values were also normalized with regard to the internal friction coefficients, $tan\varphi$, of the corresponding sands.

The resulting values of friction efficiency, $E_\varphi = tan\delta/tan\varphi$, range from 71% to 104% and are in good agreement with the typical range of friction property of geotextiles which is equal to 60%–100% of soil friction (Koerner 2005).

Two series of large-scale tests were conducted on the R 20–30 sand – HS 400/50 geotextile interface, one with the shearing direction parallel and one with the shearing direction perpendicular to the production direction of the geotextile. This was dictated by the significant difference in tensile strength of this geotextile in machine and cross machine direction, as shown in Table 2. However, nearly equal $tan\delta$ values (difference = 2.8%) were obtained for the two directions of HS 400/50 geotextile.

Effect of Shear Box Size

As explained earlier, the direct shear tests with the large-scale and the conventional shear box were conducted using the same normal stresses and equivalent shearing rates with the purpose of comparing their results. This comparison is made in Table 3 for interfaces between dry, dense sand with rounded grains and a variety of woven and non-woven geotextiles. The value of friction coefficient, $tan\delta$, from the large-scale tests on HS 400/50 geotextile is the average of the similar values obtained, as stated before, for the two directions of this geotextile. As shown in Table 3, the friction coefficient values resulted from the tests with 300 mm shear box are generally smaller or larger than the ones obtained from the tests with 100 mm shear box. The differences between the $tan\delta$ values obtained from the two shear boxes can be considered as low, since they are lower than ±6% for the non-woven geotextiles and they range from −10.4% to +13.2% for the woven geotextiles. The larger differences observed for the woven geotextiles can possibly be attributed to the structure and geometry of them. In conclusion, the aforementioned observations indicate that the results of the two tests are comparable and, therefore, that the 100 mm shear box is suitable for interface testing of materials like those used in the present study. For that reason, this conventional shear box was used for the parametric investigation presented in the subsequent sections.

Effect of Geotextile Type and Properties

As also shown in Table 3, the type of geotextile affects substantially the values of interface friction coefficient leading to differences between them as high as 31%.

Table 3. Effect of shear box size and geotextile type on R 20–30 sand – geotextile interface friction

Geotextile	Type	300 mm shear box		100 mm shear box		Difference in $tan\delta$ *
		$tan\delta$	E_φ (%)	$tan\delta$	E_φ (%)	
B 200	Non-woven	0.69	94	0.69	94	0.0
TS 50	Non-woven	0.66	90	0.63	86	+4.5%
SF 56	Non-woven	0.58	79	0.60	82	−3.4%
F 400	Non-woven	0.69	94	0.73	100	−5.8%
SG 80/80	Woven	0.76	104	0.66	90	+13.2%
HS 400/50	Woven	0.72	99	0.71	97	+1.4%
N 66447	Woven	0.67	92	0.74	101	−10.4%
H 50.145	Woven	0.63	86	0.69	94	−9.5%

$*[(tan\delta_{300\,mm} - tan\delta_{100\,mm})/tan\delta_{300\,mm}] \cdot 100$

Table 4. Effect of geotextile properties on R 20–30 sand – geotextile interface friction

Geotextile	Type	Mass per unit area (g/m^2)	Max. tensile load (kN/m)	Coefficient of friction $tan\delta$	Efficiency E_φ (%)
SF 40	Non-woven	136	8.5	0.62	85
SF 56	Non-woven	190	12.8	0.60	82
SF 77	Non-woven	260	20.0	0.63	86
SF 111	Non-woven	375	29.0	0.57	78
TP 240	Woven	240	50.0/50.0	0.60	82
TP 310	Woven	310	66.0/66.0	0.57	78
TP 400	Woven	400	86.0/86.0	0.60	82

However, non-woven geotextiles generally present $tan\delta$ values in the same range as woven geotextiles. Considering the properties of non-woven or woven geotextiles of the same types and manufacturers (Table 4), the $tan\delta$ value does not present a consistent variation with increasing mass per unit area and tensile strength of the geotextile. The abovementioned observations indicate that the sand – geotextile interaction behavior depends mainly on the surface characteristics of the geotextiles which are strongly influenced by the geotextile type.

Effect of Sand Grain Shape and Size

The results of direct shear tests conducted with four different geotextiles and two sands having the same grain size and differing in grain shape are shown in Table 5. It is easily observed that the values of friction coefficient are higher in sand with subangular grains than in sand with rounded grains. On the contrary, the friction efficiencies, E_φ, are higher in the sand with rounded grains indicating a more effective mobilization of soil friction in comparison with the sand with subangular grains. The same trend is also noticed on the basis of the results reported by Anubhav and Basudhar (2013) for two woven geotextiles in contact with one rounded and one angular particle sand, having φ values equal to those of the sands tested in the present study. This behavior is attributed to the larger difference between the $tan\varphi$ values compared to the difference between the $tan\delta$ values of the sands differing in grain shape. Presented in Table 6 are the results of direct shear tests conducted with one non-woven and one woven geotextile without apertures in contact with three sands having the same (rounded) grain shape and differing in grain size. Although an increase of friction coefficient with decreasing sand grain size is obvious only for the non-woven geotextile, the friction efficiency,

Table 5. Effect of sand grain shape on sand – geotextile interface friction

Geotextile	Type	Rounded sand (R 20–30)		Subangular sand (S 20–30)	
		$tan\delta$	E_φ (%)	$tan\delta$	E_φ (%)
SF 56	Non-woven	0.60	82	0.78	73
SG 80/80	Woven	0.66	90	0.76	71
H 50.145	Woven	0.69	94	0.92	86
N 66447	Woven	0.74	101	0.82	77

Table 6. Effect of sand grain size on sand – geotextile interface friction

Rounded sand	Grain size D_{50} (mm)	Non-woven geotextile (SF 56)		Woven geotextile (SG 80/80)	
		$tan\delta$	E_φ (%)	$tan\delta$	E_φ (%)
R 20–30	0.71	0.60	82	0.66	90
R 30–40	0.51	0.66	94	0.67	96
R 40–100	0.25	0.72	96	0.66	88

$tan\delta/tan\varphi$, increases with decreasing sand grain size in both geotextiles with the exception of R 40–100 sand – SG 80/80 geotextile interface. This increase may be possibly attributed to the more efficient mobilization of soil friction by the larger number of grains in contact with the geotextile, as the sand grain size decreases.

5 Conclusions

Based on the results of this investigation and within the limitations posed by the number of tests conducted and the materials used, the following conclusions may be advanced:

- The interaction at the sand – geotextile interface can be described by linear failure envelopes presenting negligible adhesion values and friction coefficient values ranging from 71% to 104% with regard to the internal friction coefficients of sands.
- The direct shear tests conducted with 300 mm and 100 mm square shear boxes gave comparable values of interface friction coefficient. Therefore, the 100 mm shear box is appropriate for interface testing of materials similar to those used in the present investigation.
- The sand – geotextile interaction behavior depends on the surface characteristics of the geotextiles which are strongly influenced by the geotextile type.
- The rounded shape and the size decrease of sand grains were found to mobilize more effectively the soil friction at the sand – geotextile interface.
- The aforesaid conclusions are limited to uniform sands with grain sizes similar to those used in this investigation. Also, the effect of well graded backfill materials on the soil – geotextile interaction is not discussed in the present study.

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