Geomembrane-Geotextile Interface Friction

Rustam Effendi

Departement of Civil Engineering, University of LambungMangkurat

E-mail: rustamff@googlemail.com

Abstract: *In geotechnical constructions incorporating geomembranes and geotextiles, the interfacestrength of the two geosynthetics is of the most concern. Some researchers found considerably low values of the strength from various devices. This research aimed at contributing the interface strength database with a ring shear device for simulating large displacements commonly mobilised in the field when failures occur. The interfacing geomembranes were VLDPE, smooth HDPE, PVC, and textured HDPE. Values of* $\square_{residual}$*for the geomembrane-geotextile interfaces were found to be independent of stress level. They vary widely from 6.1° to 33.8°, and are controlled mainly by the texture and stiffness of geomembranes, and the types and arrangement of filaments composing the geotextile. The lower value is for a smooth HDPE with a geotextile comprising glossier filaments, while the higher value is mobilised by the textured HDPE against a geotextile with filaments that are best-interwoven.Of all interface combinations, the ring shear tests with a smooth HDPE geomembrane always resulted in lowest residual interface strengths.*

KEYWORDS: interface strength, geomembrane, geotextile, ring shear device.

1. INTRODUCTION

The use of the combinations of geomembranes and geotextiles is common for landfill liners, tailing impoundments, heap leach pads, impermeable layers in embankments, slope protections,and liquid barrier systems. The installation of the geotextiles here is meant to protect geomembranes from damage through direct contact with adjacent soils or with unexpected, foreign objects. They are also used as drainage. Nevertheless, some researchers found that the interface strengths of the combinations were somewhat low (Martin, Koerner, and Whitty 1984; Negussey, Wijewickreme, and Vaid 1988; Weiss and Batereau 1987; William and Houlihan 1986; Yegian and Lahlaf 1992; Wiess and Batereau 1987)although slightly high values onthe interface of a PVC film and nonwoven geotextile were identified by Wiess and Batereau(1987).

Most of the interface strengths were taken from the peaks of the strength-displacement curves. They were developed from the very limited horizontal displacement of the direct shear devices. In the field, however, failures occur through large displacements. The general implications are that the methods, apparatus, and sample dimensions in tests vary widely. Comparisons between studies reveal that tests on similar materials give reasonably good agreement. However, the reported data currently available are still inadequate. The main objective of this thesis program is to contribute good data from ring shear tests to the existing but limited database. A ring shear device is preferentially selected for the testing program because of its ability to shear a sample to unlimited displacement in one direction, which is similar to the conditions in the field: other apparatuses do not satisfy this condition.

LITERATURE REVIEW

Martin et al. (1984) performed tests investigating the interface strength between geomembranes and geotextiles. For each test on a PVC geomembrane with a non- woven CZ600 geotextile, both sides of the PVC specimen were used since it was rougher on oneside. They found that the rougher side exhibited a higher friction angle ($\square$=23°) than the other side ($\square$=21°). A very low friction angle of 8°was measured in a test on the CZ600 with a smooth HDPE geomembrane. In another investigation, Negusseyet al (1988) observed an even lower frictional resistance to be mobilized with a Texe 17612 geotextile ($\square$=6.5°). The sevariation smight result from differences in the test devices that's hear the specimens in dissimilar ways, or could be material specific. However, the conclusion that the interface of nonwoven geotextiles with a smooth HDPE results in a low friction angle is also asserted by the findingsof Mitchellet al. (1990). With a direct shear device and a pull out box, they found valuesof $\square_{residual}$=9.5°to12.5°and9.5°for the respective devices. In earlier observations, Williams and Houlihan (1986) also found a similar interface friction angle of 9° from a directs heartest on a nonwovengeo textile and smooth HDPE. Williams and Houlihan (1986) further proved, using a modified direct shear, that friction resistance exhibited at the interface of geomembranes with geotextiles is dependent on the materials used. Theyobserved $\square$=10° for the tests on a smooth HDPE geomembrane with a Trevira 2125 non wovengeo textile and $\square$=12° for smooth HDPE with Trevira 1135. This variation might have resulted from the different properties of the geotextiles. The Trevira 2125 is a nonwoven, needle punched, and staple polyester geotextile; where as the Trevira 1135 is a nonwoven, needle punched, continuous filament polyester geotextile.Thegrabtensilestrengthswere25kN/mand60k N/mrespectively.

Realising that the published data for the dynamic interface strength properties of geomem- branes and geotextiles are very limited, Yegian and Lahlaf (1992) and Lahlaf and Yegian (1993) report tests using a shake table facility. They used a smooth HDPE geomembrane (GundleHD60) and a nonwoven geotextile (Polyfelt TS700) in both dry and submerged conditions.

They also conducted statics hear tests on the same interface, and prepared conditions under normal stresses varying from 3.4 to 34k : Pafor comparative purpose. The rate of shear respectively. The dynamic tests triggered with 2 to 10 Hz resulted in residual dynamicfriction angles of 10.7° and 9.6° at the first observation of sliding, for dry and submerged conditions respectively. Both static and dynamic tests seems

displacement in the statictests was approximately 1.27 m/min. A residual frictionangle of 10°and 8.5° was found from statictests for the dry and submerged condition

to give a good agreement, suggesting there is little difference between interface friction angles measured at the onset of sliding and those from static tests.

TESTING PROGRAMS

Ring Shear Device

Figure 1 shows the ring shear device deployed throughout this research program.As a shear test apparatus, the major instruments such as normal and shear pressure devices should be included. The normal pressures applied on samples through a piston were provided from air pressure (10). The shearing was mobilised with a turntable (6)connected to the lower confining ring (5). Normal loads were monitored and recorded with a load cell and horizontal loads (shearing) were measured with a pair of horizontal load cells. All the cells were connected to data acquisition system with a personal computer. The function of each component was in detail described in Effendi (2010, 2011).Normal stresses applied in the testing program ranged from about 50 kPa to 300 kPa. Some tests were performed in multistage of normal stress. Unless stated otherwise, all tests were performed at a rate of shear of 0.04 mm/s. Most results are presented in terms of residual interface friction angles, with emphasis on its variation with normal stress.

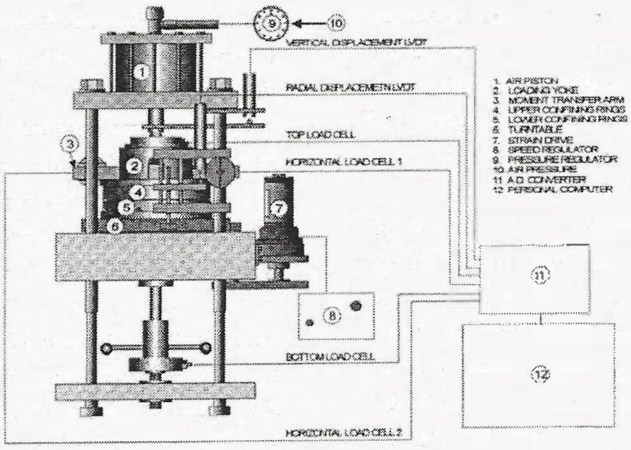


Figure 1: Ring shear device and data acquisition system

Materials and Their Placement

Four types of geomembrane were used: smooth HDPE (high-density polyethylene), textured HDPE, smooth VLDPE (very low-density polyethylene), and smooth PVC (polyvinyl chloride). The geotextiles were the nonwoven Trevira 1120 and Polyfelt TS 550. The setup for tests on a geomembrane-geotextile interface was achieved out by gluing a geotextile specimen on the annular steel platen fixed to the loading yoke and a geomembranespecimen on the base platen in the lower confining rings. This setup enabled the upper confining rings to be taken off, thereby avoiding friction between the annular steel platen and the walls ofthe upper confining rings, as illustrated schematically in Figure 2. Figure 3 shows the photographs of the specimens glued on the annular steel platens.

RESULTS AND DISCUSSIONS

Table 1 illustrates the test codes used in the following discussions. Each test is described by a code that represents the material, the stress level, multistage (if appropriate), and the order of each test. The codes refer to

VL =VLDPE,
PV =PVC,
HD = smooth HDPE,
HDT = textured HDPE,
TR = Trevira 1120,
PF = Polyfelt TS 550, and
S = multistage test.

The last two columns designate the approximate normal stress in kPa and the sequence of the tests.

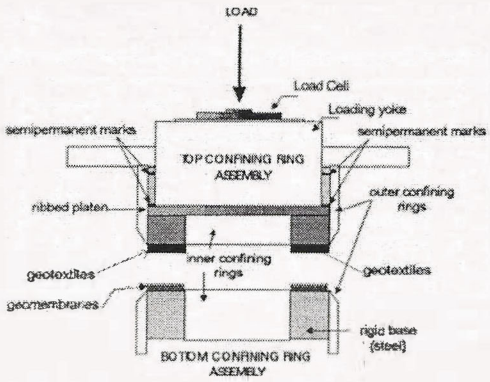
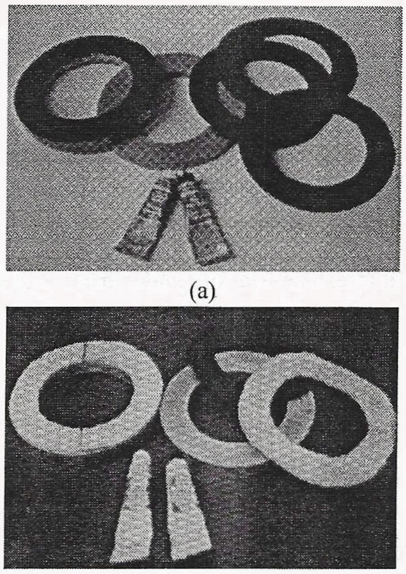


Figure 2: Setup of geotextile-geomembrane samples.



(a)

(b)

Figure 3: Specimens of (a) geomembranes and (b) geotextiles glued on annular steel platens using epoxy resin.

Table 1: Test code for ring shear tests on geomembranes with geotextiles

1	2	3	4	5
VL PVC HD HDT	TR PF	50 100 200 300	S	B C D

VLDPE-Geotextiles

Tables 2 and 3summarise the peak and the residual interface friction angles obtained from 10 tests: 6 tests on VLDPE-Trevira 1120 and 4 tests on VLDPE-TS 550. The effect of rate of shear on the interface friction was investigated by applying rates ranging from 0.04

mm/s to 0.15 mm/s in two staged tests on the Treviral120, VLTR200 and VLTR200S, at normal stresses of approximately 200 kPa. The resulting values of $\square_{residual}$ are listed in Table 4 and are depicted in Figure 5. Although there is good repeatability, a non-linear relationship is observed to occur at the interface due to the varying rates. Thevalues of $\square_{residual}$increase slightly with increasing rate of shear, and achieve a nearly constantvalue of approximately 19° at a rate of strain of0.15 mm/s. The reason that most tests in this series were still performed at a strain rate of 0.04mm/swas to maintain a consistent testmethod throughout the program ofwork. Values of$\square_{residual}$mobilised at 0.04 mm/s, as listed in Tables 2 and 3, are plotted in Figure 4 together with some of these additional data. The results suggest that $\square_{residual}$ is dependent on the rate of strain, but is independent of stress level.

Table 2: Summary of interface friction angles from ring shear tests on VLDPE-Trevira1120.

No	Name of test	σ_n (kPa)	δ_{peak} (°)	$\delta_{residual}$ (°)
1	VLTR50	48	19.0	15.7
2	VLTR50B	59	16.2	15.8
3	VLTR100	95	17.8	15.5
4	VLTR100B	99	16.9	15.4
5	VLTR200	195	19.5	16.1
6	VLTR200S	193	17.5	15.9
		301	NP	16.5

Note:
NP=no peak

Table 3: Summary of interface friction angles from ring shear tests on VLDPE-Polyfelt TS 550.

No	Name of test	σ_n (kPa)	δ_{peak} (°)	$\delta_{residual}$ (°)
1	VLPF50	49	15.9	14.2
2	VLPF50S	52	16.5	14
		115	NP	13.7
		155	NP	13.5
		213	NP	14.1
3	VLPF100	99	15.6	13.8
4	VLPF150	149	15.8	13.5

Note:
NP=no peak

Table 4: Effect of rate of strain on residual interface friction angles from ring shear tests on VLDPE-Treviral120.

No	Name of test	Rate of strain (mm/s)	$\delta_{residual}$ (°)
1	VLTR200	0.04	16.1
		0.06	16.7
		0.08	18.3
		0.12	19.0
		0.15	19.3
2	VLTR200S	0.04	15.9
		0.06	16.9
		0.08	17.4
		0.12	18.3
		0.15	19.0

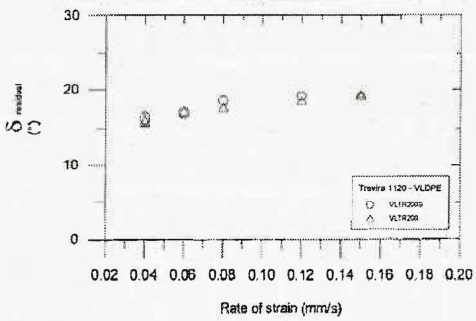


Figure 4: Effect of rate of strain on residual interface friction angles from ring shear tests on VLDPE-Trevira 1120

The values of $\square_{residual}$ developed at the interface of the VLDPE-Trevira 1120 tend to begreater than those achieved by the VLDPE-TS 550. The former ranges from 15.4° to 16.5°, whereas the latter varies from 13.5° to 14.2°. Martinet al(1984) report a value □=15° for the interface of an EPDM-nonwoven geotextile (CZ 600) using a modified direct shear apparatus with normal stresses varying from 13.8 to

103.5 kPa. In another investigationWiess and Batereau(1987), using a specially constructed flat shear device and normal stresses from 5 to 50 kPa, measured values □ranging from 11° to 14° on the interface of polyethylene (PE) with a nonwoven geotextile.

Visual observations, after each test was completed, revealed the fibers of both geotextiles seemed to slightly pull out during shear. The values of □$_{peak}$ for each test (see Figure 1) are attributed to a realignment of the fibers at the surface of the geotextile

Smooth HDPE-Geotextiles

The test series for the smooth HDPE-geotextiles comprised 6 tests on smooth HDPE- Trevira1120 and 3 tests on smooth HDPE-Polyfelt TS 550. The tests were conducted at stress levels from 50 kPa to 200 kPa. A multistage test was also performed on the smooth HDPE-Trevira 1120 using confining stresses from approximately 50 kPa to 300 kPa. A summary of the tests is given in Tables 5 and 6 , and depicted in Figure 5. Again the values of □$_{residual}$seem independent of stress level for both geotextiles. Also the tendency of the Trevira1120 to mobilise a higher friction than Polyfelt TS 550 is apparent, those less so than with the smooth VLDPE.

The values of □$_{residual}$developed at the interface of the smooth HDPE-Trevira ranged from 7.2° to 7.7° and those at the smooth HDPE-Polyfelt varied from 6.1° to 6.7°. This response is again attributed to the less glossy surface of the fibers composing the Trevira fabric. An interface friction

during the beginning of shear. Once the pulling of the fibers was fully developed and aligned to the direction of shearing, a constant interface friction angles was established. This implies that at large displacements the values of □$_{residual}$ from the tests were affected by the smoothness of the fibers of the geotextiles. The lower values of □$_{residual}$obtained from the tests on the VLDPE-Polyfelt TS 550 could have resulted from the fibers of that geotextile being glossier (from visual observation) than those ofTrevira 1120.

angle of8° was observed by Martinet al(1984)for the interface of an HDPE-nonwoven geotextile (CZ 600). It agrees very well with those obtained from the tests on the HDPE-Trevira. Mitchell et al (1990)used a modified Karol-Warner directshear device to test the interface of a so-called polished HDPE-TreviraSpunbond No. 1145 and found □ranging from 8.5° to10.5°. They also observed □of8° for the same interfacing materials using the pullout box apparatus, which is close to those achieved in this ring shear program. Using the UBC ring shear apparatus Negussey et al(1988) found a □$_{residual}$of 6.5° for tests on HDPE-dry geotextile (Texel 7621) or on HDPE-wet Texel 7621.

In comparison to the preceding data for VLDPE geomembranes, the very low values of□$_{residual}$attained in this series oftests are attributed to the very smooth, hard glossy surfaceof HDPE. However, the fibers of the geotextiles were still slightly pulled out, albeit not as much as that found with the tests on the VLDPE-geotextile combination.

Table 5: Summary of interface friction angles from ring shear tests on smooth HDPE-Trevira 1120

No	Name of test	σ_n (kPa)	δ_{peak} (°)	$\delta_{residual}$ (°)
1	HDTR50	49	NP	7.6
2	HDTR50B	48	NP	7.2
3	HDTR50S	59	NP	7.7
		111	NP	7.5
		208	NP	7.4
		299	NP	7.3
4	HDTR100	98	NP	7.7
5	HDTR200	204	NP	7.6
6	HDTR200B	202	NP	7.4

Note:
NP=no peak

Table 6: Summary of interface friction angles from ring shear tests on smooth HDPE-Polyfelt TS 550

No	Name of test	σ_n (kPa)	δ_{peak} (°)	$\delta_{residual}$ (°)
1	HDPF50	51	NP	6.7
2	HDPF100	97	NP	6.1
3	HDPF200	198	NP	6.4

Note:
NP=no peak

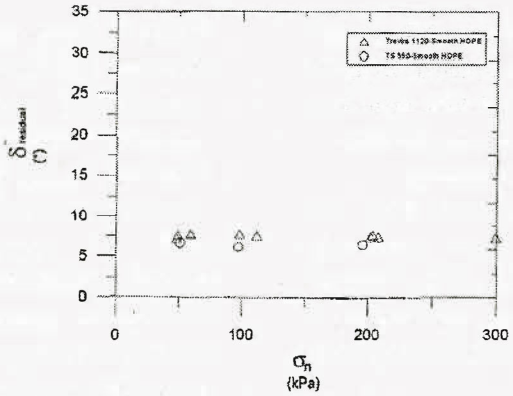


Figure 5: Residual interface friction angles from ring shear tests on smooth HDPE-geotextiles

PVC-Geotextiles

Nine ring shear tests were performed to investigate the nature of interface friction between a PVC geomembrane and these two geotextiles (Trevira 1120 and Polyfelt TS 550). Stress levels were applied between 50 kPa and 150 kPa for five tests on PVC-Trevira 1120, and 50 kPa and 200 kPa for four tests on PVC-Polyfelt.Figure 6 illustrates the resulting values of $\square_{residual}$ from both series of tests that are listed in Tables 7 and 8. The values of $\square_{residual}$from the tests on PVC-Trevira vary from31.5° to 33.8°, while those ofPVC-Polyfelt vary from 23.5° to 25.8°. Once again the angleof interface friction appears to be independent of normal stress, and higher for the Trevira geotextile. The latter results for Polyfelt agree well with □= 23° from a test on a so-calledrough PVC-nonwoven CZ 600 reported by Martin et al (1984). Ingold(1991) listed the values of $\square_{residual}$from the observations of Weiss and Batereau (1987) on the interface of a PVC film and nonwoven geotextile as varying from 16° to 24°.

Table 7: Summary of interface friction angles from ring shear tests on PVC-Trevira 1120

No	Name of test	σ_n (kPa)	δ_{peak} (°)	$\delta_{residual}$ (°)
1	PVTR50	45	33.4	32.3
2	PVTR50S	48	34.3	33.8
		103	NP	33.7
		157	NP	32.6
3	PVTR100	95	32.0	31.5
4	PVTR150	148	33.4	32.5

Note:
NP=no peak

Table 8: Summary of interface friction angles from ring shear tests on PVC-geotextiles

No	Name of test	σ_n (kPa)	δ_{peak} (°)	$\delta_{residual}$ (°)
1	PVPF50	51	25.3	23.5
2	PVPF50B	52	25	24.3
3	PVPF50S	55	26	25.7
		102	NP	25.4
		153	NP	25.7
		206	NP	25.8
4	PVPF100	102	25.3	25.0
5	PVPF150	154	25.5	25.4

Note:
NP=no peak

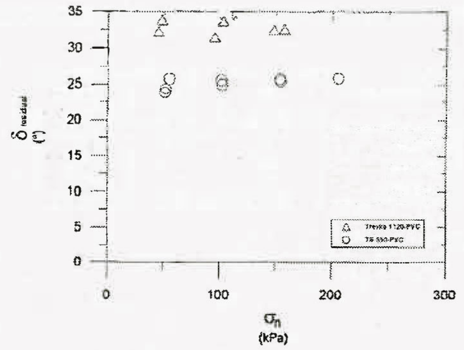


Figure 6: Residual interface friction angles from ring shear tests on PVC-geotextiles.

The very high friction generated at the interface of the PVC with both geotextiles is attributed to the texture and relative stiffness of the interfacing materials. Of all the geomembranes used throughout this research, the PVC was the softest material and the one with the roughest surface (excluding the profiled surface of the textured HDPE). The flexibility of the PVC is believed to be important to the mobilization of a very high interface friction: application ofload to the fibers of the geotextile causes them to press into the surface ofthe PVC. Consequently more contact of the fibers composing the geotextile likely took place on a softer surface.

The existence of a high friction at the interface was further proven from tests at a normal stress of 50 kPa on the interface of Ottawa sand-Trevira 1120-PVC, as shown in Figure 7. The PVC specimen was glued onto the steel base and fixed in the bottom half of the confining rings, the geotextile was then placed over it and the Ottawa sand finally placedover the geotextile. Marks were inscribed on the outer sides of the PVC and the geotextile to monitor where slip occurred. No displacement was observed at the interface of the PVC-geotextile. This demonstrated that shearing was taking place at the interface of the Ottawa sand-geotextile and the friction at the interface of the PVC-Trevira was apparently higherthan that interface.

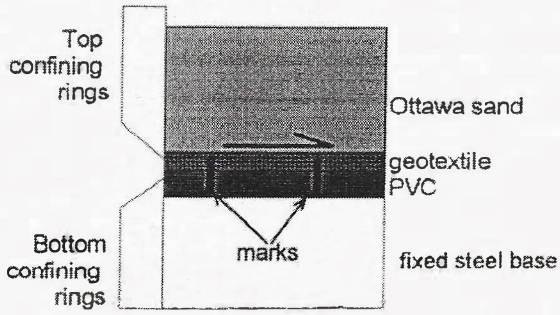


Figure 7: Arrangement of the ring shear test on Ottawa sand-geotextile-PVC

Textured HDPE-Geotextiles

Previous tests reported byEffendi (2010, 2011)for the textured HDPE with Ottawa sand and with compacted clay suggest that when a good interface stability and low permeability are of concern, then textured HDPE is the material of choice. Ring shear tests on the interface of textured HDPE with two types geotextiles, Trevira and Polyfelt, were conducted to evaluate this combination of materials. Three single stage tests and two multistage test were performed on the textured HDPE-Trevira; and, three single stage and multistage tests on the texturedHDPE-Polyfelt. Stress levels were applied from about 50 kPa to 150 kPa and the resulting values of □are summarized in Tables 9 and 10.

Figure 8 illustrates the values of $\square_{residual}$listed in the Tables 9 and 10. The values of $\square_{residual}$mobilised by the textured HDPE-Trevira 1120 and textured HDPE-Polyfelt TS 550 were 15° to 16° and 17.9° to 18.4° respectively. The values of $\square_{residual}$ for these tests seem to be independent of the applied normal stresses.

Table 9: Summary of interface friction angles from ring shear tests on textured HDPE-Polyfelt TS 550

No	Name of test	σ_n (kPa)	δ_{peak} (°)	δ_{res} (°)
1	HDTPF50	45	34.8	18.3
2	HDTPF50S	52	26.9	18.3
		107	NP	17.9
		154	NP	17.9
3	HDTPF100	100	26.5	18.4
4	HDTPF150	150	25.9	18.4

Note:
NP=no peak

Table 10: Summary of interface friction angles from ring shear tests on textured HDPE-Trevira 1120

No	Name of test	σ_n (kPa)	δ_{peak} (°)	$\delta_{residual}$ (°)
1	HDTTR50	48	22.9	16.2
2	HDTTR50S	49	20.9	15.5
		109	NP	15.0
		158	NP	15.0
3	HDTTR100	106	23.5	15.8
4	HDTTR100S	98	22.4	16.0
		155	NP	16.0
5	HDTTR150	148	18.9	15.4

Note:
NP=no peak

In contrast to the results obtained for the geotextiles with smooth geomembranes, the values of $\square_{residual}$ from the tests on the textured HDPE-Trevira are slightly lower than thosefrom the textured HDPE-Polyfelt. Visually, the diameter of filaments composing the Polyfeltis greater than that of the Trevira. In addition, the mass per unit volume for the Trevira 1120is less than that of the Polyfelt TS 550. Although similar tearing and friction phenomena also exist with the Polyfelt material, the pulled fibers left on the texture of geomembrane aftertesting were not so pronounced as those for the tests using the Trevira. Interestingly, the values of the $\square_{residual}$ are lower than those exhibited by the PVC-geotextile interface. Theexplanation for this behaviour is that the action of tearing was no longer completely mobi- lized when most of the fibers at the very surface of the geotextile specimen were already pulled out and covering the tips of the texture of the geomembrane. Visual inspection after testing revealed that pulled fibers covering the tips of the texture.

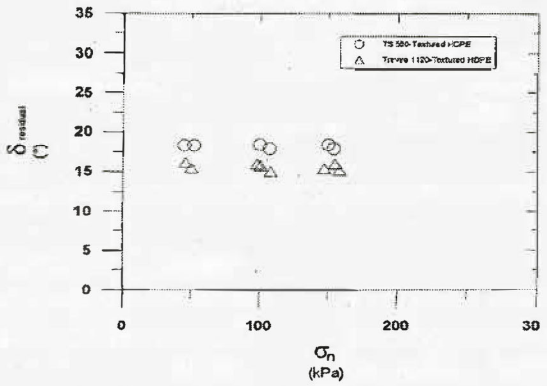


Figure 8: Residual interface friction angles from ring shear tests on textured HDPE-geotextiles

CONCLUSIONS

Results from ring shear tests on four geomembranes and two geotextiles lead to the following conclusions:

- $\square_{residual}$is independent of stress level.
- $\square_{residual}$for the smooth geomembranes with Trevira 1120 is higher than that with Polyfelt TS 550, a behaviour which is attributed to the less glossy fibers composing the Trevira than those of the Polyfelt.
- $\square_{residual}$for the textured geomembranes with Trevira 1120 is lower than thatwith Polyfelt TS 550, a behaviour which is attributed to the smaller diameter of filaments composing the Trevira than those of the Polyfelt.
- $\square_{residual}$is controlled by:
  - texture and stiffness of the geomembranes
  - type of fibers composing the geotextiles
  - arrangement of the fibers of geotextiles
- the values of $\square_{residual}$, at normal stresses from 45 to 301 kPa, are as follows:
  - VLDPE-Trevira: 15.4° to 16.5°
  - VLDPE-Polyfelt: 12.7° to 14.2°
  - smooth HDPE-Trevira: 7.2° to 7.7°
  - smooth HDPE-Polyfelt: 6.1° to 6.7°
  - PVC-Trevira: 31.5° to 33.8°
  - PVC-Polyfelt: 23.5° to 25.8°
  - textured HDPE-Trevira: 15.0° to 16.2°

- textured HDPE-Polyfelt: 17.9° to 18.4°

Generally, when issues of slope stability are a priority, the use of smooth, hard and stiff geomembranes is of the most concern. A textured geomembrane, or a smooth geomembrane with a soft surface seem to be the material of choice. If a nonwoven geotextile is used with a smooth geomembrane, a geotextile madeofless glossy fibers with smaller filaments would appear more desirable. On the other hand, a fibrous nonwoven geotextile with larger filaments that are well interwoven offers more resistance to shear displacements when used with a textured geomembrane.

REFERENCES

Effendi, Rustam. 2010. "Interface Strength of Geomembranes and Compacted Soils." *Jurnal Magister Teknik Sipil* no. 1 (1):13.

———, 2011. "Interface Friction of Smooth Geomembranes and Ottawa Sand." *Info Teknik* no. 14 (1):12.

Ingold, T. S. 1991. Friction Testing, Geomembranes Identification and Performance Testing. In *Report of Technical Committee 103 MGH Mechanical and Hydraulic Testing of Geomembranes*, edited by A. Rollin and J. M. Rigo. Cambridge, Great Britian: RILEM.

Lahlaf, A. M., and M. K. Yegian. 1993. Shaking Table Tests for Geosynthetic Interface. Paper read at Geosynthetic'93 Conference, at Vancouver, British Columbia, Canada.

Martin, J. P., R. M. Koerner, and J. E. Whitty. 1984. Experimental Friction Evaluation of Slippage Between Geomembranes, Geotextiles and Soils. Paper read at International Conference of Geomembranes, at Denver, U.S.A.

Mitchell, J. K., R. B. Seed, and H. B. Seed. 1990. "Kettleman Hills Waste Landfill Slope Failure.I: Liner-System Properties." *Journal of Geotechnical Engineering*, ASCE no. 4 (116):22.

Negussey, D., W. K. D Wijewickreme, and Y. P. Vaid. 1988. On Geomembrane Interface Friction. Vancouver, Canada: University of British Columbia.

Weiss, W., and C. Batereau. 1987. "A Note on Planar Shear Between Geosynthetics and Construction Materials." *Geotextiles and Geomembranes* no. 5:63 - 67.

Wiess, W., and C. Batereau. 1987. "A Note on Planar Shear Between Geosynthetics and Construction Materials." *Geotextiles and Geomembranes* no. 5:5.

William, N. D., and M. Houlihan. 1986. Evaluation of Friction Coefficients between Geomembranes, Geotextiles and Related Products. In *The Third International Conference on Geotextile*. Vienna, Austria.

Yegian, M. K., and A. M. Lahlaf. 1992. "Dynamic Interface Shear Strength Properties of Geomembranes and Geotextiles." *Journal of Geotechnical Engineering*, ASCE no. 5 (118):20.