Soil/Geosynthetic Interface Strengths from Torsional Ring Shear Tests

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Abstract

Torsional ring shear tests were conducted to investigate Soil/Geosynthetic Interface Strengths of various geomembranes. A selection of seven smooth and three textured geomembranes (10 total) that can be factory fabricated were sheared against two soils to investigate the range of soil/geosynthetic interface strengths. The two soils are: (1) a clayey glacial till; and (2) Ottawa fine sand. Smooth PVC and both smooth and textured HDPE geomembranes were also tested so the fabricated geomembrane interface strengths could be compared to previously published interface strengths and commonly used geomembranes. The effect of texturing and material properties on shear strength and soil interaction are presented herein and compared with existing interface strength values. To facilitate the testing, programmable video cameras were used as a data acquisition system.

INTRODUCTION

Geomembranes are an important part of the design of containment systems, such as a landfill liner systems. Geomembranes are a necessary part of a containment system to reduce leakage of hazardous material into the environment. Liner systems often involve several layers of geomembranes, geotextiles, drainage materials, and/or low hydraulic conductivity compacted soil. In several cases the low frictional resistance at interfaces between liner system layers has caused slope failures in a variety of containment facilities (Koerner (1986); Stark and Poeppel (1994); Stark et al. (1998); Stark et al. (2008); Amaya et al. (2006)). This paper provides the results of ring shear interface strength tests between ten geomembranes that can be factory fabricated and a fine to medium sand and clayey glacial till.

TORSIONAL RING SHEAR APPARATUS

Stark and Poeppel (1994), Stark et al. (1996), and Stark and Eid (1996) describe the use of a torsional ring shear apparatus to measure the shear strength of geosynthetic/geosynthetic and geosynthetic/soil interfaces. In summary, the torsional ring shear apparatus allows: (1) unlimited continuous shear displacement to occur in one direction, resulting in the development of a residual interface strength condition; (2) a constant cross-sectional area during shear; (3) minimal laboratory supervision; and (4) data acquisition techniques to be readily used. A modified Bromhead ring shear apparatus was used to measure the shear strength of the geomembrane/geosynthetic interfaces described herein. A custom specimen container was used to hold the bottom interface component in place. In tests on soil/geosynthetic interfaces, a knurled porous stone is fastened to the specimen container using four screws. An annular geomembrane specimen with an inside and outside diameter of 40 and 100 mm, respectively is secured to the top loading platen by means of a plastic ring and an adhesive. This ring shear device was used for testing because ASTM D5321 allows the use of a smaller specimen if the results are confirmed with the shear box in ASTM D5321, i.e., 0.3 m by 0.3 m. The normal stress is applied to the top platen, which sits on top of the specimen container. During shear, the bottom interface component is secured to the rotating specimen container and is displaced with respect to the top interface component which is attached to the underside of the stationary top platen. All of the interfaces were sheared at a displacement of 0.015 mm per minute.

RING SHEAR SPECIMEN PREPARATION AND TEST PROCEDURE

Geosynthetics Used in Shear Testing. The geosynthetics used in the interface shear testing and for comparison purposes are listed below with an identifier, e.g., GM1.

- (GM1) A 0.75 mm thick PVC geomembrane with one side filed and the other side smooth.
- (GM2) A smooth 1.5 mm Linear Low Density Polyethylene (LLDPE) membrane.
- (GM3) A 1.14 mm Linear Low Density Polyethylene (LLDPE) scrim reinforced liner with random spikes and bidirectional bar texture and an average asperity height of 0.7 mm.
- (GM4) A 0.75 mm thick coated woven polyethylene (CWPE) liner.
- (GM5) A 1 mm thick coated woven polyethylene (CWPE) liner with double scrim.
- (GM6) A 0.75 mm thick HDPE scrim coated with LLDPE.
- (GM7) A 0.75 mm thick polyolefin smooth geomembrane.
- (GM8) A 1.5 mm thick coextruded textured High Density Polyethylene (HDPE) geomembrane.
- (GM9) A 1.5 mm thick Smooth High-Density Polyethylene (HDPE) geomembrane
- (GM10) A 1.5 mm flat die cast extruded textured High Density Polyethylene (HDPE) geomembrane with uniform asperities and spikes. It has an average asperity height of 0.5 mm.

Geomembrane Specimen Preparation. Geomembrane specimens were cut in an annular shape with a die and secured to the plastic ring attached to the upper platen and a thin coat of nonflexible epoxy. The epoxy was allowed to cure for at least 24 hours under a normal stress of approximately 15 kPa for specimens that would be sheared at a normal stress of 17 kPa and 25 kPa for all other shearing normal stresses. In all cases the curing normal stress did not exceed the normal stress at which the test was conducted. The curing normal stress aided bonding of the geomembrane and minimized vertical displacement caused by compression of the epoxy during the consolidation and shear phases of the testing. If necessary, extruding or excess epoxy resin was sanded down to minimize the potential for wall friction prior to application of the shearing normal stress.

Glacial Till Specimen Preparation. A clayey glacial till from Urbana, Illinois was sampled in an excavation for a new building on the University of Illinois campus. The glacial till has a liquid limit, plastic limit, and clay-size fraction (minus 0.002 mm) of 24, 16, and 18. The glacial till was used to simulate the borrow source for a low hydraulic conductivity compacted soil liner. As a result, the placement of a geomembrane on top of the compacted glacial till created a good representation of the compacted soil/geomembrane interface present in landfill liner systeGM10. The glacial till was air dried, pulverized, and passed through a #40 sieve. Standard Proctor compaction tests (ASTM D698-12) indicated that the optimum water content and dry density was 8.6% and 19.8 kN/m^3. Processed soil was hydrated to that water content and thoroughly homogenized in a mixing bowl. The resultant mix was then placed in the specimen container and compacted with a tamper. The surface was made flush with the top of the container with a razor blade.

Ottawa Sand Specimen Preparation. Ottawa Sand from Ottawa, Illinois was purchased from U.S. Silica (www.ussilica.com) and used to create shear specimens that represent a drainage media, geomembrane cover soil, and/or a sand subgrade for a containment facility. The uniform fine to medium sand has a grain diameter at 50% passing, uniformity coefficient, and roundness factor of 0.74 mm, 1.17, and 0.9. The Ottawa Sand was air dried and then passed through a #40 sieve. The optimum water content and dry density was found to be 13.7% and 16.6 kN/m^3 by Standard Proctor compaction testing (ASTM D698-12). One hundred grams of air dried sand were mixed with 13.7 g of distilled water and homogenized. The specimen was then packed with a spatula and tamped into the ring shear specimen container. There were some issues with obtaining the desired unit weight for the specimen during the compaction due to the granular nature of the material. The surface of the sand was finished with a razor blade to prepare it for the geomembrane attached to the upper platen.

Video Monitoring. Programmable webcams were used as a cost effective method for collecting data continuously throughout the shear tests to provide detailed shear stress-displacement relationships, ensure the peak shear resistance was recorded, and a video recording of the entire test for inspection and display purposes. The cameras are programmed to take pictures of the dial gauges at 10 minute intervals or every 0.15 mm of displacement. After a test is concluded, the operator plots the resulting shear stress-displacement relationship using data points for every ten minutes until the peak shear resistance is past and post-peak behavior is occurring. After post-peak behavior has been completed, a 30-minute interval, i.e., a shear displacement of 0.45 mm, between data points is used to avoid over populating the shear stress-displacement relationship. Figures 1 and 2 show typical sets of shear stress-displacement relationships for the soil/geosynthetic interface testing performed herein. In particular, Figure 1 shows the shear stress-displacement relationships for the GM10/Urbana Till interface at effective normal stresses ($\sigma'_{n,s}$) of 17, 50, 100, 200, and 400 kPa while Figure 2 shows the results from shearing the same geomembrane against Ottawa Sand. The pictures obtained from the video cameras were also processed into a stop motion video that allows visualization of the shear behavior throughout the test and how the ring shear responds to the changes in shear behavior. The use of video cameras reduces the amount of laboratory supervision and makes remote monitoring of the ring shear devices possible by remotely accessing the laboratory computer. This has been an important enhancement in both geosynthetic and soil testing in this laboratory.

SHEAR STRENGTH OF GLACIAL TILL/GEOMEMBRANE INTERFACES

As part of the testing program the interface shear strength of 10 smooth and lightly textured geomembranes that can be factory fabricated were sheared against the compacted glacial till. Figure 3 shows the stress-dependent strength envelopes for the glacial till/geomembrane interfaces for comparison purposes. The three textured samples yielded the highest friction angles. GM10 had an average friction angle of 46˚. The coextruded spikes dug into the surface of the compacted till so that they plowed through the soil during shear. There was some slight gradual post peak loss. GM3 exhibited the highest strength envelope for the fabricated geomembranes due to the small spikes and extruded grid pattern on the surface of the geomembrane. Inspection of the samples post shearing suggests the extruded grid played a more significant role in developing the measured shear resistance than the small spikes, which had a tendency to shear off at high normal stresses. For comparison purposes, a 2H:1V slope, shown as a red dotted line on Figure3, corresponds to a slope angle of 26 ˚ so GM3 could be stable on a 2:1 slope if water and/or pressures do not develop at this interface. A similar comparison can be made for the other fabricated geomembranes and some of these geomembranes could be stable on 2H:1V if water and/or pressures do not develop at this interface. The other fabricated geomembranes could be stable on 3H:1V slopes if water and/or pressures do not develop at this interface.

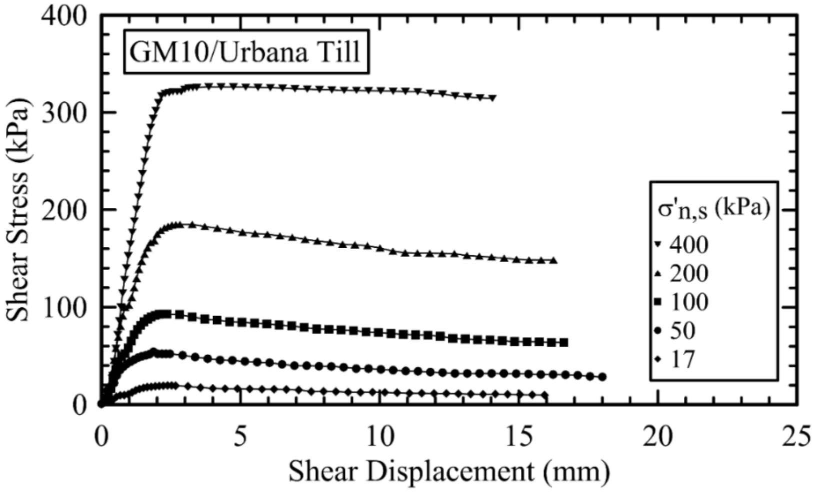

Figure 1. Shear Stress and shear displacement relationship for Geosynthetic/Glacial Till Interfaces

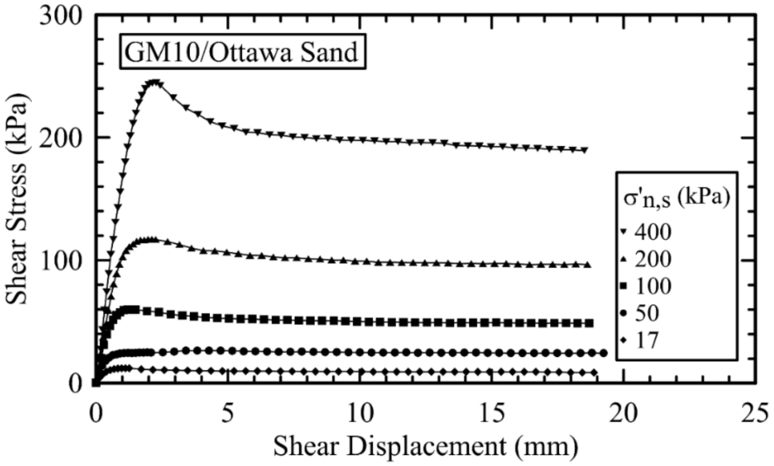

Figure 2. Typical shear stress and shear displacement relationships for Geosynthetic/Ottawa Sand Interfaces.

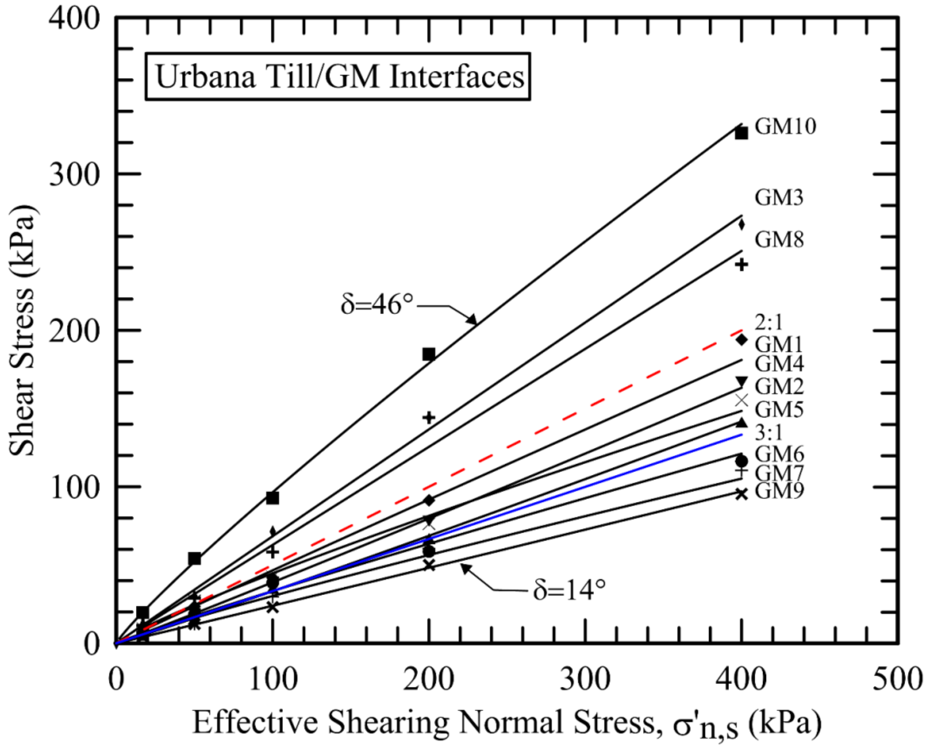

Figure 3. Urbana Glacial Till/Geomembrane Interface Strength Envelopes

For comparison purposes, two HDPE geomembranes, one textured (GM8) and one smooth (GM9), were included in the testing. The GM8 geomembrane exhibited the third highest interface strength envelope but the texturing exhibited wear, began to fray, and in some cases sheared off by the end of the test. This damage to the texturing caused a significant post-peak strength loss. The coated woven polyethylene geomembranes, e.g., GM4, 5, and 6, exhibited midrange shear resistance but showed some damage to the thin coating of LLDPE over the scrim reinforcement at $\sigma'_{n,s}$ of 400 kPa.

As expected, the PVC geomembrane, GM1, exhibited a higher strength envelope than the other smooth geomembranes because of the flexible nature of the polymer allows it to adapt to the surface of the glacial till and increase the resistance of the interface. A similar observation is presented by Hillman and Stark (2001) for geosynthetic/geosynthetic interfaces. As expected, the weakest interface tested is GM9, the smooth HDPE, with an average peak secant friction angle of 14 degrees. As noted by Hillman and Stark (2001) the rigidity of the smooth HDPE geomembrane does not allow it to adapt to the roughness of the surface of the glacial till. In addition, GM9 exhibited the lower residual interface strength and displayed circular scratches on its surface after shearing. A residual interface strength was obtained for each interface tested because the ring shear device can impart unlimited continuous displacement in one direction, which is not the case in the ASTM D5321 specified shear box.

SHEAR STRENGTH OF OTTAWA SAND/GEOMEMBRANE INTERFACES

Figure 4 presents the interface strength envelopes for the Ottawa Sand/geomembrane interfaces with a red dotted line representing a 2H:1V slope and a blue line representing a 3H:1V slope for comparison purposes. The granular nature of the Ottawa Sand led to more visible wear on the geomembranes than the glacial till because of the sand grains grinding against the geomembranes during shear. As in the till interface, GM10 yielded the highest strength envelope with an average friction angle of 31 degrees. The rigid spikes embedded themselves in the sand and performed a combing or raking action during shear. The GM8 and GM3 geomembranes again exhibited slightly lower strength envelopes than the GM10 geomembrane. Epoxy failure was an issue for the textured geomembranes, i.e., GM10, GM8, and GM3, at values of $\sigma'_{n,s}$ of 200 and 400 kPa. In these tests, the measured shear stress would increase steadily and then the geomembrane would slip. A stronger epoxy was then used for these normal stresses and shallow radial grooves were cut into the upper lucite ring in order to provide a rougher surface for gluing. After those two adjustments, tests continued without further incident. There was some extrusion of sand during shear but there was no significant vertical displacement measured during the tests.

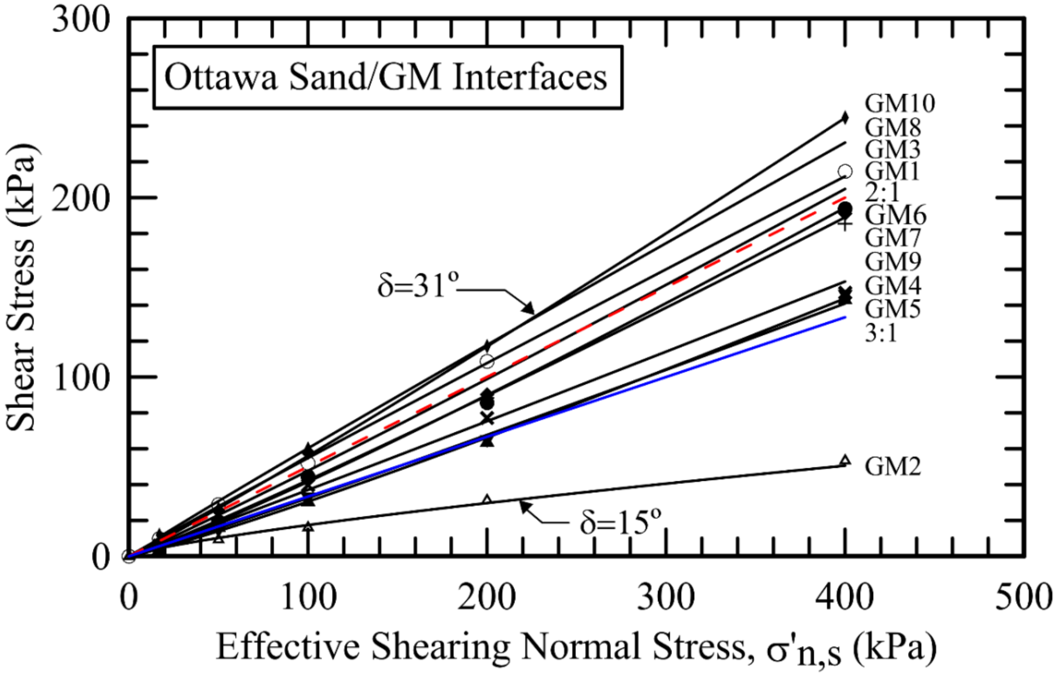

Figure 4. Ottawa Sand/Geomembrane Failure Envelopes

GM1 again achieved the highest interface strengths among the smooth geomembranes due to its soft surface being able to adapt itself to the jagged surface of the sand interface even at low normal stresses. The smooth GM2 geomembrane exhibited the lowest interface strength with an average peak secant friction angle of 15 degrees, which is significantly lower than the other geomembranes (see Figure 4). To confirm this result, the interface tests with GM2 were conducted again with the same result. Most of the interfaces experienced a post-peak strength loss and then a slower gradual decrease to the residual strength as is shown in Figure 2.

Surprisingly the smooth GM9 geomembrane exhibited a higher strength envelope than two of the coated woven polyethylene geomembranes, e.g., GM4 and GM5. In addition to those three, GM6 and GM7 also fall between the 3H:1V and 2H:1V lines, indicating that they would be stable at at slopes of 3H:1V but not at 2H:1V. There was a significant increase in the shear strength of the interface with the smooth polyolefin geomembrane (GM7) and the HDPE scrim coated with LLDPE geomembrane (GM6) exhibited comparable performance.

COMPARISON OF SHEAR TEST RESULTS

Using the shear stress-displacement relationships discussed above, the peak interface secant friction angles of the various geomembrane/soil interfaces were calculated in accordance with ASTM D5321-14 and tabulated in Table 1. In particular, Table 1 shows the glacial till/ fabricated geomembrane interfaces exhibited higher peak interface secant friction angles than the Ottawa Sand/ fabricated geomembrane interfaces, with a few exceptions such as GM9 and GM7. All three of the textured membranes, GM10, GM8 and GM3 also achieved higher strengths against the till.

Table 1. Summary of peak soil/geomembrane friction angles from ring shear testing

Geomembrane Identifier	Interface friction angles (δ) for normal stresses of 17, 50, 100, 200 and 400 kPa (degrees)	
	Urbana Glacial Till	**Ottawa Sand**
GM1	27, 25, 23, 25, 28	21, 27, 30, 24,26
GM2	29, 29, 23, 20, 21	16, 13, 16, 16, 17
GM3	36, 31, 36, 36, 34	30, 30, 37, 29, 29
GM4	21, 14, 20, 21, 24	14, 15, 18, 18, 20
GM5	17, 18, 19, 19, 20	16, 19, 18, 18 19
GM6	26, 24, 23, 26, 22	21, 21, 24, 23, 26
GM7	24, 14, 17, 17, 15	24, 23, 23, 24, 25
GM8	34, 30, 30, 36, 31	27, 29, 28, 30,32
GM9	13, 14, 13, 14, 13	19, 19, 22, 21, 20
GM10	49, 47, 43, 43, 40	35, 28, 31, 30, 31

SUMMARY

The frictional properties of soil/geosynthetic interfaces are site specific, yet the results from this ongoing testing program can be of use in selection of a geomembrane for a specific project through the comparison of the various interface shear strength envelopes presented herein. The following points summarize the soil/geomembrane interface testing to date:

1. During testing it was observed that flat die cast spikes and abrasions can achieve higher interface shear strengths than coextruded textures on both fine-grained and granular soils. The height of the extrusion is important and facilitates the spikes or extrusion penetrating the underlying soil.
2. Smooth flexible geomembranes, e.g., GM1, perform better against soil and sand than other fabricated smooth geomembranes due to their flexibility, which allows their surface to adapt

to the irregularities of the interface and increase the contact area. Only textured geomembranes, e.g., GM10 and GM8, result in higher interface strengths. However, against Ottawa sand, the smooth flexible geomembrane (GM1) achieved similar interface strengths as the textured geomembranes.

3. Textured surfaces resulted in a greater increase in interface strength in the glacial till than Ottawa Sand. When the normal stress is applied, the extrusions and abrasions embed into the underlying soil and when shearing begins they plow through the compacted glacial till leaving pronounced grooves on the surface of the specimen. Conversely, the extrusions and abrasions embed into the underlying Ottawa Sand and when shearing occurs the result is more akin to combing or raking the individual sand grains, which results in some rearrangement of the grains.
4. Programmable cameras proved to be an effective tool for monitoring long-term tests with minimal supervision and provide accurate data. The recorded images also provide a reliable record of the test and reduce the reliance on laboratory data sheets.

FUTURE TESTING

Future testing will include interface ring shear and direct shear tests between the geomembranes tested herein and various nonwoven geotextiles. In addition, other fabricated geomembranes are being added to the sample library/warehouse created at the University of Illinois at Urbana-Champaign.

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