INTERFACE SHEAR-STRENGTH PROPERTIES OF TEXTURED POLYETHYLENE GEOMEMBRANES

Eric Blond, CTT Group / SAGEOS, Quebec, Canada
Guy Elie, Solmax International, Quebec, Canada

ABSTRACT

In order to better characterize the shear-strength properties of polyethylene geomembrane, extensive shear-strength friction measurements were conducted and combined with geomembrane intrinsic properties evaluation. Over 100 shear strength measurements were conducted in a shear box apparatus per ASTM D5321, involving different geotextiles, a clayey soil and a sandy soil. It is shown that for given test conditions, the key factors influencing the shear strength properties of these interfaces are the nature of the materials involved first, and then the asperity height. An asperity height of approximately 20 mils was also observed to be a threshold value above which an increase in asperity height would not influence significantly the shear strength properties of the geomembrane.

RÉSUMÉ

Afin de mieux caractériser les propriétés de friction des géomembranes de polyéthylène, un programme d’essais combinant la mesure des propriétés de friction de différentes interfaces et l’évaluation des propriétés intrinsèques des géomembranes évaluées a été conduit. Plus d’une centaine d’essais ont été réalisés dans une boîte de cisaillement, conformément à la norme ASTM D5321. Les interfaces évaluées impliquaient différents géotextiles, un sable et un sol argileux en contact avec des géomembranes de différentes hauteurs d’aspérités. Il est montré que dans les conditions d’essai retenues, les principaux facteurs influençant les propriétés de friction de ces interfaces sont la nature des matériaux impliqués d’une part, et la hauteur des aspérités d’autre part. L’existence d’une hauteur d’aspérités limite de l’ordre de 20 mils au-delà de laquelle les propriétés de frottement à l’interface n’augmentent pas de façon significative avec l’augmentation de la hauteur des aspérités de la géomembrane est aussi démontrée.

1. POLYETHYLENE GEOMEMBRANES SURFACE TEXTURE

The most widely spread technology to manufacture textured geomembranes involves co-extrusion of the polyethylene in three layers:
- In the central layer, the polymer is extruded in a similar manner than a smooth geomembrane, which gives the material its key functional properties such as watertightness or low gas permeability;
- On the outer layers, a mixture of polyethylene and nitrogen is extruded. When this melted mixture comes out of the die, the nitrogen is expelled out of the polyethylene, making ‘bubbles’ that will create the texture of the geomembrane as they solidify, as shown of Figure 1.

It is thus possible to control the asperity height of the geomembrane – and thus the friction properties – at the time of manufacture by controlling various extrusion parameters such as the percentage of nitrogen in the mixture or the temperature of the polymer / of the air in the vicinity of the die.

The current GRI GM13 specification recommends a minimum asperity height of 10 mils (0.25 mm) as measured per GRI GM12. However, the actual asperity height of polyethylene geomembrane can be much higher. Asperity heights as high as 20 mils (0.5 mm) were previously observed on delivered geomembranes.

2. SHEAR-STRENGTH PROPERTIES

2.1 Definitions

For average ranges of normal loads, the shear strength properties of geomembrane / soils or geomembrane / geosynthetics systems are characterized as follows:
- The shear strength versus normal load relation can be defined by a pseudo ‘Mohr-Coulomb’ envelope, or a friction angle and an adhesion. However, the relation is not linear over a very large range of normal loads, as shown on Figure 2.
- For most interfaces involving geosynthetics, a peak as well as a residual shear strength can be defined. This means that the shear strength mobilized after some displacement of one surface versus the other will typically be lower than the maximum shear strength, as shown on Figure 3.

It shall be mentioned that ISO 10318 (Geosynthetics - Terms and Definitions) as well as ISO 12957 (Geosynthetics – Determination of friction characteristics – Part 1: Direct shear test) define the friction angle of a geosynthetic / material interface as the angle which tangent is defined by “the ratio of the friction force per unit area to the normal stress between two materials”. In the discussion presented in this paper, the authors are not referring to this definition. They are referring instead to the definition of ASTM
D5321, which friction angle is defined as the 'tangent' angle instead of the 'secant' angle, as shown on Figure 4.

2.2 Designing with shear strength properties - Overview

There are many methods available to analyze the stability of a slope. The simplest one involves comparison of the angle of the slope to the friction angle of the interface being analyzed.

However, many derivation of this simple approach have been developed. Although slope stability analysis does not lie within the scope of this paper, the authors felt that a few of the potential factors affecting the use of the values presented in this document shall be highlighted for further potential investigations.

First, the friction angle of the interface must be clearly defined as either the ‘secant’ or ‘tangent’ friction angle. If a design method involving the ‘secant’ angle is chosen, this angle shall be determined using test results conducted under the exact design normal load.

If a ‘tangent’ angle is used for design, the relevance of incorporating the adhesion in the design shall be evaluated. A common approach is to neglect this adhesion and to consider it as an additional safety. However, for products involving very high adhesions, this approach could be over-conservative.

Another approach is to compare directly the shear resistance of the interface analyzed with the shear stress actually applied on this interface. This approach is supposed to lead to identical results than the one involving the ‘tangent’ friction angle, but allows incorporation of potential overloads (such as trucks) in addition to the static loads.

Once the shear strength properties to be considered for stability analysis have been determined, another important factor affecting the stability of a slope is the toe. On relatively short slopes, the toe can substantially increase the stability of the slope, by providing an additional support at the bottom of the slope.
Finally, there has been numerous discussions regarding the use of either peak or residual shear resistance for design. Although this topic has a tremendous influence on the design of the project, there is no sharp rule that can be defined as the best solution applicable in every context. Given that a discussion on this topic would be too fastidious and out of the scope of this paper, the authors strongly recommend consultation of the complete proceedings of the 15th GRI conference available from the Geosynthetic Institute as a good baseline.

2.3 Specification of interface shear strength properties

As discussed above, a completed slope stability design usually combines the angle of a slope to the shear strength properties of the geosynthetics involved. Given that the interface friction properties are material dependent, it is important to include into the project’s specification some properties that will ensure that the interface shear strength will meet the projects requirement.

One approach is to include a friction angle between the geomembrane and the project-specific material, using test parameters that will reflect the anticipated service conditions. Although this approach is theoretically the best possible solution, it is practically not feasible because it would require all the potential bidders (manufacturer) to conduct shear tests for each project – which is obviously not feasible because of financial reasons, time required to do the testing, and availability of the materials to be tested.

In order to respect a good engineering practice while ensuring that the required information will be obtained from the manufacturer, the following alternate approach is recommended:

- The engineer shall conduct a theoretical analysis of what shall be the geosynthetics intrinsic properties to obtain a given interface shear strength, using data available in the literature – such as in this paper – and available geotechnical data – such as soils internal shear strength properties;
- Based on this analysis, the engineer shall specify the geomembrane’s intrinsic properties according to a simple test such as the asperity height, keeping a reasonable safety factor;
- The actual shear strength properties of selected interfaces (soil – geosynthetic or geosynthetic – geosynthetic) shall then be verified using the products that were selected for the project, once the contracts are attributed and the materials are ready to ship.
- Include in the materials conformance testing program an acceptance criteria based on the asperity height measured on the delivered geomembrane.

3. EXPERIMENTAL PROGRAM

In order to identify relations between the shear strength properties of various interfaces involving a textured geomembrane and the asperity height of the geomembrane, an extensive shear-strength testing program was developed. Over 100 shear strength measurements were conducted per ASTM D5321-02, involving geomembranes with 7 different asperity heights, 4 different geotextiles, one clayey soil and a sand. The key test parameters are summarized on Table 1 while the particle size distributions of the soils are shown on Figure 5.

Three different geomembrane thicknesses were used, as well as geomembranes manufactured from HDPE and LLDPE. It was found that none of these parameters but the asperity height would have any influence on the measured interface shear strength, given the test conditions retained for this project. As a consequence, this issue will not be discussed furthermore in this paper.

For all the tests, three normal loads were used: 27.5, 71.3 and 139.5 kPa. The shear rate was also set at a fixed value of 1.0 mm / minute.

<table>
<thead>
<tr>
<th>Material</th>
<th>Key properties</th>
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<tbody>
<tr>
<td>Structure</td>
<td>Weight</td>
</tr>
<tr>
<td>GX 1 SF</td>
<td>350</td>
</tr>
<tr>
<td>GX 2 CF</td>
<td>290</td>
</tr>
<tr>
<td>GX 3 SF</td>
<td>500</td>
</tr>
<tr>
<td>GC 1 SF (geotex)</td>
<td>N/A</td>
</tr>
<tr>
<td>Clay 'CL' per USCS classification, with ( w_c = 36 ) and PI = 18, and PSD shown on Fig. 5</td>
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</tr>
<tr>
<td>Sand 'SP' per USCS classification, with PSD shown on Fig. 5</td>
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</tr>
</tbody>
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SF: Staple fibers, CF: Continuous filament
3.1 Geomembrane – geotextile interfaces

The shear strength properties obtained on geotextile / geomembrane interfaces are presented on Figures 6 and 7.

Analysis of the results led to the following conclusion:
- The key factor influencing the geotextile / geomembrane shear strength properties is the asperity height of the geomembrane.
- Every geotextile / geomembrane interfaces exhibit similar shear-strength properties when involving a geomembrane with a given asperity height, including the geocomposite.
- The observed residual shear strength was much lower than the peak shear strength.

- The shear strength properties of a geotextile / geomembrane interface increases with asperity height up to an asperity of approximately 20 mils. Beyond this threshold value, an increase in asperity height does not provide any significant additional shear strength.

It shall be mentioned that the observation related to the similarity of shear strength properties between the tested geocomposite and geotextiles may not apply to some geocomposites, such as geocomposites involving heat-bonded geotextiles, very light weight geotextiles, or showing a poor bonding peel strength between the geotextile and the geonet.

3.2 Geomembrane – soils interfaces

The soils selected for this project are one clean sand (SP) and one clay (CL). In order to compare the interface shear strength properties to the internal properties of the soil using a similar testing concept, the internal shear strength properties of both soils were evaluated in a direct shear box apparatus.

Although a 300 mm x 300 mm square shear box (modified from the shear box used for this project) could be used successfully to measure the sands properties shown on Figure 8, a 100 mm x 100 mm square box had to be used instead for the clay with a mitigated success as a peak strength could only be estimated from the obtained set of data, with a limited confidence.

These experimental difficulties were found to be in direct relation with the applicability of the direct shear test method to the clay, which was sampled on a landfill cover being built in the Montreal area. In order to adequately fulfill its function on the project, the clay had previously been prepared: its water content was reduced from approximately 70 %, as it is in the natural deposit, down to approximately 25% in order to obtain the required hydraulic and mechanical properties, leading to the mechanical behaviour presented on Figure 9.

3.2.1 Geomembrane – sand interface

The shear strength properties obtained for the sand / geomembrane interfaces are presented on Figures 10 and 11.

Analysis of the results led to the following conclusion:
- The key factor influencing the sand / geomembrane shear strength properties is the asperity height of the geomembrane.
- An asperity height of approximately 20 mils (with the tested sand) can be observed as a threshold value above which the shear strength of the sand / geomembrane interface remains between 90 and 100 % of the internal shear strength of the sand. Beyond this threshold value, an increase in asperity height will not provide any additional shear strength to the interface.
- When the asperity height is close or beyond the observed threshold value of 20 mils, the peak shear...
strength is similar to the residual shear strength, which is in conformance with the classical behaviour of non-cohesive soils. However, residual shear strengths lower than peak shear strengths can be observed with small asperity heights.

3.2.2 Geomembrane – clay interface
The shear strength properties obtained for the geomembrane / clay interfaces are presented on Figures 12 and 13.

Analysis of the results led to the following conclusion:
- The key factor influencing the clay / geomembrane shear strength properties is the asperity height of the geomembrane.
- The interface shear strength properties appear to be lower than the estimated internal shear strength of the soil, even with the highest evaluated asperity heights.
- An asperity height of approximately 20 mils (with the tested clay) can be observed as a threshold value above which the shear strength of the clay / geomembrane interface does not increase significantly.
- The residual shear strength is typically lower than the peak shear strength.

4. DISCUSSION
4.1 Factors influencing the shear resistance
For all the tested interface involving either geotextiles, a sand or a clay, the asperity height of the geomembrane was found to influence significantly the shear strength properties of the interface.

However, the primary factor affecting the shear strength of the interface remains the nature of the interface itself, as can be observed on Figure 14: with a 20 mils asperity height, the peak shear strength mobilized with the sand / geomembrane interface is 50% higher than the one obtained with the clay / geomembrane interface; while the residual shear strength mobilized by the sand / geomembrane interface is 130% higher than the one obtained with the geotextile / geomembrane interface.

It could also be observed that there is a threshold asperity height value above which the interface shear strength will not increase significantly with the asperity height. For the three types of interface tested and the test parameters, this threshold value was found to be approximately 20 mils.

However, the cost associated to the texture of a geomembrane is proportional to the asperity height, as shown on Figure 15. Because of these cost considerations, the actual asperity height of a ‘typical’ textured geomembrane lies between 12 and 16 mils, which was found to correspond to a vast majority of the projects requirement based on historical data.

It is thus important to consider both materials cost and technical requirements issues at the design stage of a project. Without any specific requirement from the engineer, geomembranes will be delivered with a ‘classical’ asperity heights between 12 and 16 mils, while a specific asperity height of up to approximately 20 mils can be requested if the interface shear strength is found to be a critical requirement.

4.2 Peak versus residual shear strength
For all the tested products, the observed shear strength behaviour involves a peak as well as a residual shear strength. The ratio between the peak and the residual properties were found to be material dependant, with differences of up to about 100% for interfaces involving geotextiles.
5. CONCLUSIONS

Based on the data measured within this project, the following conclusions can be drawn:
- For an interface involving a textured geomembrane and any given material, the key factor influencing the shear strength properties is the asperity height, as measured per GRI GM12 test method.
- Every type of interface has its own shear strength properties. It is thus not possible to consider that the shear strength values measured with a given soil will be applicable to any other soil.
- The interfaces involving all the tested geotextiles have shown similar shear strength properties.

6. RECOMMENDATIONS

If the interface shear strength appears to be a critical concern at the design stage of a project, it is important to define properly the actual projects requirements regarding the texture of the geomembrane. This can be achieved by:
- Defining a minimum asperity height that will be in relation with the shear strength properties measured
between a geomembrane and the specific material installed in contact with the geomembrane;
- Including measurement of the asperity height in the quality control of the products delivered on-site.

7. REFERENCES


Proceedings of the 15th GRI conference (2001), Edited by the Geosynthetic Institute, including: A Marr: Interface and Internal Shear Strength Testing to obtain Peak and Residual Values; R. Gilbert: Peak versus Residual Shear Strength for Waste Containment Systems; R. Thiel: Peak versus Residual Shear Strength for Bottom Liner Stability Analyses; J.G. Zornberg: Selection of Soil Shear Strength Parameters in Geosynthetics-Reinforced Soil Design; P. Sabatini & al.: Reliability of State-of-Practice for Selection of Shear Strength Parameters for Waste Containment Systems Stability Analysis