Design considerations regarding the interface shear strength of geomembrane liners in mining applications

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Keywords: geomembrane, interface shear strength, mining, heap leach pad, tailings storage facility

ABSTRACT: Geosynthetic materials play an important role in the mining industry, providing solution containment, environmental barriers, solution conveyance features, and drainage structures. An important aspect in designing with geosynthetic materials is defining the shear strength of the interface between the geosynthetic material and the surrounding material. This is particularly true for geomembrane liner materials. Defining the interface shear strength of geomembrane liner materials is a critical component in the stability of heap leach pads, lined tailings storage facilities, and geosynthetic caps or covers. While the interface shear strength can be measured using standard laboratory methods, there are a number of design considerations that must be addressed prior to testing that can affect the testing method and results. These design considerations include: the type(s) of material that will be contact with the geomembrane liner, loading conditions on the interface, drainage conditions at the interface, and placement of the liner during construction. This paper presents discussions on design considerations that can affect the interface shear strength of geomembrane liner materials. Laboratory test results are presented showing the variability of interface shear strength that can develop depending on the materials used in test and the test loading conditions. These tests show that, under some conditions, very low interface shear strength values (as low as 5 degrees) may develop, which can lead to failure along the interface. The discussions are highlighted with actual project experience and methods to address low interface shear strength.

1 INTRODUCTION

Geomembrane liner materials are used extensively in mining applications to provide solution containment, environmental barriers, solution conveyance features, and drainage structures. Geomembrane liners are most often used as an integral part of liner systems for heap leach pads, solution containment ponds, lined tailings facilities, waste rock dump liners, and covers.

Modern liner system designs for mining projects often include a combination of natural and synthetic materials to achieve the desired performance. For example, liner bedding materials are used beneath the geomembrane liner to protect the liner and to control seepage through defects in the liner. Above the geomembrane liner, protection and drainage layers, and pipes are placed to enhance containment and for solution collection. Experience has shown that it is important consider the performance of all of these elements in the design to ensure compatibility under the anticipated operational loading conditions. Discussions regarding liner system design and performance are presented in Breitenbach and Smith (2006), Breitenbach (1995), Lupo and Morrison (2005, 2007), Lupo (2008) and Touze-Foltz et al (2008).

Typical details of liner systems used in mining applications (primarily heap leach pads and tailings facilities) are presented in Figure 1. As shown in this figure, the geomembrane liner is in direct contact with both the liner bedding and overliner materials. It is obvious from this figure that the interface friction strength between the geomembrane and the underliner and overliner will affect the overall performance of the liner system. Both interfaces must be considered in the design.

For design projects, the interface friction between the geomembrane liner and underliner/overliner materials must be measured using laboratory tests. Values of typical interface friction are available in the open literature (e.g. Williams and Houlihan, 1987; Bemben and Schulze, 1993; Stark and Poeppel. 1994; Gilbert et al , 1995; Jogi, 2005; and Gao et al, 2006), however these values cannot be used for design. As noted in Lupo and Morrison (2007), the interface shear strength can vary significantly depending on the properties of the liner bedding, overliner, and loading conditions. Figure 2 presents a summary of individual interface shear tests from several projects, showing the scatter in measured values.

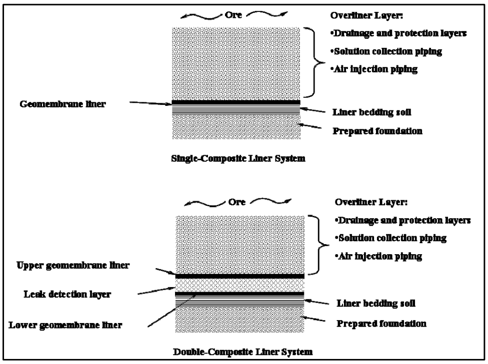

Figure 1 Typical liner system details Touze-Foltz et al (2008).

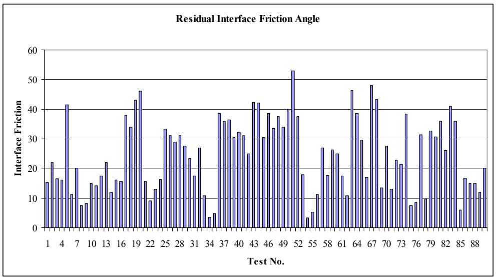

Figure 2 Interface shear test summary

As shown in Figure 2, the interface shear strength (in terms of friction angle) can range as high as 53 degrees and as low as 3 degrees. This clearly demonstrates the need for testing rather than using values stated in the open literature.

2 INTERFACE SHEAR STRENGTH TESTING

Interface shear tests are often conducted in accordance with ASTM D 5321-02 using a modified direct shear box. There are two basic configurations for interface shear testing. In the "fixed" testing configuration, the geomembrane liner is fixed to one of the shear box halves, and sheared against either the liner bedding or overliner material. In the "float" testing configuration, the geomembrane liner is allowed to float between both the liner bedding and overliner. In essence, both interfaces are tested together.

In these tests, the liner bedding and/or overliner material is placed in the shear box (compacted to the project specifications). The geomembrane liner is placed within the shear box. A normal stress is applied to the assembly. For most mining applications, the normal stress is applied for a period of 24 hours, before the application of shearing stress. This 24 hour period allows the geomembrane to conform to the surfaces of the underliner/overliner, providing intimate contact. It is very important that the materials used in the test are representative for the project and are prepared in the same manner (density and moisture content) per the project construction specifications.

During the shearing process, the shear strength of the interface increases as a function of shear displacement, until failure occurs along the geomembrane liner interface. A schematic of a typical interface shear test (in terms of shear strength versus displacement) is shown in Figure 3.

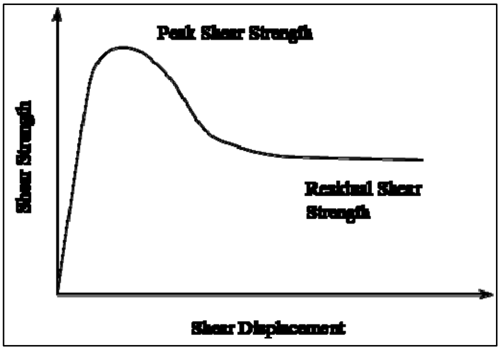

Figure 3 Typical interface shear test result

During the test, the shear strength peaks followed by a decrease in shear strength with increasing displacement. The large-displacement shear strength is termed the residual shear strength.

In the design of liner systems, the residual shear strength is often used. The rationale for using residual strength values for design stems from experience on actual mine projects. This experience has shown that mine facilities are often subjected to non-uniform loads. Under non-uniform loading conditions, some areas of the geomembrane liner may have exceeded the peak shear strength, while other areas of the liner are approaching the peak. This is particularly true in heap leach pads, where failures have occurred from using the incorrect interface shear strength (Breitenbach (1995). This approach is also consistent with recommendations from Stark and Peoppel (1994).

The data from interface shear tests is often plotted as single points of residual shear strength versus normal stress space, as shown in Figure 4. This allows a strength function (either linear or non-linear) to be fitted to the data so that it may be used in design. The easiest strength function to implement is a linear fit, which can be described using a friction angle (slope of the shear strength versus normal stress line) and adhesion value (intercept of line on shear strength axis). Although curved functions can be developed using power equations if sufficient data exists.

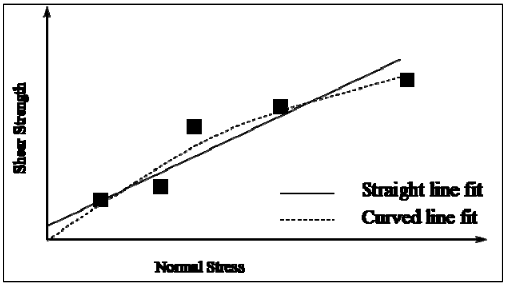

Figure 4 Interface shear strength plot

3 DESIGN CONSIDERATIONS

While the interface shear testing method is relatively straightforward, the challenge for the liner system designer is to identify and characterize underliner and overliner materials that will provide suitable interface shear strength for the desired project. Lupo (2008) discusses the design of liner systems in steep terrain applications, which are common in mining applications. Many mines, particularly in the Andes of South America, are located in areas with steep slopes, many exceeding 50 percent, or about 26 degrees. As observed in Figure 2, the majority of measured values of residual strength (in terms of friction angle) are often less than 20 to 25 degrees. Using this simplified comparison, the ground slope at a number of mines (26 degrees in this case) exceed the majority of measured interface friction values (20 to 25 degrees), therefore the liner system design needs to focus on ways to increase interface strength. Increasing the interface strength is a challenge that focuses on material selection (to increase interface shear) and site grading. At the same time, it is desirable to have a low permeability liner bedding material, so that seepage through liner defects can be controlled. As a result, interface shear tests not only provide a means to measure the interface shear strength, but the test provides an important tool for the designer to specify and design the underliner and overliner materials.

To illustrate this point, Table 1 presents the results from interface shear testing from an actual project. Interface shear strengths were conducted using 2 mm smooth and textured Linear Low Density Polyethylene (LLDPE) against a native clayey soil (liner bedding) and a coarse gravel (drainage layer). The liner bedding clayey soil classified as high plasticity clay under the Unified Soil Classification System, with a Plastic Index of 40 and a percent fines (less than 0.074 mm) of 80 percent. This material was originally selected as it was readily available through the site and had a very low permeability when compacted. The drainage layer material classified as well graded gravel, with maximum particle size of 20 mm and a fines content of less than 10 percent.

The interface shear tests were conducted in a “floating” configuration. The liner bedding soil was compacted to the project specifications (95% of the Modified Proctor Density) and 2 percent above the optimum moisture content. The drainage layer was compacted using light tamping. Prior to testing, the drainage layer was saturated to simulate solution on the geomembrane liner. As shown in Table 1, the interface shear tests for this liner system configuration indicated a very low strength (5.8 to 6.6 degrees, residual strength friction angle). All failures occurred along the liner bedding-geomembrane interface. At first these tests were considered suspect, however the results were later confirmed by several additional interface shear tests conducted by independent labs.

One solution to increase the interface shear strength of the liner system was to blend the clayey liner bedding soil with a locally available native silty sand soil. The idea was to reduce the plasticity of the clayey soil by introducing non-plastic silt and sand, thereby increasing the shear strength. Several blends were tested, however a proportion of 40 percent silty sand (by weight) to 60 percent clayey soil resulted in a significant increase in the interface shear strength (e.g. friction angle), as shown in Figure 5 and in Table 1.

Additional testing was completed to demonstrate that the blended soil had a hydraulic conductivity of less than 1 x 10^{-6} cm/sec, which met the project design requirements for liner bedding.

The example discussed above and highlighted in Table 1 and Figure 5 demonstrate how an interface shear tests can be used to modify the design of a liner system element to achieve a desired performance.

4 CONCLUSION

This paper presents a discussion on the importance of interface shear testing for liner systems with geomembrane liners. Results from numerous interface shear tests indicate a wide range of values that may be measured, depending on the geomembrane type, liner bedding and overliner materials. The wide range of values illustrates the importance of conducing individual tests for each project. It is also noted that in many mining environments, the natural slopes are close to or exceed the typical interface shear strength of geomembranes. Liner system design in steep terrain must focus on methods to increase interface shear strength.

An example is presented which demonstrates how the interface shear test can be used as a tool to design liner bedding and overliner materials to meet a desired performance level.

Table 1. Interface shear test summary

Test	Peak Friction Angle	Residual Friction Angle
Native Clay / Smooth LLDPE	7.1°	5.8°
Native Clay / Textured LLDPE	9.4°	6.6°
Blended Soil / Textured LLDPE	29.3°	27.6°

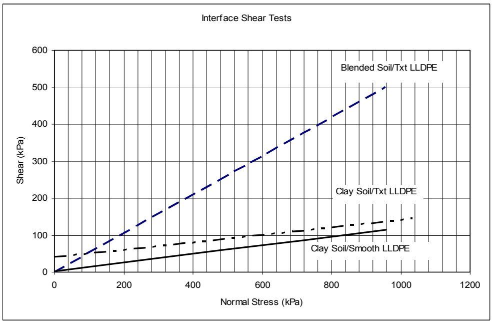

Figure 5 Results of interface shear tests

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