INTERNAL SHEAR STRENGTH OF A GEOSYNTHETIC CLAY LINER AT HIGH NORMAL LOADS

Geosynthetic clay liners (GCLs) have seen increasing usage in the mining industry. In general, geosynthetics are subjected to much higher stresses in mining than in other civil engineering applications. For example, heap leach pad heights can reach 125m (400 ft.) with vertical loads of up to 2,800 kPa (400 psi). Consequently, this is a concern over the internal shear strength of GCL under these conditions.

A series of shear box tests was conducted on a needlepunched GCL up to these high normal loads. The peak internal shear strength of Bentomat ST at 400 psi was 668 kPa (97 psi) which yields a 14° friction angle through the origin. This is much higher than the strength of bentonite alone as depicted by the large displacement angle of 6°. Thus, Bentomat ST needlepunched GCL can lower costs in mining projects by providing the low permeability of bentonite and good internal strength up to 400 psi.

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Internal shear strength of a geosynthetic clay liner at high normal loads

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ABSTRACT: Geosynthetic clay liners (GCLs) have seen increasing usage of GCLs in the mining industry. Potentially, GCLs could cut costs in the liner design of heap leach pads and tailings piles. However, little is known about the behavior of GCLs under the extremely high normal loads encountered in some of these applications.

To study the internal shear behavior of a needlepunched GCL under high normal loads two sets of shear tests were performed. The first set of tests was conducted in a standard 300 mm by 300 mm (12 in. by 12 in.) direct shear box at normal loads of 350, 700, and 1050 kPa (50, 100 and 150 psi). The second set of tests was conducted in a smaller 150 mm by 150 mm (6 in. by 6 in.) direct shear box at normal loads of 1050, 1750, and 2800 kPa (150, 250 and 400 psi). The smaller shear box was used at the higher normal loads due to limitations in the application of the higher normal stresses to the larger shear box. A common normal load of 1050 kPa (150 psi) allowed for comparing results of the two shear boxes.

Test results indicated good correlation between the small and large shear boxes. At 1050 kPa (150-psi) normal load, the peak internal strength of the GCL for the large and small shear boxes was 332 kPa (48.2 psi) and 334 kPa (48.4 psi), respectively. At the highest normal load, 2880 kPa (400 psi), the GCL had a peak strength of 668 kPa (96.9 psi).

In addition to the direct shear box test results, the peel strength test result for the same GCL sample is indicated. Peel strength tests have been correlated to direct shear strength and used as an index test in MQC and CQA test programs.

1 INTRODUCTION

A geosynthetic clay liner (GCL) is a man-made product typically consisting of a layer of sodium bentonite clay placed between two geosynthetics. GCLs contain an industry standard minimum of 3.65 kilograms per square meter of sodium bentonite clay as measured using ASTM D5993. The interlayer sodium ions on the montmorillonite clay platelets make it hydrophilic and high swelling. Sodium bentonite used in GCLs also has excellent filter cake properties resulting in maximum fluid loss of 18 ml per ASTM D5891 and a maximum hydraulic conductivity of 5×10^{-9} cm/s per ASTM D5887.

There are unreinforced and reinforced GCLs available for use. Unreinforced GCLs are typically manufactured using water-soluble adhesive and/or pressure to bond the bentonite to geotextiles or a geomembrane. Since the clay mineral montmorillonite is typically the main component of bentonite, it is well-known to have a low shear strength (Olson, 1974), these products are typically used in man-made earthen projects which are relatively flat in nature that do not present significant shear stresses or differential bearing pressures.

Reinforced GCLs are typically manufactured by needlepunching the top and bottom geotextiles together to encapsulate the bentonite layer. The physical bonding of the geotextiles enhances the internal shear strength of the GCL. Peel strength tests have been correlated to internal shear strength and are used as an index test in Manufacturer's Quality Control (MQC) and Construction Quality Assurance (CQA) test programs (Richardson, 1997). All US manufacturers of reinforced GCL currently certify to a minimum peel strength of 66 N (15 lbs.) per modified ASTM D4632.

GCLs have been manufactured since the early 1980's and have been used in landfill liner systems since 1986 (Koerner, 1996). More recently GCLs have been used in numerous mining applications, such as liners in tailings ponds and in closure (cap) applications (Miller, 1999). GCLs have a potential use in liner systems for heap leach pad applications and some GCLs have been proposed for use in current heap leach pad designs. GCLs have been shown to be compatible with the typical dilute cyanide solution which is used on heap leach pads to break down the spent ore to recover the desired mineral. In laboratory testing (Wallace, 1991), a hydraulic conductivity of <1 x 10^{-9} cm/s was reported after two pore volumes of permeation with a 600 ppm sodium cyanide solution at confining pressures greater than 210 kPa (30 psi). However, in general, geosynthetics are subjected to much higher stresses in heap leach pads than in other civil engineering applications. Heap heights can reach 125 m (Van Zyl, 1997) with vertical loads of up to 2,800 kPa. Consequently, there is concern for the internal shear strength of GCL under these conditions.

2 EXPERIMENTAL SETUP

To study the internal shear behavior of a needlepunched GCL under these extremely high normal loads two sets of shear tests were performed. The first set of tests was conducted in a standard 300 mm by 300 mm (12 in. by 12 in.) direct shear box at normal loads of 350, 700 and 1050 kPa (50, 100 and 150 psi). A schematic of the direct shear box test configuration is presented in Figure 1.

The second set of tests was conducted in a smaller 150 mm by 150 mm (6 in. by 6 in.) direct shear box at normal loads of 1050, 1750 and 2800 kPa (150, 250 and 400 psi). The smaller shear box was used at the higher normal loads due to limitations in the application of the higher normal stresses to the larger shear box. A common normal load of 1050 kPa (150 psi) allowed for comparing results of the two shear boxes. Samples used in both size shear boxes incorporated the use of textured steel gripping surfaces affixed to the upper and lower plates to achieve complete and uniform gripping of the GCL geotextiles. The reinforced GCL selected had a nonwoven geotextile on one side and a woven geotextile on the other side. Testing was conducted in accordance with ASTM D 6243 under the following test conditions. Samples were hydrated for 48 hours under each normal load and then sheared at a constant displacement rate of 1 mm/min (0.04 in./min).

3 RESULTS

Test results are summarized in Table 1. The results indicate good correlation between the small and large shear boxes. At 1050 kPa (150 psi) normal load, the peak internal strength of the GCL

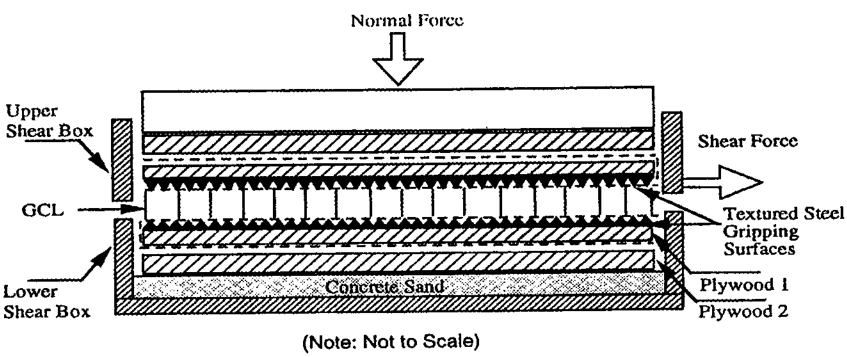

Figure 1. Direct Shear Box Test Configuration

Table 1. Internal shear strength of Bentomat ST reinforced GCL under hydrated conditions.

Shear Box Size (mm x mm)	Normal Stress (kPa)	Peak Load (N)	Large Displacement* Load (N)	Peak Strength (kPa)	Large Displacement* Strength (kPa)
300 x 300	350	13,690	3483	148	37
300 x 300	700	22,910	7259	247	78
300 x 300	1050	30,870	12,670	332	137
150 x 150	1050	7744	3367	334	145
150 x 150	1750	11,090	5048	478	217
150 x 150	2800	15,510	7117	668	306

* Large displacement measured at 50 mm for 300 by 300 shear box and 35 mm for 150 by 150 shear box.

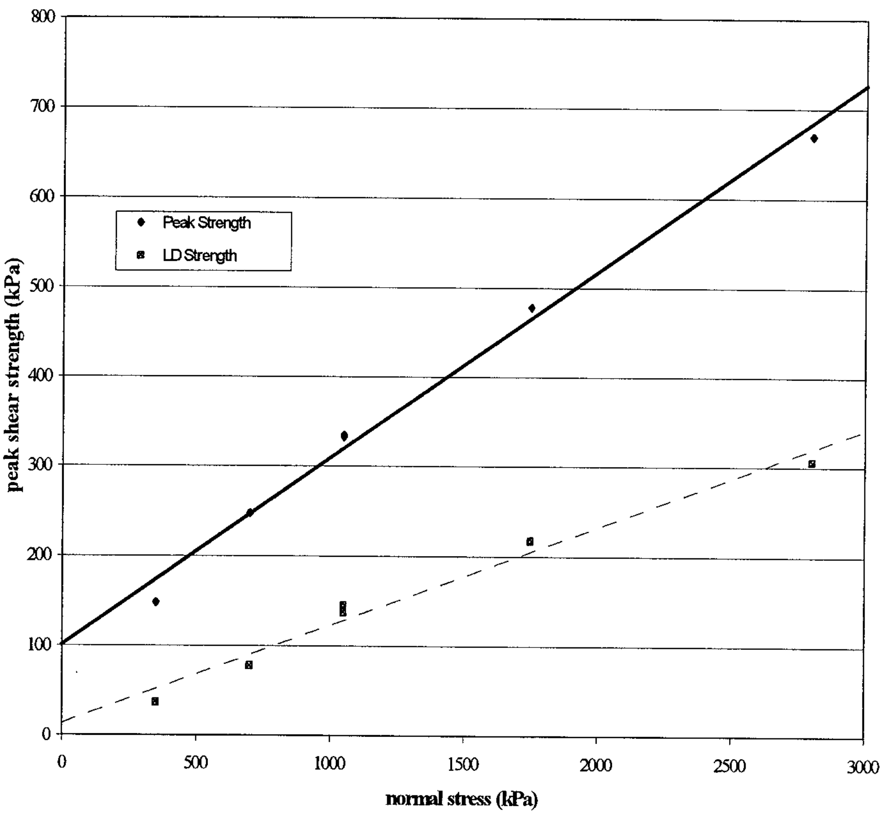

Figure 2. Internal shear strength of Bentomat ST reinforced GCL under hydrated conditions.

for the large and small shear boxes were 332 kPa (48.2 psi) and 334 kPa (48.4 psi), respectively. At the highest normal load, 2800 kPa (400 psi), the GCL had a peak strength of 668 kPa (96.9 psi). At 1050 kPa (150 psi) normal load, the large displacement (LD) strength of the GCL for the large and small shear boxes were 137 kPa (19.8 psi) and 145 kPa (21.0 psi), respectively. At the highest normal load, 2800 kPa (400 psi), the GCL had a large displacement strength of 306 kPa (44.4 psi).

Figure 2 depicts the data graphically using a traditional best-fit line for illustrative purposes. It yields a 12° peak friction angle with a peak adhesion of 100 kPa (2095 psf) and an 6° large displacement friction angle with a large displacement adhesion of 13 kPa (275 psf). The data is actually curvilinear with a point of maximum curvature at approximately 1050 kPa normal stress.

The GCL used in the above internal shear strength testing had a MQC peel strength of 110 N (25 lbs.) using a modified ASTM D4632 test method. This is a typical peel strength for reinforced GCL with a specified minimum peel strength of 66 N (15 lbs.).

4 SUMMARY AND CONCLUSIONS

It can be seen from the test results that the GCL has a high apparent peak friction angle at the highest normal stress of 2880 kPa (400 psi) of 14°. Although when comparing this peak apparent friction angle with the peak apparent friction angle of 20° for the GCL under typical landfill loading conditions of 700 kPa (100 psi) one can see the true effect of the curvilinear behavior of the GCL. This curvilinear behavior occurs in the peak internal strength of all soil-like materials as well as interfaces of soil against geosynthetic and geosynthetic against other geosynthetic materials.

However, the large displacement shear strength behavior typically does not exhibit the same dramatic curvilinear behavior. It can be seen from the test results that the GCL has an apparent large displacement friction angle at the highest normal stress of 2880 kPa (400 psi) of 6.3°. Comparing this peak apparent friction angle with the peak apparent friction angle of 6.5° for the GCL under typical landfill loading conditions of 700 kPa (100 psi) one can see the minimum effect of the curvilinear behavior on the large displacement shear strength. This minimum curvilinear behavior is also similar in the large displacement internal strength of all soil-like materials as well as interfaces of soil against geosynthetic and geosynthetic against other geosynthetic materials.

Understanding the internal shear strength behavior of GCLs under high normal load conditions is very important when one is designing a lining system for a heap leach pad. The data presented in this paper demonstrates the potential strength properties for a reinforced GCL under specific test conditions. In addition to the internal shear strength of the GCL, interface shear strength of the GCL against a geomembrane or other geosynthetic materials and soils that may be encountered in a specific design/site application should also be considered. Because of differences in surface texturing between different geomembrane manufacturers as well as other geosynthetics and varying soil characteristics, interface friction between the GCL and these materials should be determined on a site-specific basis. All testing, both internal and interface, should consider the actual site conditions regarding wetting, hydration, consolidation, and rate of loading so the proper shear strength properties are developed to allow good engineering judgment for a complete and safe design.

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