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Technical note

Average bonding peel strength of geosynthetic clay liners after short-term exposure to water and jet fuel A-1[☆]

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Abstract

The average peak and bonding peel strengths of needle-punched thermally bonded geosynthetic clay liners (GCLs) exposed to Jet Fuel A-1 are presented. Peel testing was performed on dry and saturated GCLs and the effect of stress during exposure was examined. GCLs exposed to Jet Fuel A-1 under zero stress for up to 14 days showed no statistically significant decrease in average bonding peel strength. GCLs hydrated with water and exposed to Jet Fuel A-1 at 14 kPa showed similar results with no statistically significant decrease in average bonding peel strength for up to 7 days. There was no statistically significant decrease in average bonding peel strength for thermally- and non-thermally-treated needle-punched GCLs hydrated with 14 kPa applied stress for up to 15 days. Variability in peel strength was observed depending on sample location. The average bonding peel strength of samples obtained near the edge of the roll were 45% lower than samples obtained away from the edge.

Keywords: Geosynthetic clay liner; Jet fuel; Peel; Average bonding peel strength

1. Introduction

Geosynthetic clay liners (GCLs) have gained widespread use as part of barrier systems for the containment of contaminants and as covers over waste. Another application is as containment for spills where they are installed in berms surrounding large fuel tanks. One potential failure mechanism associated with this application is a loss of slope stability due to the low internal friction angle of the bentonite used in GCLs. Shan and Daniel (1994) reported an internal friction angle of around 10° for unreinforced GCLs. Furthermore, in berm applications, there is very little normal stress and hence very low shear strength (Richardson, 1997; Mackey and von Maubeuge, 1999). Needle punching has been effectively used to substantially increase the internal stability of GCLs. In the event of a tank failure, it is not unrealistic to expect that a GCL will be exposed to hydrocarbons for a short period of time during clean-up and while repairs are made. It is important that the GCL should not fail during this period. GCL fibres (and hence the needle punching) are commonly made from polypropylene. It is unknown whether exposure to Jet Fuel A-1 can break down the polypropylene fibres and weaken the needle punching of the GCL of the short periods of exposure that may be anticipated during clean-up of a spill. Although McCaulou et al. (1995) list polypropylene as having excellent resistance against Diesel Fuel, Jet Fuel A-1 (and other hydrocarbon fuels) can be chemically different. Currently, the effect of exposure to hydrocarbons on the needle punching, and hence internal stability of GCLs, is unknown.

The average bonding peel strength of GCLs (ASTM D6496) is the average force per unit width required to separate the two geotextiles of the GCL and can be used as an index test that provides an indication of the internal shear strength. The objective of this paper is to examine the

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effect of Jet fuel A-1 on the average bonding peel strength of GCLs. The effect of stress during hydration and exposure, and of whether or not the sample is dry or hydrated is examined.

1.1. Previous studies

Shan and Daniel (1994) reported the internal friction angle of dry unreinforced GCLs is around 35° but decreases to below 10° when saturated. They reported that saturated reinforced needle-punched GCLs had an internal friction angle of 26°. Stark and Eid (1996) reported that the internal shear strength of reinforced GCLs predominately depends on the reinforcing fibre pull out and/or tearing, but the shear strength of bentonite also contributes. Fox et al. (1998) performed shear tests on needle-punched GCLs using a large-scale shear box and found that the peak shear strength increased significantly with increased normal stress.

Several researchers (Heerten et al., 1995; Richardson, 1997; Olsta and Crosson, 1999; Mackey and von Maubeuge, 1999) have correlated GCL peel strength with internal shear strength. Olsta and Crosson (1999) performed peel testing on needle-punched GCLs and reported that a GCL with a peak peel strength (maximum tensile force) of 65 N (100 mm wide sample) should result in an internal shear strength of approximately 24 kPa, which is sufficient for most low normal load applications.

Olsta and Crosson (1999) report variability in the average bonding peel strength due to manufacturing. As the needles used for needle punching wear out the peel strength drops, and typically the needles are replaced once the peak peel strength reaches a value of 65 N (ASTM D4632).

2. Testing program

A series of average bonding peel strength tests (ASTM D6496) were performed on GCLs exposed to Jet Fuel A-1. Two cases were examined: "dry" (gravimetric water content ≈8%) GCLs with zero stress applied during Jet Fuel A-1 exposure, and fully saturated (gravimetric water content ≈126% for 7 day hydration, gravimetric water content ≈143% for 15 day hydration) GCLs with 14 kPa stress applied during hydration and exposure to Jet Fuel A-1. The testing stress of 14 kPa is a stress at which GCLs are likely to experience in berm applications where there is some cover to protect the GCL. The methods used, apparatus, and procedures are described in the following sub sections.

2.1. Geosynthetic clay liners

Two GCLs were used in this research. The first was BentoFix® (BF) 501-NWL. It was a nonwoven, needle-punched, scrim-reinforced thermally treated product (with mass per unit area as listed in Table 1) denoted herein as GCL BF. Granular sodium bentonite was encapsulated between a scrim-reinforced nonwoven, and a virgin staple fibre nonwoven polypropylene geotextile. The second was BentoMat® (BM) DN. It was a nonwoven needle-punched, non-thermally treated product (with basic mass per unit area as listed in Table 2) denoted herein as GCL BM. Granular sodium bentonite was encapsulated between two nonwoven polypropylene geotextiles.

Table 1
Mass per unit area of GCL BF components

	Mass per unit area[a]	
	Specified values (g/m^2)	Measured values (g/m^2)
Cover	200 MARV[b]	237 (SD[c]; 33.3)
Bentonite layer	3660 MARV[b]	4808 (SD[c]; 406)
Carrier	200 MARV[b]	245 (SD[c]; 6.8)

[a] ASTM D5261, 2003.
[b] Minimum average roll value.
[c] Standard deviation.

Table 2
Mass per unit area GCL BM components

	Mass per unit area[a]	
	Specified values (g/m^2)	Measured values (g/m^2)
Cover	200 MARV[b]	273 (SD[c]; 21.3)
Bentonite layer	3660 MARV[b]	4626 (SD[c]; 326.8)
Carrier	200 MARV[b]	305 (SD[c]; 5.1)

[a] ASTM D5261.
[b] Minimum average roll value.
[c] Standard deviation.

Other significant properties listed by the manufacturers are similar: a nominal hydraulic conductivity of 5×10^{-11} m/s (ASTM D5084), an internal shear strength of 24 kPa (ASTM D5321), a minimum bentonite swell index of 24 ml/2 g (ASTM D5890), and a peel strength of 65 N for BM and 66 N for BF (ASTM D4632).

2.2. Jet fuel A-1

Jet Fuel A-1 is a colourless to pale yellow liquid with a kerosene-like or petroleum odour that is widely used in the northern regions of Canada. According to its material safety data sheet (MSDS), the freezing point is below −47 °C. The specific gravity at 15 °C is 0.755–0.840. Its kinematic viscosity is 8.0 mm^2/s max. at −20 °C, and its solubility in water is approximately 5 mg/l.

2.3. Apparatus

The peel testing was conducted using a Unite-o-matic constant rate extension tensile machine, with a testing rate set at 5 mm/s as specified by ASTM D6496. A high output load cell achieved the required sensitivity of 0.1 N/m and displacement was measured by a string potentiometer. The top and bottom geotextile were gripped using a set of Saunders clamps that provided sufficient clamping power to prevent sample slippage without crushing damage.

2.4. Sample preparation

100 mm × 200 mm samples were cut using a pre made template and utility knife. Care was taken not to use samples close to the edge of a roll due to lower peel strengths identified in one test series (described in upcoming section). For each test, either 5 or 10 samples were cut and prepared.

Water-hydrated samples were prepared by placing them in an aluminium tray on a thin bed of wet sand ($\approx$1 cm thick) to ensure water could evenly hydrate the GCL. Gravimetric water content varied from 116% to 132%, and 138% to 162% for samples hydrated 7 days and 15 days, respectively. Because GCLs were essentially fully saturated, water was evenly distributed through out the GCL. A 5 mm-thick semi rigid aluminium plate was placed above the GCL followed by a thin lid to reduce water evaporation or Jet Fuel A-1 vapours. Mass was placed on the aluminium plate such that each sample experienced a normal stress of 14 kPa. Once the samples were subject to stress, the tray was filled with de-ionized de-aired water, and the GCLs were allowed to hydrate for 7 days. Following hydration, the trays were opened up, the wet sand replaced with dry sand, and reassembled. With the samples under stress, the tray was filled with Jet Fuel A-1 for the specified exposure time. At the specified time, the samples were removed and tested to establish their average bonding peel strength. Fig. 1 shows the complete setup used for hydrated samples.

Dry samples were placed directly into a Jet Fuel A-1 bath and held separate from each other by geonet to ensure an even exposure. After the specified time, the samples were tested and their average bonding peel strength measured.

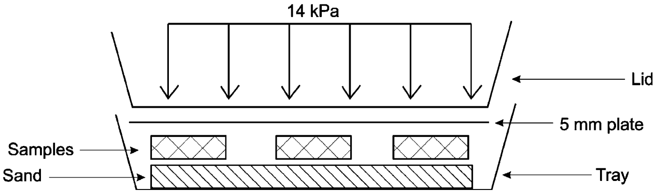

Fig. 1. Hydration and exposure set-up for samples under 14 kPa.

2.5. Testing procedure

Samples were tested using the ASTM D6496 procedure, "standard test method for determining average bonding peel strength between the top and bottom layers of needle-punched geosynthetic clay liners". The first 50 mm of the GCL was separated with a sharp utility knife and each geotextile clamped securely. The clamps and GCL were inserted into the tensile testing machine with an initial distance between the clamps of 50 mm.The testing machine was started and readings of force were taken over a distance of approximately 200 mm.The average force required to separate the GCL over a displacement from 25 to 125 mm represents the bonding peel strength of the GCL tested. The bonding peel strength, expressed in N/m, is the average force per width of the sample and, is calculated using the following equation:

$$\alpha_{\mathrm{f}} = \frac{F_{\mathrm{avg}}}{W_{\mathrm{S}}}, \tag{1}$$

where α_{f} is the bonding peel strength of the sample (N/m), F_{avg} the observed average force over a grip separation of 25–125 mm, and W_{S} the specified sample width (m).

The average bonding peel strength is the average of five samples tested.

3. Results

In presenting the results, each point shown on the figures to be discussed represents an average of 5, 10, or 15 samples tested with errors bars plotted as +/− one standard deviation. Statistical analysis was conducted using the student's *t*-test using 95% confidence intervals. GCL BF and GCL BM were hydrated under 14 kPa normal stress in de-ionized distilled water and their average bonding peel strength monitored. Tables 3 and 4 summarize the hydration time, number of samples tested and the results for GCL BF and GCL BM, respectively. GCL BF was exposed to Jet Fuel A-1 under zero stress and 14 kPa for exposure times up to 14 days. Table 5 summarizes the exposure times, number of samples tested, and the results.

Table 3
Average bonding and peak peel strength of hydrated GCL BF

Hydration time (days)	Number of samples tested	Average gravimetric water content (%)	Average bonding peel strength (N/m)	Standard deviation (N/m)	Average peak peel strength (N)	Standard deviation (N)
0	10	$\cong$8	536.3	84.0	89.5	16.6
7	15	126	613.6	157.9	97.4	16.0
15	5	148	564.3	133.7	79.7	12.8

Table 4
Average bonding and peak peel strength of hydrated GCL BM

Hydration time (days)	Number of samples tested	Average gravimetric water content (%)	Average bonding peel strength (N/m)	Standard deviation (N/m)	Average peak peel strength (N)	Standard deviation (N)
0	9	≅8	2154.9	311.6	269.0	32.5
7	5	134	1896.7	263.8	226.0	40.4
15	5	149	1889.8	245.2	247.9	28.6

Table 5
Average bonding and peak peel strength of GCL BF exposed to JetA-1

Sample condition	Exposure time in Jet Fuel A-1 (days)	Number of samples tested	Average bonding peel strength (N/m)	Standard deviation (N/m)	Average peak peel strength (N)	Standard deviation (N)
Dry	0	10	536.3	84.0	89.5	16.6
	0.0625	5	506.8	84.3	76.9	9.4
	3.8	10[a]	495.6[b]	57.0[b]	68.2	7.7
	7	10	444.5	125.0	69.7	17.0
	14	10	572.1	128.4	85.9	19.0
Hydrated	0	5	613.6	157.9	97.4	16.0
	3.8	5	562.8	51.5	84.4	9.0
	7	5	558.6	55.2	63.3	12.2
	14	5	379.8	55.9	58.2	8.1

[a] Five samples from middle of roll, five samples from edge.

[b] Average and standard deviation calculated from samples at middle of roll.

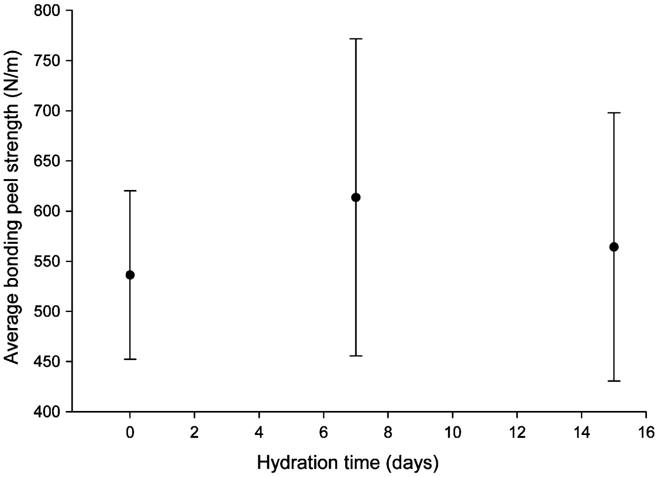

Fig. 2. Average bonding peel strength for hydrated GCL BF.

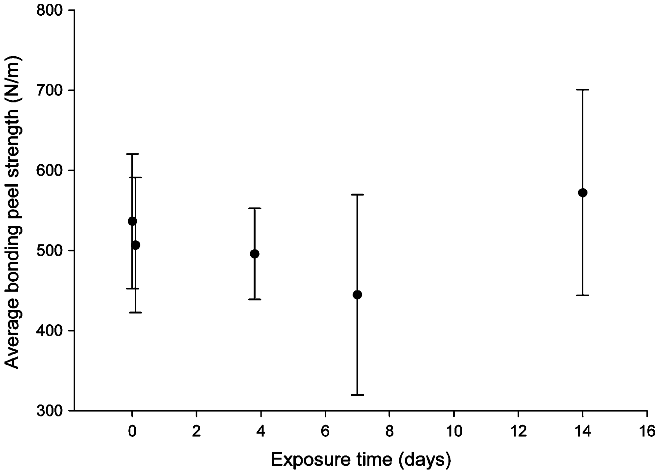

Fig. 3. Average bonding peel strength for dry GCL BF exposed to Jet Fuel A-1.

3.1. GCL BF

There was no statistically significant difference in the average bonding peel strength for GCL BF samples hydrated under 14 kPa normal stress for 15 days compared to the virgin (dry) state. For GCL BF samples hydrated under the same conditions for 7 days, there was a higher average bonding peel strength but this is attributed to roll variations. Fig. 2 summarizes the results of this test.

Tests were conducted on dry GCL samples to observe the effect of Jet Fuel A-1 on the average bonding peel strength. Dry GCL samples exposed to Jet Fuel A-1 under zero stress (Fig. 3) showed no statistically significant difference in average bonding peel strength for exposures up to 14 days, and so it is concluded that immersion in Jet Fuel A-1 had no significant effect on peel, and hence internal shear strength for exposures up to 2 weeks.

Some variability in peel strength was observed depending on sample location. In one case (dry 3.8 day Jet Fuel A-1 exposure), five samples from close to the edge, and five from the middle of the roll were exposed to Jet Fuel A-1. The bonding peel strengths of the samples from the edge were consistently 45% lower than the other samples. Table 6 summarizes the results of these tests.

To evaluate the effects of hydration on average bonding peel strength when exposed to Jet Fuel A-1, tests were conducted on hydrated samples (Fig. 4). Fig. 5 shows a comparison of the average bonding peel strength for the dry and hydrated GCL samples exposed to Jet Fuel A-1. Hydrated samples exposed for 0, 3.8, and 7 days had no statistically significant difference to dry exposed GCL samples for the same exposure time. Hydrated samples exposed for 14 days had a lower average bonding peel strength, although there is still sufficient average bonding peel strength for a berm with a 3(h):1(v) slope and 3 m or less cover based on a factor of safety of 1.5 (Mackey and von Maubeuge, 1999).

Table 6
Comparison of bond peel strength depending on roll location for GCL BF

Sample location	Bond peel strength (N/m)	
Middle	485.9	
	420.3	
	477.8	
	518.5	AVG[a] 495.6
	575.6	SD[b] 57.0
Edge	260.6	
	299.5	
	229.9	
	311.9	AVG[a] 270.4
	249.9	SD[b] 34.4

[a] Average.
[b] Standard deviation.

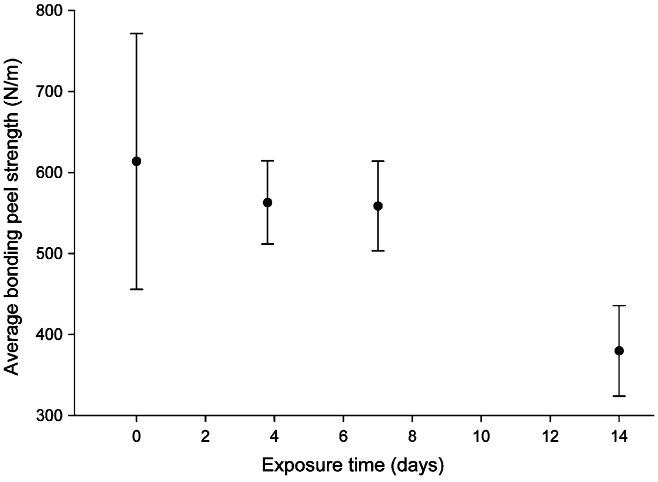

Fig. 4. Average bonding peel strength for hydrated GCL BF exposed to Jet Fuel A-1.

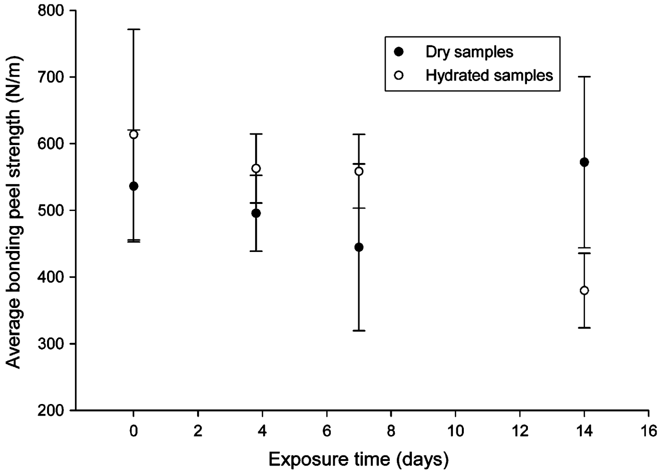

Fig. 5. Comparison of peel strength for dry and hydrated GCL BF exposed to Jet Fuel A-1.

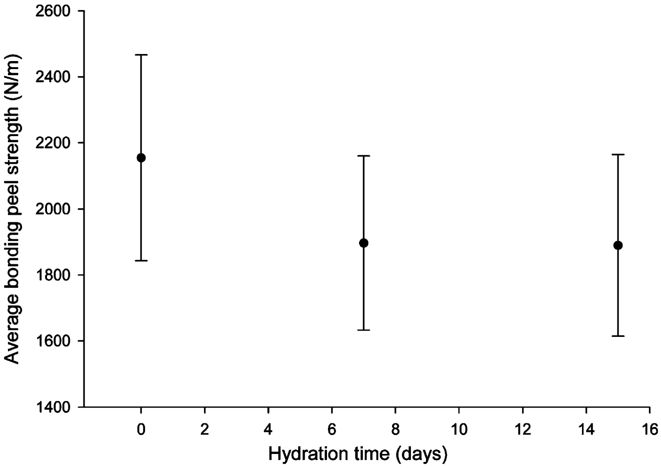

Fig. 6. Average bonding peel strength for hydrated GCL BM.

There is considerable variability in average bonding peel strength for some cases. This is attributed primarily to variation in peel strength with position on the roll.

3.2. GCL BM

There was no statistically significant difference in the average bonding peel strength for GCL BM samples hydrated at 14 kPa for up to 15 days. Fig. 6 summarizes the results of this test.

4. Discussion

The hydration of needle punched thermally treated GCL BF and non-thermally treated GCL BM did not affect the average bonding peel strength. Furthermore, there was no statistically significant decrease in the average bonding peel strength of dry and hydrated GCL BF exposed to Jet Fuel

A-1 for up to 15 and 7 days, respectively. The data obtained in this paper suggests that hydration and exposure to Jet Fuel A-1 does not affect the needle punching and hence the slope stability of GCLs in the short term (less than 2 weeks). For GCLs used on berms, it is reasonable to expect the tested GCLs to maintain the specified peel strength, and hence internal shear strength in the event of a tank failure and exposure the Jet Fuel A-1 for up to 1–2 weeks. The tests conducted are not exhaustive and engineering judgment is required in assessing the appropriateness this information to the design of barriers involving GCLs.

5. Conclusions

The ASTM D6496 standard was used to estimate the average bonding peel strength of dry and saturated GCLs exposed to Jet Fuel A-1 at 0 and 14 kPa applied stress, respectively.

1. For dry (gravimetric water content $\approx 8\%$) GCL samples exposed to Jet Fuel A-1 under zero stress for exposure times of up to 14 days, there was no statistically significant difference in peel strength compared to the virgin state (i.e. the GCL retained all its strength).
2. For samples hydrated at 14 kPa for 7 days and exposed to Jet Fuel A-1 at 14 kPa, there was no statistically significant difference in average bonding peel strength for 0, 3.8, and 7 day exposure compared to dry exposed samples for the same period. Samples exposed for 14 days had a lower average bonding peel strength, although there is still sufficient average bonding peel strength for a berm with a 3(h):1(v) slope and 3 m or less cover based on a factor of safety of 1.5 (Mackey and von Maubeuge, 1999).
3. Peel strength can vary depending on sample location in the roll. In one case, the peel strengths of the samples near the roll edge were consistently 45% lower than those taken away from the roll edge.
4. There was no statistically significant difference between the average bonding peel strength of samples hydrated with 14 kPa applied stress for 15 days and virgin (dry) samples for needle punched thermally treated GCL BF.
5. Hydration under 14 kPa applied stress for up to 15 days did not affect average bonding peel strength of needle punched non-thermally treated GCL BM.
6. There is considerable variability in average bonding peel strength for some cases. Primarily this is attributed to variation in peel strength with position on the roll.

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