PEEL AND SHEAR TEST COMPARISON AND GEOSYNTHETIC CLAY LINER SHEAR STRENGTH CORRELATION

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ABSTRACT

Multi-Component Geosynthetic Clay Liners (GCLs) are a new variation of GCLs and are fast growing in the current sealing applications. During the manufacturing process the “classic” geosynthetic clay liners is combined with either an attached film, coating, or membrane that can decreases the hydraulic conductivity of the product but can also add other features. ASTM D 6496 and EN ISO test methods give some guidance for testing the peel strength of GCLs. However, in the past multi-component GCLs were not tested according to ASTM or EN ISO test methods. To be able to suggest modifications on these test methods it is necessary to investigate the methods with current multi-component GCLs. Therefore this paper will present results on peel and shear data under varying conditions. Findings in how to separate the coating or adhered film and how the can be used in current test apparatus will be discussed. In the past correlation data between shear and peel were published and will be updated with multi-component GCLs. The results of peel and internal shear testing will be evaluated, compared and presented in this paper. Furthermore external shear test with different multi-component Geosynthetic Clay Liners against different soil types will be presented and discussed in this paper. This basic work will then be further discussed during ASTM for the development of a Standard test method for Peel testing for multi-Component Geosynthetic Clay Liners.

Keywords: Geosynthetic clay liner, peel strength, shear tests, multicomponent

INTRODUCTION

In the early days of the use of geosynthetic clay liners (GCLs) data was rarely available to prove the long-term shear resistance of GCLs. Peel strength tests have been carried out ever since needle-punched GCLs were introduced to the market in 1987 and were used to provide a quality control instrument for the production facility. At the beginning tensile shear and peel tests were compared with each other, but the tensile shear test showed inconsistent data (Maubeuge & Ehrenberg 2000), especially between different GCL product types. The tensile shear test was therefore dropped in the early days and the peel test was chosen as a manufacturing quality control (MQC) instrument. Peel strength data were not correlated against shear data until 1994 (Heerten et al. 1995). Until then the only data for slope stability calculations was gained from shear tests.

Presently internal field failures of needlepunched GCLs are unknown or have not been reported so that they either did not occur or failures were based on design or installation mistakes. This factor increased the confidence in reinforced GCLs. For the first time Heerten et al. (1995) introduced a design diagram for needlepunched GCLs in 1994 and Berard (1997) carried out additional testing showing that the testing conditions (time of hydration and shear rate) influenced the peak shear stress. Both compared the peel strength of the needlepunched GCL with the achieved shear stress.

In 2000 the peel test was standardized and first presented by Mackey & Maubeuge (1999). The peel test is based on wide width tensile test, such as ASTM D4595, resp. DIN EN ISO 10319. The report value is N/m and reports an average value of the peeling. In the meantime the peel test is a worldwide recognized standard, ASTM D6496 "Standard Test Method for Determining Average Bonding Peel Strength Between the Top and Bottom Layers of Needled GCLs", which is widely used and specified.

PERMETION THROUGH LINER SYSTEMS

Needle-punched geosynthetic clay liners (GCLS) are composite materials, and the layers are designed to work together. Needle-punching increases the internal shear strength, ensuring a firm lock between the geotextile outer layers and the bentonite core. The needle-punching process allows GCLs to exhibit a multidirectional, directionally independent, uniform shear and peel strength, which is important in many applications. Therefore the bond strength between GCL components is of particular interest. The standard peel test ASTM D6496 - which measures the strength between the carrier and cover geotextile and can be correlated to the GCL internal shear strength. As peel strength increases, so does shear stress, which means that steeper or safer designs on slopes are possible.

The GCL peel test provides a means of evaluating the needling strength of needle-punched GCLs and is an index procedure which is used to monitor the bonding strength as well as the wear of the needles during production. This is necessary since the needles are changed during production as peel test results begin to approach the minimum acceptable strength. The relationship between the internal peel strength and the peel bonding strength is described by Heerten et al. (1995), von Maubeuge et al. (2000).

In the past tensile strength test methods, such as ISO 10319, ASTM D4632 and ASTM D4595 were used as a basis for determining specimen size, testing equipment and the general test procedure subject to modifications in the rate of expansion, grip size as well as grip orientation. Since 1999 a test method is available which describes a procedure to determine the peel bond strength of needle punched Geosynthetic Clay Liners, ASTM D6496 "Standard Test Method for Determining Average Bonding Peel Strength Between the Top and Bottom Layers of Needled GCLs".

In this peel test, a GCL specimen is partially de-laminated by cutting the needlepunched bonds between the geotextiles just enough to allow each geotextile to be separately inserted into the grips of the tensile strength apparatus. The specimen is peeled at 300 mm per minute (12 in./min.) and the average peel bonding strength over a peeling distance (grip separation) of 100 mm (4 in.) is recorded as the average peel bonding strength for that individual specimen. Five specimens are tested to determine the average peel strength of a sample. The typical manufacturing quality control test frequency is performed at a minimum frequency of one test series every 20,000 m² (200,000 ft²) as recommended by ASTM D5889 "Standard Practice for Quality Control of Geosynthetic Clay Liners", whereas some manufacturers test at a higher testing frequency, every 4,000 m² (40,000 square feet) of material produced.

The following listing is a short summary of the peel test procedure.

1. A 300 mm (12 in.) long by full roll-width sample is cut from each designated GCL production roll. This sample is termed the testing roll.

2. Using a template, five 100 mm x 200 mm (4 in. x 8 in.) specimens are cut from the testing roll with the longer length oriented in the machine direction. Specimens not exhibiting proper orientation are rejected and a new specimen is cut.

3. A utility knife is used to slice the needlepunched bonds between the two geotextiles from the designated end of each specimen and the geotextiles are separated 50 mm (2 in.) apart.

4. The grips from the testing device are oriented so that the wide width of the grip is parallel to the 100 mm (4 in.) width of the test specimen and perpendicular to the applied stress. The grips must clamp the entire width of the specimen. The specimen is mounted in the testing device such that the upper grips contain the one geotextile flap and the lower grips contain the second geotextile flap. The grips should be set at a baseline distance of 50 mm (2 in.) apart. As mounted the grip will apply a 100 mm (4 in.) wide stress.

5. The tensile testing device (Fig. 1) is set to a constant rate of expansion of 300 mm/min (12 in./min). Readings of force at a rate of 20 per second are taken from 25 mm (1 in.) until 125 mm (5 in.) grip separation.

6. The average force [N (lbf)] for each specimen is then recorded and divided by the specimen width. The average peel bonding strength of all specimen is then calculated in N/m (lbf/in.).

7. A typical diagram of the reporting is shown in Fig. 2.

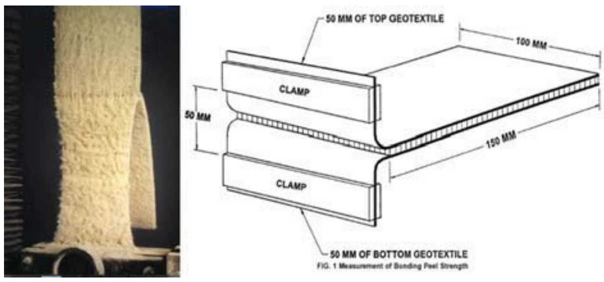

Fig. 1 GCL clamped in a peel strength testing device

In the past other methods were adjusted to run a peel test. However, with the new developed ASTM D6496 a test method is available which perfectly suits the test procedure for the determination of the peel bond strength of needle-punched GCLs.

The main difference of ASTM D6496 compared to other methods is the sample size and the final value. In the past the most test methods required that a maximum or peak value is reported. This value was then reported in N (lbs) or in N/10 cm (lbf/in.). With ASTM D6496 the reported value is an average value, because all bonding values are summarized in the average value and are not based on only one very high peel bond value (Fig. 2).

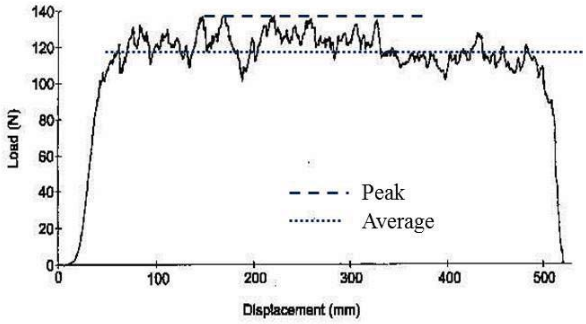

Fig. 2 Typical peel performance of a needle-punched GCL with the peak and average value marked

PEEL TESTING ON MULTI-COMPONENT GCLS

The low hydrated midplane friction angle of the bentonite alone achieves at peak approx. 9°and at residual about 4 to 5°. However in the 1980s the needle-punching technology created a uniform shear strength transmitting GCL, thus reinforcing this weak bentonit friction value. The result of investigations thereafter lead to the correlation between peel strength and shear stress.

Further studies investigated the longterm behavior of the fiber reinforcement. One research part was carried out by the BAM (Bundesanstalt für Materialforschung und -prüfung [federal agency for materials research and testing]). The results from the BAM experiments on the > 400 year functional lifetime of a needle-punched GCL from a German manufacturer were independently complimented by a series of oven-aging experiments designed to measure the oxidation rates of the fibers when exposed to air in a simulated landfill environment (Ehrenberg et al. 2008).

The second research project was carried out at TRI, a testing and research institute in Austin/Texas. This study involved using Arrhenius extrapolation methods to determine the oxidation rate of fibers when exposed to air at temperatures of 100°, 90°, 80°, 70°, and 60°C. The material tested was a needle-punched, nonwoven polypropylene geotextile made from fibers used in the on specific needle-punched GCL.

The aim of the study was to propose a generally accepted requirement that the tested geotextile should maintain over 50 % of its strength when exposed to the tested condition, which was also the basis for the extrapolation. When these data were used to extrapolate, it was found that if the textiles were continuously exposed to fresh air in a high air-flow environment, the predicted service lifetime would be about 17.8 years at 15°C. However, since these were extreme and not realistic conditions the results were compared to oxidation rates found in 8 % oxygen, which is believed to be the maximum concentration one would find in a buried application. In this case, the oxidation rate was 21 times slower than the rate found in air (21 % oxygen).

This means that the 17.8 year service lifetime would actually be 373 years in a buried application; agreeing very well with the results from the BAM. The results for these two independent studies clearly show the long term performance capabilities of the tested needle-punched GCL. However, one can be less conservative and assume that a remaining long-term tensile strength of 25 % or even 10 % would be sufficient. In this case the lifetime prediction would increase to 560 years, resp. 672 years.

With knowledge on the materials, manufacturing technology and components resin the next step with the newly developed multicomponent GCLs (Fig. 3) was to investigate the bonding behavior between the secondary polyolefin barrier and the GCL. However, it must be noted that in the case of coated GCLs the coating is extruded in the fluid state directly on top of the woven geotextile, so that there is an immediate bonding with the woven geotextile and the needle-punched fibers from the nonwoven geotextile. This is a main difference to adhered multi-components, where an adhesive glue is required to bond the secondary barrier against the GCL. This glueing can be considered as the weak spot and requires additional durability investigations to ensure the long-term bonding. It is also known from the polyolefin side that it is nearly impossible to achieve a long-term bond against a polyolefin membrane. Typically a perfect bond of any material to a polyolefin can only be achieved by thermal treatment.

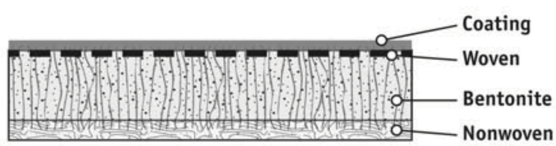

Fig. 3 Typical cross-section of a multi-component GCL

The following definition proposals are currently being discussed in the ASTM D35 terminology task group and might be added in future in the ASTM terminology standard D4439.

Multicomponent GCL, n - GCL with an attached film, coating, or membrane decreasing the hydraulic conductivity or protecting the clay core or both (Note: in this paper the attached film, coating, or membrane to the GCL are also referred to as secondary barrier)

Adhered geosynthetic clay liner (GCL), n - GCL product in which the clay component is bonded to a film or membrane by adhesion

Coated GCL, n - GCL product with at least one layer of a synthetic substance applied to the GCL as a fluid and allowed to solidify

In this study the aim was to investigate the bonding and the shearing of attached films or coatings, (secondary barriers) which are bonded to needle-punched GCLs. To determine the peel bond strength between the secondary barrier and the GCL four different needle-punched GCL types (Table 1) were selected and tested according to the peel bond test ASTM D6496 and EN ISO 13426-2.

Table 1 Brief description of secondary barrier types used with investigated needle-punched GCLs

	Secondary barrier	Barrier mass/unit area g/m²	Barrier attached against	Secondary barrier raw material
A	Coating	200	Woven	Polyethylene (PE)
B	Coating	500	Woven	PE
C	Adhered film		Woven	PE
D	Coating	100	Woven	Attactic polypropylene

To investigate the influence of hydration all samples were tested in dry condition as well as after 24 hours hydration under 10kPa confining stress. The first series of peel tests were carried out peeling the nonwoven geotextile and the composite of the woven/secondary barrier apart (Fig. 4). Basically just carrying out a regular peel strength test and considering the composite of woven/secondary barrier as one geotextile component. Compared to the expected GCL peel bond values and as stated in the GRI-GCL 3 (360N/m) all four investigated GCLs showed much higher peel bond values than the minimum requirement (360N/m). The results of the testing is summarized in Table 2.

Fig. 4 Peeling the nonwoven geotextile and the composite (woven/secondary barrier) of the GCL apart

In all cases the hydrated samples showed lower peel values than after testing under dry conditions, which could be expected (Table 3). To determine if there is a major difference between the ISO and the ASTM procedure more testing is required to make a statistical proven statement. It must also be noted that there is a high variation within a GCL production, so that these results are only a base line statement. It can also be identified that the remaining peel strength under hydrated conditions improves if more mass per unit are of coating is used.

Fig. 5 Peeling secondary barrier of the GCL

The second series of testing investigated the peel bond strength of the secondary barrier against the GCL, resp. against the woven geotextile of the GCL. In this peel test the idea was to try to peel of the secondary barrier directly from the GCL (Fig. 5), without determining the true peel bond strength of the GCL. The values achieved are listed in Table 4 and show for three of the four GCLs slightly lower values than achieved during the peel bond test as shown in Table 2. The bonding between the GCL and the coating of the type CNSL was so strong that it was impossible to delaminate for a peel bond testing. However, all the tested GCL still exceeded the recommended GRI-GCL values of > 360N/m. However, it needs to be noted that in this case there is no extra bentonite core between the coating and the woven, just pure bonding between these materials. The remaining values in percent, comparing the peel bond strength between the carrier (including the secondary barrier) and cover geotextile versus the peel bond strength of the secondary barrier alone against the GCLs are listed in Table 5 and show a remaining bonding strength between 38.7 and 100%.

With a first look at these values one might want to make the conclusion that the week shear interface might now be between the secondary coating and the GCL. However, up to now there is no data to support such a conclusion, so that the authors decided to have a closer look at the shear values and identify if there would be a correlation between the shear values and the peel bond values between the secondary barrier and the GCL.

Table 2 Peel values of investigated GCLs - cap nonwoven separated from carrier geotextile composite (woven/secondary barrier)

	dry		hydrated		dry		hydrated	
	ASTM D 6496		ASTM D 6496		EN ISO 13426-2		EN ISO 13426-2	
GCL	N/10cm (peak)	N/m (average)	N/10cm (peak)	N/m (average)	N/20cm (peak)	kN/m (average)	N/20cm (peak)	kN/m (average)
A	135,2	929	113,4	818	232,4	0,83	175,3	0,53
B	107,6	867	100,7	838	200,9	0,75	195,4	0,79
C	357,3	2797	297	2346	558,2	2	373,1	1,45
D	220,1	1826	211	1691	274,8	1,1	271,8	1,01

Table 3 Remaining peel strength of hydrated GCLs compared to dry condition (values from Table 2

	ASTM D6496	ISO 13426-2
	in % to dry	in % to dry
A	83,9	75,4
B	93,6	97,3
C	83,1	66,8
D	95,9	98,9

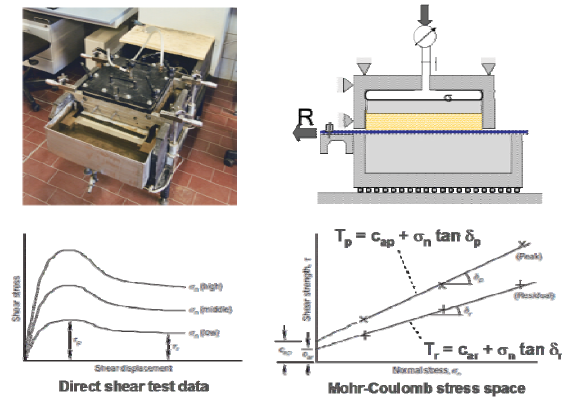

Fig. 6 Conducted interface shear box tests

SHEAR TESTING ON MULTI-COMPONENT GCLS BETWEEN THE SECONDARY BARRIER AND THE GCL

The shear tests were carried out in an apparatus according to ASTM-D-5321, ASTM D6243 or EN ISO 12957-1 using a shear speed of 10mm/h and a confining stress of 20kPa. All products were hydrated for 24 hours under the selected confining stress and the consolidation period was 24 hours. The reported maximum shear stress value is listed in kN/m² and also as a one point friction angle, without considering a possible cohesion (would only be possible to determine with minimum two different confining stress conditions). The apparatus and fixing methods are mentioned in Fig. 6.

Only three multi-component GCLs were tested, since it was impossible to carry out representative shear tests with the GCL CNSL, because a separation of the thin coating from the woven was not possible.

The coated GCLs showed that the weakest value resulted from the tensile strength of the coating rather than a shearing of the coating from the woven (Fig. 7). Only the internal shear values between the adhered secondary barrier and the woven side of the GCL showed a partly delamination of the glue from the coating and indicated that a shearing could take place. Considering that this is only a short term test, it is not known how the glue will behave in long term. The results are summarized in Table 6.

Table 4 Peel values of investigated GCLs - secondary barrier separated from the woven

	dry		hydrated		dry		hydrated	
	ASTM D 6496		ASTM D 6496		EN ISO 13426-2		EN ISO 13426-2	
GCL	N/10cm (peak)	N/m (average)	N/10cm (peak)	N/m (average)	N/20cm (peak)	kN/m (average)	N/20cm (peak)	kN/m (average)
X2N49	86,2	500	88	510	185,5	0,57	177,2	0,56
X5B53	49,5	368	65,7	521	82	0,29	96,9	0,35
LNSL	241,8	1786	193	1467	348,7	1,22	233,2	0,78
CNSL	-	-	-	-	-	-	-	-

Table 5 Remaining peel strength of dry and hydrated of coating separated from GCL compared to separation of cap geotextile and composite (including attached secondary barrier) geotextile (Table 2)

	dry		hydrated		dry		hydrated	
	ASTM D 6496		ASTM D 6496		EN ISO 13426-2		EN ISO 13426-2	
GCL	% (N/10cm)	% (N/m)	% (N/10cm))	% (N/m)	% (N/20cm)	% (kN/m)	% (N/20cm)	% (kN/m)
X2N49	63,8	53,8	77,6	62,3	79,8	68,7	101,1	105,7
X5B53	46,0	42,4	65,2	62,2	40,8	38,7	49,6	44,3
LNSL	67,7	63,9	65,0	62,5	62,5	61,0	62,5	53,8
CNSL	-	-	-	-	-	-	-	-

Table 6 Shearing test conditions and values for investigated GCLs

		Shear stress at 20 kPa Load	Consolidation	Shear speed	One point friction angle
	Test	(kN/m²)	(h)	(mm/h)	(°)
A	025-12	37,8	24	10	62
	Bottom: double sided tape and melt glue / top: Needle-plate /// Coating fix on bottom, woven and nonwoven fixed on top /// Coating torn				
B	026-12	42,4	24	10	64
	Bottom: double sided tape / top: Needle-plate /// Coating fix on bottom, woven and nonwoven fixed on top /// Coating torn out of fixing				
C	027-12	47,8	24	10	67
	Bottom: double sided tape and melt glue / top: Needle-plate /// Coating fix on bottom, woven and nonwoven fixed on top /// Coating partly torn or delaminated from woven				
D		No tests carried out; partly very thin and hard to seperate from woven			

Fig. 7 Typically performance of tearing of coating during the shear box test, rather than shearing of the interface secondary barrier to GCL due to the excellent bonding behavior

CONCLUSIONS

The aim of this investigation was to see if there is an major impact of peel values of coated or adhered film GCLs on the shear performance.

The first investigation considered the standard peel test and a delamination of the cap geotextile and the composite carrier geotextile (bentonite core between these two geotextiles), which was the secondary barrier (coating or film) bonded to the woven. Under dry and hydrated conditions it seemed that the bonding was very good and exceed the GRI-GCL recommended specification of larger than 360N/m.

The second series of testing was done by peeling of the secondary barrier from the GCL under dry and hydrated conditions. In both cases it was possible to peel of the secondary barrier and measure a peel value. However, it is questionable if this value is of interest. One coated material was very hard, nearly impossible to separate from the GCL, whereas the glue bonded secondary barrier was easiest to separate.

In the last test series shear tests were carried out, but during the shear tests with coated materials, it was obvious that since there is no wet bentonite layer between the materials, the bonding was strong enough and in nearly all cases a tearing of the coating occurred rather than a shearing. Only with the adhered film it was partly obvious that a delamination could happen in this short term test. However no statements can be made for the long-term conditions.

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