Heat-tacked overlap strength of four GCLs

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ABSTRACT
Panel separation of Geosynthetic Clay Liners (GCLs) when installed beneath a geomembrane and left exposed to ambient conditions with no cover has been attributed to an accumulation of permanent shrinkage strain from cyclic wetting and drying. Heat tacking of GCL panel overlaps is being considered as one possible approach to mitigate panel separation. This approach will require the resistance of the heat-tacked seam to exceed the force developed in the GCL panel upon shrinkage. This paper presents the results of tensile strength tests on virgin and heat-tacked specimens of four commercially available GCLs. Heat-tacked specimens were found to have reduced strength compared to the virgin specimens in both the roll and cross-roll directions. The heat-tacked samples were observed to fail in three different ways. The same GCL type failed differently when loaded in roll and cross-roll directions. Pre-engineered grooves in GCLs provided preferential locations for rupture.

RÉSUMÉ
Séparation du panneau des des géosynthétique bentonitique (GSB) lorsqu'il est installé sous une géomembrane et exposés à des conditions ambiantes sans couverture de gauche a été attribuée à une accumulation de souche rétrécissement permanent de cyclique de mouillage et de séchage. Chaleur joignant des chevauchements de panneau GSB est envisagée comme l'une des approches possibles pour atténuer la séparation du panneau. Cette approche exigera la résistance de la couture accrochées à la chaleur à dépasser la force développée dans le panneau GSB dès le retrait. Cet article présente les résultats des tests de résistance à la traction sur des spécimens vierges et accrochées à la chaleur de quatre spécimens disponibles commercialement GSB. chaleur-plaquées ont montré des force réduite par rapport aux spécimens vierges dans le rouleau et les directions de la Croix-roll. Les échantillons de chaleur-plaquées ont été observés à l'échec de trois façons différentes. Le même type GSB n'a pas différemment lors du chargement en rouleau et les orientations de la Croix-roll. Rainures préfabriqués en GSB emplacements préférentiels prévus en cas de rupture.

1 INTRODUCTION

1.1 Geosynthetic Clay Liners

Geosynthetic clay liners (GCLs) can be integral parts of modern composite liners. GCLs are often comprised of a layer of bentonite sandwiched between upper and lower geotextiles, which are commonly held together by needle punching. For some products, the needle-punched fibers drawn from the upper geotextile are thermally fused to the lower geotextile (referred to as thermal treatment). All together the total thickness of GCL is normally between 5-10 mm.

The very low hydraulic conductivity of GCL, typically with $k_w < 5\text{x}10^{-11}$ m/s when permeated with water, can make it very effective in limiting leakage through any holes in an overlying geomembrane (GM) (e.g., see Rowe et al. 2004; Rowe 2011).

GCL panels have a fixed dimension and need to be overlapped (e.g., see Fig. 1) effectively to prevent preferential leakage at the overlaps. Typically supplemental powder bentonite is placed, at a rate specified by the manufacturer, between the two overlapped panels. However for some products, a pre-engineered groove in the lower geotextile of the GCL is used to expose the bentonite in order to self-seam the overlaps without the addition of supplemental bentonite.

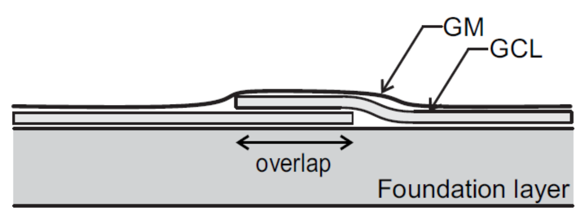

Figure 1. Illustration of a GCL overlap beneath a geomembrane (GM).

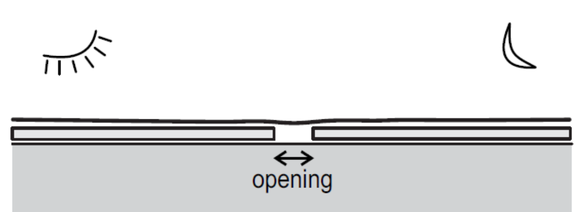

Figure 2. Illustration of loss of overlap between GCL panels beneath an exposed GM.

1.2 GCL Panel Shrinkage

GCLs may be susceptible to shrinkage under cyclic wetting and drying cycles (Thiel et al. 2006; Rowe et al. 2010). Various cases have been reported where GCLs covered by a geomembrane (GM) and left exposed for 2 to 36 months resulted a panel separation from 200 mm to 1200 mm (Fig. 2) that had an initial overlaps of 150 mm (Thiel and Richardson 2005; Koerner and Koerner 2005a, 2005b). Gassner (2009) reported 50-80 mm of shrinkage during 18 months of exposure when a 5 mm thick off-white geotextile protection layer covered the geomembrane. The use of a light colored geotextile was believed to reduce the extent of shrinkage; however, it clearly did not prevent shrinkage.

Two possible means of reducing the risk of panel separation are to increase the overlap to 300 mm and place cover soil on the GM as quickly as possible (Thiel and Rowe 2010); however in some cases it may not be possible to achieve these solutions.

1.3 GCL Overlaps and Heat Tacking

GCL panels are typically overlapped by 150 to 300 mm depending on the manufacturer, product, engineering application and exposure conditions. When immediate covering of composite liner is not possible, it appears that the technique of heat-tacking the overlaps has potential for reducing the risk of shrinkage induced separation (Thiel and Thiel 2009; Rowe et al. 2009). Heat tacking involves melting some of the fibres from the upper geotextile from one GCL panel and pressing these molten fibres into contact with the lower geotextile of the adjacent GCL panel with which they bond. Thiel and Thiel (2009) documented the use of heat tacking of GCL overlaps to prevent panel separation in a 60 ha heap leach pad at a site in Arizona. The 150 mm GCL panel overlaps were heat-tacked using a flame torch and pressed together by the weight of a sand bag that was dragged over the seam following the torch. The geomembrane was placed over the GCL on the same day but the composite liner it was left uncovered for 60 days or more before cover soil was placed over the composite liner. Rowe et al. (2010) reported that the bonded seams from the site generally performed well.

1.4 Objective

The objective of this paper is to quantify the tensile strength of four different GCLs in the roll and cross-roll directions and to quantify the tensile strength of heat-tacked GCL overlaps also in the roll and cross-roll directions.

2 METHOD

2.1 GCLs Tested

To quantify the tensile strength of seamed and un-seamed GCL in roll (machine) and cross-roll (cross-machine) direction, four different GCLs from two different manufactures were tested. Descriptions of the GCLs tested are given in Table 1. All GCLs contained natural granular Wyoming bentonite.

All four GCLs were needle-punched to improve the mechanical bond between the layers. The needle punched fibres from the upper geotextile of GCLs 1 and 2 were thermally fused to the lower geotextile, GCLs 3 and 4 were not thermally treated. GCL3 and 4 each had a pre-engineered groove intended to eliminate the need for placing powdered bentonite.

2.2 Sample Preparation

Edge samples measuring approximately 400 mm wide and 2000 mm long were taken from each GCL in both the roll and cross-roll directions. Samples were overlapped by 150 mm and were bonded using a propane flame torch and then pressed together by the operator dragging his foot over the heated seam (Figure 3). Heating melted the fibres of the lower geotextile of upper GCL and upper geotextile of lower GCL, which fused together creating a heat-tacked seam. The heat-tacked portion of the seam ranged from 30 mm to less than 110 mm. Each sample was then cut in to 5 pieces, 400 mm square, sealed in a plastic bag and transported back to lab for the preparation of the test specimens.

Test specimens, 100 mm wide x 200 mm long, were prepared prior to testing. The portion of seam other than heat-tacked were carefully cut and removed. All the specimens were at the off-the-roll moisture content.

2.3 Testing

Testing (ASTM D 6768) involved taking a 100 mm wide X 200 mm long specimen, clamping it in a tensile testing machine (Fig. 4) with a 100 mm gauge length, and subjecting it to a constant rate of elongation of 300 mm/min until complete rupture of the specimen occurred.

Five replicate tests were performed for each set of virgin and heat-tacked specimens.

Figure 3. Heat-tacking GCL panels to form a seam.

Table 1. Description of the GCLs tested.

GCL	Top GTX*	Bottom GTX*	Bonding mechanism
GCL 1	Nonwoven staple-fibre needle-punched	Woven slit-film	Needle-punched, Thermally treated
GCL 2	Nonwoven staple-fibre needle-punched	Woven slit-film needle-punched to a needle-punched nonwoven staple-fibre	Needle-punched, Thermally treated
GCL 3	Woven slit-film	Needle-punched nonwoven staple-fibre	Needle-punched
GCL 4	Nonwoven staple-fibre needle-punched	needle-punched nonwoven staple-fibre	Needle-punched

GTX = geotextile.

* Top and bottom refer to whether the GTX is on the top or bottom of the GCL as it comes off the roll

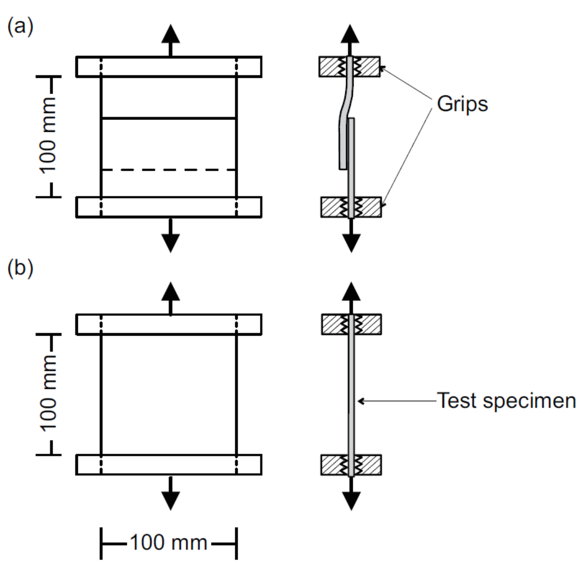

Figure 4. Tensile testing of (a) Heat-tacked specimens and (b) Virgin specimens.

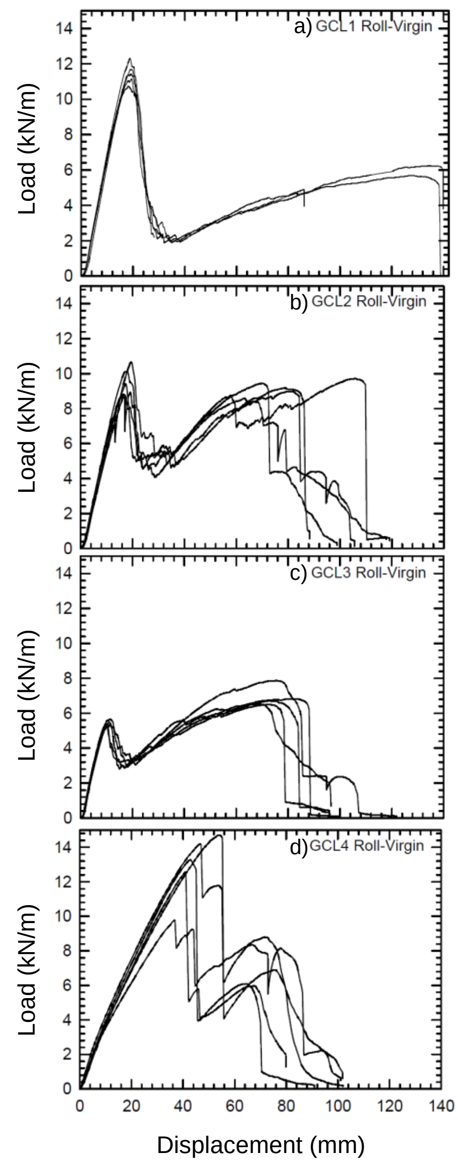

Figure 5. Load-displacement curves for four virgin GCLs in roll direction.

3 RESULTS

Figure 5 shows the load-displacement curves for the four different virgin GCLs in the roll direction. The tensile force, in each case, built up as the displacement increased and reached a peak. Sudden decreases in post-peak force were experienced for each GCL. GCLs 1, 2 and 3 all showed a gradual increase in load carrying capacity beyond the peak force. GCL4, which has both upper and lower nonwoven needle-punched geotextiles showed only a decrease in load post peak.

The maximum average tensile force was measured for GCL4 and least for GCL3. GCL4 showed the greatest variability, with a standard deviation of 1.9 kN/m and coefficient of variation of 15%, for otherwise identical test conditions. The results are presented in Table 2.

Comparing Figure 5a, b and c, GCL1 has a higher rupture strain than GCL2 and 3. GCL1 and 2 both have the same upper nonwoven geotextile. GCL1 has a woven lower (carrier) geotextile while GCL2 has a nonwoven staple fibre geotextile needle-punched to a woven geotextile as a carrier geotextile.

Table 2. Summary of maximum tensile strength (kN/m) of four different virgin GCLs in roll direction.

GCL type	Mean (kN/m)	Std dev. (kN/m)	Coef. of variation (%)
1	11.5	0.6	5
2	9.8	0.6	6
3	6.9	0.6	8
4	12.9	1.9	15

Table 3. Summary of maximum tensile strength (kN/m) of four different virgin GCLs in cross-roll direction.

GCL	Mean (kN/m)	Std dev. (kN/m)	Coef. of variation (%)
1	11.9	0.6	5
2	22.8	1.8	8
3	6.5	0.3	4
4	14.7	2.0	13

Figure 6 shows the force-displacement curve for the virgin GCLs in cross-roll direction and Table 3 summarizes the tensile strengths. In this orientation, GCL2 had the maximum peak strength while GCL3 had the minimum peak strength.

GCL1 showed a similar pattern of load-displacement response as in the roll direction. However, GCL2 was much stronger in the cross-roll direction than in the roll direction. This is because an anisotropic woven silt-film geotextile was used for GCL2, with stronger slit films in the cross-roll direction. Figure 7 shows photographs of the different failure mechanisms for GCL2 in the roll and cross-roll directions.

GCL3 and 4 both failed at the pre-engineered grooves. The upper woven geotextile in GCL3 continued to resist displacement even after the failure of the pre-engineered grooves (see Fig. 8a) but in case of GCL4 the lower nonwoven geotextile failed simultaneously with the pre-engineered groove (see Fig. 8b) and hence there is no post-peak load. Rowe et al. (2010) also reported failure of GCL4 from the pre-engineered grooves. The average strength of pre-engineered groove of GCL4, reported by Rowe et al. (2010) was 12.7 kN/m with a standard deviation of 2.8 and the average strength measured during this test was 14.7 kN/m with a standard deviation of 2.

Figures 9 and 10 show the load-displacement curves for the heat-tacked specimens in the roll and cross-roll directions. Tables 4 and 5 summarize the maximum tensile strengths of the heat-tacked specimens. The heat-tacked specimens showed different modes of failure when loaded in different directions. Compared to the virgin specimens, heat-tacked specimens had decrease in strength and exhibited a greater variability.

GCL2 recorded the maximum heat-tacked tensile force in both the roll and cross-roll directions. The minimum heat-tacked tensile force, on average, was found for GCL1 in the roll direction and GCL3 in the cross-roll direction. The ratios of average heat-tack strength to

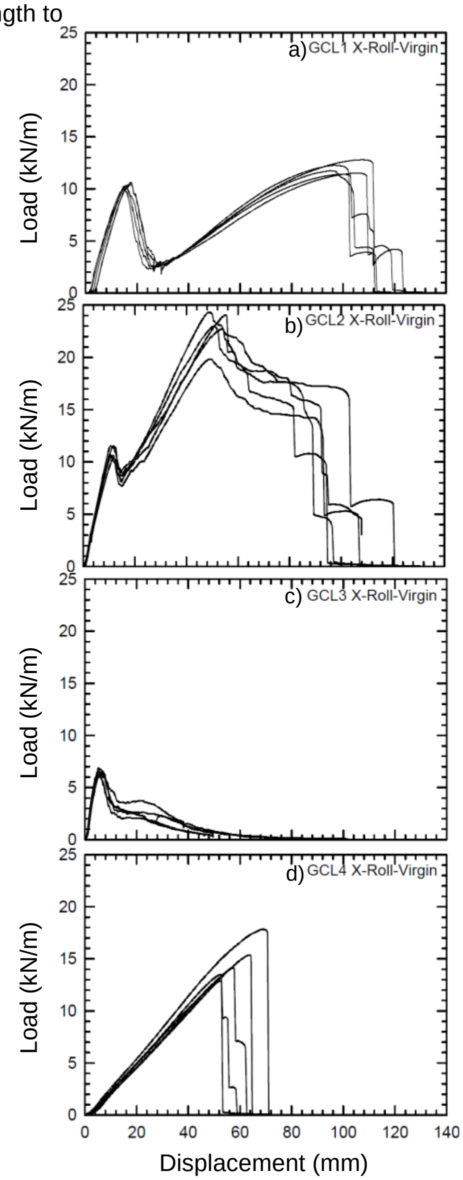

Figure 6. Load-displacement curves for four GCLs in cross-roll direction.

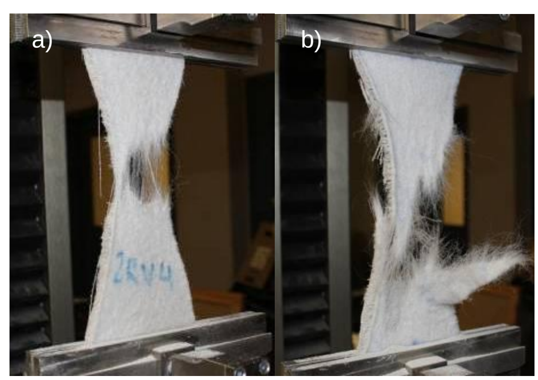

Figure 7. Failure of virgin GCL2 in a) Roll direction b) Cross-roll direction.

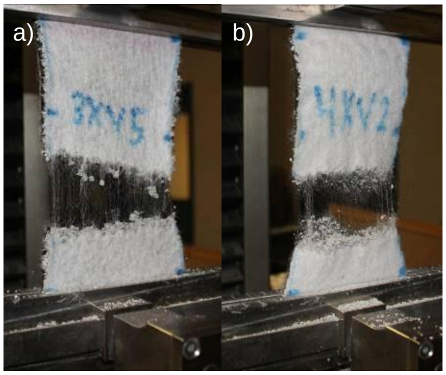

Figure 8. Failure at pre-engineered groove in: (a) GCL3, and (b) GCL4

Table 4. . Summary of maximum tensile strengths (kN/m) of four different heat-tacked GCLs in roll direction.

GCL type	Mean (kN/m)	Std dev. (kN/m)	Coef. of variation (%)
1	4.5	1.1	23
2	10.3	1.2	12
3	5.3	0.7	13
4	7.5	1.2	16

Table 5. Summary of maximum tensile strength (kN/m) of four different heat-tacked GCLs in cross-roll direction.

GCL type	Mean (kN/m)	Std dev. (kN/m)	Coef. of variation (%)
1	7.8	0.9	12
2	13.5	2.6	19
3	4.4	0.9	21
4	9.2	1.2	16

Table 6. Ratio of average maximum heat-tacked strength to virgin strength in the roll and cross-roll directions.

GCL	Roll	Cross-roll
1	0.4	0.7
2	1	0.6
3	0.8	0.7
4	0.6	0.6

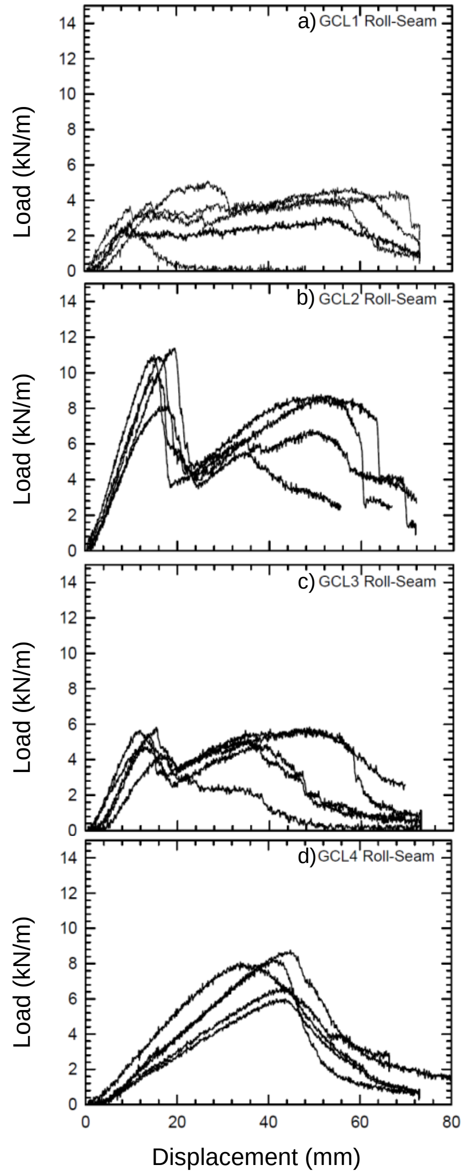

Figure 9. Load-displacement curves for four heat-tacked GCLs in roll direction

virgin strength are summarized in Table 6.

Although the lower geotextiles of both GCLs 1 and 2 had already been thermally treated and had a noticeably smoother surface compared to GCL3 and 4, this did not appear to affect the heat-tacking of overlaps, probably because only the bottom side of GCLs 1 and 2 were thermally treated and the non-thermally treated upper side of these GCLs were able to develop an effective bond with the lower geotextile upon heat tacking. The heat-tacked specimens of GCL1 and 2 did not fail at the seam except for GCL2 in the cross-roll direction, which is most likely because GCL2 has a very high strength in cross-roll direction (Table. 3). For GCL1, the lower woven geotextile failed when the specimen was loaded in the roll direction

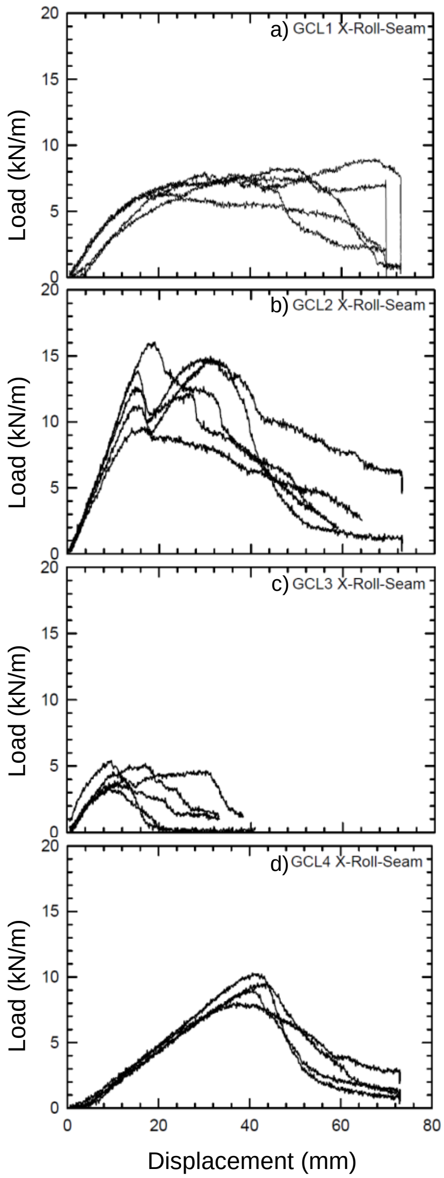

Figure 10. Load-displacement curves for four heat-tacked GCLs in cross-roll direction

and the upper nonwoven geotextile failed when loaded in the cross-roll direction.

GCL3 failed at the seam when loaded in cross-roll direction whereas partial failure of heat-tacked seam and the upper geotextile was observed when loaded in roll direction. GCL4 consistently failed at the pre-engineered groove when loaded in cross-roll direction and at the heat-tacked seam in roll direction (where there was no pre-engineered groove).

4 CONCLUSIONS

Results of tests carried out to quantify the tensile strength of heat-tacked GCL overlaps for four different GCLs from two different manufacturers were presented. These results were compared with the virgin (i.e., intact) GCL strength. In all but one case, the strength of heat-tacked seam was less than the intact specimen. The virgin specimens also generally exhibited less variability in strength (both in roll and cross-roll direction) than the heat-tacked specimens.

In the cross-roll direction, which represents the critical direction for the majority of overlaps/seams, the greatest heat-tacked strength was obtained for GCL2 and the least for GCL3.

Three different modes of failure were observed for the heat-tacked samples. Tearing of one or both geotextiles adjacent to the seam was observed when the GCL did not fail at the seam. GCLs with pre-engineered grooves failed at the grooves.

Heat-tacking of GCLs that were already once thermally treated were found to develop effective heat-tacked seams and so it appears that heat-tacking is an option for minimizing the risk of seam separation due to shrinkage for all the GCLS tested, but particularly for GCL2 (with the scrim-reinforced carrier and thermal treatment) which exhibited the highest heat-tacked strength.

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REFERENCES

ASTM. 2009. Standard test method for tensile strength of geosynthetic clay liners. ASTM D6768, West Conshohocken, Pa.

Gassner, F., 2009. Field observation of GCL shrinkage at a site in Melbourne Australia. Geotextiles and Geomembranes 27 (5), 406–408. doi:10.1016/j.geotexmem.2008.09.010

Koerner, R.M. & Koerner, G.R. 2005a. GRI White Paper #5 - In-Situ Separation of GCL Panels Beneath Exposed Geomembranes, Geosynthetic Institute, Folsom, PA, April 15, 2005, 21 p.

Koerner, R.M. and Koerner, G.R. 2005b. In Situ Separation of GCL Panels Beneath Exposed Geomembranes, Geotechnical Fabrics Report, June-July 2005: 34-39.

Rowe, R.K. (2011). “Short- and long- term leakage through composite liners”, 2011 Pan-Am and CGS Conference, Toronto, October

Rowe, R.K., Bostwick, L.E. and Thiel, R. (2009). GCL Shrinkage and the potential benefits of heat-tacked GCL seams, Geosynthetics 2009, Salt Lake City, UT, USA.,10-18.

Rowe, R.K., Bostwick, L.E. and Thiel, R. (2010). “Shrinkage characteristics of heat-tacked GCL seams”, *Geotextiles and Geomembranes,* 28(4):352-359.

Rowe, R.K., Quigley, R.M., Brachman, R.W.I., and Booker, J.R. 2004. Barrier Systems for Waste Disposal Facilities, Taylor & Francis / Spon, London, U.K.

Thiel, R. and Richardson, G. 2005. Concern for GCL Shrinkage When Installed on Slopes, GRI-18 at GeoFrontiers, GII Publications, Folsom, PA, USA, paper 2.31.

Thiel, R. and Rowe, R.K. 2010. Technical Developments related to the problem of GCL panel shrinkage when placed below an exposed geomembrane, Proc. 3rd Int. Symp. on Geosynthetic Clay Liners, Würzburg, Germany, September 15-16 2010.

Thiel, R., Giroud, J.P., Erickson, R., Criley, K., Bryk, J. 2006. Laboratory measurements of GCL shrinkage under cyclic changes in temperature and hydration conditions. In: Eighth International Conference on Geosynthetics, Yokohama, Japan, vol. 1, pp. 21–44.

Thiel, R., Thiel, C., February/March 2009. GCL shrinkage – a possible solution. Geosynthetics, 10–21