GCL Shrinkage and the potential benefits of heat-tacked GCL seams

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ABSTRACT

Shrinkage of GCL panels in composite liners left exposed to solar radiation (i.e with no cover soil/ ballast) has resulted in significant separation between initially overlapped panels in a number of field cases reported in the literature. Separations between panels of 200-450mm, and in one case of 1200mm, have been reported. In an attempt to reduce the risk of panel separation, a technique of heat-tacking the overlap between adjacent panels of GCL was employed at a leach pad in Arizona. Exhumation of six mid-slope locations in the field indicated that there was no opening of the panel over-laps at the heat-tacked seams after more than 60 days exposure. This paper reports the results of a laboratory pan shrinkage test as well as tensile tests on seams prepared at this field site. The shrinkage test generated a maximum shrinkage of about 17% in the GCL adjacent to the heat-tacked seam after 40 wet-dry cycles. The same wet-dry cycles generated a tensile stress in the seam corresponding to a 13% tensile strain in the GCL adjacent to the seam. The heat-tacked seam readily withstood this tensile force. The tensile strength of the samples tested was 10-14kN/m. The tensile strength of the sample used in the shrinkage test was controlled by the manufactured groove in the GCL adjacent to the seam and not the seam itself Although additional testing is required to confirm the findings from the tests reported herein, it would appear that the technique of heat-tacking the overlap between GCLs has potential for reducing the risk of shrinkage induced separation at GCL panel overlaps.

1. INTRODUCTION

Thiel and Richardson (2005) first publicly documented the potential problem of shrinkage of geosynthetic clay liners (GCLs) covered by a geomembrane (GM) and left exposed (i.e. with no overlying cover soil). Thiel et al. (2006) summarized six cases where GCL panels, which had reportedly been originally overlapped by 150 mm, had opened up to leave a gap between GCL panels of between 200 and 1200 mm after periods of exposure of between 2 and 36 months. Several laboratory studies (Thiel et al. 2006; Bostwick et al. 2007, 2008) were able to replicate the GCL shrinkage phenomenon and demonstrated that shrinkage of up to 25% could be induced in the laboratory by the application of cyclic wetting and drying. The laboratory work indicated that some products were more susceptible to shrinkage than others. One approach to minimizing the risk of shrinkage is to (a) overlap the panels by 300 mm (as opposed to the previously common 150 mm) and (b) place cover soil on the GM as quickly as possible (within 30 days). However in some large field applications, there is significant cost associated with increasing the amount of GCL in order to double the panel overlap. Also, in these cases, it may be impractical to cover all of the composite liner within less than 30 days. For these situations an alternative approach that would minimize the potential for the opening of the overlap would be highly desirable.

Thiel (2008) recently proposed a novel field approach to addressing the concern regarding separation of GCL panels forming part of a composite liner for a large (60ha) heap leach pad at the Carlota Mine in Arizona, USA (latitude 33^{o}N). The pad was constructed in an alluvium deposit consisting primarily of eroded Pinal Schist, Schultz Granite and Dacite materials. The subgrade upon which the liner was placed was moderately to highly weathered bedrock in the form of a gravelly, silty sand that breaks down during mechanical compaction and surface rolling. The material is of low plasticity and is subject to rapid drying in the local climate. The moisture content (MC) during compaction was 10% to 12% but due to the arid climate, the moisture content dropped off with depth. Depending on the time installed (i.e. proximity to rain events) and the location within the leach pad the subgrade moisture content may have varied between 5% and 20% when the GCL was placed. In some areas a double-nonwoven, needle-punched GCL was used because of its enhanced shear strength, even though this particular GCL experienced the greatest shrinkage in laboratory tests and in field cases where loss of overlap had been observed. In other areas where shear strength was not as critical, a woven-nonwoven, needle-punched GCL (which was slightly less expensive) was used. Each 150 mm GCL panel overlap was heat-tacked with a quick application of a flame torch followed immediately by light pressure (Figure 1). The geomembrane was then placed over the GCL (same day) but it was often 60 days or more before cover soil was placed. To verify that the GCL overlaps had remained intact, the CQA firm cut holes through the geomembrane to exhume the GCL in areas that had been unballasted for more than 60 days. Both the double-nonwoven and the woven-nonwoven GCL products were evaluated. The exhumations were performed at mid-slope in six separate areas of the project between the months of February and June. The air temperature during this period fluctuated from below 0°C to above 32°C. In every instance there was no evidence of any GCL shrinkage and the heat-tacked GCL seam was intact.

The adoption of heat-tacking as opposed to increasing the panel overlap to 300 mm as a means of addressing concerns regarding potential panel overlap separation provided significant savings at the site. However it is unknown whether the lack of observable shrinkage and the lack of separation is fortuitous (i.e. no shrinkage would have occurred in any event) or because the heat-tacking of the overlaps prevented panel separation. In particular the question arises as to whether the heat-tacking of the GCL panels would have sufficient strength to withstand shrinkage of the GCL. To provide some initial insight into this question a series of laboratory pan shrinkage tests were performed using GCL seams heat-tacked and shipped from the Carlota Mine. The tests were conducted such that the shrinkage was perpendicular to the seam and hence would have placed the seam in tension. This paper reports on the initial shrinkage test and a tensile test on a seam from the site.

Figure 1. Installer heat-tacking GCL edge seam with a 150 mm overlap.

2. TEST SPECIMENS

The nonwoven-nonwoven, needle-punched GCL used in this study consisted of two separate, overlapping pieces of GCL which were heat-tacked in the field. During testing, the GCL was wet with an amount of water equal to 60% of the dry unit weight of the sample. Initial properties of the test specimen are summarized in Table 1.

Table 1. Initial Properties of GCL Specimen tested

Test	Initial W/C* (%)	Water added (g)	Final W/C (%)	Dry mass per unit area – seamed product (g/m^2)
A	5.8	255	65.9	4490

* As received from the site

3. METHODOLOGY

3.1 Sample Preparation

Excess material was first trimmed from around the heat-tacked portion of the GCL, leaving a seamed portion approximately 125 mm wide. The seamed GCL sample was then cut to dimensions of 225 mm in the machine direction (MD) by 420 mm in the cross direction (XD), with the seam located directly in the centre. The sample was placed on a 420 mm x 620 mm aluminum baking pan, where it was secured by means of 25 mm wide bar clamps. The total specimen area between clamps was thus 225 mm by 350 mm. The aspect ratio of the sample was chosen to roughly correspond to that used in previous GCL shrinkage tests (Thiel et al. 2006, Bostwick et al. 2008).

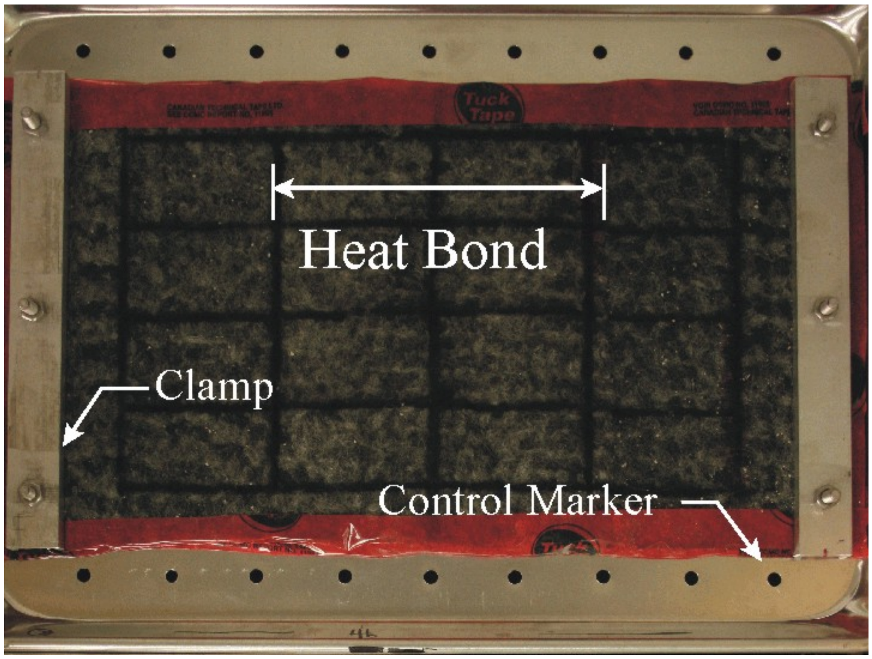

Figure 2. Pan setup immediately before commencement of testing.

Following the methodology of Thiel et al. (2006), a 25 mm border was drawn on all sides of the GCL specimen to enable hand measurements of the dimensions of the sample whilst minimizing edge effects; this resulted in an area of interest of 175 mm by 300 mm. Measurement points were also drawn at quarter points across the sample. All final calculations were based on the distance between border lines, hereafter termed the gauge distance. Moisture barrier tape was used to prevent bentonite loss from the cut edges. Figure 2 shows a pan prior to testing.

Once the sample pan was constructed, initial conditions were recorded. The specimen was then wet, by means of a commercial garden sprayer, with an amount of water equal to 60% of the sample's dry weight. To ensure a uniform spraying technique, the sample was sprayed in a back-and-forth motion, with the nozzle held approximately 50mm from the samples. Following hydration, the sample had a water content of approximately 66%.

Immediately following wetting, the sample was placed in an envelope constructed of moisture barrier tape and clear plastic sheeting to prevent moisture loss. The sample was left in a 20°C room for approximately 8 hours to hydrate. Following this equilibrium period, the sample was placed in an oven at 60ºC and left for 15 hours to dry; this applied heating cycle returned the sample to residual moisture content. This particular drying cycle is based on those used in previous laboratory studies (Thiel et al. 2006, Bostwick et al. 2008).

At the conclusion of the heating cycle, the specimen was removed from the oven and returned to the 20ºC room. Measurements were taken at key locations on the sample; the sample subsequently underwent the wetting process as described above. Handling of the sample required approximately 1 hour, resulting in a 24-hour total cycle length. The testing process was designed such that this wetting/drying cycle was repeated until such time as shrinkage has ceased. The cycle is illustrated in Figure 3.

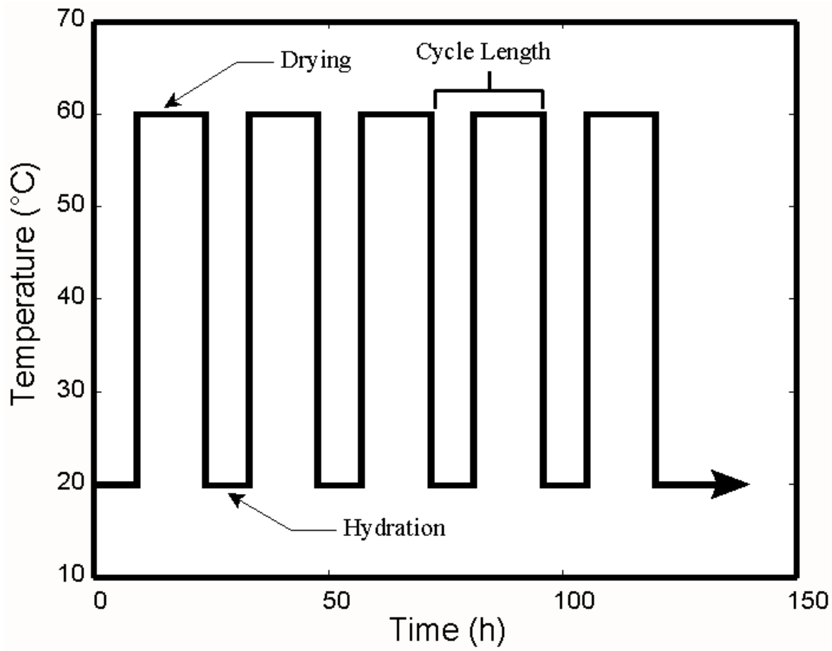

Figure 3. Hydration and Drying Cycles

3.2 Manual Strain Measurement

Initial shrinkage calculations were performed on the basis of daily hand measurements taken immediately following the drying portion of each cycle. The measurements were taken at the quarter points across the width of the sample with only the gauge distance being noted. All measurements were taken to the nearest 1.0 mm and were used to provide an independent check on the more precise measurements obtained using digital image correlation.

3.3 Digital Strain Measurement

Digital image correlation is an image processing technique which enables deformations to be tracked by comparing a series of digital images; in this case, images of the GCL sample at the end of each part of the shrinkage and swelling cycles. Using the GeoPIV code developed by White et. al. (2003), this technique was used to track the cyclic strains of the GCL sample at many locations. Upon completion of testing, fifty-one virtual "patches" measuring 128 x 128 pixels were created along the length of the sample, coincident with the border lines. Using the unique color distribution of each patch (known as the patch "texture"), these locations were then tracked in each subsequent image. By comparing the movement of each patch to that of the one located directly across from it, the cross-sample strain was obtained. This method was also used to approximate the movement of the seam, with patches located at the top edge of the sample and the visible seam edge; this is shown in Figure 4.

Digital photographs were taken with a 10 megapixel digital SLR camera mounted to a specially constructed frame. Photographs were taken twice per cycle: once immediately following the drying phase (but before applying water) and at the end of the hydration period (immediately before the drying phase). To eliminate the effects of small, unavoidable camera or pan movement, the image was calibrated by means of control markers located on the sides of the pan (see Figure 2).

White et al. (2003) have shown that the precision of GeoPIV is typically better than 1/10th of a pixel (White et al. 2003). Photographs analyzed in this paper were taken at a resolution of approximately 0.16 mm per pixel. Therefore, the analysis has an approximate error of 0.016 mm. In terms of strain, the error is dependant on the location of analysis. For cross-sample shrinkage, with a gauge length of 175 mm, the average error is 0.009%. Seam movement, which is measured over a distance of 125 mm, has an approximate error of 0.013%.

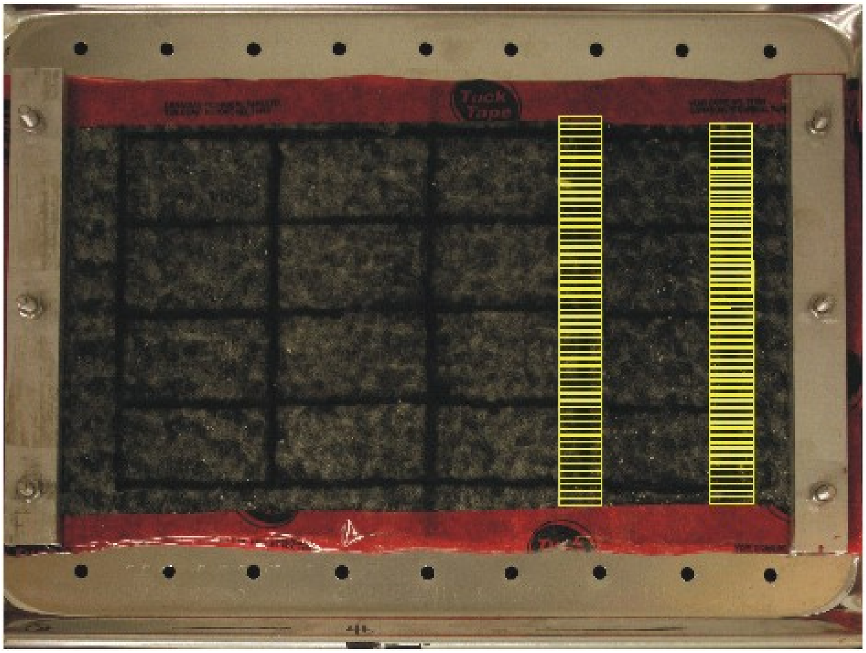

Figure 4. Virtual GeoPIV "patches" used to track seam movement

4. RESULTS

The wet-dry cycling of the testing caused the GCL to shrink across the sample (corresponding to the MD off the roll). As the number of cycles increased, this shrinkage became more pronounced. Figure 5 shows the strain across the middle of the seam versus the number of cycles. As the sample is wetted at the beginning of each cycle the GCL swells, resulting in a positive change in strain. Following drying, however, the sample shrinks, which corresponds to a negative strain. Although each subsequent wetting phase produces a relative positive strain, it is not sufficient to fully counteract the effect of shrinkage; the overall trend is a negative strain. This behavior is consistent with similar studies previously performed (Thiel et. al. 2006, Bostwick et. al. 2007, Bostwick et. al. 2008).

4.1 Location of shrinkage

In previous restrained GCL shrinkage tests, the clamping at each end of the sample caused shrinkage near the middle of the sample, with relatively little shrinkage occurring near the clamps. In this test however, the presence of the seam at the midpoint of the sample restricted strain at that location. The maximum shrinkage strain was observed near the edge of the lower seam – roughly 150mm from the left clamp. This is depicted in Figure 6.

As summarized in Table 2, the shrinkage strain at the centre of the sample was -14.2%, while the shrinkage at the centre seam was found to be 84% of the maximum strain observed on the sample.

Table 2. Summary of absolute maximum and centre strains.

Maximum strain (%)	Strain at centre (%)	Centre strain/ Maximum strain	Location of maximum strain (from left clamp) (mm)
-17.0	-14.2	0.84	150

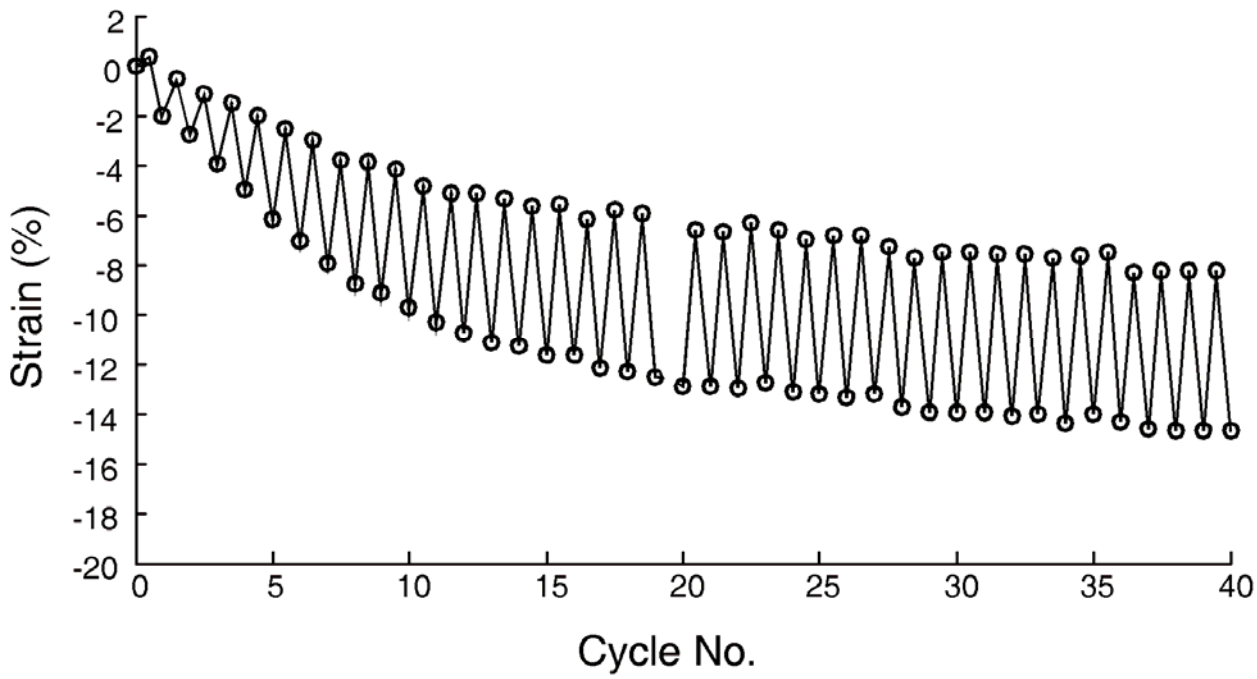

Figure 5. Shrinkage and swelling strain.

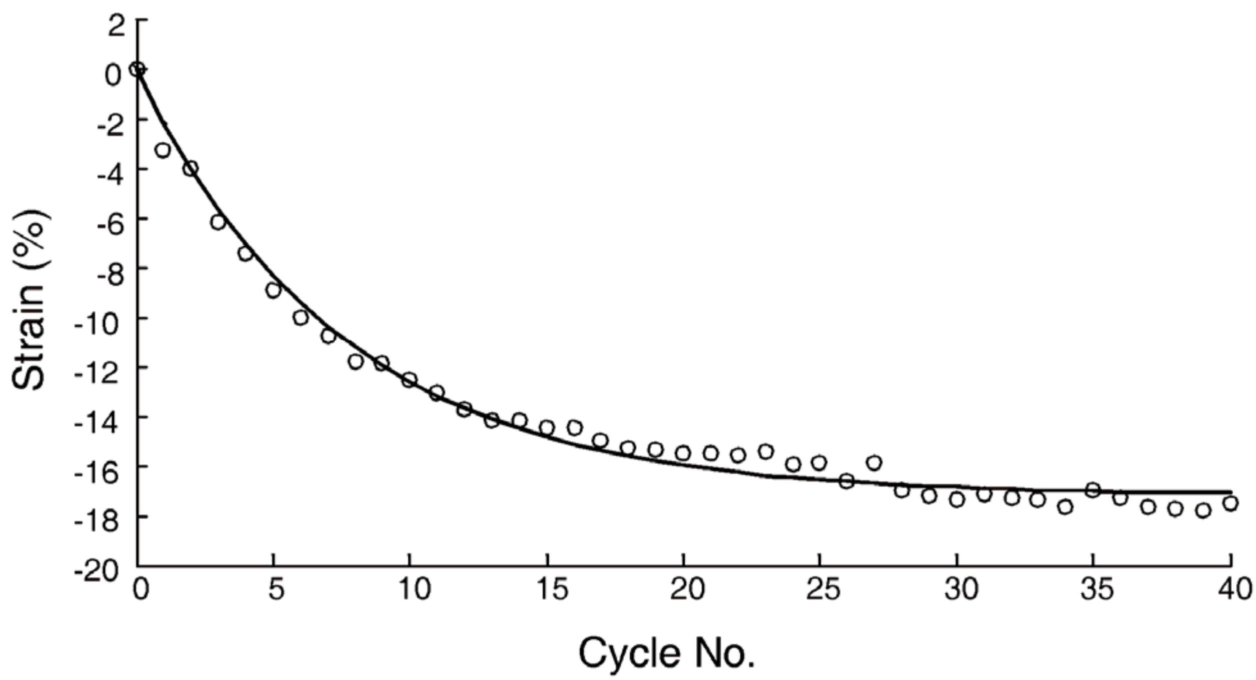

Figure 6. Maximum sample strain.

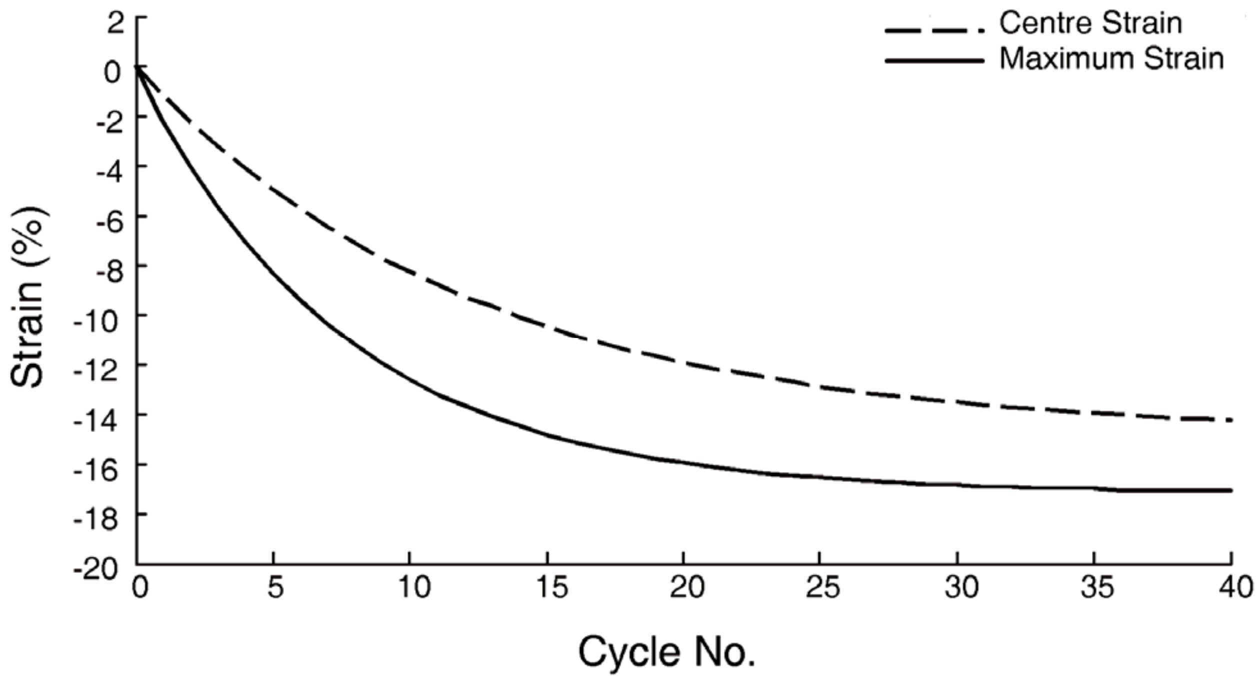

Figure 7. Comparison of maximum shrinkage strain versus that at centre of seam

4.2 Seam performance and strength

Due to the clamping and the arrangement of the samples in the pan, a tensile force was induced perpendicular to the seam as the specimen began to shrink. The tensile strain that developed in the GCL adjacent to the seam, which generated the tensile force on the seam, increased as the number of wet-dry cycles increased. To quantify this strain, the positions of the upper (visible) seam edge and a relatively stationary region near the clamp were compared and expressed as percent strain. These measurement locations are shown above in Figure 4.

As shown in Figure 8, the tensile strain in the GCL adjacent to the seam (which occurs in the cross-machine direction) exhibits similar behavior to the shrinkage between the restrained ends (which represent points of no movement in the GCL such as would, for example, occur at the mid point of each panel in a symmetric panel layout). The degree of shrinkage across the sample and the tensile strain in the GCL adjacent to the GCL seam both increased with the number of cycles.

Following the conclusion of the test at 40 cycles, the sample was removed from the pan and the remaining heat-tack strength was tested as per ASTM D4595. The results (summarized in Table 3) show that the strength of the bond following the wet-dry cycling was greater than the seam strength obtained in two tests on virgin seams. Given the method adopted for forming the seam, some variability in seam strength can be expected and it is not implied that shrinkage necessarily strengthened the seam – but it certainly did not appear to have decreased the seam strength in this case. In the tensile test, the sample failed at the pre-engineered groove at the roll edge (as shown in Figure 9), indicating that the heat-tack had in fact held; hence, it may be inferred that the seam strength was greater than the value indicated in Table 3. In these cases the capacity of the heat-tacking to prevent separation will be controlled by the GCL strength at the groove.

Table 3. Summary of parameters related to seam strength.

Maximum transverse shrinkage (%)	Tensile strain in GCL adjacent to the seam (%)	Tensile strength of sample (kN/m)	Average virgin seam strength (kN/M)	Method of failure
-17.0	13.5	14.0	10.2	Groove

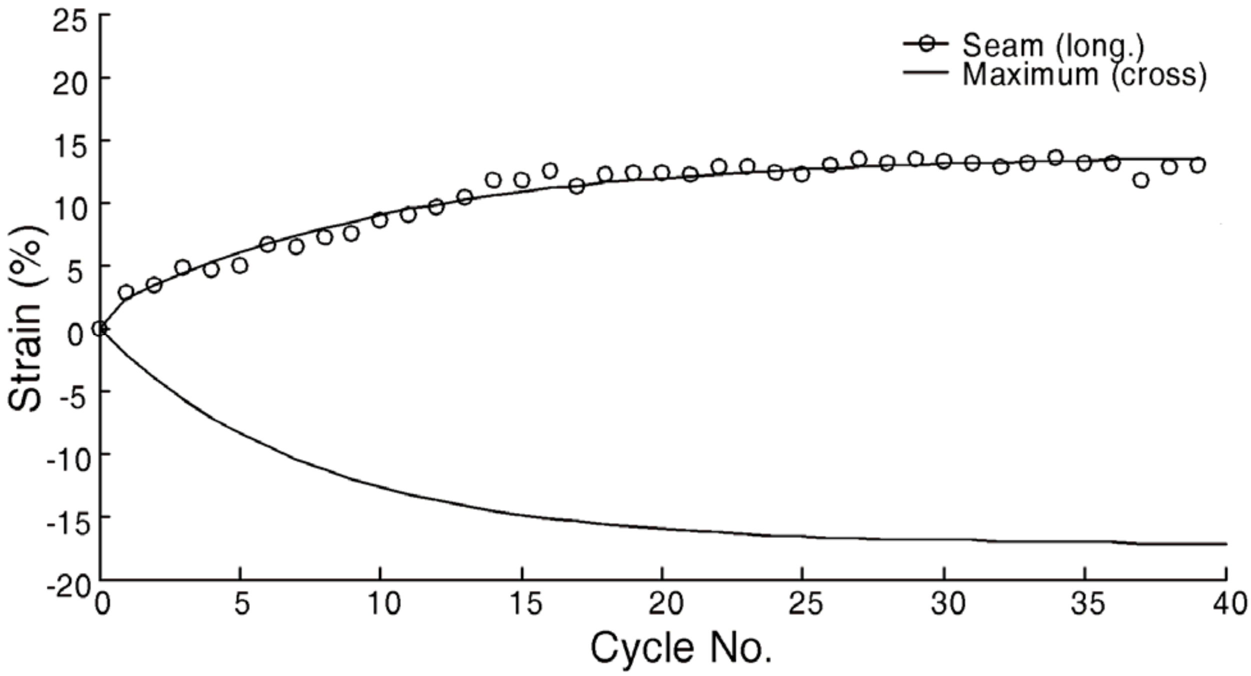

Figure 8. Seam separation as compared to absolute maximum shrinkage.

5. CONCLUSION

A technique for reducing the risk off separation of GCL panels in composite liners left exposed for in excess of 30 days was successfully employed at a leach pad in Arizona. The technique involved heat-tacking of the overlap between adjacent panels of GCL. Exhumation of six mid-slope locations in the field indicated that there was no opening of the panel heat-tacked overlaps after more than 60 days exposure. Samples of the heat-tacked seams from the field site were shipped to the Geoengineering Centre at Queen's-RMC for testing. This paper has reported on the results of a pan shrinkage test on one of these seams as well as the results of two tensile tests on virgin seams and one tensile test conducted on the sample used in the shrinkage test after 40 wet-dry cycles. The shrinkage test was conducted to generate tensile stress on the seam in a small scale simulation of the strain that might develop between the mid-points of GCL panels in a symmetric layout. In the reported tests a maximum shrinkage of about 17% was generated in the GCL adjacent to the heat-tacked seam. The same wet-dry cycles generated a tensile stress in the seam corresponding to a tensile strain of about 13% in the GCL adjacent to the seam. The heat-tacked seam readily withstood the tensile force that was generated. The tensile strength of two virgin seams was about 10kN/m. The tensile strength of the sample used in the shrinkage test (14kN/m) exceeded that of the virgin samples and the tensile failure of this specimen was controlled by the manufactured groove in the GCL adjacent to the seam. Although additional testing is required to confirm the findings from the test reported herein, it would appear that the technique of heat-tacking the overlap between GCLs has considerable potential for reducing the risk of shrinkage induced separation at GCL panel overlaps.

6. ACKNOWLEDGEMENTS

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Figure 9. Tensile failure of specimen by pre-engineered groove.

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