Comparison of field and laboratory measurements of GCL shrinkage

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ABSTRACT: The issue of geosynthetic clay liner (GCL) panel shrinkage and the potential reduction in GCL overlaps when left exposed beneath a black geomembrane reached the open literature in 2005. Idealized laboratory experiments have shown this sort of shrinkage is most likely caused by cyclic wetting and drying. Select results are presented from Queen's field data base on GCL shrinkage which now involves thirteen different configurations for otherwise nominally the same conditions on one particular silty-sand foundation soil with field-scale dimensions, when covered by a black geomembrane, but left exposed and subject to natural thermal cycling. This paper focusses on comparing field and laboratory measured shrinkage for two geotextile-encased GCLs with needle-punching and thermal treatment.

Keywords: geosynthetic clay liner; overlap; shrinkage

1 INTRODUCTION

Theoretical calculations, experimental studies and field measurements (e.g., Bonaparte et. 2002, Rowe et al. 2004, Rowe 2012, Rowe and Abdelatty 2012) all demonstrate that a properly designed and constructed composite geosynthetic liner consisting of a geomembrane (GMB) overlying a geosynthetic clay liner (GCL) can be very effective at limiting leakage. An important part of proper construction is to follow GCL manufacturer recommendations to promptly cover the GMB/GCL liner with at least 0.3 m of ballast (e.g., gravel) such that the GCL does not experience excessive wet/dry cycles from thermal exposure.

If left uncovered, one potential issue that warrants evaluation is whether overlapped seams between adjacent GCL panels remain. Koerner and Koerner (2005) and Thiel and Richardson (2005) documented six cases where initial 0.15-m-overlaps between adjacent GCL panels were lost and a gap ranging between 0.2 m and 1.2 m was observed between the panels. The GCLs were located on slopes in four of these cases, and on a relatively flat base in the other two. They were all covered only by a black geomembrane and left exposed for periods ranging between two months and five years.

Figure 1. Photograph of Queen's University Environmental Liner Test Site (QUELTS) looking north-west during construction.

The objective of this paper is to examine shrinkage of two GCLs, referred to here as GCL1 and GCL2. Both were made with granular Wyoming sodium bentonite and had the same nonwoven needle-punched cover geotextile. GCL1 had a woven slit-film carrier geotextile. GCL2 had a scrim-reinforced nonwoven carrier geotextile, made by needling the nonwoven needle-punched geotextile to the slit-film woven geotextile. Both GCLs were themselves needle-punched and thermally treated. Thermal treatment consists of melting needle-punched fibres from the cover to the carrier geotextile, and has been shown to provide better confinement at low stress than similar non-thermally treated GCLs (Lake and Rowe 2000, Beddoe et al. 2011). The focus of this paper is exclusively on GCL1 and GCL2 as there are no known published cases where their overlaps have been lost. The magnitude of the potential shrinkage of GCL1 and GCL2 obtained from laboratory index tests are compared with their measured shrinkage in the field.

2 LABORATORY SHRINKAGE

Thiel et al. (2006) developed a laboratory index shrinkage test to investigate the impact of wet/dry cycles on the dimensional stability of GCL specimens. In these tests, a known water content cycle was imparted to a GCL specimen and the change in dimension of the specimen was recorded. Their results showed an irrecoverable decrease in specimen width from the accumulation of shrinkage deformation with the number of wet-dry cycles and demonstrated the very important role of moisture cycles on the potential decrease of GCL overlaps. Bostwick et al. (2010) and Rowe et al. (2011a) extended this work by conducting a large number of index shrinkage tests to investigate the effects of specimen size, specimen aspect ratio, specimen restraint, water content, mass per unit area, and GCL type on potential GCL shrinkage under controlled conditions.

Index shrinkage test results for GCL1 and GCL2 are compared in Table 1 for otherwise comparable conditions. These specimens started out at comparable initial moisture contents ranging between 4-7%. The same mass of water was added to each specimen during hydration, but because there were small differences in specimen mass (but all specimens exceed the specified minimum value), the moisture content for the wet part of the cycle varied slightly from 51-59%. The specimens were allowed to hydrate with the added water for 8 hours at 21±1°C and then dried in an oven for 15 hours at 60°C. The shrinkage reported in Table 1 is expressed as the change in width of the specimen upon drying divided by the initial specimen width.

Table 1. Comparison of index shrinkage test results on 350 x 550 mm longitudinally restrained specimens of GCL1 and GCL2 after 40 wet/dry cycles. Data from Rowe et al. (2011a).

GCL	Test designation	Dry Mass (g/m^2)	Water added (% dry mass)	Shrinkage (% of initial width)
GCL1	R-2	5060	51	-10.0
	R-3	4880	53	-10.2
GCL2	R-2	4610	58	-10.8
	R-3	4800	59	-8.4

The two index shrinkage test results on GCL1 were within the range of results from two tests on GCL2. Both experienced less than 11% shrinkage up to 40 wet/dry cycles. Based upon the two replicate tests each reported in Table 1, there appears to be no significant difference between the shrinkage of GCL1 and GCL2 when subject to daily wet/dry moisture cycles where they were hydrated to the same gravimetric water content and then oven dried. However, just because there appears to be no significant difference in laboratory index shrinkage results does not necessarily mean there will be no difference between these two GCLs in the field – largely because of the imposed moisture cycle in the laboratory index shrinkage test. The potential difference is next examined by measuring how much these GCLs shrunk at the same site when left covered only by a black geomembrane in the field.

3 FIELD SHRINKAGE

Queen’s field data base on GCL shrinkage values now involves measurements of thirteen different configurations obtained on otherwise nominally the same conditions on one particular silty-sand foundation soil with field-scale dimensions, when covered by a black geomembrane, but left exposed and subject to natural thermal cycling. These measurements were made at Queen's University Environmental Liner Test Site (QUELTS), which is located 40 km north-northwest of Kingston, Ontario, Canada at a latitude of 44°34'14"N and longitude of 76°39'44"W. It was constructed in September of 2006. Site details have been reported by Brachman et al. (2007). A photograph of the site taken during construction is shown in Figure 1. QUELTS has also been used to: quantify the number, length, width and interconnectivity of wrinkles in a 1.5-mm-thick black high-density polyethylene geomembrane (Rowe et al. 2012); measure the daily and seasonal thermal cycles experienced by an exposed liner in south-eastern Ontario (Take et al. 2014); and investigate the implications of down-slope moisture migration along the interface of an exposed GMB/GCL composite liner (Rowe et al. 2014).

The test site consists of a 22-m-long, 3H:1V, south-facing slope section, and a 20-m-long, 3% gently sloping base section, Figure 2. Initially, it was 76 m wide in the east-west direction and had six different GMB/GCL configurations, where each configuration had three adjacent panels of the same GCL. It was reconstructed in 2012 with seven more test configurations. Test configurations include: GCLs with powdered and granular bentonite; GCLs with nonwoven/woven, nonwoven/nonwoven, and nonwoven/scrim-reinforced-nonwoven upper and lower geotextiles; thermally treated (i.e. needle-punched fibres were thermally fused to the lower geotextile) and non-thermally treated GCLs; a polymer enhanced GCL; a multi-component GCL with a laminate film facing upwards; and a GCL beneath a white geomembrane.

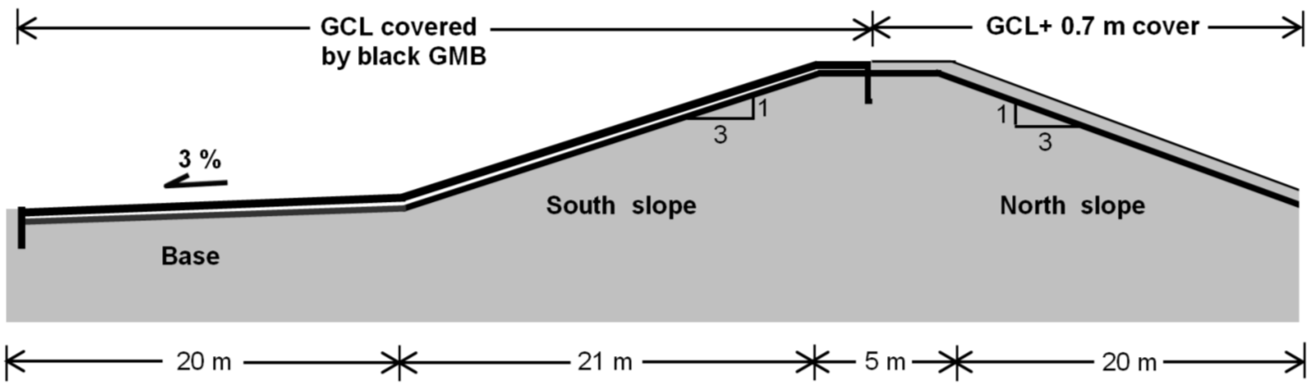

Figure 2. East-west cross section through field experiment.

GCL shrinkage was monitored by installing pairs of metal machine screws on adjacent panels at a spacing of 2 m along every overlap. Figure 3 is a photograph showing the machine screws used to track any movement at the overlap. Any reduction in GCL panel overlap was then obtained by subtracting the separation between the screws measured during periodic inspections (by cutting the geomembrane and exposing the GCL overlap) from the initial offset between the pairs.

Figure 3. Photograph of machine screws used to record movement of GCL overlap. The initial separation between the screws at this location of a GCL2 overlap was 10 cm. This photograph was taken 2.2 years after construction and shows no discernable increase in separation between the two screws since construction.

In terms of field shrinkage of GCL1 and GCL2 when covered only by a 1.5-mm-thick, black, textured geomembrane on the slope, the maximum measured reduction in overlap after 2.2 years of exposure was 250 mm for GCL1 and only 10 mm for GCL2. These correspond to maximum shrinkage strains of -5.3% and -0.2% after 2.2 years for GCL1 and GCL2, respectively. The maximum reduction in overlap was 83% for GCL1 (although no gap had formed) and a negligible 3% reduction for GCL2, both after 2.2 years. Despite having no significant difference between GCL1 and GCL2 from index shrinkage test, there was a significant difference in shrinkage measured between these two GCLs in the field. The remainder of this paper investigates the potential contribution of two factors – moisture retention on daily thermal cycles and the rate of drying – to explain the difference between field and laboratory shrinkage.

4 MOISTURE CYCLE ON DAILY THERMAL CYCLES

One significant difference between conditions the GCL experiences in the laboratory and field is the water content that the GCL attains and the moisture cycle that it may experience when subject to thermal cycles. In the laboratory index shrink tests, daily wet/dry moisture cycles were imposed, where they were hydrated to the same gravimetric water content and then oven dried. However in the field, the GCL gets its moisture from the foundation soil and hence its water content will depend on: the moisture retention characteristics of the GCL, the moisture retention characteristics of the foundation soil, the availability of moisture in the foundation soil, and the thermal exposure conditions.

To get a sense of what the moisture cycle of GCLs 1 and 2 may be when subject to daily thermal cycles, Rowe et al. (2011b) conducted laboratory experiments in 150 mm diameter by 500 mm high containers filled with the same silty sand foundation soil at the average initial field water content of 16% as at QUELTS. With a vertical stress of 2 kPa acting on the GCL, the top thermal boundary condition was subjected to daily 22-60°C cycles, with 12 hours each of heating and cooling. The resulting GCL water contents are plotted in Fig. 4 and show a daily moisture cycle of around 10% for GCL1, but less than 2% for GCL2 with a gravimetric water content of 16% in the foundation soil.

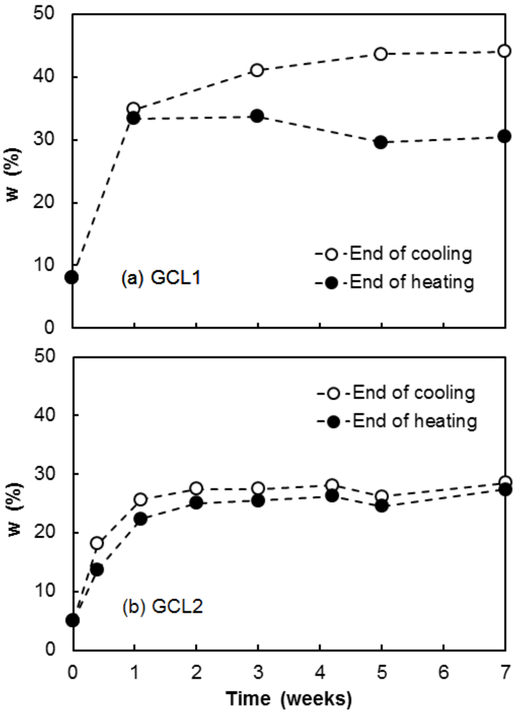

Figure 4. Gravimetric water content, w, of (a) GCL1 and (b) GCL2 when subject to daily 20-60°C thermal cycles and hydrating on a silty sand foundation layer with an initial gravimetric water content of 16%. Modified from Rowe et al. (2011b).

One reason for much smaller shrinkage of GCL2 in the field is that it may be going through less severe daily moisture cycles than GCL1. The most likely explanation for the difference in moisture cycle is that GCLs 1 and 2 have different water retention characteristics (Beddoe et al. 2011). This difference is most pronounced at low suctions (i.e., high water contents), as GCL2 attains a lower gravimetric water content near saturation than GCL1. The difference in water retention arises because the thermal treatment of needle-punched fibres is more effective at providing confining pressure to the scrim-reinforced nonwoven carrier geotextile of GCL2 than the slit-film woven carrier geotextile alone of GCL1.

5 RATE OF DRYING

The effect of the rate of drying on the amount of shrinkage in a laboratory index shrinkage test was examined for GCL1 by cyclically-drying hydrated specimens either: (i) relatively quickly in a scientific-grade forced-air oven, or (ii) much slower when air dried at room temperature. These experiments were conducted on 350 x 550 mm specimens that were restrained in longitudinal direction. Water was added to achieve GCL water contents of 60% or 100% at the end of 8 hour wet cycle at 21±1°C. The oven samples were dried for 15 h at 60°C, while the air-dried samples were placed in a large room for 5 days at 21±1°C.

The transverse shrinkage (i.e., change in width / initial specimen width) at the end of the drying cycle are plotted in Fig. 5. The shrinkage strain on oven drying was around 10% after 10 cycles when dried from either w = 60 or 100% (Figs 5 a & c, respectively). When air-dried, the rate of increase in shrinkage is noticeably greater over the first 5 cycles than oven dried. The shrinkage strain after 10 wet-dry cycles increased to 12 and 17% when air-dried from 60 and 100%, respectively (Figs 5 b & d).

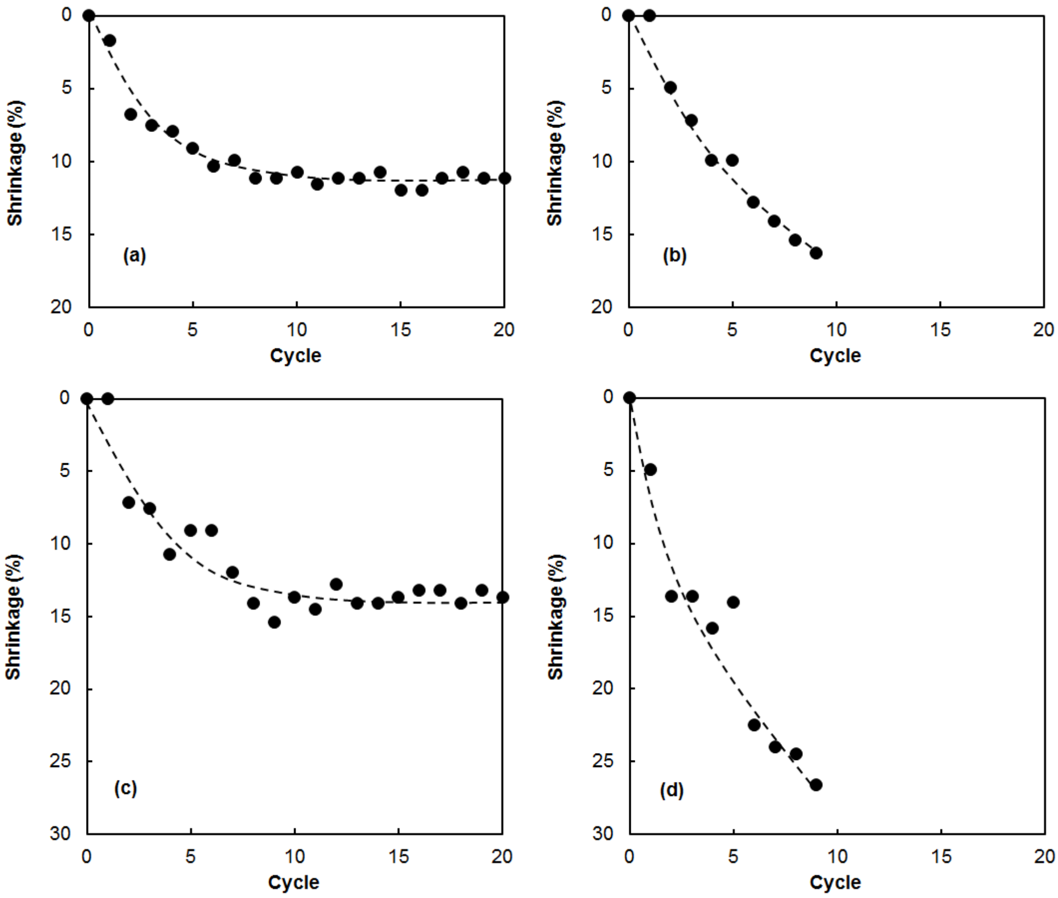

Figure 5. Index shrinkage strain of GCL1 when: a) oven dried from w = 60%, b) air dried from w = 60%, c) oven dried from w = 100%, and d) air dried from w = 100%. Longitudinally restrained specimens.

The difference in the amount of shrinkage may be related to same factors that give a different macrostructure with a slower drying rate as observed by Take et al. (2012). Figure 6 shows X-ray images of GCL specimens oven and air dried from w = 100% (i.e., the specimens used to obtain the data in Figs 5 c & d). The lighter coloured regions in Fig. 6 correspond to attenuated X-rays passing through the bentonite, whereas dark colors correspond to unattenuated X-rays passing through desiccation cracks in between dried bentonite chunks (Take et al. 2009). Air drying results in a macrostructure with larger bentonite chunks that shrink more than the smaller bentonite chunks seen with oven drying.

The shrinkage of GCL1 and GCL2 from air-dried index shrink tests are compared in Fig. 7. These were obtained on 200 x 200 mm unrestrained specimens that were hydrated to water contents of 60 and 100% (for 8 hours at 21±1°C) and then air dried at room temperature (21±1°C) for 5 days. Fig. 7 shows that GCL2 experienced much less shrinkage than GCL1 when air dried from 60 or 100%. GCL2 experienced only 3% shrinkage when air dried from either 60 or 100% (Figs 7 b & d), whereas the shrinkage of GCL1 was 8% when air dried from w=60% (Fig. 7a), and 21% when air dried from w=100% (Fig. 7c). Of particular note, 15% shrinkage was measured for GCL1 after first air-dry cycle from w = 100% in Fig. 7c, compared essentially no shrinkage for the comparable case with GCL2 (Fig. 7d). While there was no significant difference from index shrink measurements when oven dried, the difference between GCLs 1 and 2 is pronounced when air dried. This is again believed to be related to the greater effectiveness of the thermal bonding of the needle-punched fibres to the scrim-reinforced carrier geotextile of GCL2.

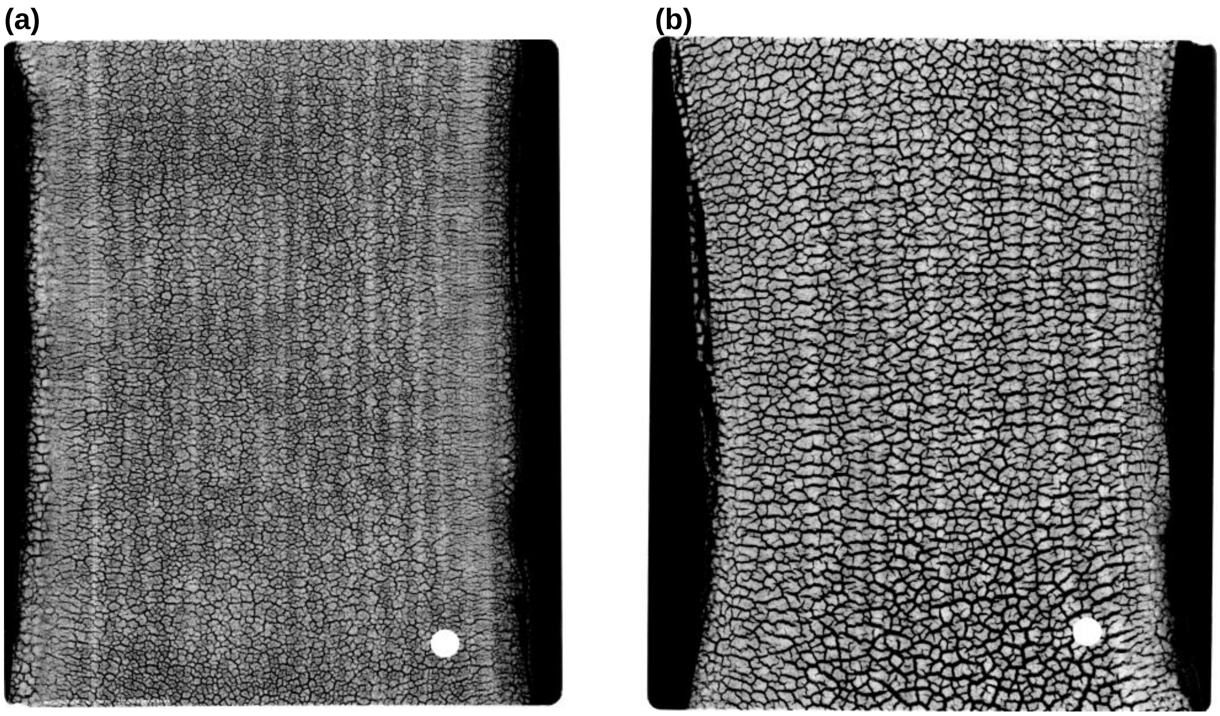

Figure 6. X-ray images of 350 x 550 mm specimens of GCL1 when cyclically (a) air-dried and (b) oven-dried from w=100%.

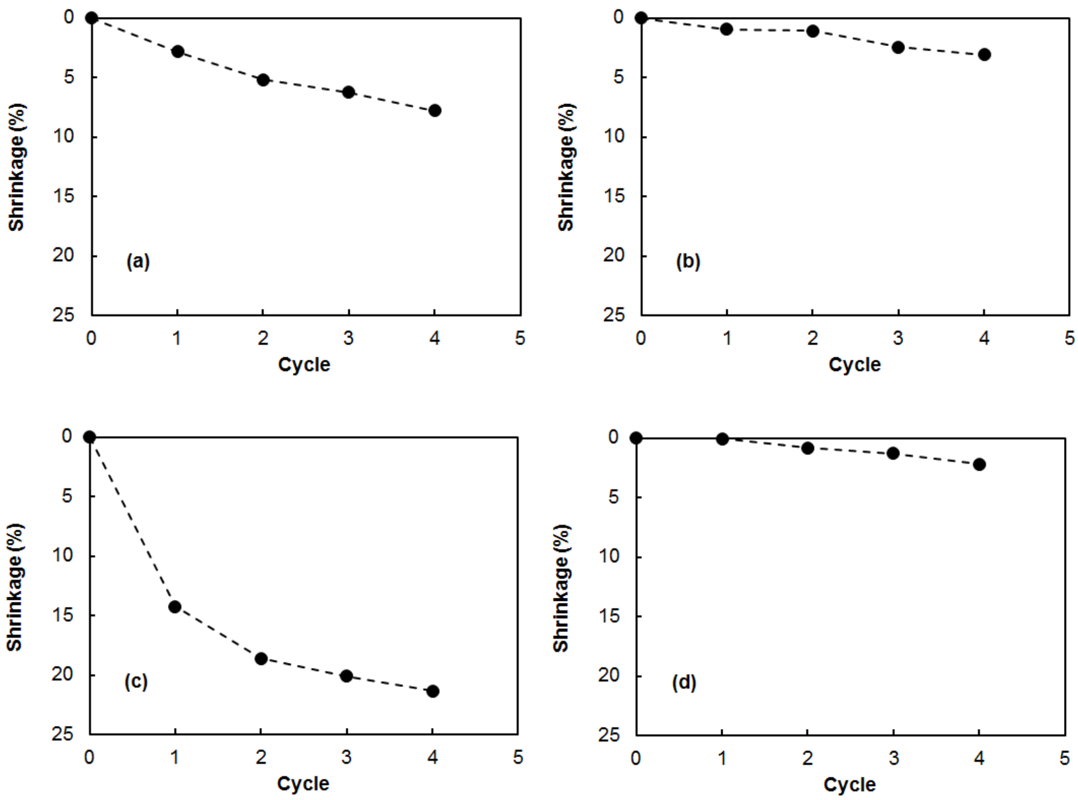

Figure 7. Index shrinkage strain when air dried from w = 60% for a) GCL1 and b) GCL2, and from w = 100% for c) GCL1 and d) GCL2. Unrestrained specimens.

6 SUMMARY AND CONCLUSIONS

Previous results from index shrinkage laboratory tests suggested there was no significant difference between the shrinkage of GCL1 and GCL2 when subject to daily wet/dry moisture cycles where they were hydrated to the same gravimetric water content and then oven dried. However, the findings in the field for these two same GCLs was much different as shrinkage values recorded at the Queen's University Environmental Liner Test Site showed that GCL2 shrunk much less than GCL1 when covered only by a black geomembrane (where the panels were initially overlapped by 300 mm). After 2.2 years of exposure, the reduction in panel overlap of GCL2 was just 10 mm (-0.2% shrinkage and a negligible 3% overlap reduction) while it was 250 mm for GCL1 (-5.3% strain and 83% overlap reduction, although no gap had formed). Differences between the moisture retention characteristics of these two GCLs (arising because of the greater effectiveness of the thermal treatment for GCL2) is one likely reason for the difference in field performance, where suctions in the GCL affect what moisture it attains from the underlying soil and possibly what moisture it retains upon on thermal heating. Under a comparable daily thermal cycle, GCL1 would be expected to experience a larger moisture cycle than GCL2.

Index shrinkage tests were then reported to investigate whether the rate of drying affected the amount of shrinkage when subject to wet/dry moisture cycles. The shrinkage of GCL1 was found to be increased by a factor of nearly two when longitudinally restrained specimens were air dried, rather than oven dried, from gravimetric water content of 100% after only 3 wet/dry cycles. Air drying then showed a pronounced difference between index shrinkage test results on unrestrained specimens of GCL1 and GCL2, where GCL1 was found to have 2.5 to 7 times greater shrinkage than GCL2 when cyclically air dried from gravimetric water content 60 or 100%, respectively.

Prompt covering of the composite GMB/GCL liner with 0.3 m of ballast (e.g., gravel) – which reduces the thermal cycle, reduces the severity of wet/dry cycle, and provides stress – is the simplest way to manage the issue of GCL panel shrinkage. There was no discernable shrinkage after seven years for either GCL1 or GCL2 when buried under 0.7 m of cover soil at Queen's test site. In addition to benefits in terms of overlap stability, cover soil would benefit GCL hydration and macrostructure and reduce the possibility of detrimental effects from moisture migration along the GMB/GCL interface if left uncovered. The results also show that GCL selection can be beneficial to managing shrinkage.

7 ACKNOWLEDGEMENTS

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