"PROTOTYPE MODELING OF GCL HYDRATION AND SHRINKAGE UNDER SIMULATED FIELD CONDITIONS"

As discussed in Thiel (2005) and Koerner and Koerner (2005), concerns have been raised about the potential for in-situ separation of overlapped GCL panels in "exposed" lining systems, where a GCL is left under a geomembrane with no soil cover for several months or years. Under these conditions, there have been some documented instances where overlapped GCL seams were compromised, resulting in gaps between the panels. A common current recommendation in such cases (and one prescribed by regulators in the state of California) is to increase overlaps to 12 inches.

The attached study presents the results of a large-scale experimental model designed to investigate the effect of simulated daily thermal cycles on GCLs under exposed geomembranes. The experiment consisted of a 24 x 16 x 20 in (600 x 400 x 500 mm) plywood box containing silty sand at 17% moisture content. The silty sand was covered with a double nonwoven reinforced GCL (DN type). The GCL sample was uniformly hydrated to 100% moisture content, placed over the soil, and then clamped at both ends (to simulate anchorage in the field). The system was insulated on all sides and sealed at the top with plexiglass. A small air gap of 2 inches (50 mm) was left above the GCL to simulate a geomembrane wrinkle.

To investigate the effect of daily temperature cycles on a GCL under an exposed geomembrane, the top of the box was heated to 60^{o} C for 8 hours and then cooled for 16 hours. This daily thermal variation was repeated over 50 cycles. During the test, the system was monitored using: (1) time domain reflectometers to measure moisture content in the soil; (2) thermocouples to measure temperature; and (3) relative humidity sensors to measure humidity in the air gap above the GCL. No water was added to the system during the test.

As the thermal cycles progressed, the temperatures in the soil increased and the moisture content decreased. Additionally, the air above the GCL gradually dried as the number of heat/cool cycles increased. Digital photographs of the GCL taken at the end of each day's heating cycle showed shrinkage of the GCL. The maximum shrinkage of the GCL at mid-sample was 4.5% after 50 cycles. For a 14.5-ft wide panel, this represents less than 8 inches of shrinkage. The commonly used overlap recommendation of 12 inches for exposed applications would therefore preserve seam integrity under these conditions.

The maximum shrinkage of the GCL at mid-sample (4.5% after 50 cycles) was much less than what was reported in pan tests by Thiel et al (2005) (20% after 10-12 cycles) and Bostwick et al (2007) (7% after 50 cycles). The authors concluded that this difference is partly due to frictional forces from soil underneath the GCL, but primarily due to less hydration of the GCL. Whereas the pan tests involved adding a large fixed volume (500 mL) of water to the GCL during each cooling cycle, the only source of water for the GCL in the attached study was water in the subsoil and in the air gap between the GCL and the geomembrane, which more closely mimics field conditions.

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Prototype Modeling of GCL Hydration and Shrinkage under Simulated Field Conditions

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ABSTRACT
Large scale experimental model was designed to investigate the effect of simulated daily thermal cycles on transient suctions for geosynthetic clay liner (GCL) and identify the relationship between initial hydration and subsequent shrinkage. The model container was constructed using rectangular boxes of Plywood, after trying many different materials and configurations. The model set up includes a soil box with dimensions of 600 × 400 × 500 mm, which was placed inside an insulated external box of 1050 × 800 × 600 mm. Rubber membranes were stretched inside the soil box to prevent leakage of water from the container. The soil container was filled with silty sand at a specified moisture content of 17% above which the GCL was placed. Insulation was placed between the two boxes to prevent the heat loss. A heater blanket system was used to apply heat to the surface and the associated changes to water content and temperature were monitored. Soil temperature and moisture content were monitored with depth using TDR system, the temperature and relative humidity of the air space were monitored using RH sensors, and the GCL deformations were monitored using high resolution photography.

1. INTRODUCTION

Geosynthetic clay liners (GCLs) are most typically comprised of a layer of low permeability clay (bentonite) sandwiched between two layers of geotextile (a nonwoven, cover geotextile and a woven, nonwoven or scrim reinforced nonwoven carrier geotextile) with the components being held together by needle-punching. GCLs are often used as part of composite liners with a geomembrane liner (high density polyethylene, HDPE) placed over the GCL. These composite liners have gained widespread acceptance for use in landfill and other liner applications such as heap leach pads.

The composite liner may remain exposed for a period of time (weeks to years depending on landfill operation) before being covered. Field cases have been reported where, after two months to five years exposure to solar radiation, upon removal of part of the geomembrane the GCL panels had been found to have shrunk in the width-wise direction leaving gaps between panels ranging between 200 mm and 1200 mm where there had initially been 150 mm overlaps (Thiel and Richardson, 2005; Koerner and Koerner, 2005, and Thiel et al. 2006).

Thiel et al. (2006) conducted tests on 60cm by 30cm GCL samples placed in aluminum baking pans and clamped at the two ends. The samples were then subjected to up to 40 cycles of heating (to 60^{o}C) and cooling (to room temperature) together with wetting during the cooling cycle. They indicate considerable shrinkage of the GCL as a result of the cyclic wetting and drying. Bostwick et al. (2007) investigated the shrinkage of a non-scrim reinforced GCL with different sizes exposed to a series of applied heating and hydration sequences in a temperature controlled room. They reported that, in comparing samples of a similar aspect ratio but different sizes, size did not play a significant role in either the rate or the magnitude of GCL shrinkage over the period of testing examined. However the question arises as to the effect of potential interaction between the GCL and the subsoil. The objective of the present research is to investigate the effect of simulated daily thermal cycles on transient suctions for the GCL on subsoil and identify the effect of foundation soil on shrinkage of the GCL under simulated field conditions. This paper reports on the test methodology and the first test conducted.

2. MATERIAL PROPERTIES

A nonwoven/nonwoven needle-punched GCL (DN type) containing granular sodium bentonite was used for this testing. This product was selected because it had previously exhibited the largest observed shrinkage in the field and the largest shrinkage in the laboratory tests conducted by Thiel et al. (2006). The initial moisture content of the GCL at the time of testing was about 5% and the mass per unit area of the GCL was 4615 g/m^2.

Soil from the Queen's composite geosynthetic liner experimental field site located in Godfrey Ontario (Brachman et al, 2007) was used as foundation soil to allow future comparison of the laboratory experimental results field data. The particle size distribution of the soil and the granular bentonite (extracted from the GCL) obtained using ASTM D422 are given in Figure 1. This data indicates that the soil is a silty-sand with 40% passing the 0.075 mm sieve. The fines were non-plastic. A series of Standard Proctor compaction tests (ASTM D 698) indicated that the maximum dry density of the soil was about 1.83 g/cm^3 at an optimum water content of 11.4% (Figure 2).

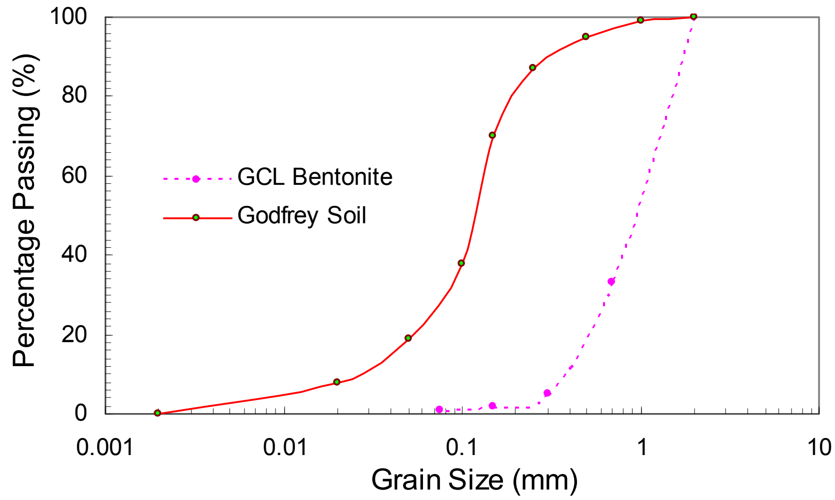

Fig. 1: Grain size distribution of DN GCL and foundation soils

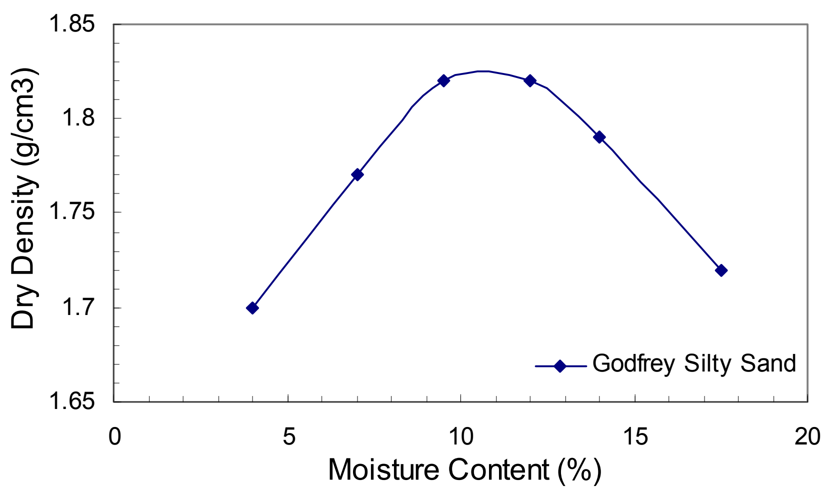

Fig. 2: Compaction curve for Godfrey foundation soil

3. EXPERIMENTAL PROGRAM

3.1 Model Container

The test cell was designed to enable potential 2D shrinkage of the GCL to be observed. The model set up involved a plywood box with dimensions of 550 × 400 × 500 mm, which was placed inside an insulated external box of 1050 × 800 × 600 mm (Fig. 3). Rubber membranes were used to line the inside of the box to prevent leakage of water from the container.

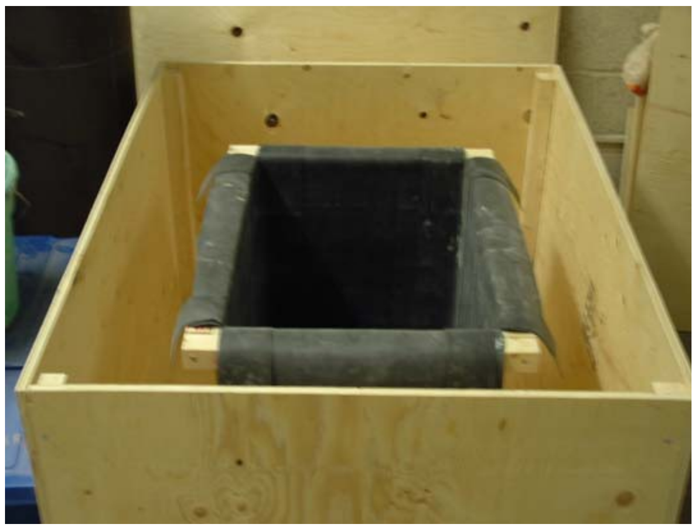

Figure 3: The big-box experimental container

3.2 Model Preparation

Bulk samples of Godfrey site soil were mixed with water to bring its water content to 17%, which corresponds to the average moisture at the Godfrey field test site. After mixing was completed, the mixture was covered with a plastic wrap and allowed to cure for 24 hours. The soil container was filled with the soil which was compacted in nine layers to a dry density of 1.65 g/cm^3, sealed, and allowed to come to moisture equilibrium (Fig. 4).

Figure 4: Sample preparation by tamping of soil layers

The GCL sample was cut to a dimension of 600 mm in the machine direction by 390 mm in the cross-machine direction and hydrated to the moisture content of about 100 % under free swell. To ensure the uniform distribution of moisture content of the GCL the water was sprayed consistently over the sample with the help of hand sprayer. The wet sample was wrapped in a plastic bag for approximately 24 hours at 20ºC to allow for proper hydration and equilibration of moisture content throughout the GCL. Markers were put on the GCL to monitor the changes in dimensions during hydration and shrinkage. To eliminate edge effects, a 25 mm border was drawn around the outside of each sample. The GCL was then, placed on top of the soil and restrained in the “long-direction” using a continuous bar clamp screwed to the container wall (Fig. 5). This clamping is intended to simulate the fact that GCLs are laid out in long panels in the field and most GCL installations include anchorage at both ends. A headspace of 50 mm was imposed on top of the GCL to investigate the role of wrinkles on potential post-hydration shrinkage, and the behaviour of the GCLs observed under thermal cycling.

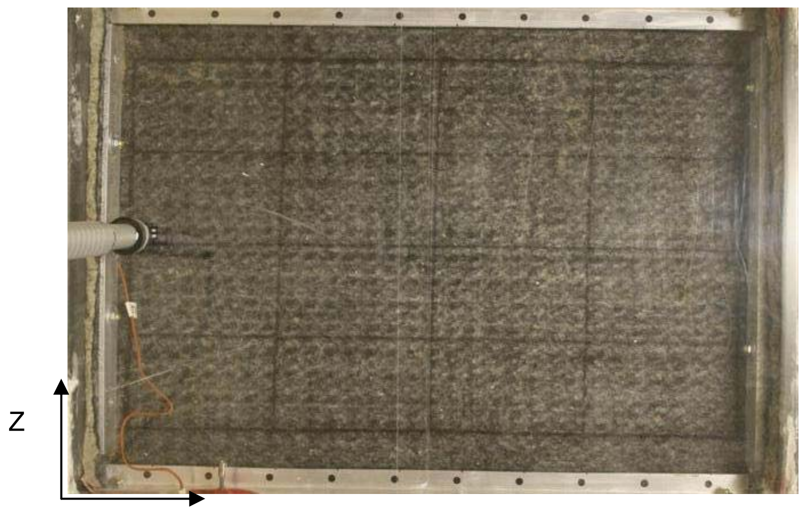

Figure 5: Installation of GCL in the big-box model

Three types of instrumentation were used to monitor the test: (i) Time Domain Reflectometers (TDR) were used for measuring moisture content in the soil, (ii) thermocouples were used for measuring temperature, and (iii) Relative Humidity (RH) sensors were used for monitoring the relative humidity of the air above the GCL. The TDR equipment consisted of a Campbell Scientific CR1000 data logger, TDR100 system, five SDMX50 50Ω coaxial multiplexers, and nine CS635 TDR probes. These waveguide probes consist of three 75mm long rods which were placed within the soil bed at predetermined locations (Table 1). Care was taken to ensure proper contact between the probe rods with the surrounding soil mass during the insertion process, as air filled gaps can have a significant effect on the calibration relationship (e.g. Siddiqui et al, 2000). TDR reading was performed during installation of the probes to verify proper performance of the instruments. The RH sensor (VAISALA HMP45A) was positioned to measure the relative humidity in the headspace on top of the GCL. Figure 6 shows the details of the instrumentation.

Table 1: Location of TDR probes and thermocouples placed within the soil

TDR Probes	X (mm)	Y (mm)	Z (mm)	Thermo-couple	X (mm)	Y (mm)	Z (mm)
TDR1	275	200	25	TC15	250	200	25
TDR2	275	200	50	TC16	250	200	50
TDR3	275	200	75	TC17	250	200	75
TDR4	275	200	100	TC18	250	200	100
TDR5	275	200	150	TC19	250	200	150
TDR6	275	200	225	TC20	250	200	225
TDR7	275	200	325	TC21	250	200	325

TDR8	275	200	425	TC22	250	200	425

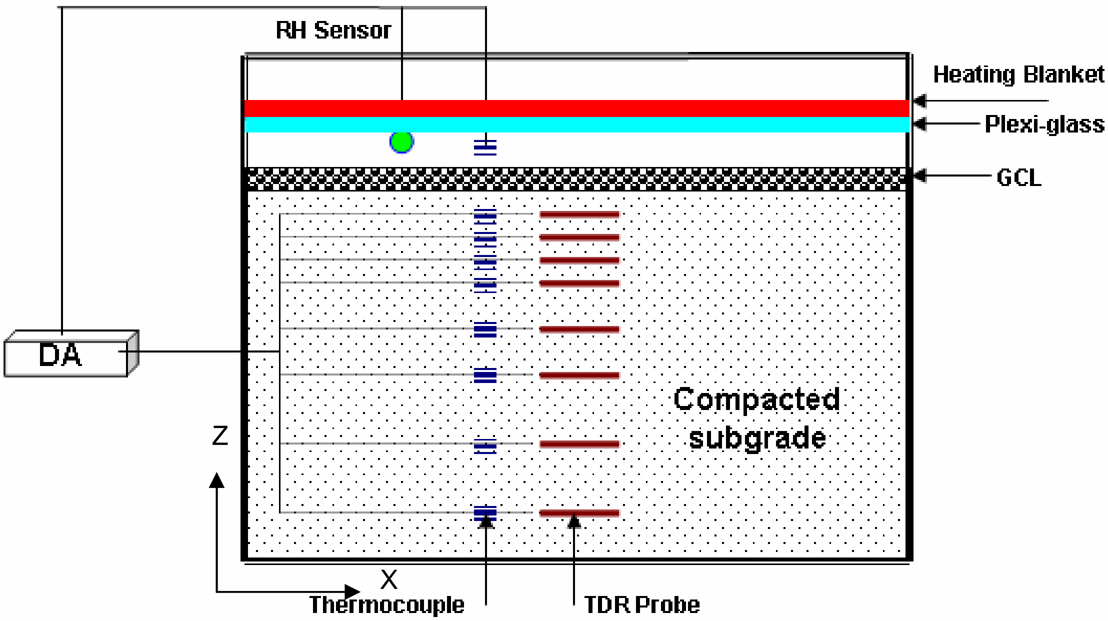

Figure 6: Schematic instrumentation details of the big-box model

To prevent shrinkage of the GCL from exposing the soil along the sides, a plastic cover was placed between the soil and GCL extending 35 mm from each of the sides. The system was sealed with plexi-glass on top of the soil box. Figure 7 shows the Styrofoam insulation around the soil box used to ensure essentially one dimensional heat and moisture flow in the soil. The insulation layer was about 200 mm thick at each side and on top of the soil box. The bottom of the box was placed on a concrete floor with a relatively constant temperature. The model was left at room temperature for about two weeks to allow moisture equilibration prior to the heating cycles.

Figure 7: Insulation details around the soil box in the model

3.3 Testing Procedure

To investigate the effect of daily thermal cycles, the temperature controller was programmed to generate cycles realistic to Canadian landfill construction (20–60ºC), whilst the bottom of the cell was kept at a constant lower temperature to simulate the thermal gradients that develop in the field. Heat was applied to the surface using the heating blanket system. The heater blanket brought the top of the box to about 60^{o}C. Heat was applied for 8 hours and the box was allowed to cool for 16 hours.

3.4 Digital Photogrammetry

Digital photographs were taken using an 8 megapixel digital SLR camera mounted to the top of the big–box (850 mm). A variable focal length lens with the disabled flash setting was employed to create uniform light conditions across the GCL. Photographs were taken at the end of the heating cycle by means of a remote program every day.

Shrinkage calculations were performed using GeoPIV (Particle Image Velocimetry), a digital photogrammetry technique developed by White et al (2003). The measurement system creates a series of “patches” on the images and calculates the displacement of the patches relative to their positions on the initial image. Using GeoPIV, “virtual strain gauges” were created along the length of the GCL and these were used to establish the strain distribution by dividing the width of the sample at each “strain gauge” at given time by the initial width at the same point and expressed as percent shrinkage.

4. RESULTS

4.1 Temperature Profile

Thermocouples were placed at eight different depths in the foundation soil to track the temperature profile in the soil. Figure 8 shows the temperature profile at the end of both the heating and cooling cycle for first, 25th and 50th cycle. The temperature profile appears to move toward higher temperature as the number of cycles increased. The initial temperature was about 23^{o} C. The temperature of the concrete at the bottom of the box appeared to accumulate some heat during the test and thus the temperature of the soil near the bottom of the box increased from 23^{o} C at the start of the test to abut 30^{o} C after 50 heat/cool cycles. During the heating cycle, the temperature at the top of the soil increased to about 60^{o} C. The rate of increase in temperature decreased with depth.

4.2 Moisture Content Profile in Subsoil

Eight TDR probes were installed in subsoil to measure the moisture content of the soil during heat/cool cycles at different depths. The volumetric moisture content profile inferred from the TDR measurements is shown in Figure 9. In general the volumetric moisture content profile moves toward lower water contents as the number of cycles increased. The initial average volumetric water content was about 29%. The average volumetric water content at depths above 150 mm decreased to about 23% after 50 heat/cool cycles. The moisture content at the bottom of the box decreased from 29% to about 26% during heat/cool cycles. There was no cracking or drying evident in the foundation soil.

4.3 Relative Humidity in Air Gap

Relative humidity and temperature in the air gap above the GCL are shown in Figure 10 for all heat/cool cycles. Relative humidity in the air gap appears to decrease with increasing temperature during the heating period, and increases during the cooling time. The peak relative humidity was about 99% at the beginning of first heat/cool cycle, which decreased to about 93% at the end of 50th cooling cycle. at the low point of the relative humidity during the heating periods, decreased from about 29% at first cycle to about 22% at last heating cycle. This indicates that the air above the GCL gradually dried as the number of heat/cool cycles increased.

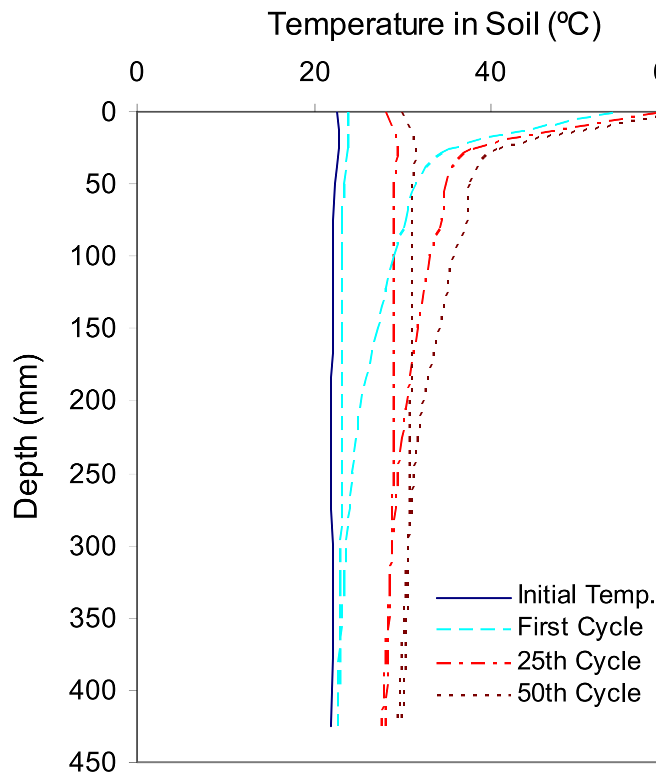

Figure 8: Temperature profile for heat/cool cycles in subsoil

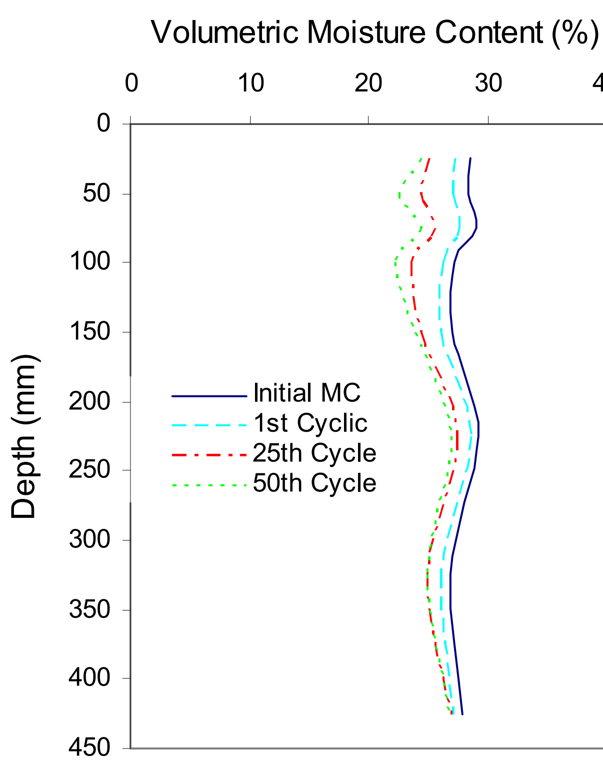

Figure 9: Volumetric moisture content profile in subsoil for heat/cool cycles

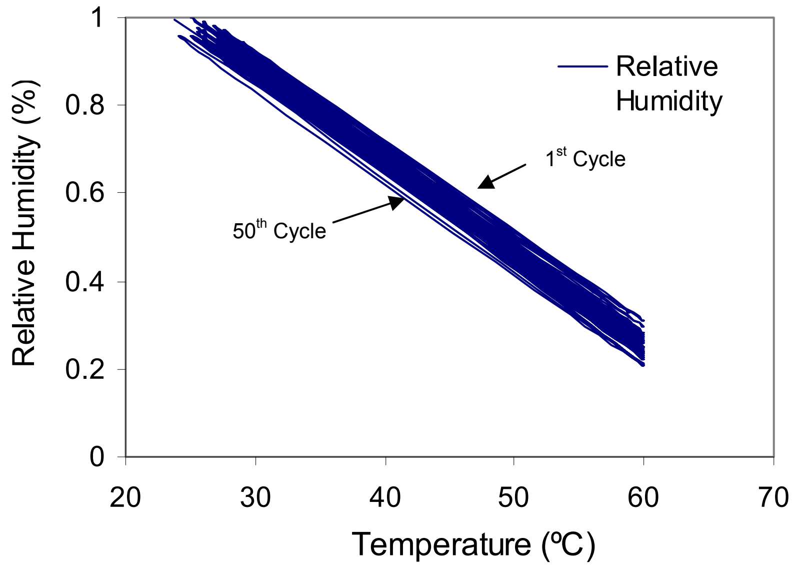

Figure 10: Relative humidity versus temperature on top of the GCL in air gap above the GCL during heat/cool cycles

4.4 GCL Shrinkage

The maximum shrinkage of the GCL occurred near the midpoint of the sample, while the strain at the ends was minimal as clamping prevented the GCL from moving at these locations. As it can be seen from Figure 11, the maximum strain of the GCL was about 4.5% after 50 cycles of heating/cooling, which equates to about 200 mm reduction in panel width for a typical panel width of 4.5 m. The maximum strain reached 4% after 15 heat/cool cycles; the accumulation of shrinkage strain was much slower for the remaining 35 cycles.

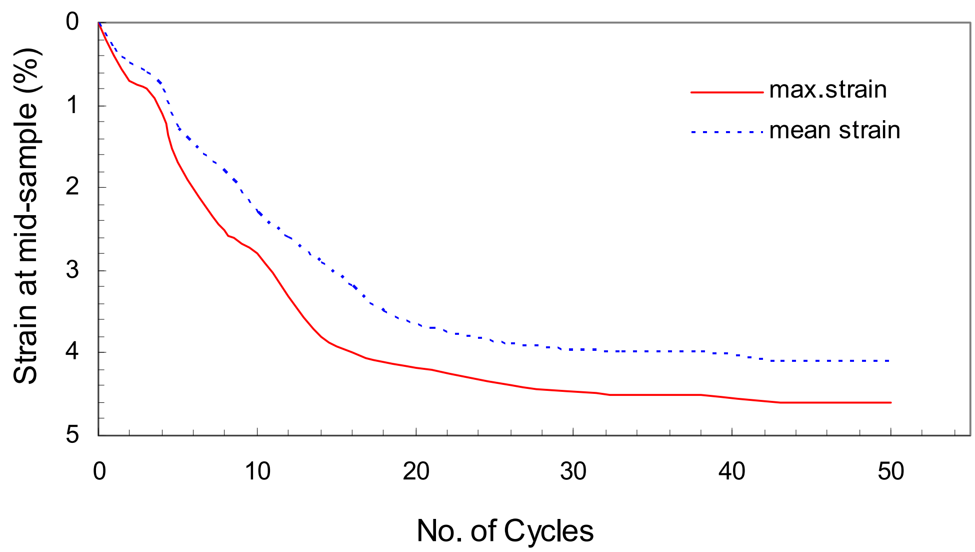

Figure 11: GCL strain at mid-sample at the end of heat/cool cycles

Previous laboratory tests of GCL on a smooth pan exposed to heating cycles of 40ºC (from room temperature to 60°C) reported by Botswick et al. (2007) had a maximum strain about 7% for the same GCL. Thus the frictional forces from soil beneath the GCL may be a factor influencing GCL shrinkage.

5. CONCLUSIONS

The physical model experiment reported in this paper appears to be able to simulate daily thermal cycles similar to the field conditions. TDR probes and RH sensors were shown to provide reasonable data that could be used to evaluate the moisture content profile in the soil and relative humidity and temperature in the air gap above the GCL. Cyclic heating and cooling conditions was found to cause shrinkage in GCL sample. However, the maximum shrinkage of the GCL at mid-sample was much less than what reported by Thiel at al (2006) and Botswick et al. (2007) in pan tests. This difference may be partly due to frictional forces from soil beneath the GCL. However the difference is probably primarily due to the lesser hydration of the GCL that could be achieved during cooling cycles when the only source of water for the GCL was that which could be taken up from the air and subsoil as it cools, as compared to the substantial water added in each cooling cycle in the pan tests. This issue is being investigated in further tests.

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