Waste Management 33 (2013) 67–73

Contents lists available at SciVerse ScienceDirect

Waste Management

journal homepage: www.elsevier.com/locate/wasman

Hydration of geosynthetic clay liners from clay subsoil under simulated field conditions

Tahmineh Sarabian, Mohammad T. Rayhani *

Dept. of Civil and Environmental Engineering, Carleton University, Ottawa, Canada K1S 5B6

ARTICLE INFO

Article history:
Received 14 November 2011
Accepted 19 August 2012
Available online 11 September 2012

Keywords:
Geosynthetic Clay Liners (GCLs)
Hydration
Clay subsoil
Thermal cycles

ABSTRACT

Use of Geosynthetic Clay Liners (GCLs) in landfill barrier design has been the focus of recent studies investigating their ability to prevent contaminant transport to groundwater. In this paper, the hydration of two GCL products placed in contact with clay subsoils at different initial moisture contents is described under both isothermal conditions at room temperature, and daily thermal cycles. The rate of hydration of the GCL and its final equilibrium moisture content were significantly influenced by the amount of moisture made available to it through the subsoil. The two types of GCLs were also found to exhibit different hydration behaviors under similar experimental conditions. The study revealed that GCLs undergoing daily thermal cycles absorbed much less moisture over time than the GCLs kept at constant room temperature (ratio 1:4). In comparison with other types of subsoils, the final equilibrium moisture content attained by the GCL from clay subsoil was significantly less than that for sand subsoil.

1. Introduction

Geosynthetic Clay Liners (GCLs) have been the focus of recent studies for their low hydraulic conductivity and ability to act as a barrier, in settings where transportation of contaminants is a concern. GCLs are widely used as environmental protection barriers in waste containment facilities, canals, surface impoundments and underground petroleum storage tanks. Typically, GCL consists of a layer of bentonite sandwiched between two layers of needle punched or stitch bonded geotextile fibers. After placement, the GCL absorbs pore water from underlying soil, swells and creates an effective hydraulic barrier to transportation of contaminants.

The hydraulic performance of a GCL is influenced by several factors, such as the bulk void ratio of the bentonite (Petrov et al., 1997), the degree of hydration (Rowe, 2005), and the self-healing behavior of bentonite used in GCLs (Babu et al., 2001). Insufficient GCL hydration was reported to cause high leakage rates through GCLs (e.g. Melchior, 1997). The rate of hydration of GCL from the underlying subsoil has received very little attention. Daniel et al. (1993) and Eberle and von Maubeuge (1997) have reported limited data on GCL hydration from sand subsoil. The type of bentonite (Bouazza et al., 2006) and the method of GCL manufacture (Beddoe et al., 2011; Rayhani et al., 2011) were shown to influence the GCL hydration. Chevrier et al. (2012) reported that the equilibrium moisture content of the GCL, from a sand subsoil, slightly decreased as the confining pressure increased from 7 to 28 kPa. The subsoil grain size distribution and initial moisture content were also shown to significantly affect the GCL hydration (Rayhani et al., 2011; Anderson et al., 2011). The GCL hydration from a clayey sand (SC) subsoil was slightly less than that for a poorly graded sand (SP) (Anderson et al., 2011).

The hydration behavior discussed above provides information for the case where the GCL is covered by a leachate collection system that protects the liner from exposure to thermal cycles. The liner, however, may be left exposed to solar radiation for a period of time (weeks to years depending on the situation) before being covered (Thiel et al., 2006). Therefore, it is important to consider the effect of thermal cycles on the degree and rate of hydration of the GCL during installation when the GCL is exposed. Rowe et al. (2011) and Anderson et al. (2011) have shown that daily thermal cycles significantly affected the hydration of GCL from sand subsoils.

In landfill applications, GCL is often used on materials with low permeability such as clays and silts to reinforce hydraulic barriers. To date there is no data in the literature examining GCL hydration from these fine grained soils under field conditions. Without a full understanding of the hydration behavior and subsequent hydraulic performance of the GCL, there are uncertainties for all GCL designers, manufacturer and users about the performance of GCLs used in a wide range of applications. Thus, this paper aims to investigate GCL hydration from a clay subsoil under both isothermal conditions, and when subjected to thermal cycles. The effect of the GCL manufacturing process, the initial moisture content of the subsoil and daily and seasonal thermal cycles on the degree of hydration of the GCL from underlying clay are described. The GCL

---

* Corresponding author.
E-mail address: mrayhani@connect.carleton.ca (M.T. Rayhani).

0956-053X/$ - see front matter © 2012 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.wasman.2012.08.010

hydration behavior on a clayey soil is also compared to the behavior on sandy soils based on data from previous studies (Anderson et al., 2011; Rowe et al., 2011).

2. Material properties

2.1. GCL

Two GCL products from two different manufacturers in North America were used in this study (GCL1 and GCL2 in Table 1). Both GCLs consisted of an essentially air dry, sodium bentonite (montmorilonite content of 50–58%) sandwiched between polypropylene geotextile layers. GCLs with montmorilonite content of less than 30% may lead to insufficient hydration and swelling (Guyonnet et al., 2009). The polypropylene fibers in the geotextile layers were held together as a composite material by the needle punching manufacturing process. The average dry reference mass per unit area of GCL1 was less (4377 g/m^2) than that of GCL2 (5275 g/m^2). The average initial thicknesses of the GCLs (as received from the manufacturer) were about 6 mm and 8.5 mm for GCL1 and GCL2, respectively. GCL1 contained fine grained bentonite with D_{50} of about 0.35 mm, while GCL2 contained coarse granular bentonite with D_{50} of 1.0 mm. The plasticity index of bentonite was measured at about 216% for GCL1 and about 262% for GCL2 according to ASTM D 4318. The cation exchange capacity of the bentonite was slightly higher for GCL2 (103 milliequivalents (meq) per 100 g of dry clay) compared to GCL1 (78 meq/100 g). The cation exchange has shown to deteriorate the hydraulic performance of GCLs used in landfill cover systems (e.g. Benson et al., 2007). The water retention curves for both GCLs were also different as measured by Beddoe et al. (2011) using high capacity tensiometers and capacitance relative humidity sensors. They reported that the screen reinforced, thermally treated GCL (GCL1) achieved a fully hydrated state at a lower moisture content and a much lower bulk void ratio than GCL2.

2.2. Subsoil

Fine grained soil from the foundation soil at the Navan Landfill in Ottawa was used as the subsoil for the experiments. The grain size distribution of the subsoil, obtained according to ASTM D 422 hydrometer test is given in Fig. 1a. The plasticity index of the soil was measured at about 22% based on ASTM D 4318 Atterberg test. As noted, the soil can be classified as low plastic clay (CL) in the USCS classification system (ASTM D 2487). The maximum dry density of the soil was obtained, using the standard proctor compaction test (ASTM D 698), as 1.43 Mg/m^3 at the optimum gravimetric water content of 28% (mass of water/mass of solids). The soil water retention curve was inferred based on the soil grain size distribution and saturation moisture content, using the data point function in Geo-Slope program (Geo-Slope International Ltd., 2007) (Fig. 1b).

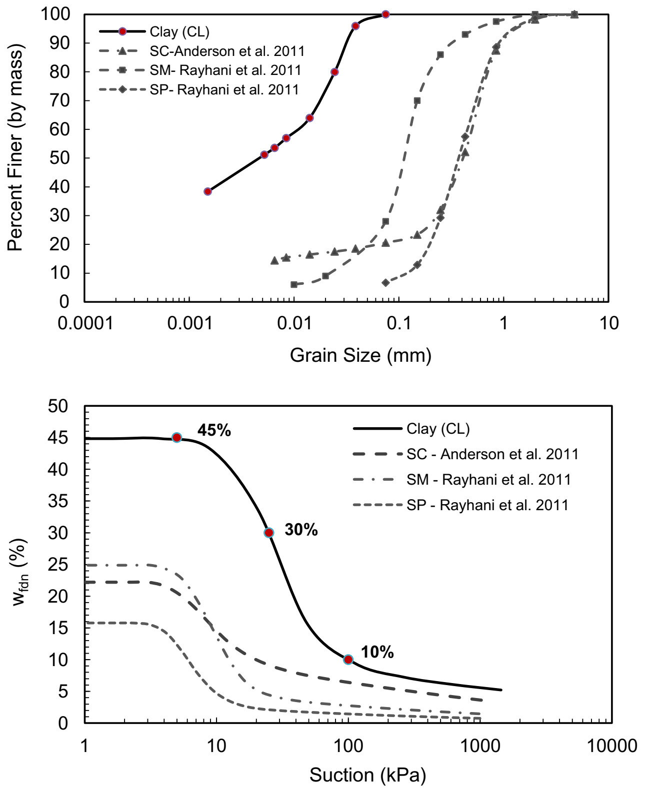

Fig. 1. (a) Grain size distribution and (b) Inferred water retention curve for the subsoil examined (w_{fdn} is subsoil's gravimetric moisture content; SC, clayey sand; SM, silty sand; and SP, poorly graded sand).

Table 1
Index properties of GCLs examined.

GCL properties		GCL1	GCL2
Mass/area	Avg. dry mass/area (g/m^2)	3965	5375
Carrier	Type	SRNW	W
	Avg. mass/area (g/m^2)	240	125
Cover	Type	NW	NW
	Avg. mass/area (g/m^2)	210	270
Structure	Interlocking	NPTT	NP
	Avg. peel strength (N)[a]	260 ± 17	204 ± 35
Bentonite	Aggregate size (mm) D_{50}	0.35	1.0
	Liquid limit (%)	265	334
	Plasticity index (%)	216	262
	Swell index (ml/2 g)[a]	24	23
	Montmorilonite content (%)[b]	50–55	53–58
	Cation exchange capacity (meq/100 g)[a]	78	103

W = Woven, NW = Nonwoven, SRNW = Scrim reinforced nonwoven, NP = Needle punched, NPTT = Needle punched and thermally treated.

[a] Tests performed by M. Hosney, Queen's University.

[b] Data from Bostwick L.E. (2010).

3. Experimental program

3.1. Sample preparation

Polyvinyl chloride (PVC) cells 150 mm in diameter and 300 mm in height were used to simulate a typical composite liner profile in the lab. This profile consisted of 250 mm of subsoil compacted to a specific moisture content, a GCL, a geomembrane, and a steel block to provide 1 kPa of normal stress on the GCL (Fig. 2). The subsoil moisture contents modeled in the experimental cells consisted of a moisture content close to the average moisture content present in the field (65%), a moisture content near saturation (45%), a moisture content close the optimum moisture content (30%) and a moisture content near the residual moisture content (i.e., near the wilting point) (10%) (Fig. 1b).

The dry clay samples were manually mixed with tap water having an average calcium concentration of 40 mg/L (similar to that reported by Rayhani et al. (2011) and Anderson et al. (2011)) to bring their moisture contents (w_{fdn}) to 10%, 30% and 45%. The subsoil was compacted using a compaction hammer into the PVC cylinders to a dry density of 1.36 Mg/m^3 (95% maximum dry density), sealed to provide a closed-system (i.e. constant mass of moisture within the cell), and left for 24 h to achieve moisture equilibrium before the GCL specimen, measuring 150 mm in diameter, was

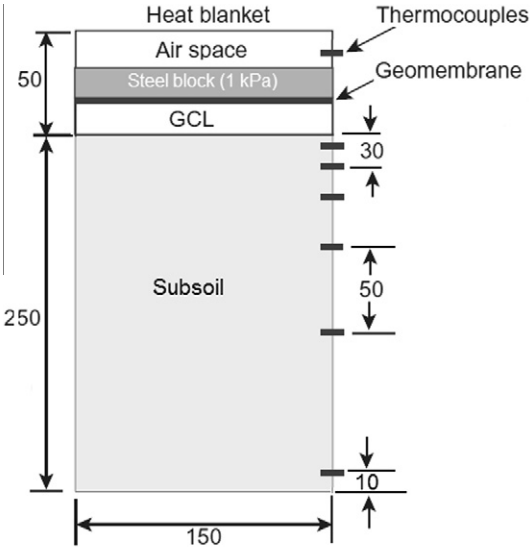

Fig. 2. Configuration of instrumented test cells used for simulating GCL hydration from subsoil (numbers in mm).

placed on top of the soil. The initial moisture contents and mass per unit area for each GCL specimen are presented in Tables 2 and 3. A series of tests with undisturbed subsoil samples at an initial moisture content of 65% was also conducted in order to study GCL hydration on subsoil with moisture content close to the average moisture content present in the field. After GCL placement, a geomembrane was also placed on top of the GCL to minimise potential evaporation into the headspace above the GCL. A 15 mm thick steel seating block (1 kPa) was placed over the geomembrane in order to maximise the contact between the GCL and the subsoil. The conditions simulated in these experiments represent the case of an exposed composite liner in a typical landfill construction.

4. Experimental procedure

GCL hydration was investigated under both isothermal conditions (Table 2) and when subjected to thermal cycles in an insulated box (Table 3). For isothermal conditions, the composite liner profiles constructed in PVC cells were simply kept at room temperature (23 ± 2 °C). The test cells were opened on a weekly basis to measure the moisture content of the GCL and track the evolution of hydration with time over a 5 month period. The GCL specimens were temporarily removed for a short period of time (less than 5 min) in order to measure their thickness and mass, for a short period of time (less than 5 min), and then returned to the cell.

For cyclic heating experiments, the test cells were placed in a thermally isolated box, surrounded with styrofoam insulation and heated at the top using a heating blanket system to provide one-dimensional thermal and moisture migration conditions. To study the effect of thermal cycles on GCL hydration, the temperature controller was programmed to generate temperature cycles similar to those observed for a geomembrane exposed to solar radiation (23–60 °C). The bottom of the cell was kept at a constant room temperature to simulate the thermal gradients that normally develop in the field. For each daily thermal cycle, the test cells were heated for approximately 8 h up to a temperature of 60 °C, and the cells were then allowed to cool for 16 h. The temperatures on top of the GCL and within the subsoil were measured using thermocouples. A typical cycle of the applied daily thermal boundary conditions is shown in Fig. 3. The applied temperature is the temperature measured in the air space above the GCL, and the thermal response of the subsoil is shown at depths of 10, 60, 150, and 240 mm. As shown in Fig. 3, the temperature in the air space above the GCL was increased to 55–60 °C, while the temperature at the bottom of the cells was kept at room temperature (23 °C). Similar to the isothermal experiments, the cells were opened weekly to measure the moisture content of the GCL test specimens.

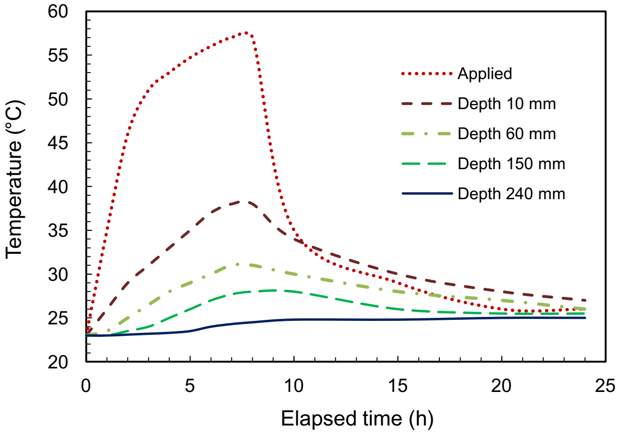

Fig. 3. Applied temperature and temperature profile in subsoil at the end of the cycles (subsoil initial moisture content, w_{fdn} = 30%).

5. Results and discussion

The moisture content of the GCL increased from its initial moisture content until equilibrium in moisture migration between the subsoil and the GCL was achieved. Tables 2 and 3 show the GCL moisture uptake over time in both the isothermal conditions experiments and the thermal cycling experiments, respectively. Figs. 4–9 show different aspects of the variation in GCL moisture content with time as discussed below.

The hydraulic performance of a GCL in a barrier system depends, among other parameters, on the degree of saturation of the bentonite in the GCL. The maximum moisture content, to which the GCL is likely to hydrate when immersed in water (w_{ref}), was measured at 118% (±5%) for GCL1 and 190% (±10%) for GCL2. Thus the degree of saturation of GCL1 at 80% gravimetric moisture content would be much higher (w/w_{ref} = 68%) than that for GCL2 at the same gravimetric moisture content of 80% (w/w_{ref} = 42%). Therefore both the gravimetric moisture content (w) and the normalized hydration (w/w_{ref}) of the GCLs are used when comparing the hydration performance of the two GCL products (Tables 2 and 3).

5.1. Influence of subsoil moisture content on GCL hydration

Fig. 4 shows the GCL moisture uptake from clay subsoil at four different initial moisture contents (10%, 30%, 45%, and 65%). As discussed earlier, these subsoil moisture contents ranged from near wilting point moisture content up to the saturation and field moisture contents. The hydration of GCLs from the underlying subsoil was highly dependent on the initial moisture content of the subsoil. Both the ultimate moisture uptake and the rate of hydration increased with increasing subsoil moisture content. At an initial subsoil moisture content close to the field moisture content (w_{fdn} = 65%), there is significant uptake of moisture by both GCLs and after 20 weeks GCL1 and GCL2 appeared to be approaching equilibrium at a moisture content of 86–106%. For an initial subsoil

Table 2
GCL hydration data under isothermal conditions.

GCL type	Subsoil	GCL	GCL moisture content (w)			Normalized GCL moisture content [a] (w/w_{ref})		
	Initial moisture content (%)	Total air dry mass/unit area (g/m^2)	Initial (%)	After 1 week (%)	After 20 weeks (%)	Initial (%)	After 1 week (%)	After 20 weeks (%)
GCL1	10	4280	4.2	13.2	47.7	3.6	11.2	40.4
	30	4165	4.9	18.5	60.7	4.1	15.7	51.4
	45	4338	5.6	25.8	76.3	4.7	21.9	64.7
	65	4093	4.9	35.2	86.3	4.1	29.8	73.1
GCL2	10	5508	5.7	14.7	48.4	3.0	7.7	25.7
	30	5305	5.7	25.7	58.6	3.0	13.5	30.8
	45	5440	5.7	26.0	84.1	3.0	13.7	44.3
	65	5186	5.7	36.3	105.9	3.0	18.9	55.7

[a] w_{ref} (mean, standard deviation, sd) : GCL1 (118%, 5%), GCL2 (190%, 10%).

Table 3
GCL hydration data under daily thermal cycles.

GCL Type	Subsoil	GCL	GCL moisture content (w)			Normalized GCL moisture content[a] (w/w_{ref})		
	Initial moisture content (%)	Total air dry mass/unit area (g/m^2)	Initial (%)	After 1 week (%)	After 6 weeks (%)	Initial (%)	After 1 week (%)	After 6 weeks (%)
GCL1	10	4602	5.6	7.5	8.9	4.7	6.3	7.5
	30	4359	5.6	10.9	14.2	4.7	9.2	12.0
	45	4461	5.6	14.0	20.3	4.7	11.9	17.2
	65	4721	5.6	15.6	21.5	4.7	13.2	18.2
GCL2	10	5065	5.2	7.0	7.8	2.7	3.7	4.1
	30	5310	5.2	8.4	9.4	2.7	4.4	4.9
	45	5010	5.2	9.3	13.5	2.7	4.9	7.1
	65	5378	5.2	10.7	13.0	2.7	5.6	6.8

[a] w_{ref} (mean, standard deviation, sd) : GCL1 (118%, 5%), GCL2 (190%, 10%).

moisture content of 45%, the moisture content of GCL1 increased to about 76% (w/w_{ref} = 64%) at equilibrium, while the equilibrium value was about 84% (w/w_{ref} = 44%) in GCL2. At an initial subsoil moisture content close to the optimum (w_{fdn} = 30%), GCL1 and GCL2 increased to equilibrium values of about 60 and 59% (w/w_{ref} = 50 and 31%), respectively. For the case with w_{fdn} = 10%, the equilibrium moisture content was similar for both GCLs ranging from 47% to 48%.

The rate of hydration of the GCLs was also affected by the initial moisture content of the subsoil. The rate of hydration for GCLs placed over the subsoil at 10% initial moisture content was less than those placed in contact with subsoil at higher initial moisture contents. At an initial subsoil moisture content of 10%, the GCLs moisture uptake was about 13–15% after 1 week, which is much less than that reached for GCLs when placed on subsoil with initial moisture content of 65% (35–36%) (Fig. 4). These results indicate that the availability of moisture for hydration plays an important role on the rate and equilibrium moisture uptake of GCLs.

5.2. Impact of the GCL manufacturing process on hydration

The method of GCL manufacture could influence the swelling characteristics of the GCL during moisture uptake and, hence, the hydraulic performance of a GCL in a barrier system by controlling the level of constraint between the carrier and cover geotextiles (Lake and Rowe, 2000; Rayhani et al., 2011; Beddoe et al., 2011). Fig. 5 compares the equilibrium moisture uptake for GCL1 and GCL2 from subsoil with different initial moisture contents. Despite the fact that both GCLs had a fairly similar uptake of gravimetric moisture (Fig. 5a), the degree of saturation (w/w_{ref}) was quite different for the two GCLs examined (Fig. 5b and Table 2). GCL1 achieved much higher (40–73%) normalized moisture contents (w/w_{ref}) for all initial subsoil moisture contents. The maximum normalized hydration of GCL2 (w/w_{ref}) ranged from 26–56% for all subsoil moisture contents, which is about 15–20% less than that for GCL1. This could be attributed to the method of manufacture of the GCLs. Both GCLs contained bentonite with similar swelling characteristics (Table 1). However, the carrier geotextiles and the level of constraint provided by the needle punching were different for the two GCLs. The woven thermally treated scrim-reinforced carrier geotextile in GCL1 provided effective anchorage (peel strength 260 N, Table 1) and hence limited the maximum moisture content when immersed in water (w_{ref} = 118%) and provided less void ratio and better hydration performance. The anchorage of needle punched fibers in GCL2 was probably less effective (peel strength of 204 N, Table 1) in constraining the maximum moisture uptake (w_{ref} = 190%). This finding is consistent with those reported by Rayhani et al. (2011) and Anderson et al. (2011) for GCL hydration on sand.

5.3. Effect of soil type on GCL hydration

Previous studies on the hydration of GCLs in contact with three different subsoils (poorly graded sand, SP; silty sand, SM; clayey sand, SC) showed that the highest moisture uptake was achieved by the GCL in contact with a poorly graded sand subsoil (Anderson et al., 2011; Rayhani et al., 2011). This was mainly considered to be related to the greater difference in suction between the sand and the GCL (Fig. 1b), allowing quicker moisture uptake from the sand than the silty sand and clayey sand. Fig. 6 compares the hydration response of GCL1 from four different subsoils (SP, SM, SC, and CL) at 10% initial moisture content. The equilibrium gravimetric moisture content of GCL1 for the three sandy subsoils (SP, SM, and SC) ranged from 79–88%, while this value was only 48% for the clay subsoil (CL) at 10% initial moisture content. As shown in the water retention curves of these soils illustrated in Fig. 1b, the initial suc-

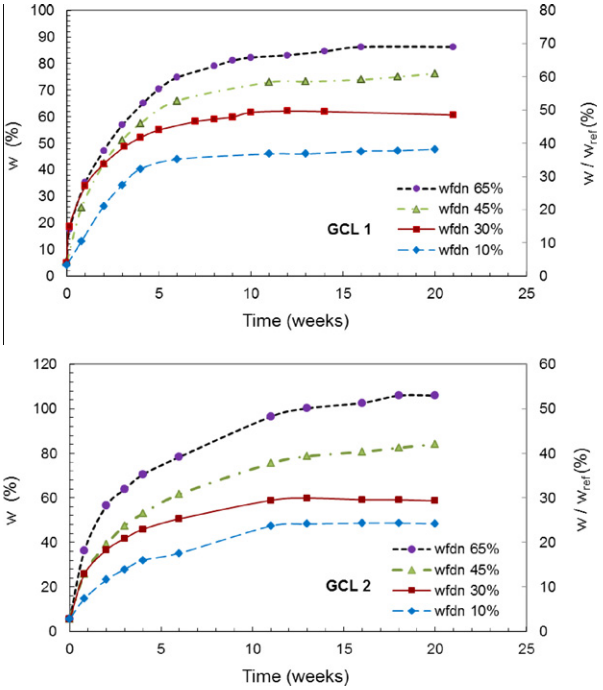

Fig. 4. GCL hydration under isothermal conditions: (a) GCL1 and (b) GCL2 (w_{fdn} = subsoil initial moisture content).

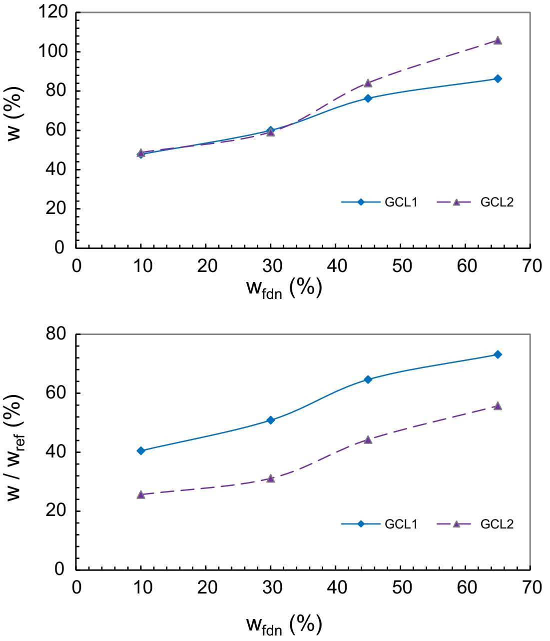

Fig. 5. Equilibrium moisture uptake for both GCLs over all subsoil moisture contents (w: gravimetric moisture content; w/w_{ref}: normalized moisture content).

tion in the clay was much higher than that in the other three subsoils. Thus the difference in suction between the clay and the GCL, at the GCL-subsoil interface, is much less than that for the sand subsoils, and therefore the equilibrium moisture content of GCL over clay was lower.

The rate of hydration of GCL from the clay subsoil was also slower than that for the other sandy subsoils (Fig. 6). After 1 week of hydration, GCL1 reached about 13% gravimetric moisture

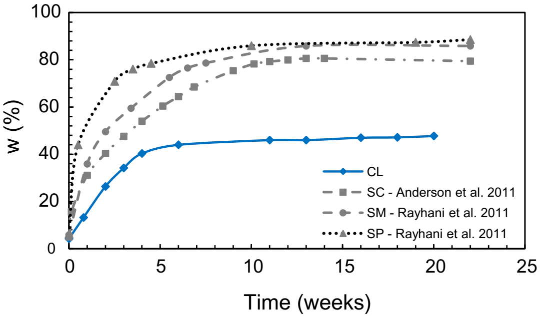

Fig. 6. Hydration response of GCL1 from different subsoils at w_{fdn} = 10% initial moisture content (SC, clayey sand; SM, silty sand; and SP, poorly graded sand).

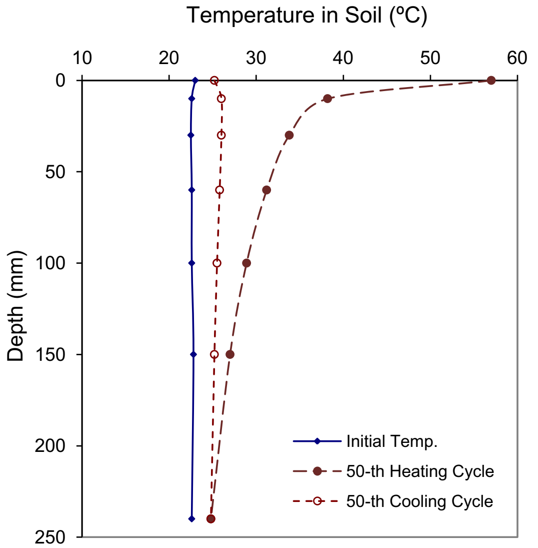

Fig. 7. Temperature profile in subsoil at the end of the heating and cooling cycles (subsoil initial moisture content, w_{fdn} = 30%).

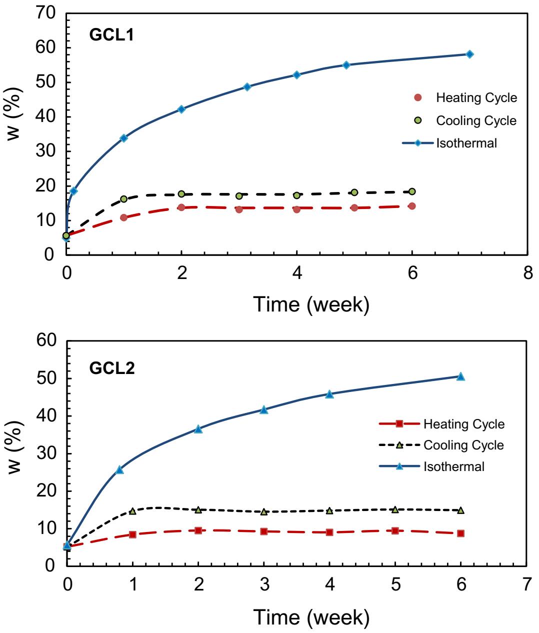

Fig. 8. Effect of daily thermal cycles on GCL moisture uptake (subsoil initial moisture content, w_{fdn} = 30%).

Table 4
Comparison of GCL moisture content for hydration with daily thermal cycles and under isothermal conditions.

GCL	Subsoil	GCL Moisture content (%)			Normalized GCL moisture content[a] (w/w_{ref}) (%)		
	Initial moisture content (%)	Thermal cycles	Isothermal		Thermal cycles	Isothermal	
		6 weeks (Equilibrium)	6 weeks	Equilibrium	6 weeks (Equilibrium)	6 weeks	Equilibrium
GCL1	10	8.9	44.0	47.7	7.5	37.3	40.4
	30	14.2	55.5	60.7	12.0	47.0	51.4
	45	20.3	66.2	76.3	17.2	56.1	64.7
	65	21.5	74.8	86.3	18.2	63.4	73.1
GCL2	10	7.8	35.2	48.4	4.1	18.5	25.7
	30	9.4	50.6	58.6	4.9	26.6	30.8
	45	13.5	61.6	84.1	7.1	32.4	44.3
	65	13.0	78.4	105.9	6.8	41.3	55.7

[a] w_{ref} (mean, standard deviation, sd): GCL1 (118%, 5%), GCL2 (190%, 10%).

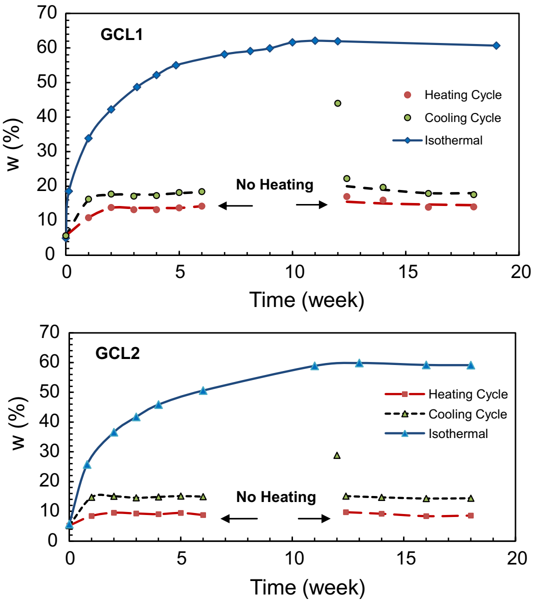

Fig. 9. Effect of seasonal cooling cycles on GCL moisture uptake (w_{fdn} = 30%).

content on the clay subsoil at 10% initial moisture content, while the moisture uptake from the other subsoils (SC, SM, SP) ranged from 31% to 44% for the same period. This difference is also attributed to the difference in the water retention curves of the subsoils. The higher suction supplied by the clay subsoil is reflected in the slower rate of hydration of the GCL.

5.4. GCL hydration under daily and seasonal thermal cycles

The initial temperature and the temperature profile within the subsoil at an initial moisture content of 30% are shown in Fig. 7 after 50 heating cycles. It is apparent from this figure and Fig. 3 that the majority of the daily thermal change occurs in the upper 100 mm of the soil, indicating that the height of the cells was sufficient to capture the daily thermal response of the soil profile. The subsoil temperature change at the bottom of the cell was relatively small with an increase of only 2 °C from the initial conditions.

Fig. 8 illustrates the moisture uptake of the GCLs at an initial moisture content of 30% when subjected to daily thermal cycles. For comparison purposes the results of these tests are plotted together with the corresponding results for similar conditions at room temperature. GCL1 (Fig. 8a and Table 3) gradually increased in moisture content until it reached its equilibrium moisture content of 14% after 6 weeks of applied daily thermal cycles. In contrast, under isothermal conditions the moisture content of this GCL increased to 55% after 6 weeks and eventually an equilibrium moisture content of 61% was achieved. The moisture uptake for GCL2 (Fig. 8b and Table 3) was also increased to an equilibrium moisture content of 9% after 6 weeks of being subjected to daily thermal cycles, while this GCL reached a moisture content of 50% after 6 weeks and an equilibrium moisture content of 59% under isothermal conditions. Thus both GCLs achieved equilibrium under thermal cycles of about 18–25% of the moisture content expected under isothermal conditions. This indicates that daily thermal cycles significantly suppressed the hydration of the GCLs and in all cases the final equilibrium moisture contents under daily thermal cycles were 25% or less of that expected under isothermal conditions (Table 4). Overnight cooling slightly increased the moisture uptake (about 5%) for both GCLs. However, it was not significant enough to prevent suppression of hydration under the action of daily thermal cycles, and the final equilibrium moisture contents were far less than those achieved under isothermal conditions at room temperature (Fig. 8).

In order to investigate the influence of seasonal cycles on GCL hydration, the heating blanket was turned off for a period of 6 weeks. As shown in Fig. 9, the gravimetric moisture content for GCL1 increased from 18% at the end of the daily thermal cycle period (week 6) to 44% at the end of the cooling span (week 12). The change in the GCL hydration was slightly less for GCL2, which increased from 15% to 29% over the same period. The difference in hydration of the two GCLs could be related to the difference in their water retention curves (Beddoe et al., 2011). Once the heating cycles resumed after week 12, the moisture contents achieved by both GCLs dropped to the same equilibrium levels observed prior to the long cooling period. This indicates that seasonal cooling periods can temporarily improve the hydration of the GCL, however, the susceptibility of hydrated GCLs to moisture loss would be expected when subjected again to daily thermal cycles.

6. Conclusions

The hydration of two GCL products from clay subsoils at different initial moisture contents was examined under both isothermal conditions at room temperature and when subjected to daily thermal cycles. It is apparent from this study that the hydration of GCL will be affected by the GCL product used, the grain size distribution of the subsoil, the local subsoil moisture content, and the thermal cycles to which the GCL is subjected. The local subsoil moisture content may vary from place to place (e.g. it may be affected by work stoppages when there is rain that could increase the moisture content of the soil at locations that had not been covered before the rain). Also the latter two variables may vary between the side slope and base of the cell in a landfill.

The subsoil moisture content greatly impacted both the equilibrium moisture content and the rate of hydration of the GCLs. For GCLs over subsoil with initial moisture contents of 10% the GCL moisture contents increased to 47 to 48% (depending on the GCL). At initial moisture contents close to optimum ($w_{fdn} = 30\%$) the GCL moisture contents reached 59–60%. The GCLs moisture content increased to values of 86% and 106% (GCL1 and GCL2) when placed over clay subsoil with an initial moisture content of 65% (the average field moisture content in Navan Landfill).

The GCL manufacturing method was also shown to have a significant effect on GCL hydration. GCL1 achieved a much higher degree of saturation (40–73%) than that of GCL2 (26–56%) for all subsoil moisture contents. This was attributed to the difference in the level of anchorage of needle punched fibers in the two GCLs, which was more effective in constraining the swelling and hence the maximum equilibrium moisture content for GCL1.

The hydration of the GCL was also affected by the grain size distribution in the subsoil. Both the equilibrium moisture content and the rate of hydration of GCL1 from clay subsoil (CL) at 10% initial moisture content was significantly less than that for the other sandy subsoils (SC, SM, SP) under similar conditions. This behavior is related to the difference in water retention curves of different soils. The difference in suction between the clay and the GCL, at the GCL-subsoil interface, is less than that for the sand subsoils, which is reflected in lower equilibrium moisture content and a slower rate of hydration of the GCL.

Subjection to daily thermal cycles significantly reduced the equilibrium moisture content of the GCL to as little as 25% of that observed under isothermal conditions at room temperature. This significant difference in the moisture uptake shows the importance of exposure conditions on GCL hydration. During a simulated seasonal cooling period, both GCLs achieved higher moisture uptake, but once the daily thermal cycles resumed, the GCL moisture content dropped down once again to the same level previously observed under the action of daily thermal cycles. This indicates the susceptibility of the GCL to moisture loss under daily thermal cycles. Early covering of the composite liner system in a landfill could limit the thermal exposure and, hence, ensure a much higher degree of hydration of the GCL.

Acknowledgement

This research was financially supported by the Natural Science and Engineering Research Council of Canada (NSERC). The writers are grateful to their industrial partner Terrafix Geosynthetics Inc., however the views expressed herein are those of the writers and not necessarily those of our partner.

References

Anderson, R., Rayhani, M.T., Rowe, K., 2011. Laboratory investigation of GCL hydration from clayey sand. Journal of Geotextiles and Geomembrane 31, 31–38.

ASTM D 2487. 2005. Standard practice for classification of soils for engineering purposes (Unified Soil Classification System), ASTM Standard 04.08, ASTM, West Conshohocken, PA, USA. pp. 249–260.

ASTM D 422. 2005. Standard test method for particle size analysis of soils, ASTM Standard 04.08, ASTM, West Conshohocken, PA, USA. pp. 10–17.

ASTM D 4318. 2005. Standard test method for liquid limit, plastic limit, and plasticity index of soils, ASTM Standard 04.08, ASTM, West Conshohocken, PA, USA. pp. 1–13.

ASTM D 698. 2005. Standard test methods for laboratory compaction characteristics on soil using standard effort, ASTM Standard 04.08, ASTM, West Conshohocken, PA, USA. pp. 80–90.

Babu, G.L.S., Sporer, H., Zanzinger, H., Gartung, E., 2001. Self-healing properties of geosynthetic clay liners. Geosynthetics International 8 (5), 461–470.

Beddoe, R.A., Take, W.A. Rowe, R.K., 2011. Water retention behaviour of geosynthetic clay liners. ASCE Journal of Geotechnical and Geoenvironmental Engineering. (Manuscript 1183, Accepted).

Benson, C.H., Thorstad, H.Y., Rock, S., 2007. Hydraulic performance of geosynthetic clay liners in a landfill cover. Journal of Geotechnical and Geoenvironmental Engineering 133 (7), 814–827.

Bouazza, A., Gates, W.P., Abuel-Naga, H., 2006. Factors impacting liquid and gas flow through geosynthetic clay liners. Geosynthetics – Recent Developments, vol. 9. Indian International Geosynthetics Society, New Delhi, pp. 119–146.

Chevrier, B., Cazaux, D., Didier, G., Gamet, M., Guyonnet, D., 2012. Influence of subgrade, temperature and confining pressure on GCL hydration. Geotextiles and Geomembrane 33, 1–6.

Daniel, D.E., Shan, H.Y., Anderson, J.D., 1993. Effects of partial wetting on the performance of the bentonite component of a Geosynthetic Clay Liner. In: Proceedings of Geosynthetics '93. IFAI. Vancouver, B.C, pp. 1483–1496.

Eberle, M.A., von Maubeuge, K., 1997. Measuring the in-situ moisture content of geosynthetic clay liners (GCLs) using time domain reflectometry (TDR). In: 6th Int. Conf. on Geosynthetics, vol. 1. Atlanta, pp. 205-210.

Geo-Slope International Ltd., 2007. Version 7.16, Build 4840, Geo-Slope International Ltd.

Guyonnet, D., Touze-Foltz, N., Norotte, V., Pothier, C., Didier, G., Gailhanou, H., Blanc, P., Warmont, F., 2009. Performance-based indicators for controlling geosynthetic clay liners in landfill applications. Geotextiles and Geomembranes 27, 321–331.

Lake, C.B., Rowe, R.K., 2000. Swelling characteristics of needlepunched, thermally treated GCLs. Geotextiles and Geomembranes 18 (2), 77–102.

Melchior, S., 1997. In situ studies on the performance of landfill caps. In: Proceedings of the International Containment Technical Conference US Department of Energy. Germantown, Maryland, USA, pp. 365–373.

Petrov, R.J., Rowe, R.K., Quigley, R.M., 1997. Selected factors influencing GCL hydraulic conductivity. Journal of Geotechnical and Geoenvironmental Engineering, 683–695.

Rayhani, M.T., Rowe, R.K., Brachman, R.W.I., Take, W.A., Siemens, G., 2011. Factors affecting GCL hydration under isothermal conditions. Geotextiles and Geomembranes 29, 525–533.

Rowe, R.K., 2005. Long-term performance of contaminant barrier system. Geotechnique 55 (9), 631–678.

Rowe, R.K., Rayhani, M.T., Take, A., Siemens, G., Brachman, R.W.I., 2011. Effect of daily thermal cycles on GCL hydration from subsoil. Geosynthetics International 18 (4), 196–205.

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: Proc. of 8th International Conference on Geosynthetics, vol. 1. Yokuhama, Japan, pp. 21-44.