GCL hydration from a clayey sand subsoil

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ABSTRACT
The hydration of different Geosynthetic Clay Liners (GCL) from an underlying clayey sand subsoil (SC) is described under simulated landfill conditions. Different types of GCLs were hydrated from the foundation soil with variations in soil type and initial moisture content under both isothermal (room temperature) and daily thermal cycles. GCL hydration is shown to be highly dependent on the initial moisture content of the foundation soil. The GCL manufacturing is shown to have a great effect on the rate of hydration and the final moisture content. Daily thermal cycles significantly decreased the moisture uptake by the GCL to below 30% of what was reached in room temperature. Compared to sand (SP) and silty sand (SM) foundation soils, clayey sand (SC) slowed the rate of hydration of the GCLs and reduced the final equilibrium moisture content attained.

RÉSUMÉ
L'hydratation de différents Liners géosynthétiques Clay (GCL) du sous-jacentes du sous-sol de sable argileux (SC) est décrite dans des conditions simulées d'enfouissement. Différents types de GSB ont été hydratés du sol de fondation avec des variations dans le type de sol et la teneur en eau en vertu des deux isothermes (température ambiante) et tous les jours des cycles thermiques. GCL hydratation s'avère très dépendante de la teneur initiale en humidité du sol de fondation. Le type de GCL est démontré qu'ils ont un grand effet sur le taux d'hydratation et la teneur en humidité finale. cycles thermiques quotidiennes a diminué significativement l'absorption d'humidité par le GCL en dessous de 30% de ce qui a été atteint à la température ambiante. Par rapport à sable (SP) et de sable limoneux (SM) des sols de fondation, argileux sable (SC) a ralenti le taux d'hydratation de la DAG et réduit la teneur en humidité d'équilibre final atteint.

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 either 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 placed over the GCL. These composite liners have gained widespread acceptance for use in landfills and other liner applications. GCLs have been shown to be highly effective at controlling contaminant migration provided they are adequately hydrated (Petrov and Rowe 1997) and the overlap between the panels is maintained (Rowe, 2005). After placement, before landfill initiation, the GCL takes up pore water from the underlying soil. While it is accepted that GCL performance is based on the degree of hydration (Petrov and Rowe 1997), the rate of hydration of a GCL from foundation soil is not well known.

Limited data on the hydration of GCLs from sand foundation soil have been reported for isothermal conditions (Daniel et al., 1993; Eberle and von Maubeuge, 1997; Rayhani et al., 2011). However, it is not clear how the properties of the specific foundation soil and GCL affect the rate of hydration. The method of manufacture (Rowe 2007; Beddoe et al. 2011) and the type of bentonite used (Bouazza et al. 2006) vary between GCLs and can influence their performance. Rayhani et al. (2011) showed that the GCL manufacturing (type), grain size distribution of foundation soil and specially the initial moisture content of the foundation soil affect the rate and degree of hydration of GCLs on a silty sand and sand subsoil. However, it is unclear how hydration is affected by other types of soil, including clay.

Daily thermal cycles can also greatly affect hydration of GCLs (Rowe et al. 2011). Although the composite liner should be covered with a leachate collection system shortly after placement of the geomembrane, it is not uncommon for a composite liner to be left exposed for a period of time (weeks to years depending on the situation) before being covered. Under these circumstances, it is important to consider the effect of thermal cycles on the degree and rate of hydration of a GCL during installation when the GCL is exposed. The objective of this paper is to build upon the previous studies of GCL hydration (Rayhani et al. 2011; Rowe et al. 2011) and investigate the hydration of GCLs when placed in contact with a clayey sand foundation soil under both isothermal conditions at room temperature and daily thermal cycles.

2 MATERAIL PROPERTIES

2.1 Geosynthetic Clay Liners

Three types of GCLs from two different manufacturers were studied. Following previous studies (Rayhani et al. 2011; Rowe et al. 2011), Bentofix NSL and NWL were selected as GCL1 and GCL2 respectively. The third GCL used was Bentomat ST, labelled as GCL 3 in this paper. The basic characteristics of the three GCLs are summarized in Table 1. All GCLs contained granular sodium bentonite with smectite content of 50-58% and had a similar swell index. The size of bentonite and the type of carrier geotextile were different for the GCLs tested.

2.2 Soil Characteristics

Clayey sand (SC in USCS classification system, ASTM D2487) was used as the foundation soil for GCL hydration. The particle size distribution of the soil, obtained using ASTM D 422 and the estimated soil water retention curves (based on the data point function in GeoStudio 2007) are given in Figure 1. A hydrometer test (ASTM D422) was also used to obtain the particle size distribution of the fine portion (Figure 1). This data indicates that the soil has about 21% fines (passing the 0.075mm sieve) and about 12% clay fraction. The plasticity index of the fine portion was measured at about 4% based on ASTM D 4318. The standard Proctor compaction test (ASTM D 698) showed a maximum dry density of 1.96 Mg/m^3 at optimum gravimetric water content of 11.3%.

Table 1 - Basic properties of GCLs tested

GCL		GCL1 (NSL)	GCL2 (NWL)	GCL3 (ST)
Avg. Dry Mass/area (g/m^2)		4509	3896	5438
Carrier Geotextile		W	SRNW	W
Cover Geotextile		NW	NW	NW
Construction		NPTT	NPTT	NP
Avg. Peel strength (N)*		94 ± 16	260 ± 17	204 ± 35
Bentonite Grain size (mm)	D_{10}	0.1	0.15	0.4
	D_{30}	0.28	0.3	0.65
	D_{60}	0.35	0.35	1.0
Swell Index (ml/2g)*		26	24	23

W = Woven, NW = Nonwoven, SRNW = Scrim reinforced nonwoven, NP = Needle punched, NPTT = Needle punched & thermally treated; *Tests performed by M. Hosney, Queen's University.

3 EXPERIMENTAL METHOD

To simulate landfill liner conditions for a variety of different tests, polyvinyl chloride (PVC) cells were used to create a typical composite liner profile. The PVC cells were 150 mm in diameter and 300 mm in height. The clayey sand was mixed with tap water with an average calcium concentration of 40 mg/L to bring its moisture content to the appropriate moisture content (w_{fdn}) of 5%, 10%, 15%, and 20% prior to placement in the test cells. Once thoroughly mixed, the soil samples were left to cure for 24 hours in sealed plastic bags. The prepared clayey sand was then compacted into the cells to a dry density of 1.75Mg/m^3, equivalent to approximately 90% of the maximum dry density. The soil was compacted into the cells in three layers, and at each level moisture content samples were taken to give the initial moisture content profile in the soil. At termination of the cells, a final moisture content profile was taken for comparison.

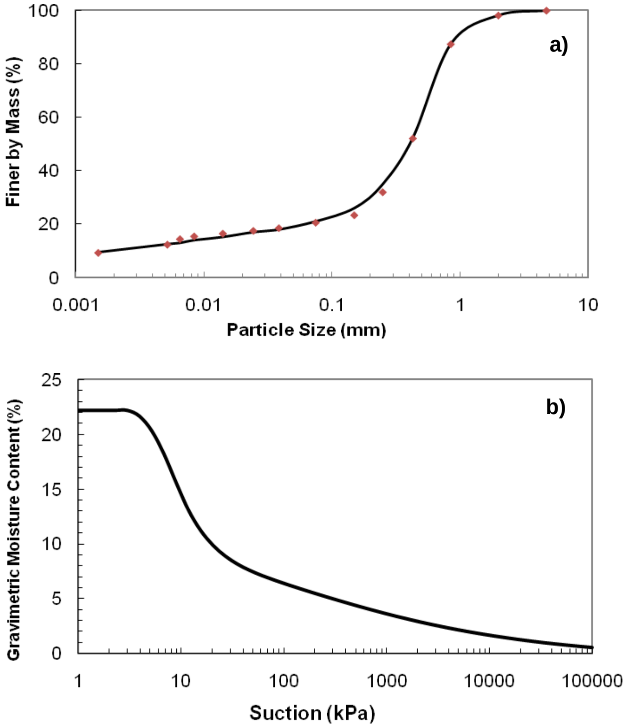

Figure 1: a) Particle size distribution, b) water retention curve of subsoil

Four 150 mm diameter samples of each of the three GCL types were placed on top of the soil. A geomembrane was then placed over the GCL. The geomembrane simulated composite liner field conditions and minimized evaporation of soil moisture. A steel seating block of 15 mm thickness (1 kPa) was placed on top of the geomembrane to ensure good contact between the GCL and the soil. The test cells were completed by sealing them to minimize moisture loss.

To evaluate the progression of GCL hydration, the PVC cells were opened on a weekly basis to take measurements. The GCL was removed for weighing and to track changes in thickness. Thickness was measured using callipers, by taking the average of three different measurements at different points on the GCL. After measurement, the GCLs were replaced to their respective cells and the cells were resealed. The GCLs were out of the cells for less than 5 min, minimizing moisture loss. The progression of hydration of the GCLs was evaluated based on gravimetric moisture content (w) but also in terms of its saturation. The maximum hydration moisture content (w_{ref}) was found for each of the three GCL types by submerging a 150 mm GCL sample in water with a 1kPa seating over the course of a week, and taking the final moisture content once the GCL reached equilibrium.

Isothermal tests involved leaving the cells to sit at room temperature (22°C). GCL mass and thickness were monitored once a week for several months. Four test cells were created for each GCL, giving a total of 12 cells. These four cells contained clayey sand subsoil at 5%, 10%, 15%, and 20% moisture contents.

The cyclic heating tests were performed with two GCL types, GCL2 and GCL3, at foundation soil moisture contents of 5%, 10%, 15%, and 20%. Test cells were surrounded with Styrofoam insulation and heated from the top using a heating blanket system to provide one-dimensional thermal and moisture migration conditions. To investigate the effect of daily thermal cycles on GCL hydration, the temperature controller was programmed to generate thermal cycles realistic to Southern Ontario, Canada (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 for 8 hours and the cells were allowed to cool for 16 hours.

Table 2: Details of isothermal GCL hydration experiments

GCL Type	Sub soil w (%)	GCL (w)		GCL (w/w_{ref})*	
		Initial (%)	after 22 weeks (%)	Initial (%)	after 22 weeks (%)
GCL1	5	9.2	23.6	6.6	16.3
	10	9.2	85.4	6.6	58.9
	15	9.2	97.5	6.6	67.3
	20	9.2	130	6.6	90.0
GCL2	5	5.0	21.5	4.2	18.2
	10	5.0	78.9	4.2	66.9
	15	5.0	87.8	4.2	74.5
	20	5.0	106.2	4.2	90.1
GCL3	5	10.6	23.3	6.2	12.3
	10	10.6	90.4	6.2	47.6
	15	10.6	99.4	6.2	52.3
	20	10.6	173.8	6.2	91.5

*w_{ref} (mean, standard deviation, sd) : GCL1 (145%, 5%), GCL2 (118%, 3%), GCL3 (190%, 5%)

4 RESULTS AND DISCUSSION

The effect of initial moisture content of the foundation soil on GCL hydration is summarized in Table 2. The maximum normalized hydration of the GCLs, whereupon the GCLs reached equilibrium moisture, was found to vary with initial foundation soil moisture content. At an initial moisture content of 5% (w_{fdn}=5%), the moisture content reached, by each of the three GCLs after 22 weeks, ranged between 12 to 18% of the maximum value (w/w_{ref}). At 10% and 15% initial subsoil moisture content, the maximum hydration ranged from 48 to 67% and 52 to 74% of the fully hydrated values respectively. For clayey sand foundation soil starting at 20% (w_{fdn}), the GCLs approached full hydration and ranged from 91 to 92% of reference value (w/w_{ref}).

The effect of GCL type (GCL1, GCL2, GCL3) on hydration can be analyzed in terms of the final gravimetric moisture content, or the final percent of saturation between the three GCLs. When comparing the GCLs at a given foundation soil moisture content, the GCL reaching the highest moisture content did not necessarily correspond with that reaching the highest saturation. In general, GCL3 reached the highest moisture content over foundation soil at all moisture contents examined; however GCL2 generally reached the highest normalized hydration (and hence degree of saturation) over the same foundation soil.

The maximum hydration attained by GCLs 1 and 2 was quite similar (Figure 2), with maximum normalized hydration usually falling within 5-10% of each other for each foundation soil moisture content. However for GCL3 on foundation soil with moisture contents 5-15%, the maximum normalized hydration was significantly less than that for GCLs 1 and 2 (Table 2). Only for the foundation soil at 20% moisture content was the normalized hydration of all GCLs similar (90-91.5%). This can all be attributed to the properties of the GCLs. GCLs 1 and 2 came from the same manufacturer and had the same type of bentonite clay and the GCLs were thermally treated to improve anchorage of the needle punched fibres to the carrier geotextile. The anchorage of the needle punched fibres by the scrim-reinforcement in GCL2 (peel strength 260N, Table 1) was effective in constraining the maximum moisture content when immersed in water (w_{ref}=118%) and provided a lower void ratio and better hydration performance.

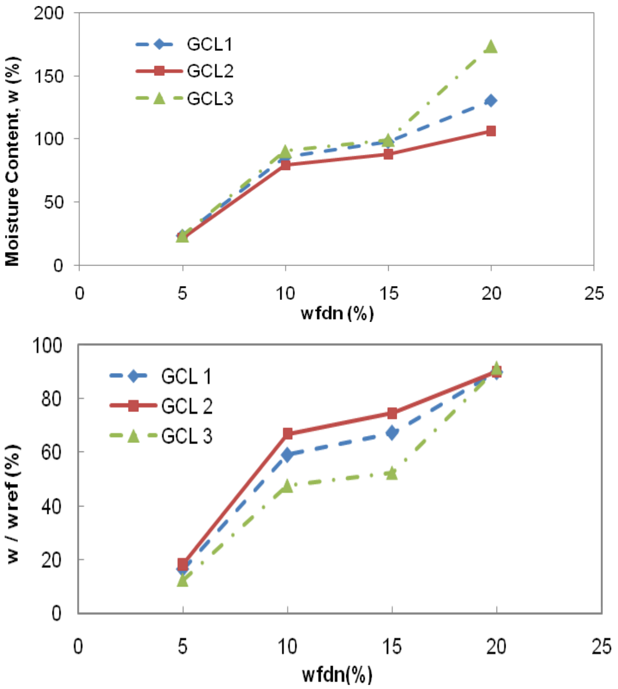

Figure 2: Effect of GCL type and initial moisture content of foundation soil (w_{fdn}) on normalized GCL final equilibrium moisture content (w/w_{ref})

The woven carrier geotextile in GCL1 (peel strength 94N, Table 1) provided less effective anchorage than the scrim reinforced nonwoven of GCL2 and therefore was less effective at limiting the maximum moisture uptake (w_{ref}=145%) and the normalized moisture content was slightly less than that for GCL2. Despite the high peel strength of 204N (Table 1), GCL3 showed the least effective anchorage of fibres and the highest maximum moisture content (w_{ref}=190%) and the lowest normalized hydration values. Thus the peel strength is not a good indicator of how well the needle punched fibres will constrain the swelling of the bentonite at low stress.

The gravimetric moisture contents of the GCL2 on a foundation soil with 15% initial moisture content and subject to daily heat cycles is shown in Figure 3 both at the end of the heating cycle and subsequent cooling (and rehydration) cycle over the first 6 weeks. After one week, the moisture contents of the respective GCLs had reached their maximum values and then stabilized with just minor fluctuations over the next five weeks. The daily heat cycle kept the GCL from reaching more than 15% moisture content at the end of the heating cycle. Overnight cooling consistently increased the moisture content of the GCLs by approximately 7%, but overall the GCLs were not anywhere close to reaching full saturation. This data indicates that under daily heating cycles the ability of GCLs to hydrate from subsoil is greatly hindered.

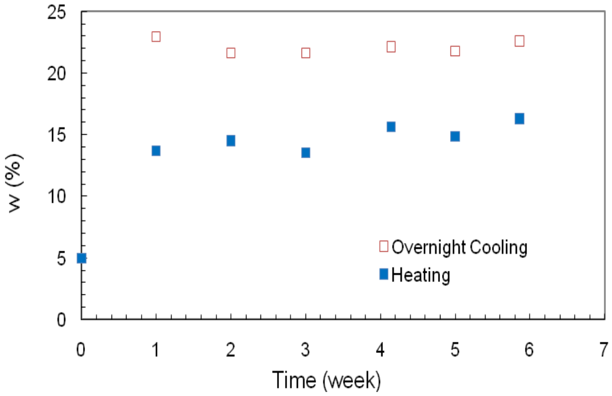

Figure 3: GCL2 hydration at the end of heating and cooling cycles (w_{fdn} =15%)

To further examine the effect of daily heat cycles on the progression of GCL hydration, the cyclic tests can be compared with hydration under isothermal conditions. Figure 4 shows the 6 week hydration of the cyclic test discussed above compared with the corresponding isothermal data. After 6 weeks the isothermal tests had yet to reach equilibrium and GCL2 had reached around 60% gravimetric moisture content. Under cyclic heating, however, GCL 2 and 3 had only reached 15% moisture content. This shows that cyclic heating greatly affects the hydration of GCLs.

To examine how clayey sand foundation soil compares with the sand and silty sand, the equivalent hydration progression was compared with those reported by Rayhani et al. (2011) for sand and silty sand foundation soils. Figure 5 shows the hydration of GCL 2 over three foundation soils (clayey sand, SC; silty sand, SM; and sand, SP) at 10% gravimetric moisture content. For clayey sand it took close to 8 weeks to reach 60% of the reference hydration, and around 13 weeks to reach equilibrium moisture. While it took significantly longer to reach 60% reference hydration for clayey sand compared to 5 weeks for silty sand and 2 weeks for sand. The final equilibrium moisture content over clayey sand was less than that silty sand and sand, reaching only 67%. These results are somewhat in line with what was expected, and can be attributed to the higher suction of the clayey sand soil.

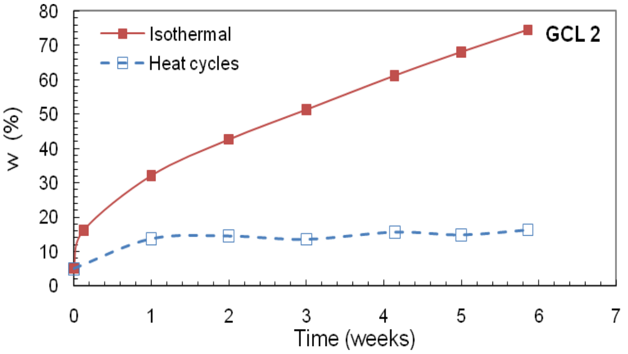

Figure 4: GCL Hydration under cyclic heating and isothermal conditions (w_{fdn}=15%)

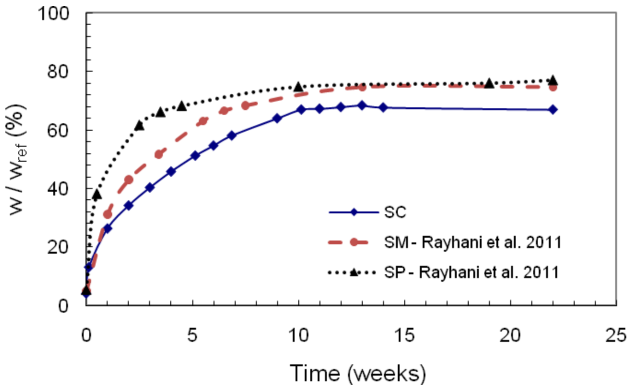

Figure 5: Hydration of GCL 2 over different foundation soils at w_{fdn}= 10%

5 CONCLUSIONS

The hydration of GCLs from underlying clayey sand foundation soil was studied. The three GCLs used and the procedures undertaken followed previous studies (Rayhani et al. 2011; Rowe et al. 2011). The evolution of hydration was studied over several months under isothermal conditions at room temperature, as well as under daily thermal cycles.

The initial moisture content proved to have a significant effect on the degree of hydration reached by the GCLs. The GCLs overlaying clayey sand at 5% moisture content only reached 12-18% of the reference moisture content of the GCL and had a very low degree of saturation, whereas the GCLs overlaying the clayey sand at 20% initial moisture reached 90-91.5% of the fully hydrated value at low (1kPa) stress. It was also found that the effectiveness of hydration on a given foundation soil depended on the method of GCL manufacture. GCL 2 showed the least swelling and highest saturation for a given foundation soil due to better anchorage of the needle-punched fibres.

Daily thermal cycles greatly influenced the ability of the GCL to hydrate from subsoil. When subjected to daily surface heat of 56˚C, the GCLs were only able to reach around 30% of moisture contents reached under isothermal conditions at room temperature.

The final equilibrium moisture content reached by the GCLs over clayey sand was less than that reached by the other foundation soils (SP and SM). These decreases can be explained by the higher suction of the clayey sand in comparison with the other foundation soils.

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