Hydration/dehydration behavior of GCLs under extreme cold environments

G.G. Carnero-Guzman & A. Bouazza
Department of Civil Engineering, Monash University, Australia

W.P. Gates
Institute for Frontier Materials, Deakin University, Australia

R.K. Rowe
Department of Civil Engineering, Queen's University, Canada

ABSTRACT: Geosynthetic clay liners (GCL) have been used as hydraulic barriers in cold climates where there is a relatively short period of above zero temperature when hydration can occur and a relatively long period of sub-zero frozen conditions when the hydration process stops. Although the GCL hydration process in cold regions has been addressed experimentally using soil column tests, the influence of low temperature (close to 0°C) and low relative humidity (< 10%) has not been considered for the experiments, which might reduce the final saturation of the GCL. The GCL hydration/dehydration phenomena under the above conditions is examined in this paper. Results from the experiment run at +1.5°C show that the final gravimetric water content (GWC) achieved is not influenced by the low temperature compared to room temperature. Results from the experiments at -2°C show that the GCL may absorb ~+12% (GWC) of water before the system becomes fully frozen.

Keywords: Geosynthetic clay liner, hydration, dehydration, ice formation, cold regions engineering, unsaturated behaviour

1 INTRODUCTION

Geosynthetic clay liners (GCL) have been used extensively as part of composite hydraulic barriers in environmental projects in the last decades with good results. In the last ten years, GCLs have also been employed to control soil contamination in harsh and remote places like Antarctica (e.g. McWatters et al., 2014a; McWatters et al., 2014b; Whelan et al., 2015; McWatters et al., 2016). In this scenario, GCL is exposed to three months of summer per year when temperature oscillates between -10°C to +5°C, while the rest of the year is exposed to freezing temperatures that can reach -40°C (McWatters et al., 2016). The relatively short period of above zero temperature when hydration can occur (summer) and the long period of sub-zero frozen conditions (winter) has the potential to adversely influence the hydration of the GCL. The hydration process is often of concern when the GCL is used as part of a composite hydraulic barriers because, for good performance of the barrier, the bentonite (active element of the GCL) needs to be well-hydrated (highly saturated) as shown by several researchers (e.g. Vangpaisal & Bouazza, 2004; Rowe & Iryo, 2005; Bouazza et al., 2006; Bouazza & Rahman, 2007; Gates et al., 2009; Benson et al., 2010; Scalia & Benson, 2011; Anderson et al., 2012; Bouazza & Gates, 2014; Bouazza et al., 2014).

When placed in the field, the hydration process and final saturation degree of the GCL is influenced, if not controlled, by several factors such as climatic conditions and subgrade types. Jones et al. (2015) hydrated the GCL with soils from Antarctica in column tests at the maximum dry density condition of the subgrade. The results showed that, under a stress of 13 kPa, GCLs reached apparent degrees of saturation values between 65 and 80%. However, other aspects related to the environment, such as low temperature and low relative humidity (RH) were not taken into consideration in those tests. Therefore, the mechanism of how hydration/dehydration occurs under cold environment conditions remains unclear.

The objective of this paper is to investigate the hydration/dehydration process under temperatures that represent the summer (+1.5°C) and winter (-2°C) seasons in Antarctica. The experiments are carried out under constant temperatures and low relative humidity for each season under load conditions that correspond to the biopiles used in Casey Station.

2 MATERIALS AND METHOD

2.1 *Materials*

The GCL examined in this study is commercially available in Australia. It consists of powdered sodium bentonite sandwiched between a nonwoven cover and a scrim reinforced carrier geotextiles, needle-punched together and thermally treated. The physical characteristics of the GCL (based on 21 samples of 75mm diameter, randomly taken from the roll) are summarized in Table 1. The mass per unit area of bentonite (M_b) was calculated as the difference between the total mass per unit area of GCL (M_{GCL}) and mass per unit area of geotextiles (M_{GT}). M_{GCL} and M_{GT} were obtained as per ASTM D5993 and ASTM D5261-10, respectively. The GCL specimens used in the current study have a mass per unit area values within 4.91~5.15 kg/m^2, which represents the dominant mass per area range. Similar mass per unit area values were utilized in investigations conducted with the same GCL by Ali et al. (2014) and Bouazza et al. (2017).

Table 1. Physical properties of GCL used in the current study.

Property		Units	Values	Standard Deviation
As-received gravimetric water content		(%)	8 ~ 10	0.65
M_{GCL} (@ as received gravimetric water content)		kg/m^2	4.41 ~ 5.30	0.32
Bentonite free swell index		ml/2g	33	
M_b (@ as received gravimetric water content)		kg/m^2	3.62 ~ 4.68	0.15
Cover geotextile (PP)	Type	-	NW	
	Mass per area, M_{GU}	kg/m^2	0.33	
	Thickness	mm	2.53 ~ 2.65	0.06
Carrier geotextile (PP)	Type	-	W + NW	
	Mass per area, M_{GL}	kg/m^2	0.47	
	Thickness	mm	2.82 ~ 2.90	0.04
Bonding process		Needle-punched and thermally treated		

W, Woven; NW, Nonwoven; PP, Polypropylene.

2.2 *Sample preparation*

As received condition (GWC ≈ 8%) GCL specimen samples of 75mm diameter were cut and the mass per area was checked to ensure it fell within the target range. The edges of the cut GCL were covered with silicone paste to prevent loss of bentonite during the experiments. The samples were set aside for 24 hours to allow the silicone to dry. The initial mass and thickness of the samples were recorded.

2.3 *Summer experiment method*

A laboratory experiment was carried out at Monash University, Australia in order to quantify the length of time needed for a GCL to reach full hydration under constant (a) load condition and (b) low temperature. The experiment followed the GCL hydration experimental method proposed by Rouf et al. (2016) but incorporated the effect of temperature on the hydration process.

Tests were run at a constant temperature of +1.5°C, which maintained the water in liquid state but was close enough to the freezing point (0°C) to represent the temperature range of the summer period registered in Antarctica. An incubator (Panasonic MIR 254) with temperature control was utilized to keep the temperature constant throughout the duration of the experiment. Four samples were tested at +1.5°C. The samples were placed on top of porous stones inside of a container filled with DI water. The container was covered to avoid loss of water by evaporation. The water level was kept constant to the height of the porous stone. A 2 kPa load was placed on top of the GCL samples. Finally, the container was placed in the incubator. The mass of the samples was recorded daily.

The temperature of the incubator was monitored using a thermocouple. While the temperature controller was kept at +1.5°C, the temperature was not homogenous inside the incubator and had a variability in the order of ±0.9°C. Particularly, the left-bottom area of the incubator temperature was ~0°C. As a result, a sample located at the left corner of the container formed ice in the GCL carrier (geotextile in contact with the porous stone) during the experiment. The ice appeared in the second day of the mass measurements and remained until day 7 when the container was moved to the middle area of the incubator where the temperature was more homogenous along that level. After the ice melted from this specimen, it left “wet prints” in the carrier and the hydration process continued until the end of the experiment. This specific case was then used to assess the influence of ice formation during the early stage of the hydration process. This sample was labeled “1T2L-I”.

GCL hydration tests were also performed at room temperature (+20°C) to examine the influence of temperatures on the hydration results. The four samples tested at +20°C were placed inside a container in the same fashion as samples cured at +1.5°C. Sample labelling was defined with respect to the curing temperature (1 or 20°C) and the applied load (2 kPa). For example: sample 3S-20T2L, represented sample 3 cured at 20°C under 2 kPa applied load. Summer experiment lasted for 36 days.

2.4 *Winter experiment method*

The winter experiment aimed to quantify the final GWC of GCL samples after 2 months exposure to constant subzero temperature. During winter, the water table freezes, therefore, the hydration process stops. GCL samples were pre-saturated from porous stones in the same fashion as described in section 2.3 above at room temperature until reaching gravimetric water contents (GWC) of 180% and 60%, which represents the highest and average GCL gravimetric water contents reported from Casey Station, respectively (McWatters, 2016).

During the test, a surcharge load of 2 or 15 kPa was applied to the GCL to simulate the field load conditions. 2 kPa load represented the load condition at the edge of biopiles in Casey Station, while 15 kPa mimicked the load condition beneath the center of biopiles. Further details of the biopiles geometry ares described in McWatters et al. (2016). The container was covered with a lid and placed into the incubator (Panasonic MIR 254) at -2°C for 2 months to allow water to freeze and to represent the winter period (subzero temperatures). The temperature was low enough to freeze the water in the container and stop the hydration process coming from the porous stone. RH measurements for the winter period were not taken due to equipment limitations, but were expected to be very low (< 15% RH).

During the experiment, the water between the porous stone and the GCL froze as ice and thus created a strong bond between the container, the porous stone and the GCL, making it impossible to take the GCL out of the container and record the mass during the 2 months. Due to the low RH, the ice that surrounded the porous stone sublimated and, at the end of this period, the container was empty (no ice or water).

The taxonomy of the tests is defined as: the initial number is related to the applied load (2 or 15kPa) and the second number is the pre-hydrated GWC of the sample (180 or 60%). 2 samples were prepared for each “load - pre-hydration” combination, therefore, a total of 8 samples were used for the experiment. Sample labelling was defined as same as item 2.3.

After the 2 months experiment, the incubator temperature was raised to +1.5°C to represent the end of the winter season. Due to that, the ice bond between the GCL and porous stone melted and the mass of the GCL samples was recorded.

3 RESULTS AND DISCUSSION

3.1 *Summer experiment results*

Figure 1 presents the average result of the summer experiment (hydration process) of the samples cured at temperatures of +1.5°C and +20°C (four samples per each temperature) and the sample with ice formed in the carrier (1T2L-I). The experiment duration was 37 days for each curing temperature. Regardless of the curing temperature, samples achieved a maximum GWC value of around 199% (≈97% of saturation), with a standard deviation of 4.3%. The results show that 1T samples continued to hydrate and were not influenced by the high RH gradient existing between the air (15%) and the samples, which tended to create migration of water in vapor state from the GCL to the air. Therefore, under the conditions of this experiment, the capillary hydration processes governed water flow over dehydration processes of vapor diffusion. Between day 9 and day 23, sample 1T2L-I had higher hydration rates than 20T and 1T samples since the mass recorded included the ice formed in the carrier of the sample. After the melting process had occurred (day 7), the carrier remained wet and served as a “direct channel” to keep the water uptake in the sample. Nevertheless, sample 1T2L-I reached maximum hydration within a similar time as the other groups.

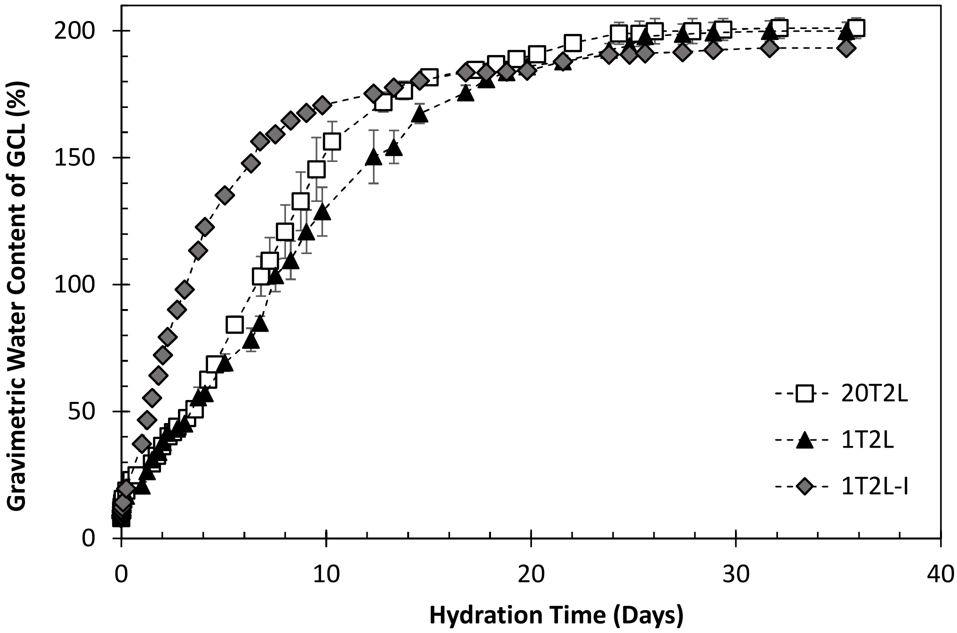

Figure 1 - Gravimetric water content versus hydration time of GCL conditioned at +20°C (20T2L), +1.5° (1T2L) and with ice formed in the carrier (1T2L-I).

From day 23 till the end, fully saturation is achieved by both groups, including sample 1T2L-I. Low temperature might have reduced the hydration rate during the transition zone (between day 0 and 23 in the experiment). Ice formation may have sped up the hydration during the transition zone (hydration rate is high), but the ice melting process maintained the hydration process until full-saturation was achieved.

3.1 *Winter experiment results*

After completing the 2 months exposure, the mass of the samples was recorded (after raising the temperature to +1.5°C and the melting process occurred). Table 2 presents the values of initial and final GWC of the GCL samples. A perusal through Table 2 indicates that the GCL GWC after winter experiment is greater than experienced at the beginning of the test. Samples pre-hydrated at 60% (60G) increased their GWC by ~10.0%, for both applied stresses (2 and 15 kPa), respectively. Samples pre-hydrated at 180% (180G) increased their GWC by ~13.5% and ~12.8%, for applied stresses of 2 and 15 kPa, respectively. Thus, high pre-hydrated samples (180G) absorbed ~3% more water than average pre-hydrated samples (60G). This difference can be related to the fact that 180G samples are in higher saturation condition than 60G samples, which, as a result, it creates a better capillary connection that facilitates the water uptake through the sample.

For a same pre-hydrated condition, the amount of absorbed water is similar for samples under 2 and 15 kPa. Hence, for the investigated stress levels in this paper (2 and 15 kPa), the influence of the applied stress level in the water uptake is negligible.

The changes in the GWC, with respect to the initial GWC value, might have occurred at the beginning of the test before complete freezing of the system that has occurred in the first days of the experiment. After the freezing of the system was completed, no more water uptake occurred.

Table 2. Initial and final conditions of GCL samples during winter experiment.

Taxonomy	N° of samples	Applied Load (kPa)	Average initial pre-hydrated GWC (%)	Average GWC (%) after winter experiment	Average Increment of GWC (%)
15L180G	2	15	176.7	189.5	12.8
2L180G	2	2	178.6	192.1	13.5
15L60G	2	15	59.2	69.1	9.9
2L60G	2	2	61.2	71.3	10.0

4 CONCLUSIONS

The “summer” experiment (hydration) results showed that the temperature difference between samples hydrated at +20°C and +1.5°C had little effect on the final GWC achieved by the GCL samples. Instead temperature influenced the hydration rate during the “transition zone” of the hydration process. Ice formation in the carrier of the GCL appeared to be beneficial for the hydration of the samples by increasing the hydration rate, but had no influence on the final GWC. The capillary hydration process governed over the vapor diffusion dehydration process because the porous stone provided continuous water access to the GCL.

In the “winter” experiment, where the temperature was held constantly negative (-2°C), the results showed that samples can absorb an average ~12% water before the system becomes fully frozen. The amount of absorbed water in the samples is primarily controlled by the pre-hydration level condition. Well pre-hydrated samples (180%) absorbed more water than average-hydrated samples (60%). The influence of the applied stress level within the range investigated in this study (2 to 15 kPa) was found to be negligible.

ACKNOWLEDGMENTS

This research was supported under Australian Research Council’s Linkage Projects funding scheme (project number LP140100516). The first author thanks the Peruvian National Program of Scholarships and Student Loans (PRONABEC) for funding his Ph.D. studies. The authors also acknowledge the funding provided to this project by Geofabrics Australasia Pty. Ltd.

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