Water content, swell index and cation exchange of GCLs due to subsoil hydration

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ABSTRACT: This study investigates the final water contents and swell indices of GCLs depending on the hydration duration. In the content of this study, traditional Na-GCL and two polymer treated GCLs (PT-GCL-1 and PT-GCL-2) were hydrated over compacted zeolite subsoil. GCL hydrations were conducted in 0.15 m diameter flexible wall permeameters under 10 kPa confining pressure for 30 days and 90 days. At the end of the hydration durations, GCLs were removed from the permeameters and bentonite samples were taken from the GCLs to determine the final water contents and swell index values. Except Na-GCL, increasing the hydration duration from 30 days to 90 days caused slight reduction in the final water contents of PT GCLs. In contrast, the final water content of 30 days hydrated Na-GCL increased from 66% to 83% at the end of 90 days of hydration. When comparing to the traditional Na-GCL, the swell indices (SI) of PT GCLs significantly affected from the subsoil hydration with time. That is, the SI of new Na-GCL was 21 mL/2g and decreased to 18 mL/2g after 90 days of hydration. However, the SI of PT-GCL-1 dramatically decreased from 38 ml/2g to 21 ml/2g after 30 days and to 11 ml/2g after 90 days of hydration. Similarly, the SI of PT-GCL-2 decreased from 29 ml/2g to 23 ml/2g after 30 days and to 9 ml/2g after 90 days of hydration. The decrease in the SI values can be attributed to the cation exchange that took place between the zeolite and GCL.

Keywords: GCL, subsoil, hydration, swell index, zeolite

1 INTRODUCTION

Geosynthetic clay liners (GCLs) have been used as composite landfill liner or cover material so as to minimize the waste transport. The high swelling capacity of bentonite and its self-healing ability decrease its hydraulic conductivity. However, to become an effective barrier, GCL needs to be adequately hydrated (Anderson et al. 2012, Rowe 2005).

After placement, GCL starts to uptake of water from the underlying soil (Anderson et al. 2012, Barclay & Rayhani 2013, Chevrier et al. 2012, Sarabian & Rayhani 2013) and once it hydrates it becomes low permeable (Bouazza et al. 2017, Bouazza & Gates 2014, Bradshaw et al. 2013, Katsumi et al. 2008, Lee & Shackelford 2005, Liu et al. 2015, Rowe & Abdellaty 2012). On the other hand, bentonite in GCL is exposed to chemical interactions (i.e. cation exchange) during hydration. Thus, the swelling characteristics of bentonite may change depending on the cation types in the interlayer region (Jo et al. 2001, 2004, 2005, Kolstad et al. 2004). For example, if divalent cations (i.e. Ca^{2+} and Mg^{2+}) are abundant in the interlayer region, only crystalline swelling can take place. In contrast, if monovalent cations (i.e. Na^{+} and K^{+}) are dominant in bentonite, both crystalline and osmotic swelling occur and the available volume of water becomes larger.

To assess the swelling ability of bentonite, swell index test is the most appropriate and simple method that can be conducted in the laboratory which can be correlated with the hydraulic conductivity as well. It is known that the higher the swell index of bentonite, the lower is the hydraulic conductivity. Furthermore, it was reported that the swell index (SI) of bentonite higher than 20 ml/2g had an excellent hydraulic behavior, $k < 10^{-9}$ m/s (Katsumi et al. 2008, Shan & Lai 2002, Sato et al. 2016).

The aim of this study is to investigate and discuss the hydration and swell index of three GCLs. For this purpose, GCLs were hydrated over compacted zeolite subsoil in flexible wall permeameters up to 90 days. Then, the changes in the final bentonite water contents and swell indices were investigated regarding to the cation exchange between the subsoil and GCL.

2 MATERIALS AND METHODS

2.1 *Materials*

Na-GCL and two polymer treated GCLs (PT-GCL-1 and PT-GCL-2) were used in this study. All GCLs were manufactured as needle-punched. The polymer treated GCLs were produced with sodium polyacrylate and sodium polyacrylamide (SAP) polymers. Some index properties of GCLs are shown in Table 1. The average initial thicknesses of the GCLs were 8.7mm for Na-GCL and 7.5mm for PT GCLs and the initial water contents of GCLs were within the range of 8-12%. The liquid limit of bentonite was determined as 240% for Na-GCL and PT-GCL-1 and 356% for PT-GCL-2 [7]. The average mass per unit area of Na-GCL was higher (9.6 kg/m^2) than that of PT-GCL-1 (8.0 kg/m^2) and PT-GCL-2 (6.0 kg/m^2).

Table 1. Some index properties of GCLs.

	Mass Per Unit Area (kg/m^2)	Initial Water Content (%)	Specific Gravity	Liquid Limit (%)	CEC (cmol$^+$/kg)
Na-GCL	9.6	8	2.64	240	73.2
PT-GCL-1	8.0	12	2.75	240	62.9
PT-GCL-2	6.0	10	2.73	356	75.2

Hydration process of GCLs was conducted with compacted zeolite subsoil in flexible wall permeameters. The subsoil was gathered from Rota Mining Co Gördes/Manisa in Turkey. According to the ASTM-D 2487-11 (USCS), the subsoil was classified as silty sand (SM). Consistency limits of the zeolite subsoil were determined by following the procedures in ASTM D4318-10. The liquid limit and plastic limit of the subsoil were 71.5% and 43%, respectively. The maximum dry density and the optimum water content of zeolite subsoil was determined in accordance with the ASTM:D698-12. As seen in Figure 1, the maximum dry density and the optimum water content of zeolite were 1.14 t/m^3 and 41%, respectively.

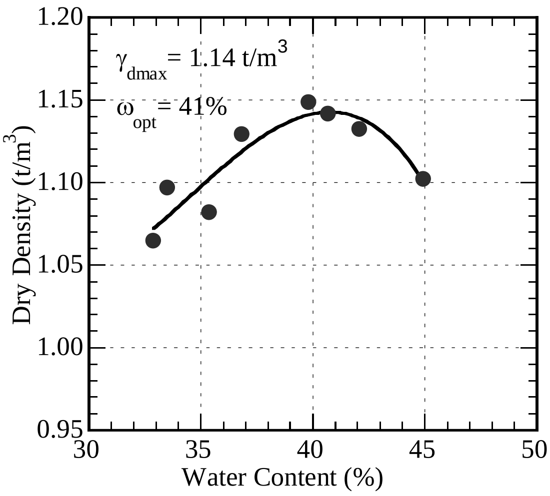

Figure 1. Compaction curve for the subsoil used for GCL hydrations.

2.2 *Methods*

2.2.1 *Experimental method*

In order to simulate a real landfill cover profile, GCL and compacted zeolite subsoil were placed in flexible wall permeameter. To prepare the experimental set up; tap water was added first to the relatively dry zeolite subsoil until the soil was reached 2% wet of optimum water content. Then, the soil was kept in a plastic bag for 24 hours to ensure uniform water distribution. The zeolite subsoil was then compacted with Standard Proctor effort in stainless steel mold with 0.15 m in diameter and 0.116 m in height.

Using a sharp razor knife, circular sample of GCL was cut from the roll of the brand new GCL and the weight of the sample and the average thickness were recorded. Then the GCL sample was placed on the top of the compacted zeolite subsoil. Geomembrane disk with 1.5 mm thickness was also placed over the GCL to minimize potential evaporation into the upper side of the system. To cover the system, a latex membrane was placed and tree O-rings were placed to both top and bottom pedestals. Then the permeameter was filled with water and 10 kPa cell pressure was applied directly by connecting the influent burette to the cell pressure port of the permeameter. GCL samples were hydrated for 30 days and 90 days on compacted subsoil.

2.2.2 *Data measurements*

At the end of the hydration durations, GCLs were removed from the permeameters and weighted. The thicknesses of the hydrated GCLs were measured at four different locations and then 0.1 m circular samples were cut from their centers to use in hydraulic conductivity tests. Note that the hydraulic conductivity part was out of the scope of this study. The bentonites in the remaining parts of the GCLs were used to determine the physiochemical properties of GCLs (i.e. water content, swell index, bound cations etc.). For this purpose, fibers which hold the geotextiles and bentonite together were cut with a sharp razor knife. Then, bentonite was taken to evaluate the change in the water content.

2.2.3 *Swell index test*

Swell index (SI) of bentonite was measured by following the methods described in ASTM:D5890-11. For this purpose, bentonites taken from the brand new GCLs and hydrated GCLs were dried in an oven and then, grinded in a mortar to get powdered bentonites. Specimens of 2 g of bentonite were poured into a 100 ml graduated cylinder filled with 90 ml of deionized water (DIW). Then, the cylinder was filled up to 100 ml level and left for swelling. The volume change of bentonite after 24 hours was recorded by reading the value on the graduated cylinder.

2.2.4 *Bound cation and cation exchange capacity determination*

The bound cation (BC) concentrations and cation exchange capacity (CEC) were determined by following the procedures in ASTM:D7503-10. To determine the major BC concentrations (i.e. Na^+, K^+, Ca^{2+} and Mg^{2+}), ammonium acetate (NH_4OAc) extract was analyzed with Pelkin Elmer DV 2100 inductively coupled plasma optimal emission spectroscopy (ICP-OES) by following Standard Method 3120 B. CEC of GCLs were determined by measuring the nitrogen concentration in the potassium chloride (KCl) extracts using photoLab S12 spectrophotometer.

3 RESULTS AND DISCUSSION

3.1 *Water contents of GCLs after hydration*

The water contents of brand new and hydrated GCLs for 30 days and 90 days over compacted zeolite subsoils are shown in Figure 2. The water contents of GCLs increased from their initial water contents with subsoil hydration. The final water content of Na-GCL increased from 8% to 83% as the hydration duration increased. However, the final water contents of PT GCLs were increased up to 30 days of hydration (i.e. 70% for PT-GCL-1 and 79% for PT-GCL-2). Further hydration caused to 5% and %3 decreases in the final water contents of PT-GCL-1 and PT-GCL-2, respectively. The loss of final water contents in PT GCLs may be attributed to: i) the differences in GCL samples (i.e. mass per unit area) and ii) cation exchange. Similar results were also reported for the GCLs that were hydrated over silty sand subsoil and calcium rich soil (Rowe and Abdelatty 2012).

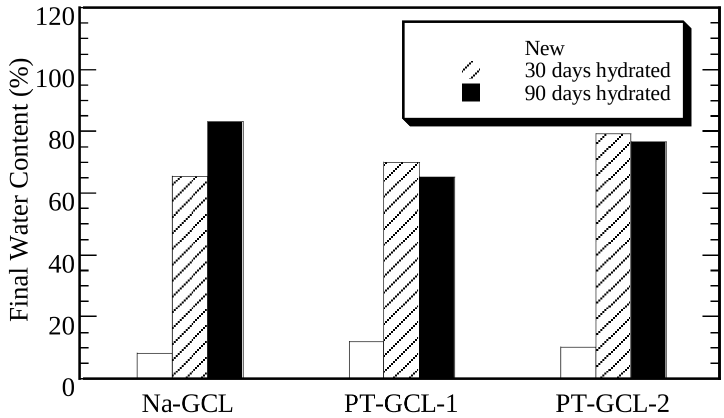

Figure 2. Influence of subsoil hydration on the final water contents of GCLs.

Figure 2 also indicates that the final water content of Na-GCL hydrated for 30 days over zeolite subsoil was lower than those of obtained for PT-GCL-1 and PT-GCL-2. In contrast, after 90 days of hydration Na-GCL reached the highest final water content among others. The changes in the water contents of GCLs may be related with the amount of monovalent cation mole fractions in brand new GCLs. That is, the monovalent cation mole fraction in brand new Na-GCL was higher than PT GCLs (i.e. 0.85 for Na-GCL, 0.55 for PT-GCL-1 and 0.61 for PT-GCL-2).

3.2 *Influence of subsoil hydration on the swell indices of GCLs*

The influence of subsoil hydration on the swelling ability of GCLs is shown in Figure 3. As seen in Figure 3, the swell indices of all GCLs decreased when the hydration duration was increased. That is, the swell index of GCL decreased from 21 ml/2g to 18 ml/2g for Na-GCL, from 38 ml/2g to 11 ml/2g for PT-GCL-1 and from 29 ml/2g to 9 ml/2g for PT-GCL-2, respectively.

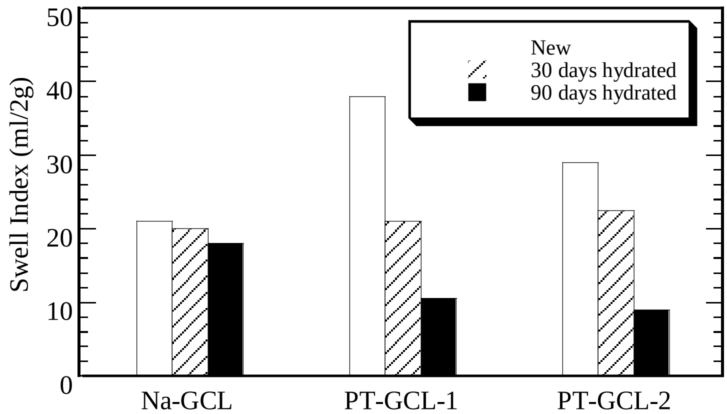

Figure 3. Influence of subsoil hydration on the swell indices of GCs.

Although the swell indices of brand new PT GCLs were significantly higher than those of obtained for Na-GCL, subsoil hydration caused dramatic decrease in their swell index values. The reduction in the swell index values are related with the chemical composition of bentonites and polymers. Since the cation replacement took place between the GCL and subsoil during hydration, the thickness of diffuse double layer surrounding the bentonite particles suppressed and hence, the swell index of GCL decreased in time. In term of swell indices, the use of traditional sodium bentonite would be better to obtain long term chemical stability for this study.

3.3 *Cation exchange during hydration*

Depending on the hydration duration, major bound cations (Na^+, K^+, Ca^{2+} and Mg^{2+}) in GCLs were determined. The exchangeable cations of GCLs are expressed in terms of mole fractions. The mole fractions of bound cations were computed by dividing the individual concentration of each cation to the total bound cation concentration. The mole fractions of monovalent and divalent cations are summarized in Table 2.

Table 2. Influence of subsoil hydration on the exchangeable complex of GCLs in terms of mole fractions.

GCL Type	Hydration Duration (Days)	Exchangeable Cation Mole Fraction	
		$X_{Na\text{-}K}$	$X_{Ca\text{-}Mg}$
Na-GCL	0	0.85	0.15
	30	0.69	0.31
	90	0.80	0.20
PT-GCL-1	0	0.55	0.45
	30	0.60	0.40
	90	0.42	0.58
PT-GCL-2	0	0.61	0.39
	30	0.50	0.50
	90	0.28	0.72

The influence of subsoil hydration on the final water content of GCL and exchangeable mole fractions of monovalent (the sum of X_{Na} and X_K) and divalent (the sum of X_{Ca} and X_{Mg}) cations are shown in Figure 4. The solid lines in Figure 4 represent the final water contents of GCLs after hydration while the dashed lines are the trend line corresponding to the exchange tendency of monovalent and divalent cations.

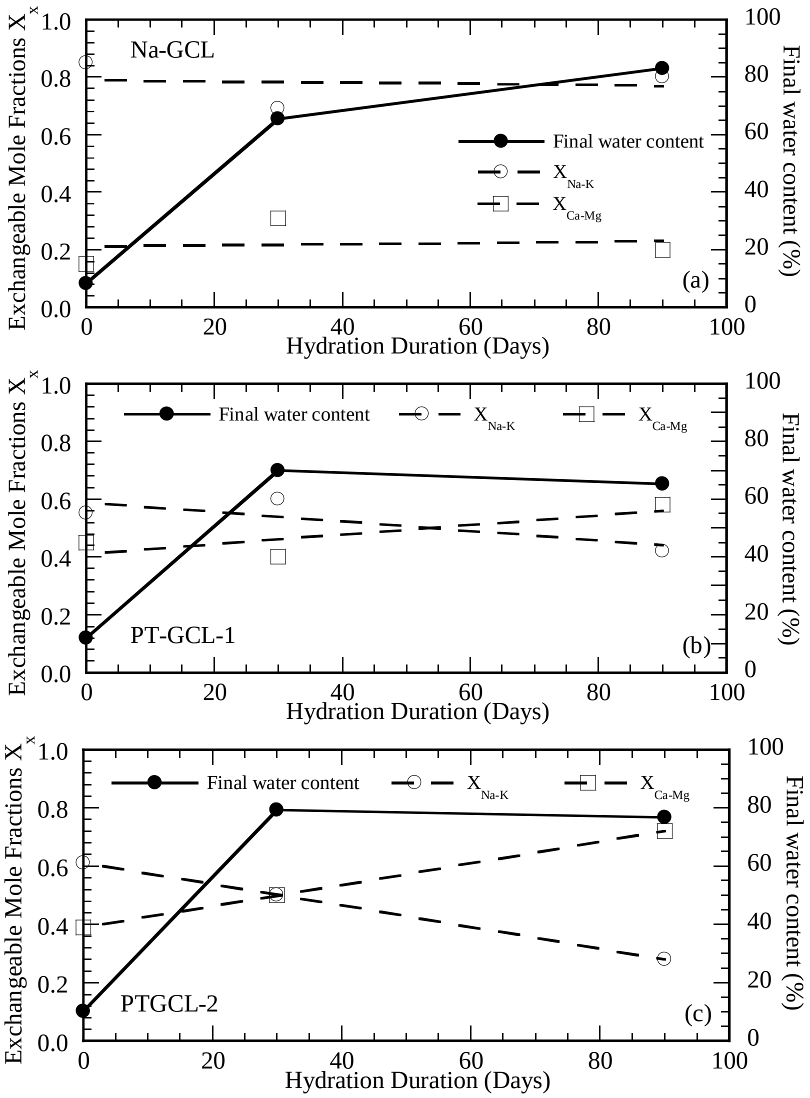

Figure 4. The influence of subsoil hydration on the exchangeable complex and final water content of: a) Na-GCL, b) PTGCL-1 and c) PTGCL-2.

Although it is negligible for Na-GCL, the mole fractions of monovalent cations decreased from their initial values while divalent cations increased during hydration for all GCLs (Figure 4). The chances in the exchangeable mole fractions correspond to the occurrence of cation exchange between the GCL and the subsoil during hydration. Although zeolite pore water was abundance of monovalent cations, it has an appreciable amount of divalent cations (i.e. 1.3 mM versus 0.8 mM). Therefore the replacement demand increased with the hydration duration.

These exchange reactions may also have an influence on the final water contents of GCLs. As seen in Figure 4a, the final water content of Na-GCL increased with time whereas the exchangeable cation mole fractions slightly changed. In contrast, the final water contents of PT GCLs, increased up to 30 days and then slightly decrease after 90 days (Figure 4b and Figure 4c). Figure 4b and Figure 4c showed that the divalent cation mole fractions became more than the monovalent cation mole fractions after about 90 days of hydration for PT-GCL-1 and PT-GCL-2 and caused to decrease in the final water contents of PT GCLs.

Similarly, the influence of subsoil hydration on the swell index and exchangeable monovalent and divalent cation mole fractions are illustrated in Figure 5. As seen in Figure 5a, the slope of the line drawn between X_{Na-K}/X_{Ca-Mg} and hydration duration is shallow with respect to other GCLs. The response of the swell index versus hydration duration is the same as well. That is, swell index of Na-GCL slightly decreased as the hydration duration increased. When PT GCLs were considered, however, the slope for monovalent cations decreased, whereas divalent cations increased. The changes in the swell indices of GCLs became significant as well (Figure 5a and Figure 5b).

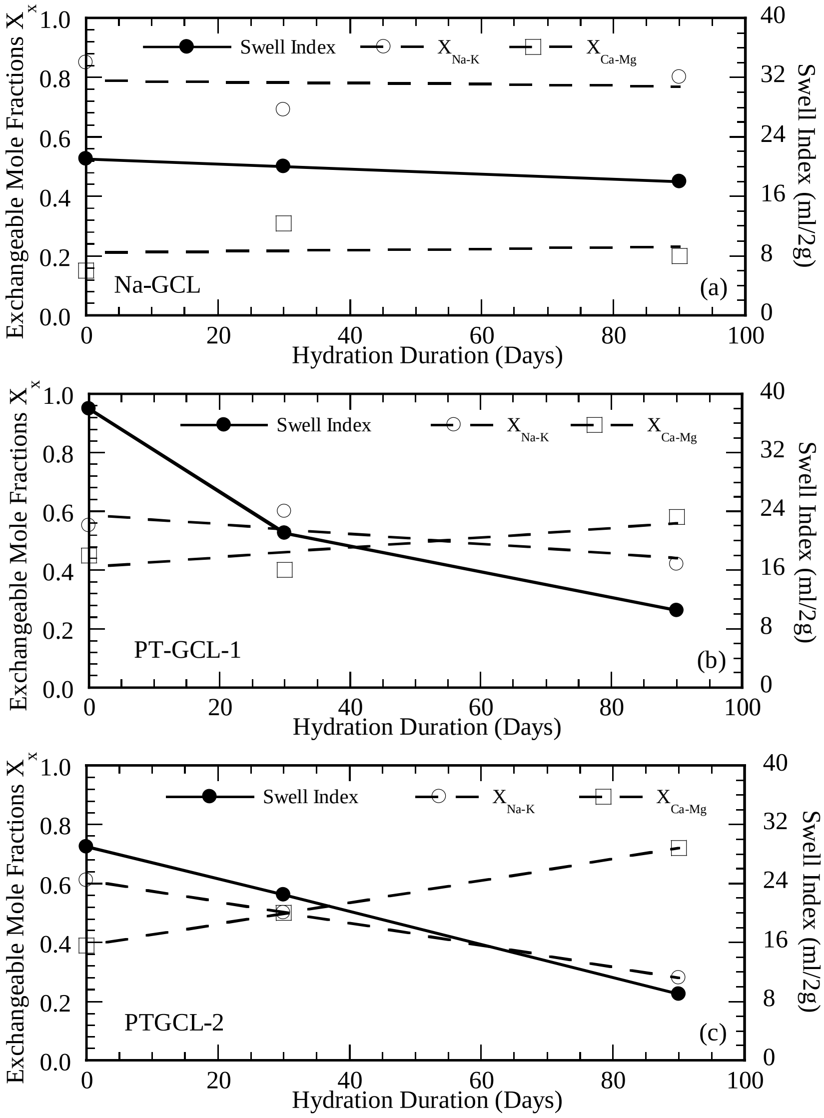

Figure 5. The influence of subsoil hydration on the exchangeable complex and swell index of: a) Na-GCL, b) PTGCL-1 and c) PTGCL-2.

4 CONCLUSIONS

Influence of subsoil hydration on the final bentonite water content and swell index of traditional Na-GCL and two polymer treated GCLs (PT-GCL-1 and PT-GCL-2) have been investigated in this study. The results are summarized below:

- The final water contents of all GCLs increased with 30 days of hydration over compacted zeolite. Depending on the GCL type, the final water contents of 30 days of hydrated GCLs were within the range of 66% to 79%.
- Except for traditional Na-GCL, increasing the hydration duration up to 90 days caused slightly decrease in the final water contents of PT GCLs. The Na-GCL reached the highest final water content after 90 days of hydration (i.e. 83% for Na-GCL, 65% for PT-GCL-1 and 77% for PT-GCL-2). Comparing to the traditional Na-GCL, it can be concluded that the polymer treatment had no increasing effect on the final water content of PT GCLs.
- Subsoil hydration caused reduction in the swell indices of GCLs. The decrement in the swell indices were much more pronounced for PT GCLs. The swell index of PT-GCL-1 and PT-GCL-2 decreased from 38 ml/2g to 11 ml/2g and from 29 ml/2g to 9 ml/2g, respectively, while the swell index of Na-GCL decreased from 21 ml/2g to 18 ml/2g after 90 days of hydration.
- The exchangeable mole fractions of monovalent cations decreased while divalent cation mole fraction increased with hydration duration. These changes in the exchange complex were attributed to the progression of cation exchange between GCL and subsoil during hydration.
- Increase in the divalent cations with subsoil hydration resulted lower final water contents in PT GCLs.
- The changes in the exchangeable cation mole fractions resulted in a dramatic decrease in the swell indices of PT GCLs rather than that of traditional Na-GCL for this study.

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