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Study of GCL shrinkage under cyclic hydration-drying effects

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ABSTRACT
One of the key challenges in implementing solid waste landfills is the high degree of control of the leachate produced in the system. The sealing of these systems is ensured by the combination of a low hydraulic conductivity compacted clay (CCL) subgrade, a geosynthetic clay coating and a geomembrane. In this context, the study of GCL performance is fundamental, as this layer acts as a hydraulic safety barrier. Currently, the main concern is the shrinkage behavior of this material, which occurs mainly during the construction phase, when exposed to the elements. Naturally, the risk of contamination of soil and water bodies increases significantly due to this problem. Recent studies have shown that the initial moisture content of GCL and the hydration and rehydration dynamics of this material by the subgrade are important factors in shrinkage behavior. Exposure to daily thermal cycles imposes a loss of moisture from the GCL to the foundation soil. However, there are certain moisture indices in which the subgrade may rehydrate this material, canceling or attenuating the significant moisture loss and consequently the shrinkage values found. Considering the tropical climatic and the field conditions to which GCL can be submitted in Brazil, the present work evaluated the shrinkage a calcium (Na-added) GCL samples submitted to 50% initial water content and with 100% initial water content, after 15 days of hydration-drying cycles. The results showed influence of GCL initial water content and shrinkage behavior. Also, this GCL showed similar shrinkage to some data found in the literature for other GCLs.

RESUMO
Um dos principais desafios na implementação de aterros de resíduos sólidos é o alto grau de controle do lixiviado produzido no sistema. A vedação desses sistemas é garantida pela combinação de um subleito de argila compactada de baixa condutividade hidráulica (CCL), um revestimento geossintético de argila e uma geomembrana. Nesse contexto, o estudo do desempenho da GCL é fundamental, pois essa camada atua como uma barreira de segurança hidráulica. Atualmente, a principal preocupação é o comportamento de retração desse material, que ocorre principalmente durante a fase de construção, quando exposto aos elementos. Naturalmente, o risco de contaminação do solo e dos corpos d'água aumenta significativamente devido a esse problema. Estudos recentes mostraram que o teor de umidade inicial do GCL e a dinâmica de hidratação e reidratação desse material pelo subleito são fatores importantes no comportamento de retração. A exposição aos ciclos térmicos diários impõe uma perda de umidade do GCL para o solo da fundação. No entanto, existem certos índices de umidade nos quais o subleito pode reidratar esse material, cancelando ou atenuando a perda significativa de umidade e, consequentemente, os valores de encolhimento encontrados. Considerando as condições climáticas tropicais e as condições de campo às quais a GCL pode ser submetida, o presente trabalho avaliou o comportamento de retração de um GCL de bentonita cálcica (sódio adicionado) com teor de umidade inicial de 50% e também com 100%, submetidos a 15 ciclos de hidratação e secagem. Os resultados mostraram influência do teor de umidade inicial na retração do GCL. Ainda, os valores encontrados para esse GCL brasileiro encontram-se coerentes com dados da literatura do tema para outros GCLs.

1. INTRODUCTION

Solid waste landfills are complex and costly geotechnical works that require high technical control for their correct operation. One of the most sensitive parts of this type of construction is ensuring tightness, preventing contamination of foundation soil and water bodies. With the objective of waterproofing the base of the landfill, hydraulic barriers (liners) are constructed. These barriers have low permeability, adsorption and self-healing ability, as well as considerable mechanical strength. Hydraulic barriers are widely used in engineering works and especially in geotechnical works (Rowe 2005; Touze and Bannour 2019).

Geosynthetic clay liners (GCLs) are geosynthetic materials that have gained technical and economic viability compared to compacted clay liners (CCLs), which can present high costs mainly due to the transport of soil material. GCLs are planar geosynthetics which structure is composed by geotextile components (needle punching fixed) and bentonite. Bentonites (typically sodium bentonite) are the most used to produce GCLs, and according to Rowe (2018), their use is known for to its low permeability to liquids and gases when well hydrated. In Brazil, the bentonites found to produce GCLs are typically calcic and are found in the region northeast of the country. Besides Sodium is added to the Bentonites in order to meet GCL requirement parameters, there is no much information in the literature regarding Brazilian GCL performances.

During GCLs installation in the field, manufacturers usually recommend a 15 cm overlap in the longitudinal direction between GCL panels and some extra inclusion of bentonite in the overlay to ensure impermeability prior to exposure before geomembrane cover (ASTM 6102; Rowe et al. 2012). Once the hydraulic barrier is constructed, an insulating cover soil layer must be applied as soon as possible within a maximum of 30 days (Rowe et al. 2009; Rowe et al. 2013). However, the construction methodology present in the country currently leads to incorrect procedures in the application of geomembranes and GCLs. In this case, de composite liner is left exposed to climate conditions (Take et al. 2012). Findings of GCL shrinkage in overlaps began to be studied by Koerner and Koerner (2005) in solid waste landfills dating from 1993. Authors understood GCL shrinkage as an isolated anomaly, a theory that was discarded when four other cases with this problem were identified.

Thiel et al. (2006) showed observations related to GCLs covered with a geomembrane, which was left exposed from two months to five years prior to soil covering finding panel shrinkage of 3.3% to 30% from the original panel width. Thiel et al. (2006) also present six case studies in solid waste landfill works (without the liner cover soil layer), where the shrinkage behavior in the overlapping regions was identified even with the application of a 15 cm overlap in the installation phase. Analyzes showed shrinkage from 20 to 120 cm and solid waste landfills with different types of GCLs (woven and nonwoven geotextiles), and different GCL weathering. Several reports in the literature show studies of shrinkage in GCL panels (Koener and Koener 2005; Brachman et al. 2014; Brachman et al. 2018). This same effect was found in laboratory analyzes in the studies of Thiel and Richardson (2005), Bostwick et al. (2007) and Acikel et al. (2018).

Researchers found potential causes for GCLs shrinkage based on the following hypotheses: (1) wetting and drying cycles, caused by exposure to temperature variation; (2) heat during the day and low temperatures at night and at dawn; (3) tensions imposed by the inclinations of the GCL; (4) GCL contraction on steep slopes; (5) shrinkage of GCL manufacturing materials – bentonite shrinkage due to desiccation and shrinkage of one or both geotextile components; (6) GCL capacity to take up moisture from the foundation soil and influence of GCL rehydration (Koerner and Koerner 2005; Thiel et al. 2006; Rowe et al. 2011; Take et al. 2012; Rowe et al. 2013; Take et al. 2015; Mukunoki et al. 2019).

Thiel et al. (2006) evaluated GCLs shrinkage by simulating field conditions (cyclic hydration-drying test) using GCLs with various initial water contents, obtained by adding water at each hydration sequence. The results showed significant deformation for different GCL initial moisture contents, showing that hydration and drying can have significant impact in GCL shrinkage. This paper focuses on GCL shrinkage effects under cyclic hydration-drying using laboratory analysis and Brazilian climate conditions. Shrinkage panel tests were used in order to evaluate the performance of a GCL commonly used in Brazil, with different initial water contents.

2. MATERIAL AND METHODS

2.1 Geosynthetic Clay Liner

The GCL used in the present research is a powder calcium (Na-added) bentonite, sandwiched between a nonwoven cover and a carrier geotextile in needle punched manufacturing process (Figure 1). This product was chosen because it is widely used in Brazil and in order to understand the behavior of GCLs with powder bentonite extracted from national territory.

(a) GCL materials (b) Bentonite

Figure 1. GCL used in this research.

In order to evaluate GCL properties, presented in Table 1, all tests were conducted at the Laboratory of Geotechnics at the Federal University of Sao Carlos, except XRD analysis that were conducted at the Structural Characterization Laboratory - LCE at UFSCar.

Table 1. GCL Properties.

Component	Properties	Symbol	Units.	GCL	Reference
Bentonite	Granularity	-	-	Powder	-
	Grainsize distribution	D_{10}	mm	-	NBR 7181
		D_{30}	mm	-	
		D_{60}	mm	-	
		D_{90}	mm	0.07	
	Plastic Index	PI	%	253%	NBR 7180
	Dry mass per unit area	MA	g/m²	3878.5	ASTM D5993
	Swell Index	SI	ml/2g	18	ASTM D5890
	Fluid Loss	FL	ml	18	ASTM D5891
	Smectite content	-	%	80%	XRD
Carrier Geotextile	Type	-	-	WGT	-
	Mass per unit area	MA	g/m²	100	ASTM D5261
Cover Geotextile	Type	-	-	NWGT	-
	Mass per unit area	MA	g/m²	270	ASTM D5261
GCL	Thermal Treatment	-	-	Yes	-
	Off-roll thickness	-	mm	7.0	ASTM D1776
	Off-roll water content	w_{ref}	%	10.34	ASTM D2216
	Hydraulic Conductivity	KTW	$m^3/m^2/s$	10^{-11}	ASTM D5887

2.2 Shrinkage tests

Two samples of GCL were analyzed in this research. The first sample, named GCL-1, was cut in the dimension of 600 mm (machine direction) by 250 mm (cross-machine direction) and was placed at aluminum pans with its initial moisture content (10.3%). The samples was clamped to the smallest dimensions using bar metal clamps. Clamps were used to simulate installation field conditions in slopes. The second sample, named GCL-2, was cut in the dimension of 700 mm (machine direction) by 350 mm (cross-machine direction). Thiel et al. (2006) and Bostiwcki et al. (2010) previously used the same methodology. In both samples, markers were used in order to monitor GCL strains after hydration-drying cycles.

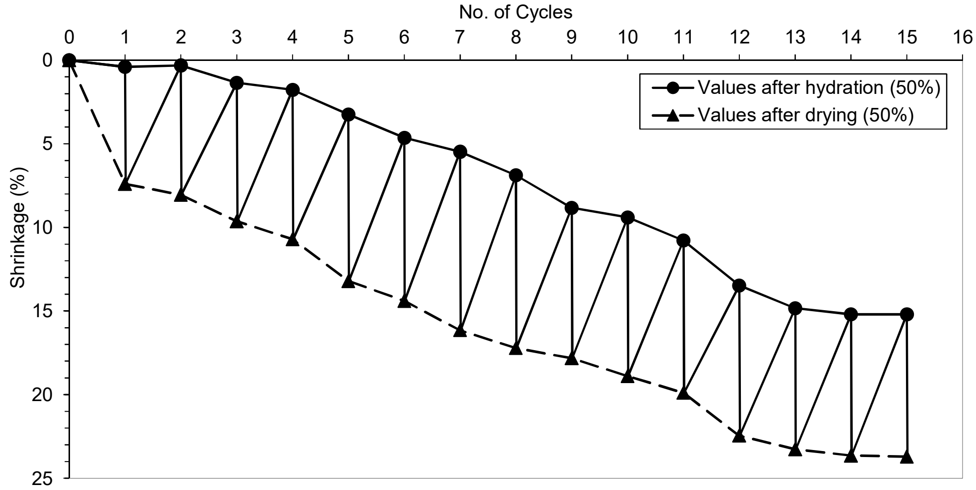
The hydration process was conducted using 550 ml of water, applied over GCL central portion area, to reach 50% initial water content. Sample 2 was moistened with 1100ml in order to achieve 100% water content. Both moisture contents were chosen as typical range of GCL water content found in the field. According to Daniel et al. (1993) and Thiel et al. (2006), field moisture of a GCL was found to be around 65% when hydrated by the subgrade. At the end of the spray-wetting step (Figure 2a), for a period of 8 hours, samples were placed in oven with constant air circulation at 60ºC and left to dry to complete 24 hours (1 cycle). After removal from the oven and cooling (1 hour), measurements of GCL strains were taken (Figure 2b). Then, a new a cycle of rehydration started. A total of 15 cycles were conducted for each sample. Photographs of each sample were taken before and after each cycle.

(a) GCL hydration (b) measurement in sample width at mid-point marks

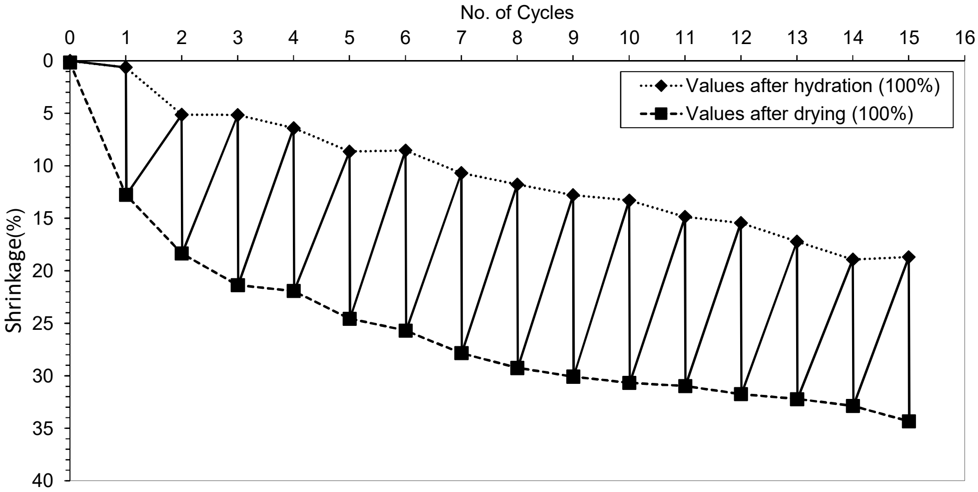
Figure 2. Hydration and measurement procedure.

3. RESULTS AND DISCUSSION

Figure 3 shows GCL shrinkage in sample width as function of number of cycles for both initial water contents. Results are plotted after hydration and after drying in order to obtain residual and reversible shrinkage. After 15 cycles of wetting and drying in GCL-1, a shrinkage of 23.7% was observed and 34.3% in in GCL-2. Figure 4 shows a comparison between results. This result show that the initial water content have influenced shrinkage and higher initial water content led to higher shrinkage. Another significant result is the residual shrinkage, expressed as the difference between GCL shrinkage after drying cycles and after hydration. At the end of the tests, it was observed 8.5% of residual shrinkage for GCL-1 and 15.5% for GCL-2.



(a) GCL-1



(b) GCL-2

Figure 3. Percentage shrinkage versus No. of cycles.

Figure 5 shows the initial sample setup compared to samples at 15 cycles of hydration and drying. These shrinkage behavior is consistent with those observed in the studies by Thiel et al. (2006) and Bostwick et al. (2010) and are significant for a relatively small number of cycles, since these materials can be exposed to weathering for years in the field. According to the present results, shrinkage limit has not been reached since the curves show that there is still a tendency to additional shrink. Consequently, more cycles would be needed to better evaluate shrinkage behavior in this GCL type.

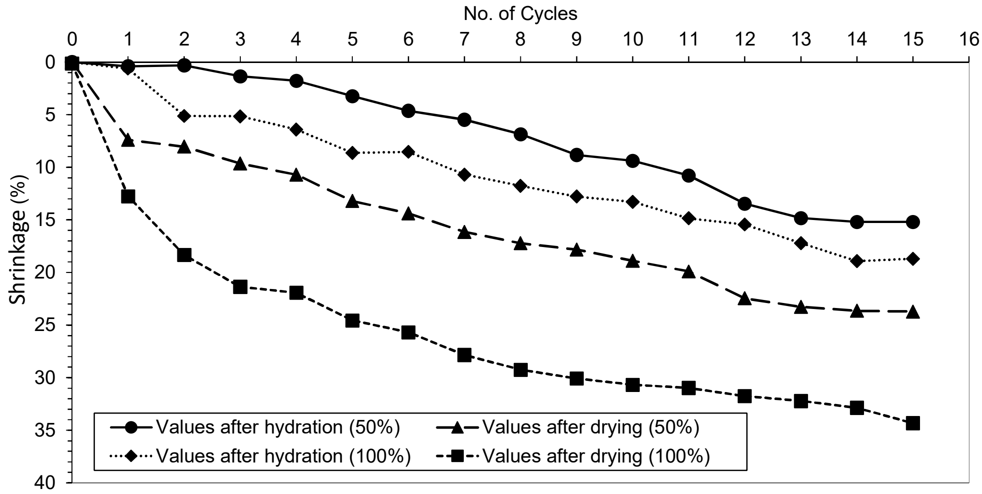
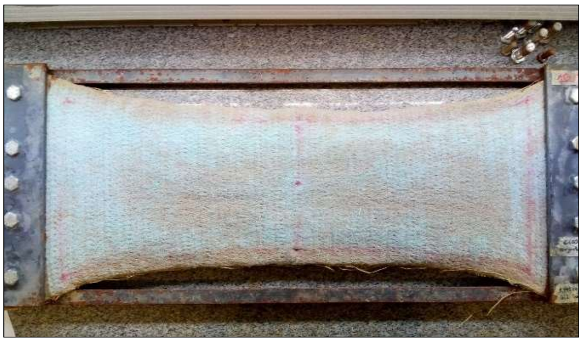


Figure 4. Comparison between percentage shrinkage with different GCL initial water content.

(a) GCL-1 before tests

(b) GCL-2 before tests

(c) GCL-1 after tests



(d) GCL-2 after tests

Figure 5. GCL samples before and after 15 hydration-drying cycles.

4. CONCLUSIONS

GCL shrinkage analysis has become increasingly necessary due to the importance of this material in ensuring the tightness of coatings in their various applications. It is necessary to analyze the performance of this material in similar condition was in the field, and establish new criteria for the implementation of safe hydraulic barriers. The present work evaluated the shrinkage of a calcium (Na-added) GCL sample submitted to 50% initial water content and with 100% initial water content, after 15 days of hydration-drying cycles.

Results show that there is influence of GCL initial water content in the shrinkage behavior. Shrinkage observed in GCL samples, with 50% and 100% initial water contents was significant. GCL hydrated with 50% initial water content presented a maximum deformation of 23.7% and a residual shrinkage of 8.5%, while GCL hydrated with 100% initial water content presented a deformation of 34.3% and a residual shrinkage of 15.6%. In addition, this GCL, made with powder calcium (Na-added) bentonite, showed similar shrinkage to some data found in the literature for other GCLs.

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