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# Effect of polymer elution on interface shear strength between bentonite-polymer composite geosynthetic clay liners and geomembranes

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## ABSTRACT

Interface shear strength between bentonite-polymer composite geosynthetic clay liners (BPC-GCLs) and a textured geomembrane (GM) was investigated and compared to the interface shear strength between conventional Na-bentonite GCLs (NaB-GCLs) and the GM. Lower peak shear strength was observed in BPC-GCL/GM interfaces compared to NaB-GCL/GM interfaces under the same normal stress. Elution of hydrated polymer gel with low shear strength into the BPC-GCL/GM interface was identified as the cause of lower interface shear strength.. Polymer elution was greatest during hydration, but also occurred during shearing.

**Keywords:** geosynthetic clay liner; polymer content; shear strength; interface; geomembrane; elution.

## 1 INTRODUCTION

Geosynthetic clay liners (GCLs) are often used in lieu of compacted clay as liners for waste containment facilities. Conventional GCLs consist of a layer of sodium bentonite (NaB) sandwiched between two carrier geotextiles.When used in a composite liner, the lower carrier geotextile of the NaB-GCL is placed in contact with the soil subgrade, whereas the upper geotextile is in contact with the geomembrane (GM). Physical stability of a waste containment facility with a composite liner is controlled by the shear strength of the interface between the GCL and the GM (Daniel et al. 1998, Qian et al. 2002, Fox and Stark 2015, Hanson et al. 2015, Suzuki et al. 2017).

Bentonite-polymer composite (BPC) GCLs have been introduced over the past decade for applications where NaB-GCLs are chemically incompatible with the leachate to be contained (Trauger and Darlington 2000, Ashmawy et al. 2002, Di Emidio et al. 2011, Benson et al. 2014, Scalia et al. 2014, Di Emidio et al. 2015, Tian and Benson 2016, Chen et al. 2018). The hydraulic conductivity of BPC-GCLs is controlled in part by viscoelastic polymer gel that fills pores between the bentonite granules (Tian et al. 2016, Chen et al. 2019, Gustitus and Benson 2020). Hydraulic or mechanical forces can induce elution of the polymer gel, leaving a thin layer of weak gel in the BPC-GCL/GM interface in a manner similar to bentonite extruded into a NaB-GCL/GM interface (Chen et al. 2017). Elution of the gel can alter the shear strength of the interface and affect the stability of the waste containment system. However, limited data are available on the shear behavior of BPC-GCL/GM interfaces.

The effect of polymer elution on the interface shear strength between BPC-GCLs and a textured GM was evaluated in this study using large-scale direct shear tests. BPC-GCLs with different proprietary polymers and polymer loading were evaluated.

## 2 MATERIALS AND METHODS

### 2.1 Geosynthetic Clay Liners

Six GCLs from two different manufacturers were used in this study: two NaB-GCLs, denoted as CS and GS; and four BPC-GCLs denoted as CP1.2, CP5.1, GP3.3 and GP10.9. The prefix of the sample identifier represents the manufacturer, and the numerical suffix represents the polymer loading in the BPC (% by dry mass). All six GCLs are commercially available in the US. Their hydraulic properties are reported in Chen et al. (2019).

The BPCs were produced by dry blending granular bentonites and granular polymers. The polymer formulations are proprietary to the GCL manufacturers. However, they contain water soluble and/or water swellable polymers. The granular bentonite or BPC in each GCL was encapsulated between a woven and a nonwoven geotextile bound together by needle-punching. Loss on ignition (LOI) was used as a surrogate measurement for polymer content for each GCL following the method described in Scalia et al. (2014). Polymer loading was examined across the GCL roll at a minimum of five locations with duplicate measurements for each location.

### 2.2 Large-Scale Direct Shear Tests

Large-scale direct shear tests were conducted following ASTM D5321 to evaluate the shear strength of the GCL/GM interface. Each GCL specimen (305 mm x 305 mm) was gently trimmed from GCL rolls using a sharp utility knife, with the sides of the specimen carefully sealed with packing tape to prevent loss of NaB or BPC. The non-woven side of the GCL was placed in contact with a 1.5-mm-thick textured HDPE GM (GSE HD Textured, GSE Environmental, Houston, TX) for testing. All tests were conducted with shearing in the machine direction. Normal stresses of 20, 100, 250 and 400 kPa were applied. Interface shearing as conducted at a constant rate of 0.1 mm/min to a final displacement of 50 mm.

Interface shear tests are conducted in many studies to simulate site-specific conditions, including hydration and consolidation (Byrne 1994, Stark and Eid 1996, Gilbert et al. 1997, Pavlik 1997, Daniel et al. 1998, Eid et al. 1999, Triplett and Fox 2001, Vukelic et al.2008, Chen et al. 2010, Daniel 2013, Fox and Stark 2015). In this study, all specimens were hydrated using DI water under a normal stress of 10 kPa for 24 h prior to shear at the target normal stress. This consistent approach was ensured that all speicmens were hydrated under similar conditions. However, the degree of hydration may have varied between different types of GCLs, and hydration of the GCLs may have been incomplete.

### 2.3 Shear Behavior of Hydrated Polymer Gels

The viscoelastic behavior of the hydrated polymer gels that elute from a BPC-GCL can affect the shear strength of the BPC-GCL/GM interface. When hydrated, viscoelastic polymers transition to behave more like liquids than solids above a certain shear stress, known as the flow stress (Mezger 2015). Flow stress of hydrated polymer gels similar to those contained in the CP1.2 and CP5.1 BPC-GCLs was measured. The polymer was hydrated to moisture contents of 200%, 500%, 1000% and 2000%, which represents a range of conditions observed during the shear tests. Flow stress of the hydrated polymer gels was determined by measuring the storage modulus and loss modulus of the gels using shear-strain-amplitude sweeps with controlled-shear deformation on an Anton Paar MCR 302 rheometer (Anton Paar, Austria). Flow stress was taken as the stress at which the storage modulus equaled the loss modulus. Amplitude sweeps were completed over a range of 0.01-10,000% shear strain, using a 25-mm-diameter sandblasted parallel plate.

## 3 RESULTS AND DISCUSSION

### 3.1 Interface Shear Stress-Displacement Behavior

Relationships between shear stress and horizontal displacement of the GCL/GM interfaces at 400 kPa are shown in Fig. 1. Similar shaped shear stress-displacement relationships were obtained at other normal stresses. The shear resistance increases rapidly after test initiation, reaching a peak shear stress at a displacement of 6.5-23 mm, which is similar to displacements reported in prior studies (Triplett and Fox 2001, Chiu and Fox 2004, McCartney et al. 2009). As displacement continues, a post-peak strength reduction occurs for all of the interfaces. Residual shear strength was not reached for any of the tests.

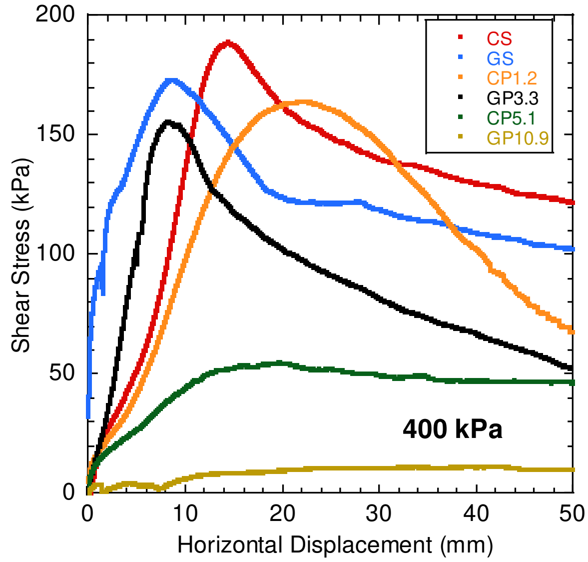


Fig. 1. Shear stress-displacement relationships of BPC GCLs to textured GM.

In Fig. 1, the peak and large-displacement (LD) interface strengths (shear stress at 50 mm) are inversely related to polymer loading in the BPC-GCLs, and are highest for the NaB-GCLs (CS and GS) that have no polymer. The interfacial displacement at peak strength for the BPC-GCLs typically is higher than for the interfaces with NaB-GCLs (GP3.3 is an exception). This trends suggest that the polymer is affecting the shear beavior of the interface.

### 3.2 Elution of polymer into the interface

During shearing, bentonite extruded into the interface for both NaB-GCLs and BPC-GCLs. For the BPC-GCLs, polymer also eluted into the interface. When the interface was separated after a shear test, a thin layer of polymer gel was present that appeared to have flowed along the non-woven geotextile of the GCL.

To assess polymer elution during different stages of shear testing, LOI was measured on sacrificial specimens of GP3.3-GCL during four points of shear testing at 250 kPa normal stress (post hydration, peak strength, and LD strength) (Fig. 2). The original GP3.3-GCL had a LOI of 5.6% ± 0.7 %, which decreased to 4.7% ± 0.4% after hydration in DI water for 24 h under 10 kPa overburden stress. After shearing to peak shear strength, the LOI was 4.6% ± 0.01%, slightly lower than the post hydration LOI. When sheared to the large displacement condition (50 mm), the LOI decreased to 4.2% ± 0.4%. Over the entire test, the LOI dropped 1.4%, indicating that 25% of the polymer was lost during testing.

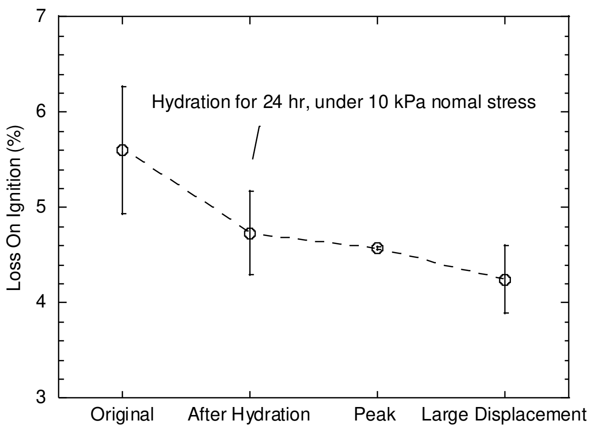


Fig. 2. Effect of hydration on polymer laoding of BPC-GCL, with lower LOI corresponding to greater elution.

The decrease in LOI, and polymer loading within the BPC, is attributed to polymer elution, as evinced by polymer present in the GCL-GM interface. During hydration, polymer elution is likely due to swelling and diffusion rather than extrusion because the normal stress was low (10 kPa). Polymer elution during shearing could be due to stresses within the BPC or the non-woven geotextile. As indicated in Fig. 2, more polymer is eluted during hydration than during shearing.

The polymer gel in the GCL/GM interface was much softer than extruded bentonite, creating a thin layer with very low shear resistance within the interface. To evaluate the resistance of the gel, a polymer of similar proprietary structure to the polymer in the CP BPC-GCL was hydrated and tested in the rheometer to determine the viscous behavior. Flow stress of the polymer gel is shown as a function of gel moisture content in Fig. 3.

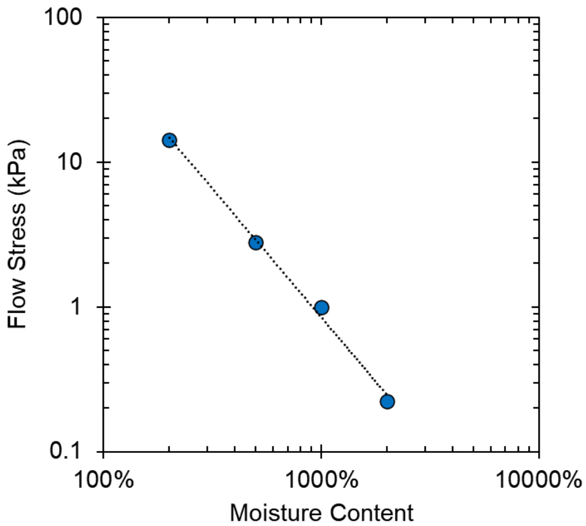


Fig. 3. Flow stress of the hydrated polymer gel as a function of moisture content for polymer hydrated with DI water.

The polymer had a maximum flow stress of 14 kPa at a gel moisture content of 200%, which is less than the peak shear stress obtained during shearing of the BPC-GCLs. The polymer gel with a 200% moisture content was notably more viscous than the polymer observed in during shear testing of the BPC-GCL/GM interfaces. The gel in the interface was visually similar to polymer hydrated to 1000% moisture content, which had a flow stress of 1 kPa. This very weak gel in the interface likely contributed to lower shear strength of the BPC-GCL/GM interfaces.

As shown in Fig. 1, both the peak and large-displacement shear strengths for the BPC-GCL/GM interfaces decrease with increasing polymer loading in the BPC-GCL. This likely occurs because more polymer is available to elute at higher polymer loading, resulting a greater amount of weak gel in the interface during shearing.

## 4 CONCLUSIONS

Large scale shear tests were conducted under normal stress ranging from 20 to 400 kPa to evaluate the interface shear strength between a textured geomembrane (GM) and GCLs containing sodium bentonite (NaB) or bentonite polymer composite (BPC). Based on the findings of this study, the following conclusions are drawn:

- BPC-GCL/GM interfaces have lower peak and large-displacement shear strength than conventional NaB-GCL/GM interfaces. The reduction in peak shear strength is attributed to elution of polymer hydrogel into the interface. Peak shear strength of the BPC-GCL/GM interface decreases with increasing polymer loading in the BPC.
- Polymer elution into the interface occurred predominantly during the hydration stage, although some elution into the interface occurred during shearing.

Additional study should be conducted to determine how type of polymer in the BPC affects the propensity for elution, and the impact of polymer type on shear strength of the BPC-GCL/GM interface.


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