Improvement on the Performance of Geosynthetic Clay Liners Using Polymer Modified Bentonite

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ABSTRACT: Polymers have been added to improve bentonite swelling capacity with the view of improving the hydraulic performance of GCLs. This paper presents an on-going study in which three bentonites were polymer-treated (0.5%, 1%, 2% by weight) and polymer-included changes to swell index and Atterberg limits were determined. The liquid limit values generally increased with polymer content, although a decrease appeared at higher concentration of some polymers. However, polymer addition had only slight effects on plastic limits. Higher polymer concentration, regardless of type, generally resulted in higher swell index values and swell percentages. Different response of bentonites to polymers occurred which is mainly due to the individual characteristics of bentonites, such as chemical composition, type of gel formation etc.

1. INTRODUCTION

Geosynthetic clay liners (GCLs) are thin (typically 5 to 10 mm) manufactured hydraulic barriers comprised of a layer of bentonite bonded between layers of geotextiles and/or to a geomembrane. They are commonly used in waste containment facilities due to their low permeability to water and ease of installation. It is known that the bentonite component provides the primary contribution to swelling of GCLs which results in their low hydraulic conductivity. Higher liquid limit and swell index values generally result in lower hydraulic conductivity (Lee and Shackelford 2005; Katsumi et al 2007); therefore improvement in these values in bentonite may provide lower hydraulic conductivity and better performance of GCLs. Some research revealed that modified bentonite can be used as catalyst or reinforcer in chemistry such as improving the conduction of polymer composite electrolytes or modifying the hydraulic conductivity and strength of cement mortars (Theng 1980; Ortego et al. 1995). Research in polymer science showed the effectiveness of polymers on improving the swelling of clay (Grandjean and Laszlo 1996; Choudalak and Gotsis 2009), but they did not connect this swelling to engineering indexes, such as Atterberg limit and swell index, normally used by geotechnical engineers. Gates et al. (2004) suggested that alkylammonium cation modified clays promoted swelling of bentonite to some leachates. Onikata et al. (1996; 1999) mixed natural bentonite with a swelling–activation agent (propylene carbonate) and found that the swelling was improved relative to natural bentonite.

This paper reports on polymer modified bentonites in which three types (cationic, non-ionic and anionic) of polymers were added to three commercially available bentonites, two of which are currently used in GCLs. Both Atterberg limits and swell index tests were conducted to check the effectiveness of polymers on improving the bentonites swelling potential and impacting on the Atterberg limits.

2. LABORATORY TESTING PROGRAM

2.1 Materials

Three bentonites were selected for the purpose of this study. Bentonite 1 was powdered sodium-magnesium bentonite from Australia and had received no further beneficiation other than drying and grinding at the plant. It is a low swelling material. Bentonite 2 was an activated powdered sodium bentonite from Australia which has had an undisclosed beneficiation (besides drying and grinding). Bentonite 2 is a moderately swelling material. Bentonite 3 was a powdered natural sodium bentonite from South Africa which received no additional beneficiation other than drying and grinding. Bentonite 3 is a high swelling material. Properties of these bentonites are provided in Table 1. Both moisture content and density were measured on as received samples.

Three polymers were all water soluble white powder and either cationic (polymer 1), non-ionic (polymer 2) or anionic (polymer 3). Polymers were provided by Ciba.

Table 1 Bentonite Properties

Samples	Bentonite 1	Bentonite 2	Bentonite 3
Composition	Na-Mg	Sodium	Sodium
Swelling	Low	Moderate	High
CEC (cmol/kg)*	116	100	92
Plasticity Index (%)	128	528	429
Moisture Content (%)	14.85	11.35	13.85
Density (g/cm^3)	2.65	2.68	2.66
Origin	Australia	Australia	South Africa

*estimated by Methylene blue adsorption (ASTM C 837)

2.2 Testing Program

2.2.1 Swell Index Tests

Swell index tests were performed according to ASTM D 5890-Swell Index (SI) of Clay Mineral Component of Geosynthetic Clay Liners. Three dry powdered bentonites with different concentrations (0.5, 1, 2 wt. %) of polymers were prepared for the tests.

The procedure of swell index was as follows: 2 g of dry bentonite, which was previously oven dried at 105±5˚C to constant weight, was added slowly to a 100mL graduated cylinder containing 90 mL of deionized water to undergo free hydration. Increments of 0.1 g of bentonite were spread over the surface of the water every 10 minutes until the whole 2.0 g were added. After a minimum of 16 hours hydration, the volume of swollen bentonite was read in millilitre, and was reported as the swell index of bentonite in millilitre per 2 g (mL/2g) of dry bentonite. Tests of specimens with different concentrations of polymers were performed according to the same procedures above. All tests were duplicated.

2.2.2 Atterberg Limits Tests

The tests were conducted according to ASTM D 4318- Standard test methods for liquid limit (LL), plastic limit (PL), and plasticity index (PI) of soils. Three polymers at different concentrations (0.5, 1, 2 wt. %) were mixed with three bentonites to observe the effect on Atterberg limits.

For liquid limits, the tests were conducted using the Casagrande method. Specimens having three different moisture contents were prepared as follows: the proper moisture content was selected to conduct the first test; then water was added to the tested sample to obtain new moisture content, the new-prepared sample was set aside for 16 hours. The third sample was prepared following the same procedure, and data were plotted to obtain a relationship from which the determined liquid limit. For plastic limit, the test was conducted by rolling the specimen into a 3.2 mm diameter thread until its water content reduced to a point at which the thread crumbled and no longer could be pressed together and re-rolled. The gravimetric water content of the bentonite at this point was determined and considered the plastic limit. Plasticity index was calculated as the difference between LL and PL. Tests of specimens with different concentration of polymers were performed according to the same procedures above. All tests were duplicated.

3. RESULTS AND DISCUSSION

3.1 Swell Index Tests

Results from swell index tests are shown in Figure 1. Bentonite 1 always had the lowest swell index regardless of the polymer content, with a maximum value achieved of 14mL/2g. Also, bentonite 1 and bentonite 3 were relatively insensitive to the polymers; their swelling percentages above the no-additive control are substantially lower than observed for bentonite 2. Bentonite 2 is the most sensitive to all three polymers, the swelling percentage of which is 80 to 160% at higher polymer concentrations.

For bentonite 1, having the lowest swell index values and lower swelling percentage suggest that gel formation was marginal by adding these three polymers. While all three polymers, regardless of their ionicity, increased the swelling of bentonite 1 by the same amount (~30% increase at 2% addition), there is some indication that levels of anionic polymer at <0.5% may have a greater impact on swelling.

For bentonite 2, with a moderate initial swell index, the SI values were significantly increased by even small addition of all the polymers. The swell index increased to 45mL/2g at 0.5% addition of polymer 1, doubling the initial SI. Further addition of polymer had little effect on SI. Polymers 2 and 3 had similar effect as polymer 1, but polymer 3 showed a greater effect at the highest concentration.

For bentonite 3, although it is a natural sodium bentonite with a high initial SI (31mL/2g), the effect of adding polymers was not significant. Only polymer 3 resulted in increased swelling of about 20% beyond the initial SI and polymer 1 added at rates of 0.5% to 1% resulted in a negative effect, but 2% addition only moderately increased the SI measured.

The addition to bentonite 2 of all three polymers at the highest rate (2%) resulted in swelling percentage >100%, but for bentonites 1 and 3 the SI were about 30% and 20%. Bentonite 1 is of low initial SI (11mL/2g) which is much lower than the threshold of industrial required SI (24mL/2g). Although increased by adding polymers, the SI values were still far from the threshold. The reason may result from the composition of the exchangeable cations in this bentonite, which comprises sodium and magnesium. The existence of Mg may degrade its capacity to form a gel. The initial SI (20mL/2g) of bentonite 2 is marginally below the industrial threshold for GCL product (24mL/g) and addition of any of the three polymers, at 0.5%, improved the SI well beyond the required SI. However, care should be taken with polymer addition beyond 1%, as the slight increase in SI may suggest that the transition of gel formation from clay control to polymer control. Although no obvious increase occurred, the Initial SI of bentonite 3 (31mL/2g) was initially higher than the industrial threshold. Other polymers should be used to further check the effectiveness on improving the SI.

3.2 Atterberg Limits Tests

The measured data from the Atterberg limits tests are shown in Figure 2. As shown, polymers only increased liquid limit values but slightly affected plastic limit values. These effects resulted in changes to the plasticity index that mostly mirrored changes in the liquid limit. Results indicate that different polymers exerted various

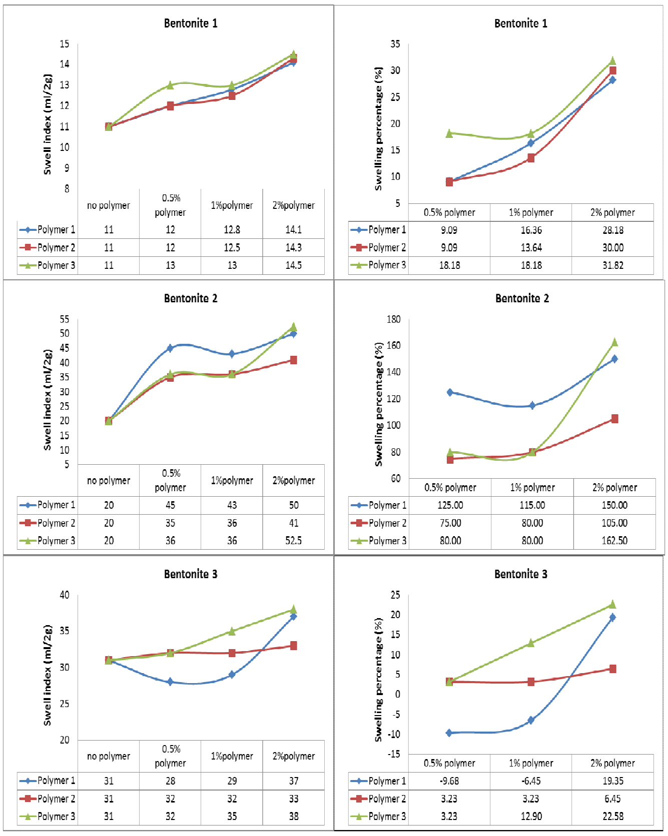

Figure 1 Swell index results of three bentonites to different polymers

influences on liquid limits of the same bentonite and the same bentonite showed different response to different polymers; a greater concentration of polymer did not always lead to higher liquid limit or plastic limit. In other words, there appears to be an optimum polymer loading in relation to liquid limit, dependent on the type of polymer (anionic, cationic, and non-ionic) and the intrinsic properties of the bentonite (low, moderate or high swelling). Of all three bentonites, Bentonite 1 had the lowest liquid limit values and bentonite 2 yielded the highest liquid limit values except for with polymer 2 at a concentration greater than 0.5%.

Bentonite 1 showed a positive response to polymer 1 with increasing concentration, but a negative effect to polymer 2 at original concentration. For polymer 3, the effect was positive to 0.5% but negative at concentrations greater than 0.5%.

For bentonite 2, addition of polymers 1, 2 and 3 at rates of 1%, 0.5% and 0.5%, respectively, increased the liquid limit, but the liquid limit decreased with higher additions, even to values lower than the original in the case of polymers 2 and 3. Polymer 2 had no positive effect on the liquid limit, and therefore, to the plasticity index of bentonite 2.

For bentonite 3, all three polymers generally imposed a positive effect on the liquid limit and resulting plasticity index, especially at lower concentration. Three polymers promoted an increased liquid limit to the levels tested, although for polymers 1 and 2, the effect beyond 1% addition was minimal.

The addition of polymer 1 increased the liquid limit of bentonite 1 by ~80% and of bentonite 2 and bentonite 3 by about 40% each at 1% addition. Polymer 3 had an even greater effect on bentonite 1 at 1% and also for bentonite 2, but not bentonite 3. Polymer 2 had little positive effect on bentonite 2, but a slight positive effect on bentonite 3. Bentonite 3 was the only one in which the addition of polymer 2 had a positive impact on liquid limit. The plasticity index is a measure of the plasticity of bentonite. High value generally provides high swelling of clay and lower permeability for GCLs. During the experiment, gel formation was obtained even at addition of 0.5% concentration for bentonite 2; therefore, lower LL values at higher concentration may suggest gel formation may shift from clay mineral style to polymer style which has a completely different structure from clay mineral.

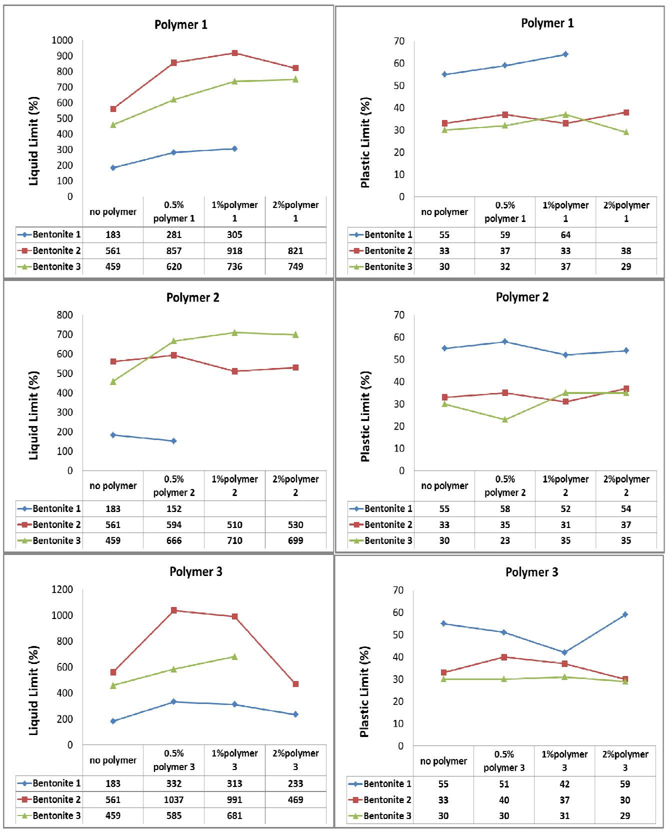

Figure 2 Atterberg limits results of three bentonites to different polymers

4. CONCLUSION

Results of laboratory tests show the changes of Atterberg limits and swell index values after adding three types of polymers (cationic, anionic, non-ionic) to three different bentonites (low SI, moderate SI and high SI). For Atterberg limits, LL values generally increased by adding polymers although a limit to the effect was observed at higher concentration of some polymers. While only slight changes occurred on PL, the resulting plastic index mirrored the changes in LL. Without considering factors such as availability, economic cost etc., the optimum content of the most effective polymers are: bentonite 1 with 0.5% polymer 3; bentonite 2 with 0.5% polymer 3; bentonite 3 with 2.0% polymer 1.

For swell index, higher concentration generally resulted in higher SI. Bentonite 3 was relatively insensitive to the polymers probably because it had an initial high SI, which is higher than the industrial threshold. While all polymer additions improved the SI of bentonite 1, with the lowest initial SI, the effects were insufficient to bring the SI value to one suitable for use in GCLs based on current industrial specifications. Bentonite 2 was the most sensitive to all three polymers, the swelling percentage of which is nearly 200% at higher concentration. Different response of bentonites to polymers is mainly due to the individual characteristics of bentonites, such as chemical composition, type of gel formation etc.

According to the relationship between Atterberg limits, swell index and hydraulic conductivity, adding polymers into bentonite may provide lower hydraulic conductivity and better performance of geosynthetic clay liners.

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