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Experimental investigation on index properties of polymerized clays

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ABSTRACT

Many engineering applications use geosynthetic clay liners (GCLs) containing sodium bentonite (NaB) as hydraulic barriers. GCLs possess low permeability and high self-healing capacity. The interaction of NaB-GCL with permeants containing highly concentrated solutes and cation valence may compromise these properties, making them unsuitable for barrier applications. Hence, several bentonite polymer composites (BPCs) have been actively explored to surmount this drawback. BPCs showed a very low permeability upon exposure to aggressive permeants compared to untreated NaB. However, their performance focusing on index properties under such exposure conditions has not been thoroughly explored due to the difference in polymer types and their confidential chemical formulations. Therefore, the present study aims to investigate the variation of Atterberg limits and swell index of a new type of polymerized bentonite (PB) with three different electrolyte solutions: NaCl, $CaCl_2$, and $AlCl_3$, each having a concentration range of 5 to 1000 mM. The results indicated that the swell index and liquid limit of NaB and PB (5% polymer dose) decreased with increased cation valence and pore fluid concentration. The comparison of NaB and PB results suggests that the properties are primarily affected by the pore fluid chemistry and its effect on clay microstructure and polymer conformation. Further, permeability tests of PB with different electrolyte solutions are in progress which helps in correlating the response of hydraulic behavior with their index properties.

Keywords: polymerized bentonite, free swell index, liquid limit, geosynthetic clay liner, permeability, bentonite polymer composite

1 INTRODUCTION

Geosynthetic clay liners (GCLs) containing sodium bentonite (NaB) are widely used as hydraulic barriers in many geoenvironmental engineering applications. The low permeability and high self-healing capacity of NaB made GCLs popular for their use in containment barriers. However, the challenges associated with the chemical incompatibility of NaB with the leachate solutions reduced their hydraulic efficacy for barrier applications (Shackelford et al., 2000; Jo et al., 2001; Chen et al., 2018). For instance, when the GCL was exposed to 0.1 M electrolyte solution containing divalent cation, the increase in permeability was reported to be 1×10^{-7} m/s (Jo et al., 2001). This value exceeds the acceptable limit of permeability criteria required for barrier applications (GRI-GCL3). Thus, GCLs containing different types of bentonite polymer composites (BPCs) have been actively explored to surmount this drawback (Keerthana & Arnepalli, 2022). Numerous studies have shown that GCLs containing BPC exhibited a low permeability compared to NaB when exposed to various chemical solutions (Scalia et al., 2011; Scalia et al., 2014; Tian et al., 2016). Tian & Benson (2019) evaluated the hydraulic behavior of BPC by permeating with a bauxite liquor having an ionic strength of 700 mM and pH=13. Upon permeation, the permeability of NaB increased to 1.5×10^{-7} m/s. In contrast, the BPC maintained a low permeability of 4.3×10^{-12} m/s. This proves the advantage of using BPC over conventional NaB on exposure to highly aggressive permeants.

Further, in the study by Salihoglu et al. (2016), the bentonite-polymer mixtures maintained a permeability lower than 1×10^{-11} m/s when permeated with coal combustion product (CCP) leachate. Similar observations were also reported by Chen et al. (2019), in which the BPC-GCLs that contained a dry mixture of NaB and a proprietary polymer maintained a low permeability upon permeation with a typical CCP leachate. Wireko & Abichou (2021) investigated the permeability of GCL containing a dry blend of NaB and a proprietary linear polymer with varying concentrations of NaCl and $CaCl_2$ solutions. Comparatively, the linear polymer-bentonite GCL specimens demonstrated a lower permeability than NaB. Furthermore, the studies by Li et al. (2021), Zainab et al. (2021), and Wireko et al. (2022) also proved the improved hydraulic efficiency of BPC to aggressive permeants over the conventional NaB. However, the behavior of polymerized bentonite (PB) focusing on index properties under such aggressive chemical exposure conditions was not well understood. This could be because of the variation arising from the difference in polymer types, polymer dose, their confidential chemical formulations, and the method adopted for treating NaB. All these factors primarily affect the clay-polymer interaction, ultimately influencing the hydraulic behavior and properties of the bentonite polymer composite. This was proven in the study by Scalia & Benson (2016), where the effect of the treatment method on the permeability was investigated. BPCs used in this study were made of wet and dry blended mixtures of NaB and polymer. The permeant used includes the $CaCl_2$ solution of 5, 50, and 500 mM concentrations. The results showed that the BPC produced by the wet method had a high swell and low permeability compared to the dry mixture. This implies that the preparation method significantly affects the index and engineering property of BPCs. Considering the polymer, properties such as molecular weight, pH, charge density, and size also affect the ultimate end performance of BPCs (Razakamanantsoa et al., 2013; Wireko & Abichou, 2021). The term PB used in the present study refers to the BPC prepared by slurry polymerization, which was similar to the method reported by Scalia et al. (2014).

The commonly used index parameters to define the chemical compatibility of PB are the free swell index, liquid limit, and fluid loss (Scalia et al., 2018). Many studies have characterized the swell index of PB only in water, and very few have examined its swelling ability in other leachate solutions (Scalia et al., 2011; Scalia et al., 2014; Scalia et al., 2018). As far as the authors are aware, no data exist concerning the liquid limit of PB under various chemical environments. Also, no significant trend was reported for fluid loss to correlate with the permeability of PB (Salihoglu et al., 2016; Scalia et al., 2018). These conclusions are made based on the data reported for GCLs containing only PB that was prepared by the method described by Scalia et al. (2014). Several studies have identified that the swell index is not a suitable performance indicator based on the correlation between the permeability and swell index of BPCs (Salihoglu et al., 2016; Tian et al., 2016; Chen et al., 2019; Tian et al., 2019; Li et al., 2021; Wireko & Abichou, 2021; Zainab et al., 2021; Wireko et al., 2022). However, all these results are related to GCLs containing the dry mixture of NaB and proprietary polymers, whose functional characterization and chemical formulations are unknown. Zainab et al. (2021) reported that the permeability of BPCs with a polymer load of less than 5% decreased rapidly as the swell index increased. The study by Tian et al. (2016) also showed that the BPC with a similar polymer load maintained a low permeability (1×10^{-10} m/s) at a swell index of 20 mL/2g. These findings imply that there could be a possible relationship between the swell index and permeability, as correlated by Keerthana & Arnepalli (2022). In contrast, Salihoglu et al. (2016) reported no systematic variation between the swell index and permeability of BPC having an equivalent polymer dose. Also, Scalia et al. (2014) suggested that the permeability of BPC was less than 1×10^{-10} m/s for all the values of swell index ranging between 18 and 30 mL/2g. It should be noted that in the BPCs used in the above studies, many were made of a dry blend of NaB and proprietary polymer, and others were prepared by the slurry polymerization method. Moreover, Scalia et al. (2018) reported that a linear relationship exists for specific polymer-treated clays but also, in contrast, indicated that the swell index is ineffective for BPCs to correlate with their permeability. All these contradictory results can be attributed to the variation in the behavior of BPCs due to different treatment techniques, polymer doses, and unknown polymer's chemical formulation. Hence, further research is required to correlate the index properties of PB with permeability by accounting for the above-said variations before making any definitive conclusions regarding the dependence of the swell index on permeability.

Unlike permeability tests, the evaluation of index properties helps in assessing the material for its chemical compatibility in less time without any significant effort. The correlations developed using index properties provide insight into the hydraulic behavior and can be used as a rapid screening test for evaluating chemical compatibility. Keerthana & Arnepalli (2022) attempted to comprehend the available data of various polymer-treated bentonites and developed a correlation between the swell index and permeability. However, these relationships cannot be generalized since the data available was limited and did not encompass a wide range of chemical permeants. As discussed previously, there are inconsistent results regarding using the swell index as an index parameter for PBs. Further, the data available for the swell index is also limited, pertaining to a specific polymer type, treatment method, permeant, and experimental conditions used for permeability testing. Hence, further research is needed to build the experimental database of index properties of PB that aid in validating the existing relationships and arriving at a universal conclusion.

Given this, the present study aims to investigate the two most important index properties of a new type of polymerized bentonite (5% polymer dose) and NaB. The swell index and liquid limit of the soil were evaluated with three different electrolyte solutions: NaCl, $CaCl_2$, and $AlCl_3$, each having a concentration range of 5 to 1000 mM. The effect of cation valence and the pore fluid concentration on the index properties was assessed. Further, the properties of PB are also compared with NaB. As the PB used in the current study differs from those used by others, this study also aims to clarify the influence of pore fluid chemistry on the measured index properties and explore their application as a potential performance indicator.

2 MATERIALS AND METHODS

2.1 Materials

2.1.1 Soils

The soil used in this study was NaB, and it was supplied by Versatile specialty mine chem, Bhuj, India. This soil was used for preparing PB by slurry polymerization process as per the procedure described by Scalia et al. (2014) and Prongmanee et al. (2018a). Though the same method was adopted, the chemical constituents used for preparing the polymer are different. As a result, the PB prepared in the current study differs from those used by others. For producing PB, NaB was first mixed into a monomer solution consisting of acrylic acid neutralized with sodium hydroxide and some secret ingredients. This mixture was agitated vigorously to enhance polymer adsorption onto the clay surface. After thorough mixing, an initiator was added to the above mixture to initiate the polymerization reaction. Polymerization was performed at 65 °C for 2.5 hours (Prongmanee et al., 2018a). The additional information regarding the polymer synthesis and the secret chemical constituents is proprietary. After polymerization, the slurry was oven-dried at 105 °C to remove the moisture, crushed using mortar and pestle, and stored in an air-tight zip lock bag until further testing. Loss on ignition test was conducted as per the method outlined in Scalia et al. (2014), and the initial polymer content in PB was quantified to be approximately 5%.

Both the soils, viz., NaB and PB (5% polymer dose), were characterized for their properties. The specific gravity of NaB was 2.54, and its liquid limit was 732%. Both the soils (NaB and PB) were classified as high-plasticity clay (CH) as per Unified Soil Classification System (ASTM D2487). PB had a specific gravity of 2.22 and a liquid limit of 394%. The swell index of NaB and PB in water was determined as 36 mL/2g and 34 mL/2g, respectively.

2.1.2 Liquids

Three electrolyte solutions, namely NaCl, $CaCl_2$, and $AlCl_3$, were used, each with a concentration range of 5 to 1000 mM, to mimic the field representative leachate solutions. Also, it aids in evaluating the effect of cation valence and concentration on the measured index properties. The electrolyte solutions were prepared by dissolving the required weight of inorganic salts in distilled water to yield the target concentration. The prepared electrolyte solutions were used to determine the index properties of the soil in various chemical environments.

2.2 Methods

2.2.1 Free swell index test

The soil was first crushed using a mortar and pestle until 100% passed through a 75 µm sieve and then oven-dried. The test was conducted using 2g oven-dried soil according to ASTM D5890 (2019). The oven-dried soil was added in 0.1g increments at 10 minutes intervals into a 100 mL measuring cylinder filled with 90 mL of test solution. After the last addition of soil, the side of the cylinder was rinsed and filled to 100 mL with the test solution. After 24 hours, the swollen volume of the soil in mL/2g was measured as the free swell index.

2.2.2 Liquid limit test

The liquid limit of soil was determined as per the guidelines presented in ASTM D4318 (2017) by using the Casagrande liquid limit apparatus. For this, the soil passing through a 425 µm sieve was mixed with the test solution using a spatula such that its consistency requires about 25-35 drops of the cup for the groove closure. The soil was then sealed in a zip lock bag and stored in a desiccator for 24 hours for hydration. After that, the soil was remixed thoroughly using a spatula and placed in the cup of the liquid limit device. Using the grooving tool, a groove was made in the soil to separate it into two halves. The cup was rotated at a rate of 2 drops per second until the groove was closed for a length of 13 mm. The number of drops required to close the groove was recorded, and the corresponding water content of the soil was measured. This was repeated for many trials to establish a plot of water content versus the number of drops. The liquid limit is defined as the water content corresponding to 25 numbers of drops.

3 RESULTS AND DISCUSSION

In general, the index properties of soil, such as the free swell index and liquid limit, are evaluated by using water as the hydrating liquid. When water was used, there was a slight reduction in the swell index of PB relative to the swell index of NaB. When NaB was treated with a 5% polymer dose, the swell index was reduced by two units. This result was in contrast to those reported in the literature. In the study by Bohnhoff & Shackelford (2013), Scalia et al. (2014), Norris et al. (2022), and others, the swell index of BPC in water was reported to be more than double the value of NaB. This increase in the swell index of BPC was attributed to the swelling nature of the superabsorbent polymer used for modifying NaB. However, the reduced swell index of PB observed in the current study can be ascribed to the fabric changes of NaB associated with polymer treatment. In PB, the polymer adsorbed onto the surface tends to flocculate the clay particles and alter its microstructure. As a result, the specific surface area available for hydration reduces, resulting in a limited swell volume and lower swell index of PB (Razakamanantsoa et al., 2013).

In contrast to the results of the swell index, the above studies indicated a decrease in the liquid limit of NaB upon polymer modification. Similarly, the present study noted an evident reduction in the liquid limit for PB. The liquid limit of NaB and PB was 732%, and 394%, respectively. These results imply that the polymer treatment may not necessarily improve the water absorption values of PB. However, the permeability of BPC was reported to be much lower than the NaB, and it was attributed to polymer clogging (Scalia et al., 2014). This aspect of the study needs further investigation evaluating the detailed mechanism of BPC in controlling the swelling and hydraulic behavior. Though it is outside the scope of this paper, based on the data presented, the observed decrease in the index properties is hypothesized to be due to the formation of a polymer membrane coating the clay particles. Further, from visual examination, the presence of clay aggregates within the polymer matrix was witnessed during the test.

The free swell index and liquid limit test results performed using different pore fluids are presented in Figs. 1-6. The following section discusses the results in the context of pore fluid concentration and cation valence and their effects on index properties.

3.1.1 Effects of pore fluid concentration and cation valence on the free swell index of PB

The swell index is found to be reduced with increasing pore fluid concentration. This trend was observed for NaB and PB in all the pore fluids, irrespective of cation valency. For example, the swell index of NaB in NaCl, $CaCl_2$, and $AlCl_3$ solutions showed a decrease of 29 mL/2g, 15 mL/2g, and 10 mL/2g when the concentration changed from 5 mM to 1000 mM. Similarly, PB showed a decrease of 20 mL/2g, 18 mL/2g, and 15 mL/2g in NaCl, $CaCl_2$, and $AlCl_3$ solutions when the concentration changed from 5 mM to 1000 mM (Figs. 1-3).

In the NaCl solution, the swell index of NaB showed a continuous decrease with the increase in pore fluid concentration. Despite the reduction in values, the swell index of NaB became almost constant in $CaCl_2$ and $AlCl_3$ solutions at higher concentrations. The swell index of NaB reached 4 mL/2g and 3 mL/2g at concentrations equal to and greater than 100 mM in $CaCl_2$ and $AlCl_3$ solutions, respectively.

It indicates that the effect of concentration on swell index becomes insignificant at higher concentrations of divalent and trivalent solutions. In other words, it can be said that the effect of change in concentration on the swell index of NaB is appreciable only up to 400 mM, 50 mM, and 20 mM concentrations in NaCl, $CaCl_2$, and $AlCl_3$ solutions, respectively (Figs. 1-3). It can be inferred that these limiting values beyond which the effect of concentration on swell index becomes insignificant are reduced with the increase in cation valence.

For PB, the swell index in NaCl solution was reduced by less than 5 mL/2g when the concentration changed from 5 mM to 20 mM. This shows that the initial decrease in the swell index was inappreciable with the increase in concentration for up to 20 mM. Beyond this concentration, the decrease in the swell index of PB was considerable. The swell index became almost constant for concentrations greater than 800 mM (Figure 1). In the $CaCl_2$ and $AlCl_3$ solutions, the swell index of PB reached a constant value beyond 20 mM concentration. This shows that the effect of change in concentration on the swell index became nil at a much lesser concentration in PB when compared to NaB.

For any given concentration, the swell index of NaB and PB decreased with the increase in cation valence (Figs. 1-3). This decrease in the swell index was predominant when the cation valence increased from monovalent to divalent rather than from divalent to trivalent. For instance, in a 5 mM solution, the swell index of NaB experienced a decrease of 14 mL/2g when the valency increased from monovalent to divalent. However, this value was reduced to 5 mL/2g when the valency increased from divalent to trivalent. The effect of change in valency on the swell index diminished after certain concentrations. For NaB, beyond 200 mM concentration, the reduction in the swell index was not more than 6 mL/2g when the valency increased from monovalent to divalent. Similarly, beyond 20 mM, the difference in the swell index was less than 5 mL/2g when the valency increased from divalent to trivalent.

In the case of PB, a minimum and maximum reduction of 4 mL/2g and 16 mL/2g in the swell index was observed when the valency increased from monovalent to divalent. However, there was no significant change in the swell index when the pore fluid changed from $CaCl_2$ to $AlCl_3$ solution. For instance, a maximum decrease of 3 mL/2g was noted in the swell index of PB at 10 mM concentration when the valency increased from divalent to trivalent. Further, at concentrations beyond 20 mM, PB exhibited similar swell index values in both $CaCl_2$ and $AlCl_3$ solutions. Considering the effect of change in cation valence, both NaB and PB exhibited a similar behavior for any given pore fluid.

At lower concentrations of NaCl solution, the swell index of NaB was higher than PB. However, beyond 20 mM concentration, PB outperformed NaB by exhibiting a higher swell index value. This demonstrates the beneficial effect of PB in terms of swelling behavior, where the conventional NaB fails to swell at higher concentrations. In contrast, the swell index of PB in $CaCl_2$ and $AlCl_3$ solutions was high only at lower concentrations. The swell index of both NaB and PB was similar and less at higher concentrations. This decrease in the swell index can be attributed to the collapse of polymer gel in PB caused by the ionic cross-linking of cation (Scalia et al., 2014). However, the lower swell index of PB in these pore fluids does not indicate that it will exhibit a higher permeability. Despite their low swelling, BPs are shown to have a low permeability to many aggressive permeants (Scalia et al., 2014). Hence, based on this groundwork reported in the literature, it can be concluded that PBs can be a potential alternative to NaB. However, the PB investigated in this study needs to be verified for its hydraulic efficacy by conducting permeability experiments.

From Figs. 1-3, it can be inferred that PB has improved swelling ability than NaB in NaCl solution (>50 mM) in comparison to divalent and trivalent solutions. As discussed earlier, the swell index of both NaB and PB is reducing with increasing concentration and cation valence. As the reduction in swell index seen in NaB is higher than that observed in PB for the same increase in NaCl concentration, the swell index of PB appears to be much higher than the swell index of NaB in NaCl solution. However, in $CaCl_2$ and $AlCl_3$ solutions, the swell index of NaB and PB are affected by the cations in pore fluid. The enhanced swell of PB relative to NaB in NaCl solution can be ascribed to the sensitivity of NaB to swelling at higher concentrations (>50 mM).

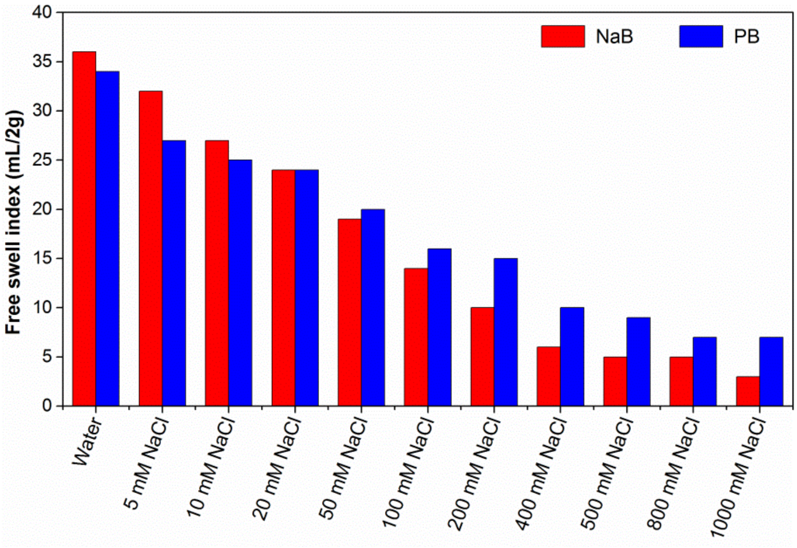

Figure 1. *Free swell index of NaB and PB at varying NaCl concentrations*

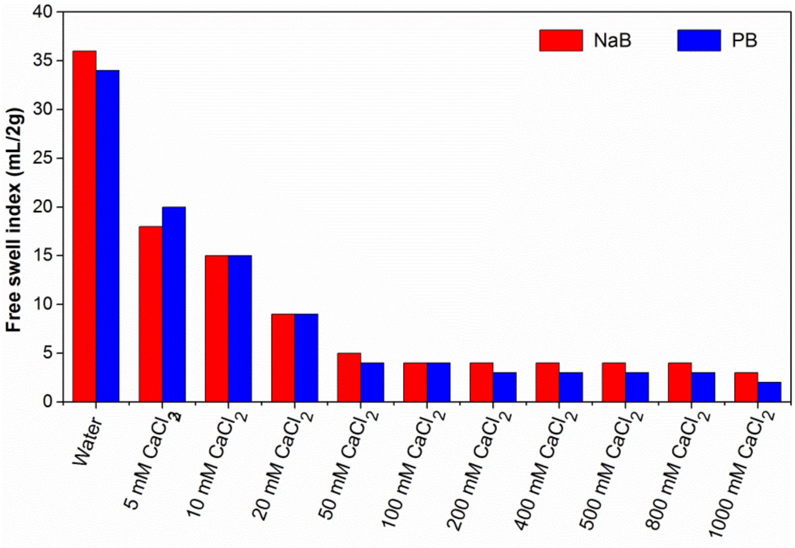

Figure 2. *Free swell index of NaB and PB at varying $CaCl_2$ concentrations*

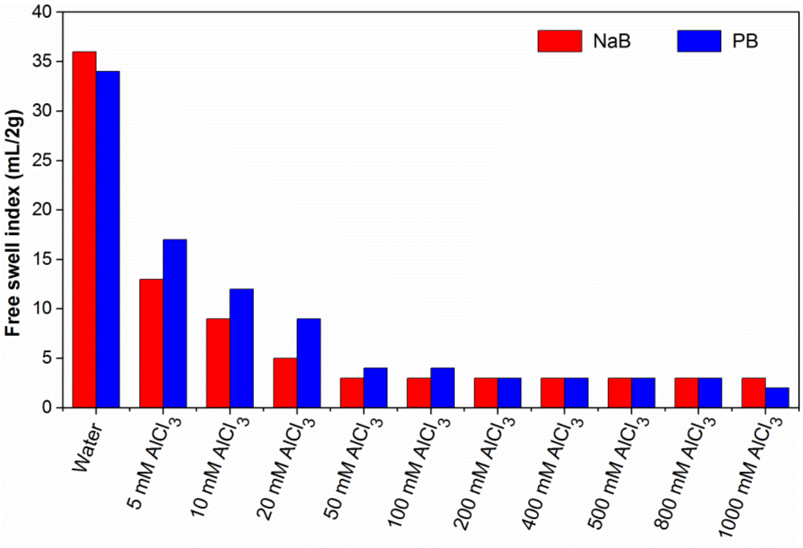

Figure 3. *Free swell index of NaB and PB at varying $AlCl_3$ concentrations*

3.1.2 Effects of pore fluid concentration and cation valence on the liquid limit of PB

The results of the liquid limit test are presented in Figs. 4-6. These results are consistent with the swell index test results. Regardless of cation valence, the liquid limit of both NaB and PB reduced with the increased pore fluid concentration. But the reduction in liquid limit was higher in NaB than PB. For example, when the concentration increased from 5 mM to 1000 mM, the liquid limit of NaB had a decrease of 611%, 544%, and 342% in NaCl, $CaCl_2$, and $AlCl_3$ solutions, respectively. On the other hand, for the same concentration increase, PB exhibited a decrease of only 119%, 149%, and 160% in NaCl, $CaCl_2$, and $AlCl_3$ solutions, respectively. The largest decrease observed in NaB is due to the initial high values of liquid limit exhibited by the soil at lower concentrations. These results signify the sensitivity of NaB upon interaction with pore fluids. In NaB and PB, with the increased concentration, a continuous decrease in the liquid limit was observed in NaCl and $CaCl_2$ solutions. However, there was no significant difference in the liquid limit of NaB and PB beyond 200 mM $AlCl_3$ solution.

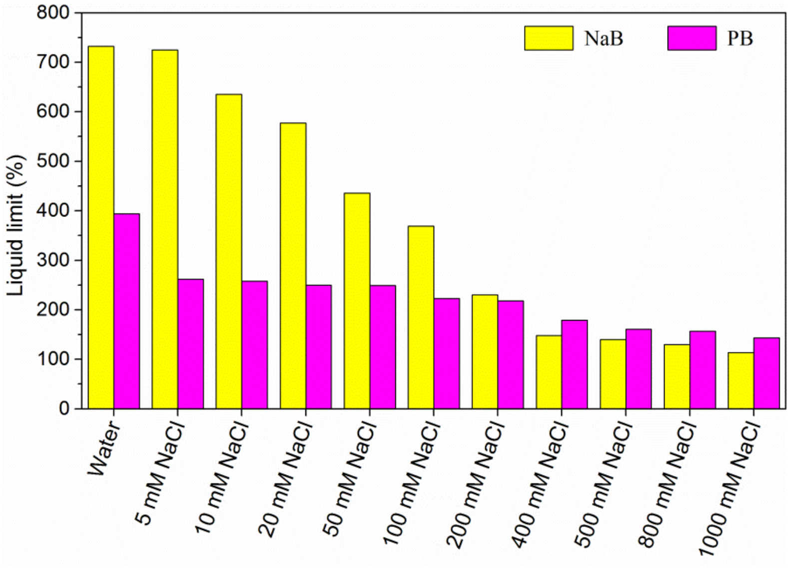

Figure 4. *Liquid limit of NaB and PB at varying NaCl concentrations*

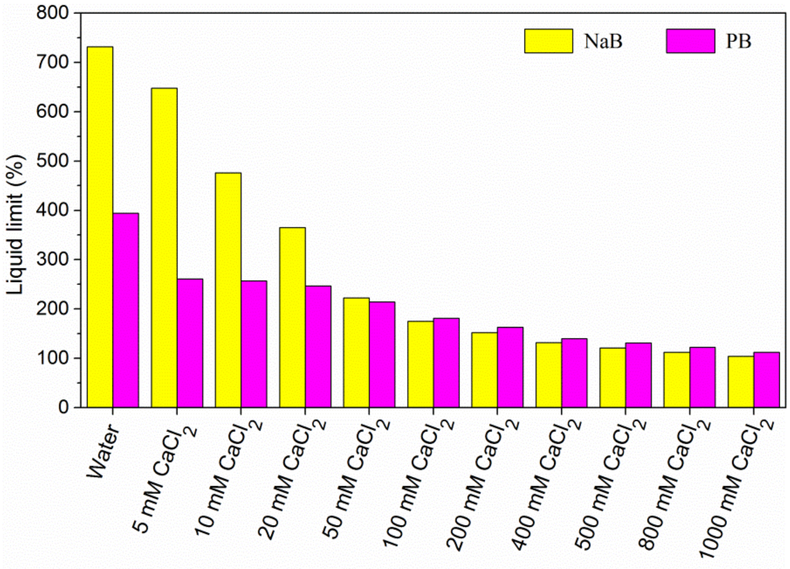

Figure 5. *Liquid limit of NaB and PB at varying $CaCl_2$ concentrations*

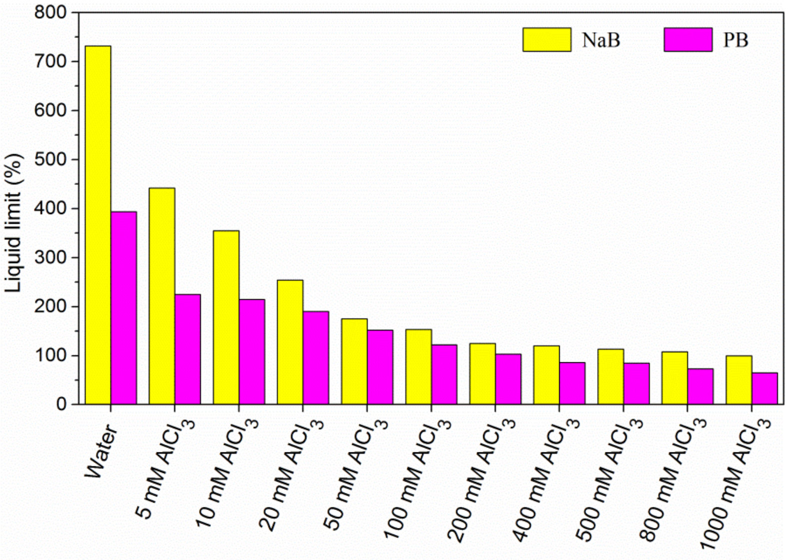

Figure 6. *Liquid limit of NaB and PB at varying $AlCl_3$ concentrations*

As the cation valence increased, the liquid limit of NaB and PB decreased (Figs. 4-6). For any given concentration, the liquid limit of both soils followed the order (highest to lowest): NaCl > $CaCl_2$ > $AlCl_3$; the soil had the maximum liquid limit value with NaCl solution and a minimum value with $AlCl_3$ solution. Moreover, the decrease in the liquid limit of NaB was significant when the valency increased from monovalent to divalent than from divalent to trivalent. For example, at 50 mM concentration, the liquid limit of NaB had a maximum decrease of 214% when the pore fluid changed from NaCl to $CaCl_2$ solution. However, when the pore fluid varied from $CaCl_2$ to $AlCl_3$ solution, NaB exhibited a decrease of only 47%. This shows that the liquid limit of NaB is significantly affected when the cation valency is changed from monovalent to divalent. This could be attributed to cation exchange reactions that considerably decrease the diffused double layer (DDL) thickness when Na^+ is replaced by Ca^{2+} (Olchawa & Gorączko, 2012). These observations are in good agreement with the swell index test results.

In contrast to the results of NaB, the reduction in the liquid limit of PB was significant only when the valency increased from divalent to trivalent than from monovalent to divalent (Figs. 4-6). For instance, at 50 mM concentration, the liquid limit of PB had a maximum decrease of 62% when the valency changed from divalent to trivalent. However, when the pore fluid changed from NaCl to $CaCl_2$ solution, PB exhibited a decrease of only 35%. This implies that the higher the cation valence, the larger is the reduction in the liquid limit of PB.

When compared to NaB, the liquid limit of PB was found to be comparatively lower, except in a few cases. Most recent studies have reported a decrease in the liquid limit of NaB after polymer addition (Bohnhoff & Shackelford, 2013). The reduction in the liquid limit of PB is attributed to the reduced amount of water held in the micro-pores due to dispersed fabric (Prongmanee et al., 2018b). With highly concentrated NaCl and $CaCl_2$ solutions, there was a drastic reduction in the liquid limit of NaB. However, PB did not exhibit such a sharp trend of decrease. As a result, at concentrations greater than 200 mM NaCl and 50 mM $CaCl_2$, PB had high liquid limit values when compared to NaB.

4 CONCLUSIONS

The study investigated the two most important index properties of liner materials, viz. free swell index and liquid limit of NaB and PB that was dosed with 5% polymer load. The tests were performed with three different inorganic solutions, including NaCl, $CaCl_2$, and $AlCl_3$, having concentrations ranging from 5 to 1000 mM. Based on the findings reported in this study, the following conclusions can be drawn:

- The increase in cation valence and pore fluid concentration decreased the swell index and liquid limit of NaB and PB. This could be attributed to the suppression of DDL thickness and the resulting microstructure modification. This behavior of PB mimicking NaB implies that the polymerized bentonite complies with the findings of DDL theory. However, this needs to be validated by conducting microstructural characterization studies.

- For NaB and PB, the effect of change in pore fluid concentration and cation valence on the index properties diminished at higher concentrations. This can be inferred as a threshold point at which all the physico-chemical reactions have taken place, and no more effects of valency and concentration are appreciable.
- For a given soil, to attain the same swell index with different pore fluids, the concentration required was increased in the order of decreasing cation valence. This effect demonstrates the dominance of cation valence over the concentration in affecting the index properties.
- Compared to NaB, PB showed a high swell index in NaCl solution at concentrations greater than 20 mM. In $CaCl_2$, $AlCl_3$, and less concentrated NaCl solutions, PB had a lower swell index than NaB. In contrast, PB had high liquid limit values than NaB upon interaction with highly concentrated $CaCl_2$ and $AlCl_3$ solutions. This difference in test results between the two index properties could be due to the variation in the test procedure, the mechanism relating to the properties, and the different indicative measures used for their determination.
- The reduced efficacy of PB in certain exposure conditions could be attributed to the polymer collapse caused by cation cross-linking. Hence, it can be inferred that similar to NaB, the polymer used in PB is also affected by pore fluid chemistry.
- There is a variance regarding using the swell index as a performance indicator for BPCs. This is due to the variation arising from the difference in polymer types, chemical formulation, polymer dose, and treatment method. In addition, the data available to these specific classes are also limited. Hence, the present study attempted to evaluate the variation of the swell index and liquid limit of a new type of PB under a wide range of chemical environments.
- Despite low swelling, many researchers have reported that PB maintains a low permeability. Though PB showed comparatively low swelling, the true behavior of PB can be assessed only by verifying its permeability. Permeability tests are essential to corroborate the results reported in this study; hence, they are currently in progress. Given the permeability test results, the potential use of these properties can be assessed for performance indicators.
- Further, correlations can be developed to assess the chemical compatibility of PB. Future studies should focus on estimating the limits of the swell index and liquid limit at which the functional relationship is a good predictor of permeability. Also, it should be noted that the above findings apply only to PB used in this study.

5 ACKNOWLEDGEMENTS

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