EFFECT OF TYPE OF LEACHATE ON SELF-HEALING CAPACITY OF GEOSYNTHETIC CLAY LINER

Jinchun CHAI¹, Kartika SARI² and Takenori HINO³

The effect of type of leachate (liquid) on self-healing capacity of the geosynthetic clay liners (GCLs) has been investigated by laboratory leakage rate tests. Four types of liquids, namely, tap water, 10 g/l NaCl solution, 100 ml/l ethanol solution and 11.1 g/l CaCl₂ solution were used. The test results indicate that the types of liquid have a significant effect on self-healing capacity of GCLs through the influence on the amount of hydration induced expansion of the bentonite inside GCLs. Free swelling index of the bentonite with the corresponding liquid can be used to evaluate the relative effect of the liquid. Also, for the conditions investigated, it seems that overburden stress (σ) on the GCL samples does not change the general tendency of the effect of the types of liquid.

Keywords: Geosynthetic clay liner, self-healing capacity, leakage rate test, type of leachate, landfill liner

1. Introduction

Geosynthetic clay liners (GCLs) are widely used as liquid retaining liners in geotechnical and geoenvironmental engineering. However, GCLs can be easily damaged during installation process and the joints between GCL panels may form weaker zones. For example, Nosko and Touze-Foltz reported an average defect density of 12.9/ha for a surveyed area of about 325 ha.

It is generally believed that GCLs have self-healing capacity owing to the expansion of bentonite, which is a main component of GCLs. There are numerous literatures which investigated the effect of types of liquid on hydraulic conductivity of GCL or bentonite, but the effect of types of liquid on self-healing capacity of GCL is not well investigated. Further, there are two types of GCLs used in engineering practice, namely geomembrane supported GCL (GM-GCL) and geotextile encased GCL (GT-GCL). Due to the different structures, their self-healing capacity and main influential factors may be different. However, most test results in literature on the self-healing capacity of GCLs are for GT-GCL and there are only few results about GM-GCL. In this study, effect of types of liquid on self-healing capacities of both GM-GCL and GT-GCL are investigated by a series of laboratory leakage rate tests under both constant head and falling head conditions.

2. Materials and their properties

(1) GCLs

One GT-GCL and one GM-GCL are tested. The GM-GCL consists of a 4 mm thick of granular bentonite layer glued onto a 0.5 mm thick of high density polyethylene geomembrane (HDPE). The GT-GCL consists of granular bentonite powders encased by geotextiles, i.e. a nonwoven geotextile as “cover” and a woven geotextile as “carrier”. The two layers of geotextile are connected by needle punched fibers with pitches of 3 mm × 4.5 mm and thermal treatment. The weight of the GM-GCL and the GT-GCL are about 53 and 49 N/m² respectively. The same type of bentonite was used in both of the GM-GCL and the GT-GCL. The bentonites used by the manufacturer are from two locations and their chemical compositions are listed in Table 1.

(2) Liquids

Tap-water, 10 g/l of NaCl solution, 100 ml/l of ethanol solution and 11.1 g/l of CaCl₂ solution were used as liquids in the tests. Values of pH and electric conductivity of the liquids are given in Table 2.

(3) Interaction behavior of the bentonite and the liquids

The liquid limit (w₁) and plastic limit (wₚ) of the bentonite with four types of liquid were measured per JIS A 1205, and free swelling index per ASTM D 5890. The results are summarized in Table 2 also.

Table 1. Chemical composition of the bentonite from Colony and Lovell at Wyoming, USA

<table>
<thead>
<tr>
<th>Chemical composition</th>
<th>Colony</th>
<th>Lovell</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quartz</td>
<td>5</td>
<td>2</td>
</tr>
<tr>
<td>Potassium feldspar</td>
<td>Trace</td>
<td>----</td>
</tr>
<tr>
<td>Plagioclase feldspar</td>
<td>Trace</td>
<td>4</td>
</tr>
<tr>
<td>Calcite</td>
<td>----</td>
<td>Trace</td>
</tr>
<tr>
<td>Opal</td>
<td>2</td>
<td>5</td>
</tr>
<tr>
<td>Clinoptilolite</td>
<td>----</td>
<td>Trace</td>
</tr>
<tr>
<td>Dioctahedralalumite</td>
<td>91</td>
<td>85</td>
</tr>
<tr>
<td>Illite</td>
<td>2</td>
<td>4</td>
</tr>
</tbody>
</table>

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Table 2. Properties of liquids and interact properties of the liquids and the bentonite

<table>
<thead>
<tr>
<th>Types of liquid</th>
<th>pH</th>
<th>EC (µS/cm)</th>
<th>wL (%)</th>
<th>wp (%)</th>
<th>Swelling index (ml/2gr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tap water</td>
<td>7.02</td>
<td>105</td>
<td>537</td>
<td>45.8</td>
<td>21.5</td>
</tr>
<tr>
<td>Ethanol</td>
<td>7.46</td>
<td>85</td>
<td>560</td>
<td>67.4</td>
<td>30</td>
</tr>
<tr>
<td>NaCl</td>
<td>7.24</td>
<td>17600</td>
<td>235</td>
<td>46.3</td>
<td>16.5</td>
</tr>
<tr>
<td>CaCl₂</td>
<td>7.60</td>
<td>199</td>
<td>165</td>
<td>9</td>
<td>9</td>
</tr>
</tbody>
</table>

Following the procedure of Method-C of ASTM D4546-96, swelling pressures of the bentonite were tested using an oedometer device. Initial water content of the bentonite was adjusted to about 30% - 100% and put into a mold of 60 mm in diameter and 20 mm in height. Apply a vertical pressure of 300 kPa for 2 hours to compress the sample. The resulting sample had a dry density of 760 kg/m³–1,020 kg/m³. Then the sample was cut into 5 mm in thickness and reset into the equipment for swelling pressure test. The tests were conducted with constant volume condition and liquid was supplied until there was no more pressure change. Swelling pressure versus final water content of the samples is presented in Fig. 1. The result shows that the tap-water and the ethanol solution have about the same swelling pressure, but the NaCl solution has much lower swelling pressure when compared under the same water content condition.

![Swelling Pressure](image1)

3. Leakage rate tests and results

Both constant head and falling head devices were used to accelerate the test program and provide a cross check on the reliability of test results.

(1) Equipment
The sketch of the equipment for constant head test is shown in Fig. 3. The devices consist of:
(a) a transparent cylinder made of acrylic resin with an inner diameter of 150 mm (wall thickness of 5 mm) and height of about 400 mm;
(b) upper and lower pedestals made of stainless steel, and a porous stone with a diameter of about 120 mm is fixed at the top of the lower pedestal;
(c) a piston made of stainless steel, which is perforated with 3 mm diameter holes at 20 mm pitch to allow for drainage, and a ceramic porous stone with a diameter of 120 mm is inserted at the centre of the
bottom of the piston; and
d) a bello-fram fixed to the top of the upper pedestal
for applying overburden pressure (\(\sigma\)).

Sealing between the cylinder and the piston is
achieved by a 4 mm diameter ‘O’ ring lubricated with
silicone grease and fixed around the piston.

A schematic description of the falling head test
device is shown in Fig. 4. The main body of the device is
made of copper, and consists of lower and upper parts.
The lower part consists of a container with 150 mm inner
diameter. A porous stone, 50 mm in diameter, is inserted
at the center of the bottom of the container. The upper
part of the device is a loading plate, 150 mm in diameter,
with a porous stone, 120 mm in diameter, inserted at the
center and in turn connected to a burette. The
cross-sectional area of the burette is 200 mm\(^2\). For both
the constant head and falling head tests, the overburden
pressure can be applied up to 200 kPa, and the GCL
specimen can be tested is 150 mm in diameter.

Set up the test and apply the desired overburden
pressure (200 kPa) and maintain for 1 hour before start
the leakage rate test. Set up water head of about 1000
mm on the top of the specimen through the burette.
Open the valve for inlet flow and start the test; and
record water level in the burette periodically. The test is
continued until the calculated apparent hydraulic
conductivity becomes stable.

(3) Conditions investigated

The result reported here is part of the results of a
comprehensive investigation program on the self-healing
capacity of GCL. The results of overburden pressure (\(\sigma\))
and apparent permittivity (\(\psi\)) of the damage holes with
different size have been reported by Sari and Chai\(^{14}\)
already. In this study, the effect of the types of liquid is
investigated mainly under the condition of diameter (d)
of a damage hole of 40 mm and \(\sigma = 0\) kPa. To further
consider the mutual effect of the types of liquid and \(\sigma\)
value, as well as referring the existing data reported by
Sari and Chai\(^{13}\), some tests were conducted under \(d = 30\)
mm and \(\sigma = 200\) kPa conditions.

4. Results and Discussion

(1) GM-GCL

To quantify the liquid flow through the healed or
partially healed damage hole, the apparent permittivity
(\(\psi\)) of the damage hole is defined as:

\[
\psi = \frac{Q}{A_i \Delta h}
\]

where \(Q\) is the total flow rate, \(A_i\) is the initial area of
damage hole, and \(\Delta h\) is head difference above and below
the GCL sample.

Permittivity (\(\psi\)) versus elapsed time curves are given
in Figs. 5(a) and (b) for \(d = 40\) mm, \(\sigma = 0\) kPa under
constant head and \(d = 30\) mm and \(\sigma = 200\) kPa under
falling head conditions respectively. It can be seen that
\(\text{CaCl}_2\) solution case resulted in the highest, and the
ethanol solution the lowest \(\psi\) value. The final \(\psi\) value
of \(\text{CaCl}_2\) case is almost 2 orders higher than that of the
ethanol case. To further quantify the self-healing capacity,
a parameter of area healing ratio (\(\alpha_h\)) is defined as\(^{14}\):

\[
\alpha_h = \left(1 - \frac{A_f}{A_i}\right) \times 100\%
\]

where \(A_f\) is the final unhealed area of a hole which can be
measured after the test. For \(d = 40\) mm and \(\sigma = 0\) and
under constant head condition, the \(\alpha_h\) values of using the
tap-water, ethanol solution, \(\text{NaCl}\) and \(\text{CaCl}_2\) solutions are
88, 90, 60 and 51 % respectively. They are the same
order as those of free swelling index (Table 2).
Relatively the larger the free swelling index, the higher
the \(\alpha_h\) value. Some photos of GCLs after the tests are
shown in the Fig. 6.

The effect of types of liquid on the self-healing
capacity of GCL can be explained by diffusive double layer (DDL) theory. According to Mitchell and Soga\textsuperscript{15}, the thickness of DDL ($1/K$) is related to square root of dielectric constant, $D$, while $D$ is reversely related to electric conductivity, $EC$ ($D \propto 1/EC$) of the solution, i.e. the larger the $EC$ value, the smaller the $1/K$ value. In addition, the higher cation concentration and higher valence of cation, the smaller of the value of $1/K$. A direct indication of $1/K$ value may be the free swelling index, in which the value for CaCl$_2$ is 9 mL/2g, which is about 42\% of the value for the tap-water case (Table 2). The thinner DDL means that under a given condition the bentonite will expand less, and leave a relative larger portion of a damage hole not being healed. The smaller $\psi$ value for the ethanol solution compared to the tap-water case may be due to the viscosity of the solution. Petrov et al.)\textsuperscript{19} reported that ethanol-water mixture with concentrations < 50\% increased viscosity and decreased hydraulic conductivity of GCL.

Comparing the results in Figs. 5(a) and (b) indicates that the general tendency of the effect of the types of liquid is not changed by the overburden stress. Sari and Chai\textsuperscript{14} discussed that $\sigma$ value has two effects. One is squeezing hydrated bentonite into a damage hole, which can increase the self-healing capacity of a GCL. Other is to hinder hydration of the bentonite around a damage hole which may reduce the self-healing capacity. After the leakage rate test, the water contents of the bentonite expanded/squeezed into the hole, as well as around the hole were measured and the results are depicted in Fig. 7 for $d = 40$ mm, $\sigma = 0$ kPa cases (constant head), and in Fig. 8 for $d = 30$ mm, $\sigma = 200$ kPa cases (falling head) respectively. The dashed lines in the figures just provide a guide for getting a picture of water content variation pattern. Note: the measured water content of the bentonite in a hole is plotted at the center of the hole for convenience, and it does not mean the sample is from the center of the hole. It can be seen that increase $\sigma$ value reduced water content of the bentonite in and around the hole, and it also reduced the difference of water content between different types of liquid. For the water content of the bentonite in the hole, in the case of the tap-water, it reduced from about 500\% to about 190\% when $\sigma$ increased from 0 to 200 kPa. While for CaCl$_2$ solution case, it did not change much. This tendency implies that increase $\sigma$ value may reduce the degree of the effect of types of liquid. However, for using the tap-water and under $\sigma = 0$ and 200 kPa cases, the thicknesses of the bentonite in the samples after the test were about 8 mm and 4 mm respectively. This means that increase $\sigma$ value will reduce the volume of the damage hole which needs to be filled by the bentonite expanded and/or squeezed into the hole. Furthermore, increase $\sigma$ value can enhance the squeezing effect. $S_a$ value can influence the squeezing effect. For $\sigma = 0$, the water contents of the
(2) GT-GCL

Unlike GM-GCL, for GT-GCL, the liquid can flow through the undamaged area even when the flow rate may be very small. To investigate the effect of the types of liquid on self-healing capacity, the flow rate ($Q_h$) through the hole of GT-GCLs is defined as follows:

$$Q_h = Q - Q_{int}$$  \hspace{1cm} (3)

where $Q_{int}$ is the flow rate through the intact part of a specimen. $Q_{int}$ value can be measured by the flow rate tests using the intact sample. Using Eq. (3) and considering the steady state condition, $Q_h$ values for four different liquids are compared in Fig. 9. It can be seen that $Q_h$ values of the NaCl and CaCl$_2$ cases are more than 4 and 3 orders higher than that of the tap-water case. The degree of the effect of the types of liquid is more than that of the GM-GCL, and it may due to the different structure of the GT-GCL compared to the GM-GCL.

Some photos of the GT-GCL samples after leakage rate tests are shown in Fig. 10. They are similar with those of GM-GCL in Fig. 6. The area healing rates ($\alpha_h$) are 93%, 99% and 51% for the tap-water, ethanol solution and NaCl solution respectively.

The water contents of the bentonite in the healed area in the hole and surrounding area of GT-GCL samples tested were measured and shown in the Fig. 11. The values are comparable with that of GM-GCL (Fig. 7), but a bit lower. It is considered may be due to some restriction from the needle punched fibers connecting two layers of the geotextiles in the GT-GCL. The bentonite in the GT-GCL specimen was obtained by cutting sub-sample from the GT-GCL specimen at appropriate locations and then separated the bentonite and geotextiles of the sub-samples.

5. Conclusions

The effect of types of liquid on self-healing capacity of the geosynthetic clay liners (GCLs) has been investigated by laboratory leakage rate tests. Four types of liquid, namely, tap-water, 10 g/l NaCl solution, 100 ml/l ethanol solution and 11.1 g/l CaCl$_2$ solution were used. Based on the test results, following conclusions can be drawn.

(1) Types of liquid have a significant effect on self-healing capacity of both geomembrane support GCL (GM-GCL) and geotextile encased GCL (GT-GCL). The mechanism of the influence is due to different thickness of diffusive double layer (DDL) formed around bentonite particles inside GCLs. The thicker of DDL, the higher the self-healing capacity. Free swelling index of the bentonite with the corresponding liquid can be used to evaluate the relative effect.
(2) For the conditions investigated, it seems that increase overburden pressure (σ) did not change the general tendency of the effect of the types of liquid. Increasing σ value can enhance the squeezing effect, and it tends to increase self-healing capacity of GCL, but it also can restrict the amount of the expansion of the bentonite due to hydration which intends to reduce the self-healing capacity of GCL.

The practical implication of the results from this study is that for design a landfill liner system, if the possible leachates will be enrich of cations, the self-healing capacity of GCLs will be limited and composite liner systems may be used.

Acknowledgements

The GCLs tested were provided by Mr. M. Mizuno at Hojo. Co. Ltd, Japan. Mr. A. Saito at Saga University, Japan provided technical support for conducting the tests reported in this paper.

References


GCL の自己修復能力における渗出溶液の性質の影響に関する研究

柴 錦春・Kartika Sari・日野剛徳

ジオシンセティックスクレイライナー (GCLs) の自己修復能力に対して、溶液の性質（種類）の影響を室内漏水試験により検討した。用いた 4 種類の溶液は、水道水、10g/l の NaCl 溶液、100mg/l のエタノールおよび 11.1g/l の CaCl2 溶液である。試験の結果によれば、溶液の性質は GCL 中のベントナイトの膨潤量に影響を与えるによって、GCL の自己修復能力を大きく左右する。また、ベントナイトの自由膨潤量は、GCL の自己修復能力における溶液性質の影響の程度を評価する指標として用いることができる。さらに、試験した条件で、上載圧力の増加に伴う溶液性質の影響の傾向に変化が認められないことがわかった。

キーワード：ジオシンセティックスクレイライナー、自己修復能力、漏水試験、溶液、廃棄物処分場ライナー