Water retention characteristics of granular and powder bentonites

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ABSTRACT

Geosynthetic Clay Liner (GCL) has become an important component of waste containment system. The GCL is laid at the as-rolled moisture condition in the field and hydrates through absorbing water from the underlying soils or compacted clay liner. The degree of hydration or saturation of the GCL is important as it can affect the performance of the GCL. Thus, the water retention curve (WRC) of GCL is important for understanding the saturation process of the GCL. The GCL consists of a layer of granular sodium bentonite clay sandwiched in between a nonwoven geotextile and a woven geotextile. Test results showed that the geotextiles are fully desaturated when the suction is greater than 2 kPa. Thus, the WRC of GCL over the larger suction range is governed by the bentonite. In this paper, the water retention of commercially available powder bentonite and granular bentonite used in the GCL are determined by direct measurement using tensiometer and indirect measurement using chilled-mirror hygrometer. The implications of the water retention characteristics of the bentonites in a GCL are discussed.

Keywords: geosynthetic clay liner, water retention curve, bentonite, granular, powder

1 INTRODUCTION

Modern landfill containment systems consist of a cover and a liner system. The purpose of the cover is to minimize the release of toxic or greenhouse gases into the atmosphere (Feng et al., 2017; Buragohain et al., 2018). The purpose of the liner system is to minimize the release of leachate into the subsoil and groundwater (Rowe, 2007, 2011; Rashid et al., 2018). Over the past decades, Geosynthetic Clay Liners (GCL) have become a popular alternative to compacted clay in cover systems and the base liner of waste containment systems (Bouazza, 2002). It consists of a thin layer of bentonite sandwiched by a cover geotextile and a carrier geotextile. The components are held together by either needle-punching or stitch bonding (Abuel-Naga and Bouazza, 2010 Bouazza et al, 2013; Acikel et al., 2018). When it completely replaces the compacted clay liner, its small thickness of 5 to 12 mm compared to the traditional clay liner thickness of at least 0.6m is attractive as it reduces construction cost and increase landfill capacity. To fulfill its barrier function in a landfill system, GCLs are required to have saturated coefficient of permeability less than $10^{-10}$ m/s and preferably, less than $10^{-12}$ m/s (Bouazza, 2002; Liu et al., 2015). In practice, the GCL is installed at the as-rolled moisture condition. To ensure good performance, GCLs need to be hydrated to over 100% in gravimetric water content (Bouazza et al., 2016; Touze-Foltz et al., 2016). The bentonite hydrates by absorbing moisture from the underlying subsoils or compacted clay liner. Hence, a key property of the GCL is its water retention characteristic which is a relationship between water content and suction, more commonly known as water retention curve (WRC). As bentonite is the main component of GCL, it has the greatest influence on WRC of GCL (Bouazza et al., 2013). The geotextiles in GCL contribute to the water retention behaviour of GCL at low suction while at higher suction, the water retention behaviour is wholly governed by the bentonite (Seiphoori et al. 2016; Leong et al., 2018). Leong et al. (2018) have shown that the geotextiles of a GCL becomes completely desaturated at less than 2 kPa suction. Hence, WRC of bentonite is important to understand the water retention behaviour of GCL in the high suction range.

Both powder and granular bentonites are used in GCLs (Maubeuge et al., 2017). This paper studies the differences in WRCs of commercially available powder bentonite and the granular bentonite used in GCLs.
2 MATERIALS AND METHODS

The granular sodium bentonite tested is obtained from TENCATE Enviromat® 5000. The powder bentonite tested is available commercially. The bentonites are shown in Figure 1 and their properties are summarized in Table 1. From Table 1, it can be observed that granular bentonite has lesser ambient moisture content and free swelling than powder bentonite but comparable filtrate loss. The higher ambient moisture content could be a direct consequence of the greater surface area of powder bentonite available to adsorb water from the air.

![Fig. 1. (a) Granular sodium bentonite obtained from GCL, (b) Conventional powder bentonite.](image)

Table 1. Properties of granular and powder bentonites.

| Properties              | Powder bentonite | Granular bentonite |
|-------------------------|------------------|--------------------|
| Moisture content (% by wt) | 13.4             | ~6.0              |
| Free Swelling (ml/2g)   | 32               | 24                 |
| Filtrate Loss (ml)      | 17.6             | 18.0               |
| Liquid Limit (%)        | 469              | 294                |
| Specific gravity (%)    | 2.75             | 2.65               |

To cover the entire suction range of WRC, two types of tests were conducted. In the suction range from 0 to 100 kPa, a Quick Draw tensiometer was used to measure the matric suction of the sample as the sample dries. For suctions above 1000 kPa, a chilled mirror hygrometer was used as per ASTM D6836-16 (2016).

The set-up using the Quick Draw tensiometer is shown in Fig. 2. Two identical powder bentonite samples are prepared by mixing the powder bentonite with water to found a homogeneous viscous slurry. The granular bentonite has initial water content ($w_0$) of 202.96% with initial void ratio ($e_0$) of 5.38. The powder bentonite has $w_0$ of 473.22% with $e_0$ of 13.01. Two sample cups, 62.5 mm in diameter and 44.6 mm in height, were lined with cling wrap and then filled with the bentonite slurry carefully to ensure no air bubbles were trapped during filling. The cling wrap ensures that the bentonite do not adhere to the wall of the sample cups on drying thus preventing formation of shrinkage cracks. In one of the sample cups, a quickdraw tensiometer was installed such that the ceramic tip was completely submerged in the bentonite slurry. The Quickdraw tensiometer was held in place using a retort stand to provide continuous matric suction reading as the bentonite sample dries. The other sample cup was placed on a weighing balance to record its weight as the bentonite sample dries. Both weight and matric suction were recorded at regular intervals until cavitation of tensiometer occurs. Once the tensiometer cavitates, the test was stop and samples were oven dried to determine the water contents. The test was then repeated by replacing powder bentonite with granular bentonite.

Chilled mirror hygrometer test is an indirect measurement of total suction. It uses dew point technique to measure total suction above 1000 kPa (Leong et al., 2003). The chilled mirror hygrometer used was the Water PotentiaMeter, WP4 shown schematically in Fig. 3. The samples of powder bentonite and granular bentonite are prepared as for the Quick Draw tensiometer test. The WP4 sample cup was half filled with the bentonite slurry and allowed to dry by evaporation. The weight of the samples and the readings of WP4 were recorded regular intervals. Kelvin’s equation given in Equation 1 was used to calculate the total suction of soil specimen from relative humidity and temperature (Fredlund et al 2012).

$$\psi_m = \frac{RT_w \rho_w}{w_v} \ln \left( \frac{u_v}{u_{v0}} \right)$$

where:
- $\psi_m$ is measured total suction (kPa),
- $R$ is universal gas constant (J/mol.K),
- $T_w$ is absolute temperature (K),
- $\rho_w$ is density of water (kg/m³),
- $w_v$ is molecular mass of water vapour (kg/kmol), and
- $u_v / u_{v0}$ is relative humidity.

![Fig. 2. Set-up for SWCC measurement using Quick Draw tensiometer](image)
The experimental data obtained from both Quickdraw tensiometer and the chilled mirror hygrometer tests were fitted using Fredlund and Xing (1994)'s SWCC equation:

\[
w(\Psi) = C \left[ \frac{w_s}{\ln(e + (\Psi/a)^n)} \right]^m
\]

(2a)

\[
C = 1 - \frac{\ln(1 + \Psi/\Psi_r)}{\ln(1 + 1000000/\Psi_r)}
\]

(2b)

where w is gravimetric water content, \(w_s\) is saturated gravimetric water content, C is a correction factor, e is natural number, \(\Psi_r\) is the residual suction, \(\Psi\) is soil suction, and a, n and m are curve fitting parameters.

### 3 RESULTS AND DISCUSSION

Figure 4 shows the drying of the bentonites with time. The drying rate of powder bentonite is faster. Fig. 5 shows the WRCs of powder and granular bentonites obtained by combining test results from the Quick Draw tensiometer and chilled mirror hygrometer tests. A noticeable scatter is observed for WRCs of both powder and granular bentonites when suction is between 1000 to 3000 kPa. This is due to the chilled mirror hygrometer, WP4 being unable to measure the total suction accurately in this range of suction. The WRCs of powder and granular bentonites are fitted with the Fredlund and Xing (1994)'s SWCC equation (Equation 2) ignoring the scatter between 1000 and 3000 kPa. The fitting parameters of Fredlund and Xing (1994)'s SWCC equations are summarized in Table 2.

Based on Fig. 5, it is clear that powder and granular bentonites behave differently at lower suction. Powder bentonite has higher water content than granular bentonite when the suction is below 1000 kPa. However, when the suction is above 1000 kPa, the WRCs tend to merge and become a single curve.

As mentioned earlier, the bentonite in GCL needs to have a gravimetric water content of at least 100% in order to perform well. A horizontal line at 100% gravimetric water content is drawn in Fig. 5. At this water content, the suction of both powder and granular bentonites are the same and is equal to 660 kPa. However, powder bentonite is able to absorb more water at suction less than 660 kPa. The difference in saturated gravimetric water content between powder and granular bentonites can be explained qualitatively by the different free swelling of powder and granular bentonites but not quantitatively. Based on free swelling given in Table 2, powder bentonite is expected to have initial saturated gravimetric water content of about 1600% while granular bentonite is expected to have initial saturated gravimetric water content of about 1200%.
as a barrier in a landfill containment system.

4 CONCLUSION

Geosynthetic clay liners have become a popular alternative to compacted clay liners in landfill containment systems. The water retention characteristic of the bentonite in the GCL is an important property as it governs the performance of the GCL. In this study, the water retention curves (WRC) of powder and granular bentonites were obtained using Quick Draw tensiometer and chilled mirror hygrometer. Both powder and granular bentonites show similar WRC when suctions exceed 1000 kPa. However, the water content of powder bentonite is much higher than granular bentonite at suctions less than 1000 kPa. The higher water content of powder bentonite implies that it has excessive swelling and shrinking behaviour and has a higher permeability than granular bentonite at comparable suction at suctions less than 1000 kPa. These characteristics are undesirable as a barrier in a landfill containment system.

The higher water content of powder bentonite can be explained by its higher free swelling compared to granular bentonite. However, the free swelling cannot be explained quantitatively by the saturated gravimetric water contents of the powder and granular bentonites. In future, powder and granular bentonites with the same free swelling should be tested and compared to check if the difference in WRCs is caused solely by free swelling.

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