Laboratory performance of two bentonites used in a Brazilian geosynthetic clay liner

L.S. Previti, Department of Civil Engineering, Mauá Institute of Technology, São Caetano do Sul/SP, Brazil
F.L. Lavoie, Department of Civil Engineering, Mauá Institute of Technology, São Caetano do Sul/SP, Brazil
T.V.B. Zanon, Solví Participações S/A, São Paulo/SP, Brazil

ABSTRACT
This paper presents the results of several laboratory tests carried out in two samples of bentonite clay, provided by the same supplier, largely used in the Geosynthetic Clay Liner (GCL) Brazilian industry for sanitary landfill liner applications. The difference between the samples was that one of them was grainy (Sample A) and the other was in powder (Sample B). The tests were natural humidity, grain size distribution, specific weight, Atterberg limits, swelling index, free expansion, swelling pressure, consolidation properties and coefficient of permeability. The presence of clay on the samples was similar: 74% for sample A and 78% for sample B, and their unit weight of solids resulted in 2.87 g/cm^3 (sample A) and 2.79 g/cm^3 (sample B). The results showed that sample B had slightly better properties than sample A when used as a liner. Its colloidal activity, which is indicative of the expansive potential of the bentonite, was 3.7 (bigger than the result of sample A, which was 3.6). The swelling test results pointed to the same direction: only the powder sample (B) reached the reference standard (≥24 mL/2g). As expected, the permeability coefficients, determined for different applied loads, reduced when the applied load was increased.

1. INTRODUCTION

One of the biggest problems affecting Brazilian's urban and environmental policies nowadays is the incorrect destination of solid waste. Over a long period in the past, due to not having regulations, it was common to adopt precarious and unhealthy solutions, such as dumps (known in Brazil as "*lixões"*). In 2010, the National Solid Waste Policy was implemented, which marked a turning point in Brazil. Sanitary landfills were constructed and prioritized in all cities which were in an irregular situation.

Geosynthetic Clay Liners (GCLs) are often formed by the association of a layer of granular or powdered bentonite between two layers of geotextile, joined by needling or by "stich bonding processes". (Because the term "bentonite" is an industrial and not a mineralogical term, the quality of bentonites used in GCLs for landfill applications may vary to a large extent. Bentonite is a mixture of a variety of minerals, the predominant mineral being smectite clay (Patterson and Murray, 1983 apud Rosin-Paumier and Touze-Foltz, 2010).

Over the last decades, worldwide concerns about environmental questions have compelled civil engineers to look for technical solutions to minimize soil, groundwater and air contamination by waste in general. This usually leads to sealed storage spaces bounded by multilayered systems where the use of geosynthetics – geomembranes (GM), geosynthetic clay liners (GCLs) and geocomposites (GC) is expanding very fast throughout the world (Bueno et al, 2002).

Sanitary landfill liners in Brazil have undergone some important changes to their configuration over the last 30 years. Initially, they were formed only by a Compacted Clay Layer (CCL). With the advent of commercializing polymeric materials in the country, the liner configuration gained an additional layer above CCL, known as the geomembrane, and currently widely used in both environmental and irrigation applications. Just over ten years ago, bentonite geocomposite started to be manufactured, whose function is to replace the compacted clay layer (CCL) leading to numerous advantages.
(Lavoie, 2016).

According to Bueno et al 2002, GCLs are manufactured hydraulic barriers consisting of a bentonite layer, usually sodium bentonite or any other cation combination bentonite, which exhibits very low hydraulic conductivity and high swelling potential, bonded to a geomembrane or sandwiched by two geotextiles. In the first case, the clay layer is mixed with an adhesive and bonded to one face of a geomembrane sheet. The clay layer can add a sealing capacity to the geomembrane but, more importantly, its swelling capacity can minimize hydraulic flow through punctures occurring during installation. In the second case, the bentonite core is fixed to the geotextiles by needling, stitching or bonding. In general, the clay blankets are 5 to 10 mm-thick when dry and weigh around 5 kg/m^2.

The natural material utilized within the GCL is sodium bentonite clay, soil of the study in this research. Due to its expansive nature when saturated, bentonite is able to seal the passage of the decomposition products of waste, such as leachate and contaminant gases.

This paper presents laboratory test results of two Brazilian bentonite samples (sample A – grainy, and sample B – in powder) provided by the same supplier. It is expected that the obtained data in this research may be incorporated into those that already exist in the scientific bibliography.

2. MATERIAL AND METHODS

The analyzed bentonite samples were both provided by a Brazilian manufacturer which produces Geosynthetic Clay Liners (GCL), one of them (Sample A) in the grainy form and the other (Sample B) in powder. Both of them were tested in the experiments described later.

2.1 Granulometry Test

The granulometry characterization was carried out according to the Brazilian standard described in the ABNT NBR 7181 standard through sieving and sedimentation.

2.2 Atterberg Limits

The consistency limits of each sample were determined according to the liquid limit (LL) test, as described in the ABNT NBR 6459 standard, and plastic limit (PL), as described in the ABNT NBR 7180 standard. The consistency index (CI), determined by the difference between the LL and the PL, indicates the activity of the clay portion of the sample.

2.3 Swelling Test and Free Expansion

The swelling test was executed according to the ASTM D5890. This test consists of the gradual hydration of 2.0 g of sieved clay in a graduated test tube filled with a volume of 90 mL of distilled water. To complete the hydration of the sample, 0.1 g is placed meticulously one at a time, and 10 ml of water is added to the tube to remove traces of soil that may have stuck to the tube wall. After a period of 16 hours, the expansion volume of the clay is registered.

The free expansion test was executed according to the ASTM D4829. In this experiment, the soil is inserted in an apparatus that confines it laterally, allowing only the soil to expand vertically. A meter is placed over the soil that measures the vertical variation of the sample. The experiment is concluded when the vertical variation stops and the soil stabilizes.

2.4 Permeability Test using an Oedometer

The permeability test and the consolidation test were performed according to the NBR 14545 and NBR 12007, respectively. The samples were tested in an oedometer. The samples were saturated with water and compressed with a constant applied load. Every 24 hours, the applied load of the sample was doubled. The suffered deformations by the soil were registered directly in the software.

The volumetric variation of the water was determined simultaneously in the burette connected to the cell in which the sample was kept. From the difference registered, the permeability coefficient of the soil was calculated after being compressed with different loads. Figure 1 illustrates the oedometer utilized in the laboratory.

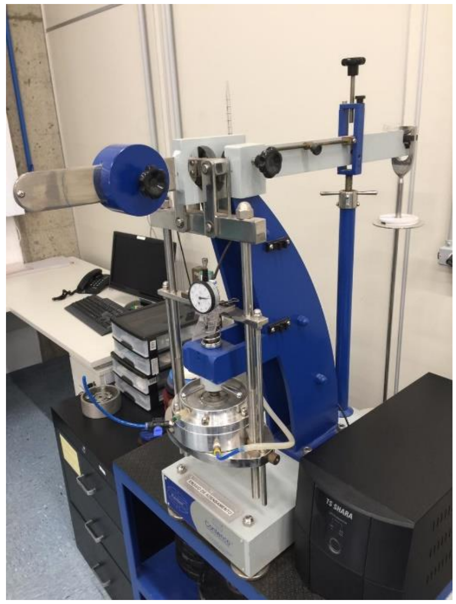

Figure 1 – Oedometer utilized in the experiments.

3. RESULTS AND DISCUSSION

3.1 Granulometry Test

The results obtained from the granulometry tests are presented in Figures 2 and 3. The presence of clay on the samples was similar: 74% for sample A and 78% for sample B. Both samples have less than 10% of sand.

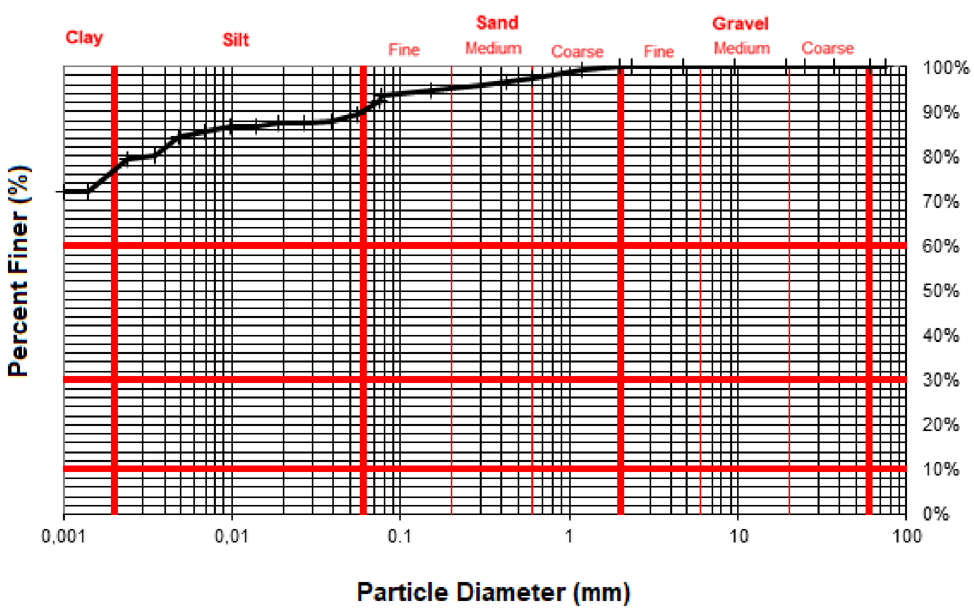

Figure 2 – Granulometry curve of sample A.

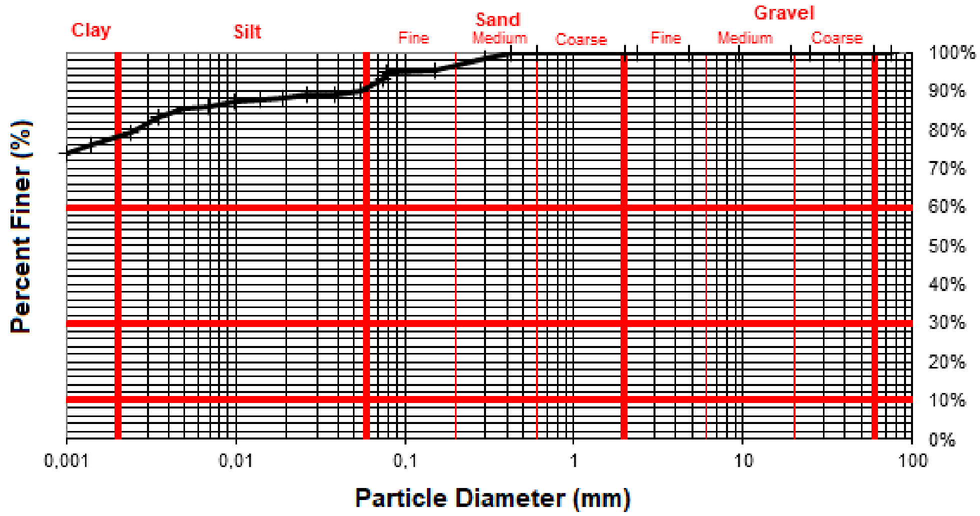

Figure 3 – Granulometry curve of sample B.

3.2 Atterberg Limits

Table 1 presents the obtained properties in the characterization tests of the samples.

Table 1 – Properties of the samples.

Property	Sample A	Sample B
ρ_s (g/cm^3)	2,87	2,79
LL (%)	323	333
PL (%)	54	43
CI (%)	269	290
w (%)	13,2	11,7

After interpreting the granulometry curves, the colloidal activity (CA) of each sample (Equation 1) was determined.

$$CA = \frac{CI}{\%\,Clay} \qquad [1]$$

This particular property correlates to the expansive capacity of the soil. The results are shown in Table 2. It can be observed that the colloidal activity of both samples is very similar.

Table 2. Colloidal activity of the samples.

Property	Sample A	Sample B
CA	3.63	3.72

3.3 Swelling Test and Free Expansion

The results of the swelling test and free expansion test are presented in Table 3. The minimum swelling ratio recommended in the international specification GRI-GCL3 is also specified. The free expansion curves as a function of time can be seen in Figures 4 and 5 for samples A and B, respectively.

Table 3. Results of the swelling test and free expansion tests.

Property	Sample A	Sample B	Minimum swelling ratio according to GRI – GCL3
Swelling (mL/2g)	20	25	24
Free Expansion (%)	162	208	-

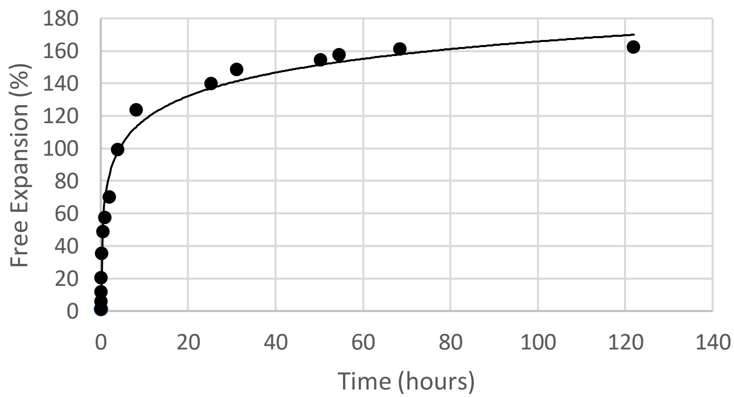

Figure 4. Free expansion of sample A in function of time.

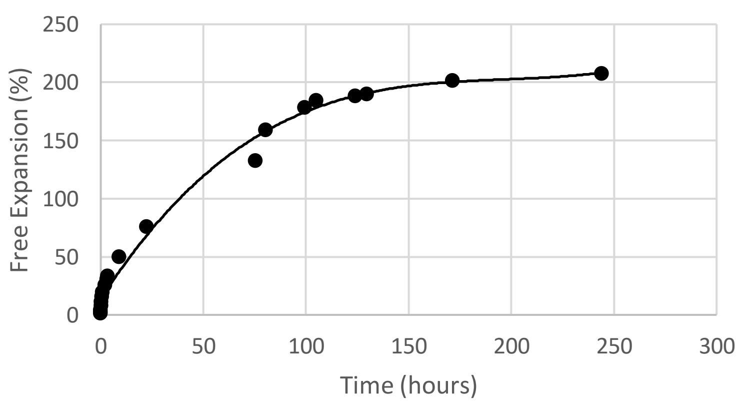

Figure 5. Free expansion of sample B in function of time.

3.4 Permeability Test I in the Oedometer

The results of the oedometer test of both samples are presented in Table 4.

Table 4. Results of oedometer test.

Sample A		Sample B	
Load (kPa)	Void Ratio	Load (kPa)	Void Ratio
12.3	1.53	12.3	1.79
12.3	2.59	12.3	3.48
24.5	2.59	24.5	3.47
49.0	2.59	49.0	3.45
98.1	2.46	98.1	3.28
196	2.17	196	2.81
490	1.47	490	2.16
980	0.99	980	1.73
1,961	0.57	1,961	1.28
490	0.80	490	1.50
98.1	1.26	98.1	1.85
12.3	1.87	12.3	2.12

Using these results, the swelling pressure of the samples were determined graphically. This property corresponds to the load in which the void ratio, after the expansion of the soil, returns to its measured level before the expansion – that is, at the beginning of the test. Figures 6 and 7 present the consolidation curves for each sample.

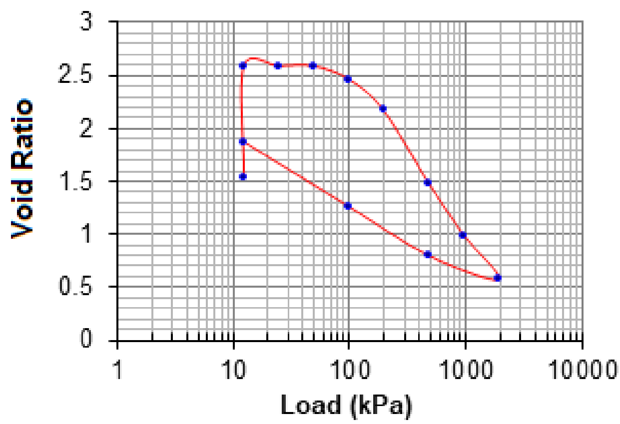

Figure 6. Sample A's consolidation curve.

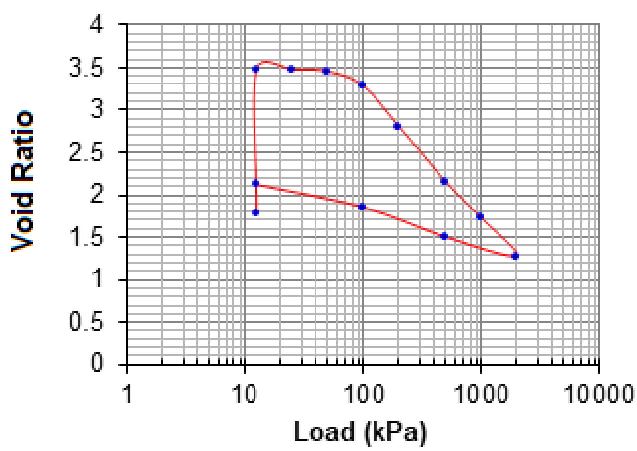

Figure 7. Sample B's consolidation curve.

It is important to note that sample A presented the minor void ratio under the highest load tested (1,961 kPa) when compared with the result of sample B. However, the oedometer curves were similar.

Table 5 shows the result of the swelling pressure for both samples.

Table 5. Swelling pressure of the samples.

Samples	Swelling Pressure (kPa)
A	470
B	870

The coefficients of permeability (k) in function of the applied load of each sample are presented in Table 6.

Table 6. Coefficients of permeability in function of the applied load.

Sample A		Sample B	
Load (kPa)	k (cm/s)	Load (kPa)	k (cm/s)
12.3	9.8×10^{-9}	12.3	5.0×10^{-8}
24.5	3.7×10^{-9}	24.5	1.9×10^{-8}
49.0	3.7×10^{-9}	49.0	4.2×10^{-9}

Regarding the determination of the permeability coefficient, the volumetric variation in the test equipment needs to be measured, and considering that the samples have a low permeability, the time needed to quantify such reduced volumetric variation was long.

The samples presented different behaviors under low loads and similar behaviors under the highest load tested. These tests were conducted by a rigid wall equipment. Bueno et al. 2002 compared two different samples of bentonite tested in a rigid wall permeameter and the flexible wall permeameter. The results showed that the flexible wall permeameter presented lower coefficients of permeability than the rigid wall permeameter.

4. CONCLUSIONS

Based on the experimental data of Bueno et al, 2002, the obtained values on the granulometric test and Atterberg limits are coherent to what is found in the literature.

Colloidal activity (CA) of both samples is significantly higher than the minimum expected for active clays, which is CA > 1.25. Because of that, it can be affirmed that the tested samples present a high expansive potential.

Regarding the results of the swelling index, it can be concluded that only Sample B reaches the minimum expected for specification GRI-GCL3.

It can also be concluded that Sample B is more expansive than Sample A, since its swelling pressure is almost the double of Sample A (870 kPa and 470 kPa, respectively). Besides that, the grainy sample had a smaller free expansion ratio than the powder sample (162% and 207%, respectively).

As expected, the permeability coefficients, determined for different applied loads, reduced when the applied load was increased.

Taking into account the data obtained by Shan and Daniel 1991, the correspondent results to applied loads until 49 kPa are coherent with those already registered in the literature. Therefore, the efficiency of using geosynthetic clay liners (GCL) in sanitary landfills was confirmed experimentally. In addition, its reduced volume compared to compacted clay, its low permeability coefficient is even more profitable when the landfill transmits high stresses to the GCL.

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