CLAY
GEOSYNTHETIC
BARRIERS

Editors

HELMUT ZANZINGER
ROBERT M. KOERNER
ERWIN GARTUNG

PROCEEDINGS OF THE INTERNATIONAL SYMPOSIUM IS NUREMBERG 2002
NUREMBERG/GERMANY/16–17 APRIL 2002

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Edited by

H. ZANZINGER
LGA Geosynthetic Institute, Nuremberg, Germany

R.M. KOERNER
Geosynthetic Institute, Folsom, PA, USA

E. GARTUNG
LGA, Geotechnical Institute, Nuremberg, Germany

A.A. BALKEMA PUBLISHERS   Lisse/Abingdon/Exton (pa)/Tokyo

Laboratory studies for the development of a GCL

B.S. Bueno & O.M. Vilar
Department. of Geotechnical Engineering, School of Engineering at São Carlos, University of São Paulo, São Carlos, Brazil

S.L. Palma & V.E. Pimentel
Ober Industria e Comercio Ltda, São Paulo, Brazil

ABSTRACT: This paper describes the first laboratory tests carried out to develop the scientific basis of the first Brazilian GCL. Since the most important component of a GCL is the clay core, larger attention was given to the selection of a clay material which could give an appropriate hydraulic conductivity and swelling potential to guarantee sealing, and self healing when slightly punctured during field installation. Two clay materials were investigated, samples A and B. Grain size distributions, Atterberg limits, rigid and flexible wall permeability tests were performed with both materials. Due to its good performance and lower cost, the B sample was selected and submitted to chemical and X-Ray tests, self healing and direct shear tests.

1   INTRODUCTION

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

GCLs are manufactured hydraulic barriers consisting of a bentonite layer, usually sodium bentonite or any other cation combination bentonite, which exhibit 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 to an adhesive and bonded to one face of a geomembrane sheet. The clay layer can add sealing capacity to the geomembrane but, more important, 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.

Ideally GCLs have the advantage over compacted clay liners (CCL) since present much lower hydraulic conductivity, high swelling potential and are easy to install and repair.

The use of GCL in Brazil is rather limited to date, since only two applications are reported so far. This paper presents preliminary laboratory tests carried out to develop the scientific basis of the first GCL to be manufactured in the country.

2   TECHNICAL REQUIREMENTS FOR A GCL

The main geotechnical requirements for a GCL are:

- low hydraulic conductivity;
- healing potential;
- chemical resistance to refuses and leachates and
- internal shear strength

Because of its small thickness a GCL must have a very low hydraulic conductivity in order to ensure sealing fulfillment. Standard hydraulic tests of GCls are with distilled water and encompass the use of either rigid or
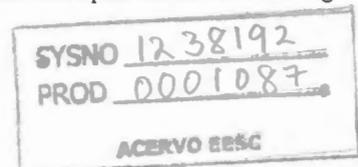
flexible wall permeameters. In order to show hydraulic equivalence to layers of compacted clay liners (CCLs) ranging from 0,30 m to 1,00 m thick and having coefficient of permeability to water (k) of the order of 10^{-9} m/s, GCLs must present k between 1 to 5×10^{-11} m/s. This requires GCL cores made up of very fine and homogeneous clays such as high quality sodium bentonites.

This clay type belongs to the group of smectites and its main mineral component is montmorilonite. Most bentonites used in GCLs, although commercially called sodium bentonite, in fact contain, apart from the dominant cation sodium, variable amounts of calcium, potassium and magnesium cations (Egloffstein 2000). The large specific surface and the great net negative superficial electric charge make bentonites able to adsorb large numbers of hydrated cations and water molecules. These molecules not only surround the clay particles but also get into the particle layer. This conferees to this clay a very large swelling capacity. It is not rare free expansions of pure dry bentonites when in contact with pure water reaching 100 to 500%. So, under confinement this material can expand and seals small holes which eventually are made during GCL installation. This is called auto healing potential.

When in contact with fluids, normally water, the clay external area, which have electrical negative net charge, is surrounded by a cloud of cations and water molecules that tend to neutralize this negative charge. This layer of water and cations attracted by the particle is called diffuse double layer. During particle arrangements the thicker the double layer the more disperse is the resulting soil structure. Disperse soils have smaller hydraulic conductivity than flocculated ones. The thickness of the double layer, T, can be estimated using Guoy-Chapman correlation, i.e.:

$$T = \alpha[D/n_0 v^2]^{0.5} \tag{1}$$

where D is the medium dielectric constant, n_0 is the ion concentration in the particle surrounding solution and v is the valence of the cation. The term α is a constant of proportionality .

According to this expression large ion concentration, presence of cations of double valence, such as calcium and magnesium, or of triple valence, such as iron and aluminum, can reduce the thickness of the double layer and therefore lead the clay system to a more flocculated state. In such situation the coefficient of permeability may increase by one order of magnitude as shown, for example, by Shan & Daniel (1991) and Schackelford et al. (2000). Taking into account these characteristics, chemical incompatibility between GCL and domestic and industrial wastes can arise under many circumstances since leachates can have wide range of chemical composition. So chemical incompatibility of GCL and materials to which it will be in contact have to be thoroughly investigated, no matter the dominant bentonite cation, and its effects must be taken into account in design. However, considering the initial stage of the research, this topic will not be addressed in this paper.

3   TEST RESULTS

Aiming the fabrication of a sodium bentonite geosynthetic clay liner, two clay samples (A and B) were taken to analysis. In order to select which bentonite should be used to manufacture the GCL, characterization tests were carried out with both samples. Table 1 presents the Atterberg limits. As can be seen sample B is far more plastic than sample A although both present very large plastic index (PI) which is an indication of high soil expansion. Figure 1 shows the grain size distributions and the curves of aggregates obtained by dry sieving. As can be seen sample A is slightly finer than sample B, although both of them present clay content over 70%. The larger percentage of aggregates of sample A (around 60%) is in the range of 0.060 to 0.040 mm and for sample B, about 70% is in the range between 0.075 to 0.045 mm. The aggregate size distribution allow to expect that water will penetrate more easily in sample B and therefore saturation and expansion will be happen quicker than in sample A.

In order to investigate the expansion potential of both clays, LNEC swelling test apparatus (Castro 1964) was used. In the performed swelling tests dry samples were only slightly compacted in a metallic mould, 15 mm thick, to simulate the unit weight of the clay core. The bottom of the sample was placed in contact with water

Table 1.   Atterberg limits of tested bentonites.

Sample	Liquid limit	Plasticity index
A	265%	209%
B	490%	432%

such that sorption occurred by capillarity. A stress of 3,5 kPa was applied to the top of the sample and the expansion was registered with time. Figure 2 show the results obtained with this test.

It can be seen that the full expansion of sample B develops in a relatively short period of time, whereas for sample A the expansion took longer to occur. As can be seen sample B is slightly more expansive than sample A. The final expansion reached about 100 and 130% for A and B, respectively.

Permeability tests were also carried out using rigid and flexible wall permeameters. In the first case a GCL disk sample was placed in the bottom of a rigid cylinder sandwiched by two 50 mm layers of coarse sand. In the second case, the sample was tested according to ASTM D 5084. Table 2 resumes average results for each test condition. As can be seen sample A was slightly less permeable than sample B but both give hydraulic conductivity in the order of magnitude expect for high quality GCLs.

In view of these results and considering that clay B was 60% cheaper than clay A, it was selected for manufacturing the GCL. Further tests have been carried out in the clay itself and in the GCL, some of which are presented ahead. Additionally sample B was investigated both chemically and with X-ray. Table 3 presents the main components of the bentonite B, whereas Figure 3 shows the X-ray diphractogram.
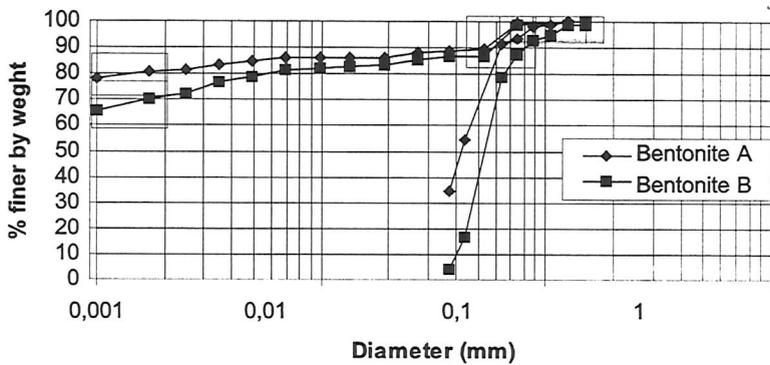

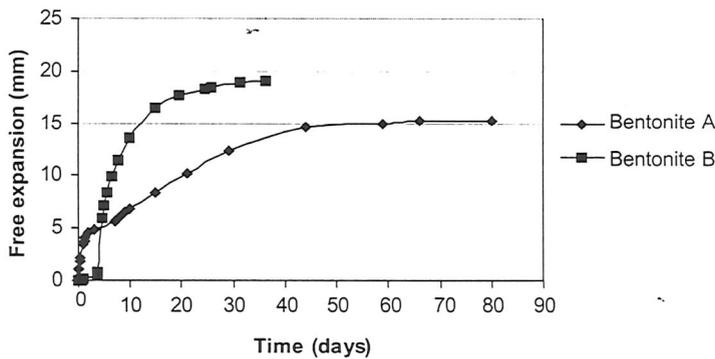Figure 1.   Grain size distributions.

Figure 2.   LNEC swelling test results.

Table 2.   Hydraulic conductivity of the tested samples.

Sample	$k_{\text{rigid wall permeameter}}$ (m/s)	$k_{\text{flexible wall permeameter}}$ (m/s)
A	3.3×10^{-10}	2.9×10^{-11}
B	1.3×10^{-10}	6.3×10^{-11}

Table 3. Chemical composition of the tested clay (sample B) – percentage by weight.

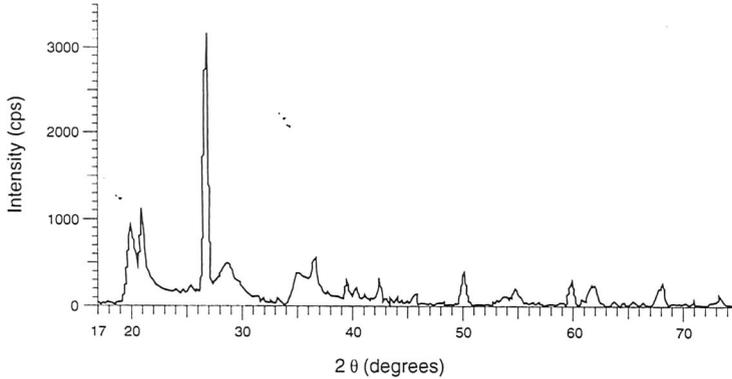| Components	Al_2O_3	SiO_2	Fe_2O_3	K_2O	Na_2O	TiO_2	CaO	MgO	P.F.
%	14.00	62.38	8.01	0.42	2.45	0.89	1.04	2.54	7.83

Figure 3. X-ray diphractogram of sample B.

Table 4. Hydraulic conductivity of punctured GCL.

Sample	$k_{5\,mm\,hole}$ (m/s)	$k_{10\,mm\,hole}$ (m/s)
B	2×10^{-10}	4×10^{-10}

The qualitative identification of the components of the sample B indicates the presence of montmorillonite, quartz, mica (muscovite) and anorthite.

Self healing tests were also performed in rigid wall permeameters aiming to investigate the capability of the GCL to swell under small pressures and block holes made during handling and installation and prevent flow through the sealing system. These tests allowed the comparison of hydraulic conductivities of original sample with those of samples in where holes of 5 and 10 mm diameters were made. The samples were punctured while dry, saturated and tested. Table 4 present the average results of three tests carried out for each test condition. The results show good auto-healing capacity, although results are slightly higher than those of virgin sample.

Since field situations can impose shear stress to the GCLs it was important to investigate its dry and saturated shear resistances. The tests were carried out simulating undrained conditions in a direct shear box using samples of 100 mm squared. The top and bottom geotextile were bonded to a wooden plate so the shear zone would occur within the bentonite mass. The stress displacement curves show an yield point that occurs for horizontal displacement between 2 to 4 mm, followed by a strain hardening behavior that leads to ultimate maximum shear stress at displacements between 12 to 16 mm. This strain hardening behavior is probably commanded by the needling filaments intercepting the shear zone, Figure 4. Shear strength envelopes for yield and ultimate conditions are shown in Figure 5.

As can be seen cohesion intercepts were small and did not varied much considering yielding and ultimate conditions. The shear angles however were quite different. The yielding strength lead to an Mohr envelope close to the classic $\phi_u = 0$ and in the ultimate condition to $\phi_u = 8°$. This shows that the influence of the needling filaments only occurs at large displacements.

Results also show that the undrained cohesion of the saturated bentonite dropped dramatically when compared to the dry sample but the undrained friction angle was quite similar to that of the dry sample. A similar stress-displacement was also observed.
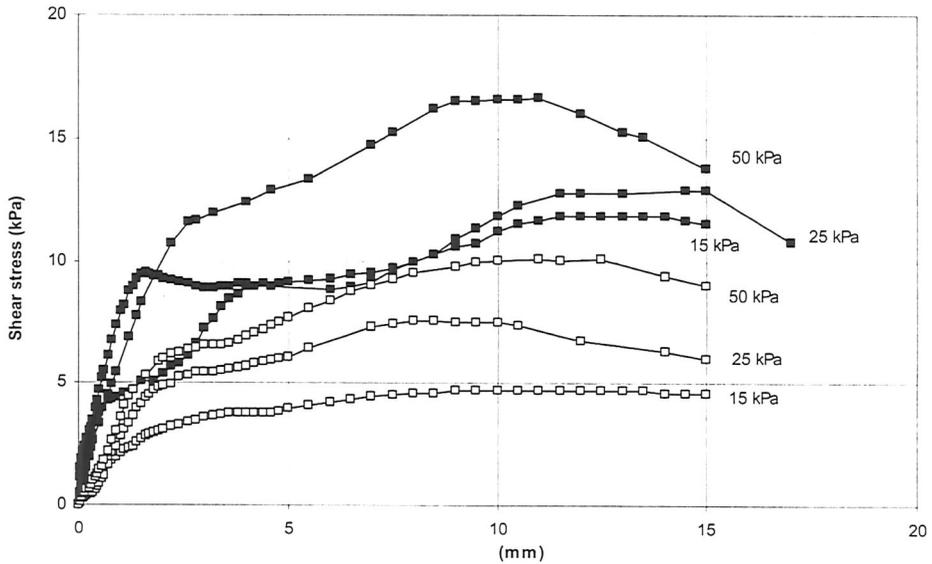
Figure 4.   Stress vs. displacement curves for dry (■) and saturated (□) GCL specimens.
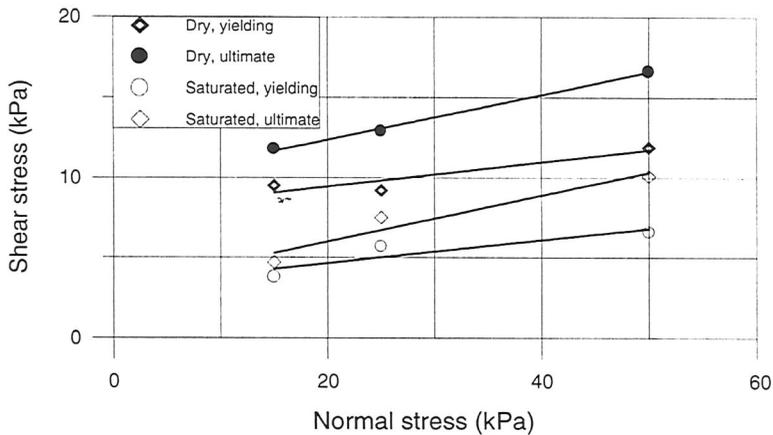

Figure 5.   Mohr envelopes for dry and saturated GCL specimens.

4   CONCLUSIONS

This paper presented the preliminary studies regarding the development of the first Brazilian GCL. After comparing two available bentonites, one sample was elected considering mainly economic reasons, since the characteristics of both were quite similar. It is shown that the chosen bentonite shows a marked free expansion and that the expansion started about five days after contact with water. However, after starting, the full expansion takes place in about 20 days. The hydraulic conductivity of the GCL was about 10^{-11} m/s, which is similar to most commercial GCL available worldwide. The shear strength of the bentonite is very small. In the dry condition, the angle of shearing strength at the ultimate condition is 8° and the intercept of cohesion reaches

about 9 kPa .The cohesion value dramatically drop to 3 kPa in the saturated condition. The GCL has shown a good self healing capacity since results of perforated samples are of same order of magnitude as those of fresh samples.

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