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Geosynthetic Clay Liners: how different solutions interact with hydraulic and colloidal properties of bentonite of GCLs

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ABSTRACT: Colloidal and hydraulic properties of natural and activated sodium bentonite were investigated with water and different solutions. The solutions were strong acid, strong base, seawater, water with different concentrations of divalent cations, simulated MSW leachate, and simulated HW leachate. Hydraulic conductivity tests were carried out on bentonite and on GCLs with different condition of hydration. On GCLs were verified also the exchangeable cations in solution in function of the concentration of divalent cations ($Ca^{2+}$and Mg^{2+}). Different treatments of the natural sodium bentonite were applied to increase the resistance of the material to the divalent cations and to improve the waterproofing properties of bentonite.

1 INTRODUCTION

Geosynthetic Clay Liners are reliable construction materials, which allow the use of a very thin bentonite layer for sealing standard use in waterproofing practice.

Since their appearance in 1985 as hydraulic barriers in waste containment systems and in transportation related waterproofing applications, GCLs have been installed in numerous realisations.

GEOSYNTHETIC CLAY BARRIER, usually known by reference to the acronym of GBR–C, is a factory-assembled structure of geosynthetic material in the form of a sheet, which acts as a barrier. The barrier function is essentially fulfilled by bentonite. It is used in contact with soil and / or other materials in geotechnical and civil engineering applications. CEN TC 189 (Geosynthetics), European Committee for Standardisation (CEN), introduced Geosynthetic Clay Liners (GCLs) with this new definition as barrier materials in environmental, transportation and geotechnical related waterproofing systems.

GBR–C characteristics are ratified for use in the construction of solid waste storage and disposal sites, and storages for hazardous solid materials; GBR–C characteristics are suggested for use as a fluid barrier in the construction of liquid waste disposal sites, transfer station or secondary containment; GBR–C characteristics are required for use on projects alongside the roads, the airports and the railways in order to protect groundwater.

GBR–C are used in various sealing solutions, where a few different soil and water contaminants come into contact with GCLs and consequently with the bentonite.

Geotextiles in GCLs act as then support and reinforcement materials, while the chemical stability of GCLs depends on the characteristics of bentonite, the low hydraulic conductivity component, that through hydration and by swelling with the right moisture, forms the barrier system.

2 BENTONITE ORIGIN AND CARACTERISTICS

The waterproofing properties of the GCLs depend, mainly, on the bentonite inside. Bentonite is a clay, from the family of the smectites, with a significant content of montmorillonite.

The origin of this material is the alteration of volcanic ash or the hydrothermal alteration of volcanic rocks.

The structure of the bentonite consisting of two types of layers: silica tetrahedral layers and aluminum octahedral layers, the two tetrahedral layers sandwich the octahedral. These three layers form one clay sheet. In the montmorillonite there is an isomorphous substitution of aluminum III by magnesium II. So there is a negative crystal charge, the excess negative charge is compensated by cations on the clay surface while the edges of the clay crystal are positive and compensated by anions.

The elementary particle is a platelet, every platelet is about 1 nm thin with surface dimension extending to about 1 µm, the various platelet are held together by electrostatic and Van der Waals forces, but they can be dispersed in submicronic particles until a specific surface area of 800 m^2/g is developed.

This capacity, to show a so big specific surface area, is one of the cause of the great absorption of water of this material. The absorption of water and the swelling of the material give the waterproofing properties to the bentonite. For knowing a bentonite we check the chemical and mineralogical composition, the cation exchange capacity and the specific surface area as structural characteristics, while for defining the possible application of a material we check the colloidal and binding properties.

Given the above, we can consider an important step of the process of production of GCL the selection of the bentonite. It is known that there are calcium, sodium, activated sodium bentonite but also in the natural sodium bentonite it is possible to find materials, all under the name bentonite, with different properties.

Bentonite is used in so many applications that it is quite easy to understand that precisely because of the structural differences among the various types it may be used so differently and diffusely.

3 BENTONITE IN GCL

We know that a way to get a first indication of the waterproofing properties of a bentonite is to check its colloidal properties but, however, the confirmation of the preliminary data is to be found through a check on the permeability of the finished product.

We also know that the permeability of a bentonite, and of a GCL, is related to the hydration way of the material, to the confining pressure and to the nature of the permeated fluid.

We know that the waterproofing properties are typically and mainly found in a sodium bentonite, so we focalize our attention on this family of clay only.

The aim of this work is to study the behavior of different bentonites in presence of contaminant solutions, to understand how and how much the contaminants affect the bentonite inside the GCL.

So we carried out some trials to check how much the different solutions affect the colloidal properties of the bentonite (natural sodium and sodium activated); we started from the bentonite (the waterproofing component in GCL) to transfer the results to the GCL. It is important to evaluate how contaminants solutions reduce the swelling, the liquid limit and the viscosity of the bentonite and whether the reaction is the same with a natural sodium bentonite and an activated sodium bentonite.

The aim is to understand the behavior of the material at different hydration conditions and how to improve the waterproofing properties also in presence of contaminants.

Firstly the tests were carried out on bentonite and then on GCL as to check the permeability of the final material as well.

4 MATERIALS AND METHODS

4.1 *Bentonites*

Three bentonites were selected, two natural sodium and one activated sodium. They have different geographic origins (see Table1), they were all clays with a high content of montmorillonite. As structural characteristic they all have a high cation exchange capacity and the mineralogical and chemical compositions show a high content of montmorillonite and a good purity of the materials. The colloidal properties of the bentonites were checked, Table 1, in order to establish their properties in distilled water firstly. The methods applied for these analysis are the standard international methods.

Those are the initial properties of the bentonites, but the real point is then to determine what it happens when the solution is not mere distilled water.

Table 1. CEC and colloidal properties of the three bentonite

Bentonite samples in distilled water	CEC (VDG P69) meq/100g	Swell index (ASTM D5890) ml/2g	Brookfield viscosity cps	Liquid limit (CNR-UNI 10014)
Bento1 (activated sodium)	106	46	3600	560%
Bento2 (natural sodium)	80	20	60	550%
Bento3 (natural sodium)	128	32	800	630%

4.2 *Solutions of contaminants*

There is a variety of different contaminants that can come in contact with the bentonite contained in the GCL as it is possible to find waters with high content of heavy metals, sea water, acid or basic solutions and typical waste liquids and the understanding of the main problems that may arise is a help to define some specific barrier for any given application. In Table 2 are reported the solutions used in this work which were prepared in the laboratory to simulate some real situations where GCL is today used and also some other ones where it is not yet used. The aim is to arrive to individuate a selective bentonite for every application; the way is to understand the course of degradation of the material, select the suitable bentonite and modify it to became more resistant if necessary.

Another important procedure to study is the bentonite hydration way and particularly: 1) have the bentonite react directly into the solutions, 2) have the bentonite react first with tap water and then, by immersion, with the solutions, 3) have the bentonite react with the solutions by sprinkling them over it, as it happens when it rains.

Concerning the second way of hydration, that foresees to completely swell the bentonite in tap water and then put it in contact with the contaminant solutions, a parameter to evaluate is the time during which the bentonite keeps the swelling and the waterproofing capacities, when in contact with those solutions.

We will see that it depends on the kind of bentonite.

Table 2. Solutions used to treat the bentonites

(a)	Distilled water	
(b)	Tap water	
(c)	CaCl$_2$ solution (102 °F)	
(d)	MgCl$_2$ + CaCl$_2$ (120° F)	
(e)	Phosphoric acid – pH 3	
(f)	Acetic acid – pH 5	
(g)	Hydrochloric acid – pH 1	
(h)	Sodium hydroxide pH = 13	
(i)	Sea water	
(j)	Solution	Acetic acid 0.15 M Sodium acetate 0.15 M Salicylic acid 0.007 M Ca^{2+} 1.00 mg/l pH 4.4
(k)	Solution	Acetone 4.0 mg/l Benzoic acid 2,0 mg/l Phenol 3,0 mg/l Methyl chloride 1,0 mg/l Cd 100 – 200 mg/l

5 EXPERIMENTAL

5.1 *Tests on bentonite*

The bentonites were firstly tested directly into the solutions and herebelow the relevant results are reported.

Table 3. Results obtained using the solutions to check some properties of the bentonites

	Bento 1			Bento 2			Bento 3		
Solution	Swell index (ml/2g)	Viscosity (cps)	Liquid limit (%)	Swell index (ml/2g)	Viscosity (cps)	Liquid limit (%)	Swell index (ml/2g)	Viscosity (cps)	Liquid limit (%)
(a)	46	3600	560	20	60	555	32	2500	559
(b)	38	2000	530	25	60	450	32	2500	489
(c)	34	1200	520	17	150	440	19	330	448
(d)	30	1650	617	15	120	458	19	420	412
(e)	35	360	582	15	120	463	26	1260	554
(f)	45	6450	645	19	0	498	31	1200	565
(g)	19	450	313	13	210	350	13	210	412
(h)	43	6900	731	29	90	521	33	270	695
(i)	7	1000	139	5	30	117	7	60	131
(j)	12	180	170	17	150	213	11	270	129
(k)	44	2400	617	27	90	509	38	2700	554

Some of those results (swell index) are in the graph (Fig. 1) to show that all the bentonites have a similar reaction to the used contaminants.

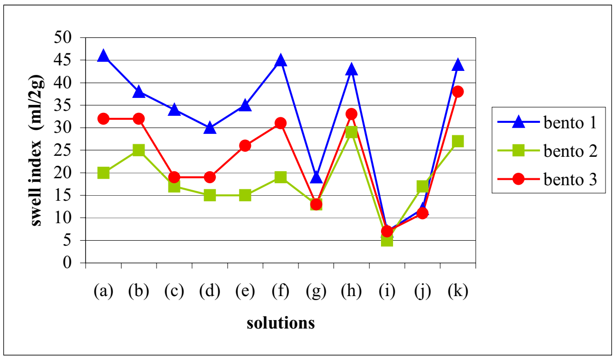

Figure 1. Swell index of the three bentonites after the contact with different solutions

Table 3 and Figure 1 show how the contaminants affect the bentonites, the three samples have a similar behaviour, in Figure 1 you can see in particular the swelling of the material. There are contaminants that degrade completely every material.

On the grounds of these results we decided to test the three bentonites with a different way of hydration, so firstly we swelled the samples in water and after we put them into the solutions. We decided to apply this second method only with the solutions that degraded the bentonites significantly and only with the most likely contaminants ((c), (g), (i) solutions).

The swell index was specifically tested.

Table 4. Swell index values (ml/2g) after bentonites become in contact with solutions (c), (g) and (i)

BENTONITE	Solution (c)			Solution (g)			Solution (i)		
	0 d[1]	10 d	25 d	3 d	10 d	25 d	3 d	10 d	25 d
Bento1 (activated sodium) European calcium bentonite activated in our plant	34	20	20	24	19	19	10	7	7
Bento2 (natural sodium) Bentonite commonly found on market	20	17	17	13	13	10	10	5	5
Bento3 (natural sodium) LCM bentonite	30	30	28	13	13	13	26	26	26

[1] Days of contact between the bentonite and the solution

It is possible to see that all the bentonites were affected by the solutions, but some of them more so and more quickly than the others.

Also the data on viscosity were checked obtaining similar results; in fact the viscosity, after 25 days, decreased around 50% for Bento 1 and Bento 2 and 25% for Bento3, in solutions (c), (g), (i). On the grounds of those results we chose Bento 3 to prepare some GCL samples.

5.2 *GCL directly put in the solutions*

We prepared some samples of GCL with the Bento 3, in order to test the swelling and the permeability of the GCL. The swelling was tested directly in the contaminants solutions.

Samples of GCL were hydrated directly in the solutions of contaminants, the heights were measured after 1, 2, 6 and 24 hours and in table 4 are reported the results obtained in this way.

Table 5. Measure of the heights of the GCL samples after free swelling at different times

Solution	T = 0 h (cm)	T = 1 h (cm)	T = 2 h (cm)	T = 6 h (cm)	T = 24 h (cm)
(a)	0,55	2,4	2,9	2,9	2,9
(b)	0,55	2,4	2,7	2,8	2,8
(c)	0,55	1,9	2,2	2,2	2,2
(d)	0,55	2,5	2,5	2,5	2,5
(e)	0,54	2,4	2,7	2,7	2,7
(f)	0,56	2,4	2,7	2,5	2,5
(g)	0,54	1,3	1,3	1,3	1,3
(h)	0,55	2	2,5	2,5	2,5
(i)	0,52	0,5	0,5	0,5	0,5

Some similar tests were carried out with different concentrations of $CaCl_2$ and the data are reported in Table 6.

Table 6. Measure of the heights of the GCL samples at different times after free swelling into some solutions with different concentration of $CaCl_2$

$CaCl_2$ (M)	T = 0 h (cm)	T = 2 h (cm)	T = 6 h (cm)	T = 8 h (cm)	T=24h (cm)
0,0125	0,55	1,9	1,9	1,9	1,7
0,1	0,55	1,1	1,1	1,1	1,1
0,5	0,6	1,2	1,2	1,2	1,2
1,0	0,6	1,1	1,1	1,1	0,9

As for the bentonite, the solutions that have the worst effect on the GCL are: (c), (g), (i), and a poor swelling was reported whenever the materials were put directly into them.

5.3 *GCLs, pre-hydrated in water*

The same experiments were carried out having first the GCLs free swell in water and then adding the solutions; the results are quite different and reported in Table 7.

Table 7. Free swelling in the solutions after free swelling in water

Solution	T = 0 h (cm)	T = 1 h (cm)	T = 2 h (cm)	T = 6 h (cm)	T = 24 h (cm)
(c)	2,9	2,9	2,9	2,9	2,9
(g)	2,9	2,9	2,9	2,8	2,8
(i)	2,9	2,9	2,8	2,7	2,7

On this material was checked the permeability as well and the results confirm the information obtained from the bentonite.

Pre-hydration of the GCLs gives the possibility to use the material also in presence of some strong contaminants.

5.4 *Selective GCL*

To improve the waterproofing properties in presence of calcium chloride solution and sea water we followed a procedure of treatment of the bentonite with an anionic polymer, the finished properties were verified by measuring fluid loss and swell index. The specific treatment produced a decrease of the fluid loss, an increase of the swell index and a reduction of the permeability. All these parameters were tested on the Bento 3 treated with different polymers.

Table 8. Swell index and fluid loss before and after the treatment of Bento 3

Additives	Swell index (ASTM D5890) (ml/2g)	Fluid loss (ASTM D5891) (ml)
Bento 3	32	12
Bento 3 + add. 1	55	6,0
Bento 3 + add. 2	55	7,2
Bento 3 + add. 3	45	8,6
Bento 3 + add. 4	60	7,7

The Bento 3 treated with the additives was tested in presence of the solutions (c) and (i). This test was carried out performing the permeation with the solutions of contaminants. We left the material Bento 3 + additive 1 swelling in water, we prepared a cake with this swelled material and we caused the permeation using the solutions.

Table 9. Behaviour of Bento 3 with additive 1 in contact to some solution

Bento 3 + additive 1	
Solution	Fluid loss (ml)
Water	1,30
Solution (c)	2,87
Solution (i)	2,95

The same material was used to prepare a sample of GCL and to test the value of permeability with standard test method for measurement of hydraulic conductivity (ASTM D5084).

The results were encouraging; on the GCL made with the treated bentonite, we obtained a value of $k = 5 \div 6 * E -12$ m/s.

6 CONCLUSIONS

High expectation has been growing for more than twenty years in GCLs and about the same time was needed for acknowledging their possible applications, but, nevertheless, the use of GCLs on barrier systems for waste storage sites even today is sometimes regarded as a new one mainly because the chemical tests carried out on GCLs are experimental and very few if compared with the work carried out on the other geosynthetics.

By now it is generally accepted that the hydraulic conductivity is related to the chemical composition of the bentonite. Therefore it is fundamental to standardize the tests methodology on GCLs and fully understand the chemistry and the behaviour of the bentonite, so that all the possible interactions between the GCLs and the polluting agents of the soil and of the leachate may be thoroughly investigated.

On the grounds of these results it is possible to conclude that the most aggressive contaminants are calcium, strong acid solutions and sea water. For what regards calcium and acid solutions the characteristic reduction on the bentonite performances depends on the exchange of ions in the crystal structure of the bentonite and consequently on the preference for divalent ions and H^+.

As far as sea water is concerned it may be noted that it acts more on the activated bentonite, even though the initial properties of that material were higher than the other ones.

The pre-hydration of the bentonite with tap water reduces the effect of the aggressive contaminants; there is the same effect on the GCLs behaviour when it comes in contact with the leachate, even though the effect is less obvious than on bentonite.

Calcium chloride on pre-hydrated GCLs produces a minimum effect on the geosynthetic clay barriers in the short period. It is important to point out that the pre-hydration of the barrier, using fresh water before it gets in contact with an aggressive contaminant, is a fundamental step for achieving better performances from the GCL barrier systems.

As the last point we mention that the polymer treated bentonite gives the opportunity to design some specific and selective barriers able to better resist to aggressive leachate throughout their working life, even if calculated for a long period of time.