Geosynthetics: Applications, Design and Construction, De Groot, Den Hoedt & Termaat (eds)
© 1996 Balkema, Rotterdam. ISBN 90 5410 836 3

The use of GCLs for landfills in Slovakia – Geotechnical and legislative requirements

R. Baslik
Bratislava, Slovakia

ABSTRACT: The geotechnical approach to the evaluation of GCLs mineral fillers is presented. The signification of the relation between liquid limit and swell characteristics, like water adsorption by Enslin, free swell and one dimensional swelling, is studied to judge the quality of mineral fillers. Similarly the relationship between liquid limit and coefficient of permeability of the mineral fillers is concerned herein.The use of geotechnical recommendation for GCLs choice is discussed. Legislative requirements on GCLs according to the Slovak technical standard is introduced.

1 INTRODUCTION

A variety of low permeability geosynthetic liners - GCLs - are used as hydraulic barriers. The presently available GCL products consist of a layer of naturally bentonite in the powdered form encapsulated between two geotextiles.

As a filler (usually mineral filler) any material supplying suitable properties can be used. For the purpose of GCLs it is predominantly the hydraulic permeability of the filler which is most important (Bishop, 1994) or its ability to contain the targered liquids (Koerner, Daniel, 1994). Therefore, the major concern regarding the fillers is to establish their hydraulic permeability. The primary quality parameter for mineral filler is its free swell (CETCO, 1994) and swell, because swell behaviour usually has a direct influence on GCL hydraulic performance. Relationship between the filler swell behaviour and its other geotechnical characteristics is important.

The objective of the study described in this paper is to obtain a better understanding of the chemical and geotechnical properties of GCLs fillers and contemporarily to develop a method for the evaluation of the mineral fillers performance in more detail.

Two main topics of the research for fillers had been selected by research team. The topics are following: (1) geotechnical assessment of mineral fillers, and (2) practical application of this geotechnical assessment.

2 MINERAL FILLERS FOR GCLs

2.1 Tested materials

The mineral fillers tested, and a brief description of them, are given in Table 1.

2.2 Geotechnical and chemical properties of materials

The quality of bentonite is usually ascertained with some type of measurement of water adsorption ability of the clay. Direct measurement of water adsorption can be accomplished using: (1) water adsorption test after Enslin Neff, and (2) free swell test. Indirect indication of water adsorption is available - the measurement of

Table 1 Summary of mineral fillers tested

Sample No.	Material	Brief description
Sample 1	Zeolite	100% zeolite tuff
Sample 2	Diatomite	Separated natural diatomite
Sample 3	Bentonite	Na-bentonite, 65% montmorillonite
Sample 4	Bentonite	Sample 3 with higher specific surface area
Sample 5	Bentonite	Na-bentonite, 98% montmorillonite
Sample 6	Bentonite/Zeolite	Mixture, Sample 4/Sample 1
Sample 7	Bentonite/Zeolite	Mixture, Sample 5/Sample 1
Sample 8	Bentonite/Diatomite	Mixture, Sample 5/Sample 2

Atterberg limits via geotechnical standard. The one dimensional swell test in oedometer apparatus is used to determine of the swelling strain of mineral fillers. Geotechnical properties (especially swelling characteristics) of the specimens are given in Table 2.

Table 2 Geotechnical properties of tested materials

Sample No.	Property tested					
	w_L %	w_P %	E_S %	F.s. %	N %	k_n m/s
1	53	41	200	2		
2	81	40	500	4		
3	388		500	18		
4	413		680	20	102	$3,5 \times 10^{-11}$
5	444	68	815	27	275	$3,2 \times 10^{-11}$
6	350		480	16	74	5×10^{-11}
7	384	61	530	19	245	$4,8 \times 10^{-11}$
8	392	56	720	20	190	$4,4 \times 10^{-11}$

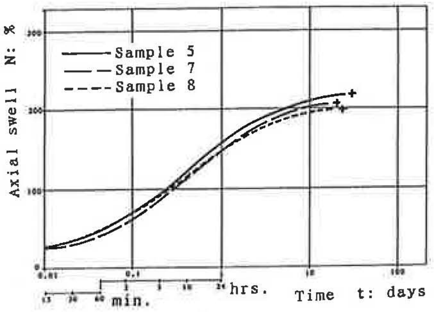
w_L - Liquid limit
w_P - Plasticity limit
E_S - Water adsorption (Enslin)
F.s. - Free swell
N - One dimensional swell (oedometer)
k_n - Coefficient of permeability normal to the plane

Significant differences in liquid limit, water adsorption and free swell between sample 1 and sample 2 on one hand and sample 5, sample 7 and sample 8 on the other hand were found. A 10% replacement of bentonite by zeolite and diatomite decreases water sorption capacity of blended specimens compared to that of origin Na-bentonite. It is supposed that this drop in the water sorption capability is caused by the decrease in the montmorillonite content of blended specimens.

Specific surface area of Na-bentonite is 14 150 $cm^2.g^{-1}$ and those of sample 7 and sample 8 15 300 $cm^2.g^{-1}$ and 17 200 $cm^2.g^{-1}$ respectively. Generally, higher specific surface area values, as the reflected crystal surface area upon which water can be potentially adsorbed by the mass of specimen, should be indicative of high-efficient water sorbents having high liquid limit, water adsorption and free swell.

Swelling process of mineral fillers is shown in Figure 1. The one dimensional swell tests were performed to determine the swelling characteristics of various mineral fillers under low normal stress.

a/ Normal pressure p = 1,37 kPa
V_o = 11,5 cm^3



b/ Normal pressure p = 10,75 kPa
V_o = 60 cm^3

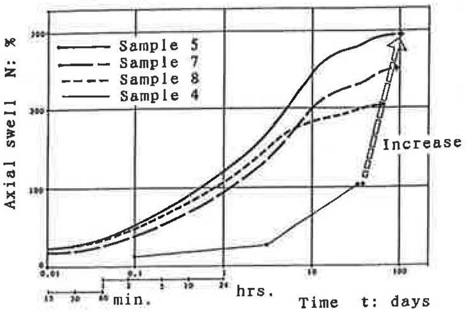


Fig.1 Swelling of mineral fillers at various normal pressure

The size of the specimens for the one dimensional swell test was 58 mm (diameter) x 4,4 mm (height) (Figure 1a) and 100 mm (diameter) x 7,5 mm (height) (Figure 1b), respectively. Initial volume of the specimens was ≈ 1,15x10^4 mm^3 (test type 1) and ≈ 6,0x10^4 mm^3 (test type 2), respectively. The normal pressure was provided by the steel plates which were placed on top of the specimens. The relationship between time and axial swell was obtained.

The axial swell (in percent) is defined by $N = \triangle h/h_o \times 100$, where $\triangle h$ is swelling deformation and h_o is initial sample height.

Figure 1 shows that the axial swell is lower for smaller specimens (samples No. 5,7 and 8) under normal pressure p=1,37 kPa (N=198-212%) than for larger specimens (samples No.5,7 and 8) under normal pressure p=10,75 kPa (N=203-295%).

Figure 1a demonstrates the different early swelling deformation rate of two specimens (different volume) during axial swell tests. It is found that when both the specimen volume and the vertical pressure decrease, the rate of swelling increases noticeably. It is also found that a larger size specimen extends the test time. Additionally the inclination of curves in Figure 1b indicates the continuing of the swell process. The reason for the continuing of swelling is the fact that the vertical pressure slows down the specimen water adsorption.

Figure 1b shows a substantial difference between the axial swell determined for two bentonites (sample 4 and sample 5). The different tendency in curves should be explained by the difference in the bentonite quality.

Particle size distribution of sample 7 and sample 8 is illustrated in Figure 2. Particle size distribution was carried out on Fritsch particle sizer Analysette 22. Both specimens indicate a high fineness. Particle size distribution of sample 5 (Na-bentonite with high content of montmorillonite) is very similar to those of sample 7 and sample 8. Both materials are characterized by the 70% content of particles less than 10 μm and 50% content of particles less than 5 μm.

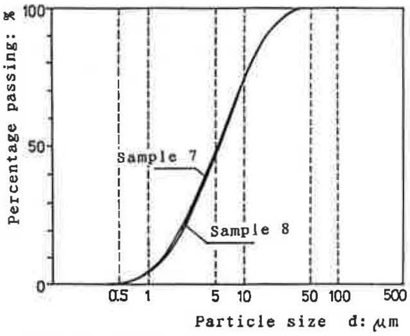


Fig.2 Grain size distribution of mineral mixtures

Thermograms of samples 1, 2, 5, 7 and 8 are shown in Figure 3.

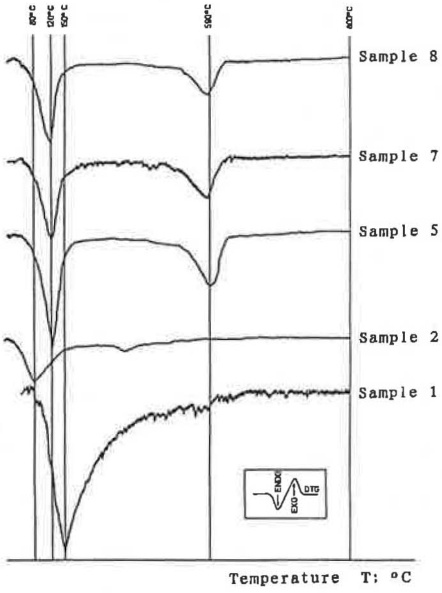


Fig.3 Thermograms of mineral fillers

Changes in the weight loss due to the release of water from the crystal structure of the specimens are defined by the endotermic peaks on the DTG curves. They are proportional to the loss in weight of specimens calculated from the TG curve, as seen in Table 3, where the results of those calculations are presented.

Table 3 Results of thermal analysis of tested materials

Sample No.	Moisture up to 105°C as evaporable water %	Ignition loss in the specimens in the temperature range of 105-420°C %	 420-750°C %	Total ignition loss to 1000°C %
1	2,32	7,51	1,16	11,16
2	3,24	4,32	1,62	9,73
5	3,73	3,73	5,42	12,88
7	4,00	3,09	4,54	11,64
8	3,70	3,91	4,78	12,39

The loss of evaporable water up to 105°C and crystallined bound water is confirmed by the intensity of the endotermic peak and endo-peak area covering a temperature range between 80 - 150°C. Herein the evaporable and crystalline water mainly from montmorillonite and clinoptilolite crystals as the moisture or in n.H_2O form are released. The second endoterm with the peak maximum at 590°C is contributed to the loss of chemically bound water in OH form from the minerals. The influence of muscovite and hydromica on the weight loss of the specimens is negligible due to their minor representation in sample 7 and sample 8 crystal structure.

All materials have been dehydrated at 750°C already. Differences in the amounts of deliberated evaporable and bound water from crystal structure of sample 5 and blended sample 7 and sample 8 are negligible. From this viewpoint a 10 % replacement of Na-bentonite by two natural minerals is not of great importance.

Mineralogical composition of mineral mixtures is illustrated in Figure 4. Both mineral mixtures are characterized by the dominant representation of montmorillonite defined by the difraction lines of high intensity at 12,.6, 4,47, 3,15 and 2,15 Å, Insignificant amounts of impurities-muscovite 11,0 Å, hydromica 9,80 Å, quartz 3,34 Å, calcite 3,03 Å and clinoptilolite 8,99, 7,87, 3,96 and 2,98 Å are detected by weak diffraction lines of corresponding minerals. The intensity of montmorillonite diffraction lines in both sample 7 and sample 8 is markedly increased than those of other minerals.

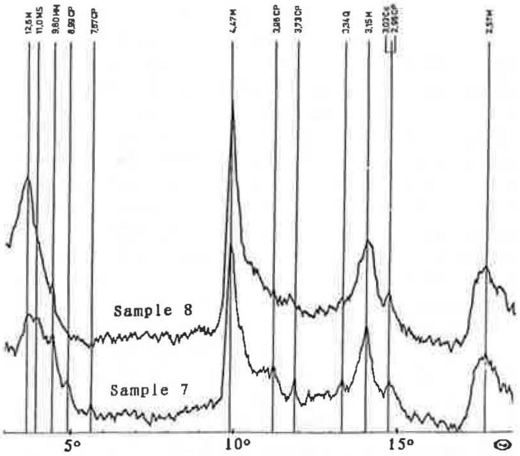


Fig.4 Diffractograms of mineral mixtures

It was detected that diffractograms of zeolite and diatomite are quite different. Clinoptilolite is the major mineral in zeolite. Minor amounts of hydromica, quartz and feldspar were also found. On the contrary montmorillonite and bentonite were detected in the mineralogical composition of diatomite. It is assumed herein that bentonite is created by the composite mixture of SiO_2 with montmorillonite. Except of quartz, also other modifications of SiO_2 α-cristoballite and α-tridymit occur in this material. Due to the clayish admixture and biological origin of diatomite, this mineral seems to be perspective for environmental sealants. As a result of these findings, it is concluded that the unique physico-chemical characteristics of montmorillonite influence above all the performance capabilities of sample 7 and sample 8.

The chemical composition of the specimens is given in Table 4.

The content of SiO_2 is the lowest and Al_2O_3 is the highest in Na-bentonite (sample 5). Bearing this in mind, the comparison of the SiO_2/AL_2O_3 ratio in Na-bentonite, samples 7 and 8 with the liquid limit, water adsorption and free swell values gives an interesting mutual relation. At the lowest

Table 4 Results of chemical analysis of tested materials

Moisture and component content (wt.%)	Sample No. 1	2	5	7	8
Moisture	4,78	4,80	4,88	4,05	4,00
SiO_2	66,72	70,68	55,28	56,53	57,81
CaO	5,25	1,54	2,10	2,10	2,03
MgO	0	2,24	3,70	3,77	3,77
Al_2O_3	13,97	8,00	19,70	18,40	17,10
Fe_2O_3	1,69	5,20	3,00	2,60	3,00
Ignition loss	10,99	10,10	11,98	11,40	11,40

SiO_2/Al_2O_3 ratio the highest sealant quality of the material is achieved, as determined by the significant geotechnical characteristics of samples (Table 2).

The results of absorptive capacity of sample 7 and sample 8 are given in Table 5.

Table 5 Absorptive capacity of tested materials

Sorption of cations and anions	Sample No.	Origin concen-tration in the solution mg.l^{-1}	Remaining concentration of the cation and anion in solutions, mg.l^{-1} 10 min.	120 min.	1 day
Cr^{3+}	7	10,50	0,05	0,05	0,05
	8		0,05	0,05	0,05
Cu^{2+}	7	14,45	0,73	0,28	0,12
	8		0,22	0,04	0,03
Mn^{4+}	7	12,41	0,02	0,02	0,02
	8		0,02	0,02	0,02
Pb^{2+}	7	39,70	0,2	0,2	0,2
	8		0,2	0,2	0,2
Zn^{2+}	7	37,10	0,43	0,14	0,08
	8		0,08	0,06	0,05
Cl^-	7	350,00	340,3	340,3	340,3
	8		340,3	340,3	339,6
SO_4^{2-}	7	550,00	556,4	557,9	556,6
	8		554,7	556,7	554,7
PO_4^{3-}	7	10,00	10,03	10,02	9,99
	8		10,00	10,02	10,02
NO_2^-	7	0,10	0,10	0,10	0,11
	8		0,11	0,11	0,10

Both materials are extremely efficient sorbents of Cr^{3+}, Cu^{2+}, Mn^{4+}, Pb^{2+} and Zn^{2+} cations. The sorption efficiency amounts to 99% within 10 minutes of testing. By the contrast with it the sorption of Cl^-, SO_4^{2-}, PO_4^{3-} and NO_2^- anions is inconsiderable.

3 GEOTECHNICAL ASSESSMENT OF MINERAL FILLER AND GCL

The results of laboratory geotechnical tests are gathered in Figure 5. Three different swell tests on water adsorption and swelling deformation of mineral fillers were performed and the results were analyzed. Figure 5a, 5b and 5c show the relationship of swelling characteristics, like water adsorption by Enslin, one dimensional swelling in oedometer apparatus and free swell, versus liquid limit. Figure 5d shows the relationship between liquid limit and coefficient of permeability normal to the plane.

Measurement of Atterberg (liquid and plastic) limits is one of indirect test for water adsorption of soils. Although liquid and plastic limits tests are very common for natural soils, they have not been frequently used as indicators of bentonite quality in the bentonite industry (Daniel, Koerner, Carson, 1993).

The liquid limit test we recommended as the principal quality control test for the quality of mineral filler being used on GCLs. As a supplementary tests we recommended the water adsorption test by Enslin as well as the free swell test.

From the geotechnical point of view the final evaluation of the test results is shown in Figure 6a. It has been found that the liquid limit as well as the swelling characteristics decisively depend on the bentonite quality. The increase of the fineness and specific surface area as well as the montmorillonite content in mineral filler has a significant effect on the swelling characteristics of mineral fillers. The higher liquid limit of mineral filler, the higher swelling characteristics and higher coefficient of permeability of GCL is observed.

Assessment of mineral fillers containing bentonite mined in Central European region is presented in Figure 6b. Figure is

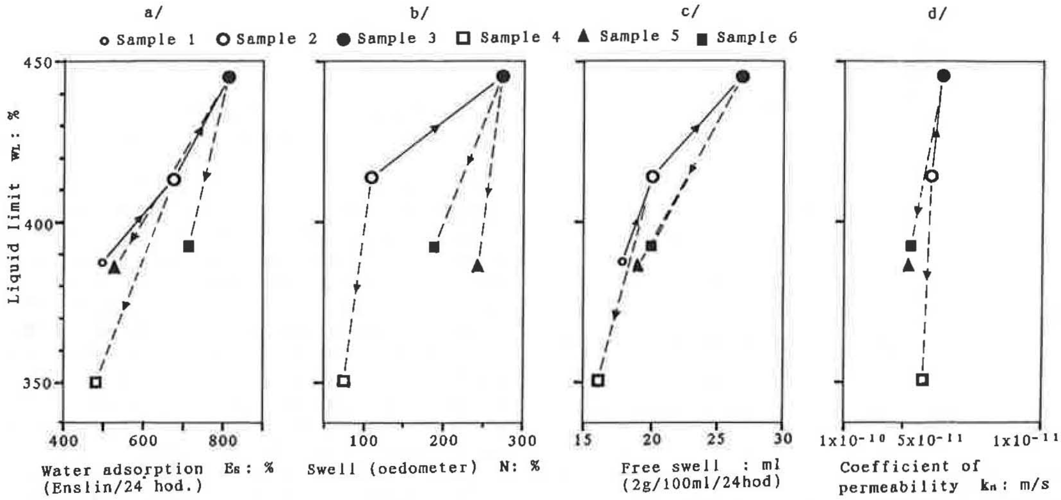


Fig.5 Liquid limit versus E_s, N, free swell and k_n for various mineral fillers

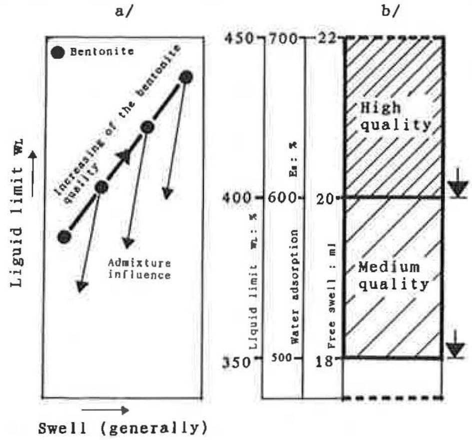


Fig.6 The mineral fillers assessment

arranged in the following manner:
(1) Medium quality mineral filler:

$$350 \leq w_L < 400$$
$$500 \leq E_s < 600$$
$$18 \leq F.s. < 20$$

(2) High quality mineral filler:

$$400 \leq w_L < 450$$
$$600 \leq E_s < 700$$
$$20 \leq F.s. < 22$$

4 GCLs IN LANDFILLS - LEGISLATIVE REQUIREMENTS IN SLOVAKIA

In Slovakia, the authorities follow the example of the foreign guidelines for landfill design and admit use of GCLs for sealing functions to the following prepared Slovak standards:

- Landfilling. General requirements
- Landfilling. Cover and recultivation of waste landfill
- Waste disposal: Sealing of the landfills. Design, construction, control and technical requirements
- Geotextile and geotextile related products on construction purposes. Basic regulations

Permeability coefficient, k_n, of the sealing geosynthetic liner for use in bottom lining systems as well as cover systems according to the Slovak standards must be equal or less than 5×10^{-11} m/s. If this is fulfil, the sealing GCL is considered capable of withstanding induced hydraulic pressure.

5 CONCLUSIONS

Several external factors may affect the physico-chemical characteristics of sample 7 and sample 8. The content of montmorillonite, natural admixtures of diatomite and zeolite, their mutual ratio in the blended materials as well as the fineness and specific surface area of the materials are of great importance. The montmorillonite content and specific surface area of the specimens influence the water sorption capability (w_L, E_S, free swell, N).

Experiments are continuing to find better arguments for the role of SiO_2/Al_2O_3 ratio in assessing the water sorption capability of the specimens. The lower SiO_2/Al_2O_3 ratio is estimated, the higher sealant quality of the specimens is achieved, as determined by the values of liquid limit and water sorption by the Enslin or free swell test. In this context the evaluation of chemical observations requires great care and multiple parallel tests are recommended.

The tested mineral mixture (sample 7 and sample 8) are extremely high efficient sorbents of chromium, copper, manganese, lead and zinc. It is supposed that the sorption of other metals is comparatively so efficient.

Material composition and geotechnical properties of the samples No. 6 and 7 are coincident with mineral filler used in commercially manufactured Slovak GCL - TATRABENT.

The liquid limit test is recommended as the principal quality control test for the quality of mineral filler suitable for GCL.

Assessment of mineral fillers containing bentonite is presented and evaluation criterion is provided.

REFERENCES

Bishop, D. (1994) Practical Aspects of Geosyntetic Clay Liners (GCLs), *Proc. SGI Conference,* Stockholm, 8 p.

CETCO (1994), Bentomat TR-409, Manufacturing quality Assurance and Quality Control Manual, *Technical Data Sheet*, 20 p.

Daniel,D.E, Koerner,R.M., Carson,D.A. (1993) Quality Assurance and Quality Control for Waste Containment Facilities, *EPA Technical Guidance Document,* 305 p.

Koerner,R.M., Daniel,D.E. (1994), A suggested methodology for assessing the technical equivalency of GCLs to CCLs, *Proc. LGA/GRI Symposium on Geosynthetic Clay Liners,* Nürnberg, 59-84.

Zanzinger,H. (1994),Qualitätssicherung bei der Produktion und bei der Verlegung von GTD, *Geokunststoff-Ton-Dichtungen GTD,* LGA Bayern, Nürnberg, 149-159.