Durability of geosynthetic liners in high pH environments

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ABSTRACT: Laboratory testing and assessments of the results have been performed on geosynthetic liners proposed to be used in a number of projects to contain high pH residues. Testing was carried out on a number of GCL's and geomembrane types to assess the potential design life of the different products when subject to the high pH residues. The impact of temperature on the design life was also considered. This paper provides a summary of the test results and assessments made for the different products and highlights how different apparently similar geosynthetic liners perform when subjected to aggressive environments.

1 INTRODUCTION

Geosynthetic liners are being specified for a wide variety of projects including applications where the liners may be subject to severe chemical and environmental conditions. Many of the applications expose the liner to a cocktail of chemicals, in conjunction with heat and / or ultra violet radiation from the sun. The durability of the liner systems under such conditions should be assessed on a case by case basis due to the potentially complex interaction of the different conditions, which may adversely affect the durability of the materials proposed.

Geosynthetic liners were considered for a number of projects where high pH residues were to be contained. The application of the liners systems was either for the base liner below the alkaline residue and/or to cap the residue.

A review of the chemical composition of the residue indicated a complex array of chemicals. A review of geosynthetic suppliers "resistance tables" suggested that the liner materials are resistant to most of the chemicals identified. Some chemicals were not listed.

Recommendations were made to the clients that specific testing should be carried out using samples of the residue and potential liner materials to assess the likely durability of the materials in contact with the residue.

A variety of geomembrane and geosynthetic clay liners (GCL) were considered for the liner systems, and hence these were included in the assessments. The proposed liner systems considered for the projects included composite liner and single liner systems. Composite liners were considered for the base liners and single liners were considered for capping systems of the facilities.

The purpose of the two liners systems was:

- Base liner to limit seepage out of the residue into the environment.
- Cap liner to limit infiltration of rainwater into the residue and to prevent contact of the rainwater with the residue, thereby reducing the volume of affected water to be managed at the facility.

2 TESTING PROGRAM

Two programs of testing were carried out to provide specific information on the proposed geomembrane and GCL materials when in contact with the residues. The testing programs involved extracting samples of the residue from the site, which were shipped to the laboratory in air tight containers to prevent oxidation and changes in the residue when in contact with air.

Samples of geomembrane and GCL materials were requested from geosynthetics suppliers that were considered for the potential supply and installation of the liner systems.

Test program one comprised testing two geomembrane types and two GCL types. Test program two comprised four types of geomembrane and three types of GCL. The results of the GCL testing for program one are reported separately in Reference (1)

(Benson et al 2008), and the details are not repeated in this paper. The results of the program one GCL tests are included in this paper.

The testing program for the geomembrane samples involved the samples being fully immersed in a sealed agitation tank with temperature control. The residue was for continuously agitated for up to 56 days and samples were subjected to different temperatures to accelerate the potential effects on the geomembrane. The residue was heated to:

- 50 and 82 deg.C for program one.
- 60, 75 and 86 deg.C for program two.

The number of temperatures and time of immersion was based on the budget constraints of the projects and the intended outcomes for each project.

The key components of the residue to which the samples were exposed are:

- pH = 12.4 to 12.7
- TDS = 15,000 to 23,000 mg/L
- High portion of heavy metals, mainly aluminium and iron.
- Calcium based oxides greater than 12,000mg/L.

Program one geomembrane samples comprises 0.76 mm thick PVC and nominal 2.5 mm thick HDPE. Program two comprised 1 mm thick high and linear low density polyethylene samples

Program one included measurements of changes of antioxidants, stabilisers and plasticisers contents, and changes in mechanical properties of the samples. Program two included measurements of changes in antioxidant and stabiliser contents only.

The three GCL samples for program two were immersed unconfined in residue at 20 deg.C and agitated for 28 days. After 28 days the samples were extracted and permeated with tap water to measure the permeability of the GCL. Seepage measurements continued until the seepage rate stabilized to a constant value.

The key properties of the three types of the GCL are presented in Table 1.

Table 1: Properties of GCL samples (program two)

	Mass of bentonite (kg/ m^2)	Type of bentonite
GCL 1-2	4.67	Powder
GCL 2-2	3.70	Powder
GCL 3-2	3.60	granular

All GCL samples were needle punched reinforced GCL's, and mass of bentonite was measured at zero moisture content.

The permeability of the GCL samples were measured for both exposed and unexposed samples of the GCL from the same bulk sample of the GCL's.

3 RESULTS

3.1 *Program One*

The results of the testing indicated that there were some changes in the mechanical properties, stabiliser, antioxidants and plasticiser contents of the geomembrane samples. The results are summarized in Table 2.

Table 2: Measured changes in Geomembrane samples

	HDPE		PVC	
	unexposed	exposed	unexposed	exposed
Plasticiser (%)			33.8	27.6
HP OIT (mins) at 150 deg.C	355	240		
S-OIT (mins) at 200 deg C	161	119		
Tensile elongation (%)	700	630	330	260

Note the changes measured relate to an immersion period of 28 days for the mechanical testing samples and 56 days for the plasticiser and antioxidant content testing. The stabiliser package used for the HDPE samples was understood to be hindered amine light stabilisers, and the plasticiser for the PVC samples was dioctyl phthalate.

The two samples of GCL of Program one returned significantly different hydraulic conductivity values. Table 3 presents the results of the permeability testing.

Table 3: GCL Hydraulic conductivities (program one)

	Unexposed (m/s)	Exposed (m/s)
GCL 1-1	2×10^{-11}	2.3×10^{-12}
GCL 2-1	2.8×10^{-11}	3×10^{-9}

GCL 1-1 is a needle punched powder bentonite GCL and GCL 2-1 is a needle punched granulated bentonite GCL. The results relate to water hydrated GCL and subsequently permeated with the residue. Note that one test of the exposed GCL measured a hydraulic conductivity as high as 1.8×10^{-8} m/s.

3.2 *Program Two*

The geomembrane samples tested comprised four different polyethylene resins with different stabiliser and antioxidant packages. The resins used for the manufacture of the geomembranes were:

- GM 1 = Marlex™ K306
- GM 2 = Marlex™ HHM 400
- GM 3 = Petromont™ 7000
- GM 4 = not provided, but low linear density polyethylene.

Stabilisers are added to the geomembrane liners to offer protection during the operational service period, and some are added to offer protection during the manufacturing process. With the S-OIT, antioxidant depletion time is measured for the antioxidants that offer protection during manufacturing at high temperatures, and contribute to thermal oxidation resistance. The HP-OIT depletion time is measured for the stabilisers added to the geomembrane liner for protection during the service life. For the purpose of this assessment the depletion time of the stabilisers was therefore calculated based on the HP-OIT.

GM 1, GM 2 and GM 3 samples were immersed for 33 days in the residue, and GM 4 was immersed for 20 days due to late delivery of samples. Standard oxidative induction times (OIT) and high pressure oxidative induction times were measured for the samples after immersion and compared to samples that had not been exposed to the residue. The OIT tests were carried out in accordance with ASTM D 3895 (at 200 deg.C) and 5885 (at 150 deg.C) respectively. The results of the measurements are presented in Table 4.

Table 4: OIT values for exposed geomembrane samples.

	Exposure temperature	HP OIT (min)	S-OIT (min)
GM 1	Virgin	770	> 150
	60°C	420	79
	75°C	290	0.6
	86°C	278	0.8
GM 2	Virgin	1140	> 200
	60°C	1120	> 130
	75°C	1000	99
	86°C	990	2.3
GM 3	Virgin	930	> 130
	60°C	960	> 130
	75°C	730	0.75
	86°C	740	0.37
GM 4	Virgin	2910	111
	60°C	2690	> 130
	75°C	2360	> 130
	86°C	2100	4.7

The rate constant for the geomembrane samples was estimated based on Arrhenius interpretation of the immersion test results of the different geomembrane samples. This interpretation allows the extrapolation of accelerated test results to field conditions, to estimate the rate of depletion of antioxidants and stabilisers.

The immersion test results were used to estimate the rate constants for the different geomembranes and from that an estimate the depletion rate in service was obtained. The service application of the geomembrane results in the geomembrane being exposed to the residue on one side only. As a first order estimate of the effect of being exposed on one side only the time for antioxidant depletion was estimated to be twice the time estimated from the rate constants related to the full immersion of the samples. This estimate was adopted due to absence of obtaining specific diffusion rates for the antioxidant compounds as they are proprietary products and details are not generally released by the manufacturers.

Table 5 presents the rate constants estimated for the different geomembranes.

Table 5 – Geomembrane rate constants.

	25°C	35°C
GM 1	0.001260	0.001560
GM 2	0.000736	0.000784
GM 3	0.000690	0.000790
GM 4	0.000248	0.000281

The time for depletion of antioxidants was estimated for service temperatures of 25 deg C and 35 deg C, and is presented in Table 6.

Table 6: HP-OIT depletion rates for different geomembranes

	STABILISER DEPLETION AT 25°C	STABILISER DEPLETION AT 35°C
GM 1	5.3 years	2.7 years
GM 2	9.0 years	5.3 years
GM 3	9.7 years	5.3 years
GM 4	27.5 years	15.2 years

The permeability of the three GCL's samples were monitored until the flow rate through the samples stabilised. Table 7 presents the results tests.

Table 7: GCL permeability for dry samples exposed to residue, and then permeated with water.

	Unexposed (m/s)	Exposed (m/s)
GCL 1-2	3.7×10^{-11}	7.9×10^{-11}
GCL 2-2	1.2×10^{-11}	1.6×10^{-11}
GCL 3-2	2.2×10^{-11}	6.3×10^{-11}

4 DISCUSSION

The discussion of the results considers the consolidated information of the two programs in relation to the performance of the geomembrane and GCL samples.

4.1 *Geomembrane samples*

From the testing it was concluded that the PVC geomembrane samples showed that some plasticiser was being leached from the samples or degraded via ester hydrolysis by the residue. A reduction in plasticiser results in increase in the stiffness of the geomembrane and possibly changes in the geometry of the geomembrane. It was estimated that based on the measured rates of depletion the plasticiser content in the geomembrane may reduce from 33.8 % to:

- 22 % in 11 years
- 17 % in 18 years, and
- 11.5 % in 28 years.

The minimum percentage of plasticiser required to ensure long term performance was not considered as part of the assessment, but it was clear that significant reduction of plasticiser occurred as a result of being exposed to the high pH residue.

The testing also indicated that there was loss of phenolic antioxidants of the HDPE geomembrane samples as indicated by the significant drop in the S-OIT values. The hindered amine stabilisers were less affected by the alkaline residue as reflected by the higher percentage retained HP-OIT results. The consolidated results of the polyethylene geomembrane samples suggested that the loss of antioxidants and stabilisers depends on a number of conditions. The following conditions were identified as impacting on the rate of depletion but are not considered exhaustive.

- Type of geomembrane resin, ie high or linear low density
- Type of antioxidant and stabiliser packages used in the manufacture of the geomembrane
- The initial amount of antioxidants/stabilisers in the geomembrane
- Thickness of the geomembrane
- Service temperature of the geomembrane.

The rate of stabiliser deletion of the GM 1 LLDPE sample was between 1.7 to 2 times the rate of depletion of the HDPE samples of similar thickness.. The rate depletion of stabiliser from GM 4 sample was significantly slower than the other three samples. The rate of stabiliser depletion is related to the molecular structure of the geomembrane material. The molecular weight of stabilisers is generally high and hence stabilisers are generally consumed or deactivated within the geomembrane. Antioxidants are relatively low molecular weight and diffuse to the surface of the geomembrane. .

The difference in the rate of consumption of the antioxidants and stabiliser is demonstrated by the significantly different rate of depletion of the thick HDPE sample of program one and the GM 3 of program two. These two samples are from the same manufacturer, sampled a few years apart. The estimated depletion time of stabiliser for the 2.3mm thick HDPE samples is 190 years at 25 deg C, where as for the 1 mm thick sample is less than 10 years. Similar findings were noted in a recent research and subsequent publication by Rimal and Rowe (2009) indicating non-linear thickness dependent OIT depletion from geomembrane liners.

4.2 *GCL samples*

The testing results indicate that the permeability of all the GCL samples tested was impacted by the high pH residue. The impact of the residue is however not consistent, with one sample permeability decreasing over time, while the other samples permeability increased.

The GCL hydrated with water and then permeated by the high pH residue resulted in a large change to the measured permeability. The permeability of GCL 1-1 resulted in one order of magnitude reduction while GCL 2-1 resulted in two orders of magnitude increase.

The GCL exposed to the residue and then hydrated with water was less impacted than the GCL samples permeated by the residue. All samples indicated an increase in permeability, ranging from 33 % to 280 % increase in measured permeability, which is less than one order of magnitude increase.

It is recognised that there may be an impact from the residue on the geotextile component of the GCL.

5 CONCLUSIONS

The following conclusion can be drawn from the results:

- The resistance of different geomembrane materials under high pH environment varies significantly and should be subject to site specific testing.
- The service life in a high pH environment may vary from less than 10 years to decades, depending on the material composition, thickness and service temperature of the geomembrane.
- In assessing service life of a geomembrane testing should be carried out to estimate the geomembrane antioxidant diffusion coefficients to consider the impact on thickness of the liner system.
- Higher temperature generally reduces the service life of the geomembrane.
- The high pH residue impacted the permeability of the GCL types tested.
- The impact on the GCL was greatest where the GCL was permeated by the high pH residue, and was less where the GCL was exposed to the residue and then permeated by water.
- The change in permeability of the GCL was to increase in most cases, expect in one case where the permeability was significantly reduced.

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