

Laboratory and in situ Studies on the Durability of Geomembranes

C. Bernhard
CEMAGREF Groupement d'ANTONY, France

H. Girard
CEMAGREF Groupement de BORDEAUX, France

F. Gousse
CEMAGREF Groupement d'ANTONY, France

ABSTRACT : Durability is an essential question for the use of geomembranes. The paper is a contribution to this question, by using, in addition to the classic tests, a molecular approach by the FTIR analytical technique (Fourier Transformation Infra Red). The tests were performed on the one hand on samples subjected to ageing processes in the laboratory, and on the other hand on samples taken from existing structures. These studies have shown good behaviour of the geomembranes when installed in normal conditions of use.

1 INTRODUCTION

Since 1973, the CEMAGREF (FRENCH INSTITUTE OF AGRICULTURAL AND ENVIRONMENTAL ENGINEERING RESEARCH) has been actively involved in the design and construction of numerous structures incorporating geosynthetics (hydraulic works, waste stabilization ponds and waste disposal facilities) including studies on the durability of the geosynthetics employed. Whilst the initial mechanical, hydraulic, physical and chemical characteristics of these materials are well known, there is need for further information on their evolution in time.

This paper is a contribution to the essential question of the durability of geomembranes, by using, in addition to the classic tests, a molecular approach by the FTIR analytical technique (Fourier Transformation Infra Red). The tests were performed on the one hand on samples subjected to ageing processes in the laboratory, and on the other hand on samples taken from existing structures.

A first laboratory study, aimed at testing the behavior of geomembranes in contact with leachates taken from two existing municipal landfills, was started in 1989. It is based on the American EPA 9090 method, and covers 5 types of geomembranes (bituminous, SBS/bituminous, PVC/DOP, PVC/EVA, HDPE, co-PP and EPDM). The samples are immersed in the 2 leachates and in demineralized water (control bath) and then subjected to various tests (mechanical and physical). The combined influence of the leachates and of temperature (20° C and 50° C) is tested. For the second laboratory study, samples

of the same geomembranes were immersed in chemicals during 4 months. The results obtained to date are presented in the paper.

Furthermore, samples of PVC geomembranes were taken from 3 existing structures to measure their evolution in real conditions. The structures included a dam, a waste stabilization pond and an irrigation basin. The samples collected were also subjected to mechanical and physical tests.

2 LABORATORY EXPERIMENTS

Table 1. Definition of geomembranes and tests performed

Geomem-brane	Thick-ness (mm)	Sorption test	Compati-bility with leachate	Compati-bility with chemicals
HDPE	2	X	X	X
PP	1.2	X	X	-
PVC/DOP	1.2	X	X	X
PVC/EVA	1.8	X	X	-
EPDM	1	X	X	X
Bituminous	3.9	X	X	-
SBS/bitum.	4	X	X	X

Three types of laboratory experiments have been

performed on selected geomembranes (Table 1) :

- sorption tests (over 4 years in contact with water) ;
- chemical compatibility with leachates (over 4 years) ;
- chemical compatibility with chemicals (acid, base, solvents).

2.1 Material and methods

2.1.1 Sorption test

A sample of geomembrane is immersed in demineralized water at a constant temperature of 23°C. Its weight is periodically measured allowing the calculation of the percentage of absorbed water in mass. This experiment has been conducted over 4 years.

2.1.2 Compatibility with leachate

The experiment has been previously presented by Artières and al. (1991). It is based on the EPA 9090 test with the following main experimental conditions :

- leachates : 2 different municipal landfill leachates (Sablé and Mézerolles) renewed every 3 to 6 months ; the composition of the leachates is analysed when sampled ; demineralized water is used as a reference in addition to the leachates ;
- temperature : 23°C for the demineralized water ; 23°C and 50°C for the leachates ;
- mechanical stress : samples are not submitted to mechanical stress ;
- duration of the experiment : 4 years at 23°C and 3 years at 50°C (since March 1990 in both cases) ;
- tests performed :
 - uniaxial tensile test (French standard NF P 84-501) on unexposed and aged (4 years) samples ; in some cases, a biaxial tensile test ("bursting test") has been carried out ;
 - micro spectrophotometric analysis (Fourier Transformation Infra Red) on HDPE, PVC and PP samples ; this method is not applicable to bituminous and EPDM geomembranes ; the photoacoustic (Fourier Transformation Infra Red) spectroscopy is then used in substitution ; these analysis has been performed every 12 months by the CNEP ("National Photo-ageing Study Center" located in Clermont-Ferrand).

2.1.3 Compatibility with chemicals

Samples of geomembranes are immersed in chemicals (Sulphuric Acid 1N, caustic soda 1N, undiluted acetone, undiluted chloroform, undiluted toluene, demineralized

water as reference). Temperature is maintained at 23°C. The samples are submitted to the same tests as for the study of compatibility with leachates. The sorption of chemical and the loss of material by the geomembrane are monitored in addition. The geomembranes tested are the same as for the precedent experiment excepted PVC-EVA, bituminous and PP.

The experiment started in June 1993. Tests (tensile tests, micro spectrophotometric analysis) were performed after one month and after 4 months of immersion.

2.2 Results

The water sorption and compatibility with leachates experiments show that, after 4 years of immersion at 23°C, there is no significant difference between geomembranes in contact with demineralized water and municipal landfill leachate. A little loss of mechanical performance is generally observed compared with the non-exposed dry samples. This difference is correlated with the ability of the geomembranes to absorb water (for instance, HDPE does not absorb water and there is no difference between dry unexposed and aged in water or in leachates samples). But for all the geomembranes tested, the behaviour in contact with water and with municipal leachates appears clearly to be the same. This statement needs however some comments :

- the samples were not submitted to a mechanical stress ; the combined mechanical and chemical stress can lead to much more damage in real site conditions ;
- PVC samples show a loss of plasticizers but only on the surface (10 to 15% loss in the first 100 µm) ; this loss is the same in contact with water and leachates ; it has not increased after 38 months ;
- bituminous geomembranes absorb the highest amount of water and an oxidation of the bitumen as well as of the SBS compound has been noticed ; this oxidation process increases with time ;
- the experiment at 50°C could unfortunately not be conducted over 3 years ; the conclusions for this duration of immersion are the same as for 23°C.

We undertook the immersion in chemicals at high concentrations to obtain more differentiation between the geomembranes. The results enable classification of the products :

- HDPE : only slightly affected by chloroform and toluene ;
- EPDM : chemical resistance similar to HDPE ;
- PVC-P : strongly affected by all solvents tested and by caustic soda ;
- Bitumen/SBS : clearly the worst behaviour. Solvents dissolve the bitumen. Caustic soda makes it brittle.

Sulphuric acid is the compound that affects it least, but the loss in mechanical properties is noticeable.

In conclusion, no significant ageing of the tested geomembranes in contact with municipal leachates has been noticed after 4 years in laboratory experiments. Compatibility tests with undiluted chemicals show however that the resistance of the different geomembranes may be very different in these extreme conditions. The choice of a material for an actual landfill site will depend on the expected leachate composition. The effect of the addition of mechanical and chemical stress should also be taken into account.

3. ANALYSES OF PVC-GEOMEMBRANE SAMPLES TAKEN FROM STRUCTURES

In the present research work, samples of PVC geomembranes were taken from 3 existing structures after 3, 7 and 10 years in service. The results obtained are summarized below.

3.1 Waste stabilization pond

This is a pond for the treatment of leachates from a household waste storage centre in the west of France. Its surface area is 500 m², its maximum depth 1.80 m, and the slope of the sides 1/1.5. It was lined with an unprotected 1 mm thick PVC geomembrane, installed on a one metre thick layer of clayey soil.

This pond, built in 1982, had to be displaced in 1992 at the time of an extension of the storage centre, which made it possible to collect samples from different parts : from the bottom (in permanent contact with the leachates), from the slopes (temporary contact with the leachates and exposure to U.V.) and from the top of the sides (exposure to U.V.).

The main tests performed (plasticizer content and uniaxial tensile test according to the French standard NF P 84-501) evidenced in particular that :

- the plasticizer content had changed little for the samples collected from the bottom of the pond, in permanent contact with the leachate : from 33% (initial value) to 31.4% after 7 years, and to 29.9% after 10 years. The greatest loss was recorded half-way up the slope (temporary contact with the leachate) and at the top, where the plasticizer content recorded was 24% and 24% to 26.5% (depending on the orientation) respectively.
- the variations of the elasticity modulus with a deformation of 5% correspond to the evolution of the plasticizer content. From 20.5 MPa (initial value), it varies

according to the area of sample collection from the pond : 33.5 MPa (on the bottom), 81 to 121 MPa (temporary contact with the leachate) and 66 MPa (on the top of the slope). A control sample protected from U.V.'s presented the same modulus as that measured at the time of manufacture, which makes it possible to validate the initial value. The tensile strength and the elongation at failure show little change with the ageing of the geomembrane for this structure.

In conclusion, the area on the slope, subjected alternately to the action of the leachate and of the U.V.'s, had suffered the most notable evolution, but the latter is minor after 10 years in service. The loss of plasticizer is much lower for the samples collected from the bottom of the pond. The very low concentration in solvents of the leachate explains its negligible effect on the PVC geomembrane.

3.2 Irrigation water storage basin

This structure is in the WEST INDIES. It is a rectangular basin (66 x 22 m at the bottom), 4.50 m deep, with steep sides (1/1). The basin was lined with an unprotected, 1 mm thick PVC geomembrane, separated from the compacted soil (silt containing pebbles) by a geotextile. In this structure, completed in August 1989, the geomembrane showed very rapid signs of deterioration. During the inspection in March 1992, the following were found :

- a general condition of tension on the geomembrane, especially in the four corners (where it had pulled away from the support over a distance of several tens of centimetres) and on the support asperities (particularly at the change of slope on the crest) ;
- breaks in the geomembrane at the top of the slope extending over several tens of centimetres.

Four samples were subjected to various tests : a virgin sample from the CEMAGREF, a virgin sample stored by the installation company, a sample taken from the bottom of the basin, and a final sample taken from the crest of the slope.

Tensile strength tests (French standard NF P 84-501) evidenced a high degree of stiffening of the samples taken from the basin and a change in the elongation at failure (225% instead of 325% for the virgin samples). The results of the burst tests (biaxial traction) evidenced the same evolution of the geomembrane with for the samples taken from the structure an elasticity modulus equal to 35 MPa, distinctly higher than that of the virgin samples (20 MPa), and a lower burst deformation (especially for the sample from the top of the slope) of 110% instead of 170%. FTIR spectrometry analyses showed that whilst the PVC matrix has not suffered any oxidation, the plasticizer content had

lowered on the surface of the geomembrane over a thickness of 50 to 100 μm (a loss equal to 15% and 22% for the aged samples as against 9% for the reference sample). Although the core of the geomembrane had remained intact, the surface loss of plasticizer is to be related to the stiffening evidenced by the mechanical tests.

Ageing and degradation of the geomembrane were thus recorded on this site after only 3 years in service. This can be explained by :

- the permanent exposure of the geomembrane to severe tropical conditions (temperature and U.V.) as the basin was emptied every morning and filled at night ;
- the permanent tension of the geomembrane due to faulty installation conditions. This tension is generally considered as a factor of accelerated ageing, further aggravated here by the cycles of draining and filling (fatigue), and by the very steep sides of the slopes (1/1).

3.3. Dam

This 15 m high dam, built in gravel material, was sealed with a 1.2 mm thick PVC geomembrane positioned on the upstream face. The geomembrane is separated from the body of the backfill by an unwoven geotextile (500 g/m^2) and a 20 cm thick layer of crushed gravel. It is covered with the same materials, plus a 50 cm layer of rockfill.

To monitor the evolution of the geomembrane, three sample areas were carried out on a slope close to the dam : the first at the foot of the slope (permanently under water), the second half-way up the slope (temporarily submerged), and the third above the normal water level. As the dam is situated at an altitude of over 1000 m, it should be noted that the top area is subject to frost in winter. On the three areas, the geomembrane was surrounded with the same materials and installed under the same conditions as for the dam (movement of trucks and compacting). These three areas were set up to be able to take regular samples of the geomembrane and a reference control sample was stored in light-proof premises.

The dam was completed in 1986 and samples were collected in 1989 (from the 3 areas) and again in 1993 (from the top two areas only). The following observations can be made from the results of the tests performed :

- tensile strength test (French standard NF P 84-501) : the tensile strength at failure had not altered significantly, but the elongation at failure had lowered from 300% in 1989 to 235% in 1993, and a slight stiffening was noted over the same period, the secant tensile stiffness at 25% deformation having increased from 16 to 23 kN/m ;
- plasticizer content (ethyl ether extraction) : from 33.5% in 1989, it had lowered slightly in the samples collected in

1993 (upper area 31.3%, mid-slope 31.8%, reference sample 32.5%).

- FTIR spectrometry : these tests, performed only on the 1993 samples, confirm that the plasticizer loss is low : 7% over the first 25 microns (top sample) and 7% over the first 100 microns (mid-slope sample). This loss is evaluated considering the core of the sample as a non-evolutive reference.

- burst test : as the tests performed in 1989 and 1993 were not absolutely identical, it is difficult to evaluate the evolution of the results. Nevertheless, it was found in both cases that the values obtained on the samples taken from the site are practically identical to those obtained from the control sample.

For this site, we have no test results on the samples from the geomembrane laid in 1986. Nevertheless, it was found that the values measured in 1989 remain above the nominal values given by the manufacturer for the tensile strength test and for the plasticizer content, and that the evolution of the geomembrane between 1989 and 1993 is low.

4 CONCLUSION

The various studies performed evidence good behaviour in time of the geomembranes concerned when they are installed in normal conditions of use. This is shown by the results obtained on the geomembranes immersed in the laboratory in the two municipal landfill leachates and for the geomembranes implemented without excessive constraints (the case of the dam and of the waste stabilization pond).

On the other hand, often rapid ageing was observed in this study for those geomembranes installed in severe conditions of use : immersion in undiluted chemicals and exposure to U.V. under tension.

REFERENCES

- AFNOR (*Association française de normalisation*) (1992) Geomembranes, determination of tensile properties, NF P 84-501, 16 p.
- Artières, O., Goussé F. and Prigent, E. (1991) Laboratory-ageing of geomembranes in municipal landfill leachates, *Third International Symposium Sardinia '91*, S. Margherita di Pula, Cagliari, Italy, 587-603.
- Fayoux, D., Goussé, F. and Rummens, F. (1993) Assesment on a PVC geomembrane in a waste disposal after 10 years, *Fourth International Symposium Sardinia '93*, S. Margherita di Pula, Cagliari, Italy, 369-378.