GeoAmericas 2020
4th PAN AMERICAN CONFERENCE ON GEOSYNTHETICS
26-29 APRIL 2020 • RIO DE JANEIRO • BRAZIL

# An Approach to Longevity and Durability of Bituminous Geomembranes (BGM)

Emilio Escobar, Coletanche Business Manager Latin America/ Axter Ibérica, Chile
Natalie Daly, Coletanche Business Manager North America/Axter Coletanche, Canada
Bertrand Breul, Technical Manager, Civil Engineering/Axter, France

ABSTRACT

Bitumen is a natural product – like clay – and its use for waterproofing dates to ancient times. Bitumen was primarily used for waterproofing irrigation canals in Mesopotamia, 4,000 years BC. Sections of these waterproofed canals are still in existence today. A bituminous geomembrane (BGM) is manufactured by impregnating a polyester geotextile with an elastomeric bitumen compound. The geotextile provides a high mechanical resistance and a high puncture resistance. The bitumen provides the waterproofing properties and ensures longevity of the framework by protecting the geotextile. The durability of a BGM is measured in terms of how its key components, namely the polyester geotextile and the bitumen, maintain their mechanical properties and low permeability over time under its operating conditions, either remaining exposed to UV radiation and weathering or covered with soil, subject to biodegradation by bacteria.

The paper presents information regarding the durability of BGM and it addresses the specific characteristics that justify its longevity, including its low thermal expansion coefficient (leading to zero stress-cracking and therefore no phenomenon of fatigue) and its quick relaxation over time demonstrated by laboratory CEBTP of the French Ministry of Transport. Results of field-testing naturally aged BGM under covered conditions after 15 and 35 years of service at an ICOLD dam in Corsica (France) are presented. Life expectancy studies were carried out by the French company ANDRA for the use of BGM for the containment of low and medium intensity nuclear wastes. These studies concluded, after seven years of testing, that biodegradation of BGM in confined conditions is longer than 300 years. And finally, the results of BGM testing in North America done by the Department of Nuclear Energy in the Brookhaven National Laboratory (Upton, NY) and the Batelle Pacific Northwest Laboratory (Richland, WA) validates a life expectancy of BGM of 300 and even 1,000 years in confined conditions.

## 1. INTRODUCTION

Bitumen has been used as a construction and a waterproofing product since ancient times. From the fourth millennium BC, the Sumerians, the Babylonians and the Assyrians exploited bitumen as hydraulic mortar for the construction of terraces, canals, dams, etc., including the famous hanging gardens of Babylon. Many ancient achievements, including the Tiger dikes at Assur (Mesopotamia), still exist today, bearing witness to the exceptional longevity of bitumen. Bitumen emerged again in the 20th century as a waterproofing material for civil engineering applications in the form of a prefabricated bituminous geomembrane (BGM) (Connan, 1999).

## 2. DESCRIPTION OF THE BITUMINOUS GEOMEMBRANE (BGM)

A bituminous geomembrane (BGM) is a synthetic waterproofing product manufactured by impregnating a non-woven, long fiber polyester geotextile and a glass fleece with a bitumen compound. The top of the structure is sanded to enhance UV resistance and to provide grip for installation workers and/or cover material. On the bottom, there is a polyethylene terephthalate (PET) film to limit penetration of any vegetation roots through the membrane (Figure 1).

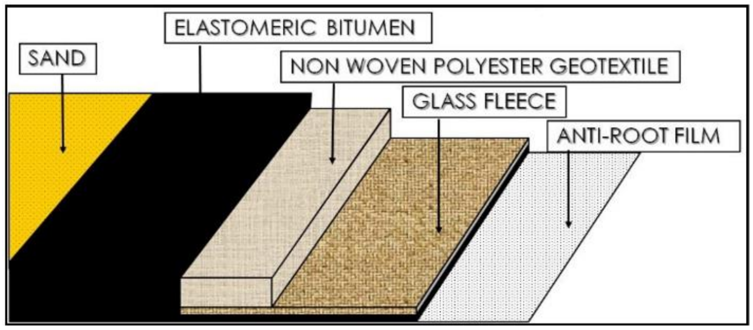


Figure 1. BGM Structure

The geotextile provides a high mechanical resistance against tear and puncturing. The bitumen provides the waterproofing properties and ensures longevity of the framework by coating and protecting the geotextile.

## 3. APPROACH ON BGM LONGEVITY

The durability of a BGM is measured in terms of how its key components, namely the polyester geotextile and the bitumen, maintain their mechanical properties and low permeability over time under the BGM operating conditions, i.e., either remaining exposed to UV radiation and weathering or be covered with soil, subject to biodegradation by bacteria. The paper will review the durability of a BGM based on actual testing of samples from job sites in several years of service life, as well as long-term durability projections based on studies done by scientific authorities.

### 3.1 Laboratory testing

#### **3.1.1 Testing of in-situ samples after up to 20 years of service life**

A testing program was carried out on BGM sample materials exhumed from two test sites in France:

- A potable water reservoir in Guazza, Corsica (France) where the BGM was deployed on top of compacted soil in 1981 and left exposed. Testing was performed after 10 years of service,
- A motorway ditch along highway A81 in Le Mans (France), where the geomembrane was installed on a sand layer of 10 cm and covered with 25 cm of limestone topsoil in 1979. Testing was performed after 14 and 18 years of service.

| BGM 4mm thick | Unit | Reference value New product | Guazza Site air = 2 years +Under water = 5 years | Under water = 7 years | Highway A81 site after 14 years under 25 cm of limestone topsoil | after 18 years under 25 cm of limestone topsoil |
|---|---|---|---|---|---|---|
| Physical Characteristics | | | | | | |
| Thickness | mm | 3.90 | 3.90 | 3.90 | 4.10 | 4.30 |
| Mass per m2 | g/m² | 4,500 | 4,500 | 4,500 | 4,700 | 4,700 |
| Mechanical Characteristics | | | | | | |
| Stress at break | | | | | | |
| Machine Direction | kN/m | 19.00 | 17.00 | 17.00 | 15.00 | 18.00 |
| Cross machine direction | kN/m | 17.00 | 15.00 | 15.00 | 15.00 | 16.00 |
| Elongation at break | | | | | | |
| Machine direction | % | 44.0 | 41.0 | 40.0 | 37.0 | 40.0 |
| Cross machine direction | % | 53.0 | 49.0 | 44.0 | 39.0 | 45.0 |

Table 1. Field -aged samples test results (La Technologie Routiere, 1999)

Test results from both sites showed that the coefficient of permeability according to Darcy's law decreased by only one power of 10 after 18 years from 6.0 x 10-14m/s to 4.0 x 10-13m/s for a BGM exposed. There was no significant reduction in tensile strength for any of the samples since the tensile properties of the BGM are derived primarily from the polyester non-woven geotextile reinforced inside the BGM. This geotextile is well protected from ageing and degradation processes by being totally impregnated and coated by bitumen.

### 3.1.2 Testing of Ospedale dam after 30 years in service

The Ospédale dam in Corsica, France was the first large rockfill dam in the world to ever use a geomembrane sealing system (GSS) using a BGM. The construction of the 26-m high, 135-m wide dam was completed in 1977.

Figure 2. Overview of the Ospédale dam in Sept. 2018 and under construction in 1977.

Like other large dams, Ospédale was reviewed after 30 years in service. In 2007 a testing program on samples exhumed from the dam was carried out to characterize the ageing of BGM in terms of its hydraulic conductivity, tensile strength, and physical-chemical properties. BGM samples were retrieved from three different locations of the upstream face (Figure 3).


Figure 3. BGM Sampling Campaign on Ospédale dam (2007)

Hydraulic conductivity of BGM was measured with the experimental cell of standard EN14150 and an adapted measuring device (Touze-Foltz et al, 2011). When subjected to a differential pressure of 100 kPa (upstream 150 kPa /downstream 50 kPa), the flow rate is measured across the BGM  This measurement allowed to conclude that most of the recorded flow through the dam occurs through the periphery of the dam and not through the BGM (Gourc , 2017).

Bi-dimensional tensile tests were carried out for three samples using a biaxial tensile strength device (standard XP P84-503 ,2008) type "burst test" on circular samples (disc diameter 0,20m). The samples were subjected to an upstream hydraulic pressure (50 kPa/minute) until leakage through the geomembrane was observed. A spherical deformation is assumed. The corresponding height of the spherical dome is recorded by IRSTEA French Ministry of Agriculture (Table

2).

| Sample | Pressure (kPa) | Dome height (mm) | Strain (%) | Ultimate tensile strength (Mpa) |
|---|---|---|---|---|
| "New" | 212 | 41 | 10 | 3.8 |
| 1 | 119 | 24 | 3 | 3 |
| 2 | 94 | 18 | 2 | 3 |
| 3 | 103 | 17 | 2 | 3.4 |

Table 2. Biaxial tensile strength of aged BGM (IRSTEA, 2017)

The results showed an average decrease of 17.5 % on the ultimate tensile strength as compared to the brand-new material, while the stiffness of the material doubled. This is well within the 25% reduction allowed by the European standard EN 133361 entitled "Geosynthetic barriers: characteristics required for use in the construction of reservoirs and dams.

Tests were performed at IRSTEA Aix (France) to characterize the softening point of the bituminous binder (Ball and Ring Temperature -BRT) and to determine the asphaltene content on two samples (Table 3)

| Sample | Ball & ring T° (°C) EN 1427 | Asphaltene content (%) NF T 60-115 |
|---|---|---|
| "New" | ≈ 100±5°C | 22 |
| | 139.5°C | 29.3 |
| | 144°C | 22.7 |
| Exposed BGM | 150°C | 35 |

Table 3. Physico-chemical properties of the BGM samples (IRSTEA)

An increase in the BRT temperature and the asphaltene content were observed on the exhumed samples as compared to the "new" material, which indicates some stiffening of the geomembrane with the time in service.

The general conclusion of the 2007 sampling campaign is that after 30 years in service, the BGM has maintained its waterproofing capability and that the reduction in its mechanical properties is well within the allowable standards.

## 3.2 Durability estimations

### 3.2.1 Required CE testing

The CE marking requires the evaluation of the durability of geomembranes by measuring the mechanical characteristics of geomembranes after artificial ageing in UV and after oxidation according to NF EN 12224. The geomembrane is exposed to an UV brilliance during 3000 hours with the cycle phase wet/dry following:

- 5 hours of exposure in heat dries, with a temperature of 50°C,
- 1 hour of watering in the water, with a temperature of the black sample of 25°C.

The energy exposure is 50 $MJ/m^2$. After oxidation, the values of tensile strength and elongation measured on the BGM are equal on average to 90 % of the measured value of a new geomembrane. The results of mechanical tests after ageing by the effect of UV and oxidation allow to estimate the life expectancy to be longer than 60 years.

### 3.2.2 The mathematical model of French nuclear safety authority

The French National Radioactive Waste Management Agency (ANDRA) is a public body in charge of all radioactive waste in France and it is controlled by the French government through an agency called ASN (Autorité de Sureté Nucléaire or French Nuclear Safety Authority). ANDRA initiated a program to seal the radioactive waste produced everywhere in France (laboratories, hospitals, etc.) for at least 300 years, which represents the life of this low and medium radioactive material. In order to determine the long-term ageing and effectiveness of existing potential covering membranes, ANDRA developed a mathematical model and calibrated it with test results on samples taken from existing structures sealed by BGM since 5, 10, 15 and 20 years. All liner samples were collected by Coyne et Belier, a well-known international consulting firm in dams and water management, from different existing sites. To ensure BGM met the criteria, ANDRA asked for numerous tests in various laboratories. After seven years of testing (conducted by ANDRA and the French Nuclear Safety Commission), the conclusion was that under the worst-case scenario, the maximum biodegraded thickness of the BGM is 1,5 mm on either side (i.e., a total of 3,0 mm out of 5,6 mm) after 300 years of service. The remaining thickness of BGM would still serve as an effective waterproofing material. The results were presented in the 4th International Conference on Geotextiles, Geomembranes and Related Products at The Hague in the Netherlands (Alonso et al, 1990).

The La Manche facility was the first radioactive waste surface disposal facility in France. A BGM was finally selected for the capping of this facility, which was completed in 1997 (Figure 4).

Figure 4. “La Manche” Radioactive Waste Storage Facility

BGM samples were collected from this site in 1997, 2005 and 2015. The tests performed included the verification of the membrane thickness, mechanical strength and water tightness, the bitumen softening temperature and asphaltene content, and the weld mechanical strength. No degradation of BGM has been found after the last testing.

Figure 5. BGM sample retrieval from La Manche repository

Every day, there is a control at every manhole on the periphery of the facility to determine if there is leaks of water through the BGM. Until now, there are no leaks of the membrane.

### 3.2.3 Studies on biodegradation of bitumen

The United States regulation for land disposal of radioactive waste ( US 10 CFR Part 61) requires that waste must remain stable for a minimum period of 300 years and thus an estimate of the rate of biodegradation of bituminous material is necessary to predict the long-term stability of low and intermediate level radioactive waste storage sites.

The Brookhaven National Laboratory of the US Department of Energy undertook a series of experiments to determine the rate of degradation of BGM samples under a variety of conditions. The tests were done in chambers with BGM samples measuring the metabolic CO2 release from these chambers under the action of very active bacteria (Barletta et al, 1986).

This test determines the rate of degradation by measuring the rate of CO2 evolution from samples using a method developed by Bartha and Pramer. The details of the experimental procedure are summarized here:

Bitumen was used to fabricate three samples of 1-cm-sized cylinders:

- Right circular cylinders of nominal diameter and height of 2 cm,
- Right circular cylinders of nominal diameter and height of 1 cm,
- Sheets approximately 1 mm thick.

The samples for each experiment were obtained by taking approximately 7 grams of one of the three sample types. Thus, for each experiment, the volume of material was constant while the surface area varied depending on the type of sample used. Three types of soil (Barnwell soil, Richland soil, Agar) were used. Two were backfill soils obtained from the low-level waste disposal sites at Barnwell, SC and Richland, WA. The third was a surface soil sample obtained at BNL. All soils were used in their field moist condition. In addition, for two experiments on Barnwell soil, conditions of full saturation and one-half field moist were used. The nutrient salts agar medium supplied all essential nutrients except a source of carbon. For most of the soil experiments, the indigenous soil microbes were used. In the single exception of Experiment 3, the soil was sterilized by gamma radiation and inoculated with Pseudomonas aeruginosa. For the two sets of experiments run in agar, inoculation was with either the mixed fungal culture prescribed in ATSM G21 or with Pseudomonas aeruginosa which is prescribed in ASTM G22. The experimental procedure was to have bitumen samples loaded into the Bartha-Pramer flasks along with the medium (agar or soil). Sets of four replicates were used in each experiment. Controls consisted of growth medium plus microbe but with no bitumen. Three replicates were used for controls. Atmospheric CO2 was excluded by means of an Ascarite filled tube. The experimental apparatus is illustrated in Figure 6. The amount of CO2 released from controls and samples was determined by titration of the 0.1 N KOH solution. The KOH solution was withdrawn from the flask at periodic intervals which varied over the course of each experiment and replaced with fresh solution. Each sample was titrated with standard HCl solution (either 0.5 or 0.1 N) and the incremental amount of CO2 generated in the sample and control flasks

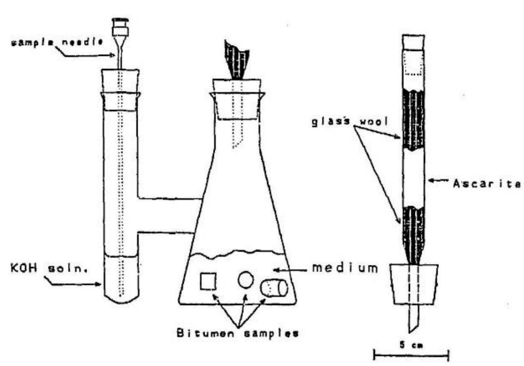


Figure 6. Experimental apparatus used in Bartha-Pramer experiments

| Experiment No | Rate (cm/yr.) |
|---|---|
| 1 | 5.78E-04 ± 1.2E-04 |
| 2 | 3.65E-04 ± 5.6E-05 |
| 3 | 2.11E-04 ± 1.4E-04 |
| 4 | 5.96E-04 ± 2.5E-04 |
| 5 | 1.05E-03 ± 1.3E-04 |
| 6 | 4.58E-04 ± 8.1E-05 |
| 7 | 6.37E-04 ± 1.6E-04 |
| 8 | 5.43E-04 ± 6.5E-05 |
| 9 | 2.44E-03 ± 4.1E-04 |
| 10 | 5.56E-03 ± 6.2E-04 |

Table 4. Degradation rates of bitumen based on cumulative CO2 released in modified Bartha-Pramer test

## 4. CONCLUSION

Based on the information presented through this article we can conclude that the BGM maintains very well its mechanical properties and its water tightness after a service period of 30 years under covered conditions. The mathematical modelling of the BGM durability indicates that the biodegradation of the BGM is a very slow process and thus it can maintain its water tightness for 300 years or more.

With regards to the durability under exposed conditions, actual testing after ten years in service show little reduction in its mechanical properties and the required CE testing of artificial UV aging indicate that durability under exposed conditions could be up to 60 years,

## REFERENCES

AMERICAN SOCIETY FOR TESTING OF MATERIALS (1996). Standard practice for determining resistance of synthetic polymeric materials. ASTM standard G21-15

AMERICAN SOCIETY FOR TESTING OF MATERIALS (1996). Standard practice for determining resistance of plastics to bacteria. ASTM standard G22-76

ASSOCIATION FRANCAISE DE NORMALISATION (2002). Géotextiles et produits apparentés - Détermination de la résistance au vieillissement dû aux conditions climatiques. AFNOR standard NF EN 12224

ALONSO, E., DEGOUTTE, G., GIRARD, H.G. (1990) . Results of seventeen years of using geomembranes in dams and basins, Proceedings of the 4th International conference on geotextiles, geomembranes and related products. The Haugue, Netherlands.

BARLETTA, R.E., BOWERMAN, B.B., DAVIS R.E., SHEA, C.E. Department of Nuclear Energy , Brookhaven National Laboratory, Upton, NY (1986).“ Biodegradation testing of bitumen”, Published in Scientific Basis for Nuclear Waste

Management X, Symposium held December 1-4,1986, Boston, Massachusetts, U.S.A. (Conference Paper)

CONNAN, J. (1999) Use and trade of bitumen in antiquity and prehistory: molecular archaeology reveals secrets of past civilizations. The Royal Society Publishing.

GOURC, J.P. (2017) Back to the first large rockfill dam with an upstream Geomembrane Sealing System (Ospedale,1979). Proceedings of 2017 Goesynthetics conference, Santiago, Chile.

IRSTEA – Institute de Recherche en Sciences et Technologies pour l'Environnement et l'Agriculture. (2007); Private report for COLAS.

LA TECHNOLOGIE ROUTIERE. (1999). Private report for COLAS.

TOUZE – FOLTZ, N. et Al (2011) Long-term Hydraulic performance of oxidized bitumen geomembranes exposed and covered; Meetings 2011, Magnan and Touze - Foltz publishers, 349-356