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BEHAVIOUR OF AN EPDM GEOMEMBRANE 18 YEARS AFTER ITS INSTALLATION IN A WATER RESERVOIR

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ABSTRACT: The purpose of this study is to evaluate the durability of an EPDM geomembrane installed 18 years ago in the water reservoir of El Boquerón (Canary Islands, Spain). To do so, samples were regularly taken from different places of the water reservoir. Samples were laboratory tested as follows: foldability at low temperature, static and dynamic puncture resistance, Shore-A hardness, tensile strength and elongation at break, seam strength and microscopic techniques. The obtained results confirm the EPDM geomembrane is still in good condition.

Keywords: Geomembrane, Waterproofing, EPDM, Durability, Water Reservoir.

1. INTRODUCTION

In its report published in Paris in 1991, the International Commission of Large Dams indicated that the first geomembrane used in a hydraulic project was made from butyl synthetic rubber [1]. It was used in 1959 to waterproof the Kualapuu reservoir in Holokai (Hawaii). In Spain, it was also this type of synthetic rubber which was originally used to waterproof water reservoirs. The use of this product began in the Ibi region, on the Mediterranean coast and extended across the entire country up to the Portuguese border, where Azud (small scale dam) in Matavacas (Huelva) was waterproofed in 1974 [2], [3].

Butyl rubber is a macromolecule which presents in its structure a large number of double bonds, of which the "TT" (trans-trans) chains are likely to be attacked by electrophilic reagents such as ozone and, consequently butyl geomembrane may experience significant degradation. The researchers looked for a synthetic rubber which was not susceptible to this phenomenon and they found this in the EPDM terpolymer. This macromolecule is comprised of three monomers: ethylene, propylene and diene, the latter being present in maximum concentrations of 5%. The first diene used was 1,3-butadiene which was then replaced by other types such as cyclopentadiene, considerably improving the initial performances [4].

2. THE RESERVOIR

The El Boquerón reservoir is located in the area of Valle de Guerra, in the municipality of La Laguna in the north of the island of Tenerife (Figure 1 and Figure 2). The Canary Islands are located in a geographical area where the maximum Global Solar UV Index in clear weather (Bournay E., 2007) is considered as high (index between 6.5 and 8.5). The technical characteristics of the reservoir are presented in Table 1.

Fig. 1 Geographical location of the reservoir.


Fig. 2 El Boquerón reservoir.

Table 1 Technical characteristics of the reservoir

Location	La Laguna
Capacity	51.747 m³
Height	11.0 m
Altitude	376.7 m
Perimeter	340.7 m
Thickness of EPDM geomembrane	1.50 mm
Area of the geomembrane laid	8,991 m²
Year of installation	1992

3. FEEDBACK

3.1 Initial Characteristics

Table 2 presents the initial characteristics of the EPDM geomembrane installed in the El Boquerón reservoir. The initial physical properties are compliant with the values declared on the manufacturer's technical data sheet. This data is consequently used as reference values for assessing the evolution over time of EPDM geomembranes.

Table 2 Initial Characteristics of the EPDM geomembrane

Characteristics (Standards)	Values
Average thickness (EN 1849-2)	1.51 mm
Shore A hardness (ISO 7619)	68
Foldability at -55 °C (EN 495-5)	Without fissures
Resistance to dynamic puncture* (EN 12691)	> 350 mm
Tensile Strength at break (ISO 527)	12.6 MPa
Stress at 300% elongation (ISO 527)	9.1 MPa
Elongation at break (ISO 527)	527%
Static puncture	
Resistance to puncture (EN ISO 12236)	
External surface	266 N/mm
Internal surface	266 N/mm
Depth of the plunger before perforation (UNE 104 317)	
External surface	40 mm
Internal surface	40 mm
Seam resistance by tensile-shear (EN 12316-2)	68 N/50 mm

3.2 Evolution Over Time

After the EPDM geomembrane was installed, samples were taken regularly and tested in a laboratory. Unless otherwise indicated, the values presented refer to samples taken from the north banks of the reservoir (bank most exposed to sunlight, and consequently most exposed to high UV and temperatures).

As far as the foldability test at low temperature is concerned (-55°C), no cracks or fissures were observed in the flexing area on the samples analyzed after 18 years of exposure. Similarly, during the dynamic puncture test, no fissures or any other type of degradation was noted in the impact area when the plunger was dropped from a height of 350 mm.

3.3 Tensile Characteristics

Figure 3 shows the evolution in tensile strength at break, stress at 300% elongation and elongation at break over the 18 years since installation of the EPDM geomembrane. It can be seen that the tensile strength has not changed significantly, while elongation at break decreases noticeably. It can also be seen that the force necessary to obtain the same 300% elongation increases over time.

We note that after 18 years of exposure, the elastic elongation of the EPDM geomembrane is larger than 190% (remains elastic to breaking point), which is very high in comparison with the majority of thermoplastic geomembranes. This data is significant as the permissible elongation determines the ability of the geomembrane to adapt to differential settlements and irregularities in the soil and therefore defines its puncture resistance in real conditions.

The decrease in elongation at break and increase in stress at 300% elongation in the period is explained by the fact that, in the case of EPDM, during the oxidation phenomenon (induced by the temperature and UV exposure), the combination reactions of the carbon chains (cross-linking) has a prevails upon the cleavage reaction of the principal carbon chain [5]. Consequently, a decrease in molecular mobility and an increase in molecular mass can be seen [5]. These reactions are similar to the process of curing used during EPDM geomembrane production.

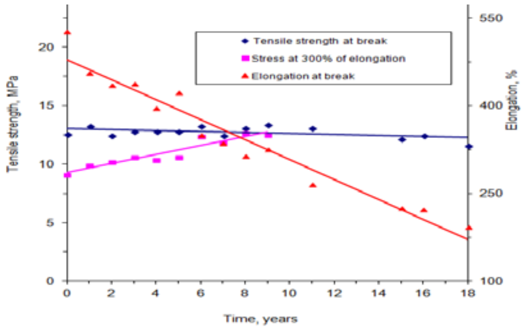

Fig. 3 Evolution over time in tensile strength and elongation at break, stress at 300% elongation.

3.4 Shore A Hardness

The Shore-A hardness value has increased over time as shown in Figure 4. The increase in the Shore-A hardness can be explained by the decrease in molecular mobility as explained in the Section of the Initial Characteristics.

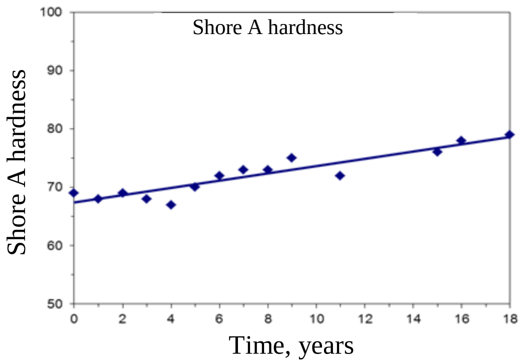

Fig. 4 Change in the Shore A hardness over time.

3.5 Resistance to Puncture

Figures 5 and 6 respectively present the static puncture resistance and the distance travelled by the plunger before perforation. The distance travelled by the plunger before perforation is a measurement which allows for the evaluation of the resistance to puncture in actual conditions as it gives an idea of the adaptability of the geomembrane to the soil conditions. The resistance to puncture stays fairly constant in time (this is confirmed by samples taken after 21 years of exposition in this same water reservoir). On the other hand, the distance travelled by the plunger before perforation decreases accordingly given the decrease in molecular mobility (the same phenomenon that explains the decrease in elongation at break). It should be noted that this last value (27 mm after 18 years) remains very high and well above the measurements usually recorded on the vast majority of thermoplastic geomembranes [6].

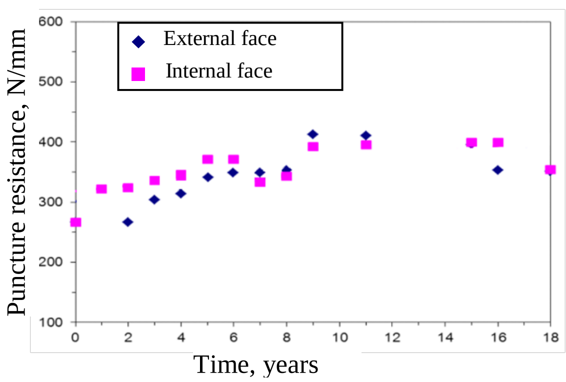

Fig. 5 Evolution in the resistance to static puncture over time.

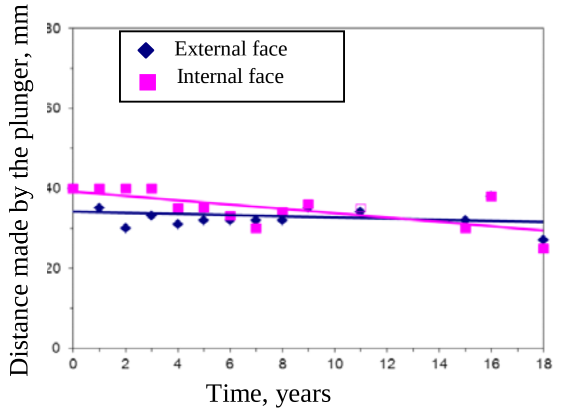

Fig. 6 Evolution of the depth of the plunger before perforation over time.

3.6 Seam Resistance

After 18 years of exposure, the value for shear resistance of seams is 645 N/50 mm. Figure 7 illustrates that, during the first 8 years, the measurements for peel resistance of seams were relatively variable. The measurements taken in the following 10 years are more consistent and show that peel resistance is fairly constant.

The variability of peel measurements is explained in part by the seaming method used at the time that consisted of applying a butyl based glue for which uniform application was not guaranteed. This is one of the reasons why, for a number of years already, butyl glue has been replaced by other systems such as self-adhesive tape which ensures better quality consistency.

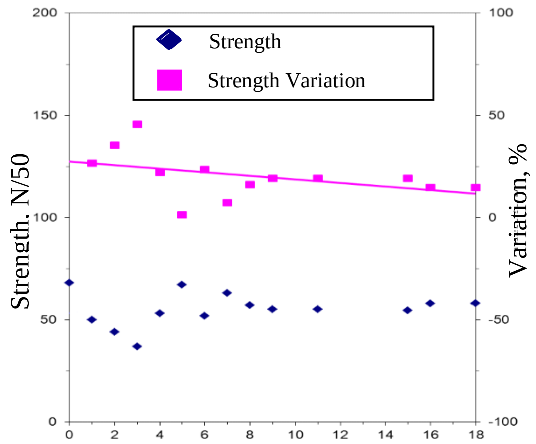

Fig. 7 Evolution of peel resistance of seams over time.

3.7 Microscopic Analyses

Observations under reflection optical microscopy (magnified 40 times) and by scanning electron microscopy (magnified 90 times) have been conducted according to the conditions documents in the literature [7] for the purpose of evaluating the condition of the geomembrane surface 18 years after installation (figure 8).

If we take into account the condition of the surface of an EPDM geomembrane that has not been exposed [8], we can see under reflection optical microscopy that after 18 years, the internal and external surfaces of the geomembrane seem to be in a good condition, with the internal surface presenting the best state of condition.

The scanning electron microscopy shows that eighteen years after installation of the geomembrane, the presence of a microporous structure can be detected confirming a slight degradation of the internal surface of the geomembrane. The external surface also presents some microcracks.

These microcracks seem relatively superficial and do not affect the mechanical resistance of the geomembrane, as proven in the evolution of the resistance at break and puncture examined above. This is explained by the highly cross-linked network of the EPDM geomembrane which distributes loads evenly across all carbon chains and limits the diffusion of potentially degrading elements [9].

These observations are to be compared with the results of the study on the surface condition conducted by Soriano et al. (2012) looking at different types of geomembranes. This study concluded that the impact of UV exposure is visible on these organic materials and that it is more significant on thermoplastic geomembranes than thermostable geomembranes such as synthetic rubbers [7].

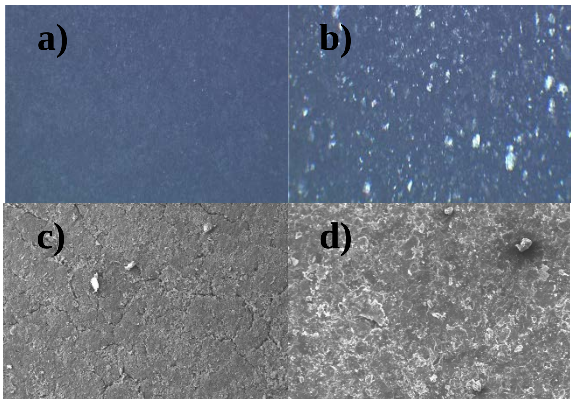

Fig. 8 18 years of exposition – microphotographs:
- x40 of the (a) external surface and (b) internal surface taken using reflection optical microscopy.
- x90 of the (c) external surface and (d) internal surface, taken using scanning electron microscopy.

3.8 Influence of the Sampling Area on Samples

For the purpose of knowing the condition of the EPDM geomembrane in other areas apart from the north bank, samples were also taken from the bottom (less exposed, due to protection from water) and the bank on the south side of the reservoir. Results obtained are presented in Table 3.

Table 3 Characteristics of the geomembrane according to exposure 18 years after installation

Characteristics	Ref.	Bank		Bottom
		N	S	
Tensile Strength, (MPa)	12.6	11.6	12.9	10.0
Elongation at break (%)	527	193	271	255
Resistance to puncture (N/mm)	266	351	367	371
Depth of the plunger before perforation (mm)	40	27	30	34
Shore A hardness	69	79	78	80
Seam resistance by tensile-shear (N/50 mm)	68	58	60	45

Regardless of their orientation and their degree of exposure, all samples analyzed after 18 years show a similar evolution in their mechanical properties. It is systematically observed that tensile strength is more or less constant, that elongation at break and the distance travelled by the plunger before perforation decreases significantly and that Shore-A hardness and resistance to static puncture increases over time. The results also show that the more apparent signs of ageing are observed on the samples taken from the north bank; the area that receives the most significant amount of solar radiation.

4. CONCLUSION

The results obtained during the periodic inspection of the EPDM geomembrane installed in the El Boquerón reservoir allows us to draw the following conclusions:

- Both foldability at low temperature (-55ºC) and resistance to dynamic puncture showed no cracks, breaks or any other indication of degradation after conducting the tests, proving the good state of conservation of the EPDM geomembrane 18 years since its installation;
- The tensile resistance that does not change significantly over the years; whereas elongation at break reduces significantly, a characteristic behavior of thermostable materials, as a result of the increase in the number of links between carbon chains (cross-linking); elastic elongation is larger than 190% after 18 years of exposure, which is very high for a geomembrane; this last property provides important information on the ability of the geomembrane to adapt to differential settling and irregularities in the soil;
- The Shore A hardness measurements increase over time; this is a consequence of the increase in the level of cross-linking in the geomembrane which reduces molecular mobility; the resistance to puncture is fairly constant and the distance travelled by the plunger before perforation, a measurement that allows us to evaluate the resistance to puncture in actual conditions, decreases over time; however, the value obtained after 18 years' exposure (27 mm) is greater than the measurement for the majority of thermoplastic geomembranes used in waterproofing;
- The shear resistance of the seams, testament to the quality of the seams, indicates that the seams between the panels are correct; the values for peel resistance of seams are relatively low and variable, given the use of an old seaming method which consisted of applying a butyl based glue to the seam area;
- The microphotographs taken by optical and scanning microscopy show a material in a good state of conservation; only micropores and some microcracks were detected but we note the complete absence of craters, fissures and micro-cracks;
- No significant differences in condition were observed between the samples taken from the

bottom (covered by water) and the samples taken from the top of the banks (exposed to weather); the area most affected by ageing was the zone located on the north bank; given that the reservoir is located in the northern hemisphere, the north bank is the one facing the equator and consequently receives the largest amount of solar radiation (UV and temperature) which is responsible for the degradation of organic material.

- After 18 years of exposure to demanding weather conditions (high temperature and UV rays), the EPDM geomembrane used in the El Boquerón water reservoir has retained the mechanical properties which are still well suited to this.

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