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GEO12-FW-017 - Integrity of HDPE Geomembranes: Effect of Weather Exposure on the Mechanical Properties of Seams

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ABSTRACT
In landfills, the geomembrane is essential to minimize the migration of pollutants into the surrounding environment. However, the performance of the geomembrane in the long-term may be compromised by weather exposure. To address this issue, a study is underway involving geomembranes exposed to weather conditions for 10 years. Samples of HDPE geomembrane and seams are cut periodically over a 10-year period and tested to evaluate the physical, the mechanical, the endurance and the seam properties. This paper is focused on the long-term durability of geomembrane seams. The 10-year peel and shear test results are compared with the currently recommended GRI-GM 19 Seam Specification, as well as with the unexposed seam properties and with the results obtained after 2, 3, or 5 years of exposure. Results have shown that the aged seams met the recommended specification and that they were not significantly affected by 10 years of weather exposure.

1. INTRODUCTION

Landfills are generally designed to protect the environment against contaminants by using composite liners. In Portugal, they typically include a high density polyethylene (HDPE) geomembrane, a geosynthetic clay liner and a compacted clay liner. The geomembrane is essential to minimize the migration of pollutants into the surrounding environment. However, the performance of the geomembrane in the long-term may be compromised by weather exposure.

As pointed out by Yako et at. (2010), compared to covered materials, exposed geomembranes have some adversely affecting conditions imposed upon them, in particular, 21 % oxygen, ultraviolet light (UV light), and temperature, which, depending on the site, may be quite high.

According to Hsuan & Koerner (1998), the service life of an HDPE geomembrane includes three stages. The first stage corresponds to antioxidant depletion, the second stage corresponds to the induction time to the onset of polymer degradation, and the third stage corresponds to polymer degradation involving the decrease in a geomembrane property to a level often taken to be 50% of the original value. As pointed out by Rimal & Rowe (2009), the service life of a geomembrane is initially controlled by the rate of depletion of antioxidants in Stage I. The depletion of antioxidants leaves the geomembrane susceptible to the oxidative degradation. In Stage II oxidation of polymer takes places without any measurable decline in mechanical properties. In Stage III oxidative degradation of polymer continues and the mechanical properties change to the end of service life.

The ideal approach of assessing long-term performance of geomembranes would be by examining actual field samples over time. In this context, a study on the evolution of mechanical properties of HDPE geomembranes exposed to weather conditions is being conducted at *Laboratório Nacional de Engenharia Civil* (National Laboratory for Civil Engineering - LNEC). The geomembranes are exposed in several waste landfills located all over Portugal. They have now been ageing for 8 to 11 years, depending on the site, here assumed as 10 years for the sake of simplicity. The samples have been cut periodically over this period and have been tested to evaluate the physical, mechanical and endurance properties of geomembrane sheets, as well as the mechanical properties of the seams.

This paper is focused on the long-term properties of geomembrane seams. Indeed, seams are vulnerable areas as result of mechanical and thermal solicitations that are imposed on them during the joining process. Despite the susceptibility of seams, the evolution in their mechanical properties remains little studied, contrary to the long-term durability of exposed geomembranes sheets, which has been extensively researched (e.g., Baleki et al. 2010; Yako et al. 2010; Rowe et al. 2003, 2009; Rowe & Sangam 2002; Sangam & Rowe 2002; Sangam et al. 2001).

The paper provides an updated data reported by Barroso & Lopes (2010) and Lopes & Barroso (2004) based on additional testing performed about 5 years later. The 10-year peel and shear test results are firstly compared with the currently used Geosynthetic Research Institute (GRI) Specification, namely, the GRI-GM 19 Seam Specification. Then, they are compared with the unexposed seam properties and, finally, with previously published data, obtained after 2, 3, or 5 years of weather exposure.

2. EXPERIMENTAL WORK

2.1 Background

The work reported herein represents a significant extension of the work reported by Barroso & Lopes (2010) and Lopes & Barroso (2004). It uses the same geomembrane seams as described therein, but includes the results of the peel and shear tests carried out after 10 years of exposure.

In brief, between 1998 and 2004, during the construction of several solid waste landfills in Portugal, geomembrane samples were prepared to be exposed. Each sample included a thermally bonded seam, which was prepared by a dual hot wedge method (Figure 1). The seam was located at the centre of the sample.

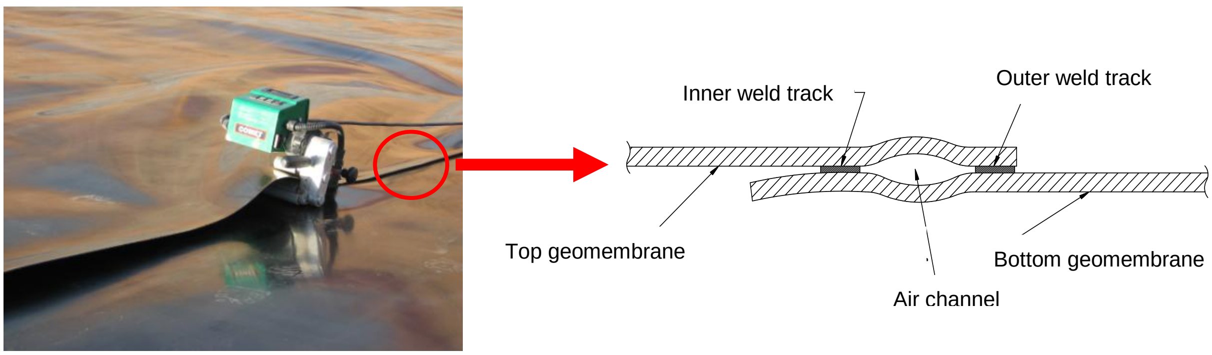


Figure 1. Dual hot wedge seam of geomembranes

As illustrated in Figure 2, samples were divided in three parts: part 1, unexposed; part 2, exposed to weather conditions with a geotextile over it; and part 3, fully exposed.

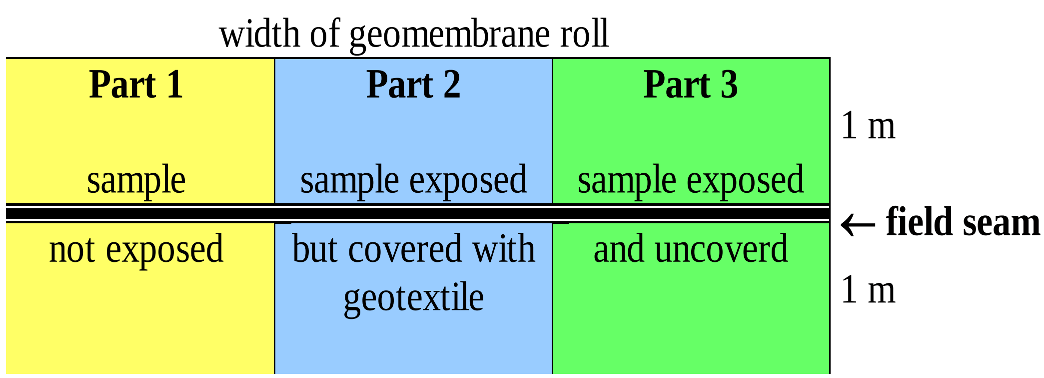


Figure 2. Scheme of welded geomembrane by field seam

Exposed seams (parts 2 and 3) were left in landfill sites. Figure 3 shows an example of a geomembrane sample exposed at the roof of a building.

Figure 4 shows the location of seamed geomembrane samples at landfill sites in Portugal.

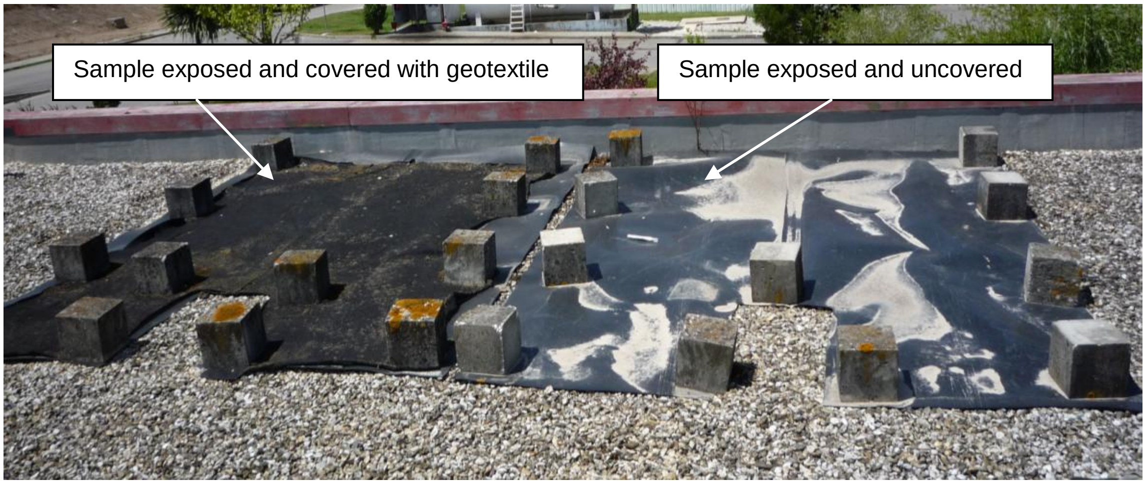


Figure 3. Example of a geomembrane sample exposed to weather conditions (landfill site 4)

Figure 4. Location of seamed geomembrane samples at landfill sites in Portugal.

The seam samples have been cut periodically over time and have been tested to evaluate the mechanical properties. Roughly, the adopted sampling frequency was approximately 2, 3, 5 and 10 years.

2.2 Materials

The geomembranes and geotextiles used in the experimental work are the ones used at the landfills where the samples are exposed.Three 2.0 mm smooth HDPE geomembranes and one 1.5 mm textured HDPE geomembrane were used. The main characteristics and location of the geomembranes are summarized in Table 1.

Concerning geotextiles, three different types of products were used in this study. Geotextiles were identical and all included photo-stabilizers. The mass per unit of area of the geotextiles ranged from 250 g/m^2 to 300 g/m^2.

Table 1. Main characteristics of the geomembranes and location at landfill sites

GMs	Thickness (ASTM D 5199)	Density (ASTM D792)	Melt Index (190 ºC/5 kg) (ASTM D1238)	Tensile Properties (ASTM D638, type IV)		Location (sites)
				Yield	Break	
A	2.0 mm (smooth)	0.944 g/cm^3	0.7-1.3 g/10 min	> 16 N/mm^2/10 %	> 20 N/mm^2/ 600 %	5, 7
B	2.0 mm (smooth)	0.942 g/cm^3	< 3 g/10 min	> 15 N/mm^2/10 %	> 27 N/mm^2/ 700 %	1, 3, 4, 6
C	2.0 mm (smooth)	0.946 g/cm^3	n/a	> 17N/mm^2/13 %	> 27 N/mm^2/700%	2
D	1.5 mm (textured)	0.940 g/cm^3	0.6-1.8 g/10 min	> 15N/mm^2/13 %	> 27 N/mm^2/600%	8

n/a = not available

2.3 Testing procedure

The 10-year peel and shear tests were carried out according to ASTM D 6392. This standard replaced the ASTM D 4437 that was used on tests performed previously, after 2, 3, or 5 years of exposure, of which the results were reported by Lopes & Barroso (2004). It should be noted that the test procedure is similar on both standards and, hence, strength values are comparable. However, the ASTM D 6392 standard is more comprehensive, in addition to peel and shear strengths, it includes peel separation, shear elongation and presents the locus-of-break codes for seam strength in peel and shear modes.

In brief, in each type of test, five specimens (150 mm×25 mm) were pulled out as shown in Figures 5 and 6 for peel and shear test, respectively. The seam is located centrally and perpendicular to length. Tests were carried out at an elongation rate of 50 mm/min. In peel test, both dual hot wedge seam were tested from outside towards the air channel.

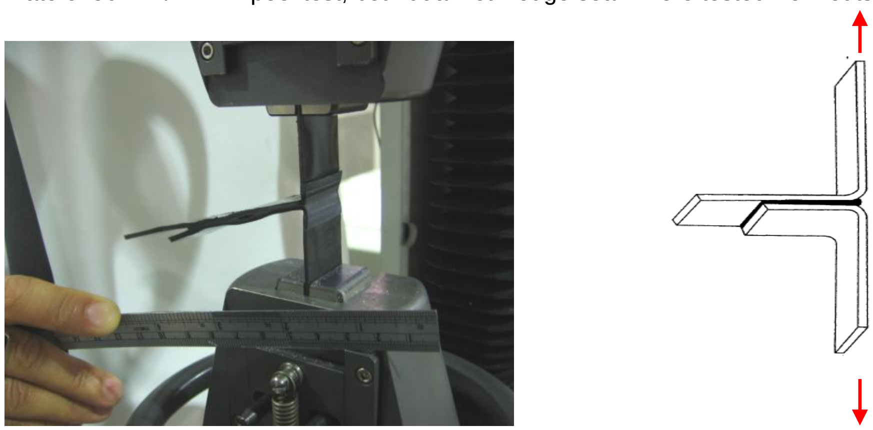


Figure 5. Peel test for seamed geomembranes

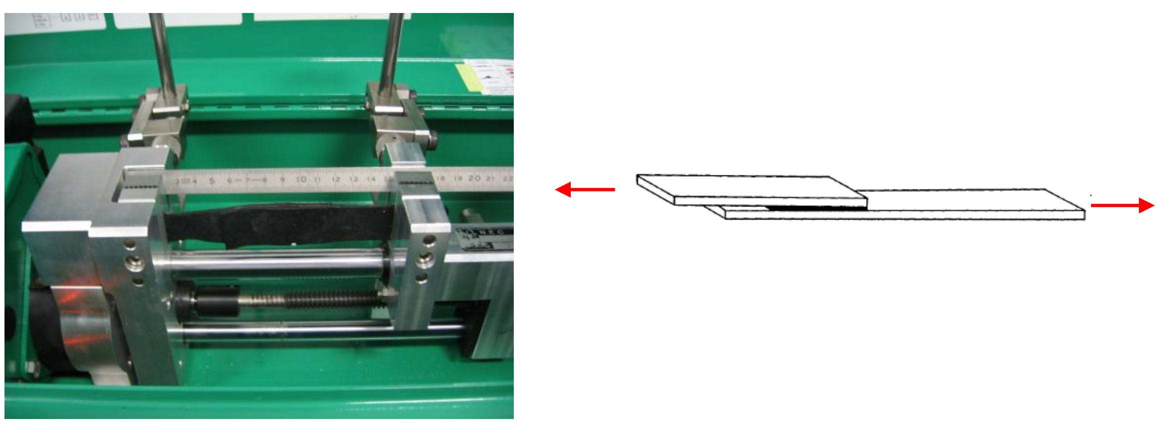


Figure 6. Shear test for seamed geomembranes

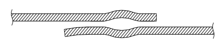
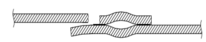
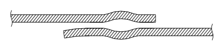
3. RESULTS AND DISCUSSION

3.1 Comparison with GRI-GM 19 Seam Specification

3.1.1 GRI-GM 19 Seam Specification

The GRI-GM 19 addresses the required seam strength (peel and shear) and related properties of thermally bonded polyolefin geomembranes. Related properties include: peel separation, shear elongation and unacceptable locus of-break patterns per their description in ASTM D 6392, in peel and shear modes. Table 2 summarizes the GRI GM 19 Seam Specification for thermally bonded, both smooth and textured, HDPE geomembranes.

Table 2. Summary of the GRI-GM 19 Seam Specification for HDPE geomembranes

Seam	Test	Properties	Geomembrane thickness	Minimum/maximum properties values (HDPE geomembranes)
 Dual hot wedge	Peel	Peel strength*	2.0 mm	≥ 21.2 kN/m
			1.5 mm	≥ 15.9 kN/m
		Peel separation	1.5 and 2.0 mm	≤ 25%
		Unacceptable break codes**	1.5 and 2.0 mm	 AD  AD - Brk
	Shear	Shear strength*	2.0 mm	≥ 28.0 kN/m
			1.5 mm	≥ 21.0 kN/m
		Shear elongation	1.5 and 2.0 mm	≥ 50 %
		Unacceptable break codes*	1.5 and 2.0 mm	 AD  AD - Brk

* value listed for peel and shear strength are for 4 out of 5 specimens; the 5th specimen must meet or exceed 80% of the given values;
**per their description in ASTM D 6392 | AD- Brk> 25%

3.1.2 Seam peel properties

Regarding peel strength, Figure 7 presents the results obtained in this study for the 10-year aged seams, as well as the GRI-GM 19 required minimum value (solid line superimposed in figure). The values obtained experimentally contain the error bars corresponding to the uncertainty of measurement, calculated according to GUM (2008).

The uncertainty in the result of a measurement reflects the lack of complete knowledge of the value of the output quantity, for which an infinite amount of information would be required. The main possible sources of uncertainty in the measurements carried out in the experimental work described in this paper include: resolution, precision and accuracy of each equipment used, results of calibrations, approximations and assumptions incorporated in the measurement methods and procedures, and operator’s influence. However, in this study, some of these variables are impossible to quantify due to the unknown variation in both seam and geomembrane properties. Thus, the uncertainties were estimated considering two components: variability of repeated measurements (type A uncertainty), and equipment specifications (type B uncertainty). The uncertainties obtained were similar to the calculated standard error (not included in this paper for the sake of brevity), showing that variability is mainly due to the intrinsic properties of the samples, to the measurement procedures and to the operator’s influence. All intervals reflect expanded uncertainties with a 95% coverage factor. In the discussion presented below, it is assumed that differences in tests results are only significant when they are higher than the uncertainties associated with the measurements.

The Figure 7 shows that all 10-year aged seams exceed the GRI-GM 19 Seam Specification by a wide margin, both in inner and outer welds. For 2.0 mm geomembranes, the smallest value of peel strength was 27.8 kN/m (sample exposed at site 5), which is 6.6 kN/m above minimum recommended. A smaller difference (4.1 kN/m) was found for 1.5 mm geomembrane (sample exposed at site 8), even though well above the current specification value.

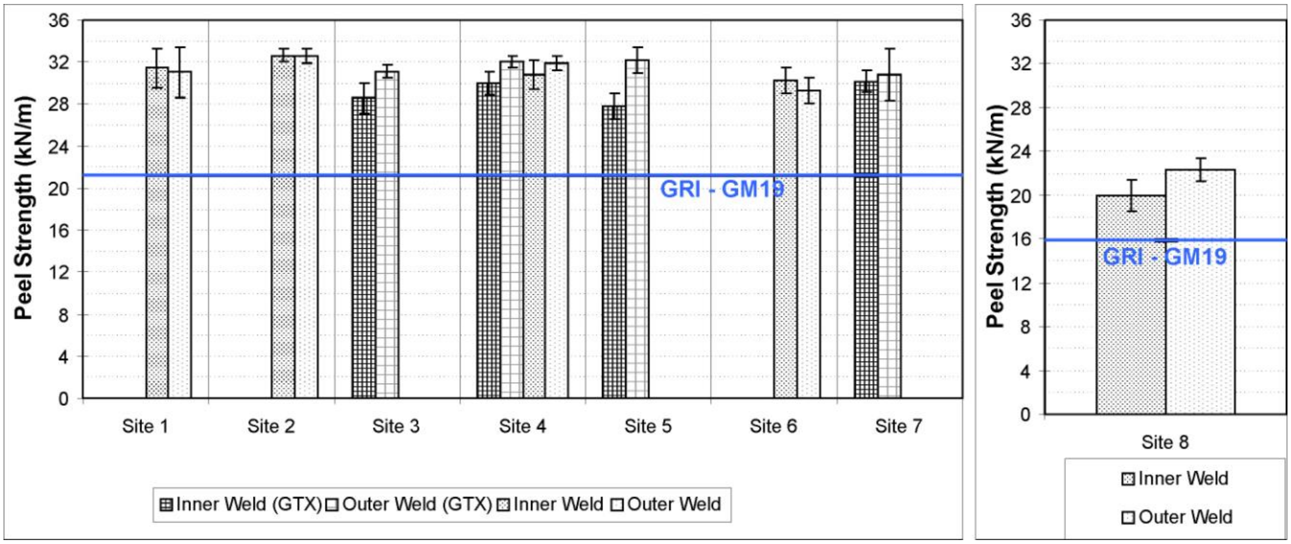


Figure 7. Peel strength for welded geomembranes

Concerning peel separation, for 2.0 mm geomembranes, it could be observed that the separation was less than the 25% required by GRI-GM 19 Specification, except for particular specimens, which was attributed to inappropriate sample preparation at sample location rather than the weather exposure. Indeed, in general, the seams tested failed outside the welded zone. This suggests that the strength of the seams was greater than the strength of the geomembrane sheet. As for 1.5 mm geomembrane, just one seam specimen presented a separation higher than 25% at inner weld, but it is questionable if that was either related to the weather exposure, or was due to poor execution of the seam at sample location.

Finally, concerning the locus-of-break pattern, from the 10-year aged seams, just one specimen presented an unacceptable break code (AD-Brk > 25%). However, this specimen was the one that did not meet the separation criterion. As abovementioned, this might be due to improper sample preparation at sample location rather than to weather exposure. So, it can be assumed that the results met the GRI-GM 19 Seam Specification.

3.1.3 Seam shear properties

The shear strength obtained for the 10-year aged seams are plotted together with the GRI-GM 19 Seam Specification in Figure 8. As can be seen, all tested seams exhibit higher strength than the current specification value. The smallest strength obtained was 34.8 kN/m, for sample exposed at site 3, which is 6.8 kN/m above minimum suggested.

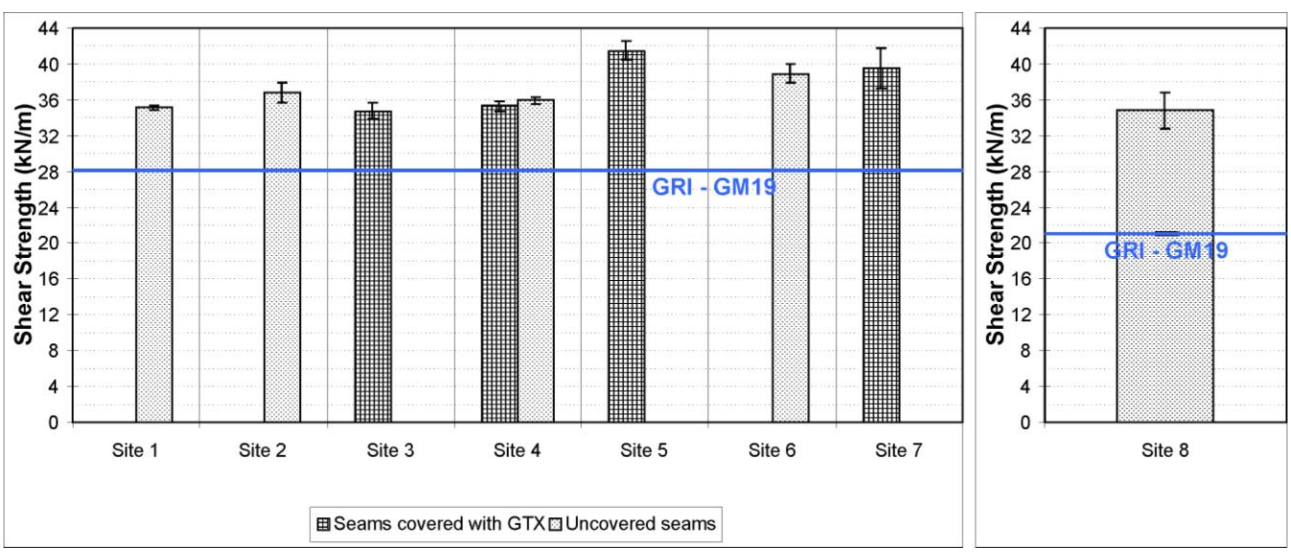


Figure 8. Shear strength for welded geomembranes

As for shear extension, all 10-year aged seams met the required minimum of 50% by the GRI-GM 19 Seam Specification.

Regarding the locus-of-break pattern, no unacceptable break codes were found, all seams met the GRI-GM 19 Seam Specification.

3.2 Influence of the weather exposure

3.2.1 Peel strength

Firstly, peel and shear tests were carried out to check if the strength of unexposed seams had changed over time. Variations obtained were very slight and may be attributed to material variability across the seam. It should be noted that the samples tested each time correspond to a different location on the seam. The variability may also be due to testing. Based on these preliminary test results, unaged peel and shear strengths are used in the comparisons presented below.

Secondly, the influence of the covering geotextile was evaluated by comparing the results of peel and shear tests for both covered and uncovered seams. It was found that the strength of the seams, both covered with geotextile and uncovered, was similar for all sites where that comparison was possible. Unfortunately, there were some sites where no samples covered with geotextile were present. Based on the close agreement of results for both uncovered and covered seams, data were processed together, although in the graphs presented below the seams covered with a geotextile are marked with “GTX”.

Figure 9 depicts the change in peel strength, as a percentage, for each sample tested as a function of seam age.

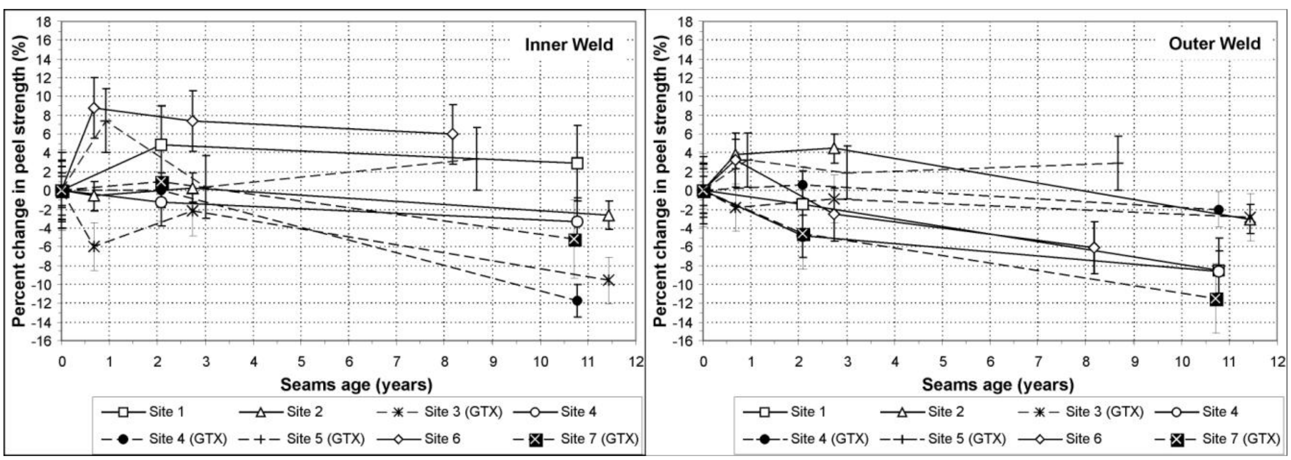


Figure 9. Peel strength as a function of seams age

It can be observed that, by taking into account the uncertainties associated to the measurements, the differences in peel strength over time can be considered as minor, both for inner and outer welds. Nonetheless, despite the scattering in data, it is possible to observe that the peel strength of the seams slightly increases in the first two years, except for seams exposed at site 3, in the case of the inner weld, and seams exposed at sites 4 and 7, in the case of the outer weld. This might be due to the increase in polymer crystallinity. Indeed, similar trend was reported by Rowe et al. (2009) for tensile properties of geomembrane sheets exposed in air. After a two year weather exposure, the peel strength tends to decrease, probably as result of the oxidation of the geomembrane due to UV light.

These results suggest that the amount of antioxidants consumed in the geomembrane has not reached the Stage III of degradation and, therefore, the peel strength of the seams remains almost unchanged, from a quantitative point of view.

3.2.2 Shear strength

The change, as percentage, in peel strength for each sample tested as a function of seam age is presented in Figure 10.

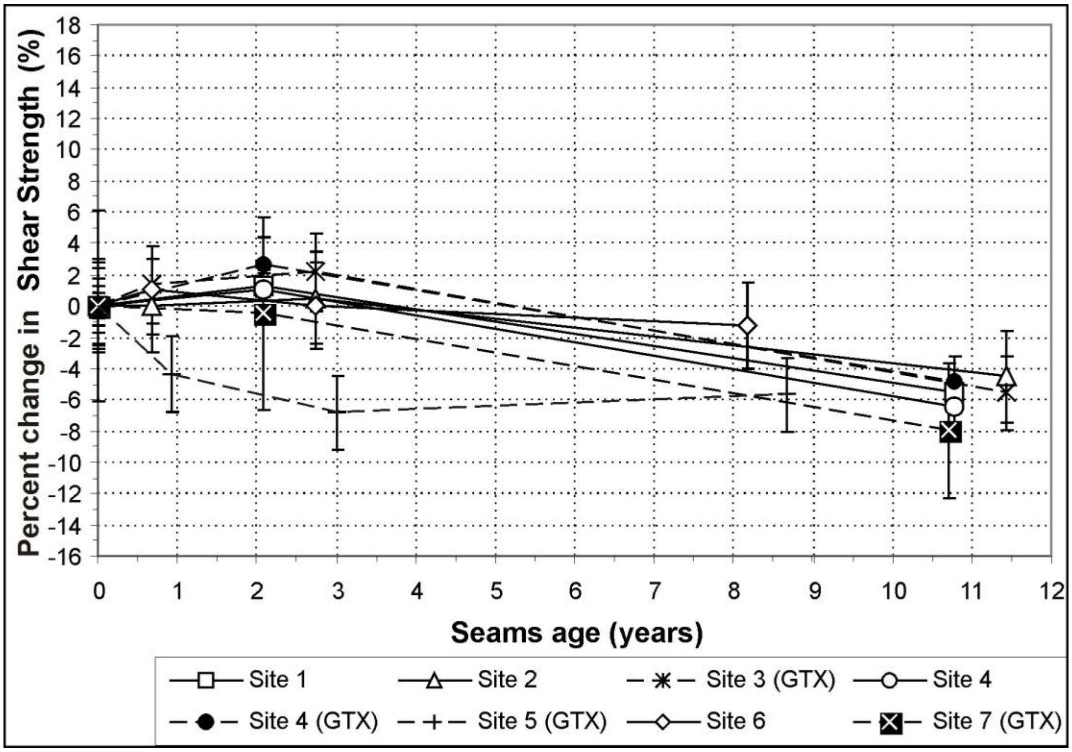


Figure 10. Shear strength as a function of seams age

As can be seen, by taking into account the uncertainties associated to the measurements, the only visible trend is a small decrease in shear strength for all seams, especially after the second year of weather exposure. Again, it appears that the amount of antioxidants consumed has not yet reached Stage III of degradation of geomembranes, so the shear strength of the seams does not present a significant decrease.

4. CONCLUSIONS

This paper presented an ongoing study on long-term performance of HDPE geomembrane exposed to weather conditions at several landfill sites in Portugal, being particularly focused on geomembrane seams. Peel and shear tests were conducted on samples that have been ageing for around 10 years. Results obtained were compared, first, with the currently recommended GRI-GM 19 Seam Specification, second, with the unexposed seam properties and, finally, with previously obtained results.

The main purpose of this research was to study the evolution in mechanical properties of the geomembrane seams (dual hot wedge seams). Another goal of this work was to verify if the aged seams still meet the GRI-GM 19 Seam Specification.

It was found that seams met the currently used seam specification. Test results presented herein also showed that the mechanical properties of the seams were not significantly affected by a 10 year weather exposure. These results suggest that the amount of antioxidants consumed has not reached Stage III of degradation of HDPE geomembranes, which is characterized by a measurable decrease in geomembranes properties.

ACKNOWLEDGEMENTS

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