Ageing HDPE geomembranes exposed to different climate conditions for 12 years

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ABSTRACT: High density polyethylene (HDPE) geomembranes are used in many geotechnical engineering applications, remaining sometimes exposed to climatological conditions for a long time. They are expected to experience degradation due to that exposure, leading to a decrease in their engineering properties. To study the degradation in the properties of field exposed geomembranes, a research program has been in progress at *Laboratório Nacional de Engenharia Civil*, since 1999. This paper addresses the degradation in the properties of HDPE geomembranes, installed at eight different locations, after 12 years of exposure. Another goal of this work is to compare the properties of exposed geomembranes with the minimum requirements currently recommended by the Geosynthetic Research Institute (GRI), in order to verify that they still meet those requirements. Samples were exhumed from different sites located all over Portugal and the properties of the geomembranes were tested in laboratory. The properties studied were: density, melt flow index, tensile properties, carbon black content, and oxidative induction time. The results have shown that the properties of the geomembranes exposed to climatic conditions presented some degradation, especially in the oxidative induction time and density. Also, they have indicated that the exposed geomembranes for 12 years even met the minimum requirements established by GRI-GM13, except for the oxidative induction time.

Keywords: Geomembranes, climatic conditions, field exposed geomembranes, degradation

1 INTRODUCTION

High density polyethylene (HDPE) geomembranes are used in many geotechnical engineering applications, remaining sometimes exposed to climatological conditions for a long time. Exposed geomembranes are subjected to severe conditions, including the effects of oxygen, ultraviolet rays (UV) and temperature, which, in countries like Portugal, can be quite high. Under these circumstances, they are expected to experience degradation that leads to a decrease in their engineering properties, hence compromising their long-term performance.
The main degradation can be due to chemical degradation of the polyethylene, which involves oxidative degradation either by ultraviolet radiation (photo-oxidation) or by thermal oxidation.

The available data on long-term performance of exposed geomembranes are based on feedback from field performance, on field investigations (e.g., Tarnowski and Baldauf 2006, Rowe et al. 2009, Baleki et al. 2010, Yako et al. 2010, Rowe and Ewais 2015) or on the degradation of the geomembranes incubated in accelerated laboratory weathering devices (Koerner et al. 2011). Correlations between field and laboratory weathering device data are quite difficult to establish. Also, there is an evident need for more data concerning the degradation in the properties of field exposed geomembranes in regions with climatologic conditions similar to Portugal.

Samples of HDPE geomembrane were exhumed from different sites located all over Portugal and the properties of the geomembranes were tested in the laboratory. Tests carried out include: density, melt index, tensile strain and strength at yield and break, carbon black content and standard oxidative induction time.

The objective of this study is to investigate the degradation that occurred in the properties of HDPE geomembranes at eight different sites, located in Portugal, after 12 years of exposure, with a view to provide some insight into the long-term performance of exposed HDPE geomembranes. Another goal of this work is to compare the properties of exposed geomembranes with the minimum requirements currently recommended by GRI-GM13 (2016), in order to verify if they still meet those requirements. The work described herein represents a significant extension of the work reported by Barroso and Lopes (2010), Lopes and Barroso (2004) and Barroso et al. (2012).

2 EXPERIMENTAL WORK

2.1 *Samples and sample locations*

The samples were prepared during the construction of several solid waste landfills in Portugal between 1998 and 2004. They consisted of part of the geomembranes roll (panel, cut in machine direction, along its entire width). Each sample included a thermally bonded seam, approximately located at the center of the sample.

The samples were either placed on easily accessible slopes or on building roofs (Figure 1), where they were exposed to climate conditions. They were installed at eight different locations in Portugal, as depicted in Figure 2.

Figure 1: Examples of geomembrane samples exposed to climatic conditions

Some geomembranes were supplied by the same manufacturer (having been manufactured with the same resin and the same additive formulation). Thus, in total, five smooth HDPE geomembranes with nominal thickness of 2.0 mm were used, herein termed as GM-A, GM-B, GM-C, GM-D and GM-E. As Figure 2 shows, GM-A was simultaneously exposed in three different locations and GM-B was exposed in two locations.

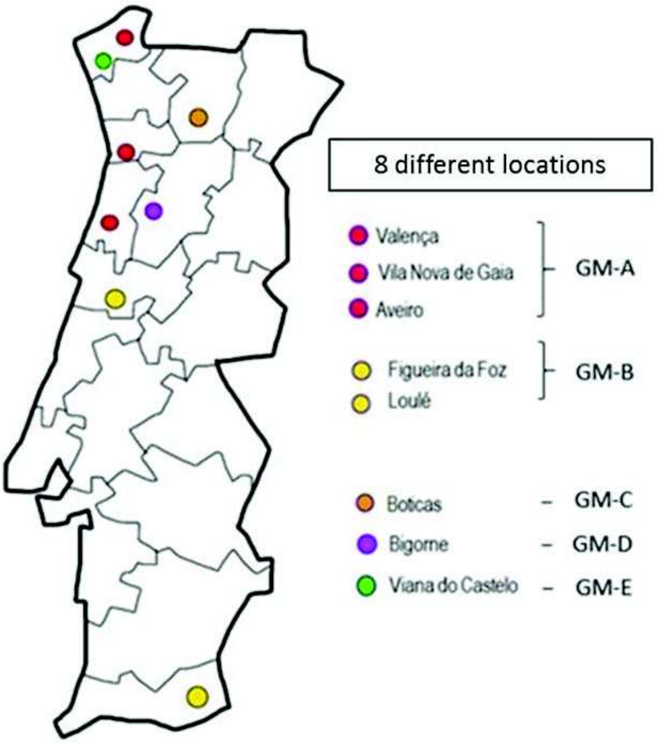

Figure 2: Location of geomembrane samples in Portugal

2.2 *Initial properties of geomembranes*

The initial properties of studied geomembranes are summarized in Table 1, according to their location. Property values are based both on geomembrane Data Sheets and on laboratory tests carried out in *Laboratório Nacional de Engenharia Civil* or by the manufacturer, under his own manufacture quality control procedure, and provided during sample preparation.

Table1. Initial properties of geomembranes exposed in different locations

Property	**Test method**	**Location**				
		GM-A (Valença, V.Nova de Gaia, Aveiro)	GM-B (Figueira da Foz, Loulé)	GM-C (Boticas)	GM-D (Bigorne)	GM-E (Viana do Castelo)
Density (g/cm^3)	ASTM D1505	0. 942*	0.940*	≥0.945*	0.940*	0.946* 0.945**
Strength at yield (kN/m)	ASTM D6693	34* 31.9**	30* 40.5**	37*	34*	34* 36.5**
Strain at yield (%)	ASTM D6693	10* 13.2**	10* 10.4**	10*	11*	13* 14.7**
Strength at break (kN/m)	ASTM D6693	55* 68,1**	55* 58,9**	56*	70*	55* 44.7**
Strain at break (%)	ASTM D6693	700* 578.2**	>700* 790.2**	>700*	≥750*	700* 830.2**
Carbon Black Content (%)	ASTM D1603	n.a.	2,0*	2-3*	2-3*	2-3 2.1**
Standard oxidative induction time (min)	ASTM D3895	n.a.	n.a.	n.a.	100*	100* 82.2**
Melt index (190ºC/5kg) (g/10 min)	EN ISO 1133	2.4* 0.96**	0.6-1.8* 0.8**	1.0*	1.0*	2.37**

Legend: *Data Sheet | ** Measured in laboratory | n.a. = not available

2.3 *Test methods*

Samples were exhumed at field sites from eight different locations in Portugal and the properties of the geomembranes were tested in laboratory. Both the properties studied and the test methods used are shown in Table 2 (Reis, 2016).

Table 2. Properties evaluated and test methods used

Property		**Test method**
Density		ASTM D1505
Tensile properties (type IV specimen taken in machine direction)	Strength at yield	ASTM D6693
	Strain at yield	
Carbon Black Content		ASTM D1603
Standard oxidative induction time (OIT)		ASTM D3895
Melt index (190ºC/5kg)		EN ISO 1133

3 RESULTS AND DISCUSSION

3.1 *Influence of climatological conditions*

The influence of climate conditions is evaluated by comparing the test results obtained for the exposed geomembranes (GM-exp) with the reference values, the latter corresponding to the initial properties of the geomembranes (see Table 1). To distinguish between the various sources of reference values, different terms are adopted. Reference values corresponding to results measured in laboratory are termed as Ref-lab and are termed as Ref-DataSheet when based on Data Sheets.

Figures 3 to 8 show the results obtained, respectively, for density, melt flow index, tensile strength and strain at yield, content of carbon black and induction time to oxidation. Values obtained experimentally contain the uncertainty bars corresponding to the standard deviation.

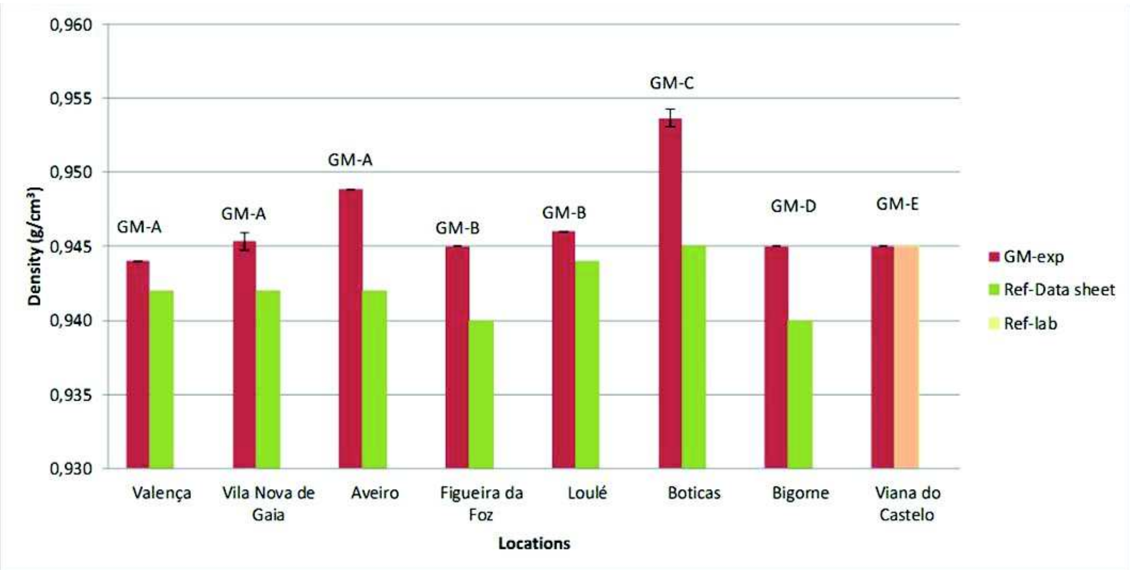

Figure 3: Comparison of the density of GM-exp with the reference values

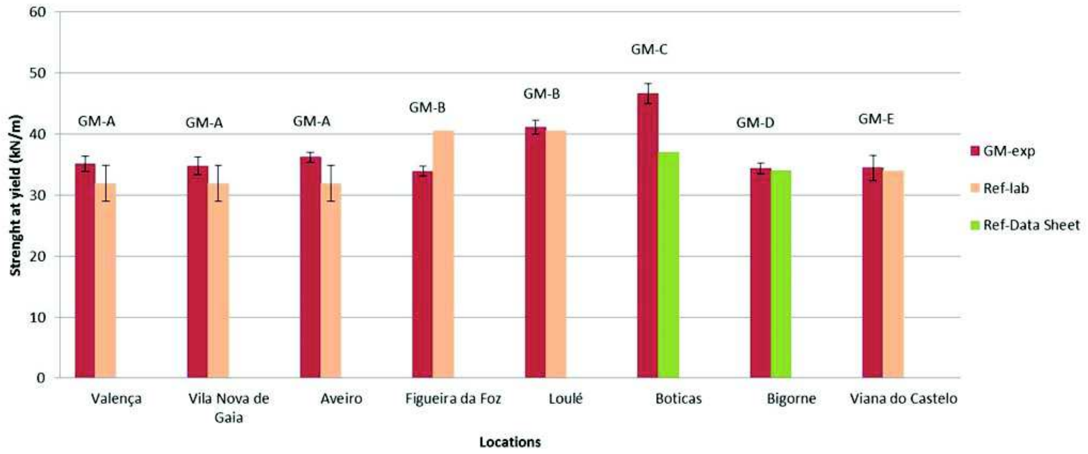

Figure 4: Comparison of the strength at yield of GM-exp with the reference values

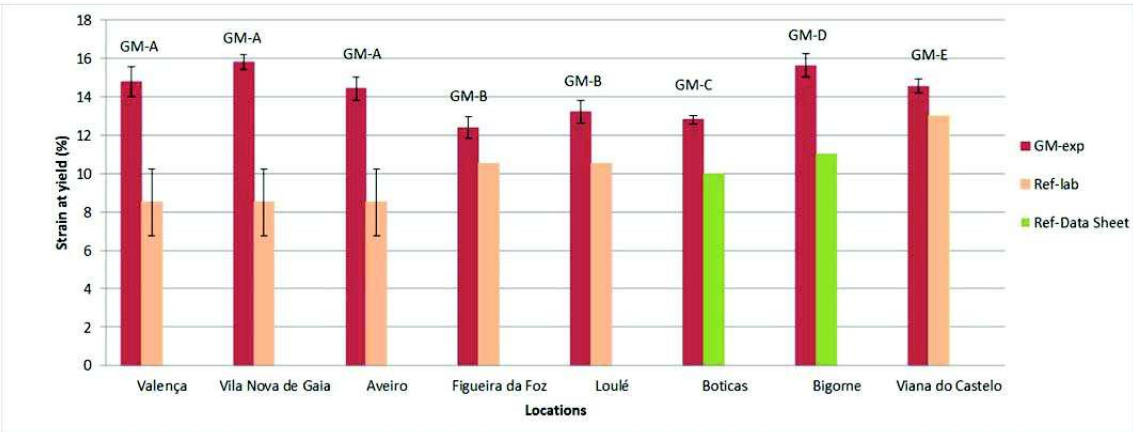

Figure 5: Comparison of the strain at yield of GM-exp with the reference values

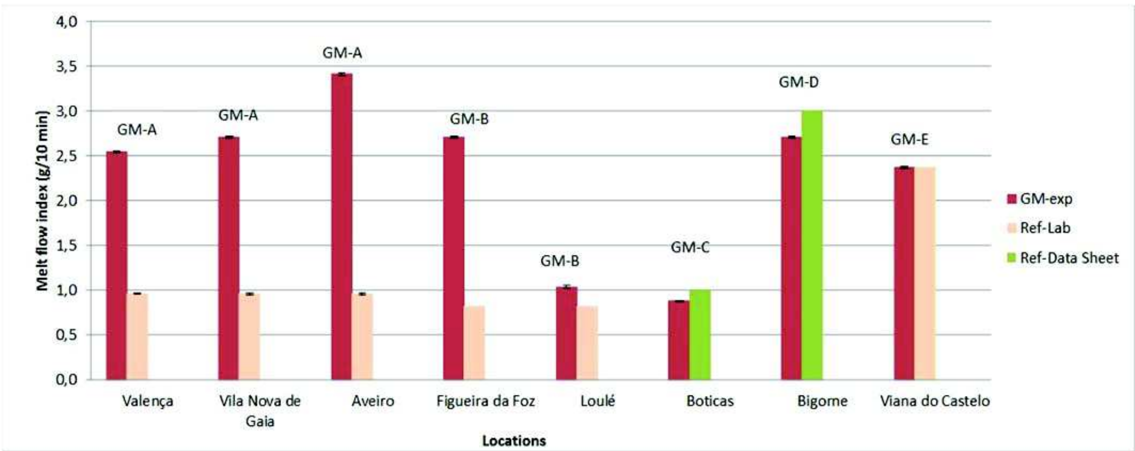

Figure 6: Comparison of the melt flow index of GM-exp with the reference values

Figure 7: Comparison of the carbon black content of GM-exp with the reference values

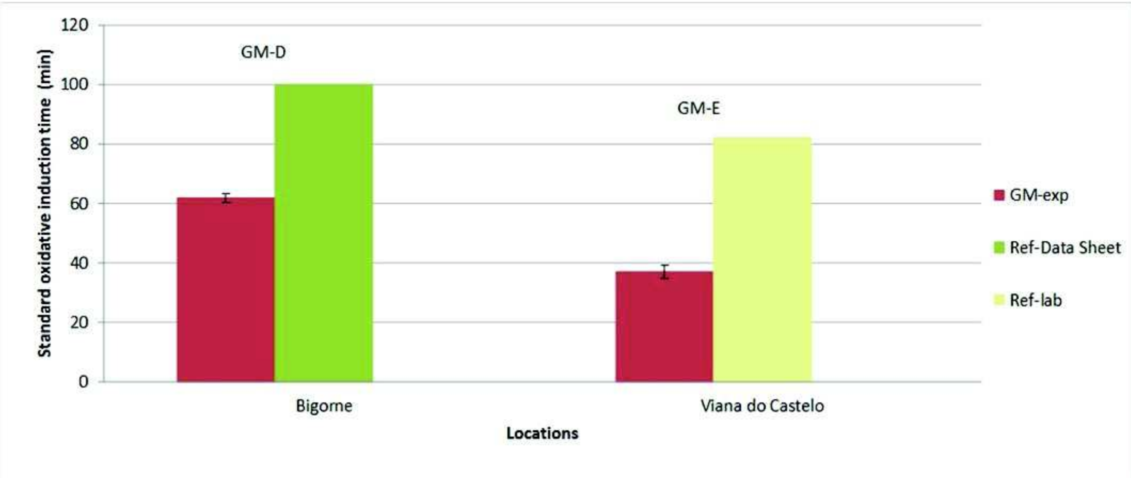

Figure 8: Comparison of the standard oxidative induction time of GM-exp with the reference values

As regards density, exposed geomembranes showed higher values than the reference values, except for GM-E, of which the values were identical, as can be seen in Figure 3. The increase in density can be related to changes in the polymer structure due to geomembrane degradation. As discussed by Rowe and Ewais (2015), geomembrane degradation can be caused by a change in the morphological structure (physical degradation), which may result in increased geomembrane crystallinity as the polymer tends to become more brittle.

Density has an impact on mechanical properties of the geomembrane (Handbook of Plastic Films, 2003). For example, increasing the density will increase the yield strength. This theory is consistent with the results obtained in the present study and depicted in Figures 4 and 5. In general, the yield strength values were higher for the aged geomembranes (GM-exp) than the reference values. Similar results were reported by Rowe et al. (2009) for a geomembrane exposed in air, at different temperatures, during 115 months. According to these authors, the increase in yield strength can be attributed to the physical ageing deriving from the increase in crystallinity.

Results obtained in this work differ from the results obtained by Rowe and Ewais (2015) who reported a slight decrease in the mechanical properties of an exposed geomembrane in the field, in a warm-hot climate, for 16 years. According to these authors, such decrease may arise from a number of factors including changes in the morphological structure of the geomembrane and photo and thermal oxidation, as well as scratches-cracks induced during the installation and/or operation. Differences between the results obtained in this study and the results obtained by Rowe and Ewais (2015) might be related with the differences in prevailing climatic conditions during exposure.

For the melt flow index (Figure 6), results obtained for exposed geomembranes (GM-exp), are higher than the reference values for GM-A and GM-B and less than the reference values for GM-C, GM-D and GM-E.

The melt flow index is inversely related to the polymer's molecular weight. As the molecular weight decreases, the melt flow index increases, and vice versa. Since the strength characteristics of polymers are related to the molecular weight, then melt flow index can be used as an indicator of polymer strength. With the increase in melt flow index, the tensile strength is expected to decrease (Handbook of Plastic Films, 2003).

Results obtained for GM-A and GM-B differ from what was expected beforehand, since both the tensile strength and the melt flow index have increased. These results are similar to the results obtained by Lodi et al. (2007). The reason for this unexpected behavior has not yet been fully understand. It seems that further research on this topic is needed before some general trends can be established.

For the carbon black content (Figure 7), as the initial values of the original material at the time of sample preparation were not available, the reference values were based on the data sheet, corresponding thus to a range between 2 and 3%, which makes it rather difficult to do comparisons. Hence, the results can be considered as inconclusive.

For the oxidative induction time, comparisons are only possible for GM-D and GM-E (Bigorne and Viana do Castelo) since for the remaining samples the initial values were not available. As can be seen in Figure 8, the OIT values were less for the aged geomembranes (GM-exp) than the reference values, suggesting that consumption of antioxidants occurred due to sample exposure to climatic conditions. This seems to give supporting evidence that climatic conditions have had an impact on geomembranes exposed for 12 years in Portugal.

Taking into account the chemical degradation model suggested by Hsuan and Koerner (1998), which relates the oxidation with the degradation, it can be assumed that the exposed geomembranes have had some degradation. According to these authors, the chemical degradation can be divided into three distinct stages: Stage I, depletion time of antioxidants; Stage II, induction time to onset of polymer degradation; and Stage III, degradation of the polymer to decrease some property or properties to an arbitrary level (e.g., to 50% of the original value). Thus, results obtained suggest that the exposed geomembranes still remain in Stage I of degradation, corresponding to the depletion time of antioxidants.

3.2 *Comparison with GRI-GM 13 Specification*

Figures 9 to 13 show the comparison between the results obtained for the samples exposed to climatic conditions (GM-exp) with the minimum requirements recommended by the GRI - GM13 (2016). This has made it possible to observe that, after 12 years of exposure, they still meet those requirements in terms of density, tensile strength at yield, strain at yield, carbon black content and induction time to oxidation. Again, values obtained experimentally contain the uncertainty bars corresponding to the standard deviation.

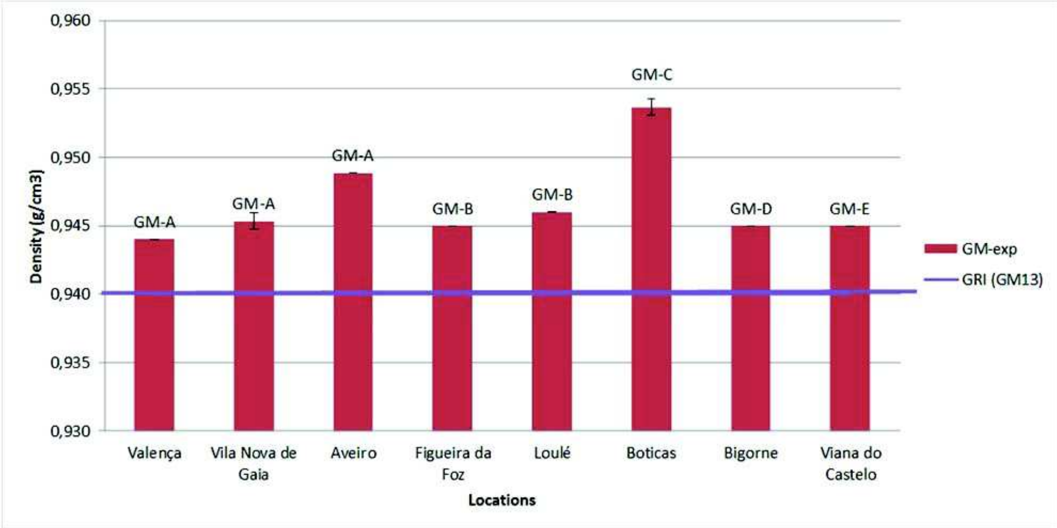

Figure 9: Comparison of the density of GM-exp with GRI-GM13

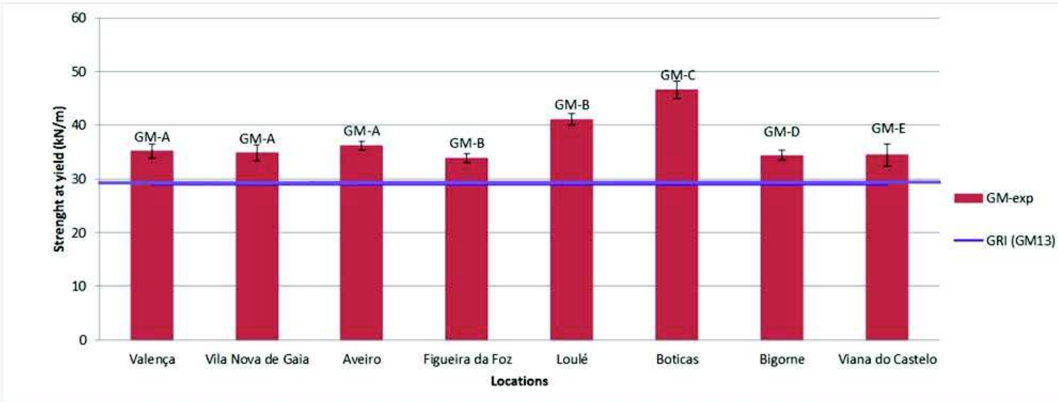

Figure 10: Comparison of the strength at yield of GM-exp with GRI-GM13

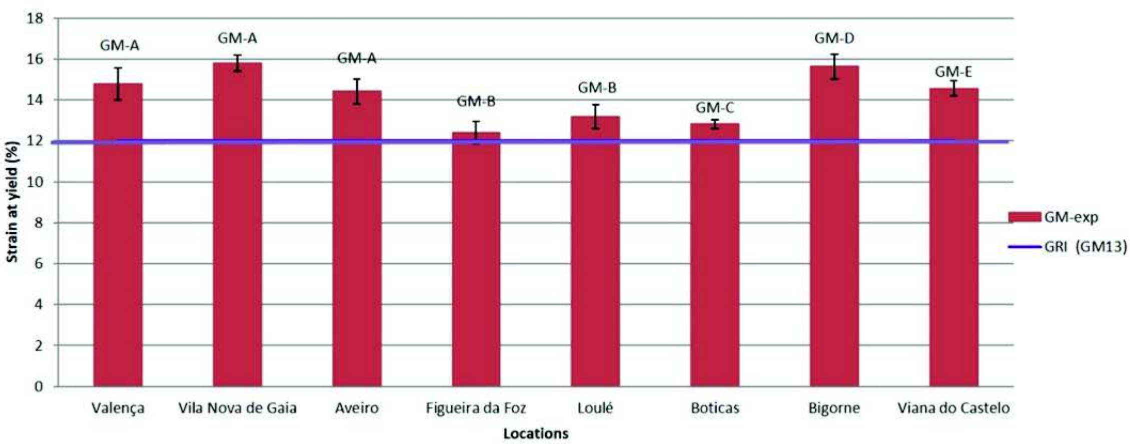

Figure 11: Comparison of the strain at yield of GM-exp with GRI-GM13

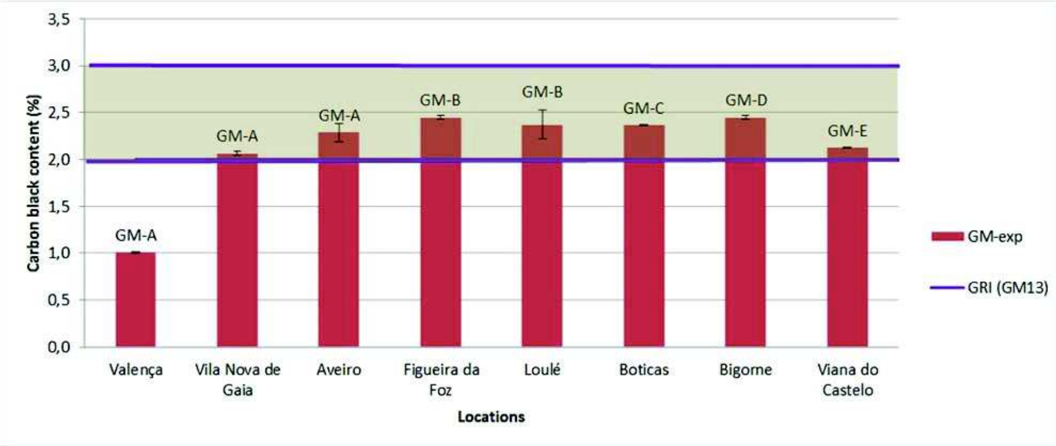

Figure 12: Comparison of the carbon black content of GM-exp with GRI-GM13

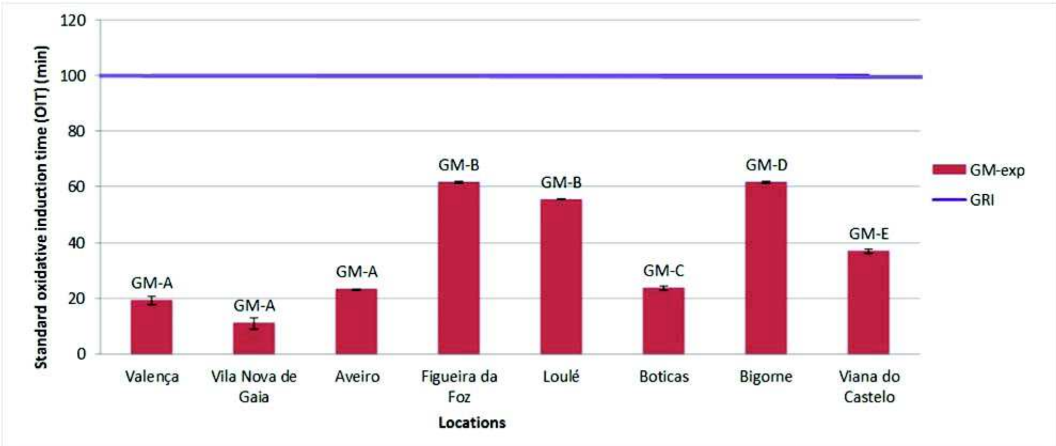

Figure 13: Comparison of the standard oxidative induction time of GM-exp with GRI-GM13

For density (Figure 9), tensile strength at yield (Figure 10) and strain at yield (Figure 11), exposed geomembranes at eight different sites in Portugal, for 12 years, still met the minimum requirements established by GRI-GM13.

For carbon black content (Figure 12), aged geomembranes also met the minimum requirements recommended by GRI - GM13, except for the sample exposed in Valencia.
For the oxidative induction time (Figure 13), none of the exhumed geomembrane samples met the minimum requirements indicated by GRI-GM13, although there was no total depletion of antioxidants.

4 CONCLUSIONS

This paper has addressed the experimental work performed on the degradation that occurred in the properties of exposed HDPE installed at eight different locations for 12 years. Another goal of this work was to compare the properties of exposed geomembranes with the minimum requirements currently recommended by the Geosynthetic Research Institute (GRI-GM13), in order to verify if they still met those requirements.

The results have shown that the properties of the geomembranes exposed to climatic conditions presented some degradation, especially in terms of oxidative induction time and density. Also, they have indicated that the exposed geomembranes for 12 years met the minimum requirements established by GRI-GM13, except for the oxidative induction time.

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