Natural weathering of geosynthetics in Portugal

Vieillissement des géosynthétiques sous l`action des conditions atmosphériques au Portugal

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ABSTRACT

This paper reports research about the resistance of geosynthetics against weathering. Several geotextiles, geonets and geomembranes were exposed to natural weathering conditions in Portugal. The degradation suffered by the geosynthetics was evaluated by tensile tests and by scanning electron microscopy.

RÉSUMÉ

Cet article évalue la résistance des géosynthétiques contre l`action des agents climatériques. Plusieurs géotextiles, geonets et géomembranes ont été exposés à des conditions atmosphériques au Portugal. La dégradation subie par les géosynthétiques a été évaluée par des tests de traction-extension et par microscopie électronique à balayage.

Keywords : geosynthetics, durability, weathering, solar radiation

1 INTRODUCTION

Geosynthetics (GSs) are polymeric materials widely applied in civil engineering structures (such as: landfills, roads, railways, dams, reservoirs or tunnels). In those applications, the GSs can be exposed to several degradation agents, such as: ultraviolet (UV) radiation and other weathering agents, high temperatures, atmospheric oxygen, acids, alkalis or microorganisms. An extended exposure to such degradation agents may affect the durability of the GSs, shortening their useful lifetime. As GSs must maintain minimum required values of certain properties during a long period of time, it is very important to evaluate their resistance against those damaging agents.

Weathering is the overall action of many environmental factors (such as: sunlight, heat, oxygen, moisture, rain, wind, dust or chemical pollutants) in altering the properties of exposed objects. Among all the weathering agents, sunlight (mainly due to the UV radiation) is considered the most damaging one for many polymeric materials. The UV region of the solar spectrum is highly energetic and can induce the formation of highly reactive free-radicals. In the presence of oxygen, these free-radicals can attack the polymeric chains of the GSs, in a process called photo-oxidation. This degradation process is usually accelerated by high temperatures and by the existence of high moisture contents on the materials.

The occurrence of photo-degradation can be easily inhibited by avoiding the exposition of the GSs to sunlight. However, the elimination of all exposition to sunlight is almost impossible in many applications. Furthermore, in some cases, the GSs can be exposed to sunlight during long periods of time (months or even years). In order to retard and/or inhibit the photo-degradation process of the GSs, chemical additives (such as: UV stabilisers, antioxidants and pigments) are often added to the composition of these materials.

The weathering resistance of the GSs can be evaluated by laboratorial tests or by exposing the materials to real conditions. The natural weathering tests are usually very long (normally several months or years), being unsuitable when fast-results are needed. Therefore, laboratory weatherometers are often used to try to reproduce, in a short period of time (a few days or weeks), the damage suffered by the GSs when exposed outdoors for a long period of time. However, there are some factors (such as: wind, dirt or chemical pollutants) that are not easy to reproduce in laboratory. So, the exposition to real weathering conditions will always give more reliable results about the durability of the GSs than any laboratorial simulation.

2 EXPERIMENTAL DESCRIPTION

2.1 *Geosynthetics*

In this work, 3 geotextiles (GTXs), 2 geonets (GNTs) and 2 geomembranes (GMBs) were exposed to natural weathering during an extended period of time. The composition of the GSs was fully known for the 3 GTXs (A, B and C) and for both GNTs (D and E): these materials were specially produced with different compositions for research purposes.

Polypropylene (PP) fibres (8 denier, 75 mm long) with different compositions were specially manufactured to produce 3 needle punched nonwoven GTXs (with a mass per unit area of 280 $g.m^{-2}$). GTX A had no chemical additives, while GTXs B and C were stabilised with 0.2% (*w/w*) of Chimassorb 944 (C944). Besides C944, GTX C had also 1.08% (*w/w*) of carbon black. The only difference between the GTXs A, B and C was the degree of stabilisation.

Woven GNTs (with a mass per unit area of 85 $g.m^{-2}$) were produced from high-density polyethylene (HDPE) with different chemical compositions. GNT D had no chemical additives, while GNT E was stabilised with 0.22% (*w/w*) of Tinuvin 783 (T783). The only difference between the GNTs D and E was the presence or not of the additive T783.

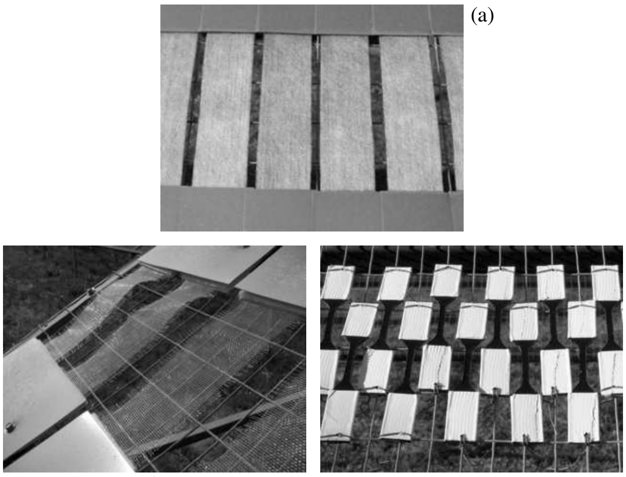
Both GMBs were produced from HDPE and were properly stabilised against UV radiation. However, the type and amount of the added stabilisers were unknown, because these were materials commercially available in the market and it is always difficult to receive to this information, often confidential, from the producers. The GMBs F and G could be distinguished by their thickness (1.5mm and 2.0 mm, respectively) and by their surface (GMB F had a textured surface, while GMB G had a smooth surface).

Proceedings of the 17th International Conference on Soil Mechanics and Geotechnical Engineering
M. Hamza et al. (Eds.)

doi:10.3233/978-1-60750-031-5-901

2.2 *Natural weathering tests*

The natural weathering tests were carried out in Portugal. The exposure site was located at latitude 41º13`N and longitude 8º39`w, with an elevation of 49 m above sea level. The samples were mounted on exposure racks, facing south with a 30º angle inclination (Figure 1).



(a) (b) (c)

Figure 1. Geosynthetic samples exposed to natural weathering: (a) geotextiles; (b) geonets; (c) geomembranes.

The GTXs were exposed to natural weathering up to 24 months, while the GNTs were exposed up to 18 months; the GMBs were exposed during a maximum period of 12 months. Test-samples were removed regularly (every 3 months for the GMBs and every 6 months for the GTXs and for the GNTs) for characterisation. The solar radiation, air temperature, rainfall, relative humidity and wind velocity were continuously registered during exposition (data not shown).

2.3 *Tensile tests*

The mechanical properties of the exposed GSs were determined according to EN 29073-3 (for GTXs), EN ISO 13934-1 (for GNTs) and ASTM D638 (for GMBs) (Table 1).

Table 1. Experimental conditions used on the tensile tests.

Tensile test	EN 29073-3 EN ISO 13934-1	ASTM D638
Specimen width	50 mm	6 mm*
Specimen length**	200 mm	64 mm
Number of specimens	5	5
Test speed	100 mm.min^{-1}	50 mm.min^{-1}

(*measured at the centre of the specimen; **between grips)

The tensile tests were performed in a tensile machine from Lloyd Instruments (model LR 50K) equipped with a load cell of 5 kN. The GTXs and the GNTs were tested using specimens with 200 mm in length (between grips) and 50 mm wide; the GMB test-specimens had a dumbbell-shape form. A minimum of 5 specimens of each GS were tested (all specimens tested in the machine direction of production).

The degradation suffered by the GSs during the natural weathering tests was evaluated by comparing the results obtained for the weathered samples with the results obtained for the reference samples (without any degradation). The tensile strength (TS) and the elongation at maximum load (E_{ML}) were the mechanical parameters used to evaluate the damage suffered by the GTXs and the GNTs. Some results are expressed in terms of percentage of retained strength (RS) (obtained by dividing the tensile strength of the weathered samples by the tensile strength of the reference samples.

The degradation suffered by the GMBs was evaluated by comparing the following parameters between exposed and unexposed samples: tensile strength at yield (TS_{YIELD}), tensile strength at break (TS_{BREAK}), elongation at yield (E_{YIELD}) and modulus of elasticity (ME).

3 RESULTS AND DISCUSSION

3.1 *Polypropylene geotextiles*

GTXs A and B (originally white) acquired a greyish coloration during the exposition to weathering, due to the accumulation of dust and filth between their fibres; the colour of GTX C (black) remained unchanged during the 24 months of exposition to natural weathering.

The GTXs had no visible signs of degradation after the first 6 months of exposition. By the 12-month, some degradation was noticed on GTX A (release of depolymerised PP fibres, which caused a considerable decrease on the thickness of this GTX). The degradation suffered by GTX A was much more pronounced after 18 months of exposition (some test-samples were almost destructed). After 24 months of exposition, GTX A was completely destructed. Table 2 shows the evolution of the TS, E_{ML} and RS of GTX A during the natural weathering test.

Table 2. Mechanical properties of GTX A before and after the natural weathering tests.

Exposition time (months)	TS (kN.m^{-1})	E_{ML} (%)	RS (%)
0	13.4 (13.6%)	76.1 (8.4%)	-
6	9.1 (20.1%)	45.0 (5.6%)	67.9
12	0.9 (26.9%)	22.1 (10.9%)	6.7
18	0.1 (37.3%)	2.6 (45.7%)	0.7
24	0	-	0

(in brackets are the obtained coefficients of variation)

The UV-stabilised GTXs (B and C) had no visible signs of degradation during the 24 months of natural weathering, which readily showed the importance of the additives on the protection of the PP fibres against degradation. However, the tensile tests showed a decrease on the TS and E_{ML} of these GTXs (Table 3 and Table 4).

Table 3. Mechanical properties of GTX B before and after the natural weathering tests.

Exposition time (months)	TS (kN.m^{-1})	E_{ML} (%)	RS (%)
0	13.5 (12.3%)	78.4 (6.6%)	-
6	10.3 (23.7%)	46.8 (3.7%)	76.3
12	7.4 (14.0%)	41.6 (5.7%)	54.8
18	6.0 (13.6%)	43.0 (5.6%)	44.4
24	3.8 (15.2%)	37.2 (7.6%)	28.1

(in brackets are the obtained coefficients of variation)

Table 4. Mechanical properties of GTX C before and after the natural weathering tests.

Exposition time (months)	TS (kN.m^{-1})	E_{ML} (%)	RS (%)
0	15.3 (10.1%)	54.6 (8.3%)	-
6	16.8 (5.8%)	44.6 (9.6%)	109.8
12	13.9 (7.2%)	36.0 (6.8%)	90.8
18	12.1 (12.0%)	34.8 (4.2%)	79.1
24	11.1 (14.9%)	33.0 (2.4%)	72.5

(in brackets are the obtained coefficients of variation)

The TS of GTX B decreased during the natural weathering tests as the exposition time increased (the E_{ML} presented a similar behaviour). After 18 test-months, GTX B had a RS of 44.4% (after the same exposition time, GTX A was almost destructed – RS of 0.7%). The incorporation of C944 on the PP fibres did not avoid the degradation promoted by weathering, but retarded it significantly. Figure 2 illustrates the mean curves tensile strength-elongation obtained for GTX B before and after the exposition to natural weathering.

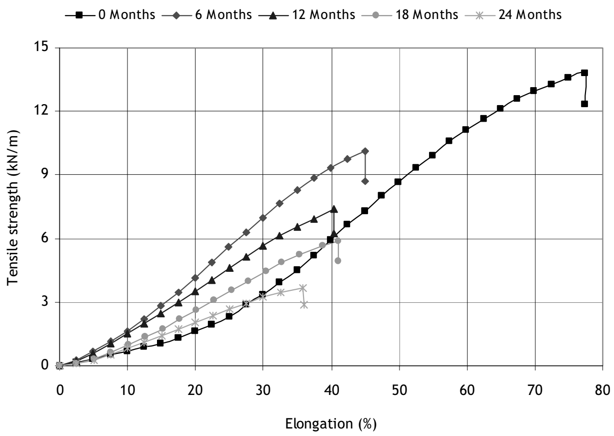


Figure 2. Mean curves tensile strength-elongation obtained for GTX B before and after natural weathering.

The TS of GTX C also decreased during the exposition to natural weathering. However, this decrease was less pronounced than the decrease observed for GTX B. Indeed, after 24 months, GTX C still had a RS of 72.5%, while GTX B had only 28.1% of its original strength. An extra protection against weathering was achieved by adding a small quantity of carbon black (1.08%) to the PP fibres. Figure 3 compares the evolution of the RS of the GTXs A, B and C during the weathering tests.

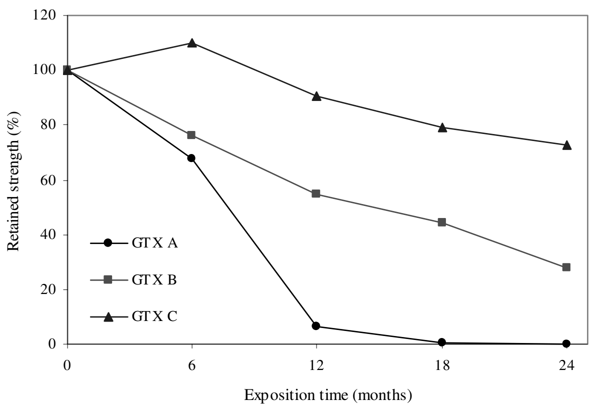


Figure 3. Evolution of the retained strength of the GTXs A, B and C during the natural weathering tests.

Scanning electron microscopy (SEM) analysis showed the degradation occurred on the PP fibres during the exposition to natural weathering. Some SEM photographs obtained for the GTXs are illustrated in Figure 4.

The unstabilised PP fibres were highly damaged after 12 months of natural weathering; the fibres disposed vertically (Figure 4a) (orientated up, perpendicular to the plane of the GTX) were all broken and the fibres disposed horizontally (Figure 4b) (on the same plane of the material) presented visible signs of degradation (such as transversal fissures).

After 12 months of exposition, the stabilised PP fibres were not as damaged as the unstabilised ones (no broken fibres, only a few fibres presented some fissures). With the increase of the exposition time, more damages were found on the stabilised PP fibres. By the 24-month of exposition, transversal fissures were easily found on the stabilised PP fibres (Figure 4c and 4d).The fibres that had C944 and carbon black were less damaged than the fibres stabilised only with C944, which is in agreement with the previous tensile results.

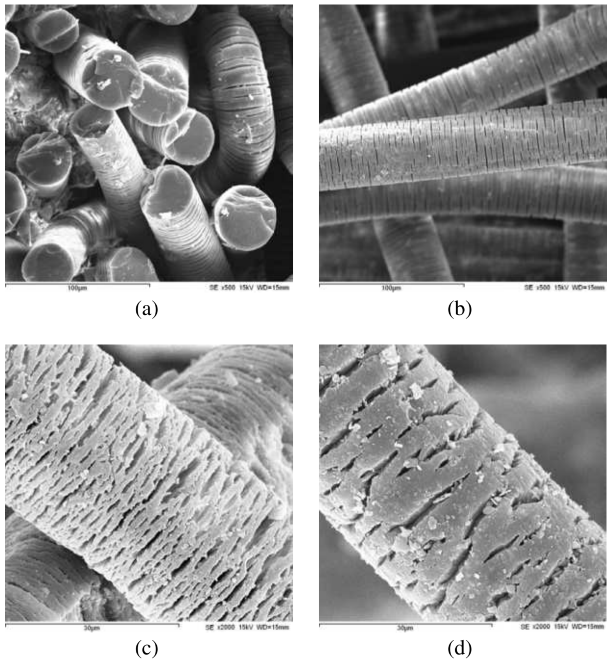


Figure 4. SEM photographs of the GTXs after exposition to natural weathering: (a) and (b) GTX A after 12 months (x500); (c) GTX B after 24 months (x2000); (d) GTX C after 24 months (x2000).

3.2 *Polyethylene geonets*

The HDPE GNTs had no visible signs of degradation after the 18 months of exposition to natural weathering. The evolution of the TS, E_{ML} and RS of the GNTs D and E are summarized in Table 5 and in Table 6, respectively.

Table 5. Mechanical properties of GNT D before and after the natural weathering tests.

Exposition time (months)	TS ($kN.m^{-1}$)	E_{ML} (%)	RS (%)
0	12.4 (2.6%)	20.5 (10.3%)	-
6	11.8 (1.3%)	21.2 (9.5%)	95.2
12	10.7 (1.4%)	20.6 (7.5%)	86.3
18	12.8 (3.0%)	21.7 (7.4%)	103.2

(in brackets are the obtained coefficients of variation)

Table 6. Mechanical properties of GNT E before and after the natural weathering tests.

Exposition time (months)	TS ($kN.m^{-1}$)	E_{ML} (%)	RS (%)
0	13.3 (2.5%)	22.4 (7.1%)	-
6	13.1 (1.0%)	24.3 (9.4%)	98.5
12	12.0 (3.3%)	30.6 (24.4%)	90.2
18	14.3 (2.9%)	22.0 (7.6%)	107.5

(in brackets are the obtained coefficients of variation)

The TS of both GNTs had a slight decrease after 6 and 12 months of exposition (after 12 months, RS of 86.3% for GNT D and RS of 90.2% for GNT E). However, after 18 months, the TS of the GNTs were higher than its original value. SEM analysis showed the inexistence of damages on the GNTs.

The HDPE GNTs had a good resistance against weathering, independently of being stabilised or not with T783. The contribution of T783 for the resistance of the GNTs against weathering may be elucidated by exposing the materials during higher periods of time.

3.3 *Polyethylene geomembranes*

The HDPE GMBs had no visible damages during the 12-month exposition to natural weathering. The mechanical parameters determined for the GMBs, before and after the weathering tests, are summarized in Table 7 (for GMB F) and in Table 8 (for GMB G).

Table 7. Mechanical properties of GMB F before and after the natural weathering tests.

Exposition time (months)	TS_{YIELD} (MPa)	TS_{BREAK} (MPa)	E_{YIELD} (%)	ME (MPa)
0	21.1 (1.7%)	21.2 (9.4%)	21.0 (2.5%)	190.6 (3.6%)
3	20.8 (1.9%)	22.2 (6.1%)	22.2 (4.1%)	162.6 (3.8%)
6	20.3 (2.0%)	20.5 (8.2%)	21.9 (4.9%)	166.6 (5.3%)
9	19.3 (1.6%)	22.7 (5.8%)	22.1 (5.5%)	155.1 (6.1%)
12	20.6 (1.1%)	21.6 (11.8%)	20.7 (4.7%)	183.9 (4.3%)

(in brackets are the obtained coefficients of variation)

Table 8. Mechanical properties of GMB G before and after the natural weathering tests.

Exposition time (months)	TS_{YIELD} (MPa)	TS_{BREAK} (MPa)	E_{YIELD} (%)	ME (MPa)
0	22.5 (1.5%)	18.2 (7.9%)	20.7 (5.2%)	224.6 (2.6%)
3	22.0 (1.5%)	17.8 (11.3%)	24.5 (1.4%)	165.6 (5.6%)
6	20.4 (1.1%)	17.4 (6.3%)	23.6 (3.8%)	151.2 (2.0%)
9	19.6 (1.6%)	17.5 (7.7%)	24.1 (2.6%)	147.0 (3.4%)
12	21.2 (0.5%)	17.9 (11.3%)	21.9 (3.0%)	178.6 (4.6%)

(in brackets are the obtained coefficients of variation)

The GMBs F and G exhibited a good resistance against the degradation caused by weathering. Indeed, after 12 months of exposition, the TS_{YIELD} of both GMBs suffered only a slight decrease and the TS_{BREAK} was almost unchanged; the E_{YIELD} suffered a slight increase after the weathering tests.

The ME of the GMBs decreased after the weathering tests, showing that the exposition to weather caused a decrease on the rigidity of the materials. The ME of the GMB G test-samples collected after 3, 6 and 9 months decreased continuously as the exposition time increased. However, an increase on the ME was observed for the test-samples analysed after 12 months. The ME of GMB F presented a similar evolution during the weathering tests. No explanations were found for this irregular behaviour of the ME of the GMBs.

SEM analysis showed the existence of lots of dust and filth on the surface of the GMBs. This accumulated dirt may retard the photo-degradation of the GMBs by impeding sunlight from reaching their surface. No microscopic damages were found on the GMBs.

4 CONCLUSIONS

The resistance of the PP GTXs was seriously affected by the exposition to weathering. Indeed, after 24 months of exposition, the unstabilised GTX was totally destructed. The TS and E_{ML} of the stabilised GTXs (B and C) suffered a considerable decrease during the weathering tests; this decrease was more pronounced for the GTX without carbon black (GTX B).

The degradation promoted by weathering was retarded by the incorporation of C944 on the PP fibres. The addition of carbon black to the PP fibres resulted in an extra protection against weathering. This shows that the service lifetime of PP GTXs can be easily extended by adding chemical additives, such as C944 or carbon black, to their composition.

The HDPE GNTs presented a good resistance against natural weathering. Even the unstabilised GNT had a RS of about 100% after 18 months of exposition. This way, it was not possible to evaluate the importance of the additive T783 in extending the lifetime of the GNTs. The protective effect of T783 may become noticeable by exposing the GNTs to natural weathering during higher periods of time.

The HDPE GMBs also presented a good resistance against natural weathering. Nevertheless, a decrease on the rigidity was observed for both GMBs.

ACKNOWLEDGEMENTS

The authors would like to thank Carvalhos Lda. (Lousã, Portugal) and Guerner & Irmãos, S.A. (Vila Nova de Gaia, Portugal) for producing, respectively, the geotextiles and the geonets studied in this work. The authors would also like to thank Lipor II (Maia, Portugal) for giving the place for exposing the geosynthetics to natural weathering.

This paper reports research developed under financial support provided by “FCT – Fundação para a Ciência e a Tecnologia”, Portugal (Project PTDC/ECM/67547/2006).

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