Natural and artificial weathering of polyethylene geonets

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ABSTRACT: The lifetime of the geosynthetics can be shortened by an extended exposition to weathering. So, it is important to evaluate the resistance of these materials against weathering. In this paper, three high density polyethylene geonets (with different chemical compositions) were exposed to weathering, both under natural and accelerated conditions. The natural weathering tests were carried out in Portugal (24 months of maximum exposure), while the artificial weathering tests were performed in a laboratory weatherometer (4000 hours of maximum exposure). The results obtained for the geonets weathered outdoors were compared with the results obtained for the geonets weathered in laboratory.

1 INTRODUCTION

During their lifetime, the geosynthetics (GSs) can be exposed to several degradation agents, such as: high temperatures, ultraviolet (UV) radiation and other weathering agents, oxygen and chemical substances like acids or alkalis. An extended exposition to these agents may have a negative impact on the durability of the GSs and, consequently, on their performance during time.

The GSs exposed outdoors are permanently subjected to the action of many weathering agents, such as: sunlight, heat, oxygen, moisture, rain, wind, dust or chemical pollutants. Exposition to sunlight (mainly due to the UV radiation) is one of the main causes for the premature failure of many polymeric materials, including the GSs.

The UV portion of the solar spectrum (from 295 nm to 400 nm) is very energetic and can promote the formation of highly reactive free-radicals, which can break down the chemical bonds within the polymeric structure of the GSs. In the presence of oxygen, this light-initiated process is called photo-oxidation.

In the majority of the situations, the GSs are only exposed to weathering during a short period of time (during the installation phase), being subsequently protected by a layer of soil or liquids. However, in some applications, the GSs can be total or partially exposed to weathering during higher periods of time.

In order to counteract the damaging effects of the weather (and extend the service lifetime of the GSs in outdoor applications), chemical additives (such as antioxidants, UV stabilisers and pigments) are often added to the composition of the materials.

The resistance of the GSs against weathering can be evaluated by accelerated laboratorial tests or by real outdoor-exposure tests (Carneiro et al. 2006 and Carneiro et al. 2008). The natural weathering tests are normally very long (several months or even years), being inadequate for routine tests. Therefore, laboratory weatherometers are often used to try to reproduce, in a relatively short period of time (a few days or weeks), the damages suffered by the GSs in natural conditions. However, there are some factors (such as wind, dirt or chemical pollutants) that are almost irreproducible in laboratory. So, the natural weathering tests will always give more reliable data about the durability of the GSs than any laboratorial simulation.

2 EXPERIMENTAL DESCRIPTION

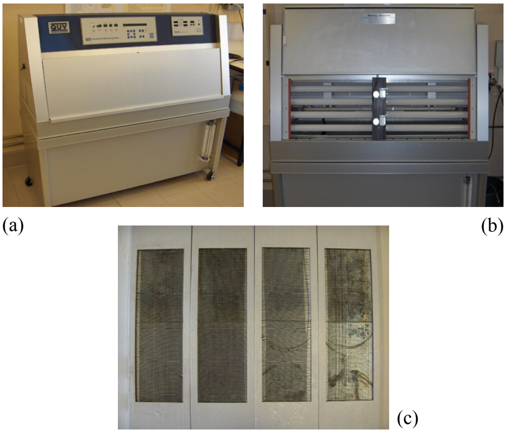
2.1 *Geonets*

Three geonets (GNTs) (85 $g.m^{-2}$) were specially produced from high density polyethylene (HDPE) filaments (linear mass of 540 denier, thickness of 2.8 mm) with different chemical compositions. GNT A had no chemical stabilisers, GNT B was stabilised with 0.22% (*w/w*) of Tinuvin 783 (T783) and GNT C had 1.05% of the pigment carbon black. The main difference between the GNTs A, B and C was the degree of stabilisation.

2.2 *Artificial weathering tests*

The GNTs were exposed to alternating cycles of UV radiation, rain and dew in a weatherometer (Q-Panel Lab Products, model QUV-spray). Fluorescent UV lamps (type UVA-340) were used to reproduce the UV radiation emitted by sunlight (UV step). Rain (flow of 5 $L.min^{-1}$) was simulated by a direct water spray against the GNTs (spray step). The water used in the spray step was treated microbiologically and purified by reverse osmosis followed by deionisation on ionic exchange columns.

In the condensation step, a water reservoir (filled with ordinary tap water) located on the bottom of the weatherometer) was heated to produce vapour, that condensates at the surface of the exposed GNTs. The weatherometer is illustrated in Figure 1.



(a) (b) (c)

Figure 1. Artificial weathering tests: (a) weatherometer closed; (b) weatherometer open – UV lamps; (c) specimen holders

The GNTs were exposed during 500, 1000, 2000 and 4000 hours to the following weathering cycle:

Step 1: UV exposure (60 ºC, 6 hours)
Step 2: Water spray (thermal shock, 10 minutes)
Step 3: Condensation (45 ºC, 2 hours)
(*Return to step 1*)

An UV irradiance of 0.68 $J.m^{-2}.s^{-1}$ at 340 nm was selected during the UV step. The total UV radiant exposure increased with the increase of the duration of the test (Table 1).

Table 1. Total radiant exposure during the UV step

Test time (hours)	Total radiant exposure (340 nm)	Total UV radiant exposure (290-400 nm)
500	0.90 $MJ.m^{-2}$	51.8 $MJ.m^{-2}$
1000	1.80 $MJ.m^{-2}$	103.7 $MJ.m^{-2}$
2000	3.60 $MJ.m^{-2}$	207.4 $MJ.m^{-2}$
4000	7.20 $MJ.m^{-2}$	414.7 $MJ.m^{-2}$

2.3 *Natural weathering tests*

The GNTs were exposed to natural weathering in Portugal (latitude of 41º13`N, longitude of 8º39`W, elevation of 49 m above sea level). The GNTs were placed in appropriate specimen holders facing south with an exposition angle of 30º (Figure 2).

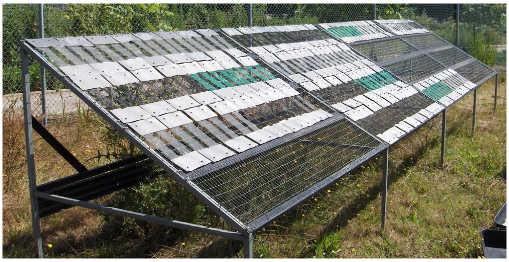


Figure 2. GNTs exposed to natural weathering

The GNTs were exposed to natural weathering during a maximum period of 24 months (from April 2007 till April 2009). Test-samples were removed regularly (every 6 months) for characterisation. The air temperature, solar radiation and rainfall were continuously registered during the 24-month outdoor exposition (Table 2).

Table 2. Weather parameters registered during the 24-month outdoor exposition of the GNTs

Exposition time (months)	Average air temperature (ºC)	Total solar radiation* ($MJ.m^{-2}$)	Total rainfall (mm)
6	22.0	3993	279
12	18.8	5948	725
18	19.7	9945	1127
24	18.3	11938	1725

*solar radiation measured between 300 and 3000 nm

2.4 *Tensile tests*

The mechanical properties (tensile strength – TS and elongation at maximum load – E_{ML}) of the exposed GNTs were determined (in the machine direction of production) according to EN ISO 13934-1 (Table 3).

Table 3. Experimental conditions used on the tensile tests

Specimen width	Specimen length*	Number of specimens**	Test speed
50 ± 0.5 mm	200 mm	5	100 $mm.min^{-1}$

*between grips; **minimum number

The degradation suffered by the GNTs during the weathering tests was evaluated by comparing the results obtained for the weathered samples with the results obtained for the reference samples (without degradation). Some results are expressed in terms of percentage of retained strength (RS) (obtained by dividing the tensile strength of the exposed samples by the tensile strength of the reference samples).

3 RESULTS AND DISCUSSION

3.1 *Artificial weathering tests*

The GNT A had no visible signs of degradation after 500 and 1000 hours of artificial weathering. On the contrary, after 2000 hours, high damages were found on GNT A: the test-samples were broken and could be easily transformed into small pieces (Figure 3).

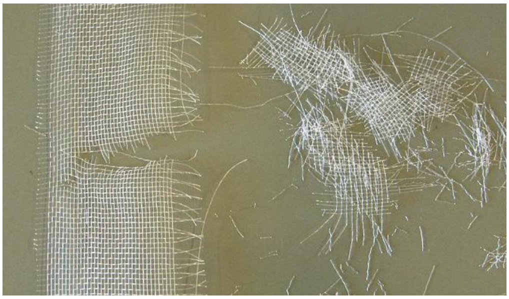


Figure 3. GNT A after 2000 hours of artificial weathering

The GNTs B and C had no visible damages after the artificial weathering tests, which early indicated the importance of the additive T783 and the pigment carbon black (respectively) on the protection of the materials against weathering. The results obtained in the tensile tests are summarized in Table 4 (TS) and in Table 5 (E_{ML}). Figure 4 shows the mean curves tensile-strength elongation obtained for GNT A.

Table 4. Tensile strength of the GNTs, before and after the artificial weathering tests

Exposition time (hours)	Tensile strength (kN.m^{-1})		
	GNT A	GNT B	GNT C
0	12.7 (2.6%)	13.3 (2.6%)	12.7 (2.2%)
500	11.4 (4.9%)	13.5 (2.2%)	12.8 (3.7%)
1000	5.0 (12%)	13.7 (1.4%)	13.0 (1.6%)
2000	0	11.8 (1.7%)	11.6 (3.3%)
4000	0	12.0 (2.4%)	11.5 (3.1%)

(in brackets are the obtained coefficients of variation)

Table 5. Elongation at maximum load of the GNTs, before and after the artificial weathering tests

Exposition time (hours)	Elongation at maximum load (%)		
	GNT A	GNT B	GNT C
0	21.4 (5.8%)	22.6 (7.5%)	22.6 (6.8%)
500	21.5 (7.2%)	23.8 (5.9%)	22.5 (6.0%)
1000	4.1 (14%)	24.0 (6.5%)	22.7 (2.3%)
2000	-	23.4 (1.7%)	23.7 (7.6%)
4000	-	24.7 (6.8%)	23.4 (1.2%)

(in brackets are the obtained coefficients of variation)

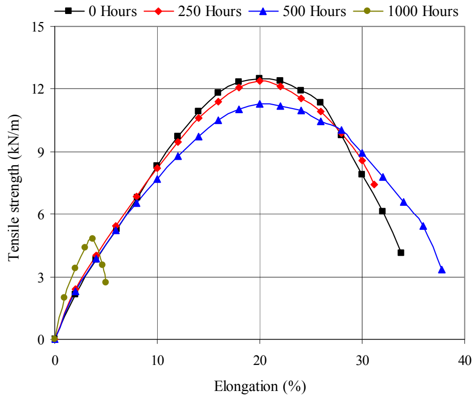


Figure 4. Mean curves tensile strength-elongation obtained for GNT A, before and after the artificial weathering tests.

The TS of GNT A decreased with the increase of the exposition time to artificial weathering; after 1000 hours, GNT A had a RS of 39.4% and an E_{ML} of 4.1% (original E_{ML} of 21.4%). GNT A had a RS of 0% after 2000 hours of artificial weathering.

The TS of the GNTs B and C remained practically unchanged after 500 and 1000 hours of exposition to artificial weathering. However, after 2000 and 4000 hours, a slight decrease occurred on the TS of both materials. Figure 5 compares the evolution of the RS of the GNTs during the artificial weathering tests.

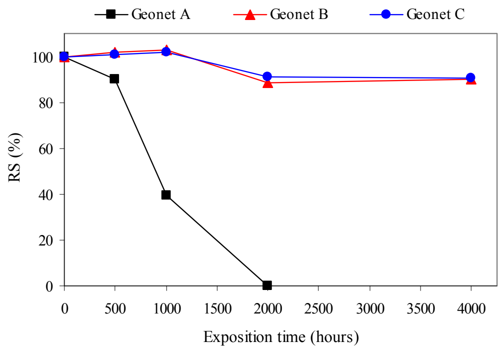


Figure 5. Evolution of the retained tensile strength of the GNTs during the artificial weathering tests.

The damages suffered by the HDPE GNTs during artificial weathering were significantly retarded by the presence of small quantities of T783 (in GNT B) and carbon black (in GNT C); in the absence of the additives, the GNTs would be completely destructed after 2000 hours of artificial weathering. This way, the artificial weathering tests distinguished, in terms of the weathering resistance, the stabilised GNTs (B and C) from the unstabilised one (A).

3.2 *Natural weathering tests*

The HDPE GNTs had no noticeable damages after 24 months of natural weathering. Indeed, even GNT A was undamaged (contrarily to what happened after 2000 hours of artificial weathering). The mechanical results (TS and EML) obtained for the GNTs, before and after the outdoor-exposure tests, are summarized in Tables 6 and 7.

Table 6. Tensile strength of the GNTs, before and after the natural weathering tests

Exposition time (months)	Tensile strength ($kN.m^{-1}$)		
	GNT A	GNT B	GNT C
0	12.7 (2.6%)	13.3 (2.6%)	12.7 (2.2%)
6	11.8 (1.3%)	13.1 (1.0%)	13.2 (1.8%)
12	10.7 (1.4%)	12.0 (3.3%)	11.3 (1.1%)
18	12.8 (3.0%)	14.3 (2.9%)	13.7 (1.7%)
24	12.0 (2.2%)	14.1 (0.8%)	13.7 (2.4%)

(in brackets are the obtained coefficients of variation)

Table 7. Elongation at maximum load of the GNTs, before and after the natural weathering tests

Exposition time (months)	Elongation at maximum load (%)		
	GNT A	GNT B	GNT C
0	21.4 (5.8%)	22.6 (7.5%)	22.6 (6.8%)
6	21.2 (9.5%)	24.3 (9.4%)	24.6 (9.3%)
12	20.6 (7.5%)	30.6 (24%)	22.1 (3.2%)
18	21.7 (7.4%)	22.0 (7.6%)	22.4 (5.4%)
24	21.2 (9.2%)	20.2 (8.0%)	23.4 (7.0%)

(in brackets are the obtained coefficients of variation)

The TS and E_{ML} of GNT A had no major changes after the exposition to natural weathering (exception after 12 months). In fact, after 24 months, the GNT A had a RS of 94.5% and an E_{ML} of 21.2% (original E_{ML} of 21.4%). So, 1000 hours in the weatherometer caused more damages to GNT A than 24 months of natural weathering.

Similarly to what happened to GNT A, the TS and E_{ML} of the GNTs B and C had also no major changes after the natural weathering tests (exceptions after 12 months). Indeed, after 24 months, both GNTs had a RS higher than 100%.

The three GNTs had an identical behaviour during the natural weathering tests. So, and contrarily to the artificial weathering tests, the 24 months of natural weathering were unable to distinguish the stabilised GNTs from the unstabilised one.

The GNTs may be differentiated by increasing the exposition time to natural weathering. In this case, it is predictable an earlier degradation of GNT A when compared to GNTs B and C (as happened during the artificial weathering tests).

The (predictable) higher resistance of the GNTs B and C against natural weathering can be ascribed to the protective effect of T783 (in GNT B) and carbon black (in GNT C).

4 CONCLUSIONS

The damages suffered by the HDPE GNTs during artificial weathering were considerably retarded by the presence of T783 (in GNT B) and carbon black (in GNT C). Indeed, after 4000 hours of exposition, the GNTs B and C had only minor damages (a slight decrease on the TS); the GNT A (unstabilised) was completely destructed after 2000 hours of artificial weathering.

The HDPE GNTs had a good resistance against natural weathering, independently of being stabilised or not with T783 (in GNT B) and with carbon black (in GNT C). This way, and contrarily to the artificial weathering tests, the outdoor tests were incapable of distinguishing, in terms of weathering resistance, the stabilised GNTs from the unstabilised one.

The GNT A was more damaged after 1000 hours (about 42 days) of artificial weathering than after 24 months of natural weathering (degradation occurred much faster in the laboratory weatherometer). This way, and since the resistance of the stabilised GNTs against artificial weathering was much higher than the resistance of the unstabilised one, the stabilised GNTs will certainly present a very good weathering resistance when exposed outdoors during periods of time higher than 24 months.

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