Effect of natural weathering on the water permeability behaviour of nonwoven polypropylene geotextiles

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ABSTRACT: A long exposition to weathering (mainly due to the ultraviolet radiation) may cause undesirable changes on the physical, chemical, mechanical and hydraulic properties of the geotextiles. In this paper, three nonwoven needle-punched polypropylene geotextiles (stabilised with different amounts of Chimassorb 944) were exposed to natural weathering in Portugal during 24 months. The hydraulic properties of the geotextiles (water permeability normal to the plane) were monitored during the 24 months of natural weathering.

1 INTRODUCTION

In their applications, the geotextiles (GTXs) can be exposed to several degradation agents (such as: solar radiation and other weathering agents, atmospheric oxygen, high temperatures or chemical species like acids or alkalis) that may affect their durability and, consequently, their performance during time.

Outdoors, the GTXs can be in permanent contact with many weathering agents: sunlight, atmospheric oxygen, temperature changes, rain, moisture, wind, dirt or chemical pollutants. Among all these agents, the ultraviolet radiation from sunlight is considered the most damaging one for the polymeric materials exposed outdoors. The ultraviolet radiation is highly energetic and, in the presence of oxygen, can induce the formation of highly-reactive free-radicals; these radicals can attack the polymeric chains of the GTXs in a process called photo-oxidation. The degradation caused by the ultraviolet radiation (and by the other weathering agents) is often retarded and/or inhibited by adding chemical stabilisers (such as, antioxidants, UV stabilisers and pigments) to the GTXs.

However, even the stabilised GTXs are not fully protected against weathering and several unwanted changes often occur on the properties of the exposed materials. This work studies the effect of weathering on the hydraulic properties of nonwoven GTXs.

The hydraulic properties determine the ability for the GTXs act as filters or drains: these properties are highly influenced by the structure-type of the GTXs, by their thickness and by the size and distribution of their pores.

2 EXPERIMENTAL DESCRIPTION

2.1 *Geotextiles*

Polypropylene (PP) fibres (8 denier, 75 mm long) stabilised with different amounts of Chimassorb 944, 0%, 0.2% and 0.4% (*w/w*), were used to produce 3 needle-punched nonwoven GTXs (G0, G2 and G4): G0 had no C944, G2 had 0.2% of C944 and G4 was stabilised with 0.4% of C944.

The GTXs had a mass per unit area of 500 $g.m^{-2}$, a thickness of about 3.8-4.0 mm and a tensile strength (EN ISO 10319) of about 26 kN.

2.2 *Natural weathering tests*

The GTXs were exposed to natural weathering in Portugal (latitude 41º13`N, longitude 8º39`W, 49 m above sea level). The test-specimens were installed on exposure racks facing south with a 30º inclination angle (Figure 1).

Figure 1. GTXs exposed to natural weathering

The GTXs were exposed to natural weathering up to 24 months (from November 2004 till November 2006). The test-specimens were collected after 6, 12, 18, 21 (only for GTX G0) and 24 months of natural weathering for physical, chemical, mechanical and hydraulical characterisation (the results obtained on the physical and mechanical tests can be found in Carneiro et al. 2008). The air temperature, total solar radiation and rainfall were registered during the 24 months of exposition (Table 1).

Table 1. Weather parameters registered during the 24-month outdoor exposition of the GTXs

Exposition time (months)	Average air temperature (ºC)	Total solar radiation* ($MJ.m^{-2}$)	Total rainfall (mm)
6	14.0	2189	318
12	17.8	5612	574
18	16.7	6146	1121
24	17.6	9475	1580

*solar radiation measured between 300 and 3000 nm

2.3 *Water permeability tests*

The water permeability tests (determination of water permeability normal to the plane) were carried out according to EN ISO 11058. This standard specifies two test-methods for this purpose: the constant head method and the falling head method. In the constant head method (used in this work), the test-specimens are submitted to a unidirectional flow of water (flow normal to their plane) under several head losses (70, 56, 42, 28 and 14 mm).

The equipment (a prototype) used in the hydraulic tests was developed by our research team (Figure 2).

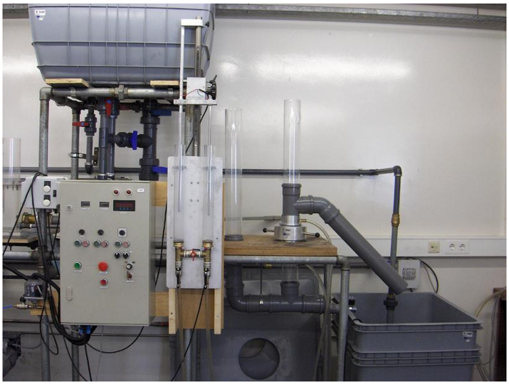

Figure 2. Equipment used in the hydraulic tests

The specimens used in the hydraulic tests (at least 5 specimens; circular shape) had a useful diameter (part exposed to the water flow) of 83.5 mm (value defined by the internal diameter of the equipment); this way, the specimens had an exposition area of 5476 mm^2. The water temperature was kept between 18 and 22 ºC.

The velocity index at 20 ºC (for any head loss *H*), ν_{20} (in $mm.s^{-1}$), can be determined by the following equation:

$$\nu_{20} = \frac{V \times R_T}{A \times t}$$

where, *V* is the water volume (in mm^3) collected during the period of time *t* (in s), *A* is the area of the specimen exposed to the water flow (in mm^2) and R_T is a correction factor for the water temperature.

The head loss *H* and the velocity index ν_{20} can be related by using the following quadratic equation:

$$H = a(\nu_{20}) + b(\nu_{20})^2$$

The plot of the head loss *H* against the velocity index ν_{20} was used to determine the velocity index for a head loss of 50 mm (ν_{20} *H*50) (the quadratic curves were adjusted in order to intercept the origin of the axes).

The results of the water permeability tests can also be expressed in terms of permittivity (Ψ). The Ψ (in s^{-1}) can be found by the dividing the velocity index ν_{20} by the head loss *H*. The permeability normal to the geotextiles (K_n, in $mm.s^{-1}$) can be determined by multiplying the Ψ by the thickness (in mm).

3 RESULTS AND DISCUSSION

3.1 *General analysis of the weathered geotextiles*

The colour of the GTXs changed from white to grey during the weathering tests due to the accumulation of dirt between their fibres.

The GTXs had no visible damages after 6 months of exposition. By the 12th test-month, some damages were visible on GTX G0 (release of depolymerised PP fibres with a consequent decrease on thickness and mass per unit area). The degradation suffered by GTX G0 increased as the exposition time increased. After 21 months, the GTX G0 was almost destructed (the total destruction of GTX G0 occurred between the 21st and the 24th month of natural weathering).

The GTXs G2 and G4 (stabilised with C944) had no visible damages after the 24 months of exposition (which showed that the weathering resistance of the PP fibres was highly enhanced by the presence of a small quantity of C944). The dirt accumulated in the structure of the GTXs G2 and G4 caused a "false" increase of their mass per unit area; the thickness of these GTXs only suffered minor changes during the 24 months of natural weathering (contrarily to what happened for the GTX G0) (Table 2).

Table 2. Thickness of the GTXs G0, G2 and G4 before and after natural weathering (EN ISO 9863-1)

Exposition time (months)	Thickness (mm)		
	GTX G0	GTX G2	GTX G4
0	3.81 (4.5%)	3.81 (2.8%)	3.97 (2.5%)
6	3.93 (1.8%)	3.91 (1.4%)	4.06 (2.1%)
12	2.83 (5.1%)	3.97 (1.6%)	4.17 (2.0%)
18	2.48 (4.7%)	3.70 (4.0%)	3.98 (1.8%)
21	1.93 (3.8%)	ND	ND
24	-	3.49 (1.7%)	4.01 (1.6%)

(in brackets are the obtained coefficients of variation); (ND – not determined)

3.2 *Hydraulic tests*

3.2.1 *Geotextile G0*

The hydraulic properties (ν_{20} and Ψ) of the GTX G0 suffered substantial changes during the 24 months of natural weathering (Figure 3 and Table 3).

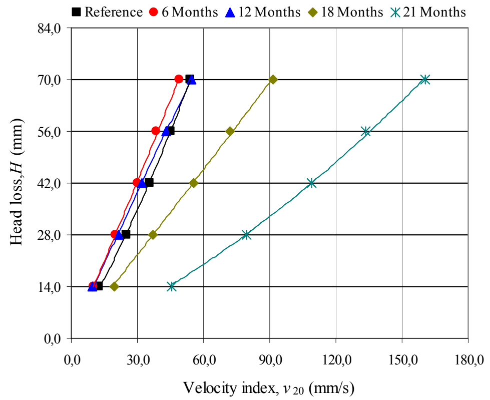

Figure 3. Plot of $H = f(\nu_{20})$ for geotextile G0, before and after the natural weathering tests (mean quadratic curves)

Table 3. ν_{20} *H*50 and Ψ *H*50 of GTX G0, before and after the natural weathering tests

Exposition time (months)	ν_{20} *H*50* (mm.s^{-1})	Ψ *H*50 (s^{-1})
0	40.9 (11%)	0.82 (11%)
6	35.1 (27%)	0.70 (27%)
12	38.2 (16%)	0.76 (16%)
18	65.3 (44%)	1.3 (44%)
21	125 (33%)	2.5 (33%)

*determined using the quadratic equation $H = a(\nu_{20}) + b(\nu_{20})^2$

(in brackets are the obtained coefficients of variation)

The ν_{20} *H*50 of the GTX G0 had no major changes during the first 12 months of natural weathering (ν_{20} *H*50 of 38.2 mm.s^{-1} after 12 test-months).

The increase of the exposition time caused a great increase of the ν_{20} *H*50 of the GTX G0. Indeed, after 21 test-months, the GTX G0 had a ν_{20} *H*50 of 125 mm.s^{-1} (after 18 months, ν_{20} *H*50 of 65.3 mm.s^{-1}).

This increase on the ν_{20} *H*50 (and on the Ψ *H*50) can be attributed to the massive degradation suffered by the GTX G0 during the natural weathering tests.

3.2.2 *Geotextile G2*

The ν_{20} and the Ψ of the GTX G2 decreased after the natural weathering tests (Figure 4 and Table 4). After 24 test-months, the ν_{20} *H*50 (18.5 mm.s^{-1}) of the GTX G2 was reduced to about half of its original value (39.7 mm.s^{-1}).

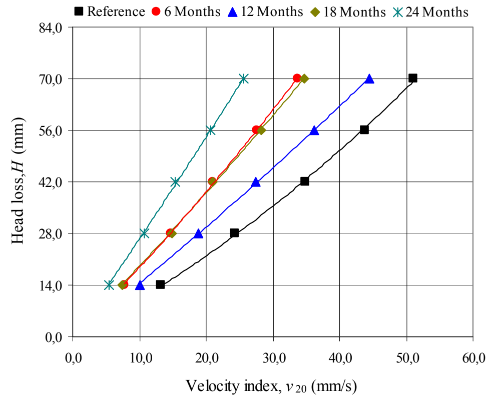

Figure 4. Plot of $H = f(\nu_{20})$ for geotextile G2, before and after the natural weathering tests (mean quadratic curves)

Table 4. ν_{20} *H*50 and Ψ *H*50 of GTX G2, before and after the natural weathering tests

Exposition time (months)	ν_{20} *H*50* (mm.s^{-1})	Ψ *H*50 (s^{-1})
0	39.7 (10%)	0.79 (10%)
6	24.9 (19%)	0.50 (19%)
12	33.0 (13%)	0.66 (13%)
18	25.6 (18%)	0.51 (18%)
24	18.5 (56%)	0.37 (56%)

*determined using the quadratic equation $H = a(\nu_{20}) + b(\nu_{20})^2$

(in brackets are the obtained coefficients of variation)

The decrease of the ν_{20} *H*50 and of the Ψ *H*50 can be ascribed to the dirt accumulated in the nonwoven structure of GTX G2. The dirt can fill up the inner empty spaces between the fibres, obstructing the water flow. Moreover, the thickness of the exposed specimens did not suffer a well-marked decrease (a substantial decrease in thickness would contribute for increasing the ν_{20} *H*50 and the Ψ *H*50).

3.2.3 *Geotextile G4*

Similarly to what happened for the GTX G2, the ν_{20} and the Ψ of the GTX G4 also decreased during the natural weathering tests (Figure 5 and Table 5). This decrease can also be imputed to the dirt accumulated in the nonwoven structure.

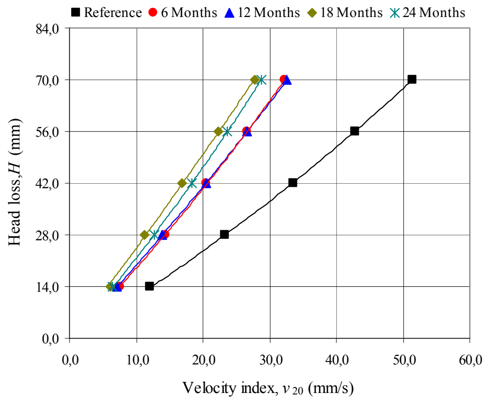

Figure 5. Plot of $H = f(v_{20})$ for geotextile G4, before and after the natural weathering tests (mean quadratic curves)

Table 5. v_{20} *H*50 and Ψ *H*50 of GTX G4, before and after the natural weathering tests

Exposition time (months)	v_{20} *H*50* ($mm.s^{-1}$)	Ψ *H*50 (s^{-1})
0	38.8 (12%)	0.78 (12%)
6	24.1 (15%)	0.48 (15%)
12	24.0 (11%)	0.48 (11%)
18	20.1 (27%)	0.40 (27%)
24	21.4 (11%)	0.43 (11%)

*determined using the quadratic equation $H = a(v_{20}) + b(v_{20})^2$

(in brackets are the obtained coefficients of variation)

3.2.4 *Comparison of the v_{20}* H50 *of the geotextiles*

The 24-month outdoor exposition caused significant changes on the v_{20} *H*50 of the nonwoven PP GTXs. However, the changes occurred on the GTXs G2 and G4 (stabilised with C944) differed significantly from the changes occurred on the GTX G0 (unstabilised) (Figure 6).

The damages occurred on the polymeric structure (loss of polymeric mass) of the GTX G0 during the exposition to natural weathering caused a significant increase on the v_{20} *H*50. The GTXs G2 and G4 had a higher weathering resistance (due to the presence of C944) than the GTX G0 and did not suffer a massive degradation. This way, the v_{20} *H*50 (and the Ψ *H*50) of these materials decreased due to the dirt clogged in their pores.

So, and in the lack of substantial damages (with a significant decrease on thickness and mass per unit area), the v_{20} (and the Ψ) of nonwovens exposed to weathering will almost certainly decrease (due to the unavoidable dirt).

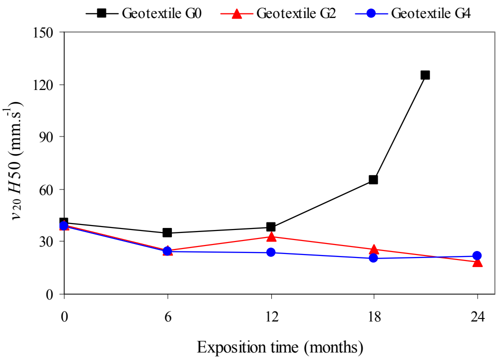

Figure 6. Evolution of the v_{20} *H*50 of the nonwoven GTXs (with different mounts of C944) during the natural weathering tests

4 CONCLUSIONS

The exposition to weathering can cause changes on the hydraulic properties of nonwoven GTXs. The v_{20} (and Ψ) of the GTX without C944 (G0) increased substantially during the natural weathering tests (due to the vast degradation of the polymeric structure of this material). On the contrary, the v_{20} (and Ψ) of the GTXs with C944 (G2 and G4) decreased during the natural weathering tests (due to the accumulation of dirt on the materials). The presence of C944 resulted in a much better resistance of the GTXs against the damaging effects of the weather.

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