

# Accelerated weathering of polypropylene geotextiles

José Ricardo Carneiro<sup>1,\*</sup>, Paulo Joaquim Almeida<sup>2</sup>  
and Maria de Lurdes Lopes<sup>1</sup>

<sup>1</sup>Department of Civil Engineering, Faculty of Engineering,  
University of Porto, Rua Dr. Roberto Frias, 4200-465 Porto,  
Portugal, e-mail: rcarneir@fe.up.pt

<sup>2</sup>Department of Chemistry and Biochemistry, Faculty of  
Sciences, University of Porto, Rua do Campo Alegre, 687,  
4169-007 Porto, Portugal

\*Corresponding author

## Abstract

This paper reports research about the durability of non-woven geotextiles when exposed to artificial weathering conditions [ultraviolet (UV) radiation, rain and dew] on a laboratory weatherometer. The geotextiles were specially manufactured from polypropylene fibers stabilized with different amounts of the additive Chimassorb 944 and the pigment carbon black. The degradation suffered by the geotextiles was evaluated by tensile tests and by scanning electron microscopy.

**Keywords:** carbon black; Chimassorb 944; geotextiles; polypropylene; weathering.

## 1. Introduction

Geosynthetics are polymeric materials widely applied in civil engineering structures (landfills, roads, railways, tunnels, dikes, dams, reservoirs) due to economic, technical and environmental advantages. Geotextiles (GTXs) are the most applied geosynthetics as they can perform functions like separation, filtration, drainage, protection and reinforcement. In those applications, the GTXs can be exposed to several degradation agents (such as weathering, oxygen, high temperatures, chemicals and microorganisms) that may affect their durability. So, it is extremely important to evaluate their resistance against those damaging agents.

Exposure to sunlight is one of the main causes for the premature failure of many polymers, including those used in the production of GTXs. The solar radiation that reaches the earth surface has wavelengths from 295 nm to 3000 nm. The non-visible ultraviolet (UV) radiation (between 295 nm and 400 nm) represents only about 4% of the solar spectrum, but is the most damaging for polymeric materials. The high-energetic UV radiation is responsible for the photo-degradation of many polymers, in a process that is usually accelerated by high temperatures and by the existence of high moisture contents on the materials.

A long-term exposure to UV radiation (and to other weathering agents) leads to the polymeric degradation of the GTXs. The easiest way to protect the materials against UV-degradation is by avoiding exposing them to sunlight. However, eliminating all exposition to sunlight is in the majority of the cases impossible and, in some situations, the GTXs can even be exposed during extended periods of time. In order to retard or inhibit the photo-degradation process, chemical stabilizers (such as UV stabilizers, antioxidants and pigments) are often added to the GTXs composition.

The most accurate way to test the resistance of the GTXs against weathering is by exposing them outdoors to real conditions. However, these outdoor-tests are usually very long (several months or even years), which makes them impeditive when fast results are needed. Alternatively, accelerated weathering tests (performed under controlled temperature and humidity conditions) are often used. Laboratory weatherometers attempt to reproduce, in a relatively short period of time (usually a few days or weeks), the damage caused by a long-term outdoor exposure. A laboratorial-scale simulation of the damage that occurs on GTXs exposed outdoors is important to predict the durability of these materials when exposed to real conditions.

## 2. Experimental description

### 2.1. Geotextiles

Polypropylene (PP) fibers (8 denier, 75 mm long), stabilized with different amounts of Chimassorb 944 (C944) and carbon black (CB), were specially manufactured to produce four non-woven needle-punched GTXs. The GTXs without the pigment CB were white (W0, W2 and W4), while the GTX with CB was black (B2). The main characteristics of the studied GTXs are summarized in Table 1.

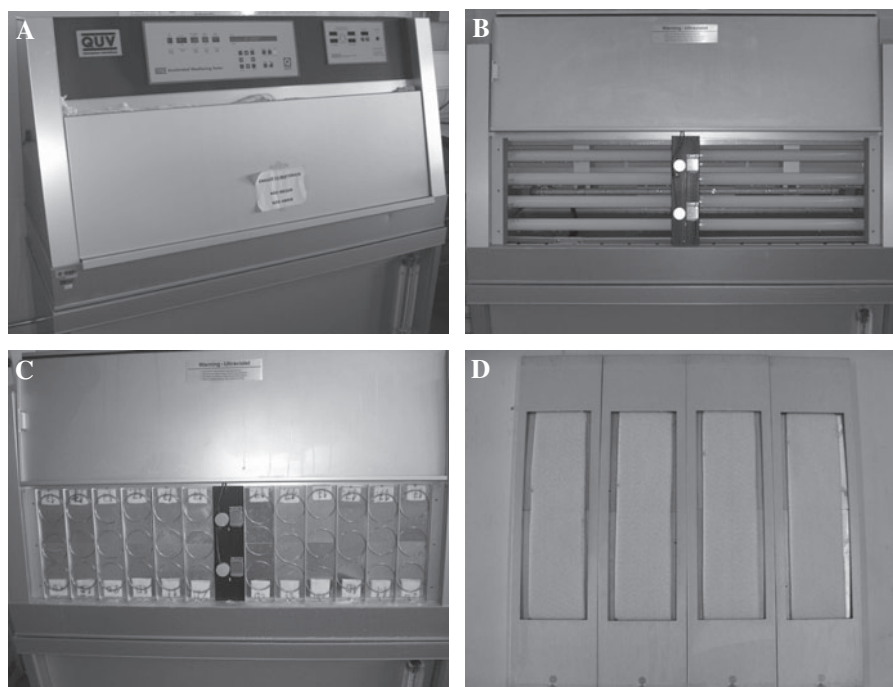
### 2.2. Artificial weathering tests

The GTXs were exposed to artificial weathering conditions (UV radiation, rain and dew) in a laboratory weatherometer (QUV/spray, Q-Panel Lab Products, Farnworth, Bolton, England) (Figure 1). The damaging effects of sunlight were simulated by fluorescent UV lamps (type UVA-340). Rain was simulated by a direct water spray against the GTXs (spray step), while dew was simulated by the condensation of water on the GTXs surface (condensation step). The water used in the spray step was treated microbiologically and purified by reverse osmosis followed by deionization on ionic exchange columns. In the condensation step, a water reservoir (filled with ordinary tap water) located on the bottom of the weather-

**Table 1** Main characteristics of the studied GTXs.

Geotextile	W0	W2	W4	B2
% of Chimassorb 944 (w/w)	0%	0.2%	0.4%	0.2%
% of carbon black (w/w)	0%	0%	0%	1.08%
Mass per unit area <sup>1</sup> (g m <sup>-2</sup> )	283 (11%)	272 (7.8%)	263 (7.6%)	284 (12%)
Thickness <sup>2</sup> (mm)	3.31 (3.5%)	3.24 (3.9%)	3.09 (4.8%)	3.03 (4.5%)
Tensile strength <sup>3</sup> (kN m <sup>-1</sup> )	13.5 (7.1%)	13.6 (7.7%)	14.2 (6.7%)	14.0 (8.1%)
Elongation at maximum load <sup>3</sup> (%)	75.0 (8.3%)	81.6 (8.4%)	75.8 (8.3%)	53.6 (5.4%)

<sup>1</sup>According to EN ISO 9864 [1] (10 specimens); <sup>2</sup>according EN ISO 9863-1 [2] (10 specimens); <sup>3</sup>according to EN 29073-3 [3] (5 specimens, machine direction of production). (In brackets are the obtained coefficients of variation.)



**Figure 1** QUV Weathering Tester: (A) QUV closed; (B) QUV open (UV lamps), without specimen holders; (C) QUV open, with specimen holders; (D) specimen holders.

ometer was heated to produce vapor, that condensates (distilled water) at the surface of the exposed GTXs.

The GTXs were placed in appropriate specimen holders and exposed during 250, 500, 1000 and 2000 h to the following weathering cycle:

Step 1: UV exposure (60°C, 4 h)

Step 2: Water spray (thermal shock, 10 min)

Step 3: Condensation (45°C, 4 h)

(Return to step 1)

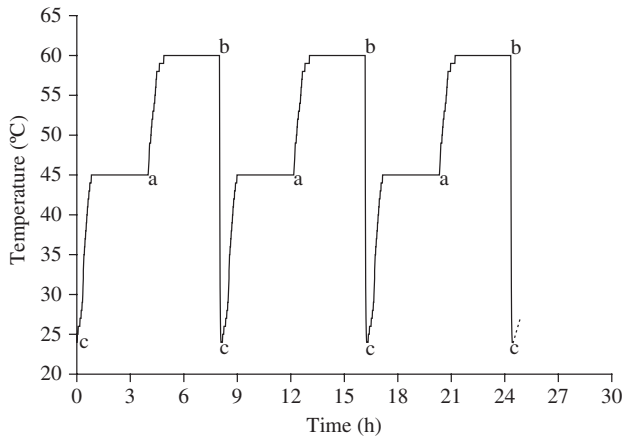
An UV irradiance of 0.68 W m<sup>-2</sup> at 340 nm was selected during the UV step (Table 2). The spray step (water at room temperature, flow of 5 l min<sup>-1</sup>) causes a thermal shock on the GTXs (the temperature decreases rapidly from 60°C to 24°C) and can also cause mechanical erosion on the materials surface. Figure 2 shows the evolution of temperature during the weathering tests. After the tests, the GTXs were dried at least for 7 days in the absence of light.

### 2.3. Evaluation of the damages suffered by the geotextiles

The mechanical properties (tensile strength and elongation at maximum load) of the exposed GTXs were determined according to the European standard EN 29073-3 [3] (Table 3, Figure 3). The tensile tests were performed in a tensile machine from Lloyd Instruments Ltd., Bogner Regis, West

**Table 2** Total radiant exposure during the UV step.

Test time	UV irradiance (340 nm)	Total radiant exposure (340 nm)	Total radiant exposure (290–400 nm)
250 h	0.68 W m <sup>-2</sup>	0.30 MJ m <sup>-2</sup>	17.3 MJ m <sup>-2</sup>
500 h		0.60 MJ m <sup>-2</sup>	34.6 MJ m <sup>-2</sup>
1000 h		1.20 MJ m <sup>-2</sup>	69.1 MJ m <sup>-2</sup>
2000 h		2.40 MJ m <sup>-2</sup>	138.2 MJ m <sup>-2</sup>



**Figure 2** Evolution of the temperature during the weathering tests (a, beginning of the UV step; b, beginning of the spray step; c, beginning of the condensation step).

**Table 3** Experimental conditions used on the tensile tests.

Specimen width	Specimen length <sup>1</sup>	Number of specimens	Test speed
50 mm	200 mm	5	100 mm min <sup>-1</sup>

<sup>1</sup>Between grips.

Sussex, England (LR 50K) equipped with a load cell of 5 kN. A minimum of five specimens were tested for each GTX (specimens tested in the machine direction of production).

The degradation suffered by the GTXs during the artificial weathering tests was evaluated by comparing the tensile results obtained for the weathered specimens with those obtained for reference specimens (without any degradation). Some results are expressed in terms of percentage of retained strength (obtained by dividing the tensile strength of the weathered specimens by the tensile strength of the reference specimens). Microscopic changes on the GTXs were characterized by scanning electron microscopy (SEM).

### 3. Results and discussion

#### 3.1. Geotextile without Chimassorb 944

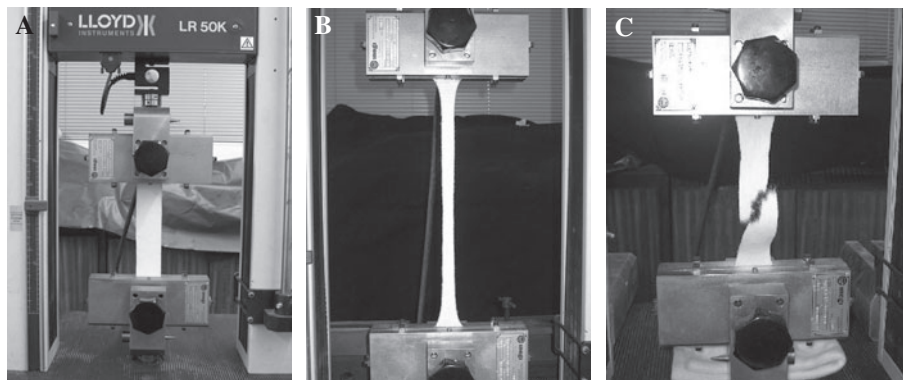
The PP fibers without C944 depolymerized completely during the artificial weathering tests. After 250 h, the GTX without C944 (W0) was already reduced into small pieces or powder (Figure 4). During the degradation process, the color of this GTX remained unchanged and no odors were perceptible due to the liberation of volatile compounds.

#### 3.2. Geotextiles stabilized with Chimassorb 944

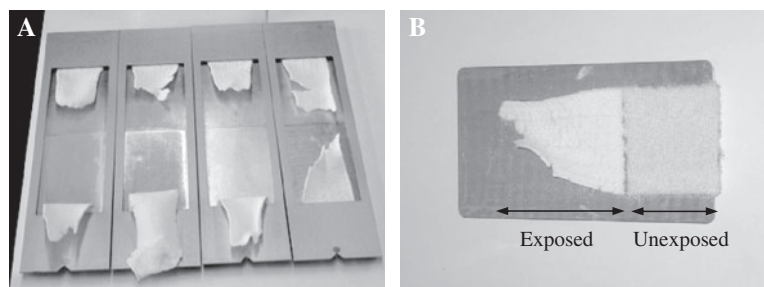
The GTXs stabilized with 0.2% and 0.4% of C944 (W2 and W4, respectively) were not completely destroyed after 250 h of artificial weathering, which readily shows the importance of the additive C944 on the protection of the PP fibers against photo-degradation. After 250 and 500 h of weathering, no visible damages were found on the GTXs. However, after 1000 h, both GTXs were releasing small pieces of depolymerized fibers (almost powder), which early indicated the existence of serious damage on their polymeric structure. After 2000 h of weathering, the GTX W2 was completely destroyed (reduced into small pieces or powder), while the GTX W4 continued to release high amounts of depolymerized fibers (but was not completely destroyed). The retained tensile strength and elongation at maximum load of the GTXs are resumed in Figures 5 and 6, respectively.

The resistance of the GTXs W2 and W4 decreased after the weathering tests, showing that even stabilized GTXs are not fully protected against the damaging effects of the weather. However, the durability of the GTXs under artificial weathering conditions was highly improved by C944. After 250 h of artificial weathering, the GTXs W2 and W4 had retained tensile strengths of 70.4% and 97.8%, respectively (in the same conditions, the GTX without C944 was completely destroyed). So, the incorporation of a small quantity of C944 was sufficient to retard significantly the degradation promoted by weathering.

The tensile strength of the GTXs decreased as the exposition time increased (the same happened for the elongation at



**Figure 3** Tensile tests according to EN 29073-3: (A) begin of the test; (B) during the test; (C) end of the test.



**Figure 4** GTX W0 after 250 h of artificial weathering: (A) general view of the specimens after the test; (B) detailed view of a damaged specimen.

maximum load). After 500 h of artificial weathering, the GTX W2 had already <50% of its original tensile strength, while the GTX W4 had a retained tensile strength of 73.9%. As already expected by the presence of depolymerized fibers, a 1000-h exposition caused a pronounced decrease on the tensile strength of the GTXs (retained tensile strengths of 9.7% and 28.3% for the GTXs W2 and W4, respectively). After 2000 h, the tensile strength of the GTX W2 was reduced to zero, while the GTX W4 was highly damaged (retained tensile strength of 7.5%). The decrease observed on the tensile strength of the GTXs was always more pronounced for the GTX W2, showing that a higher concentration of C944 resulted in a better protection of the GTXs against weathering.

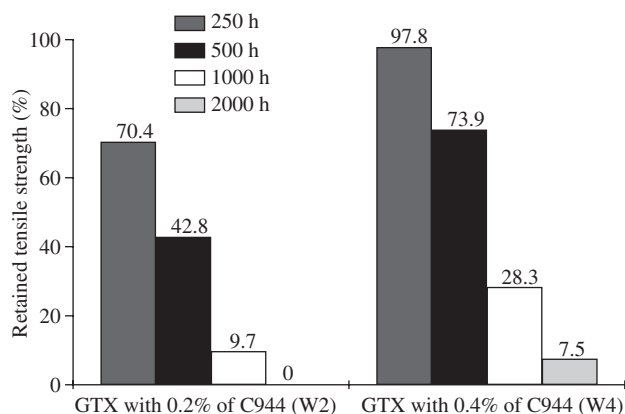
SEM analysis showed the degradation suffered by the PP fibers during the artificial weathering tests (Figure 7). After 250 h of weathering, no signs of degradation were found on both GTXs. However, after 500 h, the GTXs presented already visible signs of degradation, such as transversal fissures along their fibers. As the exposition time increased, more damages were found on the PP fibers (as already expected from the previous tensile results). After 1000 h, the fibers with 0.2% of C944 were highly damaged and, in some cases, near complete rupture (some pieces of fibers had already been lost). After 2000 h, the fibers with 0.4% of C944 were seriously damaged, being near complete destruction. For equal exposure times, the fibers with 0.4% of C944 were always less damaged than

the fibers with 0.2% of C944, which is in agreement with the previous tensile results.

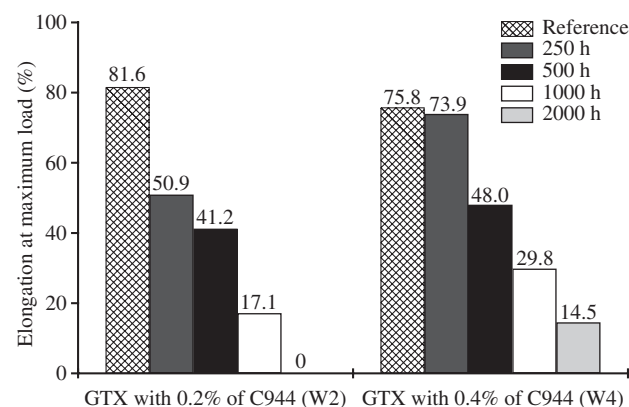
### 3.3. Geotextile with Chimassorb 944 and with carbon black

The GTX stabilized with 0.2% of C944 and 1.08% of CB (GTX B2) had no visible signs of degradation after 2000 h of artificial weathering, showing a very good resistance against photo-degradation. The retained tensile strength and elongation at maximum load of this GTX are resumed in Figure 8.

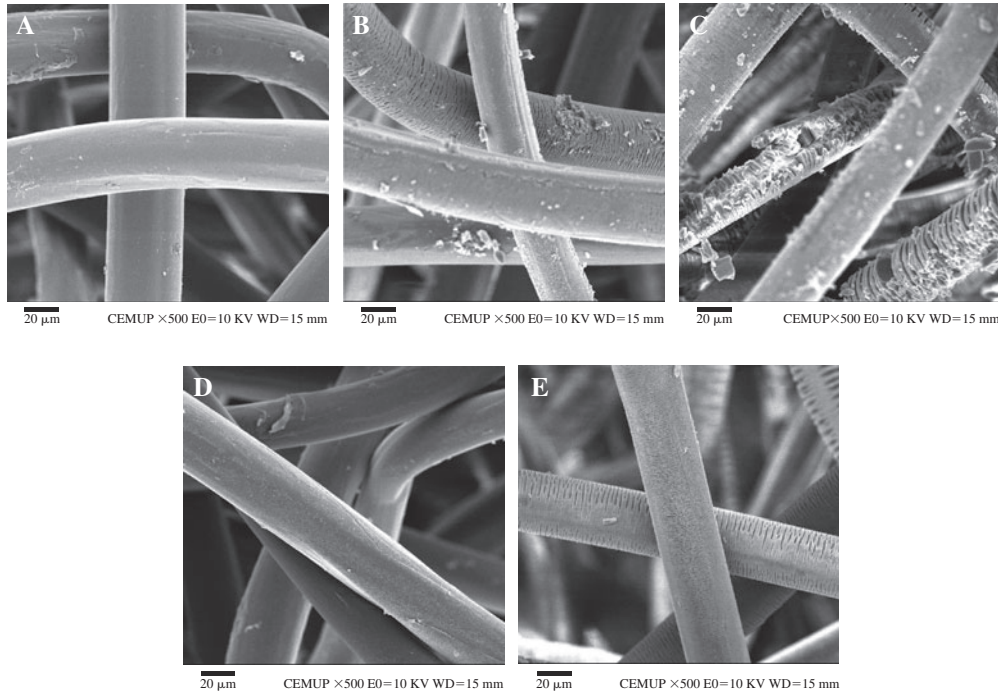
The GTX B2 presented an excellent resistance against the degradation promoted by weathering. Indeed, the tensile strength of the GTX B2 remained practically unchanged after the weathering tests. However, its elongation at maximum load suffered a considerable decrease as the exposition time increased. After 2000 h of artificial weathering, the GTX B2 still had a retained tensile strength of 98.3%, while the GTX W2 (the only difference between these two GTXs was the presence or not of CB) was completely destroyed. Thus, the resistance of the PP fibers against weathering was highly improved by the addition of a small quantity (1.08%) of carbon black. No microscopic signs of degradation were observed on the GTX B2 after 1000 h of artificial weathering. However, after 2000 h, some damage (very small superficial fissures) were found on some fibers of this GTX.



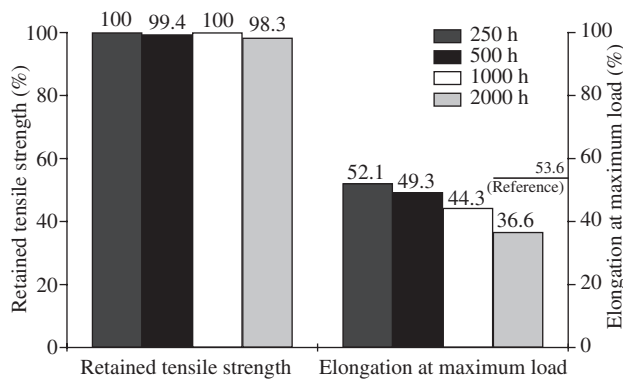
**Figure 5** Retained tensile strength of the GTXs W2 and W4 after artificial weathering.



**Figure 6** Elongation at maximum load of the GTXs W2 and W4 before and after artificial weathering.



**Figure 7** SEM photographs of the PP fibers of the GTXs ( $\times 500$ ): (A) unexposed fibers; (B) GTX W2 after 500 h; (C) GTX W2 after 1000 h; (D) GTX W4 after 500 h; (E) GTX W4 after 1000 h.



**Figure 8** Retained tensile strength and elongation at maximum load of the GTX B2 after the weathering tests.

#### 4. Main conclusions

The resistance of the PP GTXs W0, W2 and W4 was seriously affected by the exposition to the simulated weathering conditions (UV radiation, rain and dew). The PP fibers without C944 depolymerized completely and the corresponding GTX (W0) was reduced into small pieces or powder after the weathering tests. The GTXs stabilized with 0.2% and 0.4% of C944 (W2 and W4, respectively) were not completely destroyed during the weathering tests, but suffered a considerable decrease of

their tensile strength. This shows that the degradation promoted by weathering was retarded by the additive C944. A higher concentration of C944 resulted in a better protection of the PP fibers against weathering. The GTX with 0.2% of C944 and 1.08% of CB (GTX B2) was almost unaffected by the exposition to the artificial weathering tests. This way, an extra-protection against weathering was achieved by the incorporation of CB on the PP fibers.

#### Acknowledgements

The authors would like to thank CARVALHOS (Lousã, Portugal) for producing the polypropylene fibers and the geotextiles studied in this work. This paper reports research developed under financial support provided by “FCT – Fundação para a Ciência e a Tecnologia”, Portugal (research project: PTDC/ECM/67547/2006).

#### References

- [1] EN ISO 9864. Geotextiles – Determination of mass per unit area, 2004.
- [2] EN ISO 9863-1. Geotextiles – Determination of thickness at specified pressures, Part 1: single layers, 2004.
- [3] EN 29073-3. Textiles – Test method for nonwovens, Part 3: determination of tensile strength and elongation, 1992.