

## AGEING OF POLYPROPYLENE GEOTEXTILES UNDER NATURAL WEATHERING CONDITIONS

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**Abstract:** Weathering is the action of many environmental factors (such as, sunlight, heat, oxygen, ozone, moisture, rain, wind, dust, bacteria or chemical pollutants) in altering physical, chemical or mechanical properties of exposed objects. As many other polymeric materials, geotextiles can suffer deterioration when exposed outdoors for a long period of time. When attacked by the surrounding environment, the performance of the geotextiles will be adversely affected, shortening the service lifetime of these materials. Among all the weathering agents, exposition to sunlight (particularly to the ultraviolet region) is considered as the main cause for the degradation of many polymers, including those used in the production of geotextiles. In order to counteract the damaging effects of the ultraviolet radiation (and other weathering agents), chemical additives are often incorporated in the polymeric matrix of the geotextiles.

In this paper, several polypropylene geotextiles (stabilised with different amounts of the additive Chimassorb 944) were exposed to natural weathering in Portugal (41°13' N, 8°39' W) for a maximum period of 24 months. The geotextiles were placed in appropriate specimen holders facing south at an angle of 30° and samples were taken at selected intervals (6, 12, 18 and 24 months) for mechanical (tensile, tearing and static puncture tests) and physical (mass per unit area and thickness) characterisation. Microscopic changes on the geotextiles morphology were characterised by scanning electron microscopy.

**Keywords:** geotextile, polypropylene, durability, weathering, solar radiation, chemical ageing

### INTRODUCTION

During their lifetime, the geotextiles (GTXs) can be exposed to several degradation agents, such as: ultraviolet (UV) radiation and other weathering agents, oxygen, high temperatures, acids, alkalis and microorganisms. An extended exposure to such degradation agents can have a negative impact on the durability of the GTXs, causing a premature failure of these materials. So, it is very important to evaluate their resistance against those agents.

GTXs exposed outdoors are permanently subjected to the harmful action of many weathering agents (sunlight is considered the most damaging for the polymers often used in the production of GTXs). Sunlight degradation starts when the energy supplied by UV radiation promotes the formation of highly reactive free-radicals. In the presence of oxygen, these free-radicals can cause an extended degradation of the GTXs, in a process called photo-oxidation. This process is usually accelerated by high temperatures and by the existence of high moisture contents on the materials.

The easiest way to protect the GTXs against photo-oxidation is by avoiding the exposition of the materials to sunlight. However, the elimination of all exposition to sunlight is in the majority of the cases impossible and, in some situations, the GTXs can be exposed during long periods of time. The degradation promoted by photo-oxidation is usually inhibited or retarded by the incorporation of chemical additives (such as UV stabilisers or antioxidants) on the GTXs composition.

The natural weathering tests are usually very long (several months or years), which makes them impeditive when fast results are needed. In that case, we have to make predictions, which are usually based on changes on the GTXs properties measured over shorter periods of time, but under conditions much more severe than the real ones.

Laboratory weatherometers are often used to try to reproduce, in a relative short period of time (usually a few days or weeks), the damage caused by a long term outdoor-exposure. An example of accelerated weathering testing of GTXs can be found in Carneiro *et al.* (2006). However, there are some factors (such as: wind, atmospheric pollutants, accumulated filth on the materials) 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 GTXs than any artificial weathering test.

The degradation that GTXs suffer when exposed outdoors depends on the geographic location of the test site and on the weather conditions of that particular site. The weather is highly variable from site-to-site and even at the same site seasonal and yearly variations are expected to occur. This climate variability from site-to-site makes the direct comparison between test data obtained at different sites very difficult. In order to perform such type of comparisons, the weather parameters of the different exposure sites must be strictly monitored during the tests.

### EXPERIMENTAL DESCRIPTION

#### Geotextiles

Polypropylene (PP) fibres (8 denier, 75 mm long) with different amounts of the additive Chimassorb 944 (C944), 0%, 0.2% and 0.4% (w/w), were specially manufactured to produce needle punched nonwoven GTXs (500 g.m<sup>-2</sup>). C944 (a hindered amine light stabiliser) is a chemical additive used in the stabilisation of polymers against the damaging effects of oxygen and UV radiation.

### Natural weathering test

The GTXs were exposed to natural weathering conditions in the north of Portugal (latitude 41°13` N, longitude 8°39` W, elevation of 49 m above sea level). The GTXs were placed in appropriate specimen holders facing south with an exposition angle of 30° (Figure 1).



**Figure 1.** GTXs exposed to natural weathering conditions

The GTXs were exposed to natural weathering conditions during a maximum period of 24 months (between November 2004 and November 2006). Specimens were collected periodically at selected intervals (6, 12, 18 and 24 months) for physical and mechanical characterisation. Some weather parameters (such as: UV radiation, air temperature, rainfall, relative humidity and wind velocity) were continuously registered during exposition (data not shown). The knowledge of these parameters is indispensable to compare the degradation suffered by the GTXs on that particular exposure site with the degradation suffered by the same GTXs in other sites or even in laboratory weatherometers.

### Evaluation of the degradation suffered by the geotextiles

Physical tests (determination of mass per unit area and thickness) and mechanical tests (tensile, tearing and static puncture tests) were performed for unexposed specimens (without any degradation) and for the weathered specimens of the GTXs. The degradation suffered by the materials was evaluated by comparing the results obtained for the weathered specimens with those obtained for the unexposed specimens.

The mass per unit area of the GTXs was determined according to EN ISO 9864 (2004), while the thickness of the materials was determined according to EN ISO 9863-1 (2004). A minimum of 10 specimens were tested in each test.

The tensile strength of the GTXs was determined according to EN ISO 10319 (1996), while the tearing strength was determined according to ASTM D4533 (1996) (all specimens tested in the machine direction of production); the static puncture tests were performed according to EN ISO 12236 (1996). A minimum of 5 specimens were tested in the tensile and static puncture tests; in the tearing tests a minimum of 10 specimens were tested. Figure 2 shows the mechanical tests used for the characterisation of the GTXs.

The obtained mechanical results are expressed in terms of percentage of retained resistance (obtained by dividing the strength of the weathered specimens by the strength of the reference specimens).

Microscopic changes on the GTXs morphology were characterised by scanning electron microscopy (SEM).

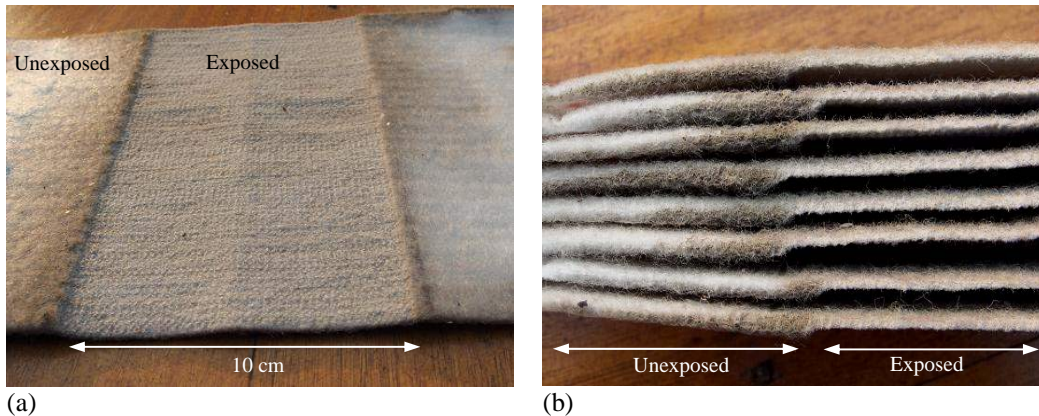


**Figure 2.** Mechanical characterisation of the GTXs: (a) tensile test; (b) tearing test; (c) static puncture test

## RESULTS AND DISCUSSION

### Visual inspection of the geotextiles

The GTXs acquired a greyish coloration (originally they were white) during the exposition to natural weathering due to the accumulation of small particles (dust, filth) between their fibres. After 6 months of exposition, no visible signs of degradation were noticed on the GTXs. By the 12-month of exposition, some degradation on the GTX without C944 was perceptible due to the release of depolymerised PP fibres; this caused a considerable decrease on the thickness of this GTX (Figure 3). The degradation suffered by the GTX without C944 was much more pronounced after 18 months of exposition (some specimens were almost destroyed). After 24 months of exposition, the GTX without C944 was completely destroyed; the GTX was reduced into small pieces that were found on the ground (taken by the wind) near the exposition site.



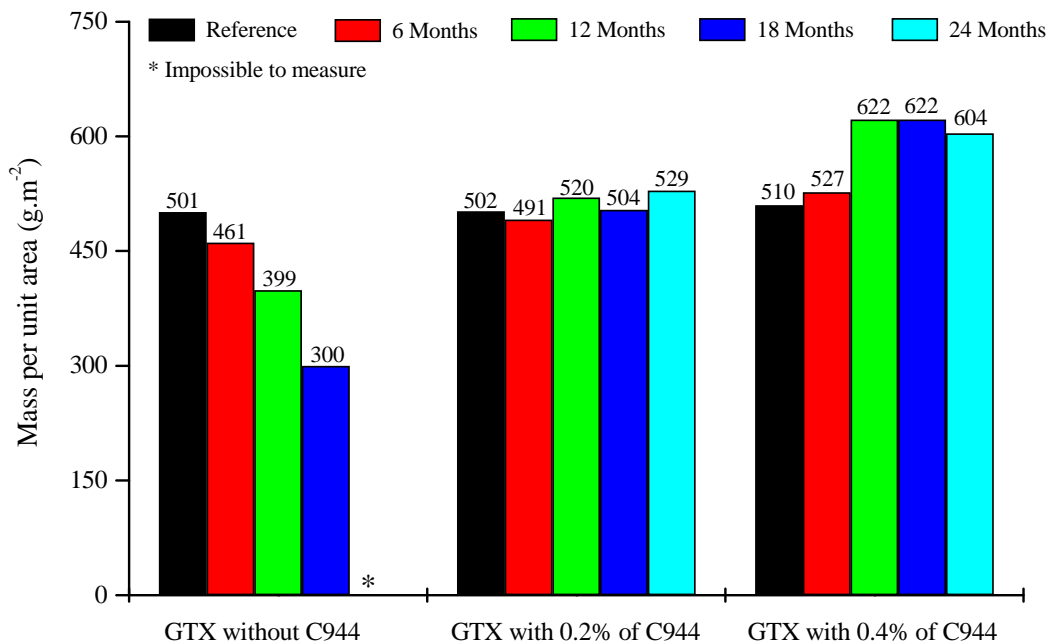
**Figure 3.** Reduction on the thickness of the GTX without C944 after 12 months of natural weathering: (a) a specimen at horizontal position; (b) several specimens at vertical position

The GTXs stabilised with 0.2% and 0.4% of C944 had no visible signs of degradation (no depolymerised fibres, no reduction in thickness) after 24 months of exposition. This early indicated that C944 protected the PP fibres against the degradation promoted by weathering. The incorporation of a low quantity of C944 (0.2%) was sufficient to avoid the destruction of the GTXs after 24 months of exposition to natural weathering.

### Physical characterisation of the geotextiles

#### Mass per unit area of the geotextiles

The evolution of the mass per unit area of the GTXs exposed during 24 months to natural weathering is illustrated in Figure 4.



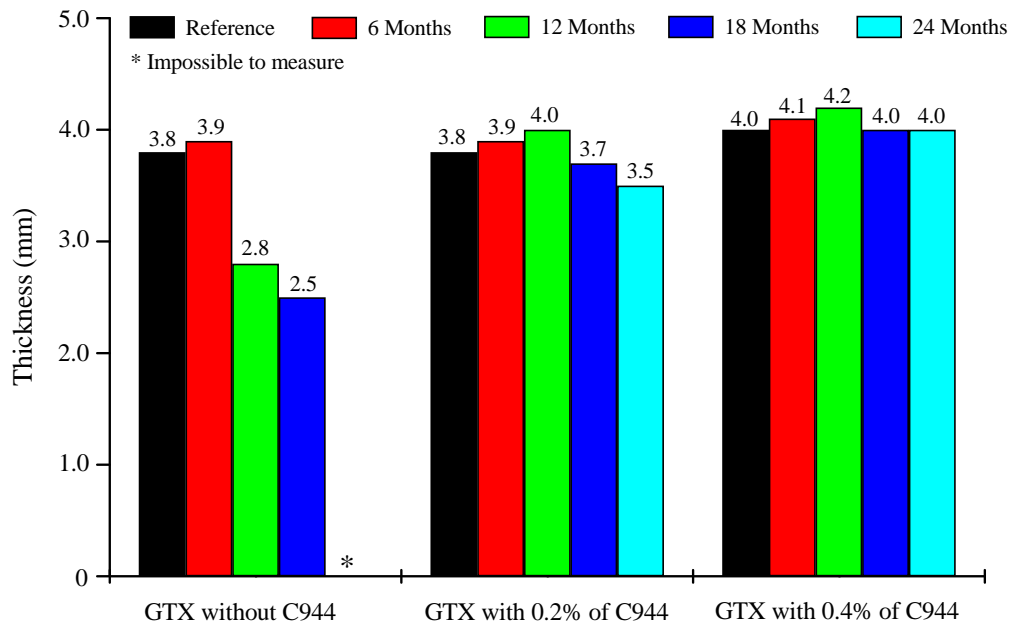
**Figure 4.** Mass per unit area of the GTXs before and after exposition to natural weathering

The GTX without C944 suffered a considerable decrease on its mass per unit area during the exposition to natural weathering. This loss of mass occurred due to the liberation of depolymerised PP fibres resultant from the degradation of this GTX. The mass per unit area of the GTXs stabilised with 0.2% and 0.4% of C944 increased during time, being this increase more pronounced for the GTX with 0.4% of C944. This increase is obviously not a gain of polymeric mass, but occurs due to the accumulation of dust and filth between the fibres of the GTXs. As the accumulated amount of dust and filth is expected to be equal for both GTXs, the lower mass presented by the GTX with 0.2% may indicate the occurrence of some depolymerisation on this material.

The evolution of the mass per unit area of the GTXs exposed to natural weathering seems to be a competitive process between the release of depolymerised fibres and the accumulation of dust and filth within the GTXs structure. The first will cause a decrease (with real loss of polymeric mass) and the second will cause a “false” increase on the mass per unit area of the GTXs.

#### Thickness of the geotextiles

The evolution of the thickness of the exposed GTXs is illustrated in Figure 5.



**Figure 5.** Thickness of the GTXs before and after exposition to natural weathering

The thickness of the GTX without C944 decreased during exposition to natural weathering due to the release of depolymerised PP fibres.

The GTX with 0.2% of C944 suffered a slight increase on its thickness during the first 12 months of exposition; after that, a slight decrease was observed. The initial increase on thickness can be explained by the accumulation of dust and filth on the material; the decrease occurred after that, may be due to the release of damaged fibres. Again, this seems to indicate that some depolymerisation occurred on the GTX with 0.2% of C944.

In the first 12 months of exposition, the GTX with 0.4% of C944 had an increase on its thickness similar to what happened for the GTX with 0.2% of C944. After that, a slight decrease was also observed. However, this decrease was not as pronounced as the decrease observed for the GTX with 0.2% of C944.

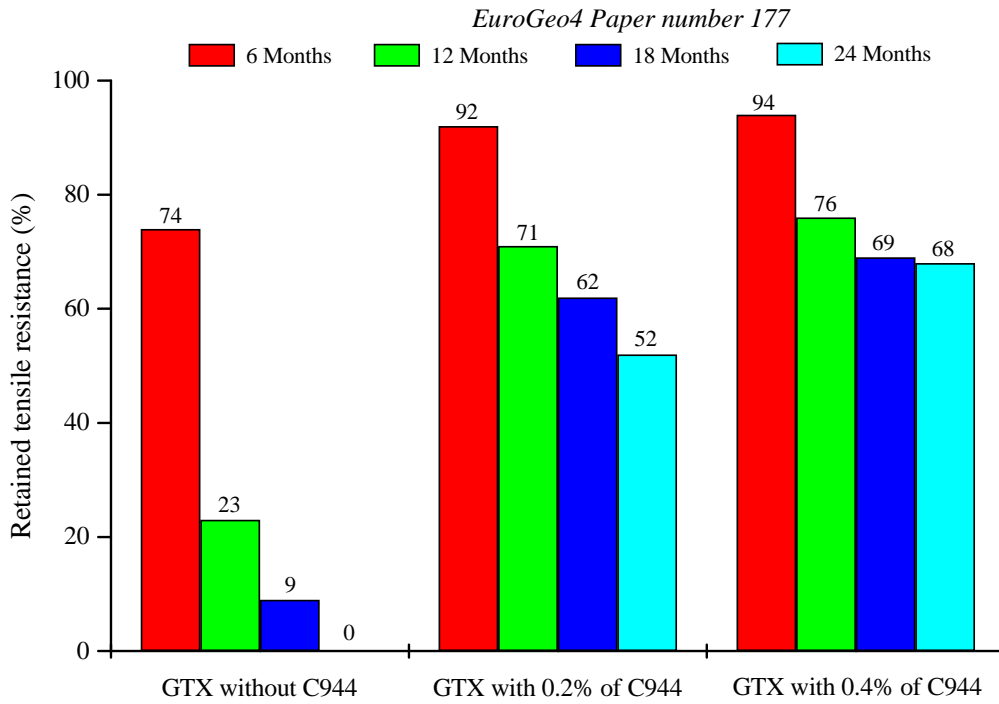
The evolution of the thickness of the GTXs exposed to natural weathering seems also to be a competitive process between the loss of damaged fibres and the accumulation of dirt in the materials.

The accumulation of dirt only caused a slight increase on the thickness of the nonwoven GTXs. This can be explained by the fact that the dirt is not being accumulated on the top of the material, but is fulfilling the inner empty spaces that exist between the fibres.

#### Mechanical characterisation of the geotextiles

##### Tensile strength of the exposed geotextiles

The GTX without C944 suffered visible damages during the exposition to natural weathering. So, a considerable reduction on the tensile strength of this GTX was expected. The GTXs stabilised with 0.2% and 0.4% of C944 did not presented visible evidences of degradation of their fibres. However, the tensile tests showed a decrease on the original tensile strength of these materials. The evolution of the retained tensile resistance of the exposed GTXs is illustrated in Figure 6.



**Figure 6.** Retained tensile resistance of the GTXs after exposition to natural weathering

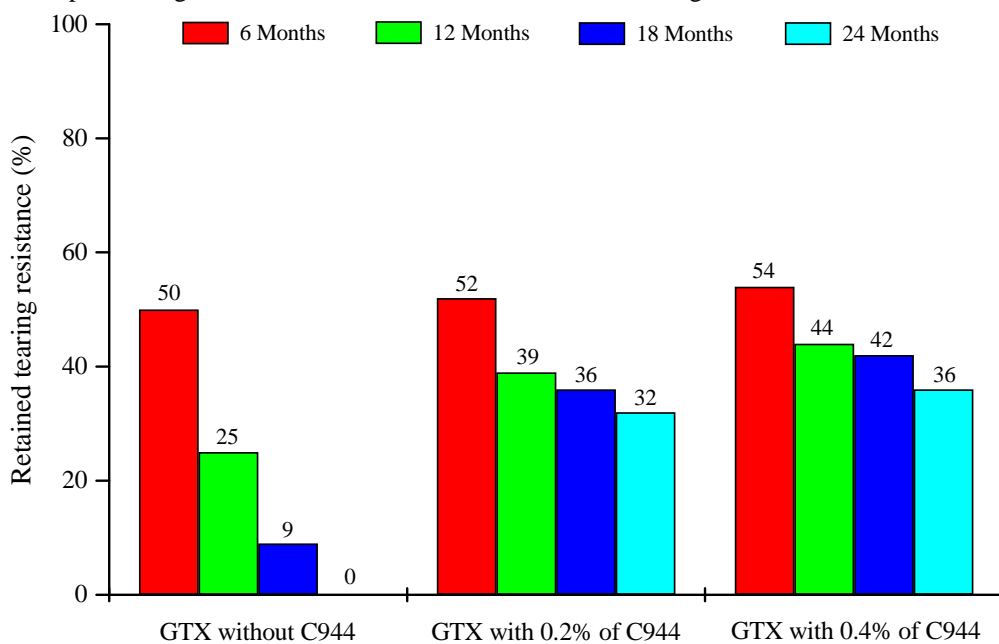
The tensile strength of the GTX without C944 suffered a huge decrease during the 24-month exposition to natural weathering. After 12 months, the GTX without C944 had only 23% of its original strength, confirming the existence of serious damages on its polymeric structure. By the 18-month, the retained tensile resistance of this GTX was already less than 10% and the material was near complete destruction, what inevitably occurred between the 18-month and the 24-month of exposition.

The GTXs stabilised with C944 also suffered a considerable reduction of their tensile strength during the natural weathering test, but in a much lower extension than the degradation suffered by the GTX without C944. After 24 months, both GTXs still had retained tensile resistances higher than 50%. The incorporation of C944 on the PP fibres was essential to retard the degradation promoted by weathering (but did not assured a total protection of the materials against this degradation agent).

The GTX with 0.4% of C944 was less damaged than the GTX with 0.2% of C944, showing that a better protection against weathering was achieved by the incorporation of a higher concentration of C944 on the materials.

#### *Tearing strength of the exposed geotextiles*

Similarly to what happened with the tensile strength, a reduction on the tearing strength of the weathered GTXs was expected. Figure 7 shows the evolution of the retained tearing resistance of the GTXs during the weathering test.



**Figure 7.** Retained tearing resistance of the GTXs after exposition to natural weathering

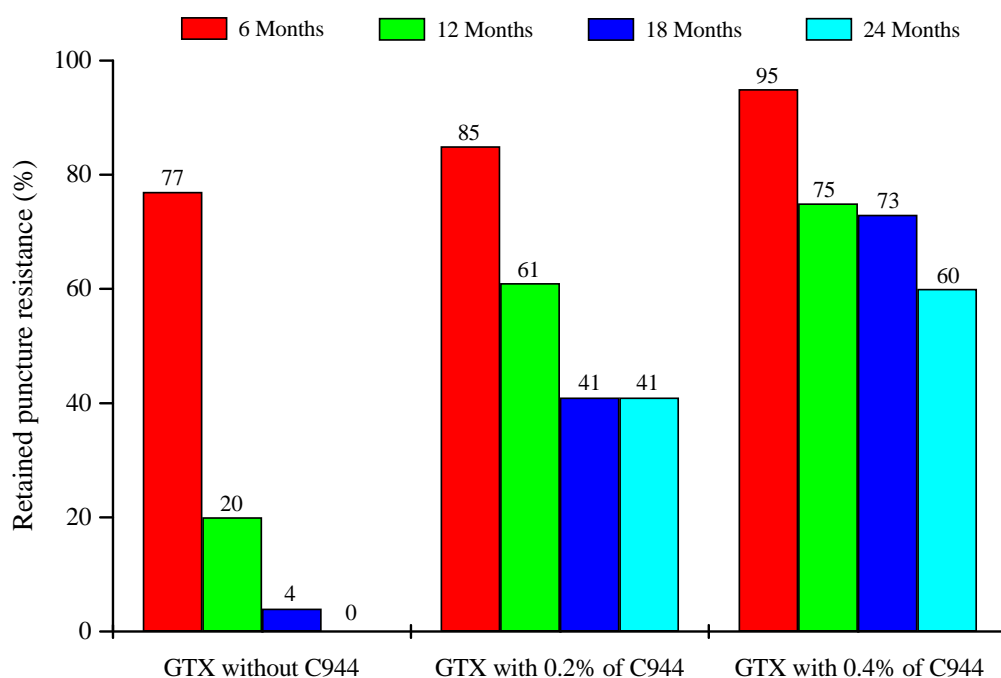
The tearing strength of the GTXs suffered a considerable decrease during the natural weathering test. After 6 months, the GTXs had their original tearing strength reduced to half and no big differences were seen between the stabilised GTXs and the unstabilised one. The tearing strength of the GTXs was much more affected by weathering than the tensile strength. For instance, after 6 months, the GTXs stabilised with 0.2% and 0.4% of C944 had retained tearing resistances of 52% and 54% and retained tensile resistances of 92% and 94%, respectively.

As the exposition time increased, the tearing strength of the GTXs continued to decrease, but not in the same way; the reduction suffered by the unstabilised GTX was higher than the reduction suffered by the stabilised ones. After 18 months, the GTX without C944 had only 9% of its original tearing strength, while the GTXs stabilised with 0.2% and 0.4% of C944 had retained tearing resistances of 36% and 42%, respectively.

Again, the GTX with 0.4% of C944 was less damaged than the GTX with 0.2% of C944, confirming that a higher concentration of C944 resulted in a better protection against weathering.

#### *Static puncture resistance of the exposed geotextiles*

As already expected from the previous mechanical results, the static puncture resistance of the GTXs also suffered a considerable decrease during the natural weathering test (Figure 8).



**Figure 8.** Retained puncture resistance of the GTXs after exposition to natural weathering

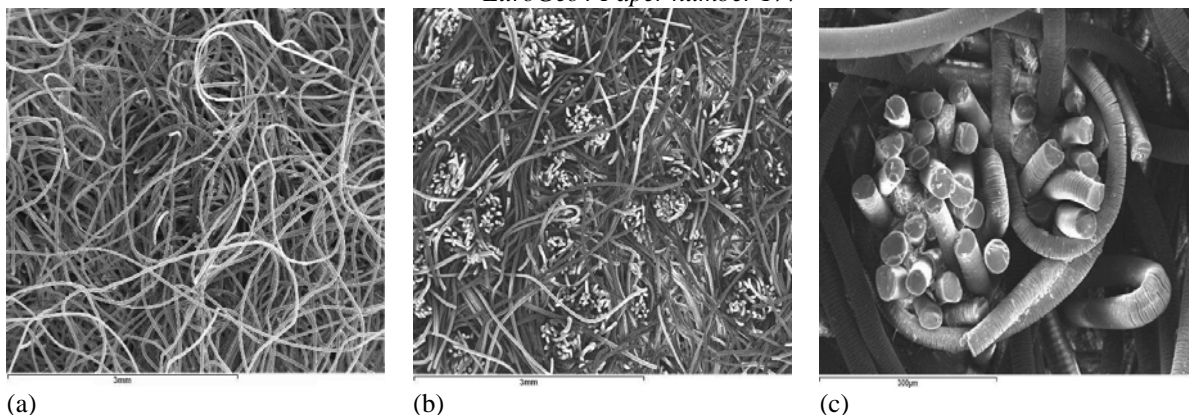
The reduction on the puncture resistance was more pronounced for the GTX without C944. Among the stabilised GTXs, the puncture resistance of the GTX with 0.4% was higher than the puncture resistance of the GTX with 0.2% of C944 (comparing weathered specimens with equal exposition times). These results are in agreement with the previous mechanical results (tensile and tearing strength), confirming that the unstabilised GTX was much more damaged than the stabilised ones and that a better protection against weathering was achieved by the incorporation of a higher concentration of C944 on the materials.

#### **Scanning electron microscopy analysis of the exposed geotextiles**

##### *Geotextiles without Chimassorb 944*

SEM analysis showed the degradation that occurred on the unstabilised PP fibres during the exposition to natural weathering. By the 6-month of exposition, some fibres presented already some damages, such as transversal fissures; it was also possible to see some dust or filth accumulated between the fibres.

After 12 months of exposition, the GTX without C944 presented a considerable decrease on its thickness, due to the release of depolymerised fibres (dust, powder). SEM analysis showed that the fibres disposed vertically (orientated up, perpendicularly to the plane of the material) were all broken and the fibres disposed horizontally (on the same plane of the material) presented visible signs of degradation (some of them were already near complete destruction). Figure 9 illustrates some SEM photographs of the GTX without C944 after 12 months of natural weathering.



(a) (b) (c)  
**Figure 9.** SEM photographs of the GTX without C944 before (a) and after (b and c) 12 months of natural weathering: (a) x20; (b) x20; (c) x200

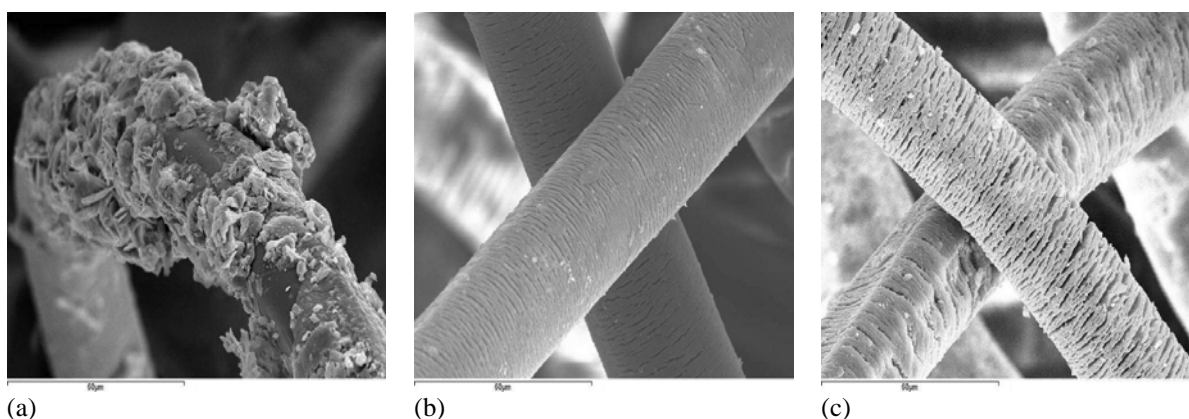
The degradation suffered by the GTX without C944 started by the upper fibres, which were successively broken and removed from the top of the material (taken by the wind or washed by the rain). Some of the little depolymerised fibres were accumulated between the empty spaces of the fibres lying under. This way, these damaged fibres can even protect the fibres lying under by impeding the solar radiation to reach them.

As the exposition time increased, the fibres were continuously suffering degradation (the thickness of the material was successively decreasing) till the complete destruction of the GTX between the 18-month and the 24-month.

#### *Geotextiles stabilised with 0.2% and 0.4% of Chimassorb 944*

After 12 months of exposition, no signs of degradation were found on the GTXs stabilised with 0.2% and 0.4% of C944. These GTXs had high amounts of dust or filth accumulated between their fibres (some fibres were completely covered by this dirt). This accumulated dirt was forming a protective layer that was impeding sunlight from reaching the fibres.

By the 18-month of exposition, the GTX with 0.2% of C944 presented visible signs of degradation, such as transversal fissures on its fibres; the dirt found by the 12-month of exposition was no longer protecting the fibres against degradation. It is important to note that in SEM analysis we are only observing the upper fibres of the GTXs (the first ones to suffer degradation). The fibres lying under are not so damaged because they are protected by the upper fibres and still have accumulated dirt between them. As the exposition time increased, more damages were found on the fibres with 0.2% of C944 (the transversal fissures become bigger and some little pieces of fibre were lost), which is in agreement with the previous physical and mechanical results. Figure 10 shows some SEM photographs of the GTX with 0.2% of C944 after 12, 18 and 24 months of natural weathering.



(a) (b) (c)  
**Figure 10.** SEM photographs (x1000) of the GTX with 0.2% of C944 after 12 (a), 18 (b) and 24 (c) months of natural weathering.

By the 12-month of exposition, the fibres with 0.4% of C944 were completely covered by dirt (similarly to what happened for the fibres with 0.2% of C944). After 18 and 24 months of exposition, some degradation (transversal fissures) was also found on the fibres stabilised with 0.4% of C944. However, these fibres were not as damaged as the fibres stabilised with 0.2% of C944 (comparing fibres subjected to equal exposition times). This way, SEM analysis confirmed that a better protection against the damaging effects of weathering was achieved by the incorporation of a higher concentration of C944 on the PP fibres.

## **MAIN CONCLUSIONS**

The resistance of the PP GTXs (stabilised or not with C944) was seriously affected by an extended exposition to natural weathering. The GTX without C944 was completely destructed after 24 months of exposition, being easily reduced into small pieces or powder. Although the GTXs stabilised with 0.2% and 0.4% of C944 had no visible signs of degradation, a considerable decrease on their tensile, tearing and puncture strength occurred during the 24-month weathering test. This shows that even stabilised GTXs are not fully protected against weathering. However, a better protection against weathering was achieved by the incorporation of a higher concentration of C944.

C944 proved to be important in the stabilisation of the PP fibres against the damaging effects of the weather. So the incorporation of chemical stabilisers, such as C944, on the GTXs composition is essential to extend the service lifetime of these materials.

**Acknowledgements:** The authors want to thank the firm CARVALHOS (Lousã, Portugal) for producing the polypropylene fibres and the geotextiles studied in this work and LIPOR (Maia, Portugal) for giving the place for exposing the geotextiles to the natural weathering conditions. This paper reports research developed under financial support provided by “FCT – Fundação para a Ciência e a Tecnologia”, Portugal.

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## **REFERENCES**

- ASTM D4533 (1996): Standard test method for trapezoid tearing strength of geotextiles.
- Carneiro, J.R., Almeida, P.J., Lopes, M.L. 2006. Durability of polypropylene geotextiles exposed to artificial weathering conditions. 5<sup>th</sup> ICEG Environmental Geotechnics: Opportunities, Challenges and Responsibilities for Environmental Geotechnics – Proceedings of the ISSMGE 5<sup>th</sup> International Congress, Thomas Telford, London, I, 399-406.
- EN ISO 10319 (1996): Geotextiles – Wide-width tensile test.
- EN ISO 12236 (1996): Geotextiles and geotextile-related products – Static puncture test (CBR test).
- EN ISO 9863-1 (2004): Geotextiles – Determination of thickness at specified pressures, Part 1: Single layers.
- EN ISO 9864 (2004): Geotextiles – Determination of mass per unit area.