Durability of a polypropylene geotextile in marine environments: 3 years data

J.R. Carneiro
Construct-Geo, University of Porto – Faculty of Engineering, Portugal (rcarneir@fe.up.pt)

M. Morais
University of Porto – Faculty of Engineering, Portugal (lmiguel.morais@gmail.com)

M.L. Lopes
Construct-Geo, University of Porto – Faculty of Engineering, Portugal (lcosta@fe.up.pt)

ABSTRACT: The geosynthetics can be used for the construction of many marine and coastal engineering structures. In these applications, the materials can be in contact with some agents capable of causing unwanted changes in their properties. In this work, a nonwoven polypropylene geotextile (stabilised with 0.4% of Chimassorb 944) was exposed *in situ* to some degradation agents often present in marine environments. The geotextile was exposed to weathering, immersed in seawater and exposed to the action of tides. These exposures were carried out in Portugal (Archipelago of the Azores, Pico and Faial Islands) and lasted for 3 years. The damage occurred in the geotextile (during the degradation tests) was evaluated by monitoring some physical (mass per unit area and thickness) and mechanical (tensile behaviour) properties.

Keywords: geotextiles, durability, weathering, seawater, Chimassorb 944

1 INTRODUCTION

The geosynthetics can be used in the construction of marine and coastal protection structures, such as: dykes, groynes, jetties, breakwaters or revetments. The advantages of using these materials include: ease of installation (and removal, if needed), low-cost, high efficiency and low environmental impact. The functions of the geosynthetics in these applications include: erosion control, reinforcement, waterproofing, separation or drainage.

In marine environments, the geosynthetics can be in contact with many damaging agents, like: solar radiation and other weathering agents, biological agents, seawater, oxygen and the action of waves, tides and currents. A prolonged exposure to these agents may cause undesirable changes in the physical, mechanical and hydraulic properties of the geosynthetics, affecting their performance and shortening their lifetime.

The polymers used for the production of geosynthetics are normally very resistant against many chemical species and against biological degradation. However, their resistances against oxidation and ultraviolet (UV) radiation are often lower (Carneiro, 2009). The oxidation process can be induced by heat (thermo-oxidation) or by UV radiation (photo-oxidation). In most cases, the geosynthetics are exposed to UV radiation during a short period of time (during the installation process), being subsequently covered by soils or by liquids. Yet, in some applications they can be total or partially exposed during longer periods of time. The damage caused by oxidation and by UV radiation can be retarded by adding chemical additives (such as antioxidants or UV stabilisers) to the composition of the geosynthetics (Carneiro, 2009).

The durability of geosynthetics can be understood as their capacity to maintain key properties during time. The expected lifetime for geosynthetics may be over 25 years in many applications and, therefore, they must have a good resistance against degradation. This way, it is important to identify exactly the conditions to which they will be submitted and estimate how those conditions will affect their properties.

In Eurogeo 5, our research team presented some results about the resistance of geotextiles against degradation agents present in marine environments (exposures *in situ* during 1 year to weathering, seawater and action of tides) (Carneiro *et al.*, 2012). This paper extends the previous work, presenting the results obtained after 2 and 3 years.

2 EXPERIMENTAL PROGRAM

2.1 *Geotextiles*

This work studied a nonwonven geotextile (designated by geotextile G4) made from polypropylene (PP) fibres (75 mm long, 8 denier) with 0.4% (*w/w*) of Chimassorb 944 (C944). C944 is a HALS-type UV stabiliser. The main characteristics of geotextile G4 can be found in Table 1.

Table 1. Main characteristics of geotextile G4.

% of Chimassorb 944 (*w/w*)	0.4
% of polypropylene (*w/w*)	99.6
Mass per unit area ($g.m^{-2}$) (EN ISO 9864)	263 (20)
Thickness (mm) (EN ISO 9863-1)	3.17 (0.14)
Tensile strength* ($kN.m^{-1}$) (EN 29073-3)	13.3 (1.6)
Elongation at maximum load* (%) (EN 29073-3)	75.8 (6.1)

*machine direction of production
(in brackets are the obtained standard deviations)

The sampling process (for the characterisation and degradation tests) was carried out according to EN ISO 9862. The specimens (prepared in the machine direction of production) were cut from positions evenly distributed over the full width and length of the geotextile (supplied in roll), but not closer than 100 mm to the edges. The specimens for the same degradation test were taken from different longitudinal and transverse positions of the roll.

2.2 *Outdoor degradation tests*

The geotextile was exposed *in situ* to three degradation tests: (1) exposure to weathering (near the sea), (2) immersion in seawater and (3) exposure to the action of tides. These tests were carried out in Portugal (Archipelago of the Azores, Pico and Faial Islands) and had a duration of 3 years (samples collected for characterisation after 1, 2 and 3 years of exposure).

The geotextile was exposed to weathering in Pico Island (latitude of 38º25'N, longitude of 28º24'W, 24 m above sea level). The test-samples were installed in exposure stands facing south with an inclination of 30º.

The immersion in seawater (depth of about 4 m) was performed in the Horta harbour (Faial Island) (latitude of 38º31'N, longitude of 28º37'W). Regarding the action of tides, the geotextile was installed on the inner wall of the northern basin of the Horta marina (Faial Island) (latitude of 38º32'N, longitude of 28º37´W). The test-samples were orientated to su-southeast (160º) with an inclination of 32.5º. The geotextile was completely immersed in high tide (exposed to the action of seawater) and totally emerged at low tide (exposed to the action of sunlight and other weathering agents).

2.3 *Evaluation of the damage suffered by the geotextile*

The damage suffered by the geotextile (in the degradation tests) was evaluated by monitoring some physical and mechanical properties. Physical characterisation included determination of mass per unit area (EN ISO 9864) and thickness (EN ISO 9863-1). Mechanical characterisation was carried out by tensile tests (EN 29073-3). The experimental conditions of the physical and mechanical tests are summarized in Table 2.

Table 2. Experimental conditions of the physical and mechanical tests

Test	Mass per unit area	Thickness	Tensile test
Test standard	EN ISO 9864	EN ISO 9863-1	EN 29073-3
Specimens size	100 mm x 100 mm	100 mm x 100 mm	50 mm x 200 mm*
Number of specimens	10	10	5
Pressure	---	2 kPa	---
Test speed	---	---	100 mm.min^{-1}

*length between grips

The parameters determined in the physical tests included mass per unit area (μ_A, in g.m^{-2}) and thickness (t, in mm). Some results are presented in terms of variation of mass per unit area ($\Delta\mu_A$) and variation of thickness (Δt), obtained by the following equations:

$$\Delta\mu_A = \mu_{A\ Exposed} - \mu_{A\ Reference} \quad (1)$$

$$\Delta t = t_{Exposed} - t_{Reference} \quad (2)$$

where, $\mu_{A\ Reference}$ and $t_{Reference}$ represent the properties before the degradation tests (undamaged samples) and $\mu_{A\ Exposed}$ and $t_{Exposed}$ represent the properties after the degradation tests.

The mechanical parameters determined in the tensile tests included tensile strength (T, in kN.m^{-1}) and elongation at maximum load (E_{ML}, in %). Some results are presented in terms of retained tensile strength (RTS, in %), obtained according equation 3:

$$RTS = (T_{Exposed} / T_{Reference}) \times 100 \quad (3)$$

where, $T_{Reference}$ and $T_{Exposed}$ denote, respectively, the tensile strength of the geotextile, before and after the degradation tests.

3 RESULTS AND DISCUSSION

3.1 *Evolution of physical properties*

The geotextile G4 acquired a greyish coloration (its original colour was white) during the exposure to weathering. This colour change occurred due to the accumulation of small particles (dust and dirt) between its fibres. Contrarily to the exposure to weathering, the immersion in seawater did not led to relevant changes in the colour of geotextile G4, but promoted the accumulation of sand within its nonwoven structure.

Like the exposure to weathering, the action of tides also provoked colour changes in geotextile G4. Indeed, it acquired green, grey and brown tones due to the attachment and growth of algae at its surface and due to the accumulation of dirt within its nonwoven structure. The evolution of mass per unit area and thickness of geotextile G4 during the exposures to weathering and to the action of tides can be found in Tables 3 and 4, respectively. Due to the accumulation of high amounts of sand (which influenced the determination of mass per unit area and thickness due to the continuously release of sand), the physical properties were not monitored during the immersion in seawater.

Table 3. Evolution of mass per unit area of geotextile G4 during the degradation tests

Exposure time (years)	Weathering		Action of tides	
	μ_A (g.m^{-2})	$\Delta\mu_A$ (g.m^{-2})	μ_A (g.m^{-2})	$\Delta\mu_A$ (g.m^{-2})
1	310 (11)	+ 47	629 (127)	+ 366
2	316 (10)	+ 53	606 (82)	+ 343
3	287 (22)	+ 24	687 (71)	+ 424

(in brackets are the obtained standard deviations)

Table 4. Evolution of thickness of geotextile G4 during the degradation tests

Exposure time (years)	Weathering		Action of tides	
	t (mm)	Δt (mm)	*t* (mm)	Δt (mm)
1	3.45 (0.14)	+ 0.28	3.61 (0.27)	+ 0.44
2	3.32 (0.14)	+ 0.15	3.70 (0.45)	+ 0.53
3	3.22 (0.09)	+ 0.05	3.76 (0.42)	+ 0.59

(in brackets are the obtained standard deviations)

The exposure to weathering provoked an increase of mass per unit area. For example, after 36 months, geotextile G4 had a mass per unit area of 287 g.m^{-2} (increase of 24 g.m^{-2}). Obviously, the increase occurred in mass per unit area was not due to the gain of polymeric mass, but reflected the dust and dirt accumulated in the nonwoven structure of geotextile G4. The exposure to the action of tides also induced an increase of mass per unit area, but much more pronounced. Indeed, after 36 months, the mass per unit area of geotextile G4 was 687 g.m^{-2} (an increase of 424 g.m^{-2} relatively to its original mass per unit area). Again, the increase of mass per unit area can be explained by the accumulation of dust and dirt in the nonwoven structure of geotextile G4 and by the growth and development of algae (which completely covered its surface).

Similarly to what happened for mass per unit area, thickness also increased after the exposure to weathering and to the action of tides (the exposure to weathering caused a lower increase in thickness than the action of tides). The increase in thickness can be explained by the same reasons pointed before for the increase of mass per unit area (thickness is determined by applying pressure and the dust, dirt and algae present in the nonwoven structure made the geotextile less compressible).

3.2 *Evolution of tensile properties*

3.2.1 *Exposure to weathering*

The exposure to weathering provoked relevant changes in the tensile strength of geotextile G4 (Table 5). Indeed, after 1 year, tensile strength was reduced to 69.2% of its original value. The increase of the exposure time led to more pronounced reductions of tensile strength (retained tensile strengths of 55.6% and 40.6% after 2 and 3 years, respectively). Like tensile strength, elongation at maximum load also decreased during the exposure to weathering (higher reductions for higher exposure times). Figure 1 shows the mean curves tensile force-elongation obtained for geotextile G4 before and after exposure to weathering. The analysis of these curves shows that, besides the decreases in tensile strength and elongation at maximum load, the exposure to weathering also provoked an increase in the stiffness of geotextile G4.

Table 5. Tensile properties of geotextile G4 before and after weathering

Exposure time (years)	T ($kN.m^{-1}$)	E_{ML} (%)	RTS (%)
0	13.3 (1.6)	75.8 (6.1)	---
1	9.2 (1.0)	44.0 (2.9)	69.2
2	7.4 (1.2)	41.1 (2.3)	55.6
3	5.4 (0.8)	34.0 (2.0)	40.6

(in brackets are the obtained standard deviations)

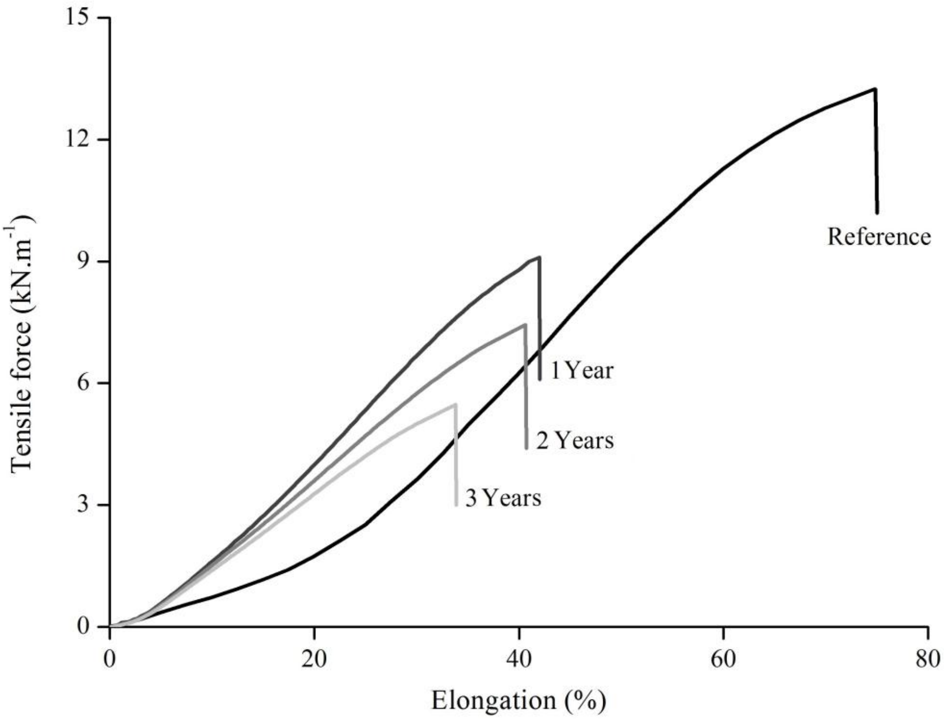

Figure 1. Mean curves tensile force-elongation of geotextile G4, before and after the exposure to weathering

The deterioration observed in the mechanical properties of geotextile G4 during the exposure to weathering can be mainly attributed to the damaging action of UV radiation. Other agents (like rain, dew or temperature changes) can also have contributed, but much less significantly. Indeed, the harmful effect of UV radiation in the deterioration of PP products is well known.

The presence of the UV-stabiliser C944 was unable to prevent the occurrence of degradation in geotextile G4 (reduction in tensile strength) during the exposure to weathering. However, it enhanced the weathering resistance of the PP fibres much significantly, retarding degradation. Indeed, in the absence of C944, the geotextile would be totally destructed (tensile strength reduced to zero) after 1 year of exposure to weathering (Carneiro *et al.*, 2012).

3.2.2 *Immersion in seawater*

The tensile strength of geotextile G4 remained practically unaltered during the 3-year immersion in seawater (retained tensile strengths between 104.5% and 109.0%) (Table 6). Contrary to tensile strength, elongation at maximum load suffered a slight decrease (identical reduction for all exposure times). The reduction occurred in elongation at maximum load was probably due to the accumulation of high amounts of sand in the nonwoven structure of the geotextile, which led to an increase of its rigidity. Globally, geotextile G4 had a good resistance against seawater (the 3-year immersion in seawater did not cause very pronounced changes in the tensile behaviour of geotextile G4).

Table 6. Tensile properties of geotextile G4 before and after immersion in seawater

Exposure time (years)	T ($kN.m^{-1}$)	E_{ML} (%)	RTS (%)
0	13.3 (1.6)	75.8 (6.1)	---
1	14.5 (1.5)	60.7 (3.5)	109.0
2	13.9 (2.1)	61.4 (4.2)	104.5
3	14.2 (1.3)	59.9 (1.9)	106.8

(in brackets are the obtained standard deviations)

3.2.3 *Exposure to the action of tides*

The tensile strength of geotextile G4 suffered a considerable increase after exposure to the action of tides (Table 7). Indeed, after 1 year, the retained tensile strength was 154.9%. Even after 3 years, the tensile strength was higher than its original value (retained tensile strength of 120.3%). The increase in tensile strength can be explained by the presence, in large amounts, of algae and dirt in the geotextile. The growth of algae promoted the formation of new bonds within the nonwonven structure of the geotextile (bonds between the algae and the fibres) and the accumulated dirt led to an increase in rigidity (such increase was perceptible by touch).

Table 7. Tensile properties of geotextile G4 before and after the exposure to the action of tides

Exposure time (years)	T ($kN.m^{-1}$)	E_{ML} (%)	RTS (%)
0	13.3 (1.6)	75.8 (6.1)	---
1	20.6 (1.5)	69.6 (6.0)	154.9
2	19.6 (2.0)	63.4 (5.5)	147.4
3	16.0 (1.0)	61.1 (4.9)	120.3

(in brackets are the obtained standard deviations)

Contrarily to tensile strength, elongation at maximum load did not increase after the exposure to the action of tides. In fact, a slight decrease occurred in elongation at maximum load (after 3 years, reduction from 75.8% to 61.1%). The mean curves tensile force-elongation obtained for geotextile G4, before and after the exposure to the action of tides, can be found in Figure 2. The analysis of these curves shows that the action of tides caused an increase in stiffness of geotextile G4 (increase due to the algae and dirt present in the nonwoven structure of the geotextile).

During the exposure to the action of tides, the test-samples were exposed for a long period of time (when they were emerged) to solar radiation and to other weathering agents. The results previously presented in section 3.2.1 showed that the action of weathering provoked a pronounced reduction in tensile strength (after 3 years of exposure, retained tensile strength of 40.6%). So, it would be expected that the action of tides could also promote some decrease in tensile strength (due to the periods in which the test-samples were emerged and in direct contact with solar radiation). However, this decrease did not occur (by contrary, there was even a pronounced increase in tensile strength). This happened because the surface of the geotextile was covered by a large quantity of algae, which protected it from being directly exposed to the damaging action of solar radiation. The dirt accumulated in the nonwoven structure (filling the empty spaces between the PP fibres) may also have delayed the degradation process by preventing solar radiation from reaching the geotextile (sunblind effect). Like before, the action of seawater (during the immersion periods) did not led to a decrease in the mechanical resistance of the geotextile.

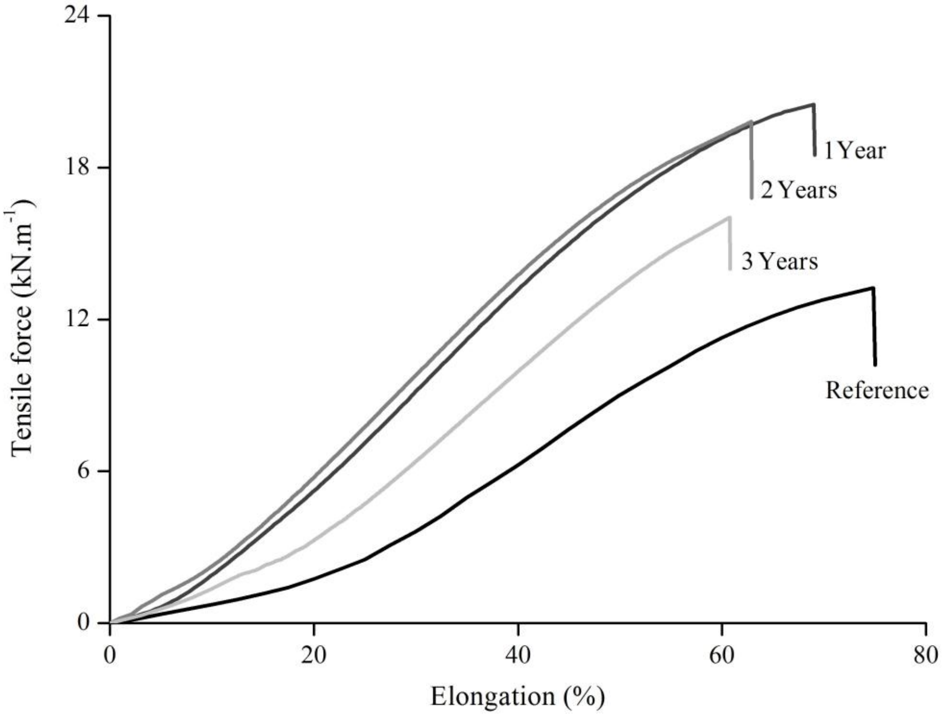

Figure 2. Mean curves tensile force-elongation of geotextile G4, before and after the exposure to the action of tides

4 CONCLUSIONS

The outdoor degradation tests (exposures *in situ* to degradation agents present in marine environments: weathering, seawater and action of tides) led to some relevant changes in the physical and mechanical properties of a nonwoven geotextile. However, the changes provoked by each degradation test were significantly different.

The exposure to weathering induced a relevant decrease in the tensile strength of the geotextile (higher decreases for higher exposure times). Contrarily to the exposure to weathering, the immersion in seawater did not cause a reduction in tensile strength. By contrast, the exposure to the action of tides led to a pronounced increase in tensile strength. Despite the differences observed in the behaviour of tensile strength, the degradation tests provoked a decrease (more or less pronounced) in elongation at maximum load. The degradation tests also caused an increase in the stiffness of the geotextile (increase due to the dirt, algae or sand accumulated in the nonwoven structure). Finally, mass per unit area and thickness suffered a “false” increase after exposure to weathering (accumulation of dust and dirt) and after exposure to the action of tides (growth of algae and accumulation of dirt).

The deterioration of the mechanical properties during the exposure to weathering can be mainly attributed to the damaging action of UV radiation. The degradation promoted by UV radiation did not occur (at least, much significantly) during the exposure to the action of tides because the presence of high amounts of algae and dirt impeded solar radiation from reaching the nonwoven structure, protecting the geotextile from photodegradation. The algae and dirt accumulated in the nonwoven structure were also responsible for the increase occurred in tensile strength after the exposure to the action of tides. Globally, the geotextile presented a quite good resistance against the action of seawater.

ACKNOWLEDGEMENTS

The authors would like to thank “Carvalhos Lda.” (Lousã, Portugal) for supplying the geotextile studied in this work, “Portos dos Açores S.A.” (Horta, Portugal) for giving the place for exposing the geotextile to the action of tides and “FCT - Fundação para a Ciência e a Tecnologia” for the financial support. J.R. Carneiro would also like to thank “FCT” for his research grant: reference SFRH/BPD/88730/2012 (grant supported by POPH/POCH/FSE funding).

REFERENCES

Carneiro, J.R.C. (2009) Durability of geosynthetics in environmental structures – the importance of chemical additives, *PhD Thesis in Environmental Engineering*, University of Porto, LXVIII-534p. (in Portuguese).

Carneiro, J.R., Morais, L.M. and Lopes, M.L. (2012) Ageing of geotextiles in marine environments, *Proceedings of the 5th European Geosynthetics Congress*, vol. 3, pp. 26-30 (CD-ROM).

EN 29073-3 (1992) Textiles – Test method for nonwovens. Part 3: determination of tensile strength and elongation.

EN ISO 9862 (2005) Geosynthetics – Sample and preparation of test specimens.

EN ISO 9863-1 (2005) Geosynthetics – Determination of thickness at specified pressures. Part 1: single layers

EN ISO 9864 (2005) Geosynthetics – Test method for the determination of mass per unit area of geotextiles and geotextile-related products.