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# Weathering resistance of an unstabilised polypropylene geotextile

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## ABSTRACT

Polymers degrade when exposed to ultraviolet radiation and other weathering agents. In this work, the weathering resistance of a polypropylene geotextile is evaluated. The geotextile, which had a mass per unit area of ≈500 g/m$^2$, was manufactured without chemical additives (i.e., 100% polypropylene) for research purposes. The geotextile was exposed to natural weathering in Portugal for a maximum period of 24 months. Samples were collected every 3 months for characterisation. The degradation suffered by the geotextile was evaluated by monitoring changes in its physical (mass per unit area and thickness) and mechanical (tensile) properties. Infrared spectroscopy was used to detect chemical changes in the geotextile. The resistance of the geotextile under natural degradation conditions was compared with its resistance under accelerated degradation conditions. To this end, artificial weathering tests were carried out in a laboratory weatherometer, where the geotextile was exposed to ultraviolet radiation, water spray and condensation. The weathering tests (both in the field and in the laboratory) induced very pronounced changes in the properties of the geotextile, which was completed destroyed. The reduction in tensile strength that occurred in 18 to 21 months in the field (>90%) was replicated in ≈10 days in the laboratory weatherometer. Infrared spectroscopy proved to be a useful technique to assess the photo-degradation of field weathered polypropylene geotextiles. Artificial weathering tests have shown their usefulness as screening tests, being a good tool to detect polypropylene geotextiles with low resistance to weathering. The use of unstabilised or poorly-stabilised geotextiles is not recommended.

*Keywords: geosynthetics, geotextiles, polypropylene, durability, weathering, ultraviolet radiation*

## 1. INTRODUCTION

The use of geosynthetics in civil engineering is nowadays a common practice due to the advantages it entails. These materials are very versatile, cost-effective, durable, environmentally friendly and easy to install, which has promoted their use in a very wide range of applications. Examples of environmental applications include, among others, waste storage, coastal protection or reconstruction, and remediation of contaminated sites. There are several types of geosynthetics, with geotextiles being one of the most common. This is explained by their ability to perform many different functions (e.g., filtration, drainage, separation, protection or reinforcement).

As other plastic materials, geosynthetics have a limited resistance to weathering. The exposure to solar radiation (mainly to ultraviolet (UV) radiation, which is highly energetic) and to other weathering agents (e.g., heat, air or moisture) can induce meaningful changes in the properties of geosynthetics, impacting their performance and reducing their service life. In most applications, geosynthetics are exposed to weathering for a short period (time required for installation operations) and are soon covered by soils or liquids. However, there are cases (e.g., in waste landfills or in coastal protection structures) where the exposure period may be long.

Over the years, experience has shown some premature failures of geosynthetics under exposure to UV radiation and other weathering agents. The reasons for this can be many, including an improper design or use of inappropriate products, e.g., due to poor chemical stabilisation. The weathering resistance of geosynthetics can be highly improved by chemical additives (added during the manufacturing process) such as UV stabilisers and antioxidants. However, and unfortunately, the stabilisation package (name and concentration of chemical additives) is not normally disclosed by the manufacturers on geosynthetic data sheets. Like other products, the quality of geosynthetics varies, with some materials having better chemical stabilisation than others (which influences their resistance to weathering).

The weathering resistance of geosynthetics can be evaluated by field (Carneiro & Lopes, 2017; Carneiro et al., 2018) or by laboratory tests (Carneiro et al., 2011). Field tests are usually time consuming (some months or years) but have the advantage of providing accurate results about the weathering resistance of geosynthetics. Laboratory tests use accelerated degradation conditions in a controlled environment and can provide results very quickly (days or weeks). However, extrapolation from laboratory behaviour to the field is often complicated.

In this work, an unstabilised polypropylene (PP) geotextile was exposed to weathering, both in the field (natural weathering tests) and in the laboratory (artificial weathering tests). The main aim of the work was to determine how long a PP geotextile without chemical additives resists the degradation promoted by weathering. In the field tests, the effects of weathering were determined by monitoring changes in the physical and tensile properties of the geotextile. Infrared spectroscopy analysis was also used to monitor degradation. In the laboratory tests, degradation was evaluated only by monitoring changes in tensile properties. The product tested in this work can be regarded as an extreme scenario (lower limit) of weathering resistance of PP geotextiles. By advance, it should be noted that the use of unstabilised geotextiles in civil engineering works is by no means recommended.

## 2. MATERIALS AND METHODS

### 2.1 Geotextile

The experimental activities were carried out with a nonwoven geotextile (needle-punched type) that had a nominal mass per unit area of 500 g/m$^2$ (manufacturer value). The geotextile, which was manufactured for research purposes, was made from PP fibres without chemical stabilisers, i.e., its composition was 100% PP. The fibres had a diameter of approximately 30-40 µm. The geotextile was white in colour.

### 2.2 Weathering tests

The geotextile was exposed to two types of weathering tests: field weathering (under natural degradation conditions) and artificial weathering (under accelerated degradation conditions). The field weathering tests were conducted in Portugal (latitude 41º13'N and longitude 8º39'W). The geotextile was exposed facing south with an inclination of 30º. The field weathering tests started in late autumn and lasted for 24 months, with samples collected for characterisation every 3 months. The climatic conditions of the exposure site can be consulted in Carneiro & Lopes (2022).

The artificial weathering tests consisted of exposing the geotextile to UV radiation (fluorescent UVA-340 lamps), water spray and condensation, simulating the effects of solar radiation, rain and moisture. These tests were performed in a laboratory weatherometer (Q-Panel Lab Products, model QUV/spray). The tests included exposures of 125, 250 and 500 hours to the following weathering cycle:

Step 1: UV radiation (4 hours; 60 ºC)
Step 2: Water spray (10 minutes; water at room temperature; flow of 5 L/min)
Step 3: Condensation (4 hours; 45 ºC)

The weatherometer remained in a loop, alternating between UV radiation, water spray and condensation steps, until the test durations were complete. The water spray and condensation steps were performed with the UVA-340 lamps turned off, i.e., in the dark. In the UV radiation step, the lamps operated with an irradiance of 0.68 W/m$^2$ at 340 nm. The total UV (290-400 nm) radiant exposures ($E_{UV}$) of the artificial weathering tests can be found in Table 1 (information about the total number of weathering cycles, N, is also present).

***Table 1.*** *UV radiant exposure of the artificial weathering tests.*

| Time (hours) | N | $E_{UV}$ (MJ/m$^2$) |
|---|---|---|
| 125 | 15.3 | 8.6 |
| 250 | 30.6 | 17.3 |
| 500 | 61.2 | 34.6 |

In addition to the previous tests, a test was carried out following, as closely as possible, the EN 12224 (2000) method. This laboratory test consisted of exposing the geotextile to a weathering cycle composed of UV radiation (5 hours at 50 ºC) and water spray (10 minutes). The test lasted for 362 hours (about 70 weathering cycles) and had a total UV radiant exposure of 50 MJ/m$^2$. The water spray step (10 minutes) lasted less than specified in EN 12224 (2000) (60 minutes). This change, which is expected to have a very small impact on the results, was necessary due to limitations in the laboratory, namely in the water purification system (the weatherometer requires the use of purified water).

## 2.3 Characterisation tests

The degradation suffered by the geotextile in the field and artificial weathering tests was evaluated by comparing the properties of weathered and intact samples. Standard methods were used to determine the physical and tensile properties of the geotextile. Results are displayed with 95% confidence intervals. In some cases, the results are expressed in terms of variation, obtained as follows:

$$\Delta X = [(X_{\mathrm{Weathered}} - X_{\mathrm{Intact}}) / X_{\mathrm{Intact}}] \times 100 \qquad (1)$$

where $\Delta X$ represents the variation of property X, and $X_{\mathrm{Intact}}$ and $X_{\mathrm{Weathered}}$ correspond, respectively, to property X before and after the weathering tests. Variations were calculated for mass per unit area ($\Delta\mu_A$), thickness ($\Delta t$), tensile strength ($\Delta T$) and elongation at tensile strength ($\Delta E_T$).

### 2.3.1 Physical tests

Mass per unit area ($\mu_A$, in g/m$^2$) and thickness ($t$, in mm) were obtained according to EN ISO 9864 (2005) and EN ISO 9863-1 (2016), respectively. Thickness was determined by applying a pressure of 2 kPa to the geotextile. The mass per unit area and thickness results correspond to the average test values of at least 10 specimens (square specimens with a side of ≈100 mm).

### 2.3.2 Tensile tests

The tensile behaviour of the geotextile was determined by two methods, depending on the samples. For field weathered samples, the EN ISO 10319 (2015) method was adopted, while the EN 20973-3 (1992) method was applied to artificially weathered samples. As a reference to monitor changes in the tensile behaviour of the geotextile, the intact sample was tested by both tensile methods. The use of two tensile methods was related to the dimensions of the specimens exposed in the artificial weathering tests, which were incompatible with the EN ISO 10319 (2015) method. Their dimensions were defined by the space available in the weatherometer.

The properties determined in the tensile tests (specimens tested in the machine direction of production) included tensile strength (T, in kN/m) and elongation at tensile strength ($E_T$, in %). Table 2 summarizes the main characteristics of the tensile tests, with N representing the number of specimens tested in each sample (minimum number), L the length (between grips) and W the width of the specimens, and $v$ the test speed. Elongation was measured based on the displacement of the grips.

***Table 2.*** *Tensile tests.*

| Method | N | L (mm) | W (mm) | $v$ (mm/min) |
|---|---|---|---|---|
| EN ISO 10319 | 5 | 100 | 200 | 20 |
| EN 29073-3 | 5 | 200 | 50 | 100 |

### 2.3.3 Infrared spectroscopy

PP fibres (mass of ≈5 mg) were removed from the geotextile and mechanically pressed to form translucid pellets. These pellets were analysed on a FTIR (Fourier-transform infrared spectroscopy) spectrometer operating in transmission mode, with a resolution of 2 cm$^{-1}$ in the wavenumber range between 450 and 4440 cm$^{-1}$. FTIR analyses were performed for the intact sample and some field weathered samples (6, 12, 18 and 21 months) – each sample was analysed in triplicate. In the latter case, the PP fibres were removed from the area directly exposed to UV radiation and other weathering agents.

## 3. RESULTS AND DISCUSSION

### 3.1 Field weathering

### 3.1.1 Visual inspection

The colour of the geotextile, originally white, turned grey during the field weathering tests. This happened due to the accumulation of dirt (e.g., dust and small particles of soil or plant species brought by the wind) on and between the PP fibres. At months 3 and 6, the geotextile showed no visible damage. By contrast, at month 9, the material released small pieces of degraded fibres (which can be described as a white or grey powder), indicating the existence of degradation in its polymeric structure. Degradation was more noticeable at month 12 – the geotextile was more fragile and the amount of degraded fibres that were released was greater. This resulted in a reduction in the thickness of the geotextile, which was easily detectable with the naked eye.

The geotextile degradation process continued in the following months of exposure, with continuous loss of fibres. At month 21, the material was highly damaged and extremely fragile – it had areas where the amount of fibres was very small and it was possible to destroy it manually. The total disintegration of the geotextile occurred between months 21 and 24. Small pieces of the material were carried away by the wind and found near the exposure site.

### 3.1.2 Physical properties: mass per unit area and thickness

The mass per unit area of the geotextile decreased significantly during the field weathering tests (Table 3). At month 9, when degraded fibres were visually detected, the loss in mass per unit area was 17.4%. As the exposure time increased, the mass loss also increased. At months 18 and 21, the geotextile had masses per unit area of, respectively, 300 g/m$^2$ (59.9% of the original value) and 157 g/m$^2$ (31.3% of the original value). The mass loss between months 18 and 21 (i.e., 143 g/m$^2$) was very large, indicating that rapid degradation of the material had occurred. Extending the exposure time to 24 months caused the complete destruction of the geotextile, making it impossible to determine its mass per unit area.

***Table 3.*** *Physical properties of the geotextile before and after the field weathering tests.*

| Time (months) | $\mu_A$ (g/m$^2$) | $\Delta\mu_A$ (%) | $t$ (mm) | $\Delta t$ (%) |
|---|---|---|---|---|
| 0 | 501 ± 45 | --- | 3.81 ± 0.08 | --- |
| 3 | 496 ± 32 | -1.0 | 4.01 ± 0.09 | +5.2 |
| 6 | 461 ± 39 | -8.0 | 3.93 ± 0.05 | +3.1 |
| 9 | 414 ± 27 | -17.4 | 2.91 ± 0.01 | -23.6 |
| 12 | 399 ± 45 | -20.4 | 2.83 ± 0.10 | -25.7 |
| 15 | 342 ± 28 | -31.7 | 2.58 ± 0.06 | -32.3 |
| 18 | 300 ± 33 | -40.1 | 2.48 ± 0.09 | -34.9 |
| 21 | 157 ± 7 | -68.7 | 1.93 ± 0.05 | -49.3 |

The decrease in mass per unit area can be explained by the degradation of the geotextile, which resulted in the release of degraded fibres in large quantities, as detected in the visual inspection. As mentioned before, the colour of the geotextile has changed to grey due to the accumulation of dirt in its nonwoven structure. This accumulated dirt is obviously being taken into account in the mass per unit area test (it is not possible to remove it before the test) and therefore contributes to increase the mass per unit area value. In this way, the values of mass per unit area presented in Table 3 are influenced not only by the degradation of the PP fibres (which results in a loss of polymeric mass) but also by the accumulation of dirt in the nonwoven structure. In this perspective, the loss of polymeric mass (due to the degradation of the PP fibres) could be even more pronounced than that indicated by the results shown in Table 3. It is interesting to compare the degradation suffered by the unstabilised geotextile with that experienced by a stabilised one (also with a mass per unit area ≈500 g/m$^2$) under the same degradation conditions (Carneiro & Lopes, 2022). As shown in Figure 1, the mass per unit area decreased in the unstabilised geotextile (for reasons already presented) and slightly increased in the stabilised one (as a consequence of the accumulation of dirt in the nonwoven structure). As additional information, the stabilised geotextile had in its composition a hindered amine light stabiliser and carbon black (Carneiro & Lopes, 2022).

As immediately indicated by the visual inspection, the field weathering tests caused a decrease in the thickness of the geotextile (Table 3). Exceptions were observed at months 3 and 6, where there may even have been a slight increase (Δ*t* of, respectively, +5.2% and +3.1%). Although the period 1-6 months did not result in very relevant changes in thickness, the period 7-9 months (corresponding to the warmer and sunnier months in Portugal) significantly affected this parameter – reduction of 1.02 mm between months 6 and 9. From that moment on, the thickness tended to decrease with increasing exposure time. At 18 months, the geotextile had a thickness of 2.48 mm, about 65% of the original value. The thickness decreased by 0.55 mm between months 18 and 21 (again warmer and sunnier months in Portugal), with the geotextile having approximately 51% of the original thickness at month 21. As for mass per unit area, the decrease in thickness can be explained by the high degradation suffered by the geotextile (UV radiation played an important role in promoting the degradation of PP fibres), with very pronounced loss of polymeric mass. The variations observed at months 3 and 6 may result from the dirt accumulated in the nonwoven structure of the geotextile, making it less compressible (thickness was determined under application of pressure, namely 2 kPa). In addition to the mass per unit area comparison, Figure 1 also compares the variation in thickness of the unstabilised and stabilised geotextiles. While the thickness of the unstabilised geotextile decreased (for reasons already discussed), the thickness of the stabilised geotextile increased (due to the accumulation of dirt in the nonwoven structure and significantly better resistance to weathering).

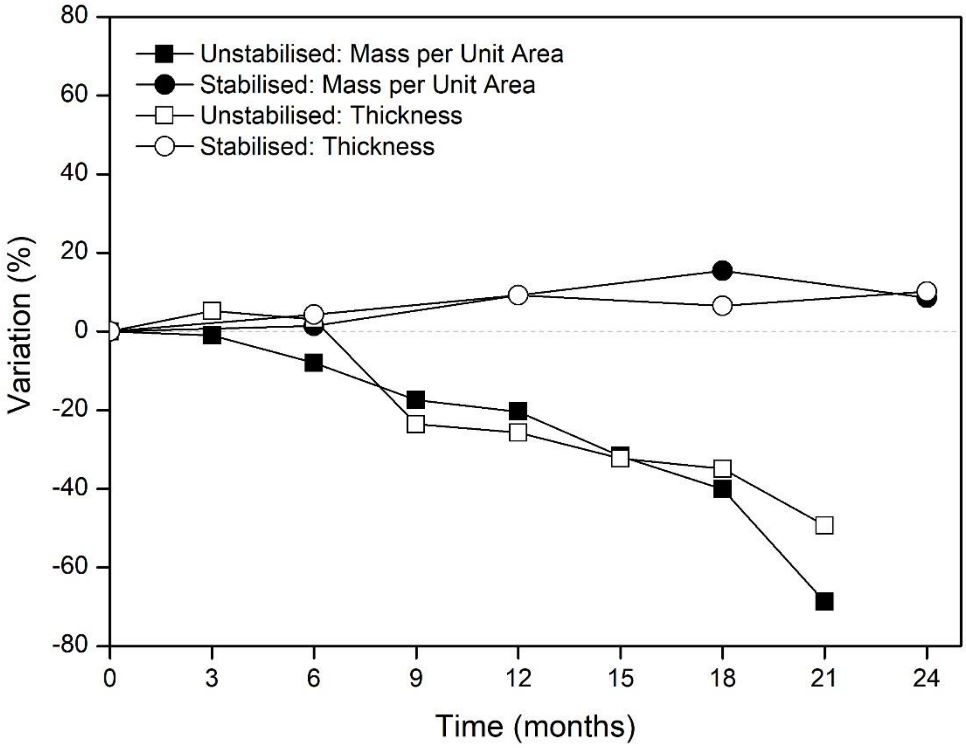

***Figure 1.*** *Percent variation of physical properties (mass per unit area and thickness) of geotextiles exposed to field weathering: unstabilised geotextile vs. stabilised geotextile. The stabilised geotextile data was collected from Carneiro & Lopes (2022).*

### 3.1.3 Mechanical properties: tensile behaviour

The results presented in the previous sections immediately indicated the existence of relevant changes in the tensile behaviour of the geotextile. The tensile properties of the material, obtained before and after the field weathering tests, can be found in Table 4. The corresponding tensile force *vs.* elongation curves (mean curves) are illustrated in Figure 2.

The exposure period 1-3 months did not cause a decrease in the tensile strength of the geotextile (ΔT of +7.1% at month 3). However, after this period, considerable changes were detected in this parameter, which tended to be more pronounced with increasing exposure time. At month 6, a 26.0% loss in tensile strength had already occurred. This loss indicates the existence of degradation in the geotextile, which was not perceptible by visual inspection. Degradation was also not undoubtedly indicated by the values obtained for the physical properties: the mass per unit area had a small decrease (ΔμA of – 8.0%), but inconclusive taking into account the 95% confidence intervals, and the thickness remained practically unchanged (Δ*t* of +3.1%).

***Table 4.*** *Tensile properties of the geotextile before and after the field weathering tests.*

| Time (months) | T (kN/m) | ΔT (%) | $E_T$ (%) | $\Delta E_T$ (%) |
|---|---|---|---|---|
| 0 | 25.61 ± 1.37 | --- | 135.9 ± 7.4 | --- |
| 3 | 27.43 ± 1.50 | +7.1 | 119.7 ± 10.0 | -11.9 |
| 6 | 18.95 ± 2.78 | -26.0 | 63.3 ± 4.7 | -53.4 |
| 9 | 12.31 ± 1.80 | -51.9 | 37.3 ± 2.8 | -72.6 |
| 12 | 6.00 ± 1.40 | -76.6 | 22.7 ± 1.3 | -83.3 |
| 15 | 2.92 ± 0.80 | -88.6 | 19.5 ± 1.9 | -85.7 |
| 18 | 2.39 ± 1.52 | -90.7 | 18.8 ± 3.7 | -86.2 |
| 21 | 0.10 ± 0.02 | -99.6 | 14.5 ± 3.4 | -89.3 |
| 24 | 0 | -100.0 | --- | --- |

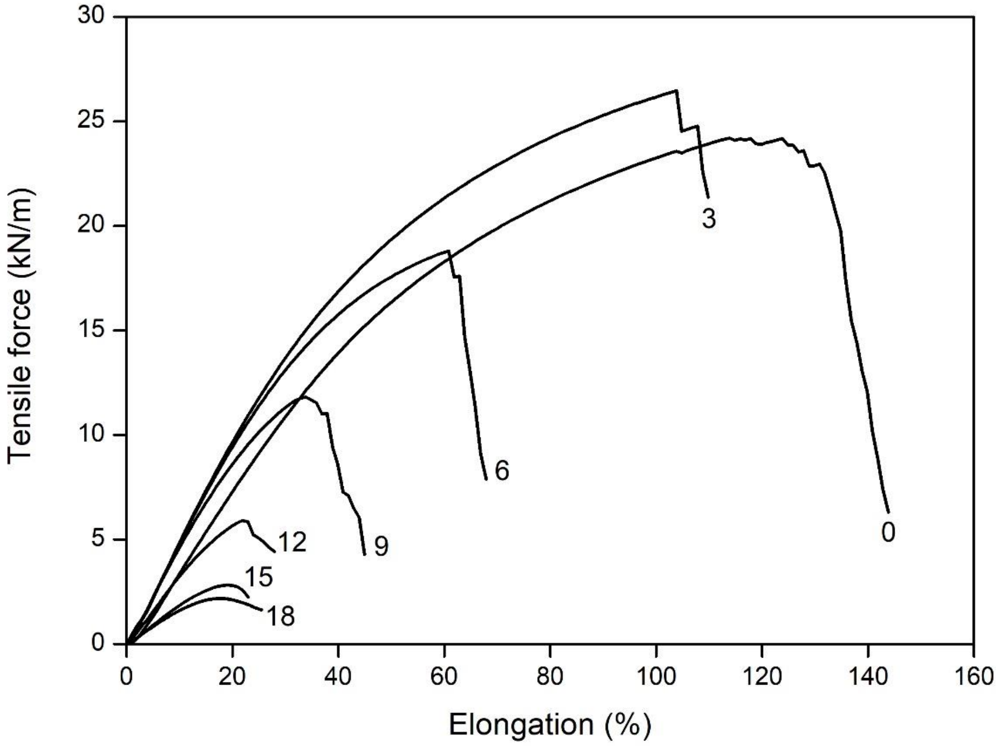

***Figure 2.*** *Mean tensile force vs. elongation curves of the geotextile obtained before and after the field weathering tests (the numbers next to the curves denote the exposure time, in months, to weathering).*

The loss of tensile strength between months 6 and 12 was very high. The 26.0% loss in month 6 turned to 51.9% and 76.6% in months 9 and 12, respectively. The deterioration of the tensile behaviour of the geotextile can be explained by the degradation of its nonwoven structure (caused by UV radiation and other weathering agents), which was easily detectable by the naked eye and evidenced by the variations that occurred in mass per unit area and thickness. The degradation process continued and, at month 18, the loss of tensile strength was 90.7%. The geotextile was very close to full degradation at month 21, presenting a tensile strength loss of 99.6%.

In general, the elongation at tensile strength exhibited the same behaviour as the tensile strength, i.e., both parameters tended to decrease with increasing exposure time. As shown in Table 4, the percentage variations that occurred in these two parameters were not even very different in some cases. Exceptions occurred, for example in month 3, where the tensile strength did not decrease (ΔT of +7.1%) and there was a reduction in the corresponding elongation ($\Delta E_T$ of -11.9%). Other examples include months 6 and 9, where percentage reductions in elongation at tensile strength were more pronounced than in tensile strength.

In addition to the changes in tensile strength, and corresponding elongation, the field weathering tests induced changes in the stiffness of the geotextile. As illustrated in Figure 2, the stiffness of the samples exposed for 3, 6 and 9 months increased compared to the intact sample. This increase in stiffness may be due to dirt accumulated in the geotextile structure. Despite being very damaged as discussed above, the sample exposed for 12 months had, at low elongations (up to about 10%), a stiffness not remarkably different from that of the intact sample (for elongations higher than ≈10%, the stiffness was lower). The stiffness of the samples exposed for 15, 18 and 21 months was lower compared to the intact sample.

The above results show that the exposure to field weathering resulted in a relatively fast deterioration of the tensile behaviour of the geotextile. However, it is necessary to take into account that the material did not have stabilisers to improve its weathering resistance. Therefore, it is interesting to compare the degradation experienced by the unstabilised geotextile, now in terms of changes in tensile strength, with that of a stabilised one (Carneiro & Lopes, 2022) exposed to weathering under the same conditions (Figure 3). The results illustrated in Figure 3 are expressed in percentage residual values, obtained by dividing the tensile strength of the exposed samples by that of the respective intact sample.

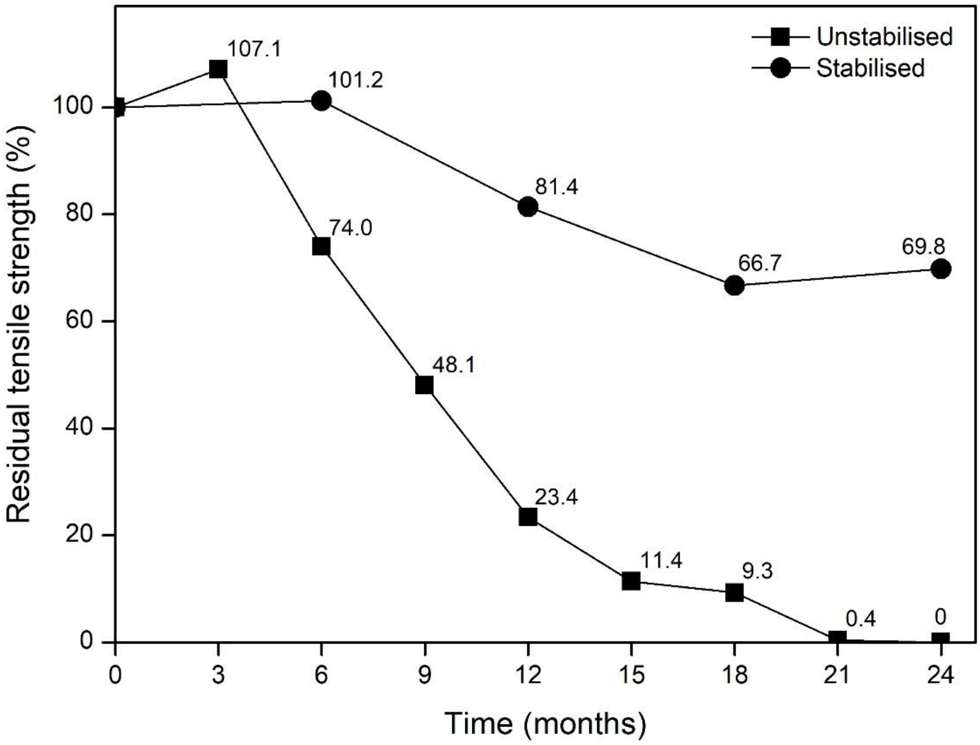

***Figure 3.*** *Residual tensile strength of geotextiles exposed to field weathering: unstabilised geotextile vs. stabilised geotextile. The stabilised geotextile data was collected from Carneiro & Lopes (2022).*

Figure 3 shows that the reduction of tensile strength was much faster in the unstabilised geotextile than in the stabilised one. For example, taking month 12 as a comparison, the geotextiles had residual tensile strengths of 23.4% and 81.4%, respectively. This comparison illustrates how the presence of chemical additives (in this case, UV stabilisers) can positively impact the weathering resistance of PP geotextiles. These compounds, which are normally present in small amounts (in this case, the stabilised geotextile had a mass percentage of PP of ≈98.7%), can significantly extend the lifetime of materials exposed to weathering (i.e., retard changes in their properties).

### 3.1.4 Infrared spectroscopy

The degradation of PP fibres was assessed by comparing the FTIR spectra obtained for weathered (6, 12, 18 and 21 months) and intact samples. Chemical alterations in weathered PP fibres can result in modifications in the FTIR spectra – e.g., increase or decrease of existing bands or appearance of new bands. The most important change in the FTIR spectra, when comparing intact and weathered samples, was the development of a new band centred at 1720 $cm^{-1}$. This band can be attributed to the presence of chemical species containing the carbonyl (C=O) group. Carbonyl compounds are normally formed during the photo-degradation process of PP.

As can be seen in Table 5, the height (absorbance) of the band at 1720 $cm^{-1}$ was not the same for all weathered samples. Indeed, with increasing exposure time, the height of the band increased, indicating the presence of more carbonyl compounds (i.e., higher degree of photo-degradation). This way, as the physical and mechanical properties of the geotextile deteriorated, the band at 1720 cm$^{-1}$ became more intense. It is, however, important to mention that the FTIR results (height of the band at 1720 cm$^{-1}$) had a relatively high dispersion, as demonstrated by the 95% confidence intervals (analyses were performed in triplicate). This could be related to the existing dirt in the weathered samples, which could have caused some interference in the FTIR analyses.

***Table 5.*** *FTIR analysis: height of the band at 1720 cm$^{-1}$ vs. exposure time.*

| Time (months) | $10^3$ Absorbance at 1720 cm$^{-1}$ (arb. unit) |
|---|---|
| 0 | 0.0 |
| 6 | 20.4 ± 16.6 |
| 12 | 37.9 ± 27.6 |
| 18 | 56.7 ± 32.8 |
| 21 | 178.4 ± 28.3 |

## 3.2 Artificial weathering: comparison with field weathering

The geotextile had visible damage (release of some broken fibres) after 125 hours (≈5 days) of artificial weathering. The increase of the exposure time promoted higher degradation. Indeed, after 250 hours, the geotextile released many degraded fibres (white powder), its thickness decreased and it was very fragile. The material was reduced to powder or small fragments after 500 hours. The artificial weathering tests did not induce relevant changes in the colour of the geotextile.

As easily understood from the above description, the tensile behaviour of the geotextile was drastically affected by the artificial weathering tests. The tensile properties of the geotextile and the corresponding tensile force *vs.* elongation curves can be found in Table 6 and Figure 4, respectively.

***Table 6.*** *Tensile properties of the geotextile before and after the artificial weathering tests.*

| Time (hours) | T (kN/m) | $\Delta$T (%) | $E_T$ (%) | $\Delta E_T$ (%) |
|---|---|---|---|---|
| 0 | 26.24 ± 1.66 | --- | 75.0 ± 3.6 | --- |
| 125 | 8.30 ± 3.54 | -68.4 | 29.6 ± 5.8 | -60.5 |
| 250 | 1.33 ± 0.86 | -94.9 | 10.3 ± 4.6 | -86.3 |
| 500 | 0 | -100.0 | --- | --- |

The tensile strength of the geotextile had a very pronounced reduction (loss of 68.4%) after 125 hours of artificial weathering. After 250 hours, the reduction in tensile strength was 94.9%, confirming that the material was critically degraded. It is interesting to note that the reduction in tensile strength in the period 1-125 hours (68.4%) was more significant than in the period 126-250 hours (26.5%). Similar to tensile strength, the corresponding elongation also decreased – the percentage reductions of both properties were not very different. Although the tensile strength (and corresponding elongation) decreased very significantly after 125 hours of artificial weathering, Figure 4 reveals that the stiffness of the geotextile remained practically unchanged for elongations up to about 15%, after which it decreased. The stiffness of the sample exposed for 250 hours decreased more markedly.

Knowing the behaviour of the geotextile in the laboratory, it is interesting to compare it with its behaviour in the field. As can be seen by analysing Tables 4 and 6, the reduction in tensile strength caused by 125 hours of artificial weathering ($\Delta$T of -68.4%) was intermediate between the reduction occurring between 9 and 12 months of field weathering ($\Delta$T of -51.9% and -76.6%, respectively). The loss of tensile strength of the geotextile after 250 hours of artificial weathering ($\Delta$T of -94.9%) was close to that occurred in the field exposures of 18 ($\Delta$T of -90.7%) and 21 ($\Delta$T of -99.6%) months. The comparison between field and artificial weathering also indicates that, using lower UV radiant exposures, the laboratory tests induced more marked changes in tensile strength. For example, 125 hours in the laboratory ($E_{UV}$ of 8.6 MJ/m$^2$) caused a greater decrease in tensile strength than 6 months in the field (predicted $E_{UV}$ of 164 MJ/m$^2$) – decreases of 68.4% and 26.0%, respectively. The faster degradation in the laboratory, despite the lower UV radiant exposure, can be attributed to the higher temperature at which the degradation process takes place. In the field weathering tests, the average air temperature in the period 1-6 months was 14.0 ºC (temperature not monitored at the geotextile surface), while 60 ºC (UV step) and 45 ºC (condensation step) were the temperatures to which the geotextile was exposed in the artificial weathering tests.

In addition to the previous laboratory weathering tests, the weathering resistance of the geotextile was further evaluated following, as closely as possible, the EN 12224 (2000) method. The results obtained by this method were the same as those obtained in the previous 500-hour test – the geotextile was reduced to small fragments or powder. As additional information, the tensile behaviour of the stabilised geotextile mentioned in Section 3.1 did not change significantly when exposed to artificial weathering tests identical to those carried out for the unstabilised geotextile (Carneiro & Lopes, 2022).

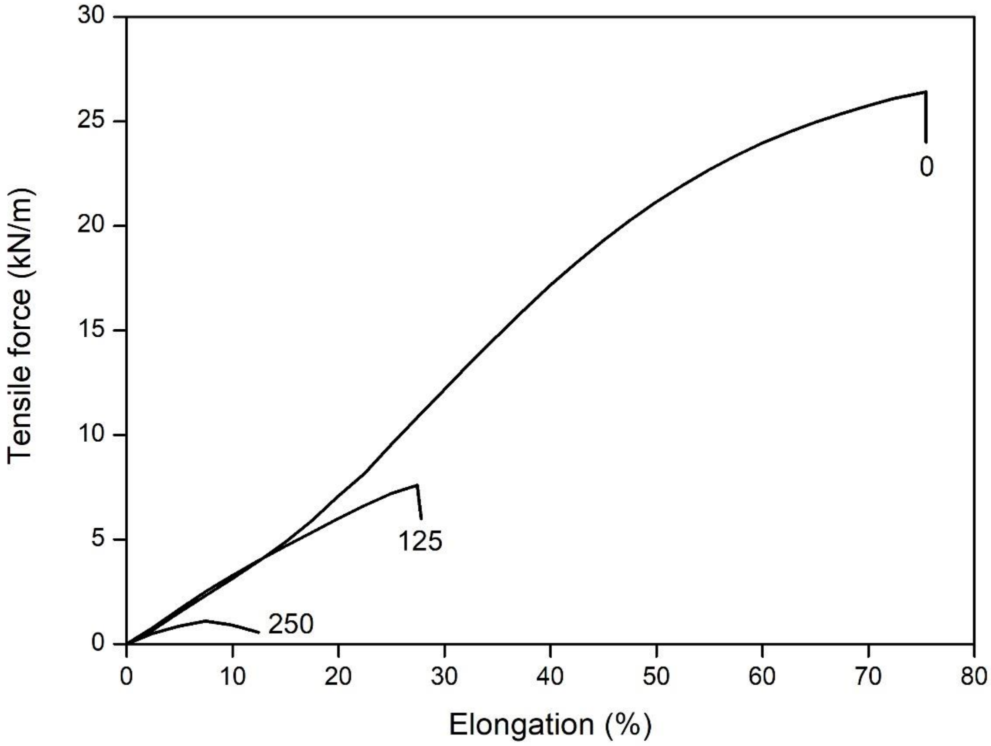

***Figure 4.*** *Mean tensile force vs. elongation curves of the geotextile obtained before and after the artificial weathering tests (the numbers next to the curves correspond to the exposure time, in hours, to weathering).*

The EN 12224 (2000) method intends to differentiate materials with low, or no, resistance to weathering from those that have some resistance to this type of degradation. According to the results obtained, the geotextile under study does not show resistance to weathering. ISO/TR 20432 (2007) is a guide aimed at determining the long-term strength of geosynthetics for soil reinforcement. This guide indicates that a geosynthetic with a residual tensile strength under 60% after the EN 12224 (2000) method should not be uncovered during installation for more than 1 day. However, it is not advisable to use PP geotextiles with low resistance to weathering, as these materials are also likely to have low resistance to oxidation induced by temperature. Premature failure of materials should be avoided in all cases.

To conclude this section, it is important to leave a note on the tensile behaviour of the intact sample. As mentioned before, depending on the weathering test, two different test methods were used to determine the tensile behaviour of the geotextile. As can be observed in Tables 4 and 6, the tensile strength of the geotextile (intact sample) did not have considerable differences when tested by EN ISO 10319 (2015) or EN 29073-3 (1992) – values of 25.61 and 26.24 kN/m, respectively. With regard to the elongation at tensile strength, differences were found between the methods, which can be explained by the different test conditions (e.g., use of specimens with different lengths and widths, as referred to in Section 2.3.2).

## 4. CONCLUSIONS

This work evaluated the resistance of an unstabilised geotextile (100% PP) to weathering under natural (field tests) and accelerated (laboratory tests) conditions. The damage experienced by the geotextile in the field weathering tests was evaluated by monitoring changes in its physical (mass per unit area and thickness) and tensile properties, and by infrared spectroscopy. In the artificial weathering tests, damage was evaluated only by monitoring changes in the tensile behavior of the geotextile.

The field weathering tests had a very pronounced impact on the physical and mechanical properties of the geotextile. Mass per unit area and thickness decreased over time (loss of polymeric mass), showing the existence of high degradation in the geotextile, which did not survive (full destruction) 24 months of field weathering. Naturally, the tensile properties of the geotextile also degraded over time. Compared with a stabilised geotextile, the unstabilised geotextile had a much lower resistance to weathering.

Chemical changes were found in the FTIR spectra of the field weathered samples. A new band (centred at 1720 $cm^{-1}$) developed as exposure time increased. The intensity of this band correlated relatively well with the physical and tensile results (i.e., higher intensity, higher degradation of properties). Therefore, it can be a good analytical marker of photo-degradation of PP geotextiles.

The artificial weathering tests also caused complete degradation of the geotextile, although much more quickly than in the field tests. The reduction in tensile strength observed after ≈10 days under artificial conditions ($\Delta T$ of -94.9%) was close to that occurred under field conditions during 18 ($\Delta T$ of -90.7%) and 21 ($\Delta T$ of -99.6%) months. The artificial weathering test following, as closely as possible, the EN 12224 (2000) method indicated that the geotextile had a poor resistance to weathering. Even so, it still resisted some time under natural degradation conditions.

The laboratory tests (under accelerated degradation conditions) proved to be a quick and viable option to detect unstabilised PP geotextiles, as they promoted their complete degradation. Contrary to the field weathering tests, the conditions of the laboratory tests are controlled and reproducible, which, together with their speed, makes them a suitable tool to screen the weathering resistance of PP geotextiles. So, they can be useful to detect and exclude materials with inadequate resistance to UV radiation.

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## REFERENCES

Carneiro, J. R., Almeida, P. J., & Lopes, M.L. (2011). Accelerated weathering of polypropylene geotextiles. Science and Engineering of Composite Materials, 18(4), 241-245.

Carneiro, J. R., & Lopes, M.L. (2017). Natural weathering of polypropylene geotextiles treated with different chemical stabilisers. Geosynthetics International, 24(6), 544-553.

Carneiro, J. R., & Lopes, M.L. (2022). Weathering of a nonwoven polypropylene geotextile: field vs. laboratory exposure. Materials, 15(22), ID 8216, 18p.

Carneiro, J. R., Morais, M., & Lopes, M.L. (2018). Degradation of polypropylene geotextiles with different chemical stabilisations in marine environments. Construction and Building Materials, 165, 877-886.

EN 12224 (2000). Geotextiles and geotextile-related products – Determination of the resistance to weathering. European Committee for Standardization, Brussels, Belgium.

EN 29073-3 (1992). Textiles – Test methods for nonwovens. Part 3: Determination of tensile strength and elongation. European Committee for Standardization, Brussels, Belgium.

EN ISO 9863-1 (2016). Geosynthetics – Determination of thickness at specified pressures. Part 1: Single layers. European Committee for Standardization, Brussels, Belgium.

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

EN ISO 10319 (2015). Geosynthetics – Wide-width tensile test. European Committee for Standardization, Brussels, Belgium.

ISO/TR 20432 (2007). Guidelines for the determination of the long-term strength of geosynthetics foi soil reinforcement. International Organization for Standardization, Geneva, Switzerland.

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