Assessment of chemical resistance of polyester and polypropylene geosynthetics in an aggressive environment

L. Naga[1]
M. Chikhaoui[1]
L. Djerbal[1]
[1]Laboratory of Environment, Water, Geomechanics and Structures (LEEGO), Faculty of Civil Engineering, University of Science and Technology Houari Boumediene (USTHB), Algiers, Algeria.

ABSTRACT: In aggressive soil reinforcement applications, geosynthetics are exposed to chemical agents that can alter their properties and reduce their mechanical performances. An accelerated aging test was conducted to explore the degradation mechanisms of geosynthetics in acidic environments and enhance the understanding of their durability. This study investigates the effects of varying concentrations of sulfuric acid (0.8 mol/L, 1.9 mol/L, and 3.1 mol/L) on a polyester geotextile and a polypropylene geogrid after one month at 80°C. Density changes were measured using a gas pycnometer, and surface morphology was analyzed with scanning electron microscopy, while mechanical behavior was assessed through tensile testing. Results indicated a slight increase in the geotextile's tensile strength and a significant decrease in the geogrid's strength. Despite these changes, both materials showed substantial resistance to chemical degradation at low strains, with minimal variation in density and no surface alteration observed microscopically.

KEYWORDS: Geotextile, Geogrid, Sulfuric acid, Mechanical behavior, Density, Surface morphology.

1 INTRODUCTION

With the exponential increase in the number of civil engineering structures and the imperative to extend their lifespan, geosynthetic products, whether derived from synthetic or natural polymers, are appearing as versatile solutions for a range of applications. These innovative materials offer significant advantages over traditional construction methods, such as the ability to perform under challenging conditions, reduced construction costs, and enhanced structural longevity (Naga et al., 2023). Various geosynthetics are available to meet the diverse service requirements of construction projects, with geotextiles and geogrid being a prominent category used for reinforcing slopes, walls, roads, and foundations.

The durability of geosynthetics in civil engineering is a primary concern, given their prolonged exposure to degrading agents (Van Santvoort et al., 1995), particularly aggressive chemicals. Such exposure can lead to damage and changes in the properties of these materials, potentially compromising the functionality of the structures in which they are incorporated. These adverse effects are mainly due to the interaction of polymers with external conditions, which are influenced by the polymer's nature (Leshchinsky et al., 2020) and its chemical additives.

Polyethylene terephthalate (PET) and polypropylene (PP) are some of the most widely used polymers in geosynthetic manufacturing due to their excellent mechanical properties (van Schoors, 2007; Maddah, 2016). However, the resistance of polyester to aqueous environments is limited. Previous studies have demonstrated that the deterioration of PET is primarily due to hydrolysis (Woodard and Grunlan, 2018), which is highly influenced by the pH of the environment(Ducoulombier et al., 2016; Nguyen-Tri et al., 2014; Krimi et al., 2016; Cho et al., 2020) . In contrast, polypropylene exhibits excellent resistance to aqueous environments regardless of pH, but it has low oxidation resistance (Hsuan et al., 2008). Numerous researchers have focused on assessing the degradation of geosynthetics on a macroscopic scale (mechanical and physical properties)(Gulec et al., 2005; Liu et al., 2013; Guimarães et al., 2017; Carneiro et al., 2018) . However, there is a lack of studies concerning the effect of degradation on the micromolecular level of these materials.

To address this gap, accelerated aging tests were conducted in the laboratory, followed by a mechanical, physical and microscopic characterization. While these accelerated tests do not fully replicate real conditions, they provide crucial insights into the material's behavior over a relatively short period, allowing predictions about its long-term performance.

This study aims to deepen the understanding of the influence of an acidic environment on the mechanical and physical properties, as well as the surface morphology of geosynthetics. This research highlights how these conditions affect geosynthetic durability by revealing macroscopic and micromolecular degradation mechanisms. This deep understanding improves geosynthetic material design and selection, ensuring their durability in harsh environments. The knowledge gained will optimize the performance and longevity of structures that use these materials, which is crucial for sustainable infrastructure projects.

2 MATERIAL AND METHODS

2.1 Geosynthetics

The geosynthetics examined in this study consist of a knitted geotextile made from polyester terephthalate (PET) and an extruded biaxial geogrid based on polypropylene (PP).

The main characteristics of the geogrid and geotextile as received are summarized in Table 1.

Table 1: Main characteristics of the geosynthetics (reference specimens).

Parameters	Quantity	
	Geogrid	**Geotextile**
Structure	Extruded geogrid	Knitted geotextile
Polymers [a]	PP	PET
Chemical additives [a]	2% carbon black content	-
Tensile strength at 0.5% strain	2.24 (± 0.129) kN/m	28.63 (± 2.52) kN/m
Tensile strength at 1% strain	6.84 (± 0.472) kN/m	84.56 (± 8.36) kN/m
Tensile strength at 6% strain	28.6 (± 1.331) kN/m	258.54 (± 16.035) kN/m
Ultimate tensile strength	38 (± 0.726) kN/m	367 (± 25.07) kN/m
Unit area mass [a]	0.33 kg/m^2	0.8 kg/m^2
Density		

In brackets is the standard deviation.

[a]Information provided by the manufacture

2.2 Accelerated aging test procedure

In this work, a geogrid and geotextile were immersed in various concentrations of diluted sulfuric acid (0.8 mol/L, 1.9 mol/L, and 3.1 mol/L) at a constant temperature of 80°C. The stock solution used had a purity of 95%. The immersion tests were conducted in the dark to protect the samples from UV exposure and lasted for one month.

To ensure a consistent solution concentration, daily measurements were performed using a pH meter, and the concentration was adjusted every 20 days. After collection, the specimens were washed with deionized water and dried at 40°C. Before testing, all specimens were preconditioned in the dark at 23°C for a minimum of 24 hours.

2.3 Assessment of damage suffered by geosynthetics

2.3.1 Mechanical behavior

Damage sustained by the geogrid (during aging tests) was assessed by tensile tests according to ASTM 6637-Method A, while the geotextile was tested according to ASTM 4595. The tensile tests were carried out on the MTS universal testing machine (Model C45) (Figure 1).

For the geogrid, the tensile tests were performed on individual rib in the cross-machine direction. For the geotextile, tests were conducted on wide strips. Each sample tested included a minimum of five specimens. The tensile strength at 0.5% ($TS_{0.5\%}$ in kN/m), at 1% ($TS_{1\%}$ in kN/m), and 6% ($TS_{6\%}$ in kN/m) were obtained from the load versus strain curves.

Figure 1. Tensile test machine.

2.3.2 Density measurement

The density of the geotextile and geogrid fibers was measured at room temperature using a gas pycnometer (Micromeritics AccuPyc II 1340) (figure 2a), with a precision of 0.0001, utilizing helium as the measuring gas. The products were cut into small fragments, as shown in Figure 2a and b, to fit into a 10 cm^3 cell. An average density was calculated from 10 measurements.

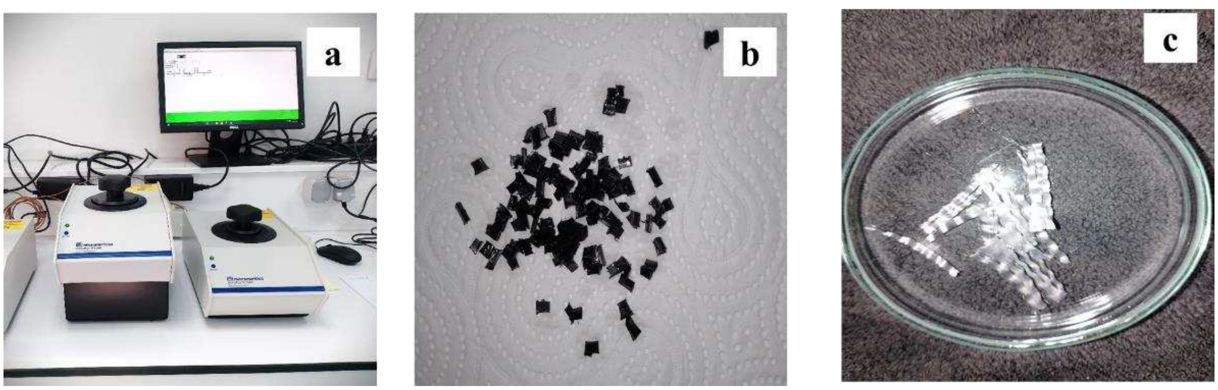

Figure 2. Density measurement: (a) gas pycnometer; (b) geogrid fragment; (c) geotextile fibers.

2.3.3 Surface morphology

Surface degradation resulting from the aging test was examined using a QUANTA 650 scanning electron microscope (Figure 3a). The imaging was performed in secondary electron mode at an accelerating voltage of 12.5 kV and a working distance ranging from 10 to 13 mm. Prior to analysis, the samples were coated with nickel using an ACE 200 metallizer (Figure 3b).

Figure 3. Instrumentation for Microscopic Analysis: (a) electronic scanning microscope QUANTA 650; (b) metallizer ACE 200.

3 RESULTS AND DISCUSSION

3.1 Tensile properties

Figure 4 shows the evolution of the corresponding tensile strength at 0.25%, 1%, and 6% strain for geotextile and geogrid as a function of sulfuric acid concentration. As shown in figure 4a, the tensile strength of geotextile at 0.25% strain ($TS_{0.25\%}$), 1% strain ($TS_{1\%}$), and 6% ($TS_{6\%}$) strain (in terms of retained value) increases slightly with increasing sulfuric acid concentration. This indicates that sulfuric acid did not cause a chemical degradation, which generally reduces the tensile strength of polyester-based products (Banna et al., 2011). This increase can be explained by two possible hypotheses: (1) the variation is simply the result of the heterogeneity of the geotextile product; (2) the fine precipitated particles (The process by which these particles are formed is still unclear) present between the geotextile fibers, as shown in figure 5, could solidify it, thus increasing the strength of geotextile.

In contrast to the geotextile, $TS_{0.25\%}$, $TS_{1\%}$, and $TS_{6\%}$ values of the geogrid experienced a significant reduction with increasing sulfuric acid concentration (the retained TS0.25%, TS1%, and TS6% values ranged between 95% and 90%). This decrease can be attributed to the oxidation of the geogrid's base polymer (PP). Indeed, sulfuric acid is a well-known oxidizing agent (Maier and Calafut, 1998) and acts as a catalyst in the oxidation process (Carneiro et al., 2014). Similar results have been reported by (Abdelaal et al., 2019). It is noteworthy that the tensile strength of both the geotextile and the geogrid in aggressive environments remains significant at low strains, regardless of the sulfuric acid concentration.

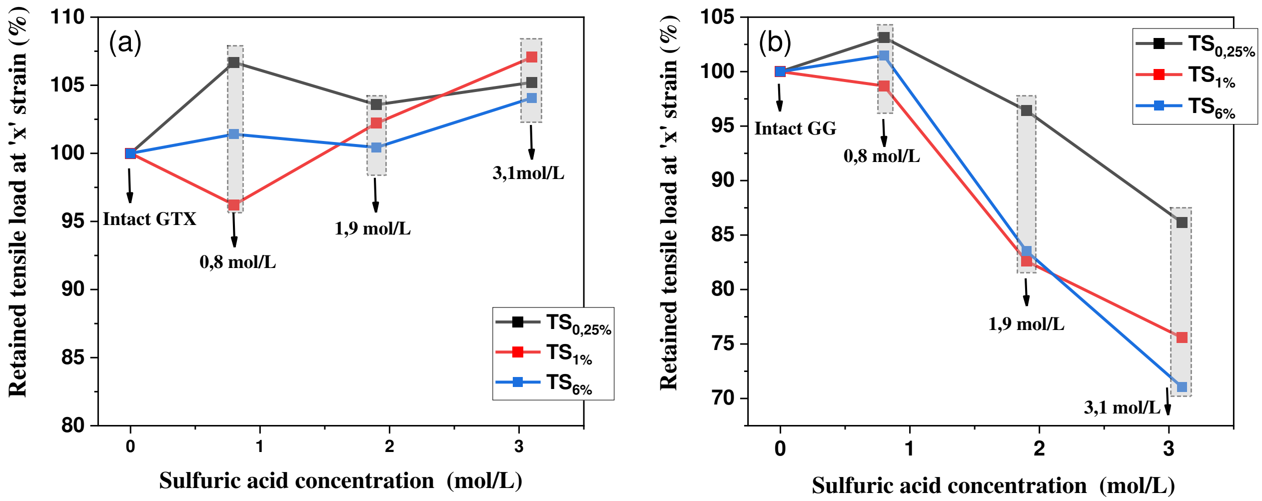

Figure 4. Evolution of retained tensile strength at 0.25% strain (.$TS_{025\%}$), 1% strain ($TS_{1\%}$), and 6% strain (.$TS_{6\%}$) as a function of sulfuric acid concentration for (a) Geotextile; (b) Geogrid.

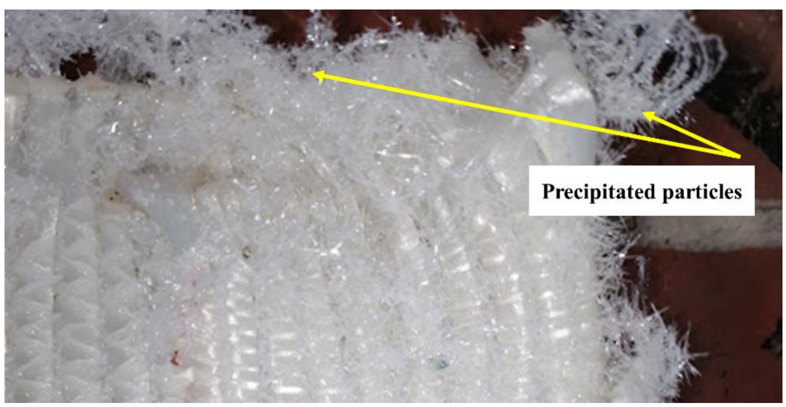

Figure5. Precipitated particles condensed on the surface and between the fibers of the PET knitted Geotextile after one month of aging.

3.2 Density results

The density of the geotextile and geogrid did not show significant variation after one month of immersion in different concentrations of sulfuric acid (see Figure 6). However, the density of the geotextile exhibited a notable variation compared to that of the geogrid, which maintained retained values close to 100% regardless of the H_2SO_4 concentration. The slight decrease in the polyester's density (2.71% reduction) can be attributed to hydrolysis, manifested by chain scission at the ester functions of the polyester. This occurs primarily in the amorphous phases of the polymer due to their sufficient free volume, allowing the rapid penetration of aggressive chemical molecules. On the other hand, although the tensile strength of the geogrid at different strains showed a significant decrease after one month of immersion (as indicated in the section 3.1), its density did not reflect any chemical alteration. This indicates that this analysis does not adequately reveal the product's degradation state. Moreover, despite the slight decrease in the geotextile's density, its tensile strength showed an increase. This can be explained by the fact that the chemical alteration of the polyester was not substantial enough to cause a change in the mechanical behavior of the geotextile.

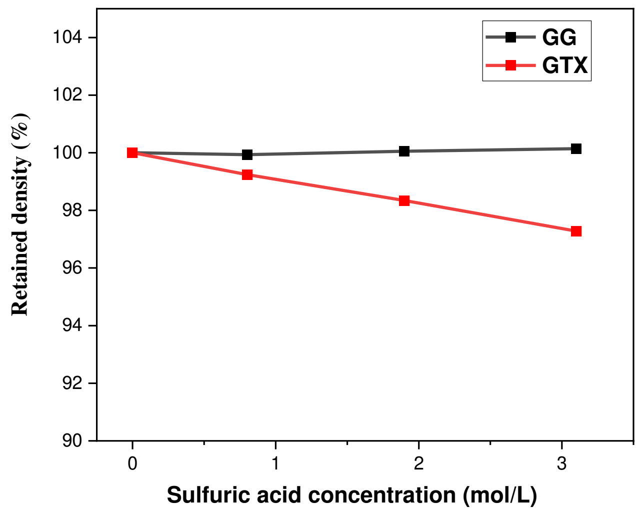

Figure 6. Evolution of retained of geogrid and geotextile as a function of sulfuric acid concentration

3.3 Surface analysis

The surface of the geotextile fibers was examined using a scanning electron microscope (SEM). The analysis was performed on both undamaged and damaged samples after one month at 80°C in a sulfuric acid concentration of 3.1 mol/L, representing the most aggressive condition. SEM micrographs (Figure 7a and c) reveal that the surfaces of the unaged geogrid and geotextile were relatively smooth, without any cracks or microcavities. This observation also holds for the aged samples (Figure 7b and d). Regarding the geotextile, its surface state after the degradation test can be explained by the fact that hydrolysis in an acidic environment primarily begins inside the fibers and gradually extends towards their surface over a prolonged aging period (Ducoulombier et al., 2016). This suggests that one month of aging is not sufficient to cause surface alterations. Concerning the geogrid, despite the oxidation process starting at the surface of polyolefin-based products (Massey et al., 2004), the surface did not show any alterations. This can be explained by the fact that the reduction in molecular weight induced by oxidative degradation was not significant enough to cause surface cracking in the geogrid.

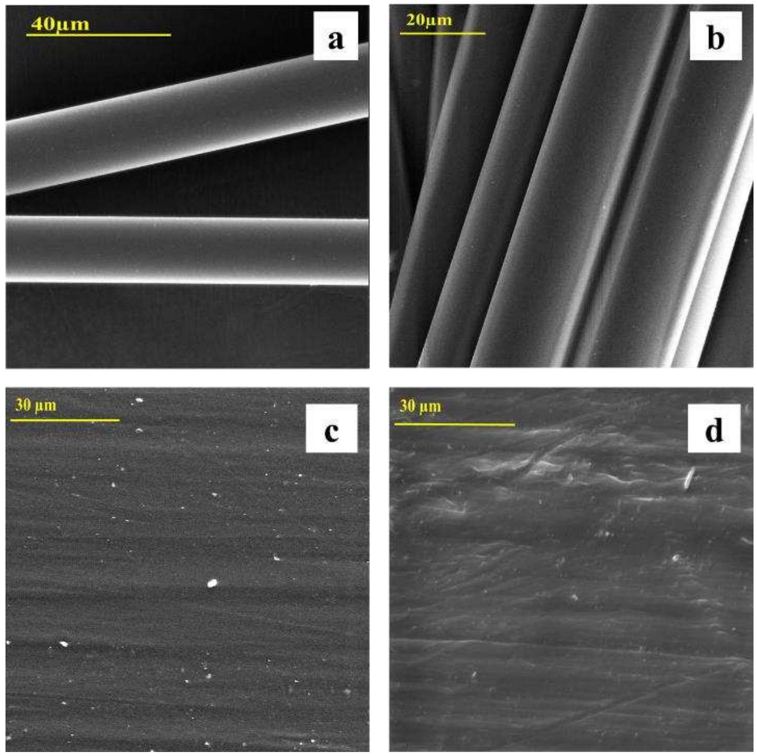

Figure 7. SEM micrographs of the surface of (a) unaged GTX ;(b) aged GTX aged;(c) unaged GG (d) aged GG in a sulfuric acid concentration of 3.1mol/L.

4 CONCLUSION

In this study, the effects of an aggressive environment on the mechanical and physical behavior, as well as the surface morphology of two types of geosynthetics, were investigated. The state of the products after degradation was analyzed using a gas pycnometer, a scanning electron microscope, and tensile tests. The following key conclusions can be drawn:

- The tensile strength of geotextile slightly increased with sulfuric acid concentration due to possible precipitates, while the geogrid's tensile strength significantly decreased due to oxidation, yet both materials maintained substantial strength at low deformations.
- After one month of immersion in varying sulfuric acid concentrations, the density of both geotextile and geogrid showed minimal variation.
- The SEM analysis revealed that both undamaged and damaged geotextile and geogrid samples, exposed to H_2SO_4 at a concentration of 3.1mol/L acid for one month at 80°C, exhibited smooth surfaces without cracks or microcavities.

REFERENCES

Abdelaal, F.B., Morsy, M.S., Rowe, R.K., 2019. Long-term performance of a HDPE geomembrane stabilized with HALS in chlorinated water. Geotextiles and Geomembranes 47, 815–830. https://doi.org/10.1016/j.geotexmem.2019.103497

Banna, M.H., Shirokoff, J., Molgaard, J., 2011. Effects of two aqueous acidic solutions on polyester and bisphenol A epoxy vinyl ester resins. Materials Science and Engineering: A 528, 2137–2142. https://doi.org/10.1016/j.msea.2010.11.049

Carneiro, J.R., Almeida, P.J., Lopes, M.D.L., 2014. Some synergisms in the laboratory degradation of a polypropylene geotextile. Construction and Building Materials 73, 586–591. https://doi.org/10.1016/j.conbuildmat.2014.10.001

Carneiro, J.R., Morais, M., Lopes, M.D.L., 2018. Degradation of polypropylene geotextiles with different chemical stabilisations in marine environments. Construction and Building Materials 165, 877–886. https://doi.org/10.1016/j.conbuildmat.2018.01.067

Cho, H.-W., Koo, H.-J., Kim, H., Kim, K.-J., 2020. Lifetime Prediction of High Tenacity Polyester Yarns for Hydrolytic Degradation Used for Soil Reinforcement. Fibers Polym 21, 1663–1668. https://doi.org/10.1007/s12221-020-9583-7

Ducoulombier, L., Dakhli, Z., Lafhaj, Z., 2016. Durability of textile facing materials for construction: Implementation of an accelerated aging test by hydrolysis. Journal of Industrial Textiles 45, 1288–1307. https://doi.org/10.1177/1528083714557059

Guimarães, M.G.A., De Mattos Vidal, D., De Carvalho Urashima, D., Castro, C.A.C., 2017. Degradation of polypropylene woven geotextile: tensile creep and weathering. Geosynthetics International 24, 213–223. https://doi.org/10.1680/jgein.16.00029

Gulec, S.B., Benson, C.H., Edil, T.B., 2005. Effect of Acidic Mine Drainage on the Mechanical and Hydraulic Properties of Three Geosynthetics. J. Geotech. Geoenviron. Eng. 131, 937–950. https://doi.org/10.1061/(ASCE)1090-0241(2005)131:8(937)

Hsuan, Y.G., Schroeder, H.F., Rowe, K., Müller, W., Greenwood, J., Cazzuffi, D., Koerner, R.M., 2008. Long-term Performance and Lifetime Prediction of Geosynthetics. Proceeding of EuroGeo 4-4th European Geosynthetics Conference. 2008.

Krimi, I., Ducoulombier, L., Dakhli, Z., Lafhaj, Z., 2016. Durability of textile facing materials for construction: Operating accelerated ageing protocol results in basic medium for lifetime estimation in conditions of use. Journal of Industrial Textiles 46, 929–949. https://doi.org/10.1177/1528083715606106

Leshchinsky, B., Berg, R., Liew, W., Kawakami-Selin, M., Moore, J., Brown, S., Kleutsch, B., Glover-Cutter, K., Wayne, M., 2020. Characterization of geogrid mechanical and chemical properties from a thirty-six year old mechanically-stabilized earth wall. Geotextiles and Geomembranes 48, 793–801. https://doi.org/10.1016/j.geotexmem.2020.06.002

Liu, Y., Gates, W.P., Bouazza, A., 2013. Acid induced degradation of the bentonite component used in geosynthetic clay liners. Geotextiles and Geomembranes 36, 71–80. https://doi.org/10.1016/j.geotexmem.2012.10.011

Maddah, H.A., 2016. Polypropylene as a Promising Plastic: A Review. American Journal of Polymer Science.

Maier, C., Calafut, T., 1998. Polypropylene: the definitive user's guide and databook, PDL handbook series. Plastics Design Library, Norwich, NY.

Massey, S., Adnot, A., Roy, D., 2004. Hydrolytic aging of polypropylene studied by X-ray photoelectron spectroscopy. J of Applied Polymer Sci 92, 3830–3838. https://doi.org/10.1002/app.20399

Naga, L., Chikhaoui, M., Djerbal, L., 2023. Contribution to the study of mechanical degradation of geosynthetic products in a saline environment, in: Geosynthetics: Leading the Way to a Resilient Planet. CRC Press, London, pp. 219–224. https://doi.org/10.1201/9781003386889-9

Nguyen-Tri, P., El Aidani, R., Leborgne, É., Pham, T., Vu-Khanh, T., 2014. Chemical ageingaging of a polyester nonwoven membrane used in aerosol and drainage filter. Polymer Degradation and Stability 101, 71–80. https://doi.org/10.1016/j.polymdegradstab.2014.01.001

Van Santvoort, G.P.T.M., Civieltechnisch Centrum Uitvoering Research en Regelgeving (Netherlands), Nederlandse Geotextielorganisatie (Eds.), 1995. Geosynthetics in civil engineering, CUR/NGO report. A.A. Balkema, Rotterdam ; Brookfield, VT.

van Schoors, L.V., 2007. Vieillissement hydrolytique des géotextiles polyester (polyéthylène téréphtalate): Etat de l'art.

Woodard, L.N., Grunlan, M.A., 2018. Hydrolytic Degradation and Erosion of Polyester Biomaterials. ACS Macro Lett. 7, 976–982. https://doi.org/10.1021/acsmacrolett.8b00424