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Laboratory Performance Testing of Two Types of Geotextiles used in Danube Hydrotechnical Works

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Abstract. The products included in the geosynthetic category (geotextiles, geogrids, geonets, geomembranes, geosynthetic clay liners, geofoam, geocells (cellular confinement) and geocomposites) have multiple civil engineering uses, being effectively used as drains and filters in civil and environmental works. The paper aims to test the performance of the geotextiles used for the ecological restoration of riverbank defences on the Danube River, between Calarasi and Braila. For this purpose, the analysed geosynthetics were subjected to hydrolysis and oxidation degradation in laboratory conditions. To evaluate the effect of the two degradation mechanisms, the specimens were subjected to tensile tests at room temperature. The three analysed parameters were tensile strength, elongation and failure mode. The results showed that the tensile strength values for the samples subjected to oxidation and hydrolysis are lower than the ones corresponding to the reference samples, while the elongation values determined after mechanical testing showed that hydrolysis influences the fibre flexibility. The failure mode of the analysed geotextiles highlighted the tendency of the samples to fail either in the calibrated area or at the grip, indicating that in use the geotextile will break in the strained region.

1. Introduction

Geosynthetics are synthetic products in the form of sheets, strips or textile fibres, woven or non-woven, in which at least one component is a polymer (synthetic or natural) [1]. These materials have been developed mainly because of the need to increase the durability of applications subjected to severe exploitation conditions [2], being suitable for many applications in hydraulic engineering (dams, basins, erosion / coastal protection, etc.) [3].

Considering the long-term performance needed for this type of materials, durability tests are required, taking into account the degradation mechanisms that affect them (ultraviolet light degradation, radiation degradation, chemical degradation, hydrolysis degradation, swelling, extraction, delamination, oxidative degradation and biological degradation), which can act independently or synergistically [4]. Therefore, geotextiles degradation may occur as a result of interactions with environmental factors under temperature conditions and mechanical stresses. The most important factors that favour chemical degradation mechanisms are the pH of the environment, solar radiation, temperature, and mechanical stress [5].

Hydrolysis degradation of the geotextiles is a process by which polyethylene terephthalate (PET) decomposes by its reaction with water, the reaction being reversible [6]:

$$H[\text{-OOC-Ø-COOCH}_2\text{CH}_2^{-}]_n\text{OH} + (2n\text{-}1)\ H_2O \rightarrow n\ (\text{HOOC} - \text{Ø} - \text{COOH}) + n\ (\text{HOCH}_2\text{CH}_2\text{OH}) \quad (1)$$

However, if the polyester fibre is degraded the reaction becomes non-reversible.

The behaviour of polyethylene subjected to hydrolysis degradation by various chemicals was considerably studied [7,8,9]. There are two types of hydrolysis degradation that can affect the geosynthetics, namely internal or external degradation [10] by damaging the polymer chain, either throughout the cross-section of the polyethylene (internal hydrolysis) or at the surface (external hydrolysis), leading to a lower molecular weight.

The other degradation mechanism studied, oxidation, is a reactive process by which the elements of a material lose electrons when exposed to oxygen and its valence is correspondingly increased, having a significant impact on geotextile material, determining its fragility, surface cracking, discoloration and most importantly molecular weight loss, which directly results in a loss of mechanical strength [4,11]. The oxidative stability of polypropylene and polyethylene geotextiles can be determined through an oven-ageing test [12].

Therefore, the aim of this study is to determine the durability of the geotextiles used for the ecological restoration of riverbank defences on the Danube River, considering that hydrolysis and oxidation degradation are two the mechanisms that will mostly affect the in-situ performance of the geosynthetics. In order to assess the degree of degradation induced by these two mechanisms, the performance mechanical properties of the two geotextiles (Terrafix and Secutex) will be evaluated.

2. Materials and methods

The two geotextiles used for laboratory determinations are Terrafix and Secutex, produced by NAUE GmbH & Co. KG. The geotextiles were tested after being used in hydraulic works for the defense of Danube’s banks in order to reduce erosion in the areas: Bala Branch, Epuraşu Island and Caleia Branch.

Terrafix geotextile (figure 1a), used on the riverbank to protect against erosion, is made of non-woven, multilayer, coloured polypropylene fibre and white polyester, sand ballast.

The second geotextile, Secutex was used on the crest, as it is a nonwoven geotextile made from short fibres which can be used in different projects, among its applications being separation, filtration, protection and drainage.

Figure 1. The analysed geosynthetics: a) Terrafix and b) Secutex.

In order to determine the performance of geotextiles in environments which can affect the mechanical properties, samples from the two materials were subjected to different temperature and pH conditions, considering the durability tests performed on them, as it can be seen in figure 2.

These determinations were established based on the requirements of the EN 14030 and EN ISO 13438 standards, being modified accordingly to laboratory conditions. The testing conditions (time, temperature, pH, reagents) are centralized in table 1.

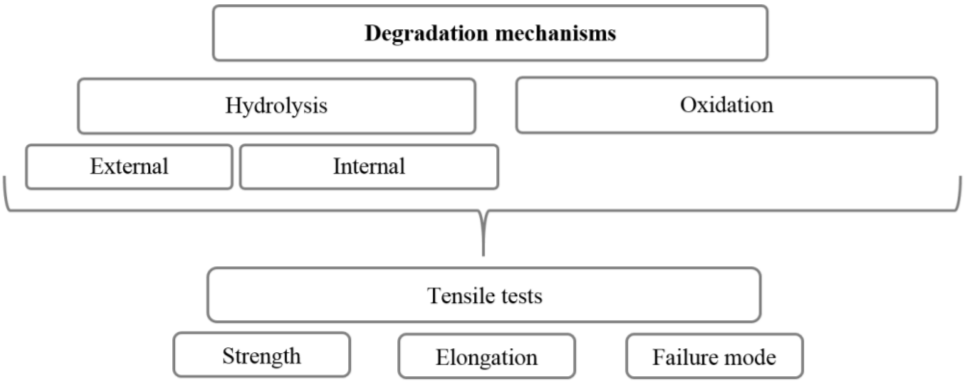

Figure 2. Experimental design of the study.

Table 1. Laboratory conditions for durability tests performed on the two analysed geotextiles (Terrafix and Secutex).

Determination		Laboratory conditions	
Hydrolysis	external	Maintaining period	30 days
		Temperature, °C	22
		pH	12
		Reagents	-
	internal	Maintaining period	30 days
		Temperature, °C	22
		pH	5
		Reagents	Calcium hydroxide
Oxidation degradation		Maintaining period	14 days
		Temperature, °C	Cicles of 110 °C/8 hours + 37 °C/16 hours
		pH	-
		Reagents	-

Durability tests were completed by determinations of tensile tests carried out in a universal testing machine MP 0.5t, model 97 with mechanical clamping jaws, at a constant speed of about 1.3 mm / min at room temperature. The tensile strength was determined using the following relationship [13]:

$$\alpha_f = \frac{F_f}{W_s} \tag{2}$$

where: α_f - tensile strength, N/m;
F_f – maximum breaking load, N
W_s – specified width of test samples, m

Also, to determine the elongation was used the following relationship:

$$Elongation = \frac{l_i - l_f}{l_i} \times 100 \ (\%) \tag{3}$$

where: l_i - initial length of the specimen, mm;
l_f - final length of the specimen, after the tensile test, mm.

All the tests were performed three times in order to ensure reproducibility and the results were determined as the average between the 3 values (the difference between these values does not exceed ± 10% from their mean value).

After the tensile tests, the failure mode of the samples was analysed, considering features like failure type, area and location.

3. Results and discussion

3.1. Hydrolysis

For the evaluation of the internal hydrolysis, the specimens were kept in an acid environment (an admixture of water and HCl was mixed with a soil, maintaining it continuously moist), while for the external hydrolysis the specimens were kept in an alkaline soil, which contained hidrated powder $Ca(OH)_2$. Figure 3 shows the tensile strengths of the geotextile materials subjected to hydrolysis degradation for 30 days. The internal hydrolytic degradation caused the mechanical strengths of the Terrafix samples to decrease from 26 kN/m (reference value) to 23,42 kN/m (a decrease of ~10%), while the external hydrolysis lead to a decrease of only 5% of the tensile strength values. However, the Secutex geosynthetic presented a more significant decrease of the mechanical resistance values. The degradation through internal hydrolysis decreased the tensile strength of the samples with an average of 35.5% (14.25 kN/m compared with the reference value of 22.1 kN/m), while after external hydrolysis the samples showed a reduction of about 29% (15.75 kN/m from the reference value equal to 22.1 kN/m).

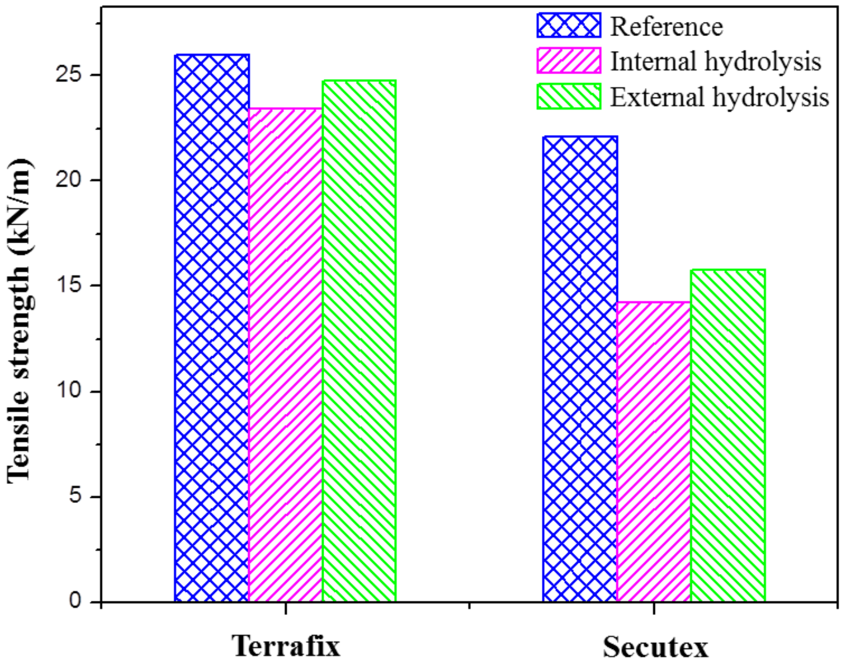

Figure 3. Tensile strength of the two analyzed geosynthetics after hydrolysis degradation.

It can be seen that the internal hydrolysis is more damaging than the external hydrolysis. The decrease of tensile strength can be explained by the fact that the hydrolysis processes depend on the phenomena of convection and diffusion transport of hydroxyl ions (OH^-) to the polymer structure, and in addition, the moisture acts as a catalyst in this chemical process [6,10].

The other analysed parameter, elongation, indicated higher values in the case of specimens subjected to internal hydrolysis tests (figure 4), with an average increase of ~56% for the Terrafix specimens, which according to Saathoff et. al [14,15] reduces the degradation which can occur during installation and allows a structural flexibility. The Secutex samples presented elongation values of ~24%. This behaviour can be explained as a result of the chemical reactions involved in this process, which influences the flexibility of polymeric fibres.

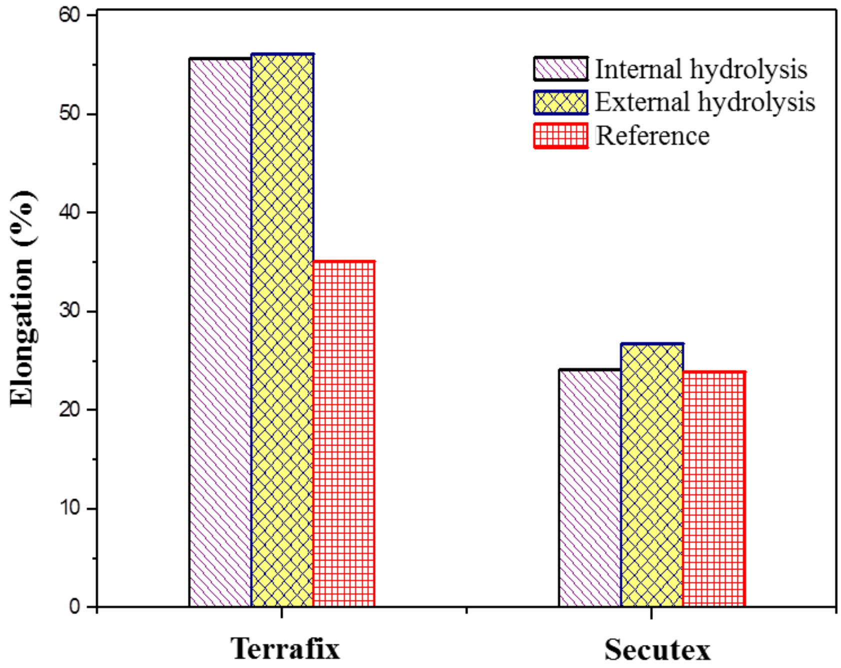

Figure 4. Elongation values of Terrafix and Secutex geotextiles after hydrolysis.

Regarding the other analysed parameter of the mechanical testing, failure mode, the Terrafix geotextile presented the breakage in the middle of the lateral calibrated area, for the specimens subjected to internal hydrolysis, while the ones with external hydrolysis degradation failed at the top/bottom of the grip, which indicates a higher pressure of the top/bottom clamping jaw. The Secutex samples subjected to internal hydrolysis showed a tendency to fail explosively at the bottom grip/tab, which could be explained by a proper distribution of stresses in the loaded strip.

The geotextile specimens damaged through external hydrolysis showed a tendency to fail angular in the middle of the calibrated area.

3.2. Oxidation degradation

The oxidation resistance of the analysed geotextiles (Terrafix and Secutex), assessed by determining the tensile strength of the materials, is shown in figure 5. It can be seen that the tensile strength decreases in the case of specimens subjected to the oxidation test by approximately 10% in the case of Terrafix and 47% for the Secutex geotextile.

The action of oxygen on the polymeric fibres causes the breaking of the polymer chains, and consequently the decrease of the mechanical resistances. The different behaviour of the analysed geosynthetics is determined by the nature of the polymer, degree of crystallization, fibre thickness, etc.

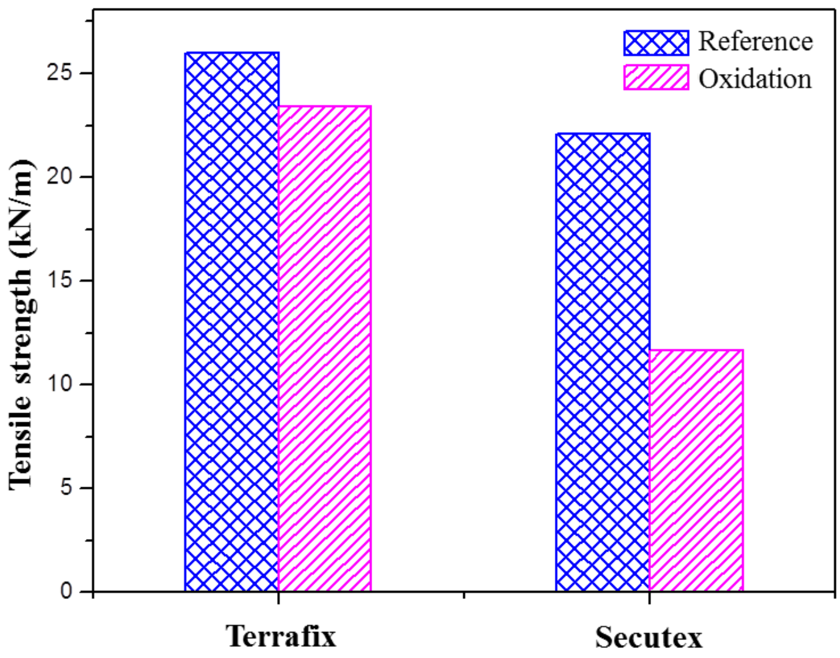

Figure 5. Tensile strength of the geotextiles after oxidation degradation.

The calculated elongation of the specimens subjected to the oxidation degradation is plotted in figure 6. The results show that for the Terrafix geotextile, the elongation values are superior to the reference. This behaviour is due to the fact that this geosynthetic is a composite material made of both polyethylene and polyester fibres, therefore the oxidizing medium can act differently on the fibres, considering that the ester fibres contain in their structure carboxyl groups ($-COO^-$). For the Secutex geotextile, which is made entirely of polyolefin fibres (polypropylene and polyethylene), the determined elongation was lower than the reference value.

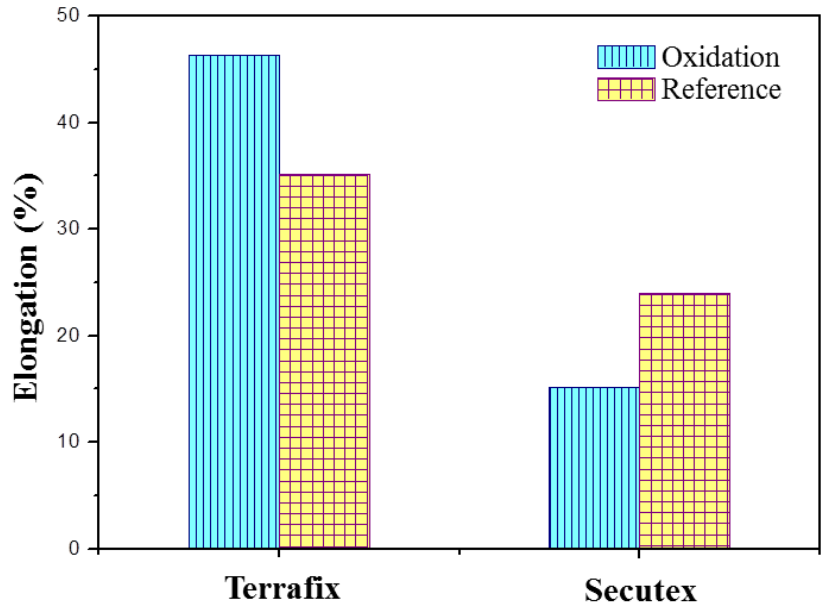

Figure 6. Elongation values of the analysed geotextiles after oxidation degradation.

The failure modes of the two geotextiles subjected to oxidation degradation showed that the Terrafix specimens tended to fail at the top/bottom of the grip, indicating a higher pressure of the clamping jaws, while the Secutex samples showed a tendency to fail at the top/bottom of the calibrated area.

4. Conclusions
The main conclusion of this work are the following:

- The performance testing of the two analysed geotextiles (Terrafix and Secutex) showed that the internal hydrolysis produces more damage to the geotextiles than the external hydrolysis.
- The Secutex geosynthetic presented a higher tendency to degrate under the influence of oxidation and hydrolysis. This behaviour could be explained considering that most reactions occur at the surface of the polymeric material, therefore the reduced thickness of this material makes it less resistant.
- The elongation values were higher after the hydrolysis degradation than after oxidation degradation, due to the chemical reactions involved in the process, which influence the flexibility of synthetic fibers.
- Considering that the Terrafix geotextile failure trend has been at the gripping area suggests that during functioning, the material may be at risk of yielding in the area where the load is applied. The Secutex geotextile samples tendend to fail in the calibrated area.

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