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Degradation of polypropylene geotextiles with different chemical stabilisations in marine environments

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HIGHLIGHTS

- The exposure to weathering led to highest damage in the geotextiles.
- The weathering resistance of the geotextiles was highly enhanced by Chimassorb 944.
- Carbon black led to an additional protection of the geotextiles against weathering.
- The geotextiles had a good resistance against the action of seawater.
- The algae and dirt protected the geotextiles from UV-degradation (sunblind effect).

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ABSTRACT

The geosynthetics applied in coastal engineering structures can be in contact with degradation agents capable of causing unwanted changes in their properties. In this work, three nonwoven polypropylene geotextiles with different stabilisation packages (different known amounts of Chimassorb 944 and carbon black) were exposed *in situ* to some degradation agents present in marine environments (weathering, seawater and action of tides). These exposures were carried out in Portugal (Archipelago of the Azores) and lasted for 36 months. The damage suffered by the geotextiles (in the different degradation tests) was evaluated quantitatively by monitoring changes in their physical (mass per unit area and thickness) and mechanical (tensile behaviour) properties. The results, among other findings, showed that: (1) weathering led to the highest damage in the geotextiles, (2) the weathering resistance of the geotextiles was highly enhanced by Chimassorb 944 and carbon black, (3) the geotextiles had a good resistance against the action of seawater and (4) the algae and dirt accumulated in the nonwoven structures during the exposure to the action of tides protected the geotextiles from UV-degradation (sunblind effect).

1. Introduction

Geosynthetics are polymeric materials used in the construction of many civil engineering infrastructures, such as: waste landfills, roads, railways, tunnels, retaining structures, reservoirs or coastal engineering structures. These materials are being extensively used in substitution of more traditional ones, proving to be an excellent solution for the construction of many different infrastructures. Nowadays there are available many different types of geosynthetics, being the most used the geotextiles (in part due to their ability to perform many different functions).

The possibilities of application of geosynthetics in coastal engineering structures are many, like in dykes, groynes, jetties, breakwaters, seawalls, artificial reefs or revetments [1,2]. The advantages of using these materials are the ease of application (and removal, if needed), low-cost, high efficiency and low environmental impact. The functions of the geosynthetics in coastal engineering structures typically include: filtration, drainage, separation, reinforcement, containment or erosion control [1,2]. Pilarczyk [1] and Bezuijen and Vastenburg [2] provide an extensive description of the available knowledge about geosynthetics in

Abbreviations: α, confidence level; C944, Chimassorb 944; Δt, variation of thickness; $\Delta\mu_A$, variation of mass per unit area; E_{ML}, elongation at maximum load; n, number of specimens; PP, polypropylene; RTS, retained tensile strength; s, sample standard deviation; t, Student's t-distribution value; t, thickness; T, tensile strength; $t_{Exposed}$, thickness of exposed samples; $T_{Exposed}$, tensile strength of exposed samples; $t_{Reference}$, thickness of reference samples (undamaged); $T_{Reference}$, tensile strength of reference samples (undamaged); μ, population mean; μ_A, mass per unit area; $\mu_{A\ Exposed}$, mass per unit area of exposed samples; $\mu_{A\ Reference}$, mass per unit area of reference samples (undamaged); UV, ultraviolet; x, sample mean.

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hydraulic and coastal engineering, explaining their different functions and their possible applications. Among other applications in coastal engineering, geotextiles (woven or nonwoven) can be used as filters and can be used to manufacture sand-filled elements (called geosystems) for coastal protection, such as geobags, geotubes or geocontainers [1,2].

In marine environments, the geosynthetics can be in contact with many degradation agents, such as: solar radiation and other weathering agents, biological agents, seawater, oxygen and the action of waves, currents and tides [3–5]. The prolonged contact with these agents can damage the geosynthetics (unwanted changes in their physical, mechanical and/or hydraulic properties), affecting their behaviour and reducing their lifetime [3–5]. Thus, and for the good performance of the structures in which they are inserted, the geosynthetics must have a quite good resistance against degradation.

The polymers used for the production of geosynthetics (such as polyolefins, polyesters or polyamides) usually have a quite good resistance against many chemical substances and against biological degradation. However, their resistance against oxidation is often relatively poor [6–8].

The prolonged contact with liquids (like seawater) may cause the extraction of chemical additives (such as stabilisers) from the geosynthetics. The liquids may also interact with the polymeric chains of the geosynthetics (for example, through hydrolysis reactions) or can be absorbed by them (swelling may occur) [9,10]. Polypropylene (PP) (polymer most used for the production of geotextiles) has a good resistance against water and against other liquids, such as acids or alkalis [11,12].

Like for other polymeric materials, the oxidation process of the geosynthetics can be induced by the action of temperature (thermo-oxidation) or by the action of ultraviolet (UV) radiation (photo-oxidation), following a complex chain reaction mechanism [6,8]. In the absence of UV radiation, the oxidation process of PP is usually very slow at ambient temperatures [13].

In most cases, the geosynthetics are exposed to UV radiation only during a short period of time (during the installation process), being subsequently covered by soils or by liquids (which protect them from UV radiation). However, in some applications (like geobags, geotubes or geocontainers used in groynes or breakwaters) they can be total or partially exposed for longer periods of time. In addition, unpredictable UV exposure may also occur (for example, due to the removal of sand by the action of waves in buried structures). The damage caused by oxidation and/or UV radiation (for example reduction in mechanical strength) can be retarded by adding chemical additives (such as antioxidants and/or UV stabilisers) to the composition of the geosynthetics [13–16]. Some polymers (like PP) have a relatively poor resistance against UV radiation and, without proper stabilisation, are unsuitable for many outdoor applications [8,15,16].

The expected lifetime for geosynthetics typically ranges from 1 year to more than 100 years, depending on the application. During that period, they must perform correctly their functions (for that, minimum values of some key properties must be maintained). Therefore, and for the proper application of geosynthetics, it is important to identify the conditions to which they will be exposed during their lifetime and predict how those conditions will affect their properties. In some cases, interactions may occur between the degradation agents of geosynthetics and therefore must also be taken into consideration [17,18].

The resistance of geosynthetics against degradation is usually predicted based on laboratory tests where the materials are exposed (often under accelerated conditions) to degradation agents [13,15,19–21]. For that purpose, the organisations for standardization (like the American Society for Testing and Materials or the European Committee for Standardization) have developed many methods (examples include [22–27]). In addition to laboratory tests, the resistance of geosynthetics against degradation can also be evaluated by field tests (degradation under real conditions) [5,16]. These tests are normally very time consuming (some months or years), being unsuitable when quick results are needed. However, and since degradation occurs under real conditions, they can provide more reliable and accurate information about the durability of geosynthetics. Contrary to the laboratory tests, there are not many standard methods for field degradation tests of geosynthetics.

The damage occurred in the geosynthetics (during the degradation tests) is normally determined by monitoring their properties. The changes occurred in mechanical resistance (mainly in tensile strength) are often used to evaluate the degree of damage. Besides its key role in reinforcement applications, tensile strength has also an important paper in the survivability of the geosynthetics during the installation process, where many times they are subjected to higher stresses than during service [10]. In some coastal engineering applications, like in geosystems, tensile strength is also an important parameter since the geotextiles have to be sufficiently strong to resist to the loads that occur during the filling of the geobags, geotubes or geocontainers with sand [2]. Due to their high tensile strength (and lower deformation), woven geotextiles are more often used in coastal engineering applications than nonwovens.

Despite the extensive application of geosynthetics in coastal engineering structures, there are not many studies in literature about their degradation in marine environments. In one of the few existing studies, Hsieh et al. [5] evaluated the weathering properties of two geotextiles (one made from PP and the other from polyester) in ocean environments and found that UV exposure was the main source of degradation.

This work studies the resistance (under real degradation conditions) of three nonwoven PP geotextiles with different stabilisation packages (different known amounts of Chimassorb 944 and carbon black) against some agents present in marine environments (weathering, seawater and action of tides). The main aims of the work included the (1) determination of changes (promoted by the different degradation agents) in some physical and mechanical properties of the geotextiles and the (2) evaluation of the effect of the stabilisation package in the degradation suffered by the geotextiles.

2. Experimental description

2.1. Geotextiles

The degradation tests were carried out with three nonwoven needle-punched geotextiles (designated by W0, W2 and B2) made from PP fibres with different chemical stabilisations: presence, or not, of the additives Chimassorb 944 (C944) and carbon black (Table 1). The materials were structurally identical and had nominal masses per unit area (values defined by the manufacturer) of 280 g·m^{-2}. Regarding the additives, C944 is a UV-stabiliser (belonging to the hindered amine light stabilisers family) and carbon black is a pigment (black colour) that can also provide protection against UV radiation.

Table 1
Chemical composition of the geotextiles.

Geotextile	W0	W2	B2
Percentage in weight of C944 (%)	0.00	0.20	0.20
Percentage in weight of carbon black (%)	0.00	0.00	1.08
Percentage in weight of PP (%)	100.00	99.80	98.72