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Durability of a Polypropylene Woven Geotextile under Climatic and Chemical Agents

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Abstract: The durability of geosynthetics against degradation agents is a relevant issue to be considered for the analysis of their life cycle and relevance to their application. Sunlight, high temperatures, oxygen, environments with acidic or alkaline pH and the presence of water are some of main degradation agents of polymeric materials. The purpose of this study is to evaluate the durability of a polypropylene woven geotextile against some climatic and chemical degradation agents that have been simulated in the laboratory, as well as to analyze the influence of the sum of these agents on the geotextile durability. Reduction factors were also defined for both weathering and chemical degradation, acting both in isolation and as the sum of degradation agents. The results showed that geotextile degradation occurs by both climatic and chemical agents and that the degradation increases with the sum of degradation agents. Furthermore, different results were obtained for the reduction factors with respect to particular conditions of degradation, which are important in defining reduction factors for the specification of geosynthetics based on conditions as similar as possible to that of the site and of the project requests. This study contributes to a better understanding of geotextile durability, which is a subject of considerable relevance in the geotechnical, environmental and scientific fields.

Key words: durability, degradation agents, geotextile

1. Introduction

The durability of geosynthetics that are exposed to degradation agents is relevant for the analysis of their life cycle and for their appropriate use in projects. Due to the increasing use of these materials under geotechnical and environmental conditions, an evaluation of their durability when exposed to degradation agents is necessary. Moreover, this is a complex issue because it depends on polymer resistance and its compatibility with the environment where it will be used, as well as other requirements of the specific project [1].

The scientific community has developed studies to better understand the behavior of geosynthetics used for various applications. Reduction factors have been introduced to projects to increase the technical efficiency of geosynthetics during their lifetime. However, the durability of these materials when they are exposed to various degradation agents also limits their application [2].

Conceptually, the durability of geosynthetics can be understood as the maintenance of their performance after they come into contact with agents that degrade their polymer chains and consequently shorten their lifetime [3]. Therefore, the durability of geosynthetics refers to their resistant to aging [4].

Geosynthetics have an acceptable durability when they are able to satisfactorily meet and maintain their functions under the conditions of a specific project [3].

Durability encompasses the occurrence of changes at the micro and macro structural levels of geosynthetics. The first involves changes in the polymer molecules, which are the basic constituents of geosynthetics, and the second involves changes to their properties [3, 5].

Geosynthetics can be used aboveground or underground. Many factors can trigger their

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degradation. Sunlight, high temperatures, oxygen, environments with acidic or alkaline pH and the presence of water, for example, are some of main degradation agents of polymeric materials [5-7].

Solar radiation, particularly ultraviolet radiation (UV), is harmful to polymeric materials, with shorter UV wavelengths having more severe effects [8]. When UV radiation reaches the surface of polymeric materials, it can cause a series of chain reactions that culminate in the scission of the polymer structure if the energy of the UV radiation is similar to, or higher than, the energy of chemical bonding of the polymer [9]. This phenomenon is called photo-degradation (or photo-oxidation in the presence of oxygen); it involves the absorption of ultraviolet radiation (UV) and subsequent oxidative reactions an in autocatalytic process, with a consequent reduction in the molecular weight of and alteration of the chemical structure of the polymers [10].

The durability of geosynthetics against weathering agents can be evaluated using natural or accelerated degradation. Accelerated weathering tests are conducted with equipment that simulates controlled climatic conditions according to standard procedures, such as the ultraviolet radiation (by fluorescent UV lamps) associated with temperature cycles, rain and/or condensation. Fluorescent UV lamps emit light in the ultraviolet region (< 400 nm), where the energy is high enough to degrade the polymer chain [9]. These UV lamps are not intended to reproduce the spectrum of sunlight itself but only the harmful effects of sunlight [11].

Chemical degradation is characterized by the breaking of intermolecular interactions between polymer chains when the polymer is exposed to solvents. Increasing the distance between the chains by reducing the attraction between them increases their mobility. This leads to swelling and softening of the polymeric material, which opens it up to other chemical attacks [12].

The objective of this study is to evaluate the durability of a polypropylene (PP) woven geotextile when exposed to climatic and chemical degradation agents in the laboratory and to analyze the influence of sum of those agents on the geotextile's durability.

2. Materials and Methods

2.1 Geotextile

The durability studies were performed on a woven geotextile of monofilament polypropylene (PP). Table 1 shows some of its properties.

The woven geotextiles were mechanically characterized by tensile strength tests using the Strip Method [13] in a Universal Testing Machine. Five specimens were tested in each degradation study.

2.2 Climatic Degradation

Climatic degradation of the PP woven geotextile was simulated in an accelerated aging chamber according to ASTM G 151 (2010) and ASTM G 154 (2006) [14, 15].

Each aging cycle required 12 hours and used the following steps:

- Step 1: 8 hours of ultraviolet radiation at 60°C (UVA-340 nm) and irradiance between 2.90 W/m^2/nm and 4.15 W/m^2/nm (Fig. 1);
- Step 2: 0.25 hours of water spray (no light) at room temperature;
- Step 3: 3.75 hours of condensation at 50°C. (Return to Step 1)

The total duration of the tests was 1080 hours. Table 2 summarizes the conditions of exposure to climatic agents used in each test.

Table 1 Properties of Geotextile Used in This Study

Properties	Value
Polymer type	Polypropylene
Mass per unit area (NBR 12568 2003)	459.6 g/m^2
Thickness (NBR 12569 1992)	1.68 mm
Ultimate tensile strength (ASTM D5035 2011)	105.4 kN/m
Strain at tensile strength (ASTM D5035 2011)	9.9%

Fig. 1 Fluorescent Ultraviolet Lamps (UVA-340 nm)

Table 2 Summary of the Exposure of Polypropylene Geotextile Woven to Climatic Agents

Duration of tests	Total cycles	Ultraviolet radiation		Water spray (0.16 L/s)	Condensation (hours)
		Hours	Total irradiance (MJ/m^2)*		
1080 hours	90	720	672.94	23 hours	338 hours

* Irradiance about the irradiation time interval (in seconds).

After exposure to climatic agents (1080 hours), some of the specimens were subjected to mechanical tests to evaluate their degradation using the Strip Method tensile strength test [13]. The remaining specimens were subjected to immersion tests in chemical solutions under the conditions described in section 2.3 to study their durability after exposure by sum of degradation agents (see section 2.4).

2.3 Chemical Degradation

The chemical degradation of a woven polypropylene geotextile due to acidic and alkaline fluids was evaluated with the following adaptation of the EN 14030/A1 (2003):

- Immersion of the specimens heated at 55°C and not at 60°C;
- Immersion of the specimens in sulfuric acid (H_2SO_4) at concentration of 0.05 mol/L (standard specifies an acid concentration of 0.025 mol/L);
- Immersion time of 30 days, which is longer than the 3 day immersion period recommended by the EN 14030/A1 (2003).

The 30-day period was established in a prior study of the chemical degradation of polypropylene woven geotextiles. In this study, more aging was observed after 30 days of immersion than after the 3-day period recommended by the standard used [16].

Table 3 summarizes the test conditions. Fig. 2 shows the conditions for the immersed samples that were heated to 55°C. During the 30-day immersion period, new solutions were added daily to compensate for the evaporation of solution. The quantity of test liquids was maintained constant at a ratio of 35 times the weight of the specimens. Furthermore, daily measurements of the immersion temperature and the pH of the fluids were performed to better control the exposure conditions from Table 3.

After each immersion, the specimens were washed and dried at ambient temperature to test their tensile strength tests with the Strip Method [13].

2.4 Geotextile Durability after Exposure by the Sum to Climatic and Chemical Agents

To analyze the sum influence of climactic and chemical agents on geotextile durability, the durability

Table 3 Test Conditions to Evaluate the Effect of Chemical Fluids on Geotextile Durability

Fluids	pH	Temperature	Exposure time
H_2SO_4 (0.05 mol/L)	1.6	55ºC	30 days
$Ca(OH)_2$ (2.5 g/L)*	12.4		

*Observation: The suspension was saturated at approximately 2.5 g/L.

Fig. 2 Sample Immersion at 55°C

of the geotextiles was analyzed after degradation to both climatic and chemical degradation agents. Then, initially the geotextile was subjected to weathering followed by immersion in chemical solutions, as separate stages of degradation. The same tests conditions were used in all scenarios (2.2 and 2.3).

Reduction factors were defined for both weathering and chemical degradation acting in isolation and sum of these degradation agents.

The mechanical resistances of the specimens after exposure by the sum to climatic and chemical agents, i.e., the degradation to climatic agent followed to chemical agent, were used to compare the durability of a woven polypropylene geotextile with the durability resulting from the ultimate tensile strength (Table 1) of the geotextile reference sample.

3. Results

Table 4 summarizes the degradation of the woven polypropylene geotextile that was exposed to climatic agents for 1080 hours tests (90 climatic cycles).

The results show that the polypropylene woven geotextiles exposed to climatic agents degraded, and this degradation caused their mechanical strength to reduce by 8.6% with an average tensile strength of 96.3 kN/m (Table 4).

Table 5 summarizes the results from the polypropylene woven geotextile chemical aging tests that used the adaptations of standard EN 14030/A1 (2003) described in Table 3.

Immersing the woven geotextiles in H_2SO_4 (0.05 mol/L) reduced their mechanical strength to 97.9 kN/m. Immersion of the woven geotextiles in $Ca(OH)_2$ (2.5 g/L) decreased their mechanical strength to an average of 98.1 kN/m. Therefore, chemical degradation of the polypropylene woven geotextile did occur in acidic and alkaline fluids.

Table 6 presents a summary of the results of exposure by the sum of climatic and chemical agents, i.e., the degradation to climatic agent followed to chemical agent, on the durability of polypropylene woven geotextile.

The results showed increased geotextile degradation with sum of degradation agents. The effect of climatic agents and the subsequent immersion in H_2SO_4 (0.05 mol/L) reduced the mechanical strength by 15.0% to an average tensile strength of 89.6 kN/m (Table 6). This is greater than the reduction caused by aging in only climatic agents (96.3 kN/m) and only acidic fluid (97.9 kN/m).

The effect of the sum of degradation factors (1080 hours in the climatic chamber and subsequent immersion in $Ca(OH)_2$ (2.5 g/L) at 55°C for 30 days) resulted in a 9.5% decrease in the mechanical strength. The average strength was 95.4 kN/m (Table 6), which is a greater reduction than that observed for the geotextile aged only by climatic agents (96.3 kN/m) or only alkaline fluid (98.1 kN/m).

Table 7 shows the results of the reduction factors obtained in the durability study by the sum of the

Table 4 Degradation of Polypropylene Woven Geotextile Exposed to Climatic Agents

Duration of tests	Total cycles	Tensile strength	Tensile strength loss
1080 hours	90	96.3 kN/m (4.1%)	8.6%

*The obtained coefficients of variation are in brackets.

Table 5 Degradation of Polypropylene Woven Geotextile in Chemical Fluids

Fluids	Tensile strength	Tensile strength loss
H_2SO_4 (0.05 mol/L)	97.9 kN/m (3.9%)	7.1%
$Ca(OH)_2$ (2.5 g/L)	98.1 kN/m (7.6%)	6.9%

*The obtained coefficients of variation are in brackets

Table 6 Sum of Climatic and Chemical Agents on the Polypropylene Geotextile Durability

Fluids	Tensile strength	Tensile strength loss
1080 hours climatic chamber aging + H_2SO_4 (0.05 mol/L)	89.6 kN/m (4.9%)*	15.0%
1080 hours climatic chamber aging + $Ca(OH)_2$ (2.5 g/L)	95.4 kN/m (4.7%)*	9.5%

Observations: *The obtained coefficients of variation are in brackets.

Table 7 Reduction Factors Obtained by the Sum of Climatic and Chemical Degradation Agents.

Conditions of degradation	Partial reduction factors (RF_P)	Reduction factors from sum degradation agents***
H_2SO_4 (0.05 mol/L) 30 days; 55°C (FR_Q)*	1.08	1.18
1080 hours climatic chamber aging (FR_C)**	1.09	
Total reduction factor (FR_T)	1.18	
$Ca(OH)_2$ (2.5 g/L) 30 days; 55°C (FR_Q)*	1.07	1.10
1080 hours climatic chamber aging (FR_C)**	1.09	
Total reduction factor (FR_T)	1.17	

Observations:
* RF_Q: Reduction factor for chemical degradation;
** RF_C: Reduction factor for climatic degradation;
*** Reduction factors for climatic agent followed by chemical agent.

climatic and chemical degradation agents. The reduction factors obtained in this study were equal to the results of total reduction factors (RF_T) for the climatic agents and acidic fluid and lower than those for the climatic agents and alkaline fluid, as shown in Table 7.

For project specifications, this case indicates that the values of the partial reduction factors (RF_Q and RF_C) should be used to obtain higher total reduction factors for project safety.

4. Discussion and Conclusion

In this study, polypropylene woven geotextile aging due to climatic and chemical agents in the laboratory was detected using the decrease in the mechanical properties of this material.

Polymers have different behaviors when they come in to contact with degradation factors based on their intrinsic chemical characteristics. Therefore, evaluating the polymeric matrix and its peculiarities is greatly important to the specification of geosynthetic performance and function throughout its design life.

The study of the influence after exposure by the sum to climatic and chemical agents on the geotextiles showed that the impact of climatic agents was subsequently increased by chemical degradation. Thus, it is important to correctly store materials prior to installation on site by following the specifications provided by manufacturers and designers. Furthermore, different results were obtained for reduction factors due to the particular degradation conditions. It is important to define reduction factors, for specific geosynthetics, based on conditions as close as possible to those of the sites where they will be used and of the projects that will use them.

Finally, this study provides a better understanding of the durability of polypropylene woven geotextiles that are exposed to climatic and chemical agents and their behavior under different practical conditions. This subject is greatly relevant in the geotechnical, environmental and scientific fields.

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