Durability characterizing of woven geotextiles container system

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ABSTRACT
Geosynthetics are made of polymeric matrix widely used in geotechnical engineering projects intended to last for generations. Specifically, in coastal hydraulic projects it is important to evaluate the geomechanical and durability behavior of geosynthetic container system - GCS. Therefore, is necessary to know the characteristics of these applied materials in relation to the exogenous environment over the long term. Four woven geotextiles are considered GCS constituent: two tests were carried out on monofilament polypropylene with UV stabilizer and two on multifilament polyester. A methodology is proposed where it is the evaluation of the variations of the mechanical behavior due to degradation processes of the material, naturally in the field or accelerated in the laboratory by condensation and ultraviolet radiation. The evaluation of the mechanical behavior is done through the striped method tensile strength test. The results, according to the materials studied, the polypropylenes are less susceptible to degradation compared to polyesters with resistance loss varying between 48% and 55%, and 73% and 98%, respectively. Analysis of geotextile materials by spectrophotometry was conducted, making comparisons between laboratory and field degradation. The analyses and correlations demonstrated to be satisfactory for characterization of durability. It was concluded that the methodology for durability analysis proved to be an important tool for predicting the long-term behavior of these materials. The procedures used for field and laboratory degradation presented similar durability results and indicated that of the studied materials, polypropylenes as the best choice as GCS.

KEYWORDS: Degradation, Durability, Geosynthetics, Geotextiles, Ultraviolet

RESUMO
Os geossintéticos são polímeros amplamente utilizados em projetos de engenharia geotécnica destinados a durar gerações. Especificamente, em projetos hidráulicos costeiros, é importante avaliar o comportamento geomecânico e de durabilidade do sistema de formas têxteis tubulares - FTT. Para isso, é necessário conhecer as características desses materiais aplicados em relação ao ambiente exógeno a longo prazo. Quatro geotêxteis tecidos são considerados constituintes de FTT: dois produzidos em monofilamentos de polipropileno com estabilizadores UV e dois em multifilamentos de poliéster. Uma metodologia é proposta onde é avaliação as variações do comportamento mecânico devido a processos de degradação do material, naturalmente no campo ou acelerado em laboratório por condensação e radiação ultravioleta. A avaliação do comportamento mecânico é feita através da tensão em faixa estreita. Os resultados, de acordo com os materiais estudados, os polipropilenos são menos suscetíveis à degradação quando comparados aos poliésteres com perda de resistência variando entre 48% e 55%, e 73% e 98%, respectivamente. A análise de materiais geotêxteis por espectrofotometria foi realizada, fazendo comparações entre a degradação laboratorial e de campo. As análises e correlações demonstraram ser satisfatórias para caracterização de durabilidade. Concluiu-se que a metodologia para análise de durabilidade mostrou-se uma ferramenta importante para predizer o comportamento a longo prazo destes materiais. Os procedimentos utilizados para degradação em campo e em laboratório apresentaram resultados de durabilidade semelhantes e indicaram que dos materiais estudados, os polipropilenos são a melhor escolha como FTT.

PALAVRAS-CHAVES: Degradação, Durabilidade, Geossintético, Geotêxtil, Ultravioleta

1. INTRODUCTION

1.1 Initial Considerations

The GCS has been used as solutions to various hydraulic and stability problems in recent decades. GCS are tubular structures produced from geosynthetics for the purpose of permanently or provisionally containing materials. They are cylindrical in shape, with heights ranging from 50 to 500 cm and the length up to 100 m. Their filling is done by dredgers or large motor pumps (Vertematti, 2015). GCS can usually be rolled, delivered, unrolled at the desired location and then filled according with the project design.

As a measure of river flood control and coastal zone disasters, there has been an increase use of geotextile in these regions in recent years. Geosynthetic container system (GCS) are some examples used in hydraulic works. They are similar as dikes or other types of coastal protection structures and usually extend longitudinally over a large distance. And, a slight improvement in design can result in a significant amount of savings. Therefore, it has a great economic benefit and thus can be established as the most effective method.

GCS are mainly used for erosion protection and control. They can be used for the construction of dikes, breakwaters, dunes, and similar structures. There are several advantages to using them. They are quick and easy to build, are cost-effective, filler materials are always affordable, and require no heavy machinery. The GCS are usually constituted of woven geotextiles and sewn, transversely and longitudinally, shaped like a tube.

This paper presents an evaluation of the geomechanical and durability behavior of GCS using mechanical and degradation tests. The GCS are structures used in hydraulic design for coastal and riverine protection. Thus, the woven geotextiles used for this purpose need to have good resistance to traction and degradation agents, mainly due to solar radiation.

1.2 Geosynthetic Container System - GCS

According to Koffler et al. (2008), it was a catastrophe that struck southwestern Holland in 1953, killing 1850 people, destroying 4500 homes and leaving 100000 people homeless, the milestone that began the history of the GCS. The search for solutions in coastal protection applications began shortly after this tragedy. Then, through the challenge presented by the Dutch authorities, engineers have proposed the use of textile products in marine structures in the form of GCS. More than 10 million square meters of geosynthetics were used in this project known as the Delta Project.

Perrier (1986), Sehgal (1996) and Jongeling and Rovekamp (1999) describe the Delta Project. According to the authors, to protect the West coast of Overijssel, a province of the Netherlands, against flooding of Lake IJsselmeer and the Ketelmeer River, a storm barrier consisting of geomembrane was constructed (Figure 1a). The material used for filling was a combination of air and water by means of insufflation. This minimized the GCS dimensions and also allowed the dam height to be adjusted quickly as needed (Figure 1b). The protective barrier of that region was composed of three GCS and the projected dimensions were: length 75 m, width 13 m and height 8.35 m (Figure 1c).

(a) storm barrier consisting of geomembrane (b) GCS inflated

(c) Overijssel region with the location of the three GCS with 75 m

Figure 1. Delta Project (from Sehgal 1996 and Jongeling and Rovekamp 1999)

1.3 Durability characterizing of woven geotextiles

From the first projects in the 1950's up to present day, there are few works that have doubts about the geosynthetic behavior regarding its durability. It can be said that the main problems in GCS are primarily mechanical damage and abrasion. Figure 2 illustrates general occurrences of GCS problems.

Leshchinsky et al. (1996) show, in Figure 2a and 2b, a break in the seam of a GCS in the city of Mobile, Alabama, and Kunz et al. (2014) detail the navigable canals of Midland, Germany, which underwent interventions and that, during the drought, GCS displacement was observed (Figure 2c). The most severe case was found in the canal surface layers, with more severe damage present (Figure 2d). Figures 2e and 2f by Alvarez et al. (2007) and Shin and Oh (2007) exhibit a typical long-lasting effect on breakwaters by seaweed. In Figures 2g and 2h, Bruscas (2015) cites GCS damage off the Ocean Shore, California, which is impacted by many beach surfers and heavy storms.

(a) local rupture – overview[1]

(b) local rupture – detail[1]

(c) displacement[2]

(d) craked[2]

(e) seaweed[3]

(f) marine flora and seaweed[4]

(g) damage – overview [5]

(h) damage – detail[5]

Figure 2. General occurrences of GCS problems (from [1]Leshchinsky et al. 1996; [2]Kunz et al. (2014); [3]Alvarez et al. (2007); [4]Shin and Oh (2007) e [5]Bruscas (2015))

The literature provides little information about the degradation of geosynthetics in civil works. However, Raymond (1999) presents a study showing the variations of geosynthetic behavior over time. For this, this author studies the properties of exhumed samples with different time intervals, indicating that the alteration of the material can cause even the rupture of geosynthetics in the work. According to Abramento (1995a) and Abramento (1995b), the durability of geosynthetics in civil works can be evaluated by exhumation of the material to evaluate its performance after use, laboratory simulations and durability assessment methods.

The degradation of a geosynthetic can occur by the action of one or more altering agents that are classified into physical, chemical and biological. Physical agents can be solar radiation or radiation α, β e γ, temperature, abrasion and mechanical damage. Chemical agents are water, acids, bases, solvents and other chemical agents, oxygen, ozone and air pollutants. Already as biological agents, they have the actions of microorganisms, such as fungi and bacteria.

Altering agents may mobilize various degradation mechanisms. According to Schneider (1988), Robenfeld and Cooke (1988), Abramento (1995a), Abramento (1995b), Budiman (1994) and Matheus (2002), the main degradation mechanisms of geosynthetics are caused by solar incidence, by the effect of temperature, installation damage, expansion due to liquid absorption, chemical reactions and the action of microorganisms.

Thus, the study of geosynthetic transformations due to degradation is fundamental. Such transformations can cause problems in the projects and even make the use of certain types of materials unfeasible. In addition, the study of alterability can define the best use of geosynthetic materials, and their susceptibility to degradation.

2. MATERIALS AND METHODS

2.1 Materials

Four woven geotextiles are considered constituent of GCS: two polypropylene (PP) monofilaments and two polyester (PET) multifilament (Figure 3). The name of each sample was a combination between polymer type and its mass per unit area: PET340, PP500, PET740 and PP925. The Table 1 presents the characterization of woven geotextiles tested.

Figure 1. Woven geotextile used.

Table 1. Reference values of the woven geotextiles.

Property	PET340	PP500	PET740	PP925
Tensile strength (kN/m)	52.5±1.6	106.2±2.0	150.7±5.2	155±1.6
Elongation at rupture (%)	16.5±1.8	20.1±1.3	34.8±1.8	28.5±2.1
Mass per unit area (g/m²)	340±8	500±9	740±23	925±25
Thickness (mm)	0.51±0.02	1.53±0.04	1.17±0.01	2.62±0.06
UV stabilizers¹	no	yes	no	yes

¹ no information displayed

2.2 Methods

Gijsman and Sampers (1997), Diesing et al. (1999), Benjamin et al. (2008), Guimarães et al. (2014) and Guimarães et al. (2015), analyze the interaction of more than one standardized procedure for the evaluation of durability based on the standard methods. These methods make analysis of geosynthetic by different procedures like oxidation and ultraviolet, natural exposure and acid attack, damage of installation and natural exposure, fluency and natural exposure, ultraviolet and immersion in acidic and basic solution. Dias Filho et al. (2016a) shows a methodology associating tests dedicated to the preparation of degraded or altered samples and Dias Filho et al. (2016b) demonstrate a model for evaluating durability.

2.2.1 Outdoor exposure

The samples were exposed to the natural climatic conditions in Campos dos Goytacazes/RJ from August 2013 to August 2015 (Figure 4a). The samples were installed on the support which has an inclination of 21°48’ degrees in relation of the horizontal which correspond to the local latitude, 21° 48′ 14″ S and 41° 19′ 26″ W. This procedure ensures a higher incidence and, consequently, greater absorption of solar radiation by the material. It was used the ISO TS 13434 and ASTM D5970. The degradation times in the field to be subjected to the tests set out in the experimental program were 90, 180, 270, 360 and 720 days.

The climatic characteristics of region during the tests of natural exposition were: maximum average temperature 33^{o}C, the minimum average temperature 20˚C, the altitude 14 m, 292 days of precipitation with a value accumulated of 1487.8 mm, relative humidity of 81%, the largest irradiation of solar energy accumulated by month was 847.7 MJ/m^2 and 13.44 GJ/m^2 for the total irradiation of solar energy to two year of analysis. Briefly, the ultraviolet radiation was 1.01 GJ/m^2, i.e., a value corresponding to 7.5% of the total cumulative incidence of solar radiation according to ISO TS 13434. Such information was obtained directly from the National Institute of Meteorology - INMET (2018).

2.2.2 Accelerated UV test

The samples were degraded by condensation and ultraviolet radiation (Figure 4b), which simulates the natural changes throughout the temperature variation between day and night; precipitation and UV radiation by the sun. The conditions replicate well the natural degradation process because they simulate with greater intensity the main mechanism of degradation in geosynthetics used in geotechnical design.

The degradation times accelerated in the laboratory to be subjected to the tests set out in the experimental program were 8, 16, 24, 32, 40, 80, 200, 400, 800, 1040, 2160 e 4800 hours. UVB lamps and ASTM D4355 guidelines were used. The UVB lamps disponible at laboratory give a short wavelength output in comparison to field exposure, but promote the degradation of materials quickly.

(a) Outdoor exposure (b) Accelerated UV test

Figure 4. Geosynthetics in degradation process in field and laboratory.

2.2.3 Spectrophotometry

The use of spectrophotometry, in turn, has been shown to be an alternative for the characterization of geosynthetics after degradation. It analyzes the spectrum and wavelength of the light source, a procedure that was used in Suits and Hsuan (2003), Yang and Ding (2006), Valente et al. (2010), Carneiro and Lopes (2017) and. Dias Filho et al. (2019). In these studies, small-sized test specimens on the order of 4 cm^2 are used, a value below the minimum for conducting five wide-width tensile tests equivalent to 3000 cm^2. Therefore, for analysis of the durability of the exhumed geosynthetic becomes a more practical procedure and without detriment to the project.

With ultraviolet–visible spectrophotometry it is possible to determine the ability of a material to absorb wavelengths between 200 and 800 nm that make up the ultraviolet spectrum and the visible range for the most common natural source of radiation, the sun, or artificially by lamps. These wavelengths are classified as UVC, UVB, UVA and visible.

3. RESULTS

For the analyzes of parameters the mechanical strength data were used in the natural degradation in the field and accelerated in the laboratory. The Table 2 shows a comparison highlighted the results of tensile strength, absorbance and UV total irradiation. The following is the routine of each stage and the final characterization according the methods. The tensile strength data obtained with these materials presented coefficients of variation below 10% and confirmed compatibility and representativity.

As can be seen from Table 2, polyesters lost tensile strength due to exposure time in the field. The reductions were 90% for PET340 and 82% for PET740. With polypropylenes, the values were 55% for both PP500 and PP925.

In the laboratory, the loss of tensile strength was greater also in polyesters. Noteworthy is the 97% reduction in tensile strength of PET340 and 73% of PET740. PET340 presented difficulties to perform the tests. Care was taken in the handling of the specimen, as the material was well degraded in the last stages of degradation. The PP500 and PP925 polypropylene materials, in turn, both lost 48% of their tensile strength. Laboratory tests degraded less PP and more PET, as expected for UVB lamp. Differences of up to 100% may be observed.

Table 2. Parameters over time for the samples in field and laboratory conditions.

				PET340				PP500	PET740				PP925
Condition	Time		UV total irradiation	Absorbance variation			Tensile strength	Tensile strength	Absorbance variation			Tensile strength	Tensile strength
				UVC	UVB	UVA			UVC	UVB	UVA		
	days	hours	GJ/m²	(%)			(kN/m)	(kN/m)	(kN/m)			(kN/m)	(kN/m)
Field exposure	0	0	0	0	0	0	52	106	0	0	0	149	147.16
	90	2160	0.12	18.59	14.79	7.9	40.91	79.9	3.47	1.98	1.69	67.13	128.14
	180	4320	0.28	22.71	18.31	9.58	19.36	69.82	2.64	3.1	1.85	51.8	113.87
	270	6480	0.4	27.53	22	10.74	12.98	67.8	6.75	6.91	5.76	46.76	88.83
	360	8640	0.49	32.34	25.69	11.91	10.81	60.05	7.72	8.08	6.12	41.72	82.71
	720	17280	1.01	34.44	28.26	14.75	5.08	47.79	12.89	12.87	6.7	26.04	66.22
Laboratory exposure	0	0	0	0	0	0	52	106	0	0	0	149	147.16
	0.33	8	0	0.32	0.01	0	51.09	103.71	-0.33	-0.73	-0.71	148.12	149.62
	0.67	16	0.01	0.65	0.02	0.01	48.94	102.01	1.3	2.47	-1.84	152.32	152.45
	1	24	0.01	1.29	0.04	0.01	50.04	99.52	0.41	0.2	0.23	150.36	147.24
	1.33	32	0.01	2.58	0.07	0.03	49.87	99.01	-1.44	0.3	-0.45	139.25	150.18
	1.67	40	0.01	5.17	0.14	0.05	45.76	97.45	0.56	2.22	-1.59	136.57	145.63
	3.33	80	0.03	7.39	6.47	8.09	43.04	96.30	0.99	0.6	-0.26	106.25	138.32
	8.33	200	0.07	14.68	15.4	10.61	29.69	97.52	1.5	2.86	-0.52	85.6	136.18
	16.67	400	0.14	23.75	18.49	7.32	20.19	95.71	2.59	4.04	-0.99	82.78	132.07
	33.33	800	0.28	26.03	19.26	7.11	17.87	88.85	1.27	2.86	1.01	58.36	126.17
	43.33	1040	0.36	28.97	22.37	6.07	10.90	85.29	0.18	1.92	5.21	51.09	122.82
	91	2160	0.76	30.16	23.68	7.64	4.720	73.94	2.32	3.77	5.26	48.21	90.48
	200	4800	1.68	33.35	27.16	11.86	1.60	47.68	2.07	3.26	7.95	40.49	76.29

Degradation procedures achieved similar endurance loss values and, according to Dias Filho et al. (2016a), correlations can be made to estimate the time required for exposure of degradation samples in the laboratory to be representative of a stipulated field condition.

Absorbance results were only observed in polyester samples. The polypropylene samples may contain some type of chemical additive, which would explain no significant variation in absorbance between the intact and degraded material. They also present less loss of strength over time compared to the studied polyesters, for both natural field and laboratory degradation. Dias Filho et al. (2019) make an evaluation of the use of spectrophotometry in geotextiles showing that the weight and the preparation of the samples for the test can be a limitation in the characterization.

Particularly, the energy x absorbance UVB curves for PET740 showed more variation to explain some tendency on results, probably the use of only one piece of specimen and its weight. According Dias Filho et al (2009), more tests could be conducted and an accurately procedure to degraded specimens needs to be determinate.

Specifically using the absorbance variation results, in turn, this correlation can also be performed. Considering an example of PET340 in Table 1, this material at 180 days of exposure in the field obtained UVB absorbance of 18.1%. For this value, tensile strength obtained in the laboratory was close to 20.19 kN/m. When comparing UV absorbance is important to ensure that accelerated degradation in the laboratory has adequate UV lamps to represent the incidence of solar radiation.

4. CONCLUSIONS

The paper presented the results of the mechanical and durability characterization in four different weights of woven geotextiles, two with monofilament polypropylene and two with multifilament polyester, by artificial and natural UV radiation. It can be appreciated that the tests result by spectrophotometry is an alternative to analyze exhumed specimen and correlation with the tensile strength properties.

The methodology, which compares the behavior of the degradation material submitted in the field with the behavior of the material subjected to degradation in the laboratory, can objectively estimate the durability of the material studied. And it was observed that the laboratory degradation procedures had a good representation of the conditions observed in the experimental field.

This paper shows the possibility to analyze the variation of the long-term behavior with chemical-physical and mechanical properties of the materials exposed to degradation agents through the correlation between the sample preparation on the field and in the laboratory. The results showed that polypropylenes resisted degradation agents more than polyesters. The test with parameters of spectrophotometry shows values of absorbance that allow to evaluate the quality of materials by the method with good results for each geotextile.

No concrete absorbance results were obtained for the polypropylene samples. Whereas for the polyester samples, the absorbance behavior was similar for both field and laboratory degradation environments.

Thus exhumed specimen can be evaluated with small piece of geosynthetic and the methodology keep being an important way to choice the geosynthetic before application.

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