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Aging of Geotextiles used in Landfill Applications - an initial study

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ABSTRACT

For large landfills, secondary liner systems are required to provide the subsurface additional protection from the contaminants. In this case, usually gravel is used as the secondary leachate collection system. This research studies different types of geotextiles forming part of geocomposite drains (GCD) sometimes used as a replacement for gravel in a leak detection system between two liners. The GCD is often promoted as having the advantage of potentially reducing strain on the underlying layers, but clogging and long-term performance of these geosynthetics are still two factors to be studied in a serious manner. The geotextile forming part of the GCD is crucial in this regard. The objective of this study is to investigate the service life of three geotextiles, all elements of GCDs intended for use in landfill applications. The geotextiles examined are gray, nonwoven, and have needle-punched polypropylene staple fibers. Produced by different manufacturers, they have different mass per unit area. The geotextiles are immersed in simulated municipal solid waste leachate and incubated in ovens at four temperatures. Samples are taken at regular intervals and tests conducted on the aged and unaged samples. Tensile and puncture tests are performed to assess changes in physical properties with aging. Changes in the performance are measured by comparing the aged values with the unaged values. The initial evaluation of the apparent rate of degradation in tensile and puncture tests are reported.

RESUMO

Em grandes aterros sanitários, sistemas de barreiras secundários são necessários para proporcionar uma proteção adicional à camada subjacente contra contaminantes. Neste caso, geralmente são usados pedregulhos como sistema de drenagem secundário para coleta de chorume. Essa pesquisa estuda diferentes tipos de geotêxteis, parte de geocompósitos drenantes (GCD), usados como substitutos do pedregulho em um sistema de detecção de vazamento entre dois liners. GCD é geralmente promovido pelas vantagens de potencialmente reduzir a deformação de camadas subjacentes, porém dois grandes fatores ainda a serem estudados são a colmatação e a performance a longo prazo desses geossintéticos. A resistência do geotêxtil que envolve a geonet é crucial nesse sentido. O objetivo deste estudo é investigar a vida útil de três geotêxteis, todos elementos de GCDs, aplicados em aterros sanitários. Os geotêxteis estudados são cinzas, não tecidos e possuem fibras de polipropileno agulhadas. Eles foram produzidos por diferentes fabricantes e possuem diferentes massa por unidade de área. Os geotêxteis foram imersos em chorume sintético de resíduos sólidos urbanos e incubados em fornos em quatro temperaturas. Amostras foram retiradas em intervalos regulares e ensaios foram realizados em amostras envelhecidas e virgens. Ensaios de tração e puncionamento foram conduzidos para avaliar as alterações nas propriedades físicas com o envelhecimento e essas alterações foram comparadas com os valores obtidos nas amostras virgens. A avaliação inicial da razão de degradação aparente em tração e puncionamento foram apresentadas.

1. INTRODUCTION

Geosynthetics are synthetic polymeric products used in many civil engineering applications. They can have different compositions and design. Some of their applications are to separate, confine, and distribute loads, as well as reinforce soil, prevent migration of soil, allow drainage of fluids, and control water pressure. Geosynthetics are often used in barrier systems for applications including mine tailings storage and municipal solid waste landfills (Koerner 2012). This function is extremely important but whether they will serve their design function for as long as needed (i.e., the “period of time during which a landfill will produce contaminants at levels that could have unacceptable impact if they were discharged into the surrounding environment; (Rowe 2005)),” is presently unknown.

Considering that each material has its advantages and limitations, barrier systems for modern municipal solid waste (MSW) landfills are a combination of many materials, natural and geosynthetics, that must work together as a system. The main purpose of a landfill-containment system is to isolate the solid waste and any fluids (e.g., leachate or gases) generated by the waste from the surrounding environment.

It is a requirement by the National Guidelines for Hazardous Waste Landfills (Canadian Council of Ministers of the Environment 2006) to design modern landfills where the functional engineering properties of materials used remain within the acceptable limits for the duration of the service life, with a lifespan ranging from approximately 100 to 1000 years. Therefore, the long-term performance of the materials used must be studied in order to quantify the rate of degradation for each engineering property, defining the service-life of these materials under landfill conditions.

Barrier systems can vary, but for large municipal solid waste landfills and hazardous waste landfills, a double composite liner system is usually required in jurisdictions with a good regulatory framework. A single barrier system is comprised of a leachate collection system (Fleming et al. 1999) and liner system (Rowe 2005). In a double barrier system, there is a secondary leachate collection system, used to monitor and collect the majority of the leakage through the primary liner (Rowe 2019), and a secondary liner system. The upper (primary) system's function is mainly to collect leachate from the waste and the common material used for this is gravel. The lower (secondary) system is used to monitor and collect most of the leakage through the primary system. It may be sand, gravel, or a geocomposite drain depending on jurisdiction. Once leachate enters this layer, it flows to a sump and can be removed. Many geocomposite drains are comprised of a geonet drainage core layer bonded to one or two geotextiles. The focus of this study is the relative performance of geotextiles forming part of three geocomposite drains sold for use in the secondary leachate collection / leak detection system.

1.1 Background

The geocomposite drains (GCD) used in this study are comprised of a geonet drainage core layer bonded to two geotextiles. They have been used in covers for modern engineered landfills (Benson, Kucukkirca, and Scalia 2010), however, they also have properties that are useful in secondary leachate collection systems. Sales brochures often claim that the benefits are (1) GCDs are a much thinner than a suitable granular layer, allowing for a more airspace and a larger volume of waste to be placed in the same volume between approved bottom and top contours; (2) they are easy to handle, lightweight and can be easily transported to a site; (3) GCD cause less strain than gravel on the underlying geomembrane.

In this configuration, the GCD is intended to drain the leachate. Thus, the geonets have to allow the flux while the upper geotextile has a separation/filtration function, allowing the passage of leachate while retaining solid particles in place. The geotextile is extremely important since, if it doesn't perform, the geonet may clog and sufficient drainage will not occur. In this research, three different geotextiles used as part of geocomposite drains are being studied; this is the first, preliminary, report on their performance.

Geotextiles can perform effectively as filters for many years (decades) if no alteration or change of their structure results from chemical attack, mechanical deterioration, mineral and bacterial clogging, accumulation of particles, or organic matter between or upstream of the fibers. Some authors have studied the influence of tensile strain on the filtration characteristics of geotextiles (Fourie and Kuchena, 1995; Fourie and Addis, 1997, 1999; Wu et al, 2008) and shown that for nonwoven geotextiles there is a decrease in the filtration opening size due to tensile loads.

A variety of environmental factors including temperature, moisture, UV radiation, thermal stress, chemical environment, mechanical stress, microbiological activity and atmospheric pollution can cause a reduction in the engineering properties of geosynthetics (Kay, Blond, and Mlynarek 2004). During the service-life of a polyolefin, physical and chemical aging can be expected (Hsuan and Koerner 1998).

While it is always desirable to evaluate long-term performance of geosynthetics by studying case histories, there is insufficient historical data of MSW engineered landfills. Therefore, it is necessary to predict the durability and longevity of the liner materials by mimicking degradation reactions at an accelerated rate. Using the Arrhenius method and the data collected from testing, the behavior of materials can be predicted at specific temperatures and leachate conditions (Hsuan and Koerner 1998).

1.2 Objective

The objective of this study is to explore, for the first time, the performance of three particular geotextiles, used in double liner composite systems, in municipal solid waste leachate.

2. MATERIALS AND METHOD

Laboratory immersion and index tests were used to assess the rate of degradation of three geotextiles forming part of three different geocomposite drains. The geotextiles were immersed in simulated municipal solid waste leachate and incubated at four different temperatures to accelerate the aging process. To quantify the change in engineering properties with aging, index tests were performed. The following sections outline these tests in detail.

2.1 Materials Tested

The three products examined in this study, denoted generically as Twb, Twd and Tyd, were produced by two different manufacturers (hereby denoted by the second letter, w and y, in the generic name), and had nominal mass per unit area, 270 g/m^2 for product “b” (third letter in the generic name) and 335 g/m^2 for products “d”. All geotextiles were gray with nonwoven needle-punched polypropylene staple fibers. These geotextiles tested were taken from the unbounded portion of the geocomposites so as not to be biased by damage in removing bonded geotextile.

2.2 Index Tests

Index tests were used to assess the change in physical characteristics of a material with age. A variety of environmental factors including temperature, moisture, UV radiation, thermal stress, chemical environment, mechanical stress, microbiological activity and atmospheric pollution can cause a reduction in the engineering properties of polyolefin geosynthetics over time and therefore must be assessed (Kay, Blond, and Mlynarek 2004).

Tensile tests were used to quantify physical degradation due to the nature of a landfill’s structure. When placing solid waste above the geosynthetic liner system, a pressure is applied to the layers and tensile forces can be developed in this configuration. An increase in the tensile load affects the filtration property of geotextiles (Wu et al, 2008). Thus, the tensile resistance must be assessed and, with aging, compared to the virgin results. The tensile tests were conducted following modified ASTM D5035, using strip method 1C. The tensile maximum force and elongation at maximum force were monitored.

To assess the extent of the interaction between in-plane strain and forces normal to the geotextile, puncture tests were performed. ASTM D4833 was used because they were all nonwoven geotextiles. Virgin and aged samples with diameter of 100 mm were tested, to assess the changes in the puncture resistance. The maximum force and axial displacement were examined.

2.3 Immersion Tests

The geotextiles were aged in four-liter glass jars placed in forced-air ovens set to 85^{o}C, 75^{o}C, 65^{o}C and 55^{o}C. These temperatures were used to accelerate the aging process. Simulated municipal solid waste leachate, referred to as Leachate 3, was used as the incubation medium (Leachate 3; Abdelaal et al. 2014).

Specimens were taken from jars at regular intervals and tested periodically. The same index tests performed on the unaged samples were conducted on the aged samples to assess how a material changes over time and to allow an evaluation of the rate of degradation in engineering properties.

3. RESULTS AND DISCUSSION

The results of tests on virgin specimens are summarized in Table 1. The tensile and puncture tests reported herein were performed on specimens aged over a 12 month period.

Table 1. Index tests on virgin samples.

Property		Twb		Twd		Tyd	
		Mean	Std Deviation	Mean	Std Deviation	Mean	Std Deviation
Mass per unit area (g/m^2)		288.8	17.8	383.4	26.3	323.3	45.46
Puncture	Maximum Force (N)	813.1	86.6	1015	261	855.1	123.4
	Axial Displacement (mm)	13.3	8.81	15.47	2.60	13.52	0.90
Tensile	Maximum Force (kN/m)	13.9	3.41	22.87	3.12	18.20	4.30
	Elongation at Maximum Force (mm/mm)	1.01	0.12	1.37	0.25	1.05	0.20

The variability of geotextiles is relatively high when compared to other geosynthetics. As manufactured products, nonwoven geotextiles have an inherent variability in properties related to their method of manufacture, the placement of fibers (way, speed), and the needle punching (spacing, speed), and the level of quality control (Rowe, 1993).

Figures 1 and 2 show the tensile results for the specimens aged at 85°C, and "best fits" to the data showing the degradation.

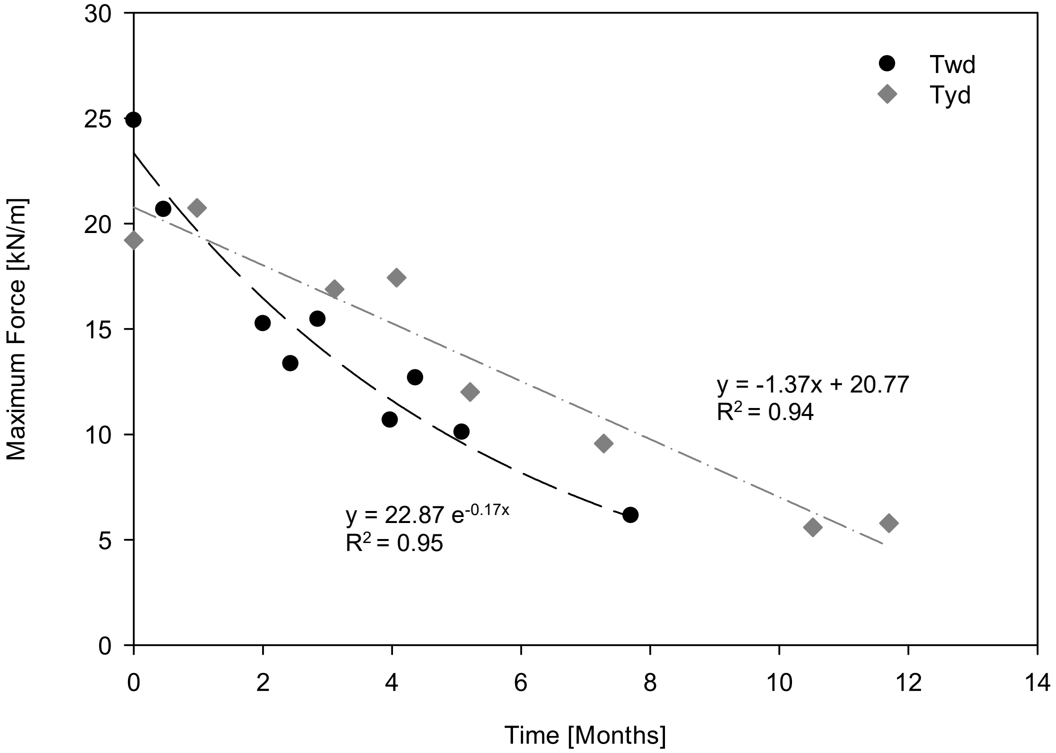

Figure 1. Tensile maximum force for specimens incubated at 85°C.

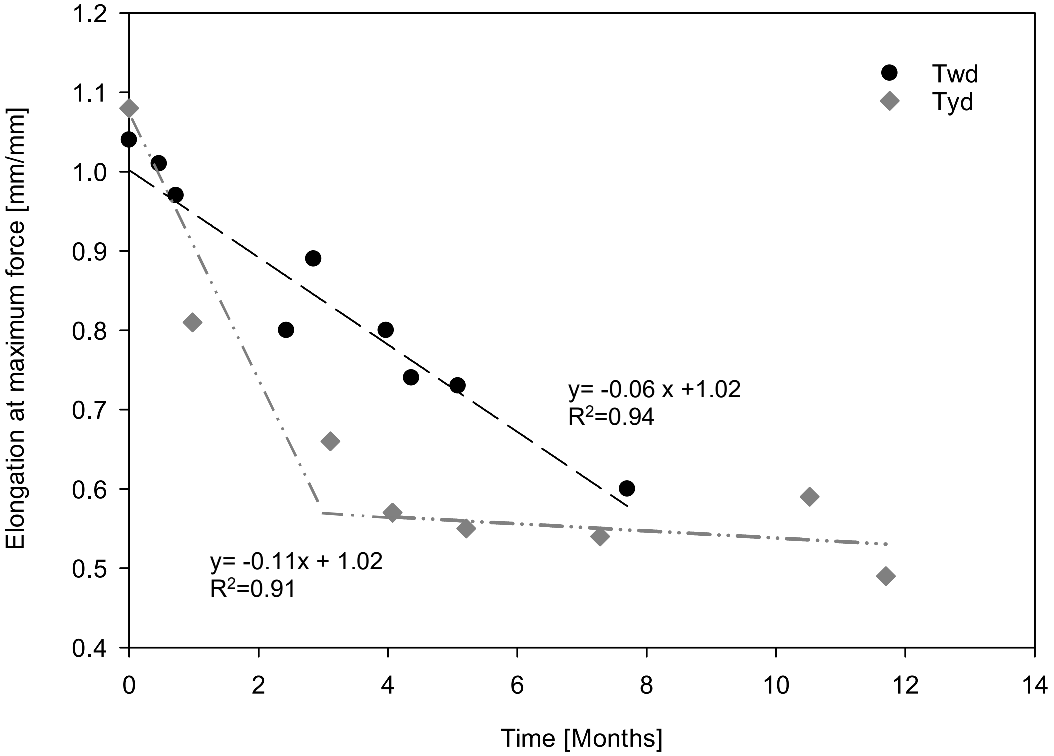

Figure 2. Tensile elongation at maximum force for specimens incubated at 85°C.

Wu et al (2008) proved that for nonwoven geotextiles, the tensile strain has a linear relationship with the apparent opening size (AOS), culminating in an increase in the mean flow rate through the plain geotextiles. Increasing the AOS size may result in more clogging in the geonet core. This can affect the transmissivity of geocomposite drains, the main engineering property to be evaluated in this material. Therefore, the tensile resistance of the geotextiles was quantified.

At 85ºC, both "d" geotextiles showed a decrease in the maximum tensile force and elongation at maximum tensile force at the first testing time just 2 weeks after the beginning of the incubation period. Geotextile Twb didn't show a clear degradation until 8 months and thus it's not presented in these graphs. Twd and Tyd have mass per unit area of 335 g/m^2 and Twb of 270 g/m^2. The results show considerable difference with the heavier geotextiles (Twd; Tyd) having a faster degradation. This is counterintuitive, but also reported by Bell and Barrett (1995). Mass per unit area is not itself a parameter expected to directly control degradation of nonwoven geotextiles. Rather, in a given environment, this will depend on the specific polymer and the additives to that polymer.

For the maximum force, the degradation is more evident after 3 months, mainly for Tyd. However, the elongation has a clear decrease from the beginning of the aging process. It is likely that the elongation for Tyd is approaching its residual value, but more tests are required to confirm this prediction.

The tensile resistance was also assessed for 75ºC, 65ºC and 55ºC. At 75ºC the maximum tensile force and elongation at maximum tensile force are showing a slight decrease, but for 65ºC and 55ºC, no substantial changes have yet been observed.

Figures 3 shows the puncture maximum force results for the specimens incubated at 85ºC.

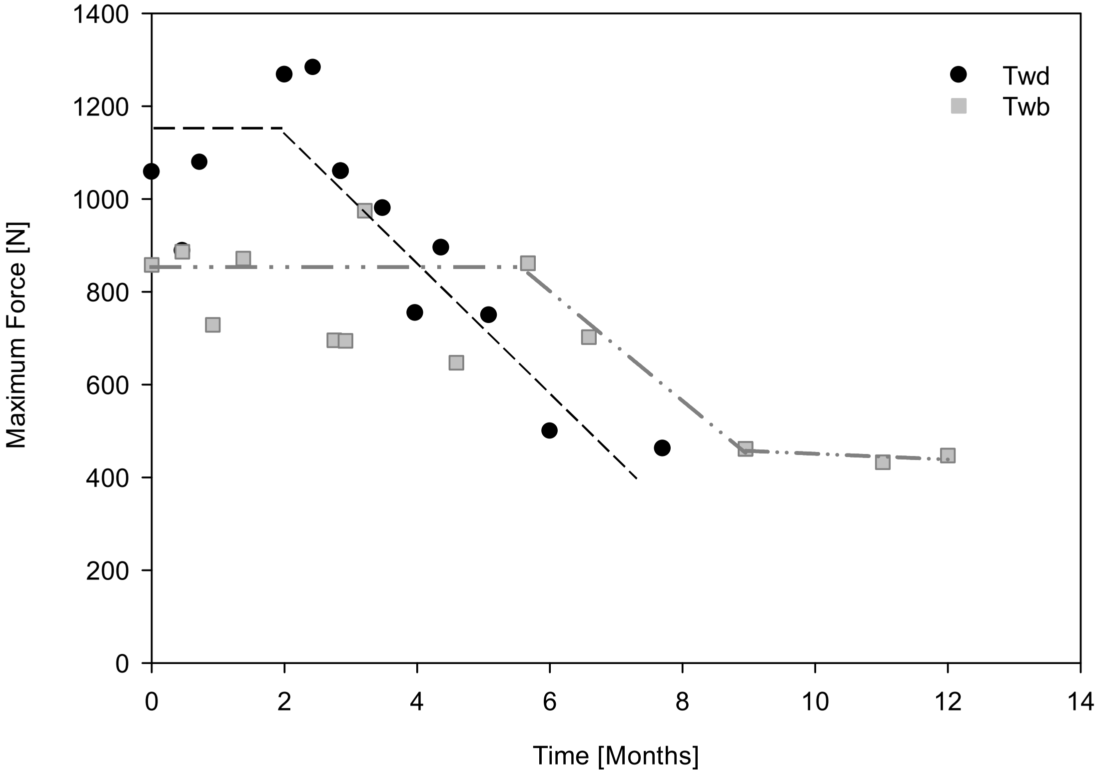

Figure 3. Puncture maximum force for specimens incubated at 85ºC.

The maximum force shows degradation after 3 months for Twd, but only after 6 months for Twb. Tyd didn't show a clear degradation until 8 months, therefore it is not presented in this graph. Twb seems to be reaching its residual value, but more tests are needed to confirm this expectation.

The axial displacement for the puncture tests didn't show any significant changes for any geotextile during the period of incubation.

As for the tensile, the puncture resistance was also assessed for 75ºC, 65ºC and 55ºC. Until now, no substantial changes occurred in any of these temperatures.

Nominal failure is defined by the point at which the physical aged values drop to 50% of their original value (Hsuan and Koerner 1998). As shown in Figures 1 to 3, substantial changes occurred in physical or mechanical properties in the geotextiles during the incubation period, but only at 85ºC. The early variation in values may be due to variability of the material, which can be quite significant for some geotextiles and geocomposite drains (Rowe, 1993; Thiel and Gatrell 2019). All four temperatures were analyzed, but only the 85°C graphs are shown in this paper as these are the ones showing the most rapid degradation.

The average temperature in the liner system for a normal active landfill is considered to be approximately 35-40°C (Rowe 2005, 2012; Islam and Rowe 2009), although temperatures of 50-60ºC and even above 85ºC have been observed at or close to the liner. To predict how long the material will last at a typical landfill site temperature, the Arrhenius method can be used to establish a relationship between property degradation and the inverse of temperature (Hsuan and Koerner 1998). During the period of this study it was only possible to assess degradation at 85ºC, but at 75ºC the properties are already decreasing. To develop an Arrhenius plot, it is necessary to have nominal failure at minimum of two and ideally three different temperatures. Therefore, it will be necessary to perform more tests, over a longer period of time, to predict how long the geotextiles would last at 35ºC; this is in progress.

4. CONCLUSIONS

When studying the long-term performance of a material, all of the properties, both physical and chemical must be studied and more research is underway. It is essential that certain design properties are met by the leachate collection system. These properties include maintaining structural integrity, ensuring adequate filtration, which limits the migration of fine particles while allowing fluid to permeate, and maintaining transmissivity.

The maximum tensile force showed a clear degradation of the property for Twd and Tyd after 3 months at 85ºC. The elongation at maximum tensile force degraded from almost the beginning of the incubation period for Twd and Tyd. Twb didn't show any clear decrease for monitored properties to date. At 75ºC the material show a slight decrease in the properties, but for 65ºC and 55ºC no significant changes could be noticed.

In the puncture tests, the maximum force presented a degradation after 3 months for Twd and after 6 months for Twb. Tyd didn't show a clear degradation for this property during the incubation period. The axial displacement during puncture test still didn't show any substantial changes for any of the materials tested.

For all properties tested, the geotextiles with more mass per unit area (Twd; Tyd) had a faster degradation. Although this is counterintuitive, it was also reported by Bell and Barrett (1995).

This is an initial study of the long-term performance of geotextiles applied in geocomposite drains promoted for use in leak detection / secondary leachate collection systems. More testing is needed to assess the performance of these materials for MSW landfills; however, some preliminary conclusions can be made from this study.

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