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Ageing of a Geocomposite Drain used in landfills applications- an initial study

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ABSTRACT

For large landfills, a secondary liner system is required to provide protection from contaminant leakage through the primary liner. A leak-detection / secondary leachate collection system is usually located between the primary and secondary liner. This layer may be sand, gravel or a geocomposite drain. This paper reports results on a geocomposite drain (GCD) comprised of a bi-planar geonet core heat-bonded to two needle-punched geotextiles. This study is investigating the service-life of the GCD for municipal solid waste landfill applications. To accelerate degradation, laboratory testing was performed by immersing the unbounded material in synthetic municipal solid waste leachate and incubating it at four different temperatures. The results obtained on specimens taken at regular intervals and subjected to index tests are reported for aged specimens and are compared to those obtained for unaged specimens. Tensile tests performed on the geonet and geotextile to assess changes in physical properties are also reported. Additionally, the geonet core was tested for standard oxidative induction time to assess the rate of antioxidant depletion. Antioxidant depletion is reported at all test temperatures, however, over the period of testing, there was no significant degradation in the physical properties under the conditions monitored. Using the Arrhenius plot for antioxidant depletion rates, the predicted length of the first stage of the time to nominal failure of the GCD in a landfill is given.

ABSTRAIT

Pour les grandes site d'enfouissement, un système de liner secondaire est nécessaire pour assurer la protection contre les fuites de contaminants à travers le liner primaire. Un système de détection des fuites / collecte des lixiviats secondaires est généralement situé entre les barrière primaire et secondaire. Cette couche peut être du sable, du gravier ou un drain géocomposite (GCD). Cet article présente les résultats d'un drain géocomposite constitué d'un noyau bi-plan de géonet lié thermiquement à deux géotextiles aiguilletés. Cette étude examine la durée de vie du GCD pour les applications dans site d'enfouissement avec déchets solides municipaux. Pour accélérer la dégradation, des tests de laboratoire ont été effectués en immergeant le matériau non lié dans du lixiviat synthétique de déchets solides municipaux et en le faisant incuber à quatre températures différentes. Les résultats obtenus sur des spécimens prélevés à intervalles réguliers et soumis à des essais index sont rapportés pour des spécimens âgés et comparés à ceux obtenus pour des spécimens non vieillis. Les essais de traction effectués sur le géotextile et le géonet pour évaluer les modifications des propriétés physiques sont également rapportés. De plus, le noyau de géonet a été testé pour le temps d'induction oxydatif standard afin d'évaluer le taux d'épuisement des antioxydants. Un épuisement des antioxydants est signalé à toutes les températures d'essai. Cependant, au cours de la période d'essai, il n'y a pas eu de dégradation significative des propriétés physiques dans les conditions surveillées. En utilisant le model d'Arrhenius pour les taux d'épuisement en antioxydants, on donne la durée prévue du premier stade du temps jusqu'à la défaillance nominale du GCD dans une site d'enfouissement.

1 INTRODUCTION

Geosynthetics are a class of man-made materials that differ in composition and design and are used in a variety of engineering applications. Geosynthetics have been used to separate, confine, and distribute loads, as well as reinforce soil, prevent migration of soil, allow drainage of fluids, and control water pressure. These materials can be used for many Civil Engineering purposes; however, they 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 the lifespan, or "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)," of these barrier systems is still relatively unknown.

Water that has percolated through solid waste and leached constituents is described by the term "leachate". This fluid can contain a combination of heavy metal ions, inorganic macro components, dissolved organic matter, and halogenated organics (Reinhart and Townsend 1997). Due to the increase of documented cases of groundwater and surface water pollution along with gas emissions from old dumps causing adverse impacts including odors, explosions or potentially explosive conditions, and global warming, regulations have been developed for municipal solid waste (MSW) landfills.

Modern MSW landfills are designed using a combination of natural and engineered systems that work together. Each material used has advantages and limitations, therefore composite liner systems are used. The purpose of a landfill-containment system is to envelope the solid waste and isolate it 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 with a lifespan ranging from approximately 100 to 1000 years.

Due to mandates by the National Guidelines for Hazardous Waste Landfills, it is required that the functional engineering properties of materials used in a landfill remain within the acceptable limits for the duration of the service life. Long-term performance of these materials must be studied in order to quantify the rate of degradation for each engineering property, allowing better understanding of the material behavior and defining the service-life of this material under landfill conditions.

Large municipal solid waste landfills and all hazardous waste landfills require a double composite liner system for supplementary protection. In a double liner system, the lower (secondary) system is used to capture the vast majority of the leakage through the primary system. Each barrier system in landfill is comprised of a leachate collection system (Fleming et al. 1999) and liner system (Rowe 2005). The Ministry of the Environment Ontario has implemented the requirement of this leachate collection system in order to collect and remove generated leachate from the landfill site (Canadian Council of Ministers of the Environment 2006). In a double liner system, the upper (primary) liner system's function is mainly to collect leachate and the common material used for this is gravel. The lower (secondary) system is used to monitor and capture most of the leakage through the primary system. It may be sand, gravel, or a geocomposite drain. Once leachate enters this layer, it flows to a sump and can be removed. A geocomposite drain used in the secondary leachate collection system is the focus of this study.

1.1 Background

A geocomposite is a material that is a combination of two or more geosynthetics. The geocomposite drain used in this study is comprised of one geonet drainage core layer bonded to two geotextiles. The material has a series of advantages including the fact that geocomposite drains are easy to handle, lightweight, relatively cost-effective, allow for quick and easy installation, and possess many high-volume flow paths for fluids. They have been used in covers for modern engineered landfills (Benson et al. 2010), however, they also have properties that are useful in secondary leachate collection systems. Additional benefits espoused for their use in leachate collection systems (Koerner et al. 1994) include:

- Geocomposite drains are a much thinner layer than the otherwise used gravel. This allows for a larger volume of waste to be placed in the same area;
- Gravel is not always readily available in some locations, so this material is a viable replacement as it can be easily transported to a site;
- Geocomposite drains can be manufactured with specifics to service a site;
- A substantial issue facing landfill design is cracks in the geomembrane, allowing water to percolate downward. Gravel tends to create indents in geomembranes when vertical force is applied, weakening the geomembrane – which leads to punctures. Geocomposite drains cause less strain then gravels on the underlying geomembrane.

The function of the leachate collection system in primary liner systems is to control the leachate head on the underlying layer, generally using a high permeability drainage layer. Since the primary layer has to transmit the majority of the leachate, it is more susceptible to clogging than the secondary layer (Rowe 2009). Therefore, this study applies geocomposite drains for use in the second layer of a double composite liner system.

Geosynthetics are designed and manufactured to have a particular function over a given amount of time. This generally accounts for the environmental conditions between manufacture and installation. Each geosynthetic is manufactured differently and therefore their molecular structures and additive compositions are different (Kay et al. 2004). During both the processing and service portions of a polyolefin's lifetime, physical and chemical degradation occurs (Hsuan and Koerner 1998).

It would be relatively simple to determine the long-term performance of geosynthetics by studying case histories, however 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

Although there is significant research studying the lifespan of HDPE geomembranes, there is a paucity of research into the longevity of geocomposite drains for use in double liner composite systems. The objective of this study is to explore and, for the first time, quantify the performance of a particular geocomposite drain in municipal solid waste landfill leachate.

2 MATERIALS AND METHOD

A series of laboratory immersion and index tests were used to assess the rate of degradation of a particular geocomposite drain. The material was immersed in simulated municipal solid waste leachate and incubated at four different temperatures to accelerate the ageing process. Index tests were performed to quantify the change in engineering properties with aging. The following sections outline these tests in detail.

2.1 Materials Tested

The AGRU America geocomposite drain (GCD) examined was comprised of two geotextiles heat bonded to a geonet (Figure 1). Geotextiles are used as filters, separators, and to protect other geosynthetics. The particular geotextile attached to this GCD had needle-punched polypropylene staple fibers and a mass per unit area of 271 g/m^2 (8 oz/yd^2). The geonet core was 6.4 mm-thick high density polyethylene (HDPE) with a bi-planar structure.

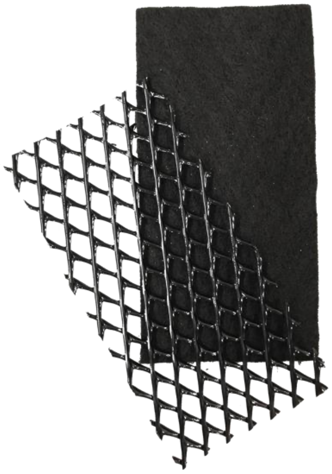


Figure 1: Unbonded Layers of Geocomposite Drain

2.2 Index Tests

The index tests conducted in this research were used to assess the change in physical and chemical 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 et al. 2004). The service-life of a polyolefin can be divided into three stages, A: depletion of antioxidants, B: induction time, and C: polymer degradation, as shown in Figure 2 (Hsuan and Koerner 1998).

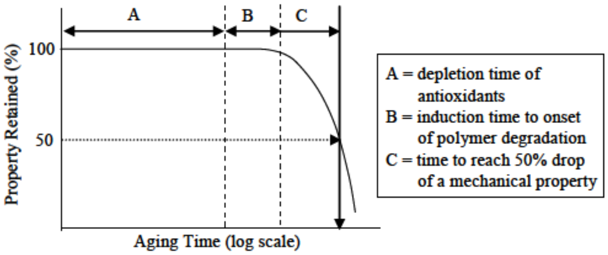


Figure 2: HDPE Ageing Stages (Hsuan and Koerner 1998)

2.2.1 Degradation of Chemical Properties

Chemical ageing is defined by the breaking of covalent bonds, leading to the reduction of engineering properties in a material (Schnabel 1981). One of the main chemical degradation mechanisms that occur is oxidation of polyolefins which is an auto-accelerating reaction, in other words, the reaction accelerates and reaches a constant rate. Antioxidant packages are added to products to extend their induction time and delay the onset of oxidation. The induction time is the period where antioxidants are depleted, and polymer oxidation reactions occur. The index test to quantify the extent of degradation of the material's chemical properties is oxidative induction time as oxidative degradation is believed to be the most harmful for HDPE geosynthetics (Hawkins 1984).

The two tests monitoring this type of degradation are high-pressure oxidative induction time (HP-OIT) and standard oxidative induction time (Std-OIT). HP-OIT tests were conducted to evaluate the presence of hindered amine light stabilizers (HALS) in the antioxidant package. Initial HP-OIT testing of the geonet core and the geotextile following ASTM 5885 showed no evidence of detectable HALS added to the geocomposite drain liner and no tests were conducted on the aged samples.

Std. OIT tests were conducted on the geonet core throughout the experiment according to ASTM D3895 using a differential scanning calorimeter (DSC). Initial Std-OIT tests were conducted on the geotextile with encapsulated 0.7 – 1.4 mg specimens at 160°C. The oxidative induction time for the geotextile was too small to be detected by the DSC and so no further Std. OIT tests were performed on the geotextile samples. For the geonet, a modified ASTM was used. Samples with a mass of 4 – 6 mg were tested at 190°C.

2.2.2 Degradation of Physical Properties

Tensile tests were used to quantify physical degradation due to the nature of a landfill's structure. Solid waste above a geosynthetic liner system applies pressure to the layers below it. Tensile forces that can develop in this configuration and hence the tensile resistance must be assessed and, with ageing, compared to the virgin results. For the geonet core and geotextile, tensile tests following modified ASTM D7179 and ASTM D5035 tests were performed. For the geonet core, specimens with one rib longitudinally and 8 cross-ribs were tested. For the geotextile, strip method 1C was used. The tensile yield force and elongation at yield were monitored.

2.3 Immersion Tests

Accelerated aging tests were performed to assess the how a material changes over time and ultimately the time to nominal failure. Individual components of the GCD were immersed in a synthetic MSW leachate (Leachate 3; Abdelaal et al. 2014). The cut coupons were placed in 4L jars and filled with Leachate 3. This jar size contained a reasonable number of samples and many jars can be fit into one oven. The ovens, into which the jars were placed were set to 55, 65, 75, and 85ºC.

Specimens were taken from jars at regular intervals and tested periodically. For the geonet, tensile specimens were removed every 2 weeks and standard OIT samples were taken every 7 days for samples in the 65, 75, and 85°C ovens and every month for the 55°C oven. When the jars were first placed in the ovens, additional samples for Std-OIT were taken every 24 hours for the first 10 days from the 85°C oven. The same index tests performed on the unaged samples were conducted on the aged samples to allow and evaluation of the rate of degradation in engineering properties.

3 RESULTS

The results of tests on virgin specimens are summarized in Table 1. Std.-OIT tests were performed in the geonet and tensile tests were conducted for both the geonet and geotextile over a period of 35 weeks.

Table 1: Index Tests on Virgin Samples

Material	Property	Mean	Std Deviation
Geonet	Std OIT	16.5 min	2.2
	Tensile strength at break	2900 N/m	1.0
	Tensile strain at break	87.8%	19.2
Geotextile	Tensile strength at yield (machine direction)	4000 N/m	1.7
	Tensile strain at yield (machine direction)	75.4%	1.8
	Tensile strength at yield (Cross-machine direction)	3200 N/m	0.2
	Tensile strain at yield (Cross-machine direction)	142.8%	1.7

The data collected for Std-OIT for the geonet core (Figure 3) shows a decrease from the beginning of the experiment to 150 days. The fastest rate of degradation was at 85°C.

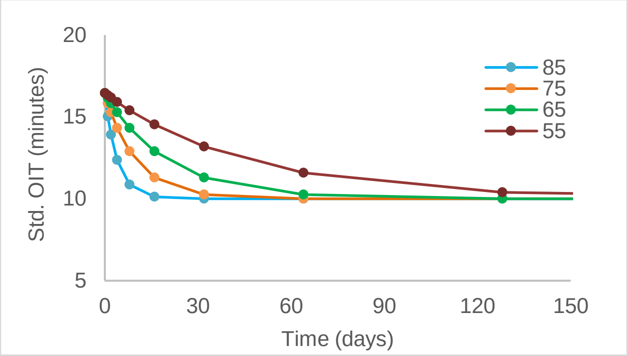


Figure 3: Standard Oxidative Induction Time for the geonet at four temperatures over a period of 150 days

Figure 4 shows the geonet tensile tests results for the specimens aged at 85°C. There was little to no change in the tensile properties with age over 35 weeks.

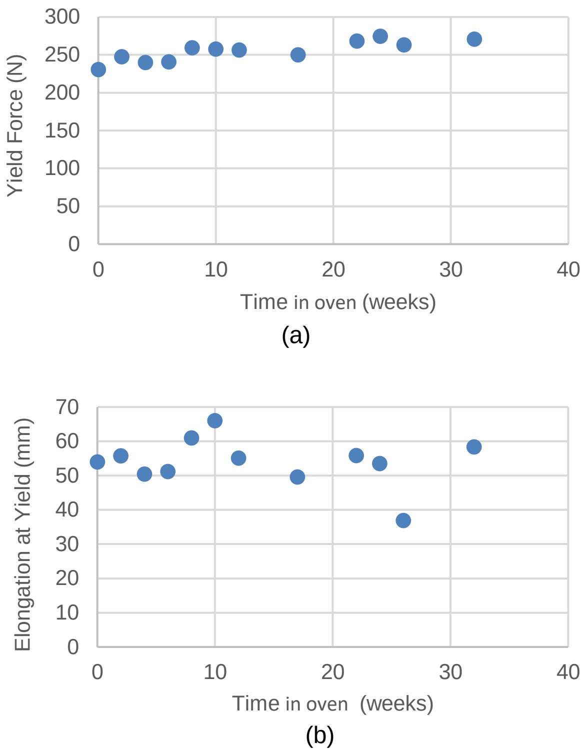
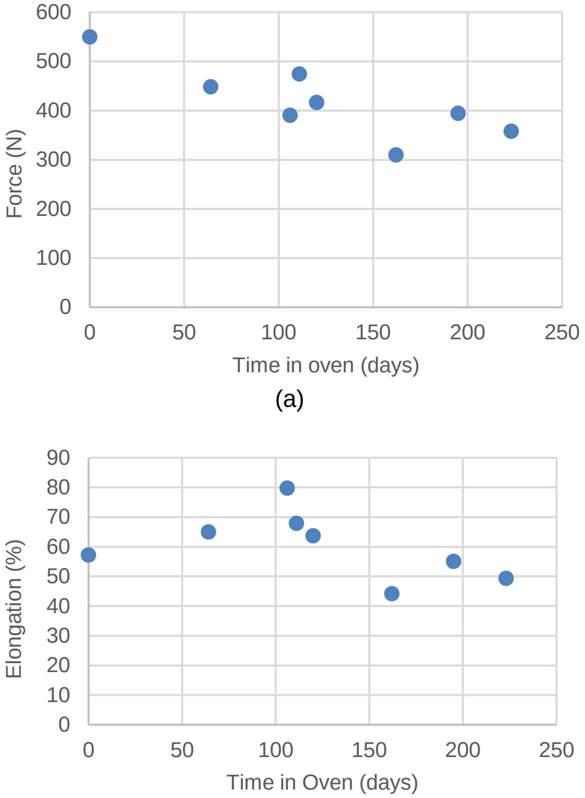


Figure 4: Geonet tensile tests results for specimens incubated at 85°C (a) Yield Force and (b) Elongation at Yield

Figure 5 and 6 show the results in the machine and cross-machine directions for geotextile tensile tests on specimens incubated at 85°C. Similar to the geonet, little change occurred in the machine or cross-machine direction, however there was high variability for this material.



(a)

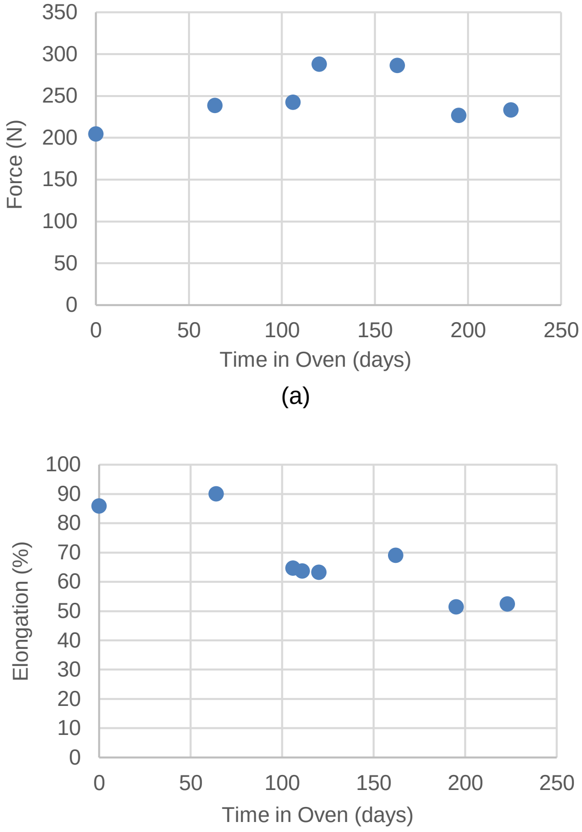
(b)

Figure 5: Machine Direction Geotextile Tensile Results for 85°C Samples (a) Tensile Yield Force and (b) Elongation at Yield

4 DISCUSSION

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 4 to 6, no substantial changes in physical or mechanical properties occurred in the geonet core or geotextiles during the incubation period. The variation in values can be due to variability of the material, since geocomposite drain present a high manufacturing variability (Thiel and Gatrell 2019). All four temperatures were analyzed, but only the 85°C graphs are shown in this paper as these would be the ones experiencing the most rapid degradation.

Although the physical characteristics did not change throughout the duration of the project, the chemical characteristics were, as shown in Figure 2. Using the data from the standard OIT tests, the Arrhenius method was used to predict how long the material will last at a real landfill site temperature. These results are only preliminary as they do not factor in the physical properties degrading, however they are able to give an estimation of the amount of time the chemical integrity of the material will withstand at landfill conditions.



(a)

(b)

Figure 6: Cross-Machine Direction Geotextile Tensile Results for 85°C Samples (a. Tensile Yield Force and b. Elongation at Yield)

The Std-OIT results were fit by a first order exponential decay function (Equation 1), where OIT_t is the OIT value after incubation time *t* (min), OIT_o is the initial OIT value (min), *s* is the antioxidant depletion rate (day-1), and *t* is the incubation time (days).

$$OIT_t = OIT_o \times e^{-st} \qquad [1]$$

Taking the natural logarithm of Equation 1 gives:

$$\ln{(OIT)_t} = \ln{(OIT)_o} - st \qquad [2]$$

The following step involved establishing an Arrhenius relationship that can be used to extrapolate antioxidant depletion at temperatures more similar to site conditions (Hsuan and Koerner 1998). The Arrhenius equation is:

$$s = Ae^{-(\frac{E_a}{RT})} \qquad [3]$$

where E_a is the activation energy in antioxidant depletion stage (J mol-1), R is the universal gas constant (8.314 J mol^{-1} K^{-1}), T is the test temperature (K), and A is a constant of the method. Taking the natural logarithm of both sides of Equation 3 gives Equation 4 (used to produce Figure 7).

$$\ln(s) = \ln(A) - \left(\frac{E_a}{R}\right)\left(\frac{1}{T}\right) \qquad [4]$$

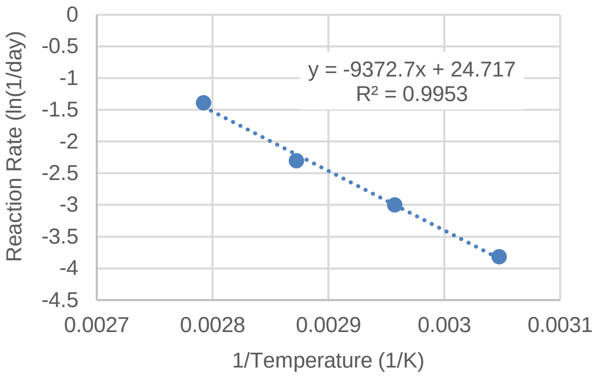


Figure 7: Arrhenius Plot of OIT depletion rate

The first stage in the life of the polyolefin materials is the time to deplete the antioxidants and this is based on the OIT depletion rate. The estimated times to Std-OIT depletion at a range of temperatures - based on the test data, the Arrhenius Equation 3 - are given in Table 2. These values are preliminary and only for Stage I (i.e., they do not include the time to physical and mechanical degradation of the material; Stages II and III - time to nominal failure).

Table 2: Antioxidant Depletion Rates in GNT core at Different Incubation Temperatures

Temp (°C)	2% of OITo	Time (days)	Time (years)
95	0.32891	6.3	0.02
85	0.32891	13	0.03
75	0.32891	7	0.07
65	0.32891	60	0.16
55	0.32891	140	0.4
40	0.32891	550	1.5
30	0.32891	1500	4.0
20	0.32891	4200	12
10	0.32891	13000	36

The average temperature in the liner system for an active landfill is considered to be approximately 35-40°C (Rowe 2005, 2012; Rowe and Islam 2009). As shown by Table 2, antioxidants would remain in the material for only 1.5 to 4 years over this temperature range, a very short period of time.

5 CONCLUSIONS

This is an initial study of the long-term performance of a geocomposite drain. Therefore, more tests are needed to assess the performance of these materials for MSW landfills; however, some preliminary conclusions can be made from this study.

The Std-OIT for the geonet core has reached residual at all temperatures after 128 days indicating that no antioxidants remain in the specimens. Using Arrhenius plot, it was estimated that the antioxidants would remain in the geonet core at MSW landfill temperatures on 35-40ºC of 1.5-4 years. The time is even less for the geotextile components.

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.

Transmissivity is the ability to allow lateral flow through the geocomposite. This is required so that hydraulic head does not build up on the secondary liner. A balance of allowing flow, while retaining upstream particles should be met by this layer (Koerner et al. 1994). One of the main functions of a geocomposite drain is to allow lateral flow of fluid through the material. This can be tested with transmissivity tests and must also be assessed with age. To allow the service-life of the GCD to be assessed for landfill applications.

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