 https://doi.org/10.1051/e3sconf/202456926003

Lifetime considerations of geotextile UV exposure before installation

David Beaumier[1*], *Stephan* Fourmont[2], *George* Koerner[3]

[1]CTT Group Sageos, St Hyacinthe, Quebec, Canada
[2]Afitex-Texel, St Marie, Quebec, Canada
[3]Geosynthetic Institute, Folsom, Pennsylvania, USA

Abstract. Geotextile are in most case intended for buried application, without exposure to sunlight. However, a short exposure to sunlight may occur before installation. Because of potential delay of installation and soil burying, the material is required to meet UV resistance. Artificial UV weathering will assess the potential risk of unintended exposure to sunlight. Photodegradation reactions consider the interactions with exposure conditions as well as polymer sensitivity to sunlight. Based on both laboratory measurements and field data, this paper evaluates the effect of light intensity, temperature and humidity with climates. Using polymer relation of its UV light sensitivity with the effective irradiance, a cumulative index is calculated for the reduction of geotextile service life from exposure to sunlight. Artificial weathering cycles for geotextiles are compared and related to the specific degradation mechanisms of polypropylene and polyethylene terephthalate. The reaction rate is correlated with temperature, respectively for each polymer. A model using radiant energy and temperature is proposed for guidance to service life prediction of partly UV-exposed geotextiles.

1 Introduction

In contrast to materials intended for direct exposure to sunlight during its service life, i.e. geomembranes for covers, ponds, canals and dams, geotextiles are subjected to temporary exposure before installation. Geotextiles are often protected against sunlight by an opaque plastic film wrapping the material for shipment and handling to field installation. Despite the preventive measures, the longevity of geotextiles will be affected by its handling before installation, and precisely its resistance to sunlight exposure. Quality assurance has indeed implemented the UV testing of geotextiles, by several organisms (BNQ, AASHTO, etc.). Material QC&QA is often based from theoretical correlations between laboratory conditions and average meteorological data. Correlations from UV laboratory testing to field tests show a lower acceleration factor of UV laboratory testing with real-life conditions [4]. Geotextiles properties may be correlated with the consideration of the intended product properties and its constituent polymers, leading to photodegradation mechanisms.

* Corresponding author: dbeaumier@gcttg.com

On one hand, climatic data from weather stations are useful to some extent in the prediction of laboratory exposures to real-life conditions. One method uses equivalent radiant energy dosage. However, the sensitivity of polymers to ultraviolet (UV) light is to be considered for modelling the photooxidation reaction. Based on photochemistry, correlations include numerous parameters, but most often resulting in insufficient data for prediction. Simplified methods for the prediction of polymeric geomembranes to natural aging are herein discussed and standardized exposure methods are compared with specific considerations for polyethylene terephthalate (PET) or polypropylene (PP) geotextiles. On the other hand, the influent properties of geotextiles on UV aging will also consider physical properties, i.e. thickness, weight per surface area, color, fibre length, and deniers. Because of its porosity, rain periods and dew also cause a soaking event, increasing the water absorption of geotextiles. Moisture will definitely accelerate the degradation of geotextiles, not only because of hydrolysis but also by antioxidant leaching and fibre oxidation, i.e. with polypropylene.

2 Background

The geosynthetics industry has gradually established increasingly stringent criteria to take account of the ageing of geotextiles under UV radiation, for consideration of the outdoor exposure before their installation and burying.

Geotextiles are mainly made out of two great families of polymers: polypropylene (PP) and polyethylene terephthalate (PET). Figures 1 and 2 describe typical molecular structures for both polymers.

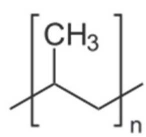


Fig. 1. Polypropylene, chemical structure.

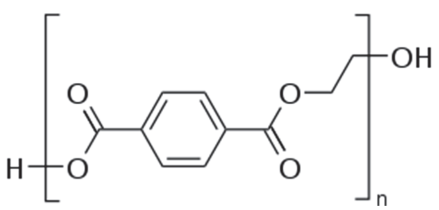


Fig. 2. Polyethylene terephthalate, chemical structure.

PP is subjected to photooxidation by chain scission of a limited number of chemical bonds: C-C, C-H, C=C. However, once that photooxidation started, free radicals are formed (C•, CO•, COO-, COOH,) and causing a greater sensitivity to UV light. Typical chain reactions to polypropylene photooxidation are described on Figure 3.

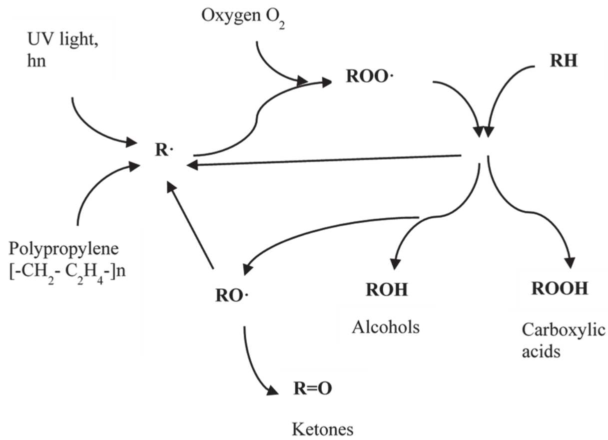
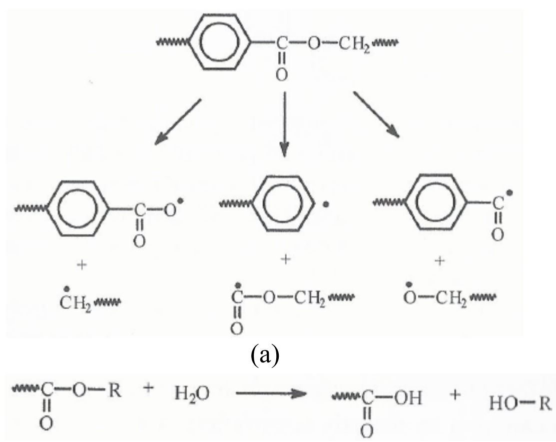


Fig. 3. Photooxidation of PP.

PET degradation to UV light occurs through scission reactions, basically Norrish type I, type II and type III. PET degrades by photolysis without the presence of oxygen. Hydroperoxides will be formed by the decomposition of ester groups within PET chemical structure. In the presence of water, photolysis will react in synergistic with hydrolysis.



(a)

(b)

Fig. 4. Degradation mechanisms with PET, photolysis (a) and hydrolysis (b) reactions [6].

The source of light exposure will also affect the sensitivity of polymers to photodegradation. The sensitivity of polymers to UV light is related to their chemistry, hence, different polymers will not be affected in the same way by the same source of UV light. Atlas (2020) covered the chemistry of photooxidation degradation mechanisms. UV radiation will affect polymers differently because of the different chemical bonds and structures of polymers and hence their different UV sensitivity. For instance, polypropylene (PP) will progressively absorb UV light below 300 nm, and polyethylene terephthalate (PET) will absorb UV light below 360 nm [8]. Energy from the absorbed UV radiation will affect chemical bonding and result in chemical degradation.

The chemical bond dissociation is related to a specific wavelength using Plank's constant, resulting in a polymer activation spectrum. The proposed approach to the chemical UV degradation of polymers uses the evaluation of spectral sensitivity. Spectral sensitivity correlates the activation spectrum to the spectrum of the light source. Using the spectral sensitivity, an effective irradiance may be modelled with an Arrhenius-type equation. The UV activation wavelength of PP is about 295 nm, but its spectral sensitivity is in the range of 340 to 380 nm [9].

The World Ozone and Ultraviolet Data Centre [7] has developed a wide range of data on both UV radiations. UV radiations are available from different sites throughout the world and are likely well-documented in North America (Figure 5). Sunlight is composed of a range of irradiance energy, varying with wavelength (spectrum). Standard sunlight spectra are also documented in ASTM G173. These spectra are specific to conditions, i.e. latitude, orientation, year time, and daytime. Data from WOUDC are more specific than models proposed by ASTM G173, perhaps, UV spectrum measurements are documented with a correlation of irradiance to wavelength, along with the most common meteorological data: UV index. The UV index is based on the erythemal sensitivity of the skin, hence, a correlation to PE is suggested for an adequate light sensitivity evaluation of a polymer, not human skin.

3 Methodology

A comparison of artificial weathering to service life is herein estimated from climatic data. Laboratory exposure with Xenon-Arc lamps exposure (ASTM D4355) was conducted to compare with the field site exposure. The site-exposed geotextile is compared to reference NPNW PP geotextiles. Tensile strength is monitored for the assessment of aging, calculated as percent retained strength from geotextiles initial values.

3.1 Material

A field exposed geotextile was used for correlation. The geotextile was a 350 g/m^2 black needle-punched nonwoven made of polypropylene staple fibres. It was first analysed by GSI. The geotextile was intended to serve as puncture protection for the underling geomembrane. Unexpectedly, the upper geotextile was left exposed to ultraviolet degradation for eight months prior to soil covering at the Pierce Creek dredge disposal facility. As a result of this miscalculation, this case history was made possible. Originally the geotextile conformed to the following minimum properties as they appear in Table 1. Properties are herein compared with reference of geotextile testing at SAGEOS, having mass per unit area of 190 and 220 g/m^2, respectively for white and gray colored NPNW PP. The purpose of this study is to correlate the observed degradation with photooxidation mechanisms of polypropylene, and correlate the behaviour to UV exposure with intrinsic material properties.

Table 1. Properties of geotextiles used at Pearce Creek as geomembrane protection material

Property	Test Method ASTM	Unit	Result
Grab tensile strength	D4632	N	1112
Grab tensile elongation	D4632	%	50-105
Trap. tear strength	D4533	N	445
Puncture (CBR) strength	D6241	N	3114
UV resistance (1)	D7238	%	70

Notes: (1) Evaluation to be on 50 mm strip tensile specimens per ASTM D5035 after 500 lt. hrs. exposure.

Moreover, geotextiles are a non-woven needle-punched fabric manufactured from 100% short polypropylene fibers. The fibers size is 3-6 denier, length is 76-102 mm. The rolls were 5.25m width and 91.44 m long.

3.2 Field investigation

The most important conditions affecting the seasonal variability of exposure conditions are the quantity and quality of sunlight, the amount of humidity, time of wetness, and the average maximum specimen temperature. Seasonal variability can vary greatly from year to year and must be accounted for in our test.

While laboratory weatherability and light stability tests are important for many geotextiles, the best way to test geotextiles is through natural exposure. Natural exposure testing has many advantages in that it is realistic, in-expensive, and easy to perform. However, most manufacturers do not have several years to wait to see if a "new and improved" product formulation is feasible.

Geotextile samples were taken in the field at the beginning of the project after 85 days of exposure and then finally after 252 days of exposure. A site photograph of the geotextile being deployed is shown in Figure 6. Figure 7 shows geotextile samples being taken at 85 days.

Fig. 6. Site photo of deployed geotextile.

Fig. 7. Photo of geotextile being sampled.

The results of the field study are shown in Figure 8. Although the data is sparse for this site during this time increment, (only three points), the half-life of the geotextile is 200 days via a linear regression of the data. We were pleasantly surprised by this finding.

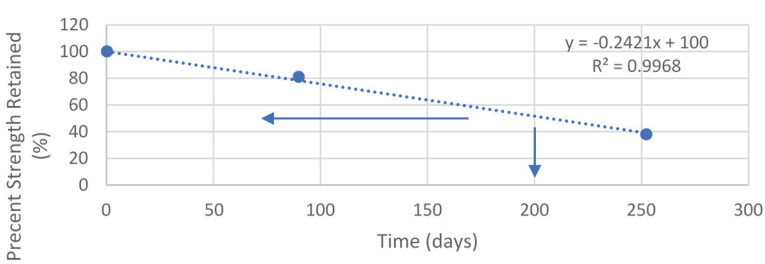


Fig. 8. Field results of percent strength retained versus time plot for the NPNW protection geotextile at the Pearce Creek Disposal Facility.

3.3 Site climate data

The exposed geotextiles were retrieved from the U.S. Army Corps of Engineers (USACE) and is identified as the Pearce Creek Confined Disposal Facility, in the Mid-Atlantic region of the USA just outside of Willington Delaware. Strips of multi-linear drainage geocomposite Draintube were also placed to collect gas from the dredge spoils. ,a dredge spoils. Figure 9

 https://doi.org/10.1051/e3sconf/202456926003

shows an aerial view of the dredge disposal facility. The site's closest town is Elk Neck, Maryland, with a longitude and latitude of 39.4848° N, 75.9848° W.

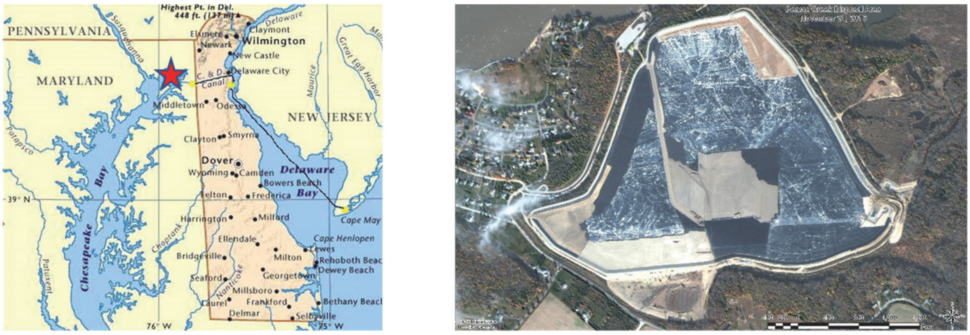


Fig. 9. Map showing location of the site and aerial photograph of the site.

Climate conditions include summers that are warm, humid, and wet; winters are very cold and snowy; and it is partly cloudy year-round. Over the course of the year, the temperature typically varies from 26°F to 86°F and is rarely falls below 13°F or above 93°F. The exposure test period was conducted in 2017, from January to August.

4 Methodology

Durability issues with exposed geotextiles are caused by three factors: light, high temperature, and moisture. Any one of these factors may cause deterioration. Together, they often work synergistically to cause more damage than any one factor would cause alone. Light spectral sensitivity varies for each polymer type. For durable materials, like geosynthetics, short-wave UV is the cause of most polymer degradation. The destructive effects of light exposure are typically accelerated when temperature is increased.

A laboratory weathering test must therefore provide accurate control of temperature. Moisture Dew, rain, and high humidity are the main causes of moisture damage. The xenon arc is the most commonly used accelerated testers for geotextiles. The equipment cross-sections are shown in Figure 10. The apparatus reproduces light, temperature, and moisture in different ways. The xenon test chamber reproduces the entire spectrum of sunlight, including ultraviolet (UV), visible light, and infrared (IR). The xenon arc is essentially an attempt to replicate sunlight itself, from 295 nm - 800 nm.

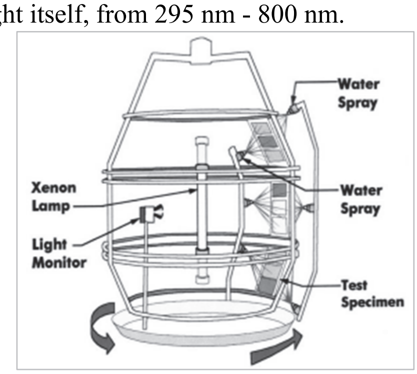


Fig. 10. Cross-section of apparatuses: Xenon-Arc type.

https://doi.org/10.1051/e3sconf/202456926003

Xenon arc testers are considered to be the best simulation of full-spectrum sunlight because they produce energy in the UV, visible, and infrared regions. To simulate natural sunlight, the xenon arc spectrum must be filtered. The filters reduce unwanted radiation and/or heat. Two boron filters were used in our experiment as described in procedure ASTM D4355 Test Method for Deterioration of Geotextiles from Exposure to Ultraviolet Light and Water (Xenon-Arc Type Apparatus). The results of the laboratory study undertaken on the NWNP geotextile samples taken in the field at the beginning of the Pearce Creek Disposal facility project are shown in Figure 11.

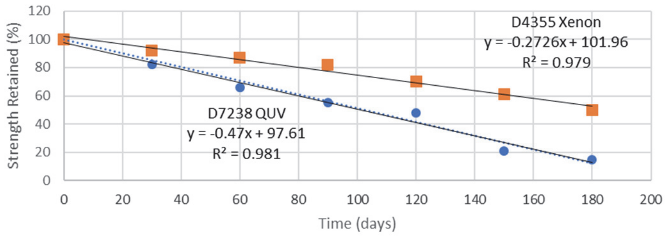


Fig. 11. Laboratory results of percent strength retained versus time plot for the NPNW protection geotextile at Pearce Creek Disposal facility.

When compared with lighter geotextiles exposed to a standard 21-days exposure to ASTM D4355, the degradation appears to be strongly related to the mass per surface area of the geotextiles. The effect of colours does not mitigate the effect of UV light by reflection, as oppose to the observed behaviour on geomembranes [5]. Figure 12 shows a comparison of the behaviour of NPNW PP geotextiles, presented by their respective mass and colour, the dotted grey shows the geotextile from Pearce Creek Disposal facility.

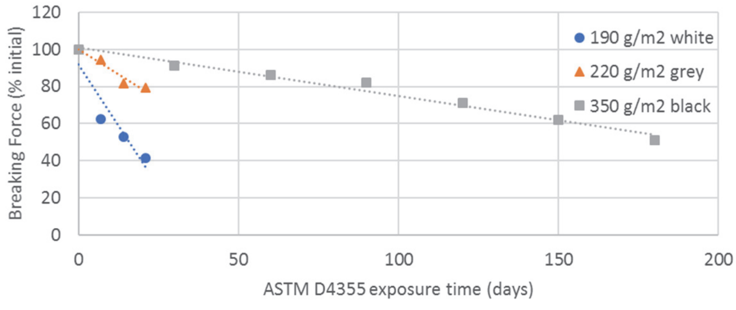


Fig. 12. Laboratory results of NPNW PP geotextiles, to ASTM D4355 UV exposure.

5 Conclusion

The resistance of geotextiles to UV light was investigated in the case of an unintended exposure before installation. The testing of geotextile for UV exposure was analysed by comparison with site-exposed samples. NPNW PP geotextiles were exposed to Xenon-Arc light per ASTM D4355. As a result, the resistance to UV light was correlated with mass per surface area and with the colour of geotextiles made of similar materials. Using polypropylene sensitivity to UV light, the projection to real-life exposure was done with the use of the UV index. Further investigations are required for the service life evaluation of polyester-based geotextiles.

References

1. ASTM G173-03 (2020). *Standard Tables for Reference Solar Spectral Irradiances: Direct Normal and Hemispherical on 37° Tilted Surface*, ASTM International, West Conshohocken, Pennsylvania, USA.
2. ASTM D4355/D4355M-21. *Standard Test Method for Deterioration of Geotextiles by Exposure to Light, Moisture, and Heat in a Xenon Arc-Type Apparatus,* ASTM International, West Conshohocken, Pennsylvania, USA.
3. Atlas Material Testing Solutions (2020). *Photooxidation & Stabilization Mechanisms*, Atlas Online Seminar.
4. Fourmont, S., Rivas, S., Koerner G., *Exposed NPNW GT Performance at a Large Surface Impoundment For Nearly One Year*, Geosynthetics Conference 2023, Advanced Textiles Association (2023)
5. Beaumier, D., Fazli, A., *Evaluation of geomembrane UV exposure using geographic and climate data*, Geosynthetics Conference 2023, Advanced Textiles Association (2023)
6. Wypych, G. (2018), *Handbook of Material Weathering, 6th edition*, Chemtec Publishing, Toronto.
7. Hare, E.W., Fioletov, V.E., Wardle, D.I., Carty, E.J. (2006). *Guide to the WMO/GAW World Ultraviolet Radiation Data Centre, Version 6.0*, Environment Canada
8. Sanga, T., Wallis, C., J., Hill, G., Britovsek, G., J.P., *Polyethylene terephthalate degradation under natural and accelerated weathering conditions*, European Polymer Journal 136, Elsevier (2020)
9. Zhenfeng, Z., Xingzhou, H., Zubob L., *Wavelength sensitivity of photooxidation of polypropylene*, Polymer Degradation and Stability 51, Elsevier (1996)
10. Jablonka M., Beaumier D., Blond E., *Long-term durability of polymeric water-resistive barriers*, 10th Annual North American Passive House Conference, Chicago, IL, USA, (2015)
11. Koerner, R.M. (1989) *Durability and aging of geosynthetics*, Elsevier Science Publishers, New York, NY, USA
12. Koerner, R. M., Hsuan, Y. G., Koerner, G. R. (2005). *GRI White Paper #6 on Geomembrane Lifetime Prediction: Unexposed and Exposed Conditions*, Geosynthetic Institute, Folsom, Pennsylvania, USA.