A Comparative Study on the Outdoor and Accelerated Weathering Tests for Non-Woven Polypropylene Geotextiles

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ABSTRACT: There are several standard accelerated weathering test methods used for geosynthetics which are required to produce the equivalent degradation results even though the light source, irradiance and spray conditions are different. Therefore, outdoor exposure and accelerated weathering tests were performed on polypropylene (PP) geotextiles using four different light sources for a better understanding of the effects of weathering. The test results obtained under four different test conditions for the combination of fluorescent UV, UV-A, xenon-arc and metal halide lamps are compared with natural weathering at the radiant exposure which is equivalent to one month exposure in southern Europe. Comparing to degradation observed from natural outdoor exposures enables assessment of the limitations, determination of the constraints, and interpretation of the data relating to accelerated weathering, all of which must be considered for service-life prediction.

Keywords: Polypropylene, Geotextiles, Weathering, Outdoor exposure, Accelerated weathering tests

1 INTRODUCTION

In most applications, geosynthetics are exposed to UV light for only limited time during storage, transport and installation and are subsequently protected by a layer of soil. The need for resistance to weathering therefore depends on the field condition of the application. The factors affecting on the degradation of polymer are solar radiation, heat and oxygen with contributions from other climate factors, such as humidity, rain etc.
Commonly, the weathering test methods can be classified into testing using artificial light sources and outdoor exposure. Since natural weathering is both seasonal and variable, tests using artificial light sources have the advantage of being able to increase the intensity of the radiation as well as of ensuring that the radiation is constant, controlled and last up to 24 h a day. EN 12224 and ASTM D4355 are most commonly used test method using artificial light sources for geotextiles and ASTM D5970 is a test method for outdoor exposure.
EN 12224 describes accelerated weathering tests with combination of fluorescent UV or UV-A lamps. EN 12224 is based on the 50 MJ/m^2 radiant exposure which is equivalent to one month exposure in southern Europe during summer. ASTM D4355 uses weather-Ometer with xenon-arc lamp that simulates the spectrum for natural daylight, including the UV region. ASTM D5970 provides a guide to evaluate deterioration of geotextiles using natural outdoor exposure.

In this study, we have performed the artificial weathering tests on PP geotextiles used for the prefabricated vertical drains (PVDs) as a filter using four different types light sources such as combination UV, UV-A, xenon-arc and metal halide lamps. To improve the correlation with outdoor exposure, PP geotextiles were exposed outdoor in Arizona and Florida according to the relevant standards.

2 MATERIALS AND TEST METHODS

2.1 *Materials*

We have used a non-woven geotextile composed of thermally bonded continuous polypropylene filaments, Typar® made by DuPont. The PP non-woven geotextile is used as a filter for PVDs in civil engineering and construction sector. The tensile properties of non-woven geotextiles are tested in accordance with ISO 10319 and the results are given in Table 1.

Table 1. Tensile properties of non-woven geotextile

Parameters	Tensile strength (kN/m)	Strain at maximum load (%)
Mean	9.16	51.0
Standard Deviation	0.14	1.3

2.2 *Test Methods*

2.2.1 *Outdoor exposure*

Polypropylene geotextiles were exposed outdoor in accordance with ASTM D5970 in New River, Arizona and Miami, Florida from June to December 2015 with 50, 100 and 150 MJ/m^2 of total UV radiant energy in the UV range. Outdoor weathering tests were performed at a tilt angle 34° and 26° from the horizontal facing south. The climate data of two test sites are given in Table 2.

Table 2. Climate data of test site (Arizona, Florida) in 2015

Site		Arizona (Desert weathering)	Florida (Inland weathering)
Latitude		33° 54’ North	25° 52’ North
Longitude		112° 08’ West	80° 28’ West
Elevation		610 m	2 m
Temperature	Summer (Avg. High/Avg. Low)	40 °C / 26 °C	34 °C / 23 °C
	Winter (Avg. High/Avg. Low)	21 °C / 8 °C	27 °C / 16 °C
Relative Humidity (Annual Mean)		35 %	76 %
Rainfall		250 mm	1 685 mm
Solar Radiant Exposure (MJ/m^2)	Total range	8 054	6 646
	UV range	349	303

a) Arizona (b) Florida

Figure 1. Natural outdoor weathering

2.2.2 *Accelerated weathering test*

EN 12224 is used for determining the UV resistance of geotextile and geotextile-related products using the usage of two light sources of UV combination and UV-A. EN 12224 is based on 50 MJ/m^2 radiant exposure which is equivalent to a month exposure in southern Europe during the summer season. In the lab-scale, the test durations are 320 h for combination UV lamps or 350 h for UV-A lamps under continuous “on” state during the water spray, whereas the test duration increases to 390 h for combination UV and 430 h for for UV-A lamps if the lamps are turned “off” during the water spray. The reason for light off during wet interval is to simulate dew effect. During the night, condensation water is absorbed by materials then it is desorbed as the material dries out. Dew plays role in determining material durability (George Wypych (2008)). ASTM D4355 covers the determination of the deterioration in tensile strength of geotextiles by exposure to xenon-arc light source, moisture and heat with the duration time of 300 h. The irradiance level is maintained at the control point to produce 0.35 W/m^2 at 340 nm and Type-S/Type-S filter combination is recommended as inner/outer filters. We also used the metal halide global lamp as a new light source that is the best match to natural outdoor sunlight even though there is no standard test method. It is similar to simulate solar infrared region, as well as solar UV and VIS region compared to other light source. The four types of light sources are used in this study as shown in Figure 2.

a) Combination UV b) UV-A c) Xenon-arc d) Metal Halide

Figure 2. Four types of light sources

To improve the correlation with outdoor exposure the spectrum of the light source shall be as near as possible to that of solar global radiation, particularly in the ultraviolet region, because polymers are generally very sensitive to changes in this spectral region. Figure 3 shows irra-

diance distribution of various light sources in which we could clearly observe the difference in pattern among four different light sources. Table 3 shows the irradiance distribution of four different light sources in UV region. UV-A lamp shows the highest irradiance in the wavelength range which causes photo-degradation of PP (Hsuan et al., 2008) while xenon-arc light source shows the lowest irradiance in the short wavelength band. The total irradiance is highest for metal halide lamp.
We have performed UV spectrum analysis and calculated the exposure times to reach accumulated irradiance of 50 MJ/m^2 using UV-VIS spectrometer (EPP2000-C, StellarNet, USA) for four different light sources. Test conditions are given in Table 4 as per EN 12224 and ASTM D4355.

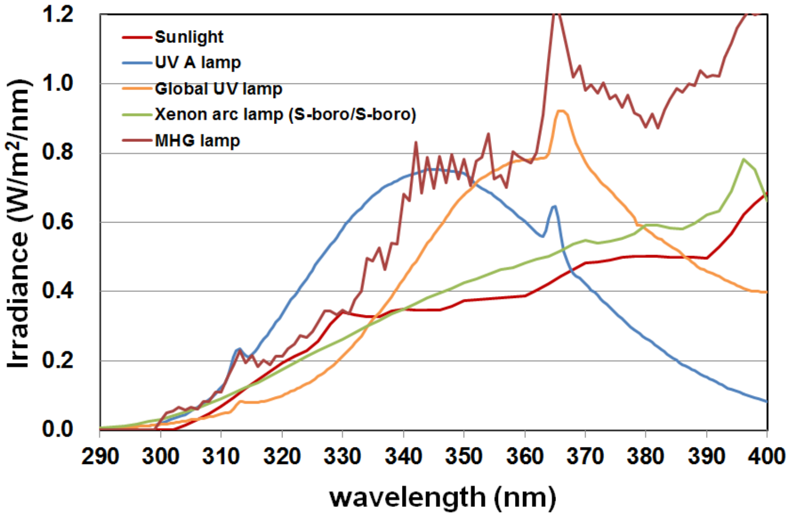

Figure 3. Irradiance vs. wavelength by light sources

Table 3. Irradiance distribution of four types of light sources

wavelength band (nm)	Measured irradiance(W/m^2)			
	Combination UV	UV-A	Xenon arc	Metal halide
290~320	1.2	3.0	2.1	2.6
320~360	17.7	25.3	13.7	22.7
360~400	24.4	11.5	23.6	40.5
Total irradiances (W/m^2)	43	40	39.4	65.8

Table 4. Test conditions of accelerated weathering test

Test method	Light source	Temperature (°C) (dry/wet)	Test Cycle (h) (dry/wet)	Duration (h) to reach 50(MJ/m^2)
EN 12224	Combination UV	50 / 25	5 / 1	320, 390
	UV-A	50 / 25	5 / 1	430
ASTM D4355	Xenon-arc	65 / 65	1.5 / 0.5	300
-	Metal Halide	50 / -	-	309

3 RESULTS AND DISCUSSION

3.1 *Outdoor Exposure*

The retained strengths of samples exposed in Arizona are much lower than those in Florida as shown in Figure 4 and Table 5. In addition, the strengths decrease sharply between 50 and 100 MJ/m^2 in Arizona since the test was performed during July and August when the average temperature is 40 °C. The surface temperature of sample was is much higher during the summer which accelerated photo-degradation of PP geotextiles. Therefore, the surface temperature of specimen should be considered more carefully in artificial weathering test considering the seasonal variation of outdoor exposure.

Table 5. Tensile properties of non-woven geotextile after outdoor exposure

Test Site	New River, Arizona			Miami, Florida		
Duration Time (day)	43	88	141	53	112	193
UV Radiant exposure (MJ/m^2)	50	100	150	50	100	150
Month	June/July	July/Aug.	Sep./Nov.	June/July	July/Oct.	Oct./Dec.
Tensile Strength (kN/m)	7.06	2.74	1.16	8.29	6.19	3.60
Standard Deviation	0.63	0.58	0.22	0.46	0.66	0.45
Retained Strength (%)	77.0	29.9	12.7	90.5	67.6	39.3

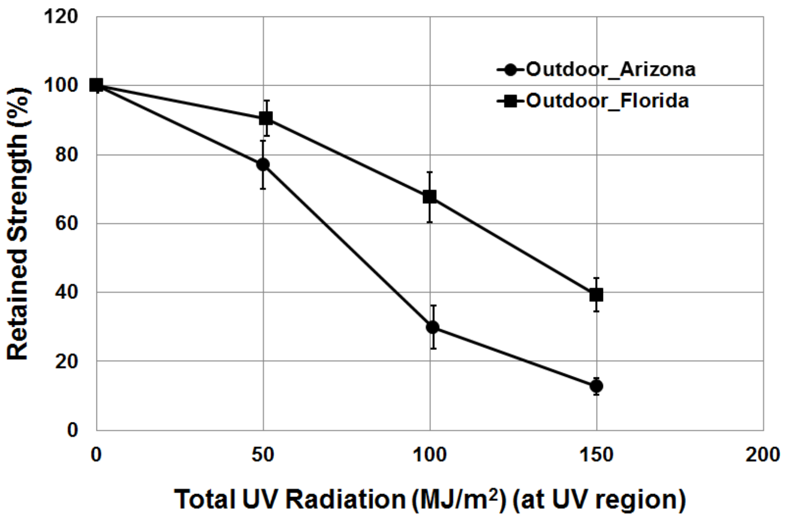

Figure 4. Reduction in tensile strength after outdoor exposure

3.2 *Accelerated weathering tests*

The retained strengths of UV exposed samples are shown in Table 6. In order to investigate the difference of retained strengths after weathering under various test conditions, t-tests were run with 95 % of statistical confidence level. P-value was used as a test criterion of difference between the mean retained strengths after weathering. In this study, the null hypothesis states that the two means are equal while the alternative hypothesis states that they are not equal. A p-value below the cut off level (0.05 in case of 95% of confidence level) suggests that the population means are different.

The t-test results are given in Table 6 and Figure 5. The retained strength is highest for combination UV lamp followed by Xenon arc and UV-A lamps with 95 % of statistical confidence. The reason for this behavior is that UV-A emits high irradiance at low wavelength in UV region. The effect of light on/off during water spray using combination UV shows significant difference with 95 % of statistical confidence. The UV degradation under “off” condition shows lower retained strength (%) than under light “on” condition. The water spray simulates the dew effect which during the night which causes contraction and extension of materials to accelerate the degradation.
The retained strengths exposed under Xenon-arc and combination UV lights show good agreement with those obtained from natural weathering test in Florida. This means that the similarity of irradiance distribution in UV region is the most important factor for artificial weathering test for good correlation with natural weathering. However, the combination UV lamp has the different spectral distribution in IR region which may causes different failure mechanism if we consider other failure modes than reduction in tensile strength.
This paper focuses on the comparative study on various standardized weathering test methods which offer the specification of the determination of the resistance to weathering for geotextiles in the field. The weathering resistances between combination UV and UV-A lamps according to EN 12224 show significant differences in retained strengths and with light on/off during water spray. Therefore, we should consider the spectral distribution of light sources, surface temperature of specimen and spray condition as important factors for artificial weathering test to improve the correlation with outdoor exposure.

Table 6. Tensile properties of non-woven geotextile after UV exposure

Test Method	EN 12224			ASTM D4355	-
Light Source	Combination UV		UV-A	Xenon-arc	Metal Halide
Light on/off at wet interval	on	off	off	on	-
Duration Time (h)	a) 320	b) 390	c) 430	d) 300	e) 309
Total UV Radiation (MJ/m^2)	50	50	50	50	50
Tensile Strength (kN/m)	8.85	8.42	6.56	8.36	4.55
Standard Deviation	0.05	0.06	0.02	0.11	0.52
Retained Strength (%)	96.6	91.9	71.6	91.2	49.6
p-value of t-test < 0.05	i) effect of light source: (a) vs. (d), (b) vs. (c) ii) effect of light on/off during wet interval: (a) vs. (b)				

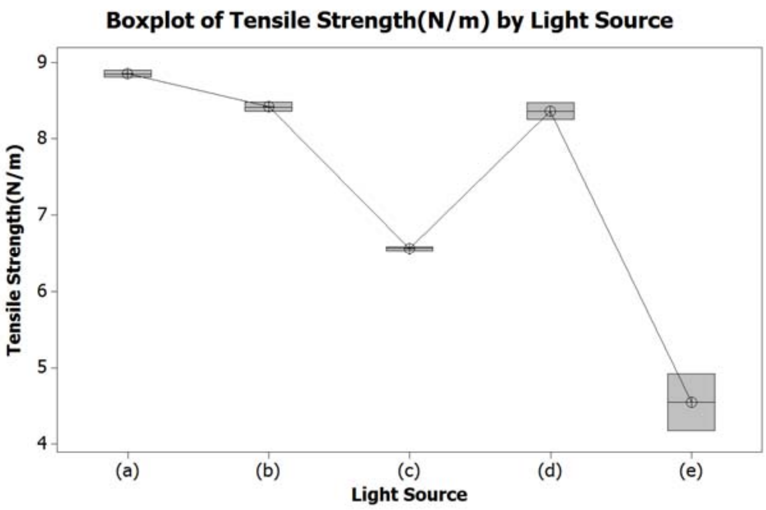

Figure 5. Retained tensile strengths after weathering with various light sources

4 CONCLUSIONS

This paper focuses on the comparative study of photo-degradation behavior of PP geotextiles which was carried out under both outdoor exposure and accelerated weathering tests with four different light sources. The weathering resistances between natural light and artificial light sources show widely differences in retained strengths. The results using xenon-arc lamp and combination UV with light 'off' during water spray show the closer retained strength to natural outdoor exposure in Miami while the retained strength using UV-A agrees well with the outdoor exposure in Arizona. These results can be guidelines for geotextile users to select appropriate weathering test methods considering the correlation with field condition.

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REFERENCES

ASTM D4355 (2006), *Standard test method for deterioration of geotextiles by exposure to light moisture and heat in xenon arc type apparatus*.

EN 12224 (2000), *Geotextiles and geotextile-related products – Determination of the resistance to weathering.*

ASTM D5970/D5970M (2016), *Standard test method for deterioration of geotextiles from outdoor exposure.*

Hsuan et al. (2008) *Long-term performace and lifetime prediction of geosynthetics*, EuroGeo4 Keynote Paper, p. 1-40.

Suits, L.D. & Hsuan, Y.G. (2003) *Assessing the photo-degradation of geosynthetics by outdoor exposure and laboratory weatherometer*, Geotextiles and Geomembranes, 21(2), p. 111–122.

George Wypych (2008) *Handbook of material weathering (4th ed.)*, ChemTec Publishing, p. 113-114