Durability of Polyester Geotextiles Subjected to Australian Outdoor and Accelerated Weathering

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ABSTRACT

Polyester geotextiles are used in a variety of engineering applications, some of which require them to be exposed to sunlight for months or even years at a time eg. protection layers in landfills, filtration layers in tailings dams etc. Photodegradation through exposure to ultraviolet radiation (UVR) is one of the primary degradation mechanisms of synthetic polymeric materials. Polyester (PET) has a higher resistance to photodegradation than unstabilized polyolefin materials such as HDPE and Polypropylene, primarily due to the inclusion of carbon-based benzene rings within the polymer structure. Extensive information relating to the degradative processes of polymers exists but research into geotextile outdoor weathering performance and durability under Australian conditions is exiguous due to the time and costs involved. This paper presents real-time outdoor exposure data on five grades of polyester geotextiles over 3, 6 and 12 months for three sites around Australia as well as accelerated UVR data obtained through exposure in a xenon-arc weathering chamber for 500h. Both sets of analyses are based on established geotextile-specific test methods. It was found that while a correlation exists between these two data sets, the strength of their relationship is heavily influenced by variability's associated with the product, limitations of the test methods and abiotic factors concomitant with outdoor exposure.

Keywords: Polyester, outdoor weathering, ultraviolet radiation, xenon-arc, durability, Australia

1 INTRODUCTION

Geotextiles have been used in Australia for over 35 years for a variety of different engineering applications due to their unique properties and ease of installation. Some applications require these materials to be exposed to sunlight for extended periods of time. Sunlight contains Ultraviolet Radiation (UVR) which has a deleterious effect on all polymers at varying rates. The rate of UVR degradation for each polymer type is primarily dependent on the chemical composition and structure, molecular weight, degree of crystallization and the presence of antioxidants and/or stabilizers. Polyester geotextiles have a natural resistance to UVR due to the inclusion of carbon-based benzene rings within the polymer structure which assist long-term stability by interrupting UV light energy (Iqbal et al. 2012).

Geotextile durability is further influenced by abiotic factors concomitant with outdoor exposure such as duration and intensity of exposure, angle and direction of exposure, season, temperature, geographic location, rainfall, wind, dust, sunlight hours, cloud cover and pollution. Biological elements such as algae, fungus and animal waste may also contribute to overall durability. Since a number of these factors work synergistically, it is beyond the scope of this work to understand the influence these have individually on ultimate geotextile durability.

Previous research into the performance of geotextiles when exposed to natural and artificial sunlight has been performed using various light sources, exposure locations and geotextile types (Baker 1997, Grubb et al. 2000, Hsuan et al. 2008, Koerner et al. 1998, Suits and Hsuan 2003). The analysis presented in this paper was performed on five grades of bidim polyester geotextiles which had been exposed to natural sunlight at three sites around Australia for 3, 6 and 12 months as well as simulated sunlight in a Xenon-Arc Weatherometer for a duration of 500h. Two rounds of data were collected.

2 LIGHT SOURCES

Two distinct light sources were used for these analyses. Natural terrestrial sunlight and light obtained through the use of xenon-arc lamps fitted with specialized daylight filters designed to closely mimic the spectral power distribution curve of sunlight.

2.1 Xenon-Arc Lamp Light

Historically in Australia, Mercury Blended Tungsten Filament (MBTF) and fluorescent lamps had been used to simulate sunlight for the purpose of accelerated UVR analysis of textiles. Development in lamp technology in combination with further research has highlighted more appropriate methods of artificial exposure for geotextiles. The light created by xenon-arc lamps fitted with specialized daylight filters provides the closest spectral match to sunlight (Figure 1). Light is produced by passing electricity through ionized xenon gas under high pressure.

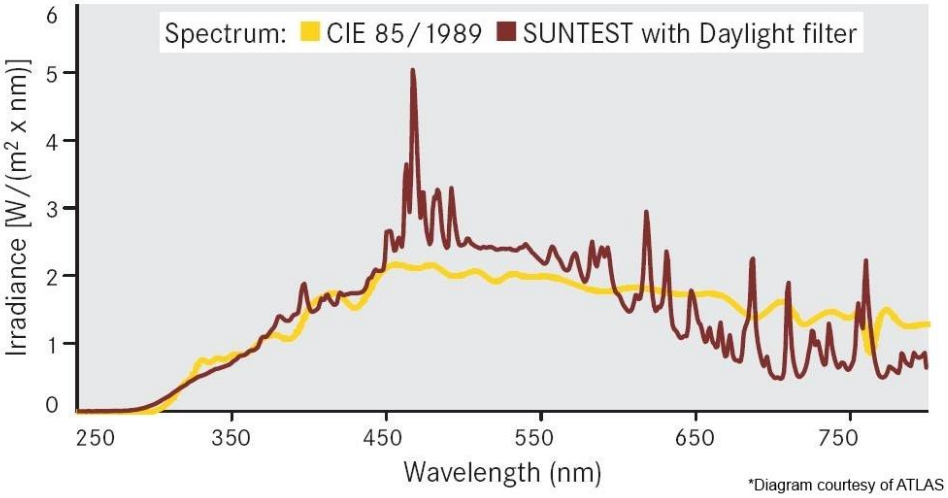

*Diagram courtesy of ATLAS

Figure 1. Spectral Power Distribution of Sunlight vs Xenon-Arc Light with Daylight Filter

2.2 Natural Sunlight

Extraterrestrial solar illuminance passing through our atmosphere and reaching the surface of the earth is called terrestrial sunlight. Sunlight is comprised of infrared (IR) radiation, having a wavelength range of 800 – 3000nm, visible light (VIS) ranging in wavelengths between 400 – 800nm and ultraviolet (UV) radiation or UVR having wavelengths of 295 – 400nm. UVR within sunlight is further categorized by the designations UV-A (315 – 400nm) and UV-B (295 – 315nm). All UV-A light passes through the atmosphere, whereas approximately 95% of UV-B and all other high frequency radiation outside these wavelengths including UV-C, x-rays and gamma rays, is attenuated by the atmosphere and the stratospheric ozone (O_3) layer such that the combined UVR portion of the spectrum contributes to 6.3% (UV-A) and 1.5% (UV-B) of terrestrial sunlight. According to Planck’s law, the wavelength of radiation is inversely proportional to its frequency (Figure 2). Shorter wavelengths have higher energy and it is these shorter wavelengths which are the most damaging to synthetic polymers such as Polyester. On a molecular level, when UV radiation hits the surface of the polymer, photons with equal or higher energy than the chemical bond strength of the polymer, displace the orbiting electron, causing a series of adverse reactions that lead to the generation of free radicals, scission of tie molecules, an increase in crystallinity and the eventual degradation of polymer properties. The photonic energy required to initiate photo-degradation in Polyester is inside the UV-A portion at 325nm (Lodi 2008).

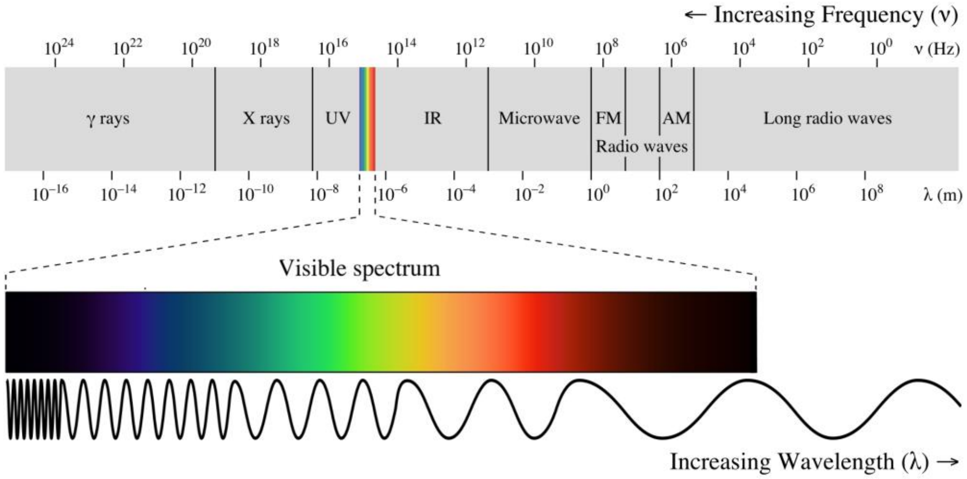

Figure 2. Electromagnetic Spectrum

3 RESULTS

Five grades of continuous filament nonwoven polyester geotextiles ranging in mass and thickness were selected for this analysis. Strength retained percentages after set periods of exposure to both natural outdoor and accelerated weathering were determined using pre- and post-exposure strip tensile tests in general accordance with *ASTM D5035-06 (2008) – Breaking Force and Elongation of Textile Fabrics (Strip Method)*. This method involves placing 50mm wide specimens in a universal tensile test machine with a 75mm gauge length between the grips and testing them at 300mm/min to failure. Strength retained percentages were determined from the results. Mass and thickness measurements were performed in general accordance with *AS 3706.1-2003 – General requirements, sampling, conditioning, basic physical properties and statistical analysis*. Given the narrow nature of the test specimens, it is reasonable to assume that variations in specimen mass, thickness and tensile properties were likely amplified due to variability's associated with the nonwoven manufacturing process. Given the close aspect ratio of MD to CMD strength values for these geotextiles, all data is presented as an average of the two directions to further reduce variability. The analysis was replicated to qualify initial results obtained in terms of test procedure and equipment variables. Coefficient of determination (r^2) values, based on Pearson's correlation coefficient (r), were generated for a number of variables using simple linear regression to identify the strongest relationships between the data sets.

3.1 Outdoor Exposure

Outdoor weathering racks were set up in Perth, WA, Adelaide, SA and on the Gold Coast in QLD, Australia in general accordance with *ASTM D5970-09 – Deterioration of Geotextiles from Outdoor Exposure*. Geotextile coupons for both Machine Direction (MD) and Cross-Machine Direction (CMD) were attached to test frames oriented 45° from horizontal and facing the equator (Figure 3). Coupons were then left exposed for 3, 6 and 12 month durations at each location. At the cessation of the nominated exposure periods, coupons were removed from the racks and cut into 50mm wide test specimens alongside unexposed geotextile coupons cut from the same roll number. Mass and thickness measurements were taken on all test specimens and then tested to determine retained tensile strength. Weather data was taken from the nearest available weather station to each set of racks and supplied by the Bureau of Meteorology's Climate Data Service as well as the Australian Radiation Protection and Nuclear Safety Agency (ARPANSA). Cloud cover was measured in Oktas which is a unit of measure describing how many eighths of the sky are obscured by cloud. Daily measurements ranging from 0 (completely clear sky) to 9 (completely obscured sky) were taken and attached to one of ten corresponding symbols. Sunlight was measured using a Campbell-Stokes recorder which focusses sunlight through a spherical glass lens designed to scorch a line into a specially designed card when the sunlight reaches a certain intensity. The length of the burn trace is directly proportional to the number of sunlight hours. Based on 22 years of data from 1990 to 2011, the Average Daily Solar Exposure for

Adelaide is between 15-18 MJ/m^2, and 18-21 MJ/m^2 for both Perth and the Gold Coast (Figure 4). This data correlates very well with average daily solar exposure data obtained for the exposure periods of this test program. Results are presented below (Tables 1, 2).

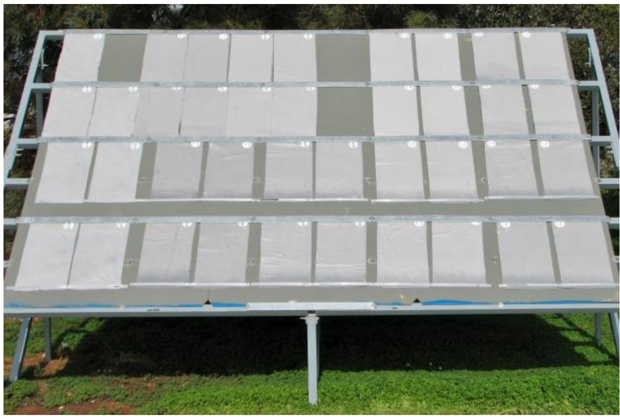

Figure 3. UV Racks

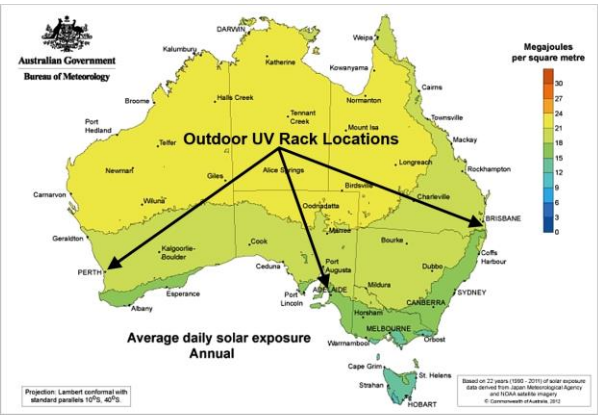

Figure 4. Australian Daily Solar Exposure Map

Table 1: Round 1 outdoor weathering test results

Exposure Dates		Mar 2011 to May 2011			Mar 2011 to Aug 2011			Jun 2011 to May 2012		
Location	*Unit of Measure*	Gold Coast, QLD	Adelaide, SA	Perth, WA	Gold Coast, QLD	Adelaide, SA	Perth, WA	Gold Coast, QLD	Adelaide, SA	Perth, WA
Exposure Time	*Months*	3	3	3	6	6	6	12	12	12
Solar Exposure-Daily Average	*MJ/m^2*	14.9	13.7	17.0	14.0	11.7	13.9	18.2	17.7	19.1
Solar Exposure-Cumulative	*MJ/m^2*	1374	1259	1564	2577	2154	2555	6666	6487	6981
Max Temp-Daily Average	*°C*	25.7	22.1	27.5	23.6	19.4	23.4	25.2	23.8	25.4
Cloud Cover-Daily Average	*Oktas*	4.3	4.8	2.5	3.6	4.9	3.6	3.9	4.7	3.8
Cloud Cover-Cumulative	*Oktas*	393	443	234	668	907	655	1447	1716	1375
Sunshine-Daily Average	*hours*	7.2	6.7	9.2	7.5	6.2	7.7	7.9	7.7	8.6
Sunshine-Cumulative	*hours*	646	610	837	1361	1116	1417	2889	2777	3124
Rainfall-Daily Average	*mm*	4.0	1.5	1.1	3.0	1.5	3.0	4.6	0.9	2.4
Rainfall-Cumulative	*mm*	364	138	104	555	270	552	1674	325	887
Sample A Mass	*g/m^2*	160	160	152	162	166	161	161	138	221
Sample A Thickness	*mm*	NA[a]	NA[a]	NA[a]	1.90	1.88	1.71	1.70	1.43	1.23
Strength Retained Efficiency	*%*	66.9	71.6	49.5	61.8	59.8	44.5	34.7	16.9	12.6
Sample B Mass	*g/m^2*	224	230	220	228	219	226	213	214	203
Sample B Thickness	*mm*	NA[a]	NA[a]	NA[a]	2.27	2.21	2.36	2.03	2.09	1.88
Strength Retained Efficiency	*%*	66.9	74.8	63.8	55.8	55.0	55.6	37.3	36.7	29.7
Sample C Mass	*g/m^2*	293	288	286	287	272	278	282	276	266
Sample C Thickness	*mm*	NA[a]	NA[a]	NA[a]	3.04	2.81	3.05	2.76	2.79	2.60
Strength Retained Efficiency	*%*	76.6	76.7	73.4	64.6	59.6	62.9	49.5	48.1	42.3
Sample D Mass	*g/m^2*	394	402	403	412	396	408	394	383	NA[a]
Sample D Thickness	*mm*	NA[a]	NA[a]	NA[a]	4.23	3.86	4.16	3.87	3.76	NA[a]
Strength Retained Efficiency	*%*	75.9	78.5	80.7	73.2	75.4	71.0	62.8	57.0	55.3
Sample E Mass	*g/m^2*	537	544	537	548	550	526	532	527	510
Sample E Thickness	*mm*	NA[a]	NA[a]	NA[a]	5.03	5.00	4.91	4.71	4.62	4.70
Strength Retained Efficiency	*%*	84.2	89.8	76.4	78.6	85.5	71.5	68.4	75.5	62.7
Average Strength Retained Efficiency Across All Grades	*%*	74.1	78.3	68.8	66.8	67.1	61.1	50.5	46.8	40.5

[a] Not Available

Table 2: Round 2 outdoor weathering test results

Exposure Dates		Jul 2012 to Sep 2012			Jul 2012 to Dec 2012			Oct 2012 to Sep 2013		
Location	*Unit of Measure*	Gold Coast, QLD	Adelaide, SA	Perth, WA	Gold Coast, QLD	Adelaide, SA	Perth, WA	Gold Coast, QLD	Adelaide, SA	Perth, WA
Exposure Time	*Months*	3	3	3	6	6	6	12	12	12
Solar Exposure-Daily Average	MJ/m^2	15.8	11.6	14.1	21.5	19.5	21.1	20.0	19.0	20.2
Solar Exposure-Cumulative	MJ/m^2	1454	1063	1292	3947	3588	3873	7259	6906	7355
Max Temp-Daily Average	*°C*	22.7	17.1	20.3	24.9	22.6	23.8	25.7	24.4	25.4
Cloud Cover-Daily Average	*Oktas*	2.8	5.2	3.5	3.2	4.6	3.5	4.0	4.8	3.6
Cloud Cover-Cumulative	*Oktas*	255	478	323	595	841	637	1453	1744	1324
Sunshine-Daily Average	*hours*	8.5	6.3	7.9	9.0	8.2	9.1	8.0	8.0	8.6
Sunshine-Cumulative	*hours*	781	582	723	1652	1514	1677	2915	2864	3148
Rainfall-Daily Average	*mm*	1.0	1.1	2.3	1.3	0.7	1.7	4.4	1.1	2.2
Rainfall-Cumulative	*mm*	89	97	213	247	129	307	1580	382	826
Sample A Mass	g/m^2	167	156	160	167	150	165	159	149	136
Sample A Thickness	*mm*	1.74	1.67	1.54	1.70	1.54	1.80	1.80	1.48	1.32
Strength Retained Efficiency	*%*	79.4	79.6	79.0	41.5	35.3	49.5	39.1	25.9	12.8
Sample B Mass	g/m^2	237	224	250	232	233	234	229	223	220
Sample B Thickness	*mm*	2.26	2.19	2.20	2.28	2.33	2.33	2.23	2.11	2.08
Strength Retained Efficiency	*%*	67.6	72.3	67.7	52.8	48.7	51.5	42.9	44.7	35.6
Sample C Mass	g/m^2	301	282	276	303	284	286	289	277	266
Sample C Thickness	*mm*	3.04	3.04	2.85	3.08	3.16	3.01	3.11	2.80	2.62
Strength Retained Efficiency	*%*	87.4	75.1	75.8	69.3	63.7	59.4	64.2	52.0	45.5
Sample D Mass	g/m^2	381	393	392	383	388	379	386	398	365
Sample D Thickness	*mm*	3.24	3.44	3.29	3.28	3.38	3.30	3.41	3.41	3.05
Strength Retained Efficiency	*%*	82.4	95.3	87.1	75.5	81.5	65.9	65.8	82.5	59.1
Sample E Mass	g/m^2	529	519	522	538	513	528	551	520	518
Sample E Thickness	*mm*	4.16	4.22	4.14	4.35	4.33	4.37	4.34	4.41	3.98
Strength Retained Efficiency	*%*	73.8	79.4	75.4	72.3	68.4	65.6	65.9	74.0	63.0
Average Strength Retained Efficiency Across All Grades	*%*	78.1	80.3	77.0	62.3	59.5	58.4	55.6	55.8	43.2

Unfortunately the Oktas scale does not take into consideration the cloud level, type or thickness, making correlations with solar radiation impractical. Outdoor data yielded good correlations with increasing mass and thickness measurements with increasing performance (Figure 5). This indicates that while the surface of the geotextile undergoes the photodegradation process, the oxidized top layer serves as a barrier to protect the remaining fibres underneath from UVR until they are removed through environmental factors such as rain and wind, exposing the fibres underneath (Figure 6). This suggests that mass and thickness play a significant role in long-term outdoor durability.

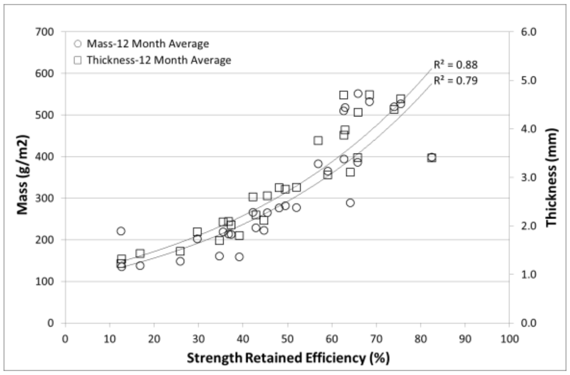

Figure 5. Mass and thickness vs strength

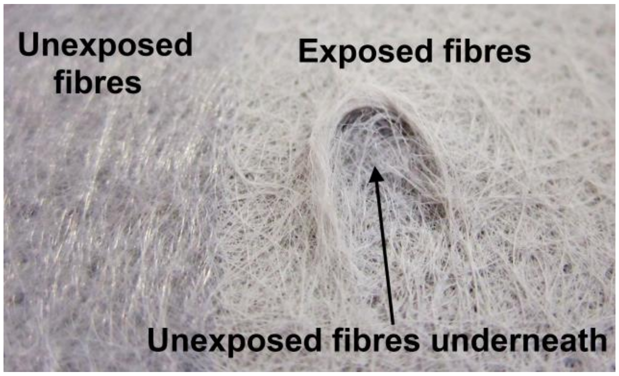

Figure 6. Exposed vs unexposed fibres

Further analysis of the data indicates a strong relationship between the increasing average solar radiation and the decreasing sample average strength retained efficiencies (Figure 7). This supports the current understanding of the photodegradation mechanisms of Polyester.

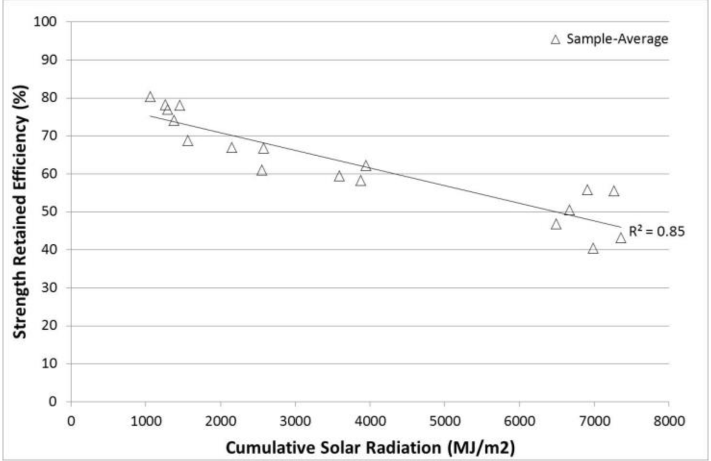

Figure 7. Solar radiation vs strength

3.2 Accelerated Exposure

Due to the lengthy time and costs involved in real-time outdoor analysis, accelerated exposure is often chosen by manufacturers and research facilities for quality control purposes and/or comparative analysis between products. Accelerated exposure analysis was performed in general accordance with *AS 3706.11-2004 – Determination of durability - Resistance to degradation by light, heat and moisture* which is an index test requiring geotextile coupons to be exposed to simulated sunlight in 120 min cycles (90 mins of light followed by 30 mins of light and water spray). An ATLAS Suntest XXL+ flatbed weatherometer fitted with three 1700W air-cooled xenon lamps was used for this analysis (Figure 8). The temperature and humidity were maintained at 65°C and 50% respectively. The equipment maintained a minimum level of irradiance at the control point to produce 0.35 W/m^2/nm at 340nm. As with the outdoor analysis, coupons were cut into 50mm wide pre- and post-exposure test specimens and strength retained percentages determined after 500h exposure.

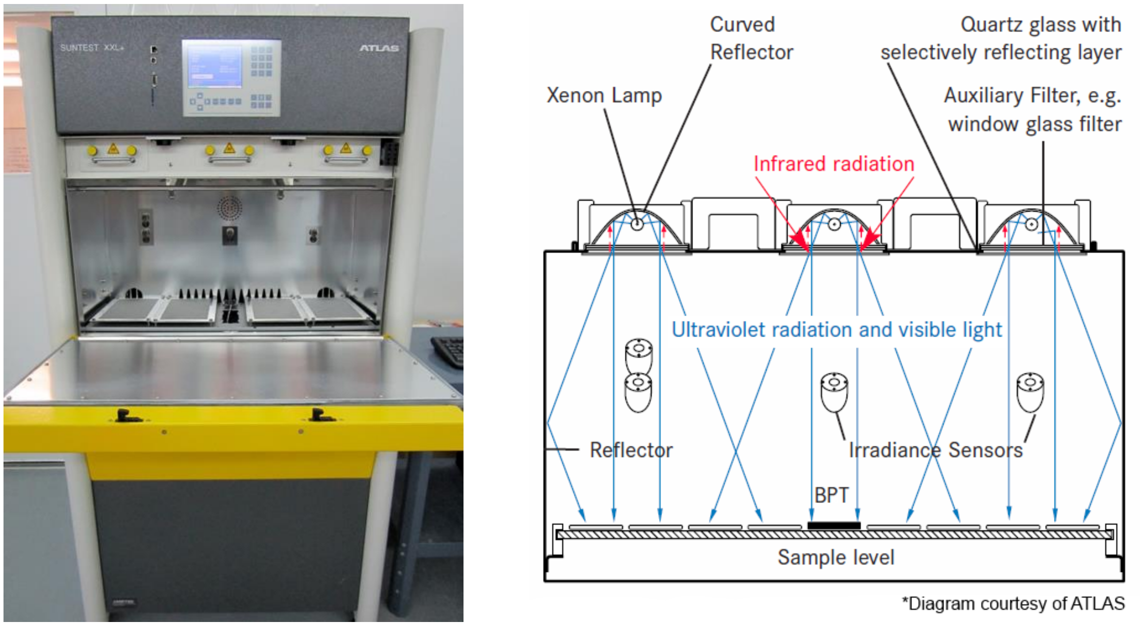

*Diagram courtesy of ATLAS

Figure 8. ATLAS Suntest XXL+ Weatherometer

The deterioration curve obtained from the results of this test method enable the user to determine the tendency of a geotextile to degrade when exposed to radiation, water and heat. The method does not account for variability of natural outdoor or site-specific conditions (eg. humidity, temperature, atmospheric pollution, wind, sunlight hours, rainfall etc). Results are presented below (Table 3). The results indicate a reasonably good correlation between increasing mass and increasing thickness with increasing performance supporting earlier work by Koerner et al. 1998 (Figure 9).

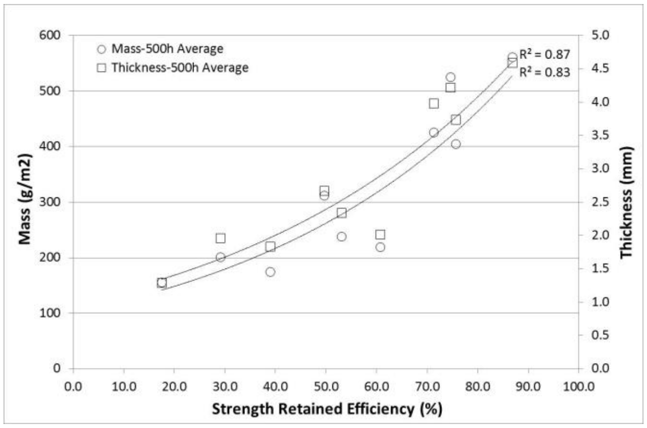

Figure 9. Mass and thickness vs strength retained efficiency after 500h accelerated exposure

Based on previously published ratios between Global Solar Radiation (295-3000nm), UVR+VIS (295-800nm), UVR (295-400nm) and UVR (340nm), it is possible to calculate the actual measured radiation values for these ranges for Rounds 1 and 2 (CIE 1989). Calculations indicate that 500h in a weatherometer operated as described above, produces only approximately 20% of the actual outdoor solar radiation measured over a 12 month period in Australia which equates to 2.4 months outdoor exposure in terms of radiation alone (Table 4). This direct comparison cannot be relied upon however, when assessing a geotextiles long-term performance. If the strength retained averages of all grades for both rounds are compared for both 500h accelerated (55.7%) and 12 month outdoor (46.0%) analysis, then the equivalent average outdoor exposure time increases to 9.8 months. This indicates that additional reactions within the accelerated chamber are having an increased degradative effect on the test specimens. This may include non-photonic reactions such as oxygen diffusion, moisture hydrolysis and, perhaps primarily, thermally influenced free radical and oxidative reactions given the increased temperature of 65°C (Zielnik 2013).

Table 3: Accelerated weathering test results

	Unit of Measure	Round 1	Round 2	Average
Exposure Time	*hours*	500h	500h	500h
Sample A Mass	*g/m^2*	156	175	166
Sample A Thickness	*mm*	1.29	1.84	1.57
Strength Retained Efficiency	*%*	17.5	38.9	28.2
Sample B Mass	*g/m^2*	201	238	220
Sample B Thickness	*mm*	1.96	2.34	2.15
Strength Retained Efficiency	*%*	29.1	53.0	41.1
Sample C Mass	*g/m^2*	219	312	266
Sample C Thickness	*mm*	2.02	2.67	2.35
Strength Retained Efficiency	*%*	60.7	49.6	55.2
Sample D Mass	*g/m^2*	405	426	416
Sample D Thickness	*mm*	3.74	3.98	3.86
Strength Retained Efficiency	*%*	75.6	71.3	73.5
Sample E Mass	*g/m^2*	525	561	543
Sample E Thickness	*mm*	4.22	4.59	4.41
Strength Retained Efficiency	*%*	74.6	86.8	80.7
Average Strength Retained Efficiency Across All Grades	*%*	51.5	59.9	55.7

Table 4: Outdoor vs accelerated radiation levels

	Global Solar Radiation (Annual)	UVR + VIS (Annual)	UVR (Annual)	UV (Annual)
Wavelength	*295 - 3000nm*	*295 - 800nm*	*295 - 400nm*	*340nm*
Unit of Measure	*MJ/m2*	*MJ/m2*	*MJ/m2*	*MJ/m2*
Outdoor Round 1 (12 Month Average)	6711	3295	360	3.1
Outdoor Round 2 (12 Month Average)	7174	3523	384	3.3
Outdoor Average (12 Month Average)	6942	3409	372	3.2
Accelerated for 500h (Round Average)	1384	680	74	0.630
Percentage of Accelerated to Outdoor	19.9%			

4 CONCLUSION

Five grades of continuous filament polyester geotextiles were exposed for 3, 6 and 12 months on 45° north-facing racks at three locations around Australia. The same five grades were also exposed to 500h accelerated exposure in a xenon-arc weatherometer. Replicate tests for both sets of analyses were performed to support initial data. Results indicate strong correlations between increasing mass/thickness and increasing strength retained values for both types of exposure. There was also a very good correlation between increasing solar radiation with decreasing tensile performance for the outdoor exposed coupons. The radiation levels between the two methods yielded different results in terms of exposure time and tensile strength retained with only approximately 20% xenon-arc radiation after 500h of the 12 month average outdoor solar radiation. The observed difference in tensile performance for equivalent radiation exposure is believed to be linked in part to the increased temperature of the xenon-arc chamber, which may have augmented other degradation mechanisms such as moisture hydrolysis and thermally-induced free radical production.

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