Correlation between standard accelerated UV tests and onsite UV degradation for high strength woven polyester reinforcement geotextiles in New Zealand

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ABSTRACT: Ultraviolet (UV) radiation is critical to geosynthetic resins. It causes polymer bond breakage leading to loss of all properties including discoloration, tensile strength and tensile elongation. This paper presents the test results of outdoor weathering of a high strength woven polyester reinforcement geotextile at site locations in Auckland and Christchurch, New Zealand. The onsite exposed samples are tested for loss in tensile strength and elongation over time and compared with results of accelerated UV lab tests. The standard accelerated UV lab tests for geotextiles include the Xenon Arc Test according to ASTM D4355 and the QUV Test according to EN 12224. These results help establish some form of correlation between standard accelerated UV lab tests and onsite UV degradation of high strength woven polyester reinforcement geotextiles in New Zealand.

Keywords: Reinforcement geotextile, UV degradation, outdoor weathering, accelerated UV lab test

1 INTRODUCTION

Ultraviolet (UV) radiation is electromagnetic radiation of wavelengths 100 nm to 400 nm, while visible light is electromagnetic radiation of wavelengths 400 nm to 700 nm and infrared radiation consist of wavelengths from 700 nm to 1 mm. The Sun emits a combination of UV radiation, visible light and infrared radiation; some of which is absorbed by the Earth's thick atmosphere. UV radiation is subdivided into UV-A (315 nm to 400 nm), UV-B (280 nm to 315 nm) and UV-C (100 nm to 280 nm) radiation. The UV radiation that reaches the Earth's surface is largely UV-A radiation with a small amount of UV-B radiation.

The exposure of a geosynthetic material to UV radiation generally has a negative impact on its intended engineering performance. It causes polymer bond to break or scission of main polymer chain, resulting in property changes over the exposure period (CUR 243, 2012). This is especially important when it concerns reinforcement applications because the material loses tensile strength and becomes more brittle. The general practice is to cover the reinforcement material, typically with a layer of soil cover, within a short period of time to minimise the loss of tensile strength and embrittlement. Very often questions are raised concerning how long is a reasonable and practical time limit to allow for before it should or can be covered up and how much of tensile strength loss and embrittlement happens during that period of exposure.

Accelerated UV lab test standards are available to benchmark the performance of geosynthetics against UV degradation. These accelerated tests that are set on standard artificially generated UV spectrum and intensity, are important in determining comparative UV degradation performance of geosynthetics but they have limitations for a variety of reasons. The UV radiation levels incident onsite is dependent on its geographical latitude and altitude; climatic and weather conditions; ground shading and reflectivity conditions; just to name a few. As such correlation between actual onsite exposure and standard lab test is a difficult subject. However, when such standard tests are calibrated with onsite UV degradation tests, they can then be used in a reliable way to predict UV degradation resistance under similar prevailing conditions.

It was with this in mind that a testing program was undertaken in New Zealand. A woven polyester geotextile of nominated ultimate tensile strength of 1000 kN/m in the machine direction (MD) and 100 kN/m in the cross direction (CD), commonly used for embankment basal reinforcement, was chosen as the test specimen. Controlled sites free from external disturbances were chosen for the exposure sites. Auckland was chosen as the representative location for North Island conditions while Christchurch was chosen as the representative location for South Island.

2 ONSITE WEATHERING TEST PROTOCOL

The protocol for the outdoor weathering exposure considered sampling of the high strength woven polyester reinforcement geotextile (Mirafi® PET1000/100) for outdoor weathering exposure for 5, 14, 28 and 42 days. The selected exposure locations are within secured compounds to rule out disturbance or damage due to external factors. Samples are laid basically flat to reflect the geotextile laid out condition at construction site.

2.1 *Sites for outdoor exposure*

Figure 1 shows the two sites selected for the outdoor exposure of the geotextile samples.

Auckland yard	**Christchurch yard**
Address: 14 Goodman Place, Penrose	Address: 24 George Bellew Road, Harewood
Co-ordinates: 36° 55′ 07″ S 174° 48′ 28″ E	Co-ordinates: 43° 29′ 53″ S 172° 31′ 52″ E
	

The actual locations of the test are shown with ●

Figure 1. Two sites selected for the outdoor exposure test.

2.2 *Sampling and exposure procedure*

The following procedure was followed:

- The high strength woven polyester reinforcement geotextile samples were pre-cut into 2 m wide x 1 m long panels at the factory and wrapped with protective wrapping to protect the samples from sunlight and transportation damage.
- A set of 5 samples for each location was prepared which included 4 samples for exposure testing at the designated site and 1 sample kept wrapped to be used for the control.
- At each site a 200 g/m^2 nonwoven geotextile was first placed on plywood boards followed by the high strength woven polyester reinforcement geotextile samples and fixed down on a plywood board. Each sample was clearly identified.
- The boards were then placed in locations where they were exposed to the maximum amount of sunlight for the exposed period.
- The samples were left to be exposed to rain and sunlight during exposure period at each site.
- The location chosen were away from warehouse traffic to ensure the samples were free from any disturbance that could cause damage to the geotextile.
- After each exposure period, the sample was carefully removed, folded and wrapped with the plastic wrapper to be sent to the laboratory for testing.

Figure 2 shows the geotextile sample preparation process for exposure at the Auckland yard.

Figure 2. Geotextile sample preparation process for exposure at the Auckland yard.

3 TEST RESULTS

The onsite exposed samples were tested according to ISO10319 at a GAI-LAP accredited lab. Accelerated UV tests which included the Xenon Arc Test according to ASTM D4355 and the QUV Test according to EN 12224 were conducted to establish correlation between them and onsite UV degradation.

3.1 *Real time exposure test results*

Table 1 shows the test results of MD peak tensile strength and strain at peak strength for the samples exposed in Auckland. Table 2 shows the test results of MD peak tensile strength and strain at peak strength for the samples exposed in Christchurch.

Table 1. Test results of MD peak tensile strength and strain at peak strength for Auckland exposed samples.

Sample No.	Exposure			Peak tensile strength (MD)		Strain at peak strength (MD)	
	Start	End	(days)	(kN/m)	(% retained)	(%)	(% retained)
1	-	-	0	1099.4	-	11.5	-
2	24/3/2017	29/3/2017	5	1101.2	100.2	11.1	98.7
3	24/3/2017	7/4/2017	14	1087.4	98.9	10.9	98.7
4	24/3/2017	21/4/2017	28	1023.0	93.0	10.7	83.8
5	24/3/2017	5/4/2017	42	998.9	90.9	10.4	83.7

Table 2. Test results of MD peak tensile strength and strain at peak strength for Christchurch exposed samples.

Sample No.	Exposure			Peak tensile load (MD)		Strain at peak load (MD)	
	Start	End	(days)	(kN/m)	(% retained)	(%)	(% retained)
6	-	-	0	1095.5	-	11.5	-
7	8/6/2017	13/6/2017	5	1103.2	100.7	11.1	97.2
8	8/6/2017	22/6/2017	14	1089.9	99.5	10.9	95.3
9	5/5/2017	7/6/2017	33	1079.0	98.5	10.7	93.7
10	5/5/2017	16/6/2017	42	1054.6	96.3	10.4	90.9

The peak tensile strength retention after 42 days of exposure was 91% for sample exposed in Auckland (see Table 1) while the peak tensile strength retention after 42 days of exposure was 96% for sample exposed in Christchurch (see Table 2). For reinforcement geotextiles it may be more relevant to understand the retained strength at working strain levels than at peak levels. For embankment basal reinforcement applications, working strain levels typically may vary between 2% to 5%.

Table 3 shows the test results of MD tensile strengths at 2% and 5% strains for the samples exposed in Auckland. Table 4 shows the test results of MD tensile strengths at 2% and 5% strains for the samples exposed in Christchurch. At strain levels of 2% and 5%, it appears that there has been no measured loss in tensile strengths for up to 42 days of samples exposure at both Auckland and Christchurch (see Tables 3 and 4), even though a drop in peak tensile strength over time is seen.

Table 3. Test results of MD tensile strength at 2% and 5% strains for Auckland exposed samples.

Sample No.	Exposure	Tensile strength at 2% strain (MD)		Tensile strength at 5% strain (MD)	
	(days)	(kN/m)	(% retained)	(kN/m)	(% retained)
1	0	153.9	-	388.7	-
2	5	165.6	107.6	397.9	102.4
3	14	168.2	109.3	404.0	103.9
4	28	191.0	124.1	433.3	111.5
5	42	162.5	105.6	394.8	101.6

Table 4. Test results of MD tensile strength at 2% and 5% strains for Christchurch exposed samples.

Sample No.	Exposure	Tensile strength at 2% strain (MD)		Tensile strength at 5% strain (MD)	
	(days)	(kN/m)	(% retained)	(kN/m)	(% retained)
6	0	176.3	-	415.1	-
7	5	186.1	105.6	431.4	103.9
8	14	187.4	106.3	435.6	104.9
9	33	177.3	100.6	425.3	102.5
10	42	182.1	103.3	435.7	105.0

3.2 *Recorded UV Data*

Data from the National Institute of Water and Atmospheric Research (NIWA) ground based measuring sites located in Auckland and Christchurch has been used to compare the strength loss in the samples to the measured radiant energy for the period of exposure for each site. Solar radiation contains three types of measurement namely global, diffuse and direct. The global solar radiation measured in MJ/m^2 which includes both radiation from direct sunlight and from diffuse (scattering) sources in the earth's atmosphere such as clouds was obtained from NIWA hosted New Zealand's National Climate Database. The details for the solar radiation experienced at each site are as follows:

- Auckland (see Figure 3):
  - Latitude -36.96177dec.deg, Longitude 174.7764dec.deg, Elevation = 5m
  - Measuring period 24th March to 4th May
- Christchurch (see Figure 4):
  - Latitude -43.53074dec.deg, Longitude 172.60769dec.deg, Elevation = 6m
  - Measuring period 5th May to 15th June for 33 day and 42 day samples
  - Measuring period 8th June to 22nd June for 7 day and 14 day samples

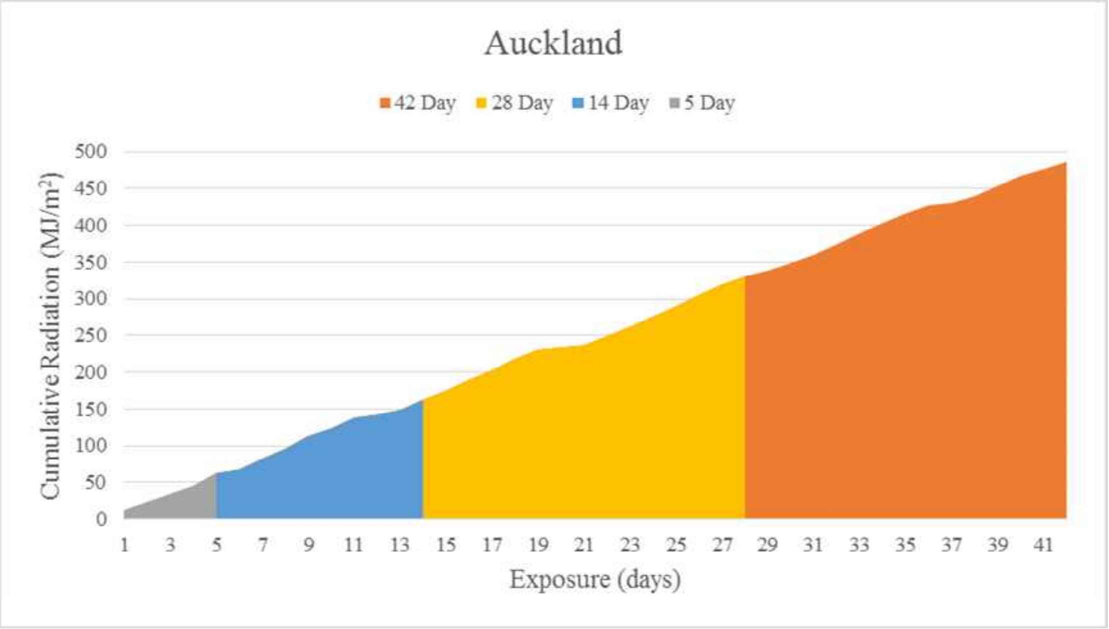

Figure 3. Solar radiation experienced at Auckland site over days of exposure.

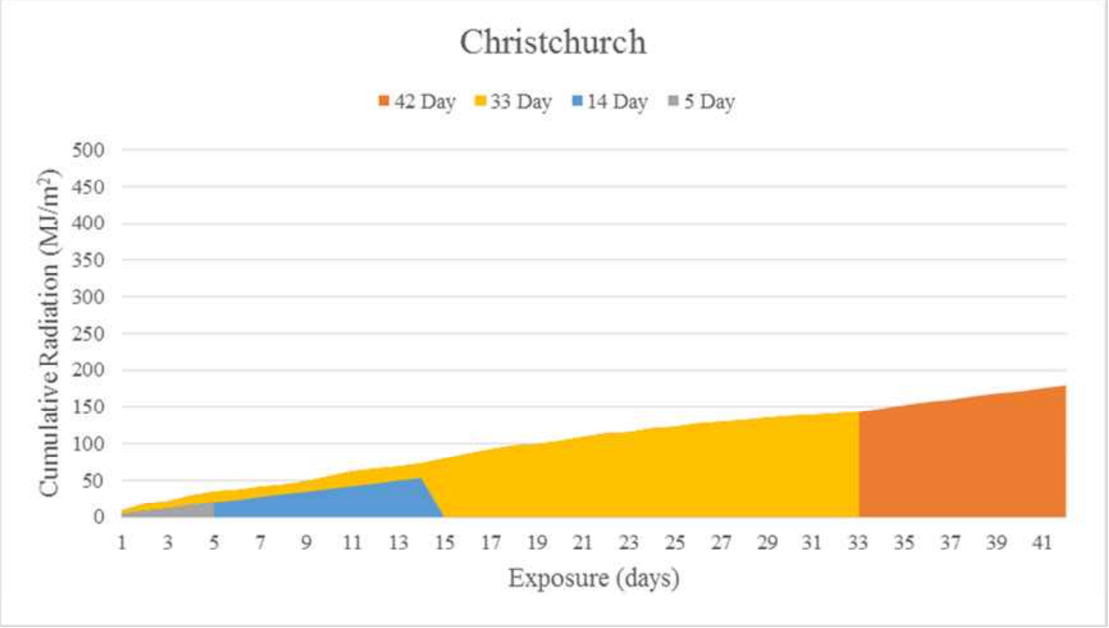

Figure 4. Solar radiation experienced at Christchurch site over days of exposure.

The graphs clearly show higher level of solar radiation at the Auckland site when compared with the Christchurch site where the testing occurred later into the autumn months. The 5 day and 14 day testing in Christchurch occurred towards the end of the 42 day test resulting in lower radiation values for this period late into autumn. Sunshine hours have also been taken measured and the results shown in Table 5.

Table 5. Results of sunshine hours for each site for the test period.

	Auckland Site				Christchurch Site			
Exposure Days	5	14	28	42	5	14	33	42
Sunshine Hours	43.8	95.8	144.1	225.2	32.7	73.1	113.6	167.4
Average (hr)	8.76	6.84	5.15	5.36	6.54	5.22	3.44	3.99

The results in Table 5 above indicated that there is no meaningful relationship between recorded sunshine hours and solar radiation.

3.3 *Accelerated UV test results*

The samples used for the accelerated UV tests were taken from the same geotextile roll as those used for onsite weathering tests. Both the accelerated UV tests were conducted at GAI-LAP accredited labs. Table 6 shows the test results of peak tensile load and strain at peak load for the Xenon Arc accelerated UV test conducted according to ASTM D 4355. Table 7 shows the test results of peak tensile load and strain at peak load for the QUV accelerated UV test conducted according to EN 12224.

Table 6. Xenon Arc accelerated test results according to ASTM D4355.

Sample	Exposure	Peak tensile load		Strain at peak load	
No.	(hours)	(kN/m)	(% retained)	(%)	(% retained)
11	0	1212.1	-	9.6	-
12	50	1082.7	89.3	10.5	109.4
13	100	999.0	82.4	9.2	95.8
14	200	821.2	67.8	9.0	93.8
15	300	790.5	65.2	8.8	91.7
16	500	684.6	56.5	8.0	83.3

Table 7. QUV accelerated test results according to EN12224.

Sample	Exposure	Peak tensile load		Strain at peak load	
No.	(hours)	(kN/m)	(% retained)	(%)	(% retained)
17	0	1279.7	-	10.7	-
18	50	1124.3	87.9	9.8	91.6
19	100	1017.3	79.5	8.9	83.2
20	200	875.4	68.4	8.9	83.2
21	300	790.6	61.8	8.5	79.4
22	430	753.2	58.9	8.9	83.2

4 DISCUSSIONS

The standard accelerated UV lab tests for geotextiles typically use the peak tensile strength for relating the loss in tensile strength with exposure time. As such for correlating these standard accelerated UV lab tests with real time onsite weathering characteristics, the peak tensile strength will be used as the benchmark. For the real time onsite weathering exposures, the late summer into autumn season, which coincides with the peak construction period in New Zealand, was chosen for the exposure to represent an average condition for the exposure intensity. Figure 5 shows the residual strength (as a % of the original peak tensile strength) versus exposure days for real time onsite weathering exposures in Christchurch and Auckland and the accelerated UV tests according to ASTM D4355 and EN 12224.

The recommended exposure period for reinforcement geotextile to weathering after removal from its protective wrapping is generally based on evidence that shows little or no loss in tensile strength over the recommended exposure period. If for some unexpected circumstances the exposure period is exceeded, then correlation factors established between accelerated UV tests and onsite UV degradation tests may be used to estimate residual strength.

The rate of tensile strength reduction with time for all tests appear to be linear over the duration of tests. The rate of strength reduction for samples subjected onsite weathering in Christchurch is 0.1% per day while the rate of strength reduction for samples subjected onsite weathering in Auckland is 0.25% per day (see Figure 5). The rate of strength reduction for samples subjected to the accelerated UV test according to ASTM D4355 is 2.7% per day while the rate of strength reduction for samples subjected to the accelerated UV test according to EN 12224 is 3% per day (see Figure 5). Therefore, the accelerated UV test according to ASTM D4355 corresponds to acceleration factors of 27 and 11, when correlated with the real time onsite weathering in Auckland and Christchurch respectively. And the accelerated UV test according to EN 12224 corresponds to acceleration factors of 30 and 12, when correlated with the real time onsite weathering in Auckland and Christchurch respectively.

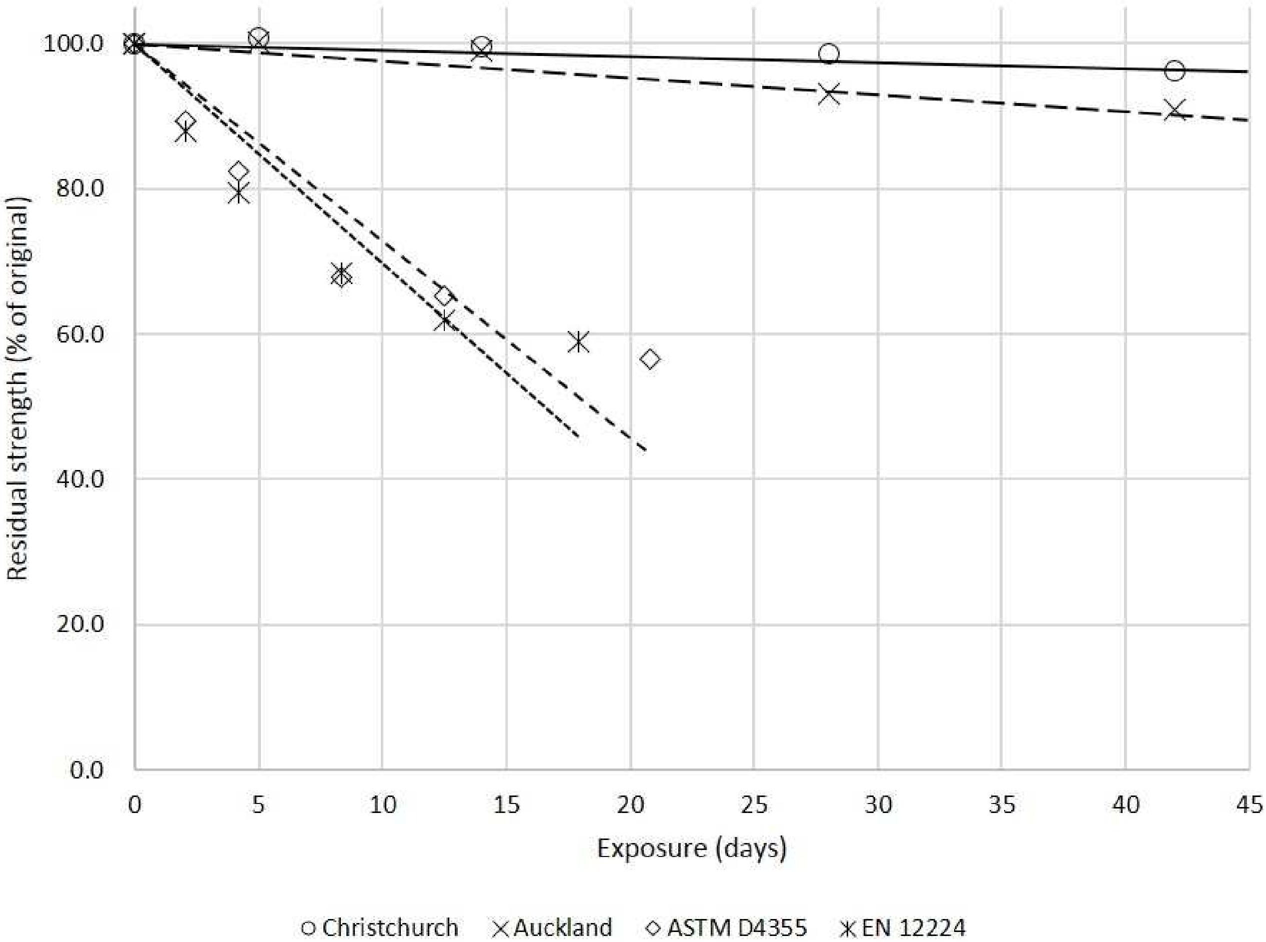

Figure 5. Residual strength versus exposure days for real time exposures and accelerated UV tests.

The cumulative 42 day solar radiation was measured at 486.71 MJ/m^2 and 179.48 MJ/m^2 for Auckland and Christchurch respectively. This ratio of 2.7 in increased solar radiation for Auckland compares favorably to the ratio for onsite weathering rates for the two sites over the same 42 day period of 2.5.

The loss in peak tensile strength over 14 days of real time onsite weathering exposure is 1.1% and 0.5% for Auckland and Christchurch (see Tables 1 and 2). The loss in strain at peak tensile strength over 14 days of real time onsite weathering exposure is within 5% for both Auckland and Christchurch (see Tables 1 and 2). This shows that there is hardly any significant loss of peak tensile strength for a weathering exposure of 14 days for both Auckland and Christchurch. The loss of less than 5% of strain at peak tensile load also shows that embrittlement is not a concern for a weathering exposure of 14 days for both Auckland and Christchurch. Furthermore, there is no apparent loss in tensile strength at working strain levels of between 2% and 5% for up to 42 days of weathering exposure for both Auckland and Christchurch (see Tables 3 and 4). The results therefore support the general recommendation of construction period weathering exposure of not more than 14 days in New Zealand for the concerned geotextile may be allowed. The prudent practice however is to cover the reinforcement geotextile material, typically with a layer of soil cover, as quickly as possible on the construction site.

5 CONCLUSIONS

The rate of strength reduction for the concerned geotextile samples subjected to onsite weathering in early autumn is 0.25% per day and 0.1% per day for Auckland and Christchurch respectively. The accelerated UV test according to ASTM D4355 corresponds to typical acceleration factors of 27 and 11 when correlated with the real time onsite weathering for the concerned geotextile in Auckland and Christchurch respectively. The accelerated UV test according to EN 12224 corresponds to typical acceleration factors of 30 and 12 when correlated with the real time onsite weathering for the concerned geotextile in Auckland and Christchurch respectively. For the concerned geotextile, a construction period weathering exposure of not more than 14 days in New Zealand is typically acceptable.

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