Ultraviolet Degradation of Synthetic Liners and Coated Fabrics

A look at the impact of ultraviolet light on the degradation of synthetic liners and coated fabrics as conducted through scientific testing. By **John Scheirs** and **Rod Parry**.

John Scheirs and Rod Parry of material testing laboratory ExcelPlas Geomembrane Testing Services say the most common question posed is: "If a sample lasts for 12 months in the UV chamber in the laboratory, how long will it last in the field?"

Whilst this is a simple question, the answer can be quite complex, says John, who explains this in some detail in this article.

The amount of UV light that reaches the Earth varies according to the location, and the map overleaf illustrates the global UV irradiance measured in kilolangleys. A kilolangley (kLy) is a measure of UV exposure per square meter of surface area. For example (and as seen on the chart), NSW receives double the UV dose of Germany (compare 170 kLy/yr to 85 kLy/yr), so the degree of UV degradation of liners in NSW would be expected to be double that of liners in Germany.

Ultraviolet light can cause chain reactions and bond breaking of polymeric materials due to the penetration of short wavelength energy. The UV spectrum wavelengths between 300 nm and 400 nm are the most damaging towards polymeric geomembranes because they cause bond rupture on a molecular structure level.

UV light is composed of a range of wavelengths from the very short wavelength (180 nm) which is highly energetic and very damaging to the longer wavelength (380 nm). The wavelength ranges of the classifications are shown in the Table below.

Type of UV light	Wavelength, nanometer (nm)
UV-A	320-380
UV-B	280-320
UV-C	180-280 (screened out by the ozone layer)
Natural Terrestrial Sunlight	295-800

Table 1: Range of wavelengths for UV Radiation

It is important that accelerated UV exposure testing is performed using light sources that best match natural sunlight.

The main types of accelerated weathering equipment are shown in Table 2.

As modern liners and geomembranes generally have a high level of UV resistance, natural weathering studies must be run for prohibitively long periods to give meaningful longevity estimates [Martin, 2005]. For this reason accelerated weathering is employed to gauge the expected in-service weathering performance of geomembrane materials in a more timely fashion.

However, correlating an accelerated weathering exposure period to a natural weathering service life is quite difficult, because UV weathering depends on many variables.

Accelerated weathering testing allows test results in shorter time periods as the exposure is continuous and irradiation more intense. Common accelerated weathering testing methods are also shown in Table 2.

Xenon arc lamps give the best match to terrestrial sunlight but are expensive to run and replace (>$US2000 each) and therefore QUV-B lamps are generally used.

QUV Testing

ASTM Standard D-7238 'Standard Test Method for Effect of Exposure of Unreinforced Polyolefin Geomembrane Using Fluorescent UV Condensation Apparatus', covers the specific procedures and test conditions that are applicable for exposure of unreinforced polyolefin geomembranes (eg HDPE, LLDPE, fPP) to fluorescent UV radiation and condensation in a QUV apparatus.

Type of Weathering Chamber	Test Method	Type of Source	Comments
Xenon Ci-65 and Ci-5000 Weather-O-Meters	ASTM G155 cycle 1*.	xenon arc lamp with a borosilicate inner and outer filter	Best simulates the UV band of natural sunlight but is expensive to run
Carbon arc lights	Obsolete	Carbon arc lights	Unrealistic acceleration as they produce too much of the wavelengths between 325 to 425 nm
QUV	ASTM D-7238 GRI GM-11 (1600 hrs)	QUV fluorescent tube (UVB lamps; 280-320 nm)	Most commonly used for testing geomembranes. Note that they reduce the higher wavelengths of light

Table 2: Accelerated Weathering Equipment for Indoor Testing

Test specimens are exposed to fluorescent UVA 340 lamps under controlled environmental conditions. Note while UVA 340 lamps are standard for this method other types of fluorescent UV lamps, such as UVB-313, can also be used based upon discussion between involved parties. However, if the test is run with another type of fluorescent UV lamp, such as UVB-313, this should be considered as a deviation from the standard and clearly stated in the test report.

UVB-313 and UVA-340 fluorescent lamps generate different amounts of radiant power at different wavelength ranges; thus, the photochemical effects caused by these different lamps may vary. UVB-313 lamps are more damaging as they emit shorter wavelength (hence more energetic) UV radiation. The test typically runs for 1600 hrs during which time the sample is exposed to a 20 hr UV cycle at 75 degrees Celsius followed by 4 hr condensation at 60 degrees Celsius. After exposure, the per cent retained S-OIT (and/or HP-OIT) are determined.

The photograph below shows the QUV panel apparatus with the hood open.

Xenon Arc Exposure

The xenon-arc Weather-o-meter (also known as the Atlas Weather-o-meter) exposes the geomembrane to UV light from a jacketed, water-cooled xenon lamp that operates at a calibrated light intensity of 0.35 W/m^2 at 340 mm and over a range of wavelengths that closely match those in terrestrial sunlight.

This test is formalised in ASTM G26 and ASTM D-4355 but as it is more expensive to run than the QUV panel UV exposure (ASTM D-7238/ GRI GM-11), the QUV fluorescent UV condensation apparatus method is most widely used to test geomembranes.

The geomembrane samples are periodically sprayed with water to simulate rain and dew and the geomembrane temperature is kept between 60-80 deg.C depending on the test protocol.

The xenon-arc Weather-o-meter thus uses both UV exposure and heat exposure to simulate outdoor weathering. While it is difficult to correlate xenon-arc Weather-o-meter testing with natural outdoor exposure, correlations can be drawn as shown in Table 3.

The calibrated output of the Xenon arc light source used in ASTM test method D4355 is 350 mW/m^2 and the output for the fluorescent UV light source used in D7238 is 710 mW/m^2.

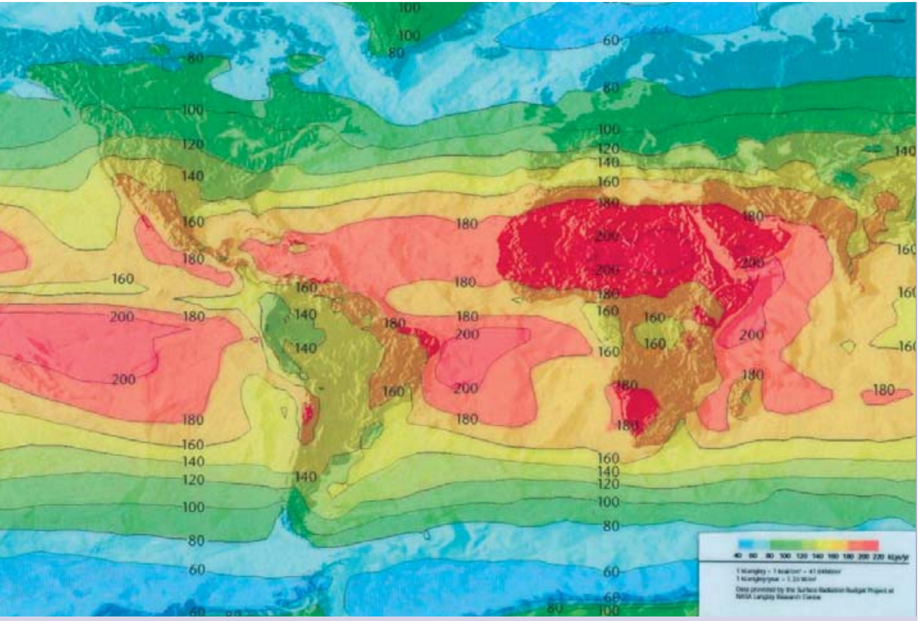
The intensity of the QUV (D7238) source is thus about twice that of the Xenon arc (D4355) source. So 500 hours in the QUV is equivalent to twice as long natural exposure to 500 hours in the Xenon chamber (see Table 3).

For correlations between laboratory UV degradation testing and actual field UV exposure rates, we must also look at the duration of natural sunlight over a 24 hour period. The natural variation in sunlight intensity due to the earth's rotation about its axis is termed 'diurnal' and refers to this 24 hour cycle that is repeated daily. If the solar irradiance level is averaged over a 24 hour period, the average is approximately 24 per cent (of peak solar intensity).

Table 3 shows that the 500 hour Xenon arc UV test correlates to roughly one-half to two years of field exposure, while it takes roughly twice as long – one to four years in the field – to get to the same UV irradiance levels achieved in QUV testing.

Comparison of Accelerated UV Ageing Methods

While the UVB bulbs emit radiation with wavelengths shorter than 300 nm, and this radiation is likely damaging to the geomembrane samples, natural sunlight contains no significant UV radiation with wavelengths below 300 nm. For this reason any comparison between



Global UV irradiance

fluorescent UVB exposure and natural sunlight is imperfect and underestimates the natural service life of the material [Martin, 2005].

By comparing a six year natural weathering study with a 20,000 hour accelerated weathering study, it has been shown that there is a rough relationship of approximately 1000 hours of accelerated QUV weathering being equal to one year of natural exposure [Martin, 2005].

RULE OF THUMB – A rough correlation used in the paint and coatings industry is of 500 to 1500 hours of accelerated exposure equaling approximately one year of real life exposure [Wagner and Ramsey, 2003]. A relationship of 1000 hours of accelerated weathering equating to a year of natural weathering is used as conservative basis for the purposes of giving warranties.

UV light intensity is measured by irradiance and is usually expressed in watts per square meter at a given wavelength. The weather-o-meters are run at 0.35 watts/m2 and 340 nanometers (nm), an industry accepted protocol, which matches one of the conditions in Florida.

The temperature of exposure is also important, as the higher the temperature, the more degradation will occur. A black panel in the machine measures this temperature and is set at 63°C. The backing on the sample may change the actual sample temperature.

In Xenon testing 2000 hours in the weather-o-meter is approximately 140 kilolangleys (kLy) per year, which is typical of one year exposure in Miami, Florida.

For HDPE the weather-o-meter on a wet and dry cycle still gives a correlation of approximately 2000 hours being roughly one year of outdoor weathering (although this is highly dependent on geographic location). Geographic location, along with changes in climate and elevation, affect actual UV performance.

It should also be noted that there is increased severity of UV radiation in higher elevation areas. In fact, for every 0.5 km increase in elevation, UV exposure increases by 3.5 per cent. Sunshine variations remain the key variable when correlating accelerated and outdoor exposure data.

UV degradation of HDPE and PVC manifests itself by crazing and a loss of physical properties especially the tensile elongation at break. The tensile elongation at break decline is more sensitive than tensile strength due to the formation of oxidised species on the exposed surface of the geomembrane. This brittle surface layer forms cracks that significantly affect the tensile elongational properties.

The failure point after weathering is often arbitrarily taken as a 50 per cent reduction in the original tensile strength at break value. At the 50 per cent point, surface crazing (a crosshatched pattern caused when the sample is flexed) becomes evident on the geomembrane surface.

References:

Martin, D. and Eng, P., *Advanced Thin Film Geomembrane Technology For Biocell Liners and Covers* available from Layfield Geosynthetics and Industrial Fabrics Ltd. (2005).

Wagner, N., and Ramsey, B. *QUV Accelerated Weathering Study: Analysis of Polyethylene Film and Sheet Samples.* Technical Document by GSE Lining Technology, Inc., Houston, TX. (2003).

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City	Annual Mean Sunshine normalised to 24 hr day	Annual Average UV Irradiance (mW/m2)	Equivalent time of exposure to 500 hrs xenon arc (ASTM D-4355) (years)	Equivalent time of exposure to 500 hrs QUV (ASTM D-7238) (years)
Atlanta, GA	0.34	213,701	0.8	1.7
Chicago, IL	0.28	143,607	1.2	2.5
Hartford, CT	0.28	143,607	1.2	2.5
Orlando, FL	0.37	230,797	0.8	1.5
Phoenix, AZ	0.42	317,986	0.6	1.1
San Antonio, TX	0.34	256,441	0.7	1.4
San Diego, CA	0.39	247,893	0.7	1.4
Seattle, WA	0.20	76,932	2.3	4.6
Washington, DC	0.31	157,284	1.1	2.3

Table 3: Equivalent Outdoor UV Irradiance Exposure for 500 hrs of Laboratory UV exposure for ASTM D-4355 (Xenon Arc) and ASTM D-7238 (QUV apparatus)