Atlas Application Note 113

Photodegradable Plastics

State-of-the-Art

ASTM Standard Weathering Testing

Atlas Material Testing Technology

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ATLAS MATERIAL TESTING SOLUTIONS

AMETEK

Photodegradable Plastics

State-of-the-Art ASTM Standard Weathering Testing

1. Introduction

At the end of its life, plastic, and more specifically plastic packaging, ends up in the environment as waste. Massive amounts of plastic waste accumulate on the ground and in the sea every year contributing to the growing issues of landfill overflow and marine pollution. Bio- or photodegradable plastics are a trend that could help to address this issue by reducing the amount of time it takes for plastics to breakdown from natural processes.

Photodegradable plastics can be produced in a comparable way to their conventional variants. The trick to faster photodegradability lies in special additives that when exposed to UV radiation activate a two-part oxidation process causing the plastic to degrade [1]. In the first step, photo-oxidation takes place initiated by UV radiation, heat, and oxygen causing the polymer matrix of plastics to begin to break. Next, carbon dioxide- and water-induced degradation pathways begin to occur as encouraged by humid environments. Ultimately, biomass is created via microorganisms. Quick-degrading plastic typically takes around a year to fully breakdown in landfills. But, although they are designed to degrade faster, photodegradable plastics still must achieve a certain lifetime and properly function for their intended application. This is where weathering testing comes into play.

***Figure 1**: Plastic waste. Image courtesy of the authors of "The future of plastic". Nat Commun. 9, 2157 (2018). https://doi.org/10.1038/s41467-018-04565-2*

2. State-of-the-Art ASTM Standard Weathering

Materials made from photodegradable plastics are intended to deteriorate rapidly when exposed to solar radiation, oxygen, heat, and moisture. Like with any new material, one needs to gain experience with the degradation rates of photodegradable plastics. The reapproved ASTM weathering test methods for exposure of photodegradable plastics

- ASTM D5208-14 in xenon arc instruments (reapproved 2022) [2]
- ASTM D5071-08 in fluorescent UV devices (reapproved 2021) [3], and
- ASTM D5272-08 outdoors (reapproved 2021) [4]

represent the currently available methods of testing (Table 1).

ASTM Test Method	Apparatus	Irradiance ($W/m^2 nm$)	Black Panel Temp. (°C)	Chamber Air Temp. (°C)	Rel Humidity (%)	Dry/Wet (min)	Light (min)	Dark (min)
D 5071-06; cycle 1	Ci Series / Xenotest 440 / SUNTEST XXL+/XLS+	0.35 (340 nm)	63 (BPT)	-	-	-	continuous	-
D 5071-06; cycle 2	Ci Series / Xenotest 440 / SUNTEST XXL+/XLS+	0.35 (340 nm)	63 (BPT)	-	-	102/18	continuous	-
D 5071-06; cycle 3 Light Phase D 5071-06; cycle 3 Dark Phase	Ci Series / Xenotest 440 / SUNTEST XXL+	0.35 (340 nm) -	63 (BPT) 38 (BPT)	- -	- 95	102/18 -	1080	 360
D 5208-14; cycle A Light Phase D 5208-14; cycle A Dark Phase	UVTest (UVA-340 lamp)	0.89 (340 nm) -	50 (BPT) 40 (BPT)	- -	- 100	- -	1200	- 240
D 5208-14; cycle B Light Phase D 5208-14; cycle B Dark Phase	UVTest (UVA-340 lamp)	0.89 (340 nm) -	50 (BPT) 40 (BPT)	- -	- 100	- -	240	- 240
D 5208-14; cycle C	UVTest (UVA-340 lamp)	0.89 (340 nm)	50 (BPT)	-	-	-	continuous	-

Table 1: ASTM standard weathering cycles for xenon and fluorescent-UV instruments

2.1. ASTM Xenon Exposures

ASTM D5071-08 is the standard for testing inside xenon weathering chambers using the Daylight filter. Opposite to UVA-340 based testers, xenon chambers will provide the full solar spectrum (Figure 2), which can be beneficial for achieving results that are consistent with natural weathering. Both flatbed and rotating rack xenon type instruments are suitable., ideally equipped with a humidifier, which is required for Cycle 3 during the dark phase. The recommended Atlas xenon weathering instruments are the SUNTEST® XXL+ (5° inclined exposure), Xenotest® 440, or Ci Weather-Ometer® (see Figure 3). All are suitable for running all three cycles. Guidance on the test settings of three different cycles is given in Table 1.

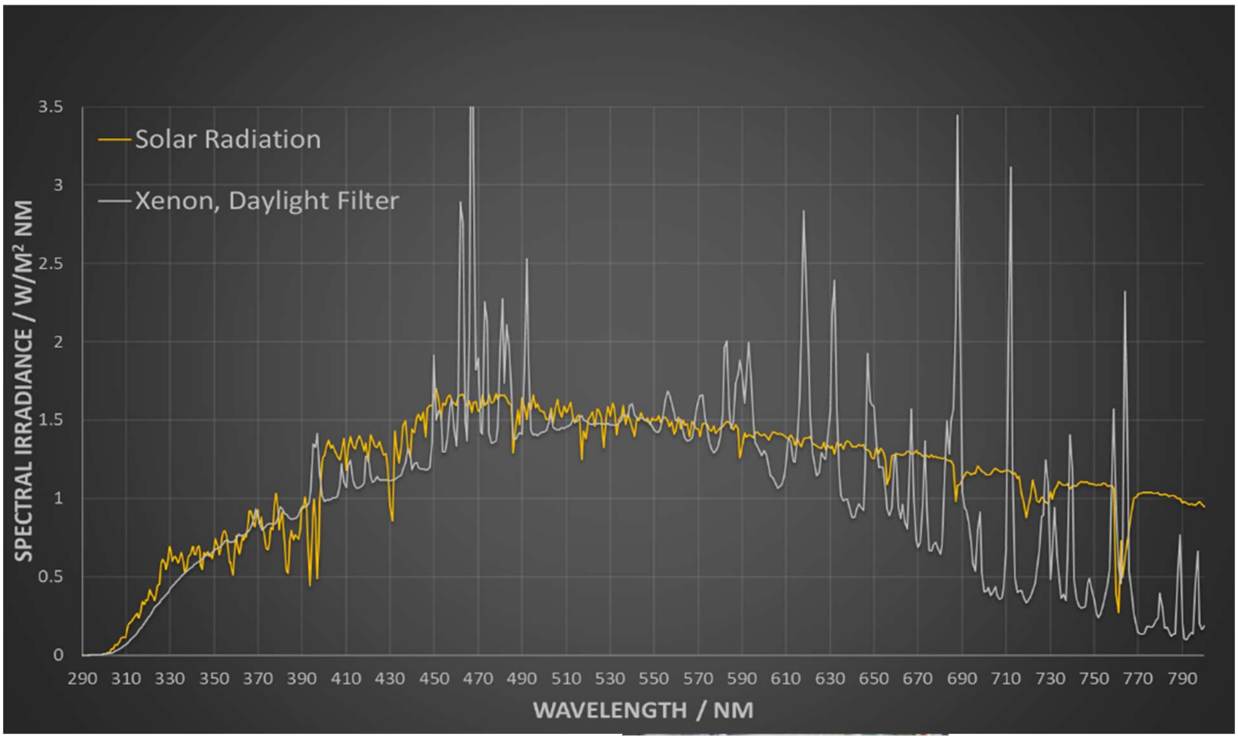

Figure 2: *Atlas SUNTEST XXL+ with daylight filter (Type I, cut-on ~295 nm) compared to natural solar radiation*

***Figure 3** (from left to right): Atlas Xenotest 440, Atlas SUNTEST XLS+, Atlas SUNTEST XXL+*

Specimen Preparation Inside Xenon Chambers

When applicable, test specimens should be prepared inside xenon weathering chambers using the available standard specimen holder with backing. The following lists the available standard specimen holders by xenon instrument type:

- Specimen size 135 mm x 45 mm (SUNTEST XXL+, XLS+)
- Specimen size 90 mm x 75 mm / 135 mm x 45 mm / 270 mm x 45 mm (Xenotest 440)
- Specimen size 67 mm x 47 mm / 67 mm x 145 mm (Ci3000/3300/4000/4400/5000)

Note, the results of laboratory exposure cannot be directly extrapolated to estimate absolute rate of deterioration by the environment. The acceleration factor is material dependent and can be significantly different for each material and for different formulations of the same material. However, exposure of a similar material of known outdoor performance, a so-called control material, at the same time as the test specimens allows comparison of the durability relative to that of the control material.

***Figure 4:** Atlas standard specimen holders with backing for Ci instruments (2 x left) and Xenotest 440 (3 x right)*

2.2. ASTM UV-Fluorescent Exposures

ASTM D5208-14 is the standard practice for exposure of photodegradable plastics in a fluorescent UV device using UVA-340 lamps (Figures 5, 6). UVA-340 lamps provide a great spectral match to natural UVB radiation and the short wavelength range of UVA. It is missing, however, the long wavelength UVA, VIS, and NIR wavelength ranges. The Atlas UVTest® is the applicable instrument for ASTM D5208-14. Three different test cycles are described (see Table 1). Use Cycle C for materials that will be used for toxicity testing after exposure. This is essential because cycles that use condensation can wash away by-products of photochemical degradation.

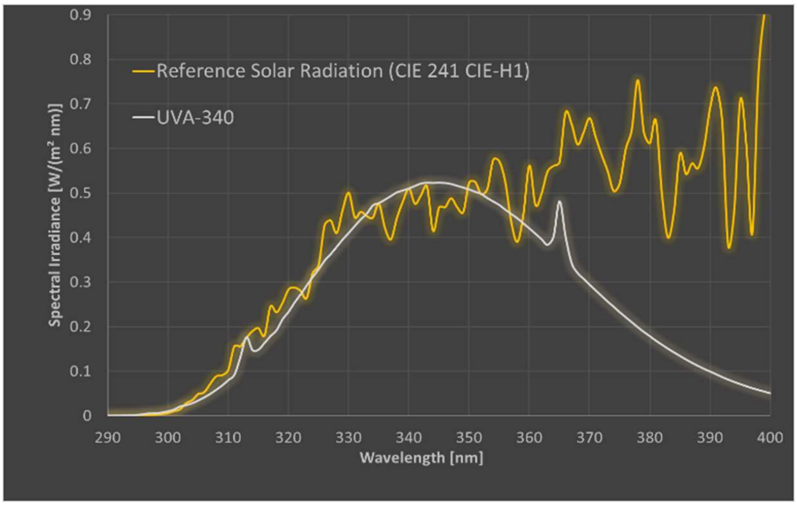

Figure 5: *Atlas UVTest with UVA-340 lamp vs. natural solar radiation*

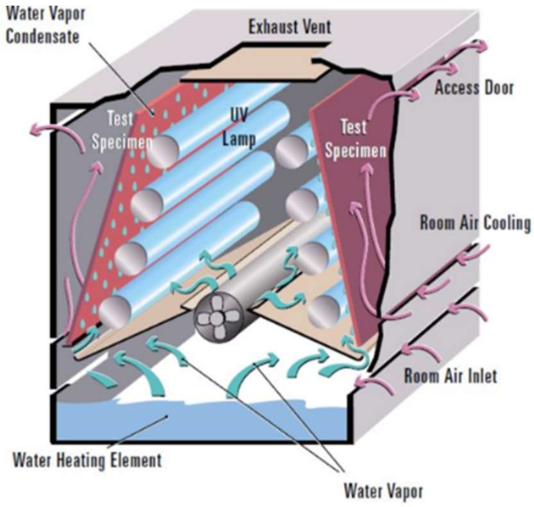

Figure 6: *Atlas UVTest design schematics*

Specimen Preparation Inside UV-Fluorescent Chambers

Unless otherwise specified, expose at least three replicate specimens of each test and control material. It is recommended to prepare test specimens inside UV-Fluorescent chambers using the available standard specimen holder with backing:

- Specimen size 3 x 12 inch (UVTest)

Best practice is to reposition specimens to minimize any effects from temperature or UV variation. Reposition the specimens horizontally at least every third day by

(1) moving the two extreme right-hand holders to the far left of the exposure area, and
(2) sliding the remaining holders to the right (see side to side rotation below).

Reposition the specimens vertically so that each specimen spends the same amount of exposure time in each vertical position (Figure 7).

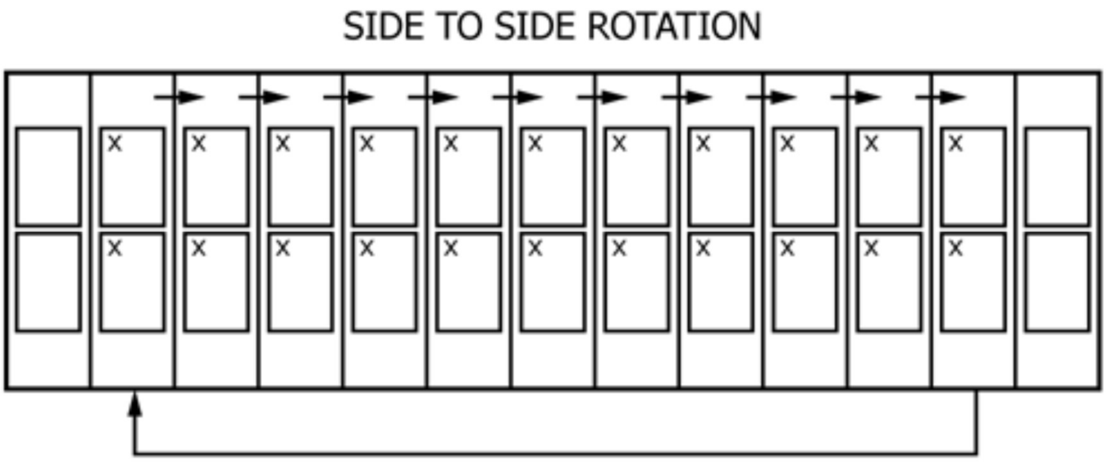

Figure 7: *Specimen rotation*

2.3. ASTM Outdoor Exposures

Finally, ASTM D5272-08, is the standard practice for natural outdoor exposure. It is performed by mounting samples to 5° exposure racks and leaving them to degrade naturally. Ensure that a UV radiometer records the UV radiant exposure for the entire test

duration (mounted at an angle of 5° from the horizontal, facing the equator). Inspect samples regularly to check for degradation. The major benefit of outdoor testing is that the results are real-world data that can be used as the baseline for comparison with accelerated laboratory testing results to evaluate correlation and acceleration of your laboratory test to the natural environment.

Specimen Preparation 5° Outdoor Exposure Racks

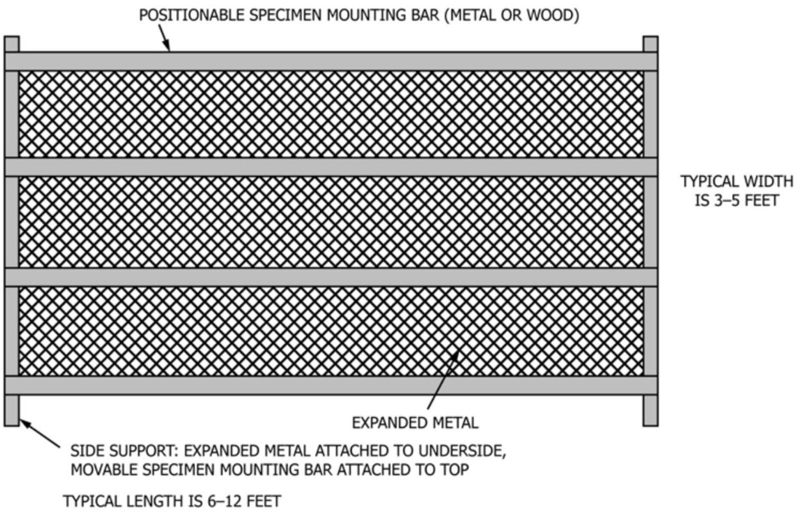

Figure 8: *Specimen mounting for outdoor exposure*

Two rack description are provided. One for using standard racks with plywood backing. Another one as shown in below drawing makes use of expanded metal (mesh metal) attached to the underside of the rack. Note that there is less air circulation around the specimens when rack exposures with plywood backing are used. Degradation rates will be higher because specimen temperatures will be higher. Finally, racks are typically adjustable to hold any dimension of samples.

3. Benchmarking, Acceleration, Correlation

Just how much faster (acceleration) is a xenon or UV-Fluorescent test compared to a natural exposure? And how well do the laboratory tests reproduce the natural processes (correlation) of an outdoor exposure in a certain geographical region? When designing a study to answer these questions, we typically compare the accelerated test (ASTM D5071/D5208) to the real time exposure (ASTM D5272) at one or more natural benchmark climates such as Miami, FL (USA) or Sanary (France). Both sites continuously record UV radiant exposure, air temperature, black panel temperature, and relative humidity. Miami represents a well-known sub-tropical climate, somewhat representative of other regions

Figure 9: *Standard 5° exposure racks at benchmark exposure site near Miami (Florida)*

like India, South-East Asia, or South China. Sanary represents a Mediterranean climate delivering high amounts of radiation and heat like many other South European regions and represents, in many instances, a European “worst case” climate.

To determine the level of acceleration, you would compare the time required to reach a certain level of photodegradation. For example, you may find that your product reaches a 50 % photodegradation level in Miami after 208 days (approximately 5.000 hours) and in Sanary after 415 days (approximately 10,000 hours). When your product in a SUNTEST XXL+ just needs 1,000 hours to reach the same 50% degradation level, then the acceleration would be 5 for Miami and 10 for Sanary. You can proceed now with other additive levels until you have reached the wanted balance between photo stability and photo durability.

4. Literature

[1] https://www.atl-dunbar.co.uk/polythene-alternatives-for-packaging/

[2] ASTM D5071-06, Standard Practice for Exposure of Photodegradable Plastics in a Xenon Arc Apparatus.

[3] ASTM D5208-14, Standard Practice for Fluorescent Ultraviolet (UV) Exposure of Photodegradable Plastics.

[4] ASTM D5272-08, Standard Practice for Outdoor Exposure Testing of Photodegradable Plastics.

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