Atlas Application Guide 112

Adhesives and Sealants

Accelerated Weathering Testing

Atlas Material Testing Technology

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Introduction

Adhesives and sealants include a broad variety of products and applications. Adhesives can include pressure sensitive (PSA) or cured products (thermosets, UV/EB; moisture or chemically cured) of various chemistries (acrylics, epoxies, urethanes, etc.) and can be one (1K) or two (2K) component varieties. Forms include glues, tapes, and films and caulks in both permanent and repositionable/removable products across a variety of industries such as automotive, building and construction materials, signs and labels, textiles, packaging, etc.

Figures 1 and 2. *Commercial Examples of sealants and adhesives.*

Sealants include various forms including liquid applied barriers, edge tapes and seals, and extruded products such as caulks and formed seals used in frame construction, fenestration products and building systems such as exterior insulation façade systems (EIFS), architectural curtain walls, and automotive manufacturing.

Adhesives and sealants are critical components of many products; understanding their performance and service life in various environments is critical. Key test methods to determine service life, select candidate formulations, or investigate the long-term durability of complete products are static and accelerated outdoor exposures as well as laboratory weathering testing.

Laboratory UV and weathering testing standards and methods use either Fluorescent/UV or xenon-arc instruments. Outdoor static natural weathering exposures at benchmark locations such as South Florida Test Service in Miami, Florida and DSET Laboratories near Phoenix, Arizona, or other locations are also customarily performed. Sealants and adhesives are often exposed under compressive or tensile stress in user-provided fixtures to better replicate end-use conditions, or full products (such as window systems) are exposed in their end-use orientation (Figure 3).

Factors of Weathering

When materials are exposed to environmental stress factors, ageing and degradation might occur. The adverse effects of exposure to environmental stresses are what is known as "weathering" and they can be seen on materials located both indoors and outdoors. Degradation due to solar radiation (or sunlight), heat, and humidity are often a concern when organic and polymeric materials, such as adhesives, are intended for outdoor use. The photochemical effect of sunlight on a polymeric or organic material depends on the absorption properties and the spectral sensitivity of the material. The wavelengths that typically have the most critical effect range from 295 to 400 nm (the ultraviolet radiation or UV). Solar radiation can cause the formation of radicals which can lead to matrix and additive degradation.

Figure 3. *Test house at Atlas South Florida Test Service for exposure of window sealants in end-use.*

Temperature is also an important factor in weathering. Surface temperatures under irradiation depend on absorption and insulation properties of the material. Typical maximum temperatures of irradiated surfaces are represented by black painted metal plates (black standard temperature/BST -sensors with backside insulation or black panel temperature/BPT sensors without backside insulation). High temperature can cause thermal degradation, but also accelerate other degradation and diffusion processes. Temperature cycles can also cause mechanical stress by expansion and contraction which might impact the adhesive strength.

	Miami, Florida, USA (26°N, 81°W)	**Phoenix, Arizona, USA (34°N, 112°W)**
Climate	Subtropical, humid	Dry desert climate
Climate zone (Köppen-Geiger)	Af/Aw	BWh
Annual global radiant exposure (295 – 2450 nm) [MJ/(m²)]	6664 (26° S)	8381 (34° S)
Annual UV radiant exposure (295 – 400 nm) [MJ/(m²)]	404 (26° S)	454 (34° S)
Average ambient temperature [°C]	23.7	22.6
Average daily maximum black panel temperature/BPT [°C]	52.6 (26° S)	52.8 (34° S)
Average relative humidity RH [%]	78	31
Annual rainfall [mm/a]	1493	273
Time of wetness TOW [%] (2000 - 2003)	52 (5° S)	3 (5° S)

Table 1*. Average climatic parameters (2000 – 2019) of reference sites in Miami, Florida and Phoenix, Arizona.*

Finally, moisture in the form of relative humidity or as liquid water (rain or dew) has an influence on material performance. Moisture can cause hydrolysis reactions in some instances, but moisture cycles can also cause mechanical stress to a material which might also impact the adhesive strength. These stresses together can lead to cracking and delamination effects, even though the adhesive is not directly exposed to the environment.

Table 1 gives an overview of the most important weather parameters of the two most frequently used "benchmark" reference locations.

Effects of Weather Factors on Adhesives

Adhesives have a wide range of applications such as transportation (automotive, rail), and architectural, amongst many others. In most of these applications, the adhesives themselves are not directly exposed to the environment. However, in some of applications one or more weathering factors might affect the adhesive performance.

Adhesive materials often do not see direct sunlight in their end use. But, if adhesives are used to fix transparent materials, photochemical ageing might take place from the radiation passing through the substrate (glass or plastic). Temperature is also a concern as most materials heat up when exposed to solar radiation.

***Figure 4**. Exposure Rack in Phoenix/Arizona, 45° facing south*

For polymeric substrates, there is potential of moisture diffusion as well, which might affect the adhesive. These factors together may cause ageing of the adhesive itself or the combination of the adhesive and the substrate.

Ageing of adhesives typically reduces the adhesive bonding strength and can lead to fracture or delamination, especially in combination with mechanical effects. If adhesives are used with transparent substrates, hazing and discoloration might appear.

Another factor that should not be neglected if adhesives are used with polymeric substrates is the diffusion of additives and stabilizers from the adhesive into the polymer or vice versa. In this case, unexpected ageing effects may occur. It is important to test the compatibility and the long-term performance of the combined materials.

Light and Weather Fastness Testing Technology

The simplest, and also the most realistic, approach to test the stability of materials to weather is to expose them outdoors in real weather conditions. This is commonly done at locations such as South-Florida or Arizona. These locations not only offer extreme climatic conditions, but they are also used as reference, or benchmark, locations.

Exposures can be as simple as putting the test specimen(s) on a rack (Figure 4). However, considerations have to be made on specific details of the exposure. Which exposure angle should be used for the test? And should the specimen(s) be exposed with or without an insulating backing? Answering these questions is not always easy. In the end, the more similar the exposures are to the end-use environment, the more likely it is to achieve realistic results.

Even though outdoor exposures can be considered the most realistic way to perform weathering tests, there are some downsides. Natural testing relies on actual weather conditions, is time consuming, the potential for acceleration is limited, and results often are hard to reproduce. Therefore, accelerated testing using artificial light sources is necessary for effective and reproducible product development. The core of each weathering test instrument is the light, or radiation source, known as the “lamp”. Throughout a hundred years of accelerated weathering testing, different radiation sources have been used ranging from historic carbon-arc lamps to modern xenon-arc technology and Fluorescent-UV technology, which today are the main types of light sources used in artificial testing of materials, such as coatings, plastics, textiles, paper, and adhesives amongst many other applications.

Xenon-arc lamps provide a spectral irradiance that is similar to the full-spectrum range of natural solar sunlight including the UV, visible, and infrared wavelengths. With appropriate optical filters, window-glass filtered solar radiation can be simulated for interior material testing (Figure 5), as well as for outdoor and warehouse and/or retail setting testing. Xenon-arc lamps produce heat and need effective cooling by either air or water. Test specimens are typically mounted on a test rack which rotates around the lamp (or lamps) to increase uniformity (also referred to as rotating rack instruments, Figure 6). The counterpart to rotating rack instruments are flatbed instruments which have the light source located in the ceiling of the chamber directly above the sample tray. Both designs typically provide features to control the climatic conditions such as chamber air temperature and relative humidity, surface temperatures (BST or BPT), and also to provide water spray to simulate the effects of rain and dew.

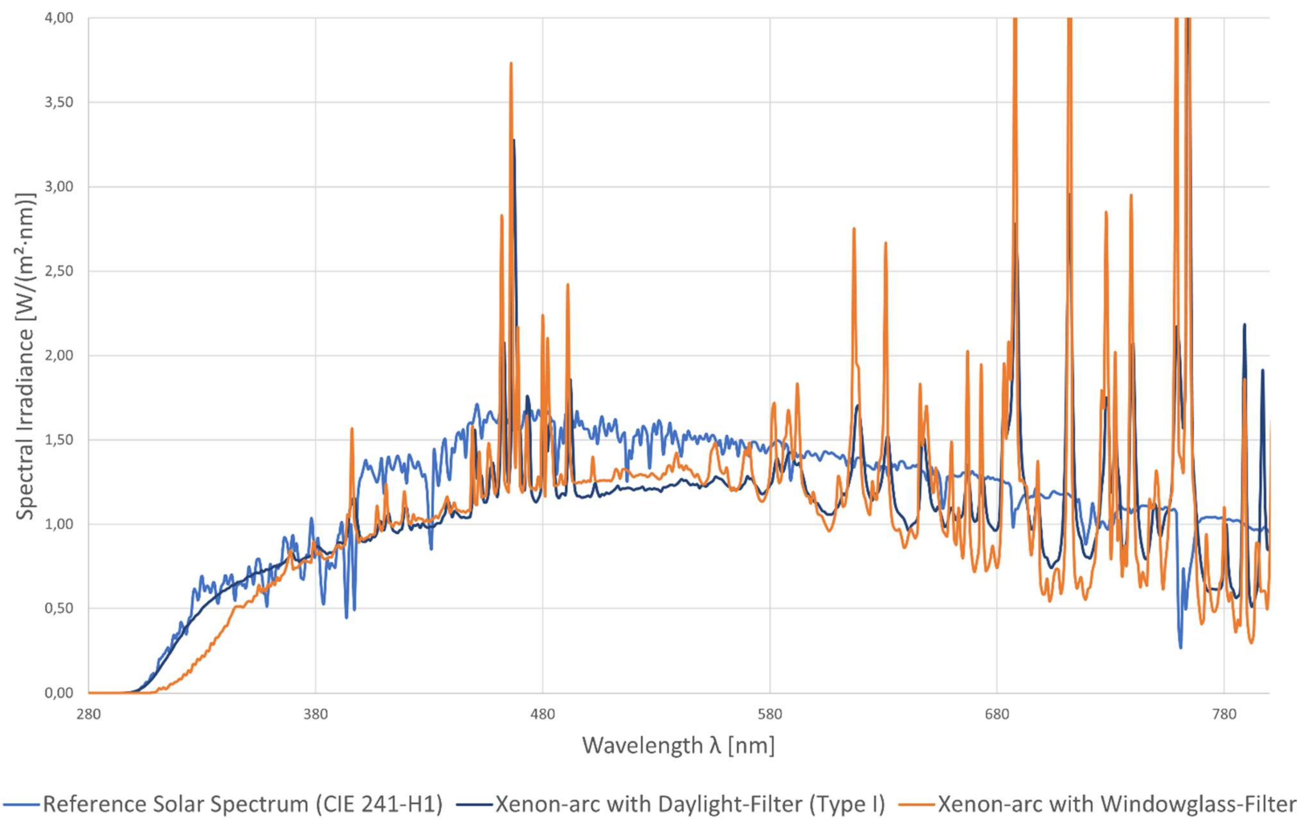

Figure 5. Spectral irradiance of Xenon-arc radiation with “Daylight” and “Window-glass” filters compared to the reference solar spectrum according to CIE 241.

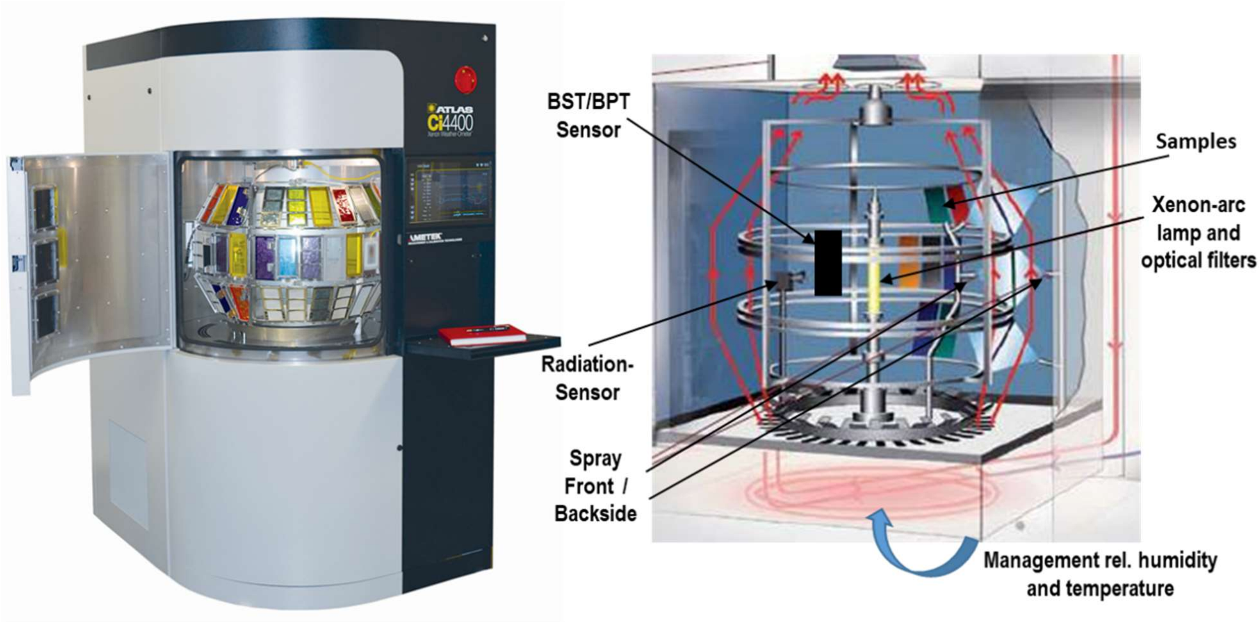

__Figure 6.__ Example of a rotating rack type Xenon-arc instrument (Atlas Ci4400 Weather-Ometer).

Fluorescent-UV lamps only provide the most critical part of the solar spectrum: the UV. Different lamp types are available, but the most commonly used and most realistic is the UVA-340 lamp with a peak irradiance at 340 nm (Figure 7). Due to the absence of longer wavelength radiation, effects which require visible light, such as dyestuff degradation, are not realistically simulated. Due to the absence of visible and IR radiation, there are no solar loading (thermal) effects, and the specimen color does not influence the surface temperature (Figure 8).

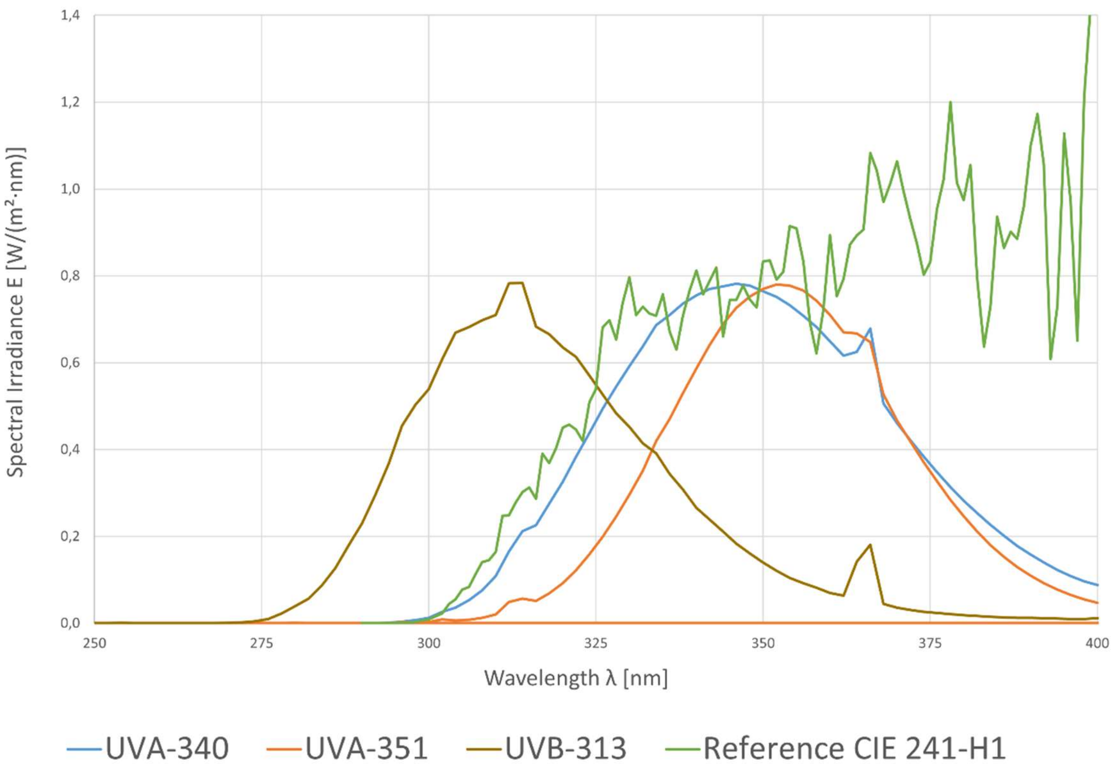

__Figure 7.__ Spectral irradiance of Fluorescent UVA-340, UVA-351 and UVB-313 lamps and the reference solar spectrum according to CIE 241.

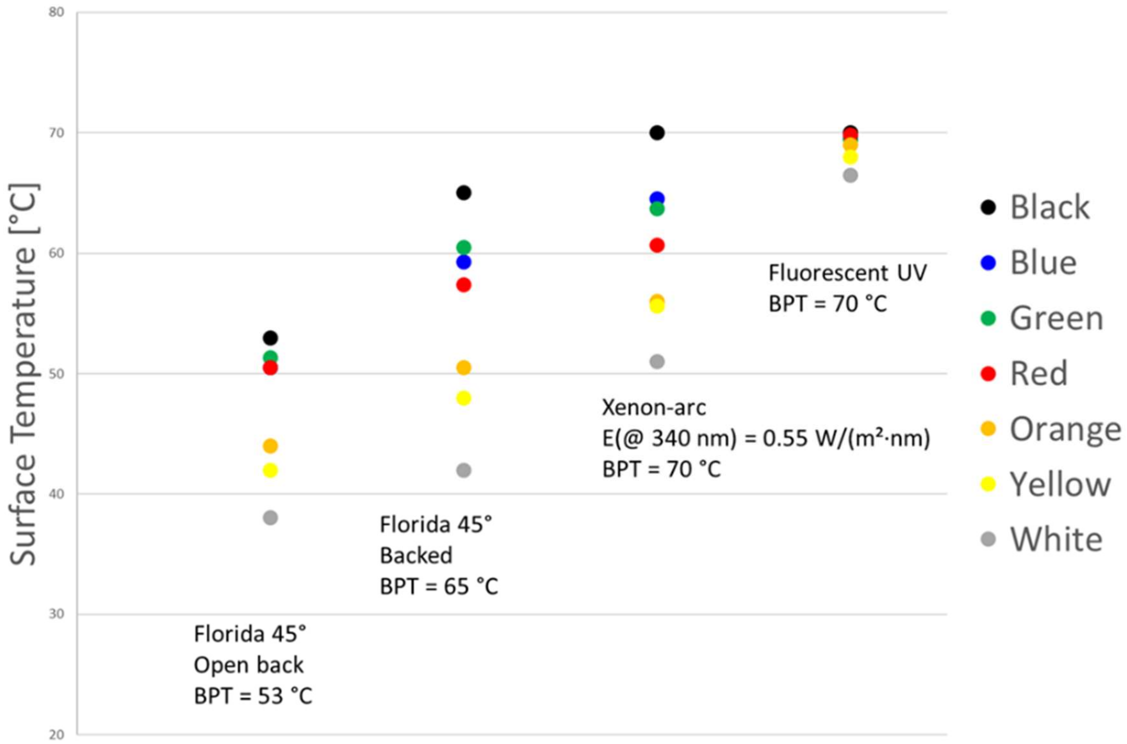

Figure 8. *Surface temperatures of differently colored metal panels in Florida (at 45° facing southwards, backed and unbacked) and in a Xenon-arc and a Fluorescent-UV instrument*

Fluorescent-UV devices typically use an array of lamps. Moisture can be provided by condensation or by spray (Figure 9). Specimen temperatures are controlled by the chamber air and measured with a BPT sensor.

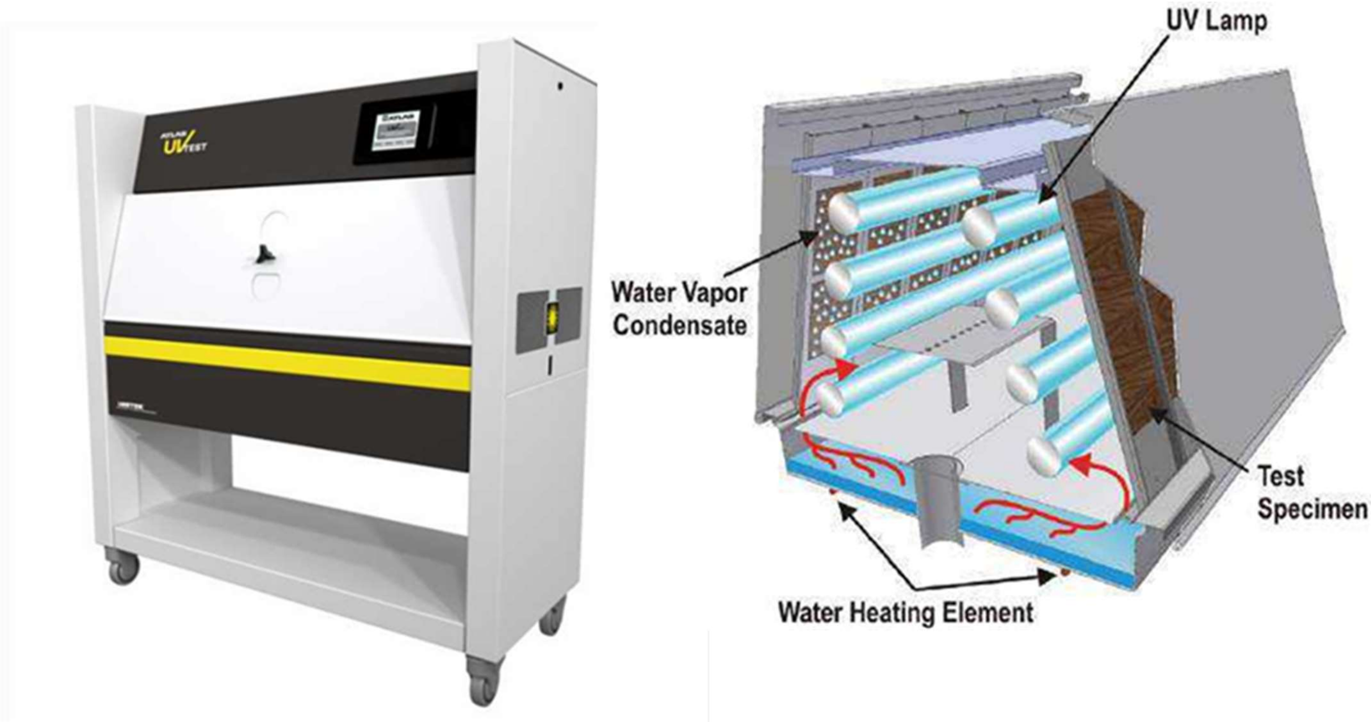

Figure 9. Example of a Fluorescent UV instrument (Atlas UVTest).

Test Methods and Standards

There are two general international test standards for adhesives including or related to weathering. One is ISO 9142 (2004) "Adhesives — Guide to the selection of standard laboratory ageing conditions for testing bonded joints" which refers to the ISO 4892 series of standards related to weathering testing of plastics, including xenon-arc, Fluorescent-UV, and the outdated carbon-arc technology. There is also ASTM D904-99 (2021) "Standard Practice for Exposure of Adhesive Specimens to Artificial Light" which refers to ASTM G154 for Fluorescent-UV testing and to ASTM G155 for xenon-arc testing.

ISO 9142 and ASTM D904 do not define all test parameters which are required for reproducible testing. This might be addressed in future revisions. Table 2 shows the parameters of the most common xenon-arc test cycles and Table 3 the most common Fluorescent-UV test cycles for outdoor and indoor applications as also used in other industries. Test methods for adhesives for automotive or rail applications most often refer to one of those methods.

Outdoor applications (artificial weathering): Xenon-arc lamp with daylight filters (general)					
Test method	**Exposure period**	**Narrowband irradiance [W/(m²·nm)]** [a)]	**Surface temperature BPT [°C]** [b)]	**Chamber temperature [°C]**	**Relative humidity %**
ISO 9142 based on ISO 4892-2 Method A	102 min dry	0.51 (at 340 nm)	63	38	50
	18 min water spray	0.51 (at 340 nm)	-	-	-
ASTM D904 based on ASTM G155 and SAE J2527	40 min dry	0.55 (at 340 nm)	63	38	50
	20 min water spray	0.55 (at 340 nm)	63	38	50
	60 min dry	0.55 (at 340 nm)	63	38	50
	60 min water spray	-	-	38	95
Indoor applications (irradiation, Lightfastness): Xenon-arc lamp with window glass filters					
ISO 9142 based on ISO 4892-2 Method B	Continuously dry	1.10 (at 420 nm)	63	38	50
ASTM D904 based on ASTM G155	Continuously dry	1.10 (at 420 nm)	60	38	50

a) Broadband irradiance control (300 nm - 400 nm) may be used as alternative. The corresponding values can be found in the referred standards.
b) Black standard temperature control (BST) may be used as alternative. The corresponding values can be found in the referred standards.

Table 2. *Xenon-arc testing standards*

Outdoor applications (artificial weathering): Fluorescent UVA-340 lamps			
Test method	**Exposure period**	**Irradiance [W/(m²·nm)]**	**Surface temperature BPT [°C]**
ISO 9142 based on ISO 4892-3 Method A	8 h dry	0.76	60
	4 h condensation	-	50
ASTM D904 based on ASTM G154	4 h dry	0.83	60
	4 h condensation	-	50
Indoor applications: Fluorescent UVA-351 lamps (daylight behind window glass)			
ISO 9142 based on ISO 4892-3 Method B	Continuously dry	0.76	50
ASTM D904 based on ASTM G154	Continuously dry	0.83	60

Table 3. *Fluorescent-UV testing standards*

Material degradation and service life prediction can be complex and depends on the material, the environment, and the lifetime expectation. That is why most test methods do not define test durations. However, some do include minimum requirements, such as ASTM D904, which requires 168 hours of testing or multiples thereof, or unless a significant change is achieved in a shorter time.

Test specimens for weathering testing should be prepared as similar as possible to the final product. Exterior applications should be tested according to the corresponding weathering method with water spray, if relevant in the end use environment of the test specimen.

It is always recommended to support artificial testing with outdoor exposures at a reference location according to ASTM G7 or the ISO 877-series. Even though not necessarily accelerated, these natural tests provide a much more realistic and deeper insight in the end-use performance of any material and provides the basis for service life prediction studies.

Standards References

ISO 877-1:2009 Plastics - Methods of exposure to solar radiation - Part 1: General guidance

ISO 877-2:2009 Plastics - Methods of exposure to solar radiation - Part 2: Intensified weathering using concentrated solar radiation

ISO 877-3:2018 Plastics - Methods of exposure to solar radiation - Part 3: Intensified weathering using concentrated solar radiation

ISO 4892-2:2021, Plastics - Methods of Exposure to Laboratory Light Sources - Part 2: Xenon-arc lamps

ISO 4892-3:2016 Plastics - Methods of Exposure to Laboratory Light Sources - Part 3: Fluorescent UV lamps

ISO 9142:2003 Adhesives - Guide to the selection of standard laboratory ageing conditions for testing bonded joints

CIE 241:2020 Recommended Reference Solar Spectra for Industrial Applications

ASTM G7:2021 Standard Practice for Natural Weathering of Materials.

ASTM G154:2016 Standard Practice for Operating Fluorescent Ultraviolet (UV) Lamp Apparatus for Exposure of Nonmetallic Materials.

ASTM G155:2021 Standard Practice for Operating Xenon Arc Light Apparatus for Exposure of Non-Metallic Materials.

ASTM D904:2021 Standard Practice for Exposure of Adhesive Specimens to Artificial Light.

More Information

There are several documents and recorded online seminars, giving additional guidance:

Weathering and Lightfastness Test Methods for Polymer Applications - Atlas Standards Guide SG103
https://lp.atlas-mts.com/guide-about-weathering-testing-of-polymer-materials

Basics of Polymer Degradation in Weathering - Atlas Technical Guide TG102
https://lp.atlas-mts.com/technical-guide-basics-of-polymer-degradation-in-weathering

Most Important Weathering and Lightfastness Testing Standards - Atlas Standards Guide SG101
https://lp.atlas-mts.com/guide-about-major-weathering-testing-standards

Photooxidation & Stabilization Mechanisms of Polymers - Atlas Online Seminar
https://lp.atlas-mts.com/online-seminar-photooxidation-and-stabilization-of-polymers

In addition to the international standards development organizations ISO and ASTM, there are industry organizations specifying requirements and test methods for adhesives and sealants:

The Adhesives and Sealants Council: https://www.ascouncil.org

International Union of Laboratories and Experts in Construction Materials, Systems and Structures: https://www.rilem.net/

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