Natural Direct Weathering Testing

Introduction

Direct weathering, where products or test samples are directly exposed to the weather, is the simplest and most common type of weathering test. This type of testing can be performed anywhere; however, over the decades (1) benchmark locations representing typically severe climate types have been identified, and (2) exposure parameters such as mounting and orientation have been standardized within ASTM International (ASTM), the International Standards Organization (ISO), and other standards development organizations (SDO) as well as by historical practice. Of the various weathering techniques available, it can be said that only outdoor natural direct weathering testing is "real" in that other techniques inevitably distort the natural balance of the environmental stress factors. The disadvantage of natural direct weathering is that it occurs in real time and may take years or decades to complete. However, it is the reference to which all other tests must be compared (correlation) and should always be performed to validate the results of other testing techniques such as laboratory accelerated artificial weathering.

Direct Weathering

Direct weathering, also known as outdoor or natural weathering, is defined as an exposure to direct sunlight and other elements of weather. This is typically accomplished by mounting the material on some type of fixed exposure rack. The standard racks shown in Figure 1 are made from anodized aluminum and face toward the equator (i.e., directly south in the Northern Hemisphere) at a fixed angle. The typical sample size is 150 x 305 mm (6" x 12"). common angles of exposure are near horizontal (5°), 45° (the most common), vertical (90°) and equal to the site latitude (26° and 34° for south Florida and central Arizona, respectively). Exposures conducted at 90° do not provide the most severe conditions, but often match the end-use of the material tested closer than any other angle. Direct weathering tests follow the overarching parent standards ISO 877 Plastics, *Methods of Exposure to Direct Weathering, to Weathering Using Glass-filtered Daylight, and to Intensified Weathering by Daylight Using Fresnel Mirrors*; ISO 2810 Paints and Varnishes, *Natural Weathering of Coatings – Exposure and Assessment*; ISO 105-B03 Textiles, *Tests for Colourfastness –Colourfastness to Weathering: Outdoor Exposure*; and ASTM G7, *Recommended Practice for Environmental Exposure Testing on Nonmetallic Materials*. In addition, there are many material specific standards which define the weathering parameters. In addition, one and two-axis (altazimuth) solar trackers can be used to slightly increase the solar exposure and provide increased exposure to dynamic wind load for special applications such as photovoltaic solar panels.

Figure 1. Fisheye view of standard test racks in south Florida.

Open-Backed Exposures

Open-backed exposures are natural weathering tests conducted by either fastening or clamping the specimens at their extremities so that the majority of the material will be exposed to the circulation of ambient air on all sides of the sample (Figure 2). Typical materials for exposure on an open backed rack are glass, free films, plastic, metal sign material, coil, coatings, plastic lenses such as taillight assemblies, tensile bars, and other self-supporting materials. Materials normally used against a substrate should not be exposed in this manner since the backside cooling of the material resulting from wind and natural convection will not allow the specimen to attain the same thermal environment that it will experience in its end-use. The early failures of many vinyl products and paint coatings in real service life were due to the continued use of the open backed method.

Figure 2. Standard 45° open-back test racks with retention/mask flaps in south Florida.

Backed Exposures

Backed exposures (Figure 3) are outdoor weathering tests conducted by mounting the specimens to a substrate (usually 12 mm [1⁄2"] paper-faced plywood) to simulate the end-use thermal environment of the material. Polyvinyl chloride (PVC) siding, roofing membranes, and automotive molding would be typically exposed on a backed exposure rack. Since weathering processes are a synergistic reaction to all factors of weathering (solar radiation, temperature, moisture, etc.), the ability to maintain the proper thermal environment of a material in a simulation of end-use conditions is fundamental to good exposure practices.

Backed vs. Open-backed

What will happen if a material is mounted in a backed exposure when the end-use of the product will be in an open-backed configuration? Since the thermal environment of a backed exposure is potentially 15°C higher than open-backed, the material may degrade in an unrealistic fashion. Unnecessary time and money may be spent to try to fix this problem, either with additional expensive additives or stabilizers or simply failing a material from further production, even though it may be acceptable in its end-use service environment. The "backed vs. open-backed" question is too often overlooked by weathering experimenters.

Figure 3. Backed 45° test racks in Arizona.

Definition of a Panel and Sample

At Atlas Weathering Services Group test sites, a panel is defined as any flat specimen up to 305 mm (12 in) along one edge (Figure 4). The specimen must be sufficiently rigid to be self-supporting and can be mounted without special handling in a standard panel rack equipped with a mask. All AWSG panel racks are equipped with masks preset to either 152 mm (6 in), 229 mm (9 in), or 305 mm (12 in). Panel fees apply for panels up to 152 x 305 mm

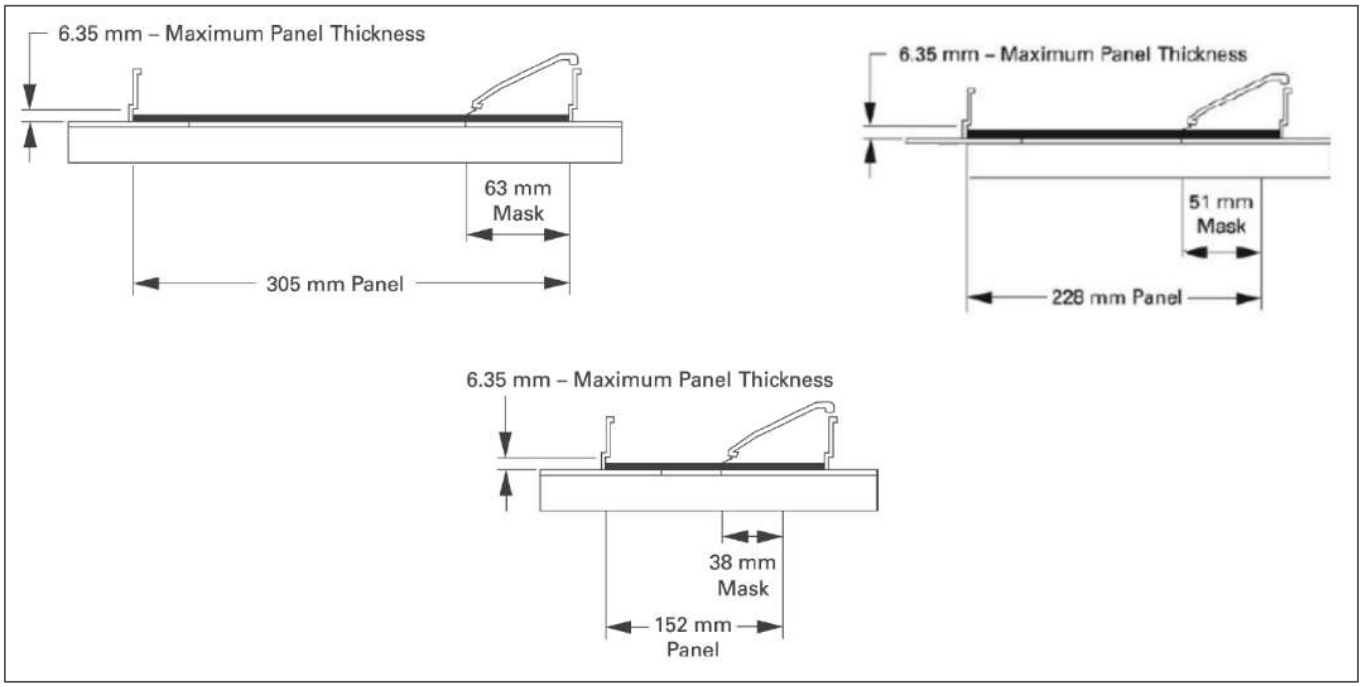

Figure 4. Standard sizes for test panels.

(6 x 12 in). All specimens outside the panel definition shall be considered samples, and fees apply to samples up to 305 x 305 mm (12 x 12 in). For larger specimens, multiples of the stated sizes, or any portion thereof, will be used to determine fees.

Figure 5. Standard panel rack showing mask/retention flaps.

Black Box Exposures

A special type of outdoor exposures was developed for testing automotive coatings. Black Box exposures simulate the air space heat-sink characteristics of an automobile body. They consist of a black-painted, open metal box about 150 x 200 cm (60" x 80") in length and width and 25 cm (10") deep (Figure 6). The panels on exposure cover the open top of the box. For many coatings and automotive paints, Black Box exposures provide greater rates of degradation than those provided by standard 5° open-backed exposures because the Black Box produces higher panel temperatures during the daytime and achieve longer time-of wetness.

Figure 6. Black Box testing for automotive coatings in south Florida.

Black Box panel temperatures are comparable to those encountered on the hoods, roofs, and deck lids of automobiles parked in direct sunlight. ASTM Standard D4141M Method A, *Standard Practice for Conducting Accelerated Outdoor Exposure Tests of Coatings* specifies the use of this Black Box exposure method.

Special Test Fixtures

It is often required to test three-dimensional products or other special test samples that do not fit the normal definitions for flat panels and samples, and these may require special mounting or test fixtures. Some examples of these are Figure 7, a custom test house for several types of building products and Figure 8, a large rotating solar tracking carousel.

Figure 7. Custom test house for building materials.

Figure 8. A solar tracking carousel for automobiles and other large objects.

How Long Do I Need to Test?

Of course, the answer to this question depends on the item being tested and how long the material is expected to last in its typical service life. This may be as short as a few days or even hours for items such as golf ball coatings or beverages, printing inks, or photodegradable plastics.

By comparison, items such as house paint, highway signs, sealants, electrical insulators, and roofing membranes may need to be tested for 5, 10, 15, or even 30 years, or longer, to achieve 100% confidence in the material's durability. The overarching test methods do not provide guidance on how long to test or how to evaluate the effects of weathering. A good general rule is to test to failure, that way you will have a better understanding of how the product degrades over time.

However, customers often cannot afford to wait for materials to sit in these natural conditions without making some assumptions. The only other option is to accelerate the test in some manner. The two most popular techniques are accelerated outdoor weathering using solar tracking and concentration and laboratory artificial weathering using solar simulation.

Variability Due to Climate

Climate at the test site can significantly affect the material failure rates and modes. Different climates obviously have different amounts of radiant energy, temperature, moisture, and pollutants, which will undoubtedly lead to different test results. Also, Acts of Nature may result in long-term variations in the climate. Volcanoes can eject incredible amounts of ash and pollutants into the air that can lower maximum air temperatures and radiant exposure levels. The warming and cooling of the Eastern Pacific Ocean, creating the El Niño and La Niña conditions, cause two- to three-year variations in temperatures, moisture, and wind currents in many affected areas of the

world. Hurricanes (cyclones) can cause severe damage to specimens exposed in the subtropical climate of south Florida if weathering laboratories do not take precautions to protect specimens. Variations in the concentration of ozone in the atmosphere can cause higher or lower amounts of UV radiant energy to reach the earth's surface.

Variability Due to Time of Year

Solar radiant energy, temperature, and moisture vary considerably with time of year. These seasonal variations can cause significant differences in the rate of degradation in many materials and must be considered in comparing results of short-term (less than one or more full years) exposures. A test start in winter may show differences than the same test duration and test specimens starting in summer, particularly for tests shorter than 1 or 2 years.

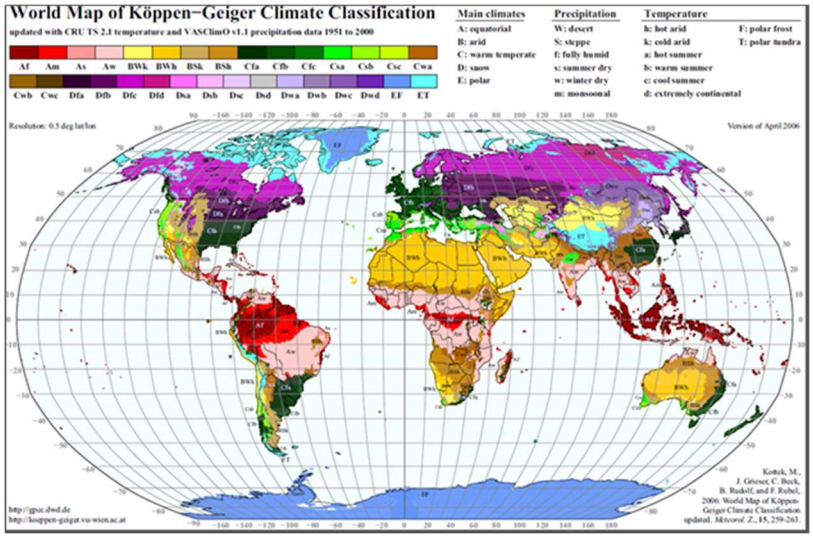

Figure 9. Köppen-Geiger climate classification system.

Variability Due to Year-to-Year Climatological Variations

Because average temperature, hours of sunshine, and moisture can vary considerably from year to year at any given location, comparisons of test results of even full-year exposures can be difficult. Therefore, results from a single exposure test cannot be used to predict the absolute rate at which a material degrades. Several years of repeat exposures are needed to get an "average" test result for any given site. When comparing to historical data it is often best to use 10 year, or longer, averages to even out annual variations.

Figure 10. Atlas SFTS main site in Miami (top) and special project site (bottom).

Variability Due to Test Design

Every exposure test has some variability inherent in its design. Specimen placement on an exposure rack, location in the test field, and specimen mounting configurations can all lead to test variability. While the variability of outdoor exposures cannot be denied, weathering tests performed by trained, experienced experts should always be included in any R&D program. These test methods provide baseline information on the durability of new materials. ASTM G141, *Addressing Variability in Exposure Testing on Nonmetallic Materials* is a good reference which further addresses the variability that is common to weathering test methods.

Climate Zones

There are many climates where your product may be used, and the Köppen-Geiger climate classification system (Figure 9) provides a useful tool for characterizing them. In terms of material degradation, particularly of polymeric materials, several benchmark climates have been historically used for most weatherability testing.

The subtropical region of the southern tip of Florida, in particular, has been a weathering benchmark location characterized by warm year-round temperatures and high levels of moisture (humidity, condensation, and rainfall) producing a high level of wet time, all of which are particularly damaging to polymers. This area is home to many paint company test sites. Atlas operates the South Florida Test Service in Homestead (Miami) (Figure 10).

A second major benchmark location is the high desert characteristic of the Sonoran Desert in Arizona. This region is characterized by high temperatures, particularly in summer, punctuated by low temperatures, especially during the nighttime in winter. Moisture levels are quite low in terms of both relative humidity and rainfall. Several automotive OEMs operate exposure sites in this area as the high temperatures and solar radiation are particularly damaging to automotive interiors. Fenestration devices are also frequently tested here as are other products likely to be damaged by high temperatures and strong direct solar radiation. Atlas operates the DSET Laboratories exposure site in New River (Phoenix), Arizona (Figure 11). DSET is also home to Atlas' Solar Test Center for solar renewable energy product testing. A key feature of the Arizona test site is the use of Fresnel solar tracking and concentrating devices for accelerated natural weathering.

Figure 11. DSET Laboratories site in New River (Phoenix), Arizona

Test Site Data

	Florida SFTS	Arizona DSET	Sanary, France
Latitude	25° 52' N	33° 54' N	43° 08' N
Longitude	80° 27' W	112° 8' W	5° 49' E
Elevation	3 m	610 m	110 m
Avg. High Temperature			
Summer	34° C (93° F)	39° C (102° F)	23° C (73° F)
Winter	26° C (79° F)	20° C (68° F)	9° C (48° F)
Avg. Relative Humidity	78%	37%	76%
Total Rain	1685 mm	255 mm	700 mm
Total UV 295-385 nm	280 MJ/m²	333.5 MJ/m²	382.4 MJ/m²*
Total Radiant Energy 295-3000 nm	6588 MJ/m²	8004 MJ/m²	5500 MJ/m²

* Data measured from 300-400 nm

Average Monthly UV and Total Radiant Energy (MJ/m²)

	26° South (Miami)		34° South (Phoenix)	
Month	UV	Total	UV	Total
January	20.0	505	20.1	490
February	22.5	545	19.8	546
March	26.5	618	24.7	633
April	28.0	612	33.3	755
May	28.0	609	38.6	786
June	25.7	543	36.8	770
July	24.7	532	35.1	745
August	24.0	543	32.5	756
September	22.3	540	29.3	711
October	21.7	555	25.8	705
November	18.0	490	19.2	582
December	18.6	496	18.3	525
Annually	280.0	6588	333.5	8004

Figure 12. Climatological and solar radiation data for several test sites.

General test site climatological and solar radiation data for south Florida and Arizona (and the Sanary Mediterranean test site) are shown in Figure 12. Detailed data can be downloaded from the Atlas website. Weather data is collected in World Meteorological Organization (WMO)-class weather stations and a variety of solar radiation measuring devices which are placed at several common exposure angles to record both direct and under glass radiation. In addition, other sensors such as black and white thermometers and time of wetness sensors record other key weathering parameters (Figure 13).

Figure 13. Representative solar radiation and weather monitoring station.

While other worldwide locations have similar climates (such as Hainan Island (CN) and Okinawa (JP) for hot/humid and the Kalahari desert for hot/ dry), Miami and Phoenix have historically long been global reference weathering sites. Atlas has assembled a network of owned or affiliated exposure test sites around the world as part of the Atlas Worldwide Exposure Network (WEN) (Figure 14) and can manage coordination of exposures in multiple global locations.

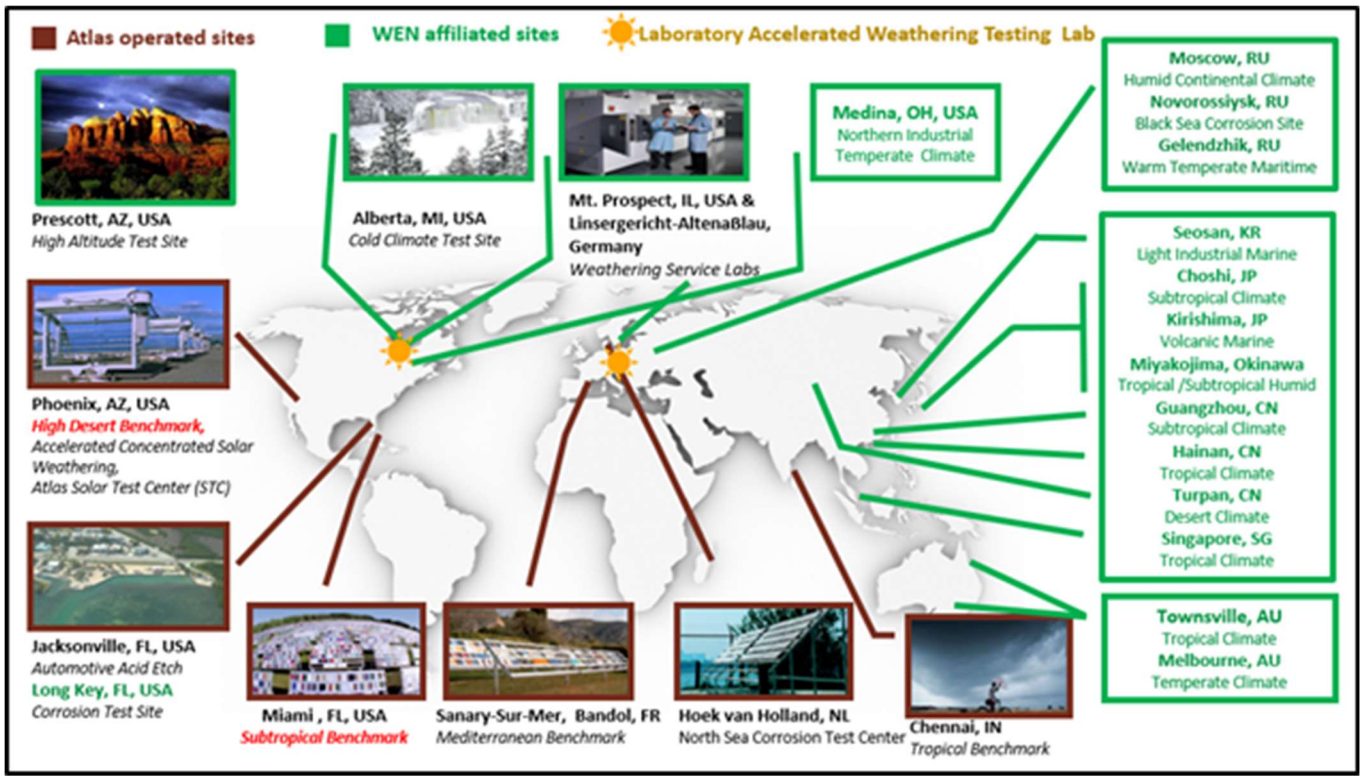

Figure 14. Worldwide exposure network of approximately 25 sites for global weather testing.

Summary

Direct weathering exposes samples to the primary stresses of cycles of solar radiation, temperature, and moisture as well as secondary stresses such as atmospheric pollutants. Exposures are typically conducted on test racks facing the equator and elevated at a tilt angle from the horizontal to maximize solar radiation. However, any product can be tested in any orientation in custom test fixtures, or structures can be built to accommodate special sample types. Different exposure angles may receive different ratios of direct to diffuse solar radiation and are typically specified in global test standards or specific material specification tests such as by ASTM, ISO, or others. Exposures are conducted at in the land locations away from salt atmosphere. At standard benchmark locations, such as South Florida and Arizona, both whether and solar radiation data are monitored. Other locations, such as those in the Atlas Worldwide Exposure Network are also available to test to local climates. Outdoor testing should always be conducted to validate the results of accelerated weathering techniques as no laboratory technique can fully reproduce the complex short and long-term cycles of the primary stress factors of temperature, moisture, and solar radiation, nor the secondary stress factors such as biological agents and atmospheric pollutants. Only outdoor testing is “real” and should always be the benchmark to which accelerated testing is compared.

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