Natural Outdoor Testing: An Important Component of a Light Stability Testing Program

Eric T. Everett
Q-Panel Lab Products,
Cleveland, Ohio, USA

Abstract

Light stability and weatherability data is necessary for the selection of new materials and the improvement of existing materials. It also is necessary for estimating the service life of a product. The main causes of material degradation are bright lighting, sunlight, high temperature, and moisture. The importance of natural sunlight testing is often overlooked. Outdoor exposure is used to test the durability and lightfastness of materials and is an important supplement to accelerated laboratory testing. Outdoor testing provides real time results and is versatile. Test specimens can be exposed directly outdoors or behind glass to reproduce an indoor environment in which products are exposed to sunlight through window glass.

This paper reviews basic procedures of outdoor weathering and discusses some of the related effects on the durability of materials. Some of the more important testing options and issues are reviewed such as: effect of the exposure angle, mounting methods, behind glass and direct exposures, and the seasonal variability in exposure conditions.

Introduction

Weathering tests offer an initial view on the expected performance of the material to the environment. Natural and accelerated weathering tests are not, however, simply a case of setting test specimens out in the sun or placing them in an accelerated weathering apparatus and watching what happens. A meaningful test involves a more thorough understanding. There are a number of important factors to be carefully considered when planning and conducting a weathering test: the cause and effect relation between the weather and the material, and the subtle difference in exposure techniques. To achieve the most reliable test results, these fundamentals must be appreciated.

Overview of Weathering Concepts

In the development of new materials and the improvement of existing materials, weatherability data is necessary to determine product durability. The main weathering forces that are responsible for material degradation are sunlight, high temperature, and moisture.

Sunlight is an important cause of damage to organic materials. Short wavelength ultraviolet light is recognized as being responsible for most of this damage. Short wavelength UV is responsible for damage such as strength loss, cracking and crazing, embrittlement, delamination and hazing. Visible light, on the other hand, is responsible for color loss, yellowing, color change, etc.

Sunlight Spectrum. The electromagnetic energy from sunlight which reaches the earth is normally divided into ultraviolet light, visible light, and infrared energy. Sunlight can be measured by its Spectral Power Distribution (SPD) which is defined as the "Intensity of a light source as a function of the individual wavelength." Figure 1 (following page) shows the spectral power distribution (SPD) of noon mid summer sunlight. Infrared energy (not shown) consists of wavelengths which are longer than the visible red wavelengths and starts above about 760 nanometers (nm). Visible light is defined as radiation between 400 and 760 nm. Ultraviolet light consists of radiation with a wavelength shorter than 400 nm.

The UV region itself can be divided into three distinct wavelength ranges, only the UVA and UVB reach the Earth's surface:

UVC - wavelengths less than 280nm
UVB - wavelengths between 280-320nm
UVA - wavelength between 320-400nm

In actuality, no UVC reaches the Earth's surface; wavelengths below 295-300nm are filtered out by the atmosphere.[1] It is the UVA and the shorter UVB which are primarily responsible for photodegradation.

The visible portion of the solar spectrum is responsible for a limited amount of physical degradation.[2] This is due to the fact that only a certain few materials are susceptible to degradation from visible light. Some dyes and pigments are sensitive to wavelengths in the lower regions of the visible spectrum. This degradation will manifest itself as color changes in most materials, but without any changes to other physical properties, such as strength loss, cracking and crazing, embrittlement and delamination.

Printed materials, paper, and dyes are affected by the visible wavelengths.

Infrared radiation causes heat buildup to occur on radiated specimens, but it has not otherwise been associated with causing significant deterioration to occur. The IR will be a factor in some deterioration because absorption of these wavelengths will cause specimen temperature to rise, and this, in turn, will lead to an increase in the rate of photodegradation.

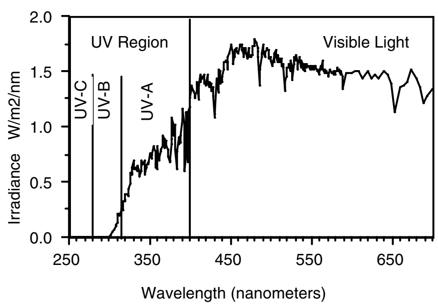

Figure 1.The Sunlight Spectrum

For simulations of direct sunlight, we believe artificial light sources should always be compared to what we call the “Solar Maximum” condition: global, noon sunlight, on the summer solstice, at normal incidence. This is the most severe condition found in outdoor service, and therefore controls which materials will fail. Graphs labeled "sunlight" in this paper refer to Solar Maximum.

Photochemical degradation is caused by photons of light breaking chemical bonds. For each type of chemical bond there is a critical threshold wavelength of light with enough energy to cause a reaction. Light of any wavelength shorter than the threshold can break the bond, but longer wavelengths of light cannot break it - regardless of their intensity (brightness). Therefore, the short wavelength cut-off of a light source is of critical importance. For example, if a particular polymer is only sensitive to UV light below 295 nm (the solar cut-off), it will never experience photochemical deterioration outdoors. If the same polymer is exposed to a laboratory light source that has a spectral cut-off of 280 nm, it will deteriorate. Although sources that produce shorter wavelengths produce faster tests, there's a possibility of anomalous results if a tester emits these unrealistic wavelengths.

Accelerated laboratory weathering and outdoor exposure testing provide reproducible results for materials exposed to specific sets of conditions. Both types of testing are intended to determine material durability and improve material formulation.

Moisture and Temperature

Although sunlight is typically regarded as the most severe climatic cause of degradation, the effects of moisture and temperature also play a very important role in material deterioration. Even without the effects of sunlight, both high temperatures and moisture can cause chemical reactions in materials, which lead to degradation.

Outdoor Weathering

The importance of outdoor testing is often overlooked. Exposure testing outdoors is an important supplement to accelerated laboratory weathering testing. It provides real time results and exposes test specimens to complex weather patterns not easily duplicated in an accelerated laboratory environment. Test specimens can be almost any material or shape, including: painted metal panels, textiles, molded plastic parts, or complex assemblies of different materials.

Florida and Arizona are recognized as international benchmarks for durability testing of materials. Florida has high intensity sunlight, high annual UV, high year-round temperatures, high annual rainfall, and high humidity. When combined, these factors create the harsh climate that makes Florida the ideal location for testing exterior product durability. Because they provide something of a “worst case,” Florida weather conditions typically produce faster deterioration than the weather in more northern locations. This is one of the reasons that companies test in Florida.

Arizona features a hot, dry, high UV radiation environment, particularly suited for the weathering of materials under conditions, including: high UV radiation, large temperature fluctuations, and low moisture. Arizona exposure testing has become popular because the annual total solar and total UV radiation exceeds Florida by about 20%. This is attributed to Arizona’s significantly higher percentage of sunlight in the direct beam portion (i.e., the solar radiation from the sun that has not been scattered by the atmosphere) of the solar spectrum.

In addition, maximum air temperatures in Arizona are commonly 15ºF (-9ºC) hotter than those in Florida, and Black Panel temperatures may be 20ºF (-6ºC) hotter.

Arizona also has extreme temperature fluctuations that subject materials to changes in volume due to expansion and contraction. Arizona’s unique climate is especially useful for testing certain types of materials. Particularly affected are: color and gloss of coated materials, color stability, heat aging, and physical properties of plastics, coatings on plastics, lightfastness and tensile strength of textiles.

Exposure Methodology

Various mounting and exposure techniques are available for conducting natural outdoor exposure tests.[3] Each has advantages and limitations, depending on the material or product’s end use application. Care must be taken to select the appropriate exposure methodology to assure that test results are as useful as possible.

This paper outlines some of the more significant outdoor weathering issues, including:

- Effect of Exposure Angle
- Mounting Techniques
- Effect of Mounting on Temperature and Moisture
- Seasonal Variations in Exposure Conditions

Choosing a Specimen Exposure Angle and Mounting Method. Not all outdoor exposures are equal. The specimen mounting technique and the exposure angle have a significant effect on each of the following critical test parameters:
- Solar Energy Dosage
- Specimen Temperatures
- Moisture and Time of Wetness (TOW)

Exposure Angle

To maximize sunlight dosage, test specimens are normally mounted facing toward the Equator. Any object exposed outdoors will receive more solar energy when the sunlight strikes it directly, than when the light strikes it at an angle.[4] Therefore, the angle at which a test specimen is exposed affects the amount of solar radiation that it receives. In Florida and Arizona, the sun reaches a very high zenith (i.e., height above the horizon) during the summer. The sun is almost directly overhead. Therefore, in the summer, the specimens exposed at 5º from the horizontal receive more total solar energy than those exposed at 45º. In the winter, when the sun doesn't reach as high in the sky, the specimens exposed at 45º receive more total solar energy.

Therefore, the angle of exposure, sometimes called "tilt angle," has a significant impact on a specimen's response to its environment. Tilt angle determines the specimen's dosage of solar radiation and rate of heat build-up and cool down. Tilt angle also influences the amount of time that the specimen is wet due to dew formation, rainfall, or drying winds.

As a general rule, the exposure angle should be representative of the material's expected service environment. Exposure at the correct angle ensures that the test will be realistic and increases confidence in the results. Following are the most commonly used exposure angles. All angles are measured from the horizontal.

45º South. This angle is regarded by many as the typical outdoor exposure angle and is the angle of choice for many industries. This is the standard exposure angle for most industrial textiles. It is the most widely used tilt angle for materials that do not have a specific end-use angle.

5ºSouth. This angle is utilized for automotive exterior products and other materials which are normally used at or near a horizontal angle in service. The slight tilt allows water to drain off the test specimens. Compared to 45º, this tilt angle is harsher because it receives more annual solar radiation, especially during the summer months when higher temperatures enhance the effects. This 5º tilt angle also collects more dew and retains moisture longer than does the 45º tilt angle.

90º South. This fixed, vertical angle is most commonly used for residential coatings. This angle is the most realistic for building materials, but is not widely used because of slower test results. A vertical angle results in greatly reduced solar radiant exposure, lower exposure temperatures, and fewer hours of wetness. The panels are typically exposed in offset racks, so that water cannot drip from the upper panels onto the lower panels.

Common Mounting Methods

Natural weathering exposures are typically conducted in standard frames or racks designed to securely hold test specimens in place without causing damage and without interfering with the progress of the test. Test fixtures used for natural weathering exposures may be made from wood, aluminum, or stainless steel. Most racks used in the industry are made from aluminum and are easily adjusted to any angle of exposure.

The basic exposure rack is typically 5 feet by 12 feet and consists of a support framework, with the specimen mounting hardware on top. There are two basic mounting systems: one for flat, rigid, self-supporting panels and another for three-dimensional products, parts, or components.

Direct Exposures

A widely used mounting method for most materials is direct exposure. Test specimens are mounted on an exposure rack so that the front surface of the test specimen faces the sun and has no cover. Direct exposure specimens are affected by all elements of the atmosphere. Test methods for direct exposure of materials are covered by ASTM G7, *Practice for Atmospheric Environmental Exposure Testing of Nonmetallic Materials*.

The direct exposure rack is highly adaptable and can hold a variety of specimens. The most common test specimen used in direct exposures is a flat, self-supporting panel. The panel is usually made of aluminum, steel, wood, or plastic. The "standard" specimen is a 12 inch long panel, although the racks can quite easily accommodate panels as small as 5 inches and as large as 48 inches. Panels are normally fastened into place by an aluminum extrusion that covers the top 2.5 inches. This extrusion also acts as a mask.

Open Backed Mounting

Specimens on the direct exposure frame may be exposed either with or without backing. An open backed exposure is the most commonly used method for rigid panels, glass, free-films, plastic and metal sign material, coil coatings, and plastic lenses (taillight assemblies, etc.). In these exposures, test specimens rest on an open framework, usually facing South, and are open to the elements on both the top (face) and the bottom (rear). This mounting method is typically used for exposure of textiles.

Backed Mounting

Non-rigid specimens, three-dimensional parts, and specimens requiring higher temperatures are often mounted over a plywood backing. These are commonly called "backed" or "plywood-backed" exposures. This solid backing will typically result in greater total wet time and higher temperature exposures than in an open backed mounting.

Under Glass Exposures

Glass of any type filters out part of the sunlight spectrum. The majority of the shorter, more damaging wavelengths cannot pass through ordinary window glass. Figure 2 shows the UV region of direct summer sunlight, compared to sunlight filtered through ordinary window glass (single strength, untinted, 0.125 inch thick). As the figure shows, ordinary glass is essentially transparent to light above about 370 nm. However, the filtering effect becomes more pronounced with decreasing wavelength. The most damaging wavelengths below about 310 nm are completely filtered out.

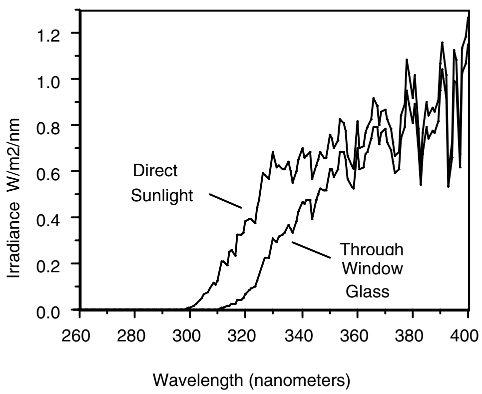

Figure 2. Sunlight Through Window Glass

Under-glass exposures are used to test materials intended for interior use. Test specimens are exposed inside a ventilated framework, 3 inches below a glass cover. The glass is typically single-strength window glass. The glass filters out the most damaging portion of sunlight - the short wavelength UV. The cover also protects the specimen from direct rainfall and most condensation. However, the material is subject to normal humidity variations. A typical frame contains 6 exposure sections with an area of about 30 inches x 48 inches each.

The glass cover must be cleaned periodically to prevent dirt and mildew build-up, which might affect the solar transmittance of the glass. Most under glass exposures are conducted with the specimens mounted on a wood backing. The glass frames are typically positioned at a 45º angle, although a 5º exposure angle in Southern Florida is used to increase the amount of solar radiation received by the specimens. Test methods for under-glass exposure of materials are covered by ASTM G24, *Practice for Conducting Exposures to Daylight Filtered Through Glass.*

Upholstery fabrics used by the automotive industry are usually exposed differently from other textile materials because their degradation conditions differ. Upholstery fabrics are typically exposed to less intensive radiation because it is filtered through glass; however, they are subjected to extremely high temperatures (which in a closed car can reach up to 100ºC). The combined effect of radiation and high temperature affects fiber properties in applications where fabric is also subjected to high stresses and abrasion.[5]

The weathering conditions of automotive upholstery fabrics strongly depend on the type of glass used in the car windows. Most automotive windshields use laminated glass which has an intermediate layer of polyvinyl butyral containing a UV absorber that absorbs light below 380nm. Some manufacturers use UV-absorbing films which should give similar protection. Tinted automotive glass is able to absorb UV radiation below 340 nm. In addition, a temperature increase from 60ºC to 90ºC doubles the degradation rate of fabric exposed to the same level of radiation. Temperatures above 70ºC cause a rapid photoyellowing effect.[5]

Seasonal Variability in Exposure Conditions

There are important seasonal variabilities in exposure conditions. These differences are particularly important for products having a short service life. The most important differences are:

- Quantity and Quality of Sunlight
- Amount of Humidity and Time of Wetness (TOW)
- Average and Maximum Specimen Temperature

These factors need to be taken into account for determining test duration. Seasonal variability can vary greatly from year to year. It is best to account for start/finish times, so that a complete year exposure is simulated.

Timing exposures by the amount of radiant exposure they receive will reduce some of this inherent variability. The use of Total Ultraviolet (TUV) energy as a means of timing exposures will further help to compensate for the seasonal differences in the weathering effect produced (i.e., 295-383 nm).

Conclusion

Various mounting and exposure techniques are available for conducting natural exposure tests. Each method has its advantages and limitations, depending on the product's material composition and end use application. Care must be taken to choose the proper exposure methodology to assure that the test results are as meaningful as possible.

Weatherability information is necessary for the selection of new materials and the improvement of existing materials. The forces that cause product degradation vary greatly from location to location throughout the world. Both Florida and Arizona have become accepted internationally as benchmark locations for testing. Each has a climate that allows for rapid testing, yet under different conditions.

References

1. M. Luckiesh, *Artificial Sunlight*, D. Van Nostrand, Co., Inc, New York, 1930

2. W. R. Mathew, *Predicting the Effects of Weathering on Color*, Plastics Engineering, May, 1986.
3. Exact exposure techniques and test protocols are detailed in standard test methods published by the American Society for Testing and Materials (ASTM), the International Standards Organization (ISO), and other technical organizations.
4. *Normal Incidence* is the term used to describe the condition when the sun is at 90º (right angles) from the specimen surface.
5. Wypych, Jerry, Weathering Handbook, Chemtech Publishing, Toronto, 1990.

Biography

Eric Everett received his B.A. from Baldwin-Wallace College and M.A. from Case Western Reserve University in 1987 and 1989, respectively. Eric is employed as a Technical Specialist for Q-Panel Lab Products Co. He has 10 years of experience in standards development. He is Secretary for ASTM G03 Committee on Weathering & Durability and ASTM D01.27 Subcommittee on Accelerated Tests for Protective Coatings. He is also a member of ANSI /ISO IT9.3 on Stability of Color Pictorial Images.