Weathering Methodology

A Discussion and Comparison of Accelerated Ultraviolet Test Methods

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Introduction

As anyone who has spent time outdoors knows, sunlight can be potentially damaging to the skin. It is equally damaging to a great variety of manufactured materials, especially when synergistically combined with fluctuating temperature, humidity and condensation conditions. Over time, this cumulative damage may cause degradation of the original physical properties of the material, such as cracking, peeling, pitting, loss of adhesion, loss of strength or structural ability, etc. It may also cause visual degradation such as color change and fading. Each specific material, and even different colors of the same material, may have a different sensitivity to ultraviolet (UV) degradation.

Accelerated UV weathering test chambers are designed to simulate natural sunlight and provide a means for manufacturers to assess the relative resistance of their product, or various formulations of their product, to degradation in the field. Accelerated UV weathering is applicable to a wide range of organic materials including textile, plastic, rubber, wood, glass, paint, stain, coating, and other organic materials. It has been in use for nearly a century by diverse manufacturing sectors such as industrial, automotive, aerospace, defense, electronics, communication, furniture, textile, home appliance, toy, and more.

Why Perform Accelerated UV Weathering?

The ultimate goal of accelerated UV weathering is to provide accurate UV degradation information in a fraction of the time required in real-world field environments. Obviously, it is impractical to wait several years to determine the actual weathering resistance of a product. Properly designed UV weathering programs can simulate years of service life degradation in a few months or less.

Testing can be adapted to need, or developed to evaluate specific desired characteristics such as polymer degradation, color change, or specific climatic environments. The testing can be performed to generate failure modes, determine time to failure, compare or rank competing materials or formulations, or to meet or define a quality control requirement.

Accelerated UV aging is cost effective by providing improved R&D formulation, reducing time-to-market, and increased quality control.

Understanding Sunlight

In order to understand UV aging, it is necessary to have a basic understanding of sunlight. Sunlight consists of electromagnetic energy of various wavelengths. Sunlight intensity varies by geographical location, and since it is filtered by the atmosphere, cloud cover, pollution, etc., the intensity of sunlight at any given wavelength varies not only from season to season, but constantly throughout the day.

Sunlight is typically divided into three categories of light: ultraviolet, visible and infrared. Ultraviolet light is comprised of the shortest wavelengths, 400 nanometers (nm) or less. Visible light, or light that is readily visible by humans, consists of wavelengths from 400 – 760nm. Longer wavelengths comprise the infrared range.

Weathering Degradation

Weathering degradation typically comprises three elements: sunlight, temperature and moisture.

Sunlight – The most damaging sunlight wavelengths are in the UV range and are further broken down into UV-A, UV-B and UV-C.

- UV-A: approximately 315-400 nm
- UV-B: approximately 270-315 nm
- UV-C: approximately 270 nm or less.

UV-C is typically filtered out by the atmosphere, so UV weathering concerns are confined to UV-A and UV-B ranges, and shorter visible light wavelengths. These wavelengths are generally responsible for polymer degradation.

The spectral sensitivity of a material is the amount of damage incurred by that material at various wavelengths of light. This value can vary greatly between similar materials. UV wavelengths, and to a lesser extent some shorter visible wavelengths, provide photochemical reactions by breaking the chemical bonds in materials. This loss of chemical bonding is what is typically described as material degradation.

Each material has a unique threshold energy. Light of wavelengths shorter than this threshold energy will cause chemical bonds to break, while longer wavelengths will not, despite their intensity. Therefore, UV-B is considered the most damaging polymer-degrading natural wavelengths. In general, wavelengths above the threshold are more likely to affect color change.

Although infrared wavelengths do not cause photochemical reactions, they do increase temperature. Increasing temperature, whether due to irradiation or environment, is directly proportional to increased oxidation rates in the UV wavelengths. Since darker colors absorb more light energy, they are more susceptible to light-induced heat effects.

Temperature – Fluctuations in temperature impart physical stress to materials via expansion and contraction. This is often a concern for laminated or coated materials, where differential expansion/contraction can lead to increased physical stress, loss of adhesion, or delamination.

Moisture – Whether in the form of humidity or condensation, moisture changes the rate, and possibly mode, of material degradation. Moisture is the most difficult element to accelerate in testing since it requires application and drying cycles to properly simulate diurnal cycles.

UV Weathering Testers

Three types of UV testers commonly used to perform accelerated UV testing are Carbon Arc Weathering test chambers, Xenon Arc Weathering test chambers and Fluorescent UV. As would be expected, all three methods have some commonality in design:

Specimen Temperature Control. This is typically provided by a Black Panel or Standard Black Panel that is placed alongside the test specimens. The black panel provides temperature feedback to the instrument similar to a thermostat. Note that since black absorbs more thermal energy than lighter colors, test specimens may be subject to slightly lower temperatures than the test protocol defines. Some more recent specifications also require White Panel temperature information, although control is still via Black Panel.

Humidity Control. This is typically provided by heating a reservoir of water to generate steam. Wet bulb/Dry bulb sensors calculate the relative humidity in the chamber and provide feedback to the steam generator.

Light/Dark Cycle. Some test profiles require the test specimens to be exposed to continuous light during exposure. Other test profiles require light periods followed by dark periods to simulate diurnal cycles. The duration of each cycle can vary by test profile. The light/dark cycle is typically controlled by either a mechanical cam specific to the required cycle, or can be programmed through controlling software.

Moisture/ Water Spray. Similar to light/dark cycles, some exterior exposures also require a water spray cycle to simulate dew or rain, erode surface materials, or apply a thermal shock. The timing and duration of the spray varies with the test profile, typically in conjunction with the specific light/dark cycle. Water spray is controlled via a mechanical cam specific to the required cycle, or can be programmed through controlling software.

Specimen Mounting. In Carbon Arc and early Xenon Arc units, test specimens are mounted to a barrel-like rack in flat metal specimen holders. The barrel/specimens revolve around a central light source at a specific distance. The rotation reduces errors caused by potential intensity variations in the light source. Specimens with more complicated geometries require special preparation and mounting to ensure they will fit in the test chamber and remain at the proper distance from the light source.

Fluorescent UV units use flat metal specimen holders at a specific distance from the light source. However, the specimens are positioned on a flat panel. Older units require periodic rotation of test specimens and changing of lamps to reduce intensity variation in the light source. Newer units eliminate this need via light sensor feedback. Note that all of these units are designed for flat, plaque-like test specimens of roughly 3 x 6 inches (specific sizes vary by unit and model). Again, specimens with more complicated geometries require special preparation and mounting to ensure they will fit in the test chamber and remain at the proper distance from the light source.

Recently, “platform” Xenon Arc units have been developed, in which a series of xenon lamps shine down on a flat surface. The specimen base is large enough to accommodate samples of approximately 16 x 28 inches, and can be adjusted approximately three inches to proper distance some more complex geometries. The additional specimen size can also be an advantage for producing standard test specimens for physical testing if required after exposure.

While each of these methods has inherent strengths and weaknesses, all three have multiple parameters which can be adjusted to best match expected service environments. The main difference in the varying types of UV weathering test chambers is their approach and ability to properly simulate natural sunlight.

Spectral Comparison of UV Weathering Testers

Developed in the early 1900’s, Enclosed Carbon Arc weathering test chambers are some of the earliest UV testers created. As such, they have a strong historical value in comparing materials. They generate light spectra by arcing energy across carbon rods. Irradiance, the intensity of generated light, is uncontrolled beyond maintaining a specified distance between the test specimens and the light source. Exposure durations are controlled by hours of operation of the test unit. Unfortunately, the light spectrum produced does not correlate well with natural sunlight. The light spectrum produced has two very large spikes in the visible light range of approximately 350-390 nm range (visible light), with very minimal light emitted below 350 nm. The light source generates only a very small portion of light in the UV-A range, missing UV-B (where a majority of polymer degradation occurs) completely. As such, Enclosed Carbon Arc exposures tend to be slow and may not reach the spectral sensitivity threshold of test material, causing correlation of test materials to actual field materials to be poor.

Sunshine Carbon Arc was developed in the 1930’s. Light spectra and intensity generation are basically identical to Enclosed Carbon Arc. Exposure durations are controlled by hours of operation of the test unit. The main advancement offered is the use of Corex D filters, which improve correlation of emitted spectra with natural sunlight. However, there is still a large spike in the 390 nm range. The UV range was increased to include UV-B, but also runs deep into UV-C. The cutoff point for natural sunlight is approximately 290 nm. Sunshine Carbon Arc delivers light energy down to approximately 260 nm, which can cause degradation in materials that would not normally degrade in natural sunlight. Again, correlation between testing and actual field materials can be poor.

Xenon Arc weathering test chambers use a xenon bulb to emit a full spectrum of UV, visible and IR light, closely mimicking natural sunlight. However, they emit unwanted radiation in the low UV range, similar to Sunshine Carbon Arc. To correct this, exposures are performed with filters or filter sets specifically chosen to more closely match expected field service conditions of the item under test. There are a few general classes of filters, and within each class there may be several different filters which allow for very specific spectra selection. As such, a properly developed test profile will closely simulate the full spectra that a test material would see in the field. Exposure durations are controlled by hours of exposure, or more typically, kilojoules per square meter (kJ/m^2) of energy received by light sensor. This helps eliminate potential differences between separate Xenon Arc units to create more reproducible test results. The most common irradiance monitoring settings are 0.35 or 0.55 watts per square meter (W/ m^2) at 340 or 420 nm. In general, 340 nm is used when physical degradation is the main concern, and 420 nm when dye or pigment degradation is being studied.

As xenon lamps age, the emitted irradiance across the spectra decreases. As described above, the irradiance is controlled at the wavelength monitored (typically 340 nm). However, the additional energy required to maintain intensity at 340 nm can disproportionately increase intensities in wavelengths above 340 nm. Despite this, properly developed test plans generate good correlation with field results.

Fluorescent UV testers ignore the visible and IR spectra, focusing on the damaging UV range. The units utilize various types of fluorescent lamps to emit UV spectra, generally up to 340 nm. Unlike xenon lamps, fluorescent lamps demonstrate stable spectra over time.

FS-40 lamps were the first widely used fluorescent lamps. They emit UV below the solar cutoff, and can produce erroneous results in some materials, most notably plastics and textiles. However, they tend to exhibit good correlation for exterior coatings.

UVB-313 fluorescent lamps are basically an upgrade of FS-40 lamps and emit similar spectra, but with greater intensities that significantly accelerate exposures.

UVA-340 fluorescent lamps eliminate most of the UV spectrum below the solar cutoff, providing a better correlation to natural sunlight. This improvement allows for acceptable correlation testing for most plastics, while maintaining good coating correlation.

Exposure durations for Fluorescent UV are controlled by hours of operation of the test unit. Irradiance in older units is controlled by light source/specimen distance. More recent units are irradiance-controlled via sensor feedback, similarly to xenon arc units. Benefits of

Fluorescent UV units include shorter duration exposures, low cost, and better temperature correlation between light and dark colors.

Conclusion and Notes

Historically, specific UV weathering test chambers have been used by differing segments of industry – some due to method matching the tester with the product, and some due to historic precedence or data. However, due to better spectra matching, irradiance control, reliability, reproducibility and cost, Xenon Arc Weathering test chambers and Fluorescent UV are increasingly becoming the methods of choice.

A common question asked by manufacturers is how durations equate to actual field life. While some industries have generic calculations to attempt to collaborate test data to field service life, no definitive correlation exists without very specific studies comparing the specific material, color, manufacturing methodology to actual field life at a specific geographic location. Even under these conditions, the correlation is at best an educated estimate.

Despite technological advances, no test unit can completely reproduce all potential field service conditions a product may encounter. UV weathering test chambers are merely a tool used to gauge relative weathering resistance of product or material. Specifically, to reliably and reproducibly generate product failure modes, compare time to failure, rank competing materials or formulations, or to meet or define a quality control requirement.

Acknowledgments and Reference Material

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