Weather Testing of Paints and Coatings

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Originally published in Atlas SunSpots, Volume 43, Issue 93, Spring, 2013.

Although paints have been used since our earliest civilizations, one of, if not the first, references to formal paint testing appeared in "Practical Paint Tests in 1907" [1] by Edwin Fremont Ladd and published by the North Dakota Agricultural College, Government Agricultural Experiment Station of North Dakota. A series of vertical test "fences" were constructed in 1906 and faced on both sides with four types of lumber.

In 1907, the Paint Manufacturers Association commissioned an exposure test of various formulations of white, gray and yellow exterior paints; these were non-commercial formulations so as not to disparage any particular

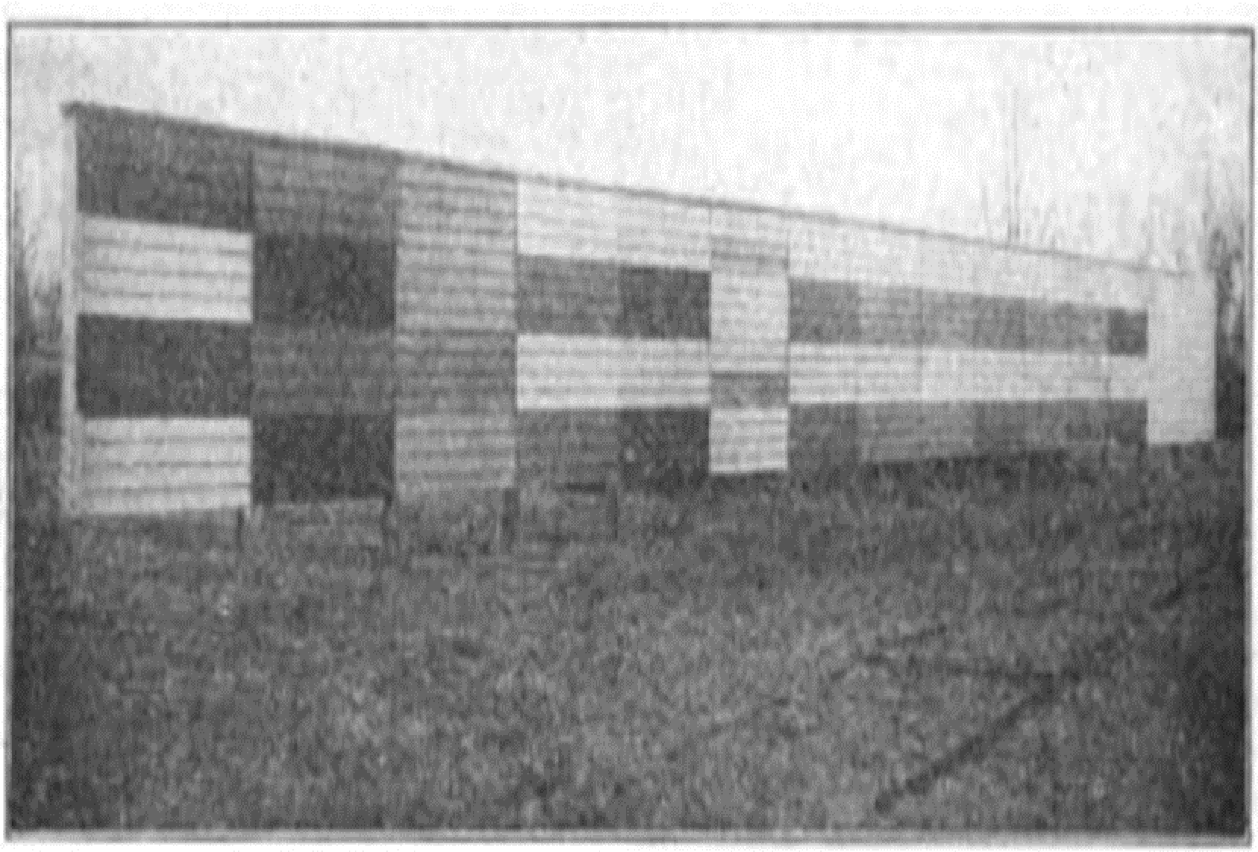

Figure 1: Earliest reported paint weathering "test fence," 1906, Fargo, ND, faced east and west. Rusting nails stained the coatings.

manufacturer's product. The fences were oriented north-south and paints exposed both east and west facing (Figure 1). Most testing is now performed in more severe climates such as subtropical south Florida, and panels are now oriented south or north facing (Figure 2). However, little else has changed in most outdoor weathering testing for wood coatings in the intervening 106 years as evidenced in ASTM's Paint and Coating Testing Manual [2]. In fact, today we often still call exposure racks "test fences."

Paint Weathering Fundamentals

Whether a basic house paint, a high performance automotive or aerospace coating, a durable architectural paint, or a protective or functional coating such as a bridge or anti-graffiti coating, all products face three fundamental weatherability issues. First, the binder (for film-formers) must remain intact without adverse degradation. Second, the coating must remain adhered to the substrate. And third, the coating must also retain key properties: appearance, such as color and gloss, or functional performance such as reflectivity for a cool roof coating or corrosion protection for a bridge or industrial plant. A lot can happen outdoors to degrade these three factors and cause coating failure. We must adequately test products both during R&D to understand how to improve their durability and determine their service life, as well as understand their performance in various climates, with different application methods and substrates, and other critical variables.

Figure 2: South (shown) and north facing paint panels in Florida. Panels are offset to avoid runoff contamination.

Effect of Weather on Coatings

The most damaging weather elements are solar radiation, moisture and heat. The ultraviolet (UV) portion of sunlight contains sufficient energy to break chemical bonds and initiate free radical degradation mechanisms for most organic materials. This is especially true for the shorter UV-A and UV-B wavelengths. Some coatings chemistries, such as epoxies and polyesters, are quite sensitive to this UV and not long-lived outdoors while others, such as fluoropolymers, are extremely UV resistant. The UV resistance of many coatings can be substantially improved with stabilizing additives, but not

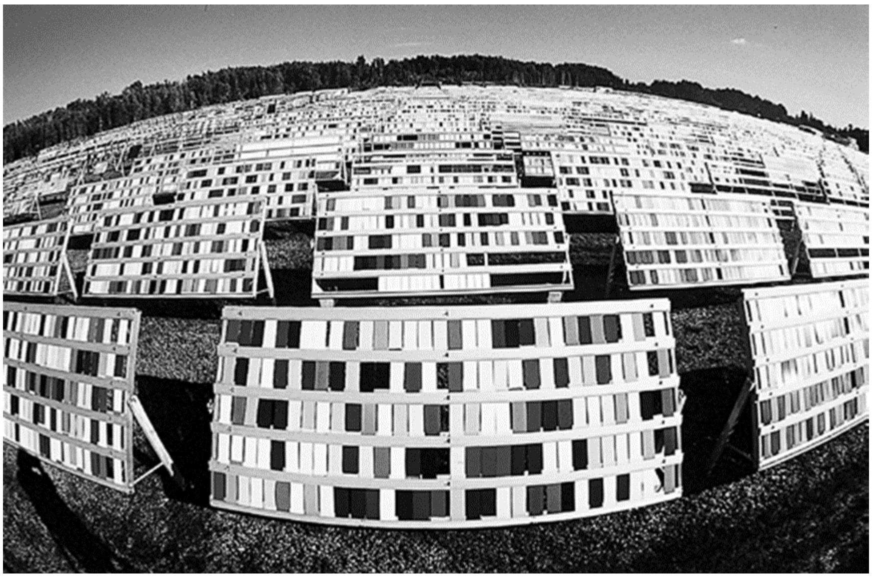

Figure 3: Fisheye view of some of the "test fences" at South Florida Test Service near Miami, the world's largest exposure facility and primary coatings benchmark climate.

***Figure 4**: EMMAQUA® solar concentrator for accelerated weather testing.*

indefinitely. Many stabilization schemes still leave the coating surface largely unprotected, and this is where most of the damage originates. Surface degradation often exhibits as loss of gloss, chalking, microcracking and crazing, pigment color fade or binder yellowing. If UV passes through the coating it can degrade substrates such as wood, causing the binder to lose adhesion and fail.

Longer wavelength UV-A and visible light can also initiate photodegradation; many colorants, especially organic ones, and photo-degradation products, such as hydro-peroxides, are sensitive to these wavelengths. The near infra-red in sunlight causes many colors to heat up as anyone with a dark colored car in a hot sunny climate knows well; this heat may directly cause degradation such as that related to thermal-mechanical movement and can also increase the loss rate of stabilizers and accelerate chemical degradation and mechanisms.

Moisture is a key degrading factor for many coatings and substrates, both organic and inorganic. Many coatings degrade due to hydrolysis reactions. Others fail from the physical action of hydrodynamic swelling and shrinking moving from wet to dry and back. Moisture can leach out stabilizers and provides a habitat for biological organisms such as mold and mildew. Some coatings need to be moisture permeable to allow the substrate to "breathe" such as concrete coatings, while others must be moisture impermeable like anti-corrosion coatings to protect the substrate.

***Figure 5**: EMMAQUA® water sprays provide thermal shock or night time dew wetting.*

Each of these three main weather factors (heat, light, moisture) is not independent; light can affect temperature which in turn affects moisture. Plus, the outdoors is not steady-state; each of these factors changes at any location in cycles and ranges which vary by hour, day, season and year in complex and non-reproducible patterns. Service use, such as pipe coatings in an industrial plant or offshore marine coatings, can be subject to many important additional stresses. Add to this list many secondary climate factors such as wind, atmospheric pollutants and others and you can see the armada of stresses coatings must endure.

Key Weather Testing Climates

There are many climates in the world. In general, the three that are commonly identified as having the greatest degradation effects on materials, including coatings, are hot/wet (subtropical/tropical), hot/arid (desert) and temperate (higher latitude freeze/thaw). A specific coating, depending on its chemistry and functional requirements, may perform very differently in each of these environments. This generally requires outdoor testing in more than one climate. With that being said, the hot/wet subtropical climate of the southern tip of Florida has

Figure 6*:* Ci5000 Weather-Ometer® rotating rack xenon instrument and SUNTEST® XXL+ flatbed xenon instrument

historically been used as the primary weathering testing benchmark for coatings of all types. This is due to the combination of high solar radiation, elevated temperatures and extreme moisture that has been found to be very degrading to organic materials. Other world locations have similar climates, such as Atlas' Chennai, India site, but south Florida has emerged as the *de facto* primary global benchmark for the comparative testing of coatings.

Many coatings performance standards require south Florida exposure testing. Several global coatings companies maintain test sites in south Florida as do commercial testing companies such as Atlas' South Florida Test Service (Figure 3). Atlas has, however, established a Worldwide Exposure Network of approximately 25 global test sites for product manufacturers requiring testing to other regional climates.

South Florida coatings exposures may be conducted at various orientations. Today, direct exposures are oriented toward the equator (e.g., facing due south in the northern hemisphere) and most global test sites are located in the bands of 15-35° latitude where solar radiation is high, and temperatures are warm. However, there are some temperate and cold weather sites as well, and these can be important for coating/substrate systems sensitive to moisture freeze/thaw conditions.

Hot arid sites, such as Atlas' DSET Laboratories in Arizona's Sonoran Desert near Phoenix, Arizona or the Kalahari Desert in South Africa, are also used for coatings testing, especially for automotive paints (in conjunction with South Florida). On average, Arizona receives about 20% more total UV than south Florida but with less than 5% of the "wet time" and with much higher summer and lower winter (below freezing) temperatures. Arizona exposures can be more severe where UV degradation is the dominant failure mode, and for color fade where colorant degradation is primarily a direct photon-absorption process.

A Matter of Degrees

While the original 1906 Fargo test fences were vertical, other exposure angles have since emerged. As most painted wood is used vertically, 90° inclined equator-facing exposures are most common, with alternate exposure facing away from the equator out of direct solar radiation for mildew testing. However, wood used horizontally such as decking, or other horizontally-used coatings such as concrete stains, traffic control marking, etc., on other substrates are typically exposed at near-horizontal 5º inclination to avoid standing water. Due to the height of the sun, a vertical exposure receives about half the solar radiation of a horizontal one (this is highly dependent on latitude and other factors, however). In Florida, the wet time of a horizontal specimen will be greater than for a vertical orientation.

Architectural and other coatings on non-wood substrates, including metals and wood-plastic composites, are often exposed at either 45° inclination angle or “station latitude” which is 26° for south Florida and 34° for Arizona. The 45° exposure is most common globally as it provides a good compromise for “direct normal incidence” through the year as the sun elevation varies seasonally with a reasonable wet time although 5° and 26° provide about 10% more UV annually. In Arizona, with more UV being present in the direct solar beam due to low atmospheric moisture, the 5° provides about 7% and 34° near 11% greater UV dose.

By comparison, south Florida delivers about 75% and Arizona 100% more solar radiation than a specimen receives in Germany, so testing for 2 years at these sites provides an approximate 4-year (UV) equivalent to Germany. Of course, other factors such as moisture and temperature are not comparable.

Coatings R&D and testing can’t always wait for natural outdoor exposure tests, they take too long for most formulation decisions. Hence the need for more accelerated testing, and two main methods have emerged: accelerated outdoor testing using concentrated sunlight, and laboratory testing using solar and climate simulation.

Atlas pioneered using concentrated sunlight for coatings testing in the EMMA® and EMMAQUA® devices (Figure 4) in 1958. These use ten specialized Fresnel reflectors to concentrate sunlight, including the UV, onto test specimens. These devices track the sun during the day and focus ten images of the sun onto the test target. The test specimens are then cooled so that their temperatures are near to what they would be on a static test fence. Periodic water sprays can be programmed to provide wetting or thermal shock during the day and/or nighttime dew wetting typical of south Florida, or operated dry (Figure 5).

As only the direct beam sunlight is focused, the actual concentration factor is about 8x over a natural exposure. This acceleration is seasonally dependent upon the sun and the test acceleration is therefore highest in summer. Special variations for temperature and moisture control are possible to provide better correlation to static exposures for these factors. The technique is widely employed for automotive and architectural coatings on metal; the low thermal conductivity and temperature/ moisture sensitivity of wood is not optimal for this method. Due to the specialized dry atmospheric requirements, these devices are suitable only for operation in arid climates such as Arizona.

***Figure 7**:* Inside of an Atlas UVTest showing UV lamps, Black Panel Temperature Control and ergonomically designed specimen retention clips.

Moving Weather into the Lab

Laboratory-induced weathering was initiated with Atlas’ introduction of carbon arc lamp devices in 1915 for UV color fade testing. With subsequent technological developments in solar simulating light sources and environmental controls, the primary method in accelerated coatings testing is represented by Atlas’ Weather-Ometer ®, Xenotest® and SUNTEST® devices employing specialized xenon arc lamps and optical filters. Together with advanced controls of temperature, humidity and water delivery, these xenon arc devices represent the “gold standard” in laboratory accelerated weathering (Figure 6), particularly in their ability to provide an extremely good match to full spectrum solar radiation. This spectral match, more than any other factor, has been very technically challenging for testing device developers.

An alternative exposure apparatus known as a “fluorescent-condensation” device is based on UVA-340 fluorescent UV lamps (Figure 7). Light exposure typically alternates with a dark moisture condensation period. These devices, such as the Atlas UVTest, are widely employed in coatings R&D. This technique is relatively inexpensive and very useful in screening large numbers of binder formulations for UV and moisture resistance. As correlation with outdoor weathering can be poor for appearance properties such as gloss and color fade, it is not generally considered to be a weathering device. However, lack of correlation to outdoors largely is due to the limited spectrum of the UV lamps and restricted temperature control compared to xenon arc based devices.

The spectral match to actual solar radiation, coupled with good control of temperature, humidity and moisture delivery, has made xenon arc testing to ISO, DIN, ASTM and other international and corporate standards indispensable and a key component of coatings R&D and service life estimation. While xenon weathering devices were first introduced by Atlas in 1954, the technique gained widespread acceptance after 1979 with the introduction of automatic irradiance (light intensity) monitoring and control. The technique was especially adopted by the automotive industry for exterior paint and trim following key failures of early base coat-clear coat systems, then by interior with problems regarding instrument panels and textiles.

Standard committees such as ISO, ASTM, SAE and others created standard test methods based on best available knowledge and technology at the time. Sadly, the process of standards modernization in these large bodies is often compromised with a desire for the lowest technology and backwards compatibility. This came to a head, especially in the USA's automotive industry in the early 2000's when many OEM's abandoned the outdated standards in favor of fundamental science and improved instrument technology.

A Better "Mouse Trap"

Automotive coatings are among the higher-performing systems in use today. These require high appearance retention for ten years and performance in many climates globally on challenging substrates. To underscore their importance, the paint line is the most expensive part of an automotive plant, and the paint system is the most expensive part of a vehicle.

Recently, following some key research with EMMAQUA® devices, a consortium of researchers including Ford Motor, Boeing, Atlas, and others, experimented with improved xenon arc spectral match filters and test cycles for automotive and aerospace coatings to better correlate with south Florida exposures [3]. For automotive coatings, in particular, both the spectral match and amount and form of water delivery have proven to be critical as the more an artificial test deviates from the natural processes the less likely results will agree with real time. This work has resulted in a substantially improved test method (at least for high performance automotive coatings) that may be proposed as an international standard. This science-based approach should serve as a model to the rest of the coatings standards development organizations.

Summary

Only outdoor weathering in various actual climates is "real." However, given today's highly durable coatings systems, the requisite test time is unrealistic to meet R&D requirements.

Therefore, accelerated testing which generally can provide up to about a 5-10x acceleration over real time (test method and material dependent), is necessary. Two accelerated weathering test methods have emerged: Fresnel sunlight concentrators and xenon arc weathering devices. These techniques require a high degree of technology, but as tools, they still require good science and test methods to use them properly. Any accelerated test result should ultimately be validated with real time outdoor testing in one or more climates.

References

[1] Edwin F. Ladd, Practical Paint Tests In 1907; Issue 81 Of Bulletin (North Dakota Agricultural Experiment Station, Fargo), North Dakota Agricultural College, Government Agricultural Experiment Station for North Dakota, 1908.

[2] Joseph V Koleske, editor, Paint and Coating Testing Manual: 15th Edition of the Gardner-Sward Handbook, ASTM International, 2012.

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