WATCHING PAINTS WEATHER:

One Company's Journey to Understand the Exterior Durability of Paints and Coatings

By Leo Procopio, Paintology Coatings Research LLC

FIGURE 1—Aerial view showing a portion of the Dow Exposure Station in Spring House, PA.
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When asked by those outside the paint and coatings industry what they do for a living, coatings scientists are often tempted to offer some levity and respond with the line, **"I watch paint dry."** Of course, on the surface it sounds quite dull, but unbeknownst to the inquisitors, the joke is on them because the drying and curing of coatings is actually a very complex process that has generated decades of intense scientific study.

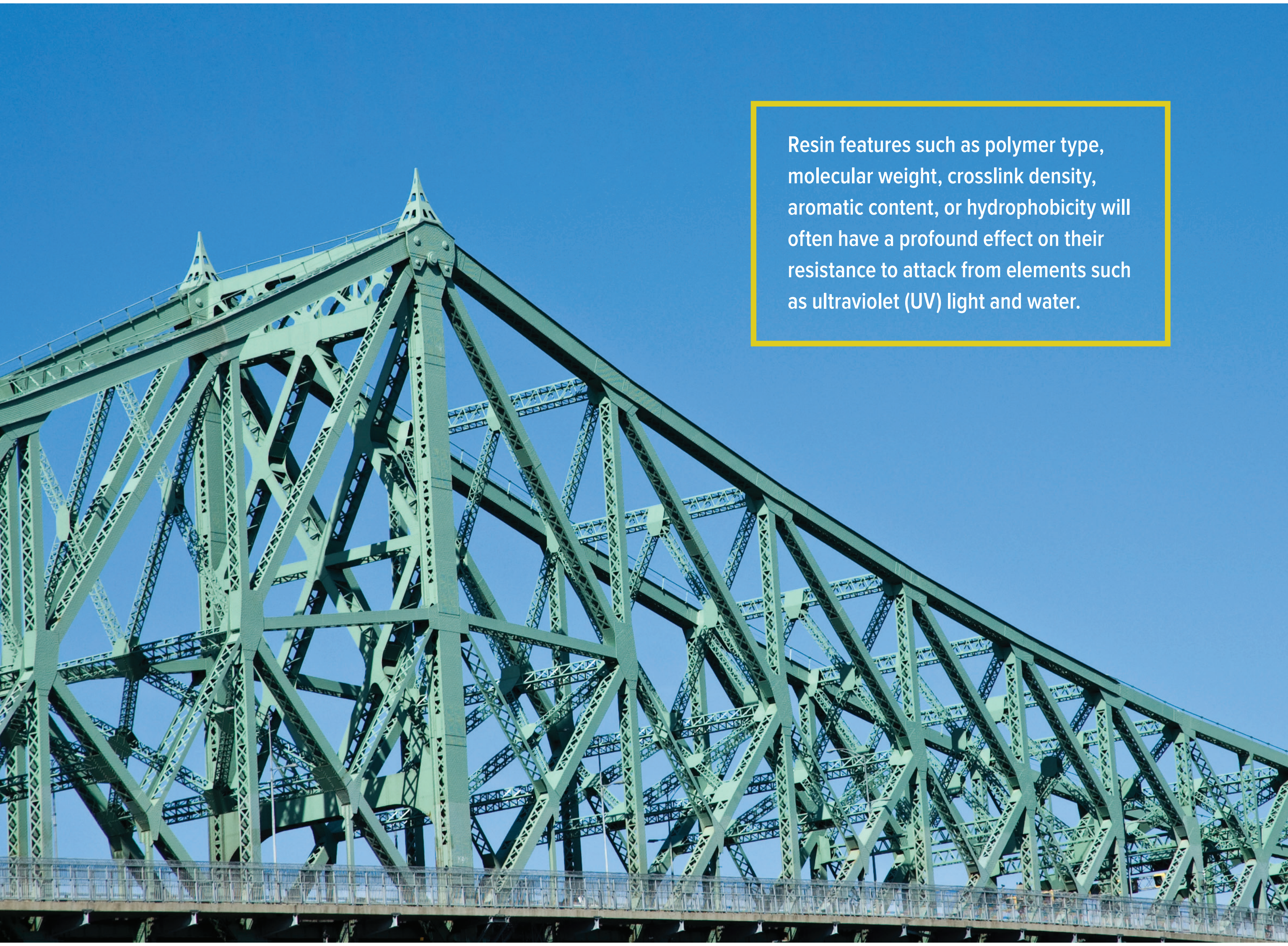
One can imagine that those inquirers might also think that the only thing more boring than watching paint dry would be watching it weather over time. How wrong they would be! In fact, understanding how coatings hold up to weathering is critically important for the success of the industry.

Many raw material suppliers, coatings manufacturers, and coatings end users have exterior testing programs in place to evaluate the effect of weathering on their products. Such programs are useful throughout the various stages of product development from guiding initial experiments and prototypes to product optimization and commercialization.

In this article, one such program that has been evolving for nearly seven decades is profiled. *CoatingsTech* had the unique opportunity to visit Dow's Exposure Station in Spring House, PA, to tour the facility and discuss the science behind weathering paints with John Calderaio, exposure station manager, and Katherine Davis, marketing manager for North America. Both are members of Dow's Coating Materials business unit. Dow is a leading materials science company and global raw material supplier to the coatings industry.

THE SCIENCE OF PAINT DURABILITY

As long as paints and coatings have been used outdoors, coatings scientists have been trying to find ways to make them last longer. The durability of coatings in the face of environmental stresses is a key property for exterior coatings. Depending on the location and climate in which they are put into service, exterior coatings experience various levels of exposure to destructive elements such as sunlight, water (e.g., rain, ice, condensation, humidity, or immersion), dirt, corrosive salts, changes and



Resin features such as polymer type, molecular weight, crosslink density, aromatic content, or hydrophobicity will often have a profound effect on their resistance to attack from elements such as ultraviolet (UV) light and water.

extremes in temperature, impact (e.g., from hail), and microbiological attack (e.g., mold, mildew, algae).

In addition to the many environmental factors, there are numerous raw material and formulation design variables that will influence the weatherability of a coating. Resin features such as polymer type, molecular weight, crosslink density, aromatic content, or hydrophobicity will often have a profound effect on their resistance to attack from elements such as ultraviolet (UV) light and water.

For example, bisphenol A-type epoxy resins, with their high levels of aromaticity, will typically lead to very quick chalking and gloss loss outdoors, sometimes in a matter of months, due to photodegradation by UV light. On the other hand, topcoats based on fluoropolymers such as polyvinylidene fluoride (PVDF) can perform well for decades due to resistance of their carbon-fluorine bonds to photolytic and chemical attack.

Every ingredient in a coating formulation (resin, pigment, additives) may have an effect on weathering performance. Another well-known example is the widely used pigment titanium dioxide (TiO_2), which can generate radicals via photocatalysis in the presence of UV light, water, and oxygen. Those free radicals can then attack and degrade the binder, eventually compromising both aesthetic and protective properties of the coating film.

Other ingredients can assist in the fight against the elements. Additives such as UV absorbers or hindered amine light stabilizers (HALS) can be used to combat the effects of photodegradation and the generation of free radicals. Corrosion-inhibiting pigments help a coating resist the deleterious effects of water and salts that will attack an underlying metal substrate.

The vast number of variables that can be manipulated in the design of formulated coatings, along with the many environmental factors facing an exterior coating in service, creates complexity for the product development process. For coatings scientists, this complexity requires the development of deep insight into how the variables affect weatherability, which can be addressed through testing under both accelerated and natural exposure conditions.

Accelerated laboratory weathering is used because, as the term implies, it can speed up the acquisition of relevant data. Natural weathering studies can often take years before meaningful change or failure is observed, so accelerated testing provides a way to advance the product development cycle more quickly. Accelerated test methods do not replicate exactly what a coating experiences in the real world but are designed to provide a standard method for simulating exposure to certain weathering elements.

Some common accelerated weathering methods used in the coatings industry include ASTM D4587[1] (exposure to fluorescent UV and condensation) and ASTM D6695[2] (Xenon arc exposure with water spray), both designed to simulate exposure to sunlight and a source of water. These methods are useful for evaluating properties such as gloss and color retention and chalking resistance.

For corrosion resistance, ASTM B117[3] (continuous salt spray exposure) is commonly used, while better correlation with real-world exposures is often found with ASTM D5894[4] (exposure to cycles of salt fog, UV, and condensation) and other cyclic methods that incorporate more than one environmental stressor.

Accelerated testing can provide very useful information for making decisions on product development, but correlation with natural weathering is usually not exact. No accelerated method can accurately reproduce all the environmental stressors that a coating experiences across various climates. Therefore, accelerated methods should not completely supplant exterior exposure testing in product development processes.

When developing new raw materials and coating formulations, exterior exposure testing in a real-world environment is usually a required step to demonstrate performance. If exposure testing is bypassed on the way to commercialization, formulators run the risk of unexpected performance failures in the field.

Calderaio notes that accelerated weathering is extremely useful during the development process to weed out poor performers, but exterior weathering studies are necessary as proof statements for the final products.

THE DOW EXPOSURE STATION

Dow has been testing the weatherability of waterborne coatings at the Dow Exposure Station for nearly seven decades. Rohm and Haas (which was later purchased by Dow) initiated the first exterior exposures in 1950, when painted panels were exposed on the rooftop of the company headquarters in Philadelphia.[5,6]

In 1953, the first architectural coating based on a waterborne acrylic latex polymer (RHOPLEX™ AC-33) was commercialized in the United States. In the same year, the Dow Exposure Station was established on a farm in Newtown, PA. It was moved in 1983 to its current location in Spring House, PA, and will celebrate 70 years of continuous operation next year.[6] Both employees and customers affectionately refer to it as the Spring House Farm or the Paint Farm, signifying both its agricultural roots and current use for paint and coatings research. Over the decades, the exposure station has been instrumental in advancing both the science of paint weathering and the commercial success of acrylic latex paints.

The Spring House site is in eastern Pennsylvania, about 30 miles north of Philadelphia, and is the central hub for exterior weathering studies at Dow. It experiences all seasons, including ample rainfall, high temperatures in the summer, and freeze-thaw cycles in the fall and winter. The exposure station encompasses approximately 8.5 acres of fields dedicated to panel exposures and substrate preparation (*Figure 1*).

With more than 1,000 exposure racks, there are approximately 40,000 panels with about 150,000 test areas on those panels. Each test area represents one or more coats of a coating or coating system. Depending on the type of coating, periodic evaluations of the panels record multiple properties such as gloss, color, chalking, cracking, flaking, dirt pickup, mildew and algae growth, efflorescence, and corrosion.

Based on the number of panels, paint systems and properties evaluated, data collection is a key job for the exposure group. Approximately 1 million subjective readings are made each year. A select group of panel readers are employed to maintain consistency of the subjective readings over time and across panel series. New panel readers go through a rigorous training period of up to a year, during which they shadow an experienced reader and go through training series and round-robin evaluations to become calibrated with the other readers. The ultimate goal is to collect consistent and reliable data.

In addition to subjective readings, Dow has also implemented an imaging system called eXposure Vision™ that accounts for an additional 2.25 million readings and collects more than 750,000 images annually. Approximately 2.5 million additional readings are also made with instruments for color and gloss, as well as for other properties such as solar reflectance, Y-reflectance, and moisture content. All data is stored in an electronic database, where it can be easily retrieved and analyzed by Dow scientists.

Panels are monitored for varying amounts of time depending on the purpose of the exposure series. During a tour of the site, Calderaio points out the oldest panels at the site from a series prepared in 1954. A cementitious panel coated with a formulation containing the first acrylic architectural binder, RHOPLEX AC-33, is still proudly displayed and looks surprisingly good. Calderaio notes there are currently

Calderaio explains one misconception about exterior weathering is that it always takes a long time to get meaningful results. For some series, Dow observes differentiation in only 6 to 12 months.

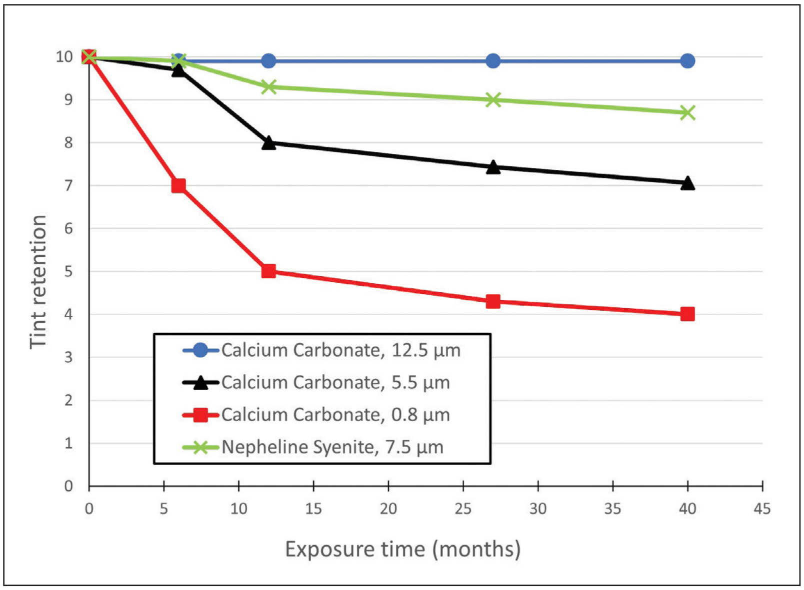
series from every decade since the 1950s still on exposure at the Spring House site. Most series of architectural paints, however, will be monitored for up to approximately three years, and then a decision is made whether to continue them or make space for new panels. Even with the large number of racks available, space is always at a premium.

Calderaio explains one misconception about exterior weathering is that it always takes a long time to get meaningful results. For some series, Dow observes differentiation in only 6 to 12 months. He also mentions how it is important to monitor panels very early in their exposure history, as initial failures can occur very quickly in some cases due to weather events.

For example, after exposing a series, panels are evaluated within the first three months, and sometimes even sooner, such as after the first rain event. The early contact with water can lead to failures like blistering, which might recover over time and be missed if not for early monitoring. Weather events that happen in the early stages of exposure, such as rain or freezing temperatures, can have a huge effect on long-term performance, Calderaio says. Tracking weather is an important function for the exposure station, and a weather station is on site that tracks temperature, surface moisture, wind speed, and the amount of rain.

It is also possible to accelerate the results of exterior weathering, Calderaio notes. Although not as fast as laboratory methods such as the UV/condensation or Xenon arc methods noted above, strategies such as using pre-weathered pine boards, exposing panels facing southward at a 45° angle, using no primer, or using only a single topcoat are all methods the exposure station utilizes to get faster results from exterior weathering. In addition, exposing panels at other locations with more aggressive environments is another way to accelerate exterior weathering. Very few substrates, particularly wood, are dimensionally stable and a primer and two topcoats are typically required to provide long-term weathering resistance. Such a multicoat system, while highly recommended for the best performance, can take years or even a decade to show meaningful differences within a series of quality paints.

FIGURE 2—Tint retention vs. exposure time for flat architectural paints prepared with various extender pigments. Paints were applied to cedar panels and exposed south vertical at the Spring House, PA, site.



EXPOSURE STATION MISSION

While most studies at the Spring House station support the North American coatings market, all geographic regions utilize the data and learnings generated by the site. Calderaio explains that about half of the space contains exposure series generated by research and development groups within Dow and supports both product development and technical service projects. The data generated by the site aids in Dow's efforts to invent and introduce new resins and additives to the market, as well as in helping customers in their coating formulation development.

About 25% of the space contains exposure series generated by the exposure group for various purposes,

FIGURE 3—Dow has many exposure stations spanning the globe across multiple regions and encompassing a variety of climates.

Weather events that happen in the early stages of exposure, such as rain or freezing temperatures, can have a huge effect on long-term performance.

including benchmarking of competitive materials and commercial paints, as well as "learning" series designed to explore formulation variables such as PVC level, TiO_2 grades, and extender types.

An example of a benchmarking study, as Calderaio describes, would be a series of approximately one hundred commercial paints placed outdoors annually in two sheens (e.g., flat and semigloss), in both white and tinted colors, and on multiple substrates. Such a large series would be exposed at the Spring House site, and replicate series would also be exposed at other Dow locations, such as sites in Glen St. Mary, FL, and Torrance, CA. Preparing and following such extensive exposure series may seem daunting but is commonplace for the exposure group.

Figure 2 shows an example of the type of formulating knowledge that can be gained from a "learning" series. Various extender pigments were substituted for one another in a flat exterior architectural wall paint (52% PVC, 35% VS), including calcium carbonate and nepheline syenite extenders of varying particle size. Paints were tinted with 4 oz. of phthalo blue colorant and applied on cedar boards. Panels were exposed vertically in a south-facing direction (south vertical) for 40 months at the Spring House site and monitored for tint retention (rated on a 1 to 10 scale, 10 = best). The results show a clear dependence of tint retention on extender particle size.

The remaining portion of the field holds exposure series submitted by customers such as coatings manufacturers, as well as other Dow businesses. Davis emphasizes that the exposure station is a great asset for both Dow and its customers. Many paint manufacturers do not have such an extensive exposure field, and Dow assists them in gathering vital exposure data by placing and evaluating their panels at the site.

In addition, Dow can share valuable knowledge about formulation variables, gleaned from various "learning" series, to aid in formulating efforts. Data from large series comparing commercial paints can show a customer how their product's performance stands up versus the market, but such extensive series would be too time-intensive and cost-prohibitive for many manufacturers to reproduce on their own.

LOCATION, LOCATION, LOCATION

Although the Dow Exposure Station in Spring House is its largest site for weathering paints and coatings, it is by no means the only site that Dow utilizes. Dow maintains a global network of exposure stations, spread across geographic regions and spanning a variety of climates (*Figure 3*). Regional sites are used in a manner similar to those at Spring House but with an emphasis on regional formulations.

Of course, the durability of a coating will depend on the climate in which it is exposed, so regional paints should be evaluated in the regional climate to provide relevant information. The locations of the various Dow exposure stations span the range of climates, from dry to moist, tropical to temperate, inland to coastal, and intense heat to freeze-thaw cycles. Performance of a particular coating will vary depending on where it is exposed, and the ability to test coatings across multiple locations is a key advantage for Dow's exposure program.

For example, the Glen St. Mary site in Florida is surrounded by trees, has high humidity, and rarely has freeze-thaw cycles. The climate there is conducive to mildew and algae growth, particularly for panels exposed vertically in a north facing direction (north vertical). It is a good site to differentiate coatings for their mildew and algae resistance compared with Spring House. *Figure 4* demonstrates the difference between the sites and shows panels containing the same set of paints and exposed north vertical for 18 months. Spring House is clearly a less hospitable environment for microbiological growth compared with the site at Glen St. Mary.

Another example of performance variation due to local climate is shown in *Figure 5*, which graphs ratings for cracking resistance (on a 1 to 100 scale, 100 = best) against exposure time for the same flat exterior architectural coating (57% PVC, 33% VS) across four sites in the United States. The paint was applied in two coats on yellow pine panels, and panels were exposed at a 45° angle in a southerly direction (south 45°) The ratings are averages across multiple panels at each site and show clear performance differences due to local climate conditions.

Figure 6 shows one last example to demonstrate the importance of location. The cold-rolled steel panels in *Figure 6* were coated with the same waterborne acrylic direct-to-metal coating and exposed south 45° for two years at two different locations. The difference in corrosion resistance is obvious, and it is not a surprise that the panel exposed in a coastal marine environment (Sea Isle City, NJ) performed much worse than the panel exposed at an inland site (Spring House). The Sea Isle City site is very aggressive for corrosion resistance as the panels are located very close to the ocean and exposed to airborne salt

FIGURE 4—Replicate cedar panels with the same series of architectural paints, exposed north vertical for 18 months at the Spring House and Glen St. Mary sites.

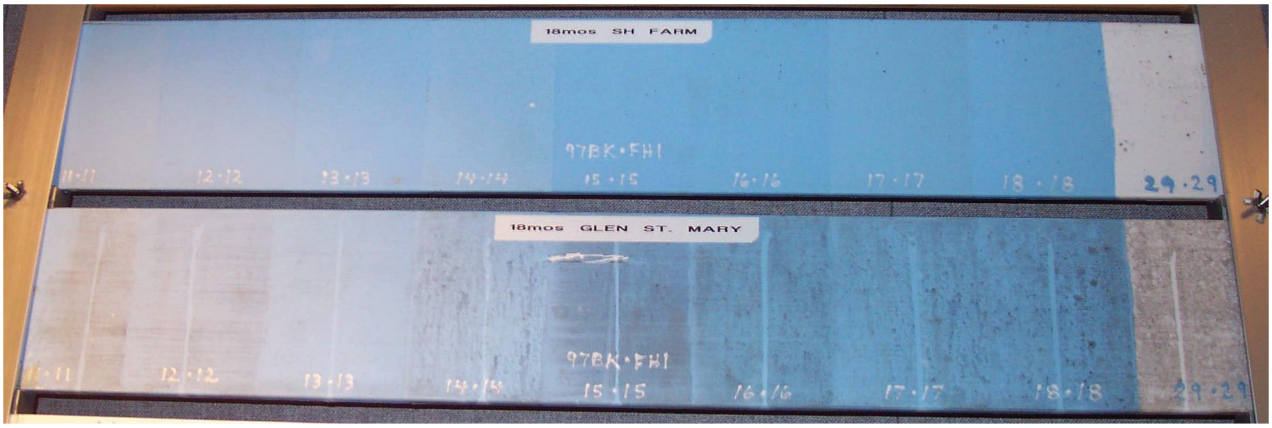


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FIGURE 5—Cracking resistance vs. exposure time for the same flat architectural paint (two coats) on yellow pine, exposed south 45° at four different sites.

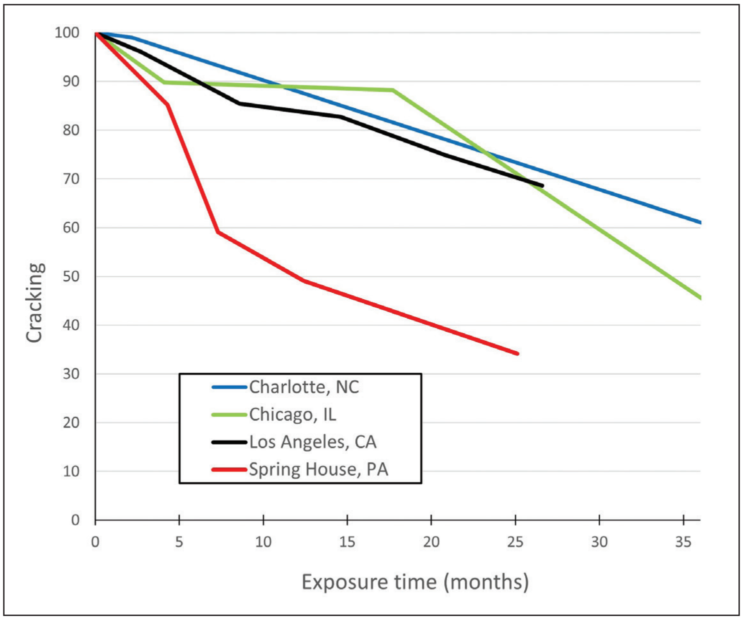

FIGURE 6—Cold-rolled steel panels coated with the same waterborne acrylic direct-to-metal coating and exposed south 45° at Sea Isle City, NJ, (left) and Spring House, PA, for two years.

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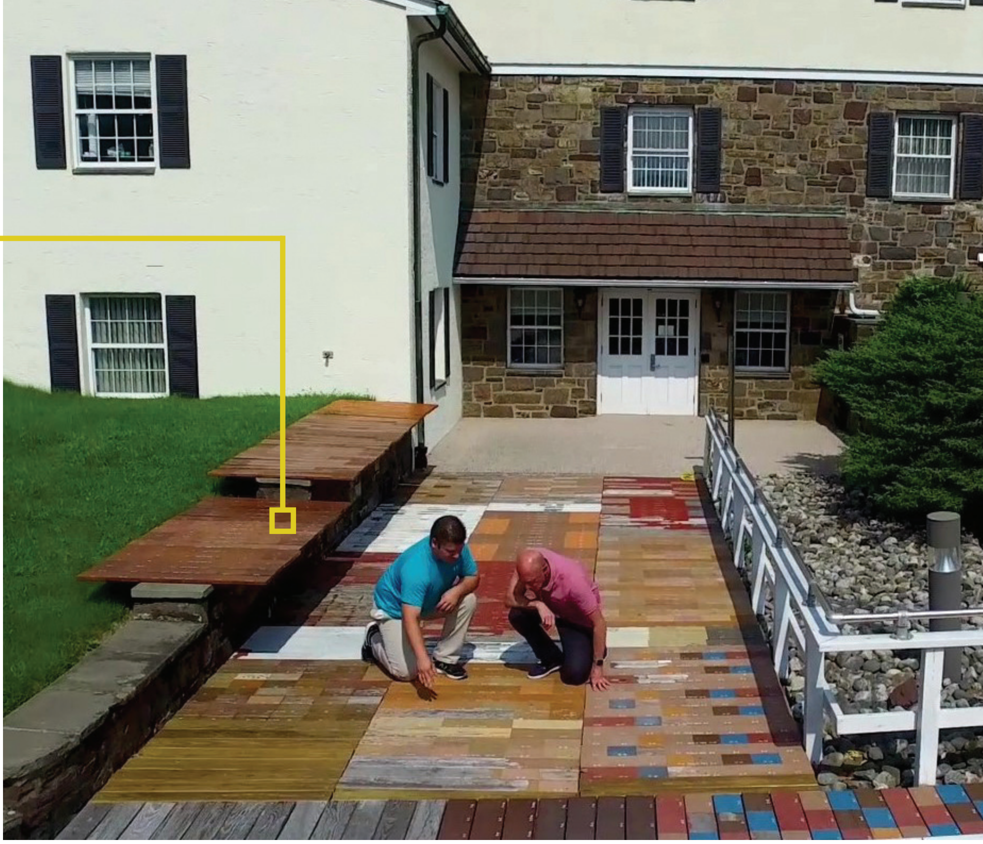

FIGURE 7—Test area for evaluating transparent, semi-transparent, and opaque deck stains.

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spray. The Sea Isle City site is leveraged for the study of protective coatings due to its corrosive climate.

DIRECTION AND ANGLE

Calderaio explains that in addition to the choice of exposure site, another key consideration when designing an exposure series is the direction and angle of exposure. *Table 1* describes some of the key panel orientations used at the Dow exposure stations. North vertical exposures, for example, are characterized by slower drying surfaces due to less-direct sun exposure. This feature makes north vertical exposures very useful for the study of properties related to time of wetness, such as resistance to mildew growth, wet adhesion, blister resistance, and efflorescence. On the other hand, south vertical (SV) exposures are subjected to more intense sunlight and represent a good orientation for studying gloss, color and tint retention, and resistance to chalking.

Unlike vertical orientations, panels exposed facing south at a 45° angle (south 45°) receive more intense radiation because the sunlight strikes the panel surface on the perpendicular axis. In addition, panels tend to retain water at this angle. The south 45° orientation does not replicate the exposure conditions faced by most exterior house paints in normal use (i.e., vertical walls), but paints exposed south 45° tend to deteriorate more rapidly than paints oriented vertically. For that reason, the south 45° orientation is used as an accelerated test for gloss and color retention, as well as for accelerated grain cracking and loss of adhesion over wood substrates. Because panels accumulate a higher amount of moisture overnight but then dry out completely during the day, south 45° exposures lead to greater expansion and contraction of the wood compared to vertical exposures.[6]

Panels placed in a face-down orientation (horizontal down) provide a simulation of conditions that exist under the eaves of a building's roof, for example. Higher levels of moisture build up in these locations due to condensation and the lack of direct sunlight. Face-down exposure is useful for evaluating tannin staining or carbonate frosting.

Calderaio characterizes the face-up orientation (horizontal up) as the toughest orientation for coatings, with intense exposure to sunlight and ponding water, creating an aggressive environment. Face-up exposures are typically only used for coatings designed for horizontal applications such as elastomeric roof coatings and deck coatings. At the Spring House Exposure Station, in addition to racks in the horizontal up orientation, the exposure group also maintains a deck area that receives foot traffic to even more closely simulate the real-world exposure of deck stains. Boards containing multiple test areas of transparent, semi-transparent, and opaque deck stains are exposed, and they can be swapped out for new boards as the coatings fail (*Figure 7*).

TABLE 1—Description of key panel orientations used for exterior weathering studies in the Northern Hemisphere.*

DIRECTION	ANGLE	ABBREVIATION	PRIMARY PROPERTIES OF INTEREST
North	Vertical	NV	Dirt pickup Mildew growth Wet adhesion Efflorescence Wax bleed
South	Vertical	SV	Chalk adhesion Chalking resistance Tint retention Gloss and color retention Surfactant leaching
South	45°	S45	Grain cracking Accelerated adhesion failures Gloss and color retention
Face-Down	Horizontal	HD	Wood tannin staining Frosting Corrosion
Face-Up	Horizontal	HU	Mainly used for horizontal applications like coatings for decks, roofing and sports surfaces

* Note: For sites in the southern hemisphere, the directions (north/south) are reversed for vertical and 45° orientations.

SUBSTRATES

A variety of substrates are employed in Dow's exposure program. For architectural coatings, paints are applied to typical building materials, including bare wood (white and yellow pine, cedar, redwood), fiber cement, and vinyl siding. Stucco and masonry substrates are prepared on site and commonly used. Various types of metals (e.g., steel, galvanized steel, aluminum) are employed for industrial coatings. Composite substrates, such as wood/plastic composite boards that are popular for residential and commercial decks, are also used for evaluating deck stains and coatings, in addition to wood boards such as pressure-treated pine and cedar.

Although bare wood is less prevalent today as a siding material in the United States, Davis explains how Dow still uses it as a key test substrate for exterior architectural coatings. While other siding materials such as vinyl have become more popular due to its lower maintenance requirements, wood siding is still used in some regions of the country, and exterior wood trim is still common.

Wood is a difficult substrate for paints, due in part to its dimensional instability when subjected to moisture and temperature extremes. Expansion and contraction of the wood is a major source of failures such as grain cracking. Yellow pine in particular is used a lot for testing architectural coatings because it is a good substrate for observing early cracking failures, Calderaio says.

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Dow has recently been doing work to better understand the performance of coatings applied over wet wood, Davis says, particularly in the context of deck coatings. Coatings applied over wood with high moisture content can lead to early failures, but historical exposure testing has relied mainly on dry wood as a substrate. One goal for Dow is to learn more about how to design binders and formulations to perform better when applied over wet wood. So, in addition to other substrates such as vinyl, bare wood is still a relevant substrate for Dow's exposure testing program.

In addition to using fresh substrates, the exposure team also uses a portion of its rack space to weather uncoated substrates for later use. For example, the team found that cracking failures are accelerated for paints applied to weathered bare wood. *Figure 8* shows an example comparing a series of paints over both fresh and weathered (three months) white pine panels. The coated panels were exposed south 45° for two years at the Spring House site, and the differences are dramatic.

While performance over bare wood provides valuable information about a paint, most architectural coatings are applied to previously painted substrates. To simulate that situation, the exposure group also prepares weathered panels for repainting. Panels are coated with an exterior alkyd or latex paint and then weathered until the surface is chalked, which makes adhesion of subsequent paints more difficult. The chalked panels are then used as a test substrate for evaluating new paints.

EXPOSURE VISION™

While many of the evaluations performed by the Dow exposure group involve subjective readings done by a human panel reader, Dow has been working for many years on methods to improve the process. The company has developed an in-house system known as eXposure Vision™, which allows for faster and more frequent processing, imaging, and rating of panels.

As Calderaio explains, panels are fitted with an identification chip when placed outdoors. When they are ready to be rated, panels are temporarily removed from the exposure racks and loaded into a special rack that is then fed into an automated panel imaging system (*Figure 9*). The system identifies the panel using the ID chip, ensuring that data and images collected are assigned to the correct series, panel and specific test area. Panels are automatically run through the instrument, where properties such as gloss and color are measured. Digital images are taken and analyzed with image analysis software for rating properties such as cracking and flaking. Panels are placed back into a rack and then returned to the field for exposure.

The automated process allows panels to be monitored more frequently and enables more individual data points to be captured. The massive amount of data and images is stored in a database, which allows easy access and analysis by Dow's scientists. Captured images are used to facilitate visualization of the weathering process and are an effective tool for sharing information with customers.

FIGURE 8—A comparison of panels prepared from fresh white pine (two boards on top) and white pine weathered for three months before coating (two boards on bottom). Panels were coated with the identical series of paints and exposed for two years in a south 45° orientation in Spring House, PA.

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WHAT'S NEXT FOR THE DOW EXPOSURE STATION

The Dow Exposure Station is still innovating and advancing the science of weathering for paints and coatings after decades of operation. Over the years, numerous customers have visited the site for discussions and tours of the exposure field. During field tours, customers are given the chance to see the weathered panels firsthand and gauge the performance of their own coatings. As with the rest of the world, a big change came to the exposure station in March 2020, when in-person customer visits and tours were shut down due to the global pandemic.

Although the pandemic interfered with customer visits, the team adapted and found an interactive way to have effective virtual tours. With Dow and customer teams in their respective offices, a live feed from the field is now used to show panels. While the in-person contact is surely missed, the virtual tours have several benefits and have received good feedback from customers, Davis says. One advantage is that more customers can attend the meeting, because there is no limitation imposed by travel expense. Prior to the pandemic, typical customer visits involved two or three participants, but the virtual tours have no limit to the number of attendees.

Virtual field tours can now also be recorded for later viewing by team members who cannot attend. As business travel begins to normalize to pre-pandemic levels, Davis says she expects that for some customers, virtual tours will be preferred, while others may use a hybrid approach where some team members visit in person while others attend virtually. Either way, the team is excited by the ability of this new tool to facilitate customer collaboration.

CONCLUSION

After nearly 70 years, the mission of the Dow Exposure Station continues to be generating accurate and reliable information on the weatherability of paints and coatings to aid in Dow's development and sales of its products, to assist customers in their formulation efforts, and to advance the understanding of paint weatherability.

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FIGURE 9—Racks of exposure panels waiting in line to be automatically fed into the eXposure Vision™ panel reader.

Whether it is using robotics to automate certain aspects of the paint weathering process, the application of digital image collection and analysis to allow faster and more accurate capture of data or using new collaboration tools to enable closer relationships with customers, the Dow Exposure Station is moving the science of paint durability into the future. Who knew watching paints weather could be so interesting! ❊

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LEO J. PROCOPIO is president and owner of Paintology Coatings Research LLC. Email: lprocopio123@yahoo.com.