# Development and Deployment of a High Throughput Exterior Durability Program for Architectural Paint Coatings

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*This article describes a new high throughput system for evaluating the exterior durability of architectural coatings undergoing natural weathering. The motivation for the design and deployment of this system is the ability to better understand the range and distribution of "real world" performances by testing more exposure scenarios than would be possible by traditional means. The system integrates inventory management, sample handling, and tracking with automated data acquisition, analysis, and archival capabilities including the use of environmental sensors, machine vision, and informatics. One of the unique characteristics of this system is that it not only facilitates the evaluation of more samples per unit time per unit resource compared to traditional methods, but it also produces more objective data per sample analysis.*

## INTRODUCTION

There are many challenges to developing architectural coatings for exterior applications. The array of surfaces to be coated in architectural applications can be particularly challenging, ranging from wood to cementitious to metallic. For any one of these, there are a diverse number of subtypes and unique challenges that exist. For example, many species of wood with widely varying properties, which ultimately influence service life, have been used in construction over the years.[1] Furthermore, any of these types of wood may be a part of pristine new construction or remodeling efforts where the integrity of the surface may be compromised through aging or a buildup of previous coatings. A superior coating must first adhere to the substrate being coated and then withstand the sun's radiation, airborne contaminants, wet and/or dry conditions, thermal cycling, mechanical stress, and biological attack. Climates vary considerably as a function of geography, as well as from year to

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year at a single location. Moreover, a single geographic location may contain several microclimates dependent upon direction or orientation of a coated surface or even proximity to specific structures or landforms. There are numerous descriptions of these conditions in the literature with a recent review given by Martin[2] and new details regarding the complications of angular dependence given by Hardcastle.[3]

To assess the performance of an architectural coating and its suitability to a particular application, one often exposes the coating of interest to either artificial or natural weathering conditions while monitoring physical or chemical changes in the coating. The nature of these changes is dependent upon the mode of failure and failure mechanism. Examples of failure modes include blistering, cracking, mold growth, chalking, tannin staining, gloss loss, and tint loss. The mechanisms leading to these failures are inevitably complex, and in many cases there are competing pathways that are influenced by chemistry, formulation, the particular application, and a changing environment.

In the case of artificial or laboratory exposures, one of the goals has been to create apparatus and protocols to, in many cases, accelerate the onset of failure while producing repeatable experimental conditions. The achievement of this goal has been met with varying degrees of success.[4,5] Ultimately, one would like to be able to accurately predict from these experiments the "real world" performance of a particular coating.

For natural weathering, climatic variation over time and location makes it virtually impossible to repeat an experiment, and, hence, the absolute performance results. On a practical level, however, the process of developing new and hopefully better architectural coatings often involves simultaneously testing several coatings, typically the result of an experimental design to probe the effects of specific variables like chemistry or formulation. In this case, the relative performance or rank order of the coating's performance with respect to the experimental design is of interest. The information from this type of experiment is easily augmented by the inclusion of specific extensively studied coatings that are used as pass or fail controls for failure modes of interest.

An operative definition of an exposure scenario is a coating over a single substrate type that is exposed at a single location and direction. Over time, a sample exposed in this way will be subjected to a changing environment that could be described in terms of variables such as temperature, moisture, radiation, airborne contamination, and many others. If the multidimensional space defined by these variables is referred to as exposure space then the evolution of these variables over time for a coating being tested may be referred to as an exposure trajectory.

Because of the previously described diversity of application and environmental variables, it is often important to study a coating of interest under a number of exposure scenarios. The number of individual exposure scenarios and, likewise, tests, grows geometrically as more variables are probed. The number of individual exposure tests would be given by the following equation.

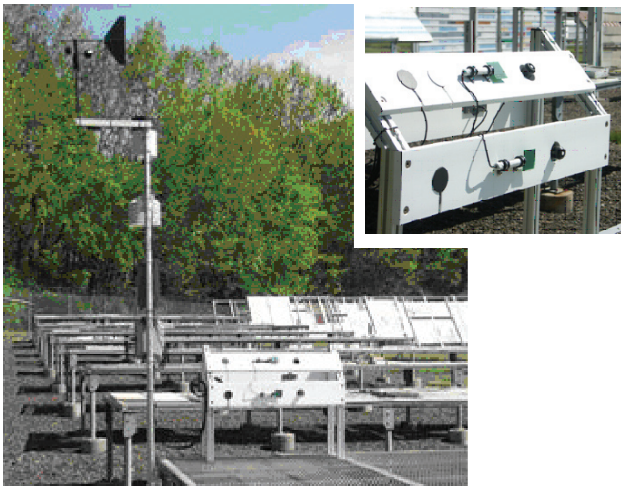
$$N_{\text{exposure tests}} = (N_{\text{coatings}}) \times (N_{\text{locations}}) \times (N_{\text{directions}}) \times (N_{\text{substrates}})$$

For a modest hypothetical study involving 32 coatings on eight different substrates exposed at four locations, in four different directions, there are 4096 individual exposure tests being conducted. Each coating in this study is in fact subjected to 128 different exposure scenarios defined by 128 unique combinations of location, direction, and substrate. A distribution of absolute performances as a function of time for a single coating or relative performances for all coatings is thusly defined over the exposure space sampled by the 128 individual trajectories. Re-exposing the samples under the same exposure scenarios gives rise to new trajectories, helping to better define the range and distribution of performances. In principle, these distributions are analogous to the distributions one might find in "real world" applications. In practice, however, the choice of exposure scenarios is often weighted more towards those extreme conditions that are known to elicit the presentation of particular failure modes.

One's ability to predict the range or distribution of "real world" performances of an architectural coating, based upon the results of a single exposure trajectory whether natural or artificial, is limited to those cases where there is a dominant well-understood failure mechanism. Similarly, the prediction of a range or distribution of "real world" performances under different exposure scenarios where there are competing degradation pathways and multiple modes of failure is likely to require the sampling of multiple trajectories over a larger exposure space.

A coating's performance is often assessed quantitatively over time using either instrumental methods or by a rating system in conjunction with human observation. In the first case, there are the usual sources of noise in the measurement that can be minimized by a number of best practices like regular calibration. In the latter case, there are additional sources of variability associated with any subjective rating system that relies upon human observation. For example, there is variability in one person's ability to rate performance due to factors like lighting conditions and fatigue. Another source of variability results from the way different people perceive and consequently rate a coating's performance. To some extent this can be minimized through extensive training, round-robin testing of replicate

Figure 1—Weather station and directionally dependent sensors.



samples, and retraining. However, there will always be an element of subjectivity involved. Unfortunately, many failure modes observed for architectural coatings can only be rated visually.

To improve ones ability to understand, and hopefully one day model and predict the range and distributions of an architectural coating's "real world" performance, a number of capabilities are needed. A short list of some of these needs follows:

(1) The ability to sample large representative exposure spaces over multiple trajectories.

(2) The ability to quantitatively characterize those trajectories.

(3) The ability to assess performance objectively and reproducibly.

(4) The ability to assess performance frequently.

(5) The development of models that explain and predict the evolution of a coating's performance from an exposure trajectory.

In short, items (1) through (4) call for more experiments with higher quality assessments that are made more often. At a time when costs are constantly being driven out of the development process, this can only be accomplished by improvements in efficiency. This article describes a high throughput system aimed at meeting these first four needs. With additional work, over time, the data generated should facilitate the development of new, better models for predicting the range and distribution of an architectural coatings performance.

## DESCRIPTION OF THE SYSTEM

Rohm and Haas Company (now Dow Coating Materials) has developed a high throughput system, eXposure Vision™, for the analysis of a coating's exterior durability.[6] The product of any successful high throughput system is actionable information that can be used to make sound decisions during a new material's discovery and development cycle. For a large exterior exposure program, achieving high levels of sustainable throughput requires a highly integrated comprehensive systems oriented approach. The eXposure Vision system integrates inventory management, sample handling and tracking with automated data acquisition, and analysis and archival capabilities including the use of environmental sensors and machine vision. Results are accessed through the system's informatics capabilities, providing for the rendering and visualization of the data generated along with contextually relevant chemistry and formulation data.

### *Sample Management*

In its present configuration, the system is optimized to handle coated substrates which have nominal dimensions of 36″ x 6″ x 0.5″. Each substrate is divided into six distinct test areas. Information about the substrate type, coatings being tested, and exposure scenario are associated with a unique identity for each substrate and stored in a primary SQL Server database. An RFID (radio frequency identification) tag is attached to the back of each substrate, providing a machine-readable identity and linkage to the information in the primary database. Samples are transported using specially designed carriers that hold 12 substrates each and golf carts modified to transport four carriers simultaneously. There is a one-to-one correspondence between this configuration and the physical layout of the racks where the samples are exposed.

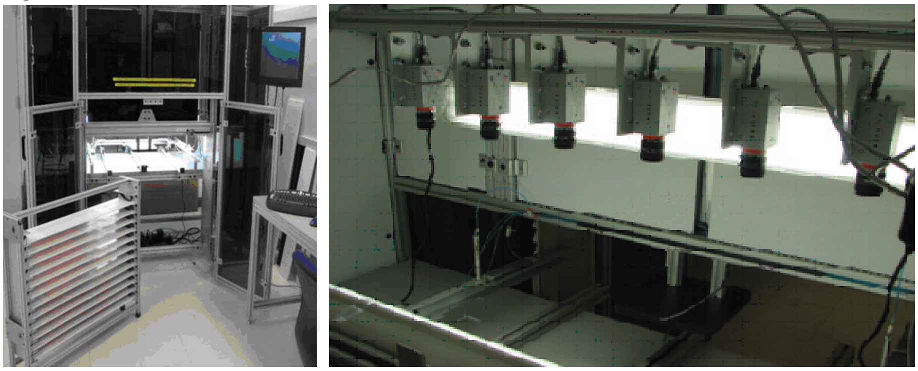
### *Environmental Sensors*

The basis for the environmental sensor subsystem is a HOBO™ weather station produced by the Onset Corporation that measures ambient temperature, humidity, rain fall, wind direction, and speed. HOBO silicon pyranometers, leaf wetness sensors, and temperature probes mounted in black copper discs are mounted in vertical south facing, 45° south facing, and vertical north facing orientations and directions. This weather station and directional dependent sensors are shown in *Figure* 1. The pyranometers have a spectral response in the 300 to 1100 nm range. Readings from each of these sensors are logged hourly and transferred to the primary database twice a day.

### *Automated Board Scanner*

The ABS (Automated Board Scanner), depicted in *Figure* 2, acquires images of the samples and stores them in a separate image database. A carrier containing 12 sub-

Figure 2—The Automated Board Scanner, board carrier, and cameras.



strates (72 samples) is manually placed in the automated board scanner, and the "Go" button is clicked on the software. The ABS selects one substrate at a time from the carrier, identifies it via the integrated RFID reader, and moves it into a controlled lighting environment where each sample area is imaged by one of six Pixelink model PL-A782 6.6 megapixel color firewire cameras. The images are automatically stored in the database and the substrate returned to the carrier. The ABS then proceeds to the next substrate. The entire process proceeds under computer control. The total time required to image the 72 samples is approximately 10 min.

### *Machine Vision*

The MV_Engine is a computer program that analyzes images in the image database and stores the results in the primary system database. It also reduces the resolution of the images to approximately one-fourth of the resolution of the original image and stores these de-resolved images in the primary system database. The MV_Engine is designed to operate in a distributed computing environment. Multiple instances of the program can run on multiple CPUs of a single computer and/or on multiple computers within the system's high-speed 1 gigabite network. A scheduling program, which is aware of these instances, dynamically assigns the analysis of images to each instance.

There are two discrete paths for analyzing the performance of coatings from images. The first involves the analysis of the overall characteristics (background) of the coatings appearance. For example, environmental contamination on a white coating can be tracked by monitoring the whiteness of the sample relative to its original state over time. Tint retention, staining, and yellowing can be tracked analogously. The second analysis path involves identification and classification of discrete features or defects in the image. This is accomplished by first separating the defects from the background using an adaptive thresholding algorithm. Once identified, a number of descriptive metrics are calculated for each defect. Select metrics are then used to classify each defect. Examples of defect classes include cracks, flakes, and spotty mildew. The number, size, and spatial distribution of specific defects are used to assign an objective rating from 0 (worst) to 100 (best) for a particular failure mode. Additional information, related to the statistical distribution of defect characteristics like size, may be calculated if desired.

### *Informatics*

All of the data is accessed using a desktop client, GAMES (Green Acres Machine Vision Explorer Suite). A user may use GAMES's database searching capabilities to find series of interest in the primary system database. Once selected, the data for that series is downloaded by GAMES, organized, and rendered to the screen depending upon a person's particular needs. All data is organized according to an exposure hierarchy (location, direction, substrate type, panel number, and panel area), and this hierarchy is then rendered to the user interface as a familiar navigation tree. The user navigates through the data by selecting branches and nodes of the tree as desired. GAMES renders the data as either a panel layout, spreadsheet, graphically, or as images. GAMES provides access to chemistry, formulation, and other properties of the coatings, allowing the user to select the properties of interest and add them to the particular rendering. An example of this is given in *Figure* 3. By drilling down to the panel level in the

Figure 3—GAMES rendering of chemistry and performance as a panel layout where performance metrics are colored to indicate performance. If the user moves the time slider forwards and backwards in time, the display is instantly re-rendered.

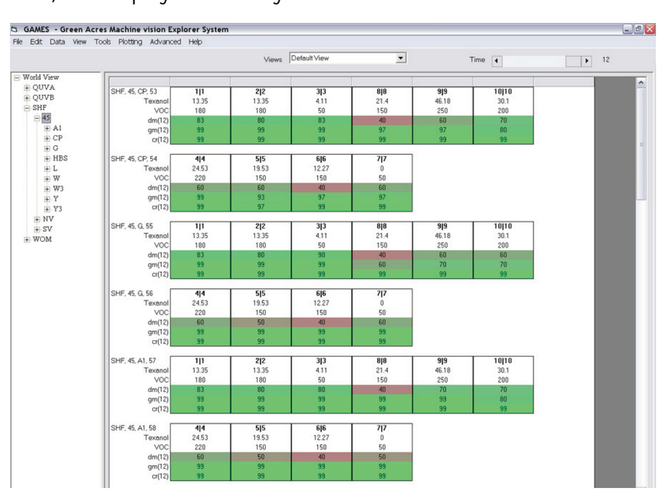


Figure 4—Example of the depiction of images in GAMES.


navigation tree, the images for that panel are rendered as shown in *Figure* 4. The user may choose to look at a specific test area, and may go forward and backwards in time to watch the evolution of defects over time.



## DEPLOYMENT SUMMARY

Presently, over 5,000 samples are undergoing testing in the system, with over 100,000 images collected thus far. It is anticipated that this sample load and throughput level will triple over the next two years as new samples enter the system for testing. As a matter of practice samples being tested facing south at 45° are imaged approximately every 30 days, with north and south vertical exposures imaged at approximately 60-day intervals. Many of these images are currently being used to calibrate and optimize the MV_Engine. The details of this process will be the subject of a future publication.

While still in the early stages of deployment, there have been a few unforeseen benefits of the system, mostly related to the increased frequency of measurement. For example, on a number of occasions, coating failure has been detected months earlier than it would have been if semi-annual or annual measurements were being made. For some highly specialized studies, weekly measurements have been made with the observation of relatively dramatic coating changes within a week's time period. Moreover, there is at least anecdotal evidence at this point suggesting that these changes may be related to specific climatic events.

## ACKNOWLEDGMENTS

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(6) eXposure Vision is a registered trademark of the Rohm and Haas Company with patents pending in the U.S., EU, Mexico, and China.