Effects of Moisture, Location, and Angle on Automotive Paint System Appearance During Natural Weathering

by Henry K. Hardcastle III
Atlas Material Testing Technology LLC*

This article presents results from a simple Design of Experiment (DOE) in natural outdoor weathering. Results show comparative effects of three weathering variables: moisture, exposure angle, and exposure location. The experiment design reveals rank importance of the study variables and links characteristics of the outdoor weathering environment with appearance degradation of coatings. The DOE data follows gloss retention of four automotive paint systems over 96 months in subtropical Florida and desert Arizona. The article discusses some of the root causes and co-variables which may explain automotive paint appearance degradation.

INTRODUCTION AND BACKGROUND

The Moisture Variable

Researchers know moisture plays a key role in weathering of many materials and often place moisture in a set of three primary weathering variables with sunlight and temperature. Researchers use southern Florida as a weathering reference environment because of its relative humidity, rain, condensation, and the important effect moisture plays in weathering. Researchers also make great efforts to include moisture variable control in artificial weathering tests for both simulation and acceleration of natural outdoor weathering degradation.[1] Moisture represents an important focus for weathering studies, exposure standards, service life prediction

---

Presented at the 3rd European Weathering Symposium, Confederation of European Environmental Engineering Societies, September 13–14, 2007, Krakow, Poland.

*45601 N. 47th Ave., Phoenix, AZ 85087-7042.

methodology, and weathering device design.[2-7] Several recent studies also show the important effect of moisture on material degradation rates and characteristics of automotive coating systems.[6,7] Because of these historic and recent perspectives of moisture's role in degradation of automotive coatings, a research goal was identified to perform a simple weathering experiment designed to help quantify the role of the moisture variable compared to other weathering variables on auto coating degradation. One study objective included using natural outdoor weathering rather than artificial or accelerated methods. Another study objective included tracking long-term degradation (longer than five years outdoor weathering) in order to characterize the naturally occurring long-term appearance degradation pattern, rather than only the initiation portion of the degradation function. In 1998, researchers planned a simple DOE to meet these objectives and began exposure and measurement of commercially available automotive paint systems. This simple study illustrates the important and powerful role moisture can have on weathering degradation rates and underlines the care and consideration researchers need to use to incorporate the moisture variable into experiments and tests aimed at predicting material end-use outdoor performance.

The DOE Approach to Weathering Experiments

Traditional natural outdoor weathering studies ordinarily consist of simple exposures of material specimens in outdoor environments for periods of time while making intermittent measurements of material characteristics throughout the exposures. Sometimes the measured characteristic (also known as "output variable" or "dependent variable") is graphed on a y-axis with some appropriate measurement of exposure duration on the x-axis to form a curve or degradation function. These exposure trials are typically observational in nature as researchers do not try to influence the naturally occurring environmental variables (also known as "input variables" or "independent variables") causing the degradation.

Sometimes researchers construct actual experiments using these outdoor exposure trials. An example may be when a researcher considers different additives or amounts of a single additive in a system to promote outdoor weathering durability. The researcher sets up an experiment subjecting specimens with varying types or amounts of additives to an outdoor weathering exposure trial. Degradation curves can then be analyzed to assess the best additive or best amount. In this style of experiment, however, the researcher is controlling the material variable. The additive type or amount represents the independent variable controlled by the researcher. The researcher usually does not control environmental variables as a part of this type of weathering experiment and, consequently, gathers no information on how changing environmental factors affect the degradation characteristics.

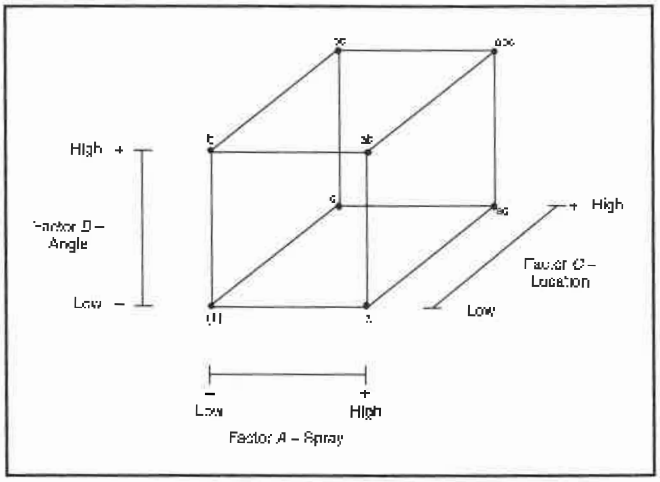
More recently, weathering researchers have begun considering effects of environmental variables on degradation characteristics by performing experiments on standard specimens while varying environmental factors in artificial weathering devices to determine how different levels of an environmental factor (the independent variable in this case) affects a degradation function. For example, an experiment may expose standard specimens to different relative humidity levels while holding other variables constant (such as spectral power distribution, irradiance level, temperature, etc.). Typically, these experiments vary only one environmental factor at a time under artificially controlled conditions. This approach is sometimes known as an "OFAT" (one-factor-at-a-time) experiment.

The OFAT approach to natural outdoor weathering research is extremely difficult to perform correctly. It is realistically impossible to only vary one environmental factor at a time in a natural outdoor exposure. Therefore, OFAT experiments typically utilize artificial weathering devices to only vary a single independent weathering variable while holding other factors constant. Natural outdoor environments, however, never generate single factor variation while other factors remain constant! The phrase "n-dimensional hypervolume" underscores the dynamic multi-variable outdoor environment's interaction with materials.[8] Likewise, for this reason, single OFAT weathering experiments can be considered highly artificial and over-simplistic constructs offering only meager information relating back to material performance in the natural outdoor weathering environment hypervolume. OFAT experiments simply do not have the power to characterize weathering processes occurring in the n-dimensional hypervolume of the natural weathering environment. DOE approaches, however, do.

"Design of Experiments [DOE] is the simultaneous study of several process variables. By combining several variables in one study instead of creating a separate study for each, the amount of testing required will be drastically reduced and greater process understanding will result. This is in direct contrast to the typical one-factor-at-a-time approach or OFAT which limits the understanding and wastes data. Additionally, OFAT studies cannot be assured of detecting the unique effects of combinations of factors (a condition to be later defined as an interaction)."[9]

A weathering DOE, therefore, is simply a traditional DOE which varies several weathering factors (variables) simultaneously to characterize the effects of individual factors and their interactions on the study material. DOEs include two types: fractional factorial (sometimes called screening experiments) and full factorial

Figure 1—The 2^3 factorial design weathering experiment.



DOEs. Researchers typically use fractional factorial experiments to narrow a collection of many suspect variables down to a few significant variables and identify the variables that warrant further investigation while screening out variables that do not. Once identified in screening approaches, full factorial DOEs then can be performed for robust characterization of the main effects and interactions of the few key variables. For this study, the screening experiments were presented in separate publications.[10,11]

Design and implementation of DOEs using natural weathering factors may present considerable difficulties in natural environments. The power and efficiency of weathering DOE approaches, however, often outweigh these difficulties and justify using weathering DOE approaches.

DESIGN OF EXPERIMENT

Researchers planned a simple natural weathering DOE to help understand the effects of moisture on gloss degradation of automotive coatings. The study objectives included obtaining information which compared the effects of moisture to two other weathering factors: exposure location and exposure angle. These three variables—moisture, exposure location, and exposure angle—naturally fit into a 2^3 full factorial DOE. *Figure* 1 shows this weathering DOE modified from Montgomery.[12]

Weathering DOE Trials

This DOE included eight long-term weathering exposures varying the three factors (moisture, exposure angle, and location) simultaneously. The experiment design varied the three factors in an orthogonally balanced manner. Contrasting trials varied each factor to a low (-) and high (+) setting independently of the other factor settings. All eight exposures began within three days of November 20, 1998, and continued throughout the 96 months reported here within. Every three months, the exposed automotive coating specimens were measured and the measurements were plotted against exposure time in order to obtain the degradation curves for each of the eight exposures. In this manner, the DOE characterized the long-term weathering degradation for each variable setting. All specimens were exposed in the backed condition.

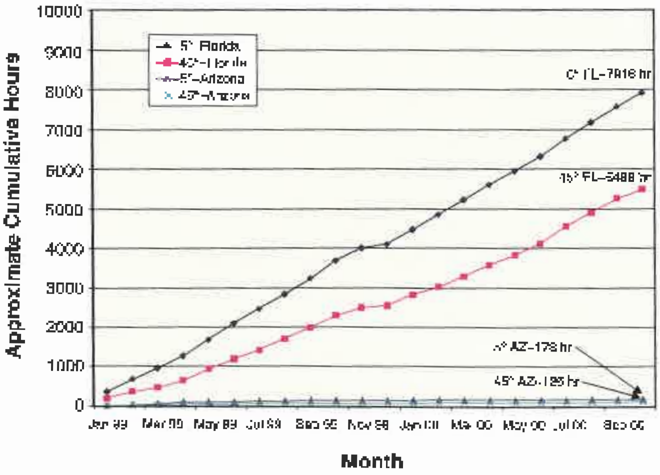
Exposure and Independent Variables

Varying independent environmental factors in a natural outdoor weathering experiment may seem paradoxical. "Controlling" a natural environment makes it un-natural. For example, it would be difficult to perform a DOE that actually controlled the temperature of exposed specimens using heating elements while still maintaining the natural cyclic temperature patterns found in outdoor exposures. Still, opportunities exist to control some variables in outdoor exposure without introducing artificial or unnatural weathering conditions. In this DOE, the design achieved control over two factors without introducing artificial and unnatural environments: the exposure angle and exposure location factors. The third factor—moisture—required an artificial application of moisture spray.

The Moisture Variable

In order to characterize the effect of moisture in this DOE, four of the eight trials exposed specimens on racks with water spray. Essentially identical to non-spray racks except for the moisture, the spray racks applied a light rain-like water spray on exposed speci-

Figure 2—Approximate cumulative time of wetness.



mens. A spray nozzle applied high purity de-ionized water to wet specimens exposed on spray racks. A single spray event lasted 60 sec. Eight spray events occurred at the beginning of each hour from 08:00 hr until 16:00 hr during each day of the exposure. Trials shown in *Figure 1* with the moisture spray variable set high (+) exposed specimens on spray racks while trials with the moisture spray variable set low (-) exposed specimens on racks with no spray. In this way, the DOE characterized the effect of an artificially introduced moisture spray on the weathering degradation of the auto paint systems.

It is interesting to consider some of the co-variables associated with the moisture spray factor in this experiment. The eight controlled one-minute sprays represent one source of the moisture in this experiment. However, another important source of moisture co-varies with the location factor and the angle factor. *Figure 2* shows naturally occurring approximate time of wetness for Arizona and Florida at 5° and 45° exposure angles during an early period of the exposures. Both location and angle appear to affect the naturally occurring time of wetness. Almost every night, moisture condensed from the surrounding air mass immerses exposed specimens under millimeters of liquid water in southern Florida.

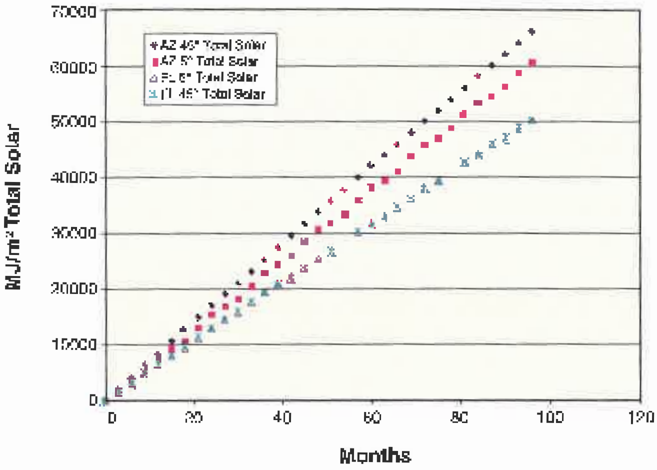
The Exposure Angle Variable

In order to characterize the effect of exposure angle in this DOE, four of the eight trials exposed specimens on racks oriented 45° from the horizontal facing true south while four trials exposed specimens on racks oriented at 5° from the horizontal. Trials shown in *Figure 1* with the angle variable set high (+) exposed specimens on racks set at 5° while trials with the angle variable set low (-) exposed specimens on racks set at 45°. This represents an example of controlling a variable in a natural weathering DOE without introducing an artificial effect. In this way, the DOE characterized the effect of changing the exposure angle (and all co-variables associated with exposure angle) on the degradation curves of the auto paint systems.

It is interesting to consider some of the co-variables associated with exposure angle. Radiant exposure (sometimes referred to as dose) represents one co-variable associated with exposure angle. Cosine effects vary solar intensities and accumulated radiation with changing exposure angle. *Figures* 3 and 4 show this effect of the total solar radiant exposure and total ultraviolet radiant exposure respectively during the experiment.

Exposures at 45° in Arizona accumulated total solar radiant exposure (dose) slightly faster than at the 5° exposure angle. The 34° latitude of the Arizona exposure site is closer to the 45° exposure angle than the 5° exposure angle under the relatively clear Arizona sky and accounts for the faster rate (see *Figure* 3).

Figure 3 —Arizona and Florida total solar radiant exposure.



On the other hand, observations in southern Florida show little differences in total solar radiant exposures between 5° and 45° exposure angles. The 26° North latitude exposure location is close to the median between summer and winter solstice in southern Florida. Additionally, a much more diffuse sky dome in southern Florida (compared to Arizona) may help average direct and diffuse total solar radiant exposure, as shown in *Figure* 3.

Exposures at 5° in Arizona accumulated UV (ultraviolet) radiant exposure (dose) faster than at the 45° exposure angle in Arizona. Specimens exposed at 5° see more of the north sky dome than specimens exposed at 45°. Diffuse UV energy reflects from aerosol particles in the north part of the sky dome back to specimens exposed at 5°. This diffuse light scattering effect is more pronounced for shorter wavelengths (UV) and explains why the earth's sky appears blue. For the same

Figure 4—Arizona and Florida total ultraviolet radiant exposure.

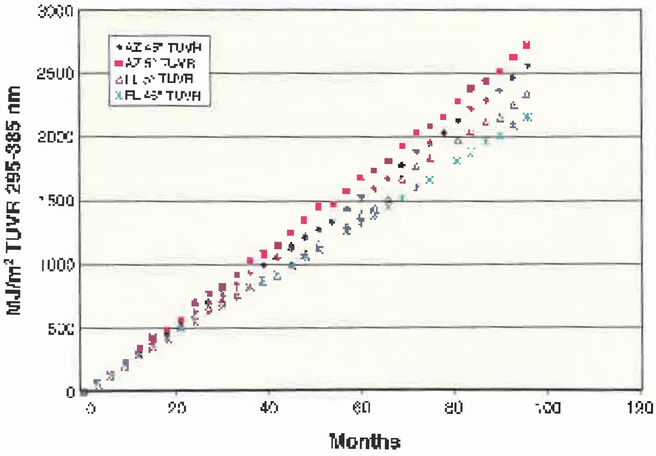


Figure 5—Trial 1: No spray—45°—Arizona.

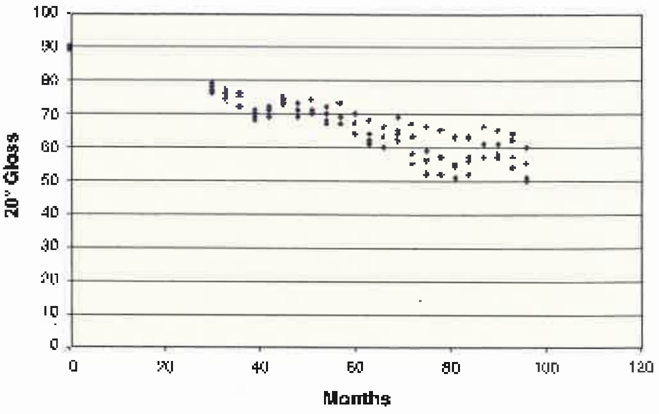


Figure 6—Trial 2: With spray—45°—Arizona.

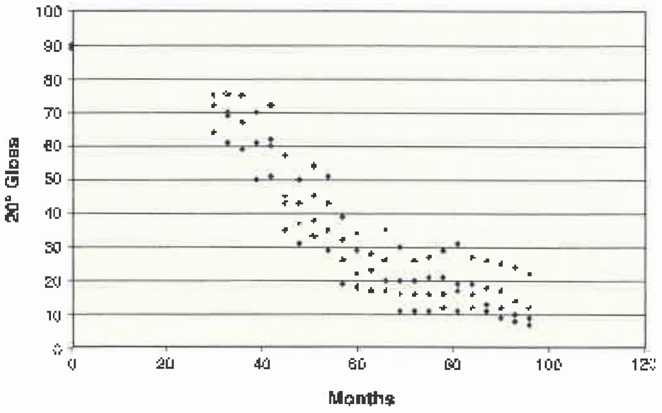


Figure 7—Trial 3: No spray—5°—Arizona.

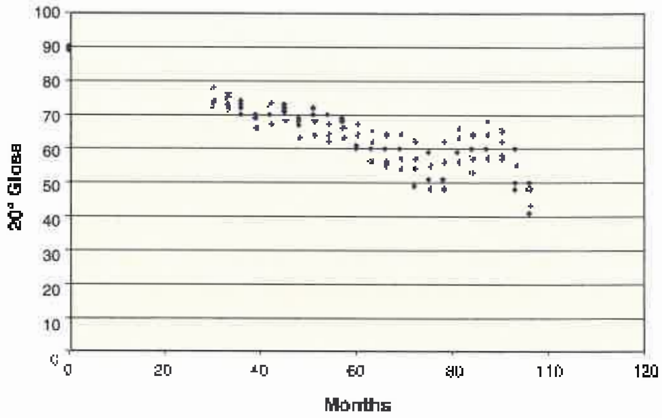


Figure 8—Trial 4: With spray—5°—Arizona.

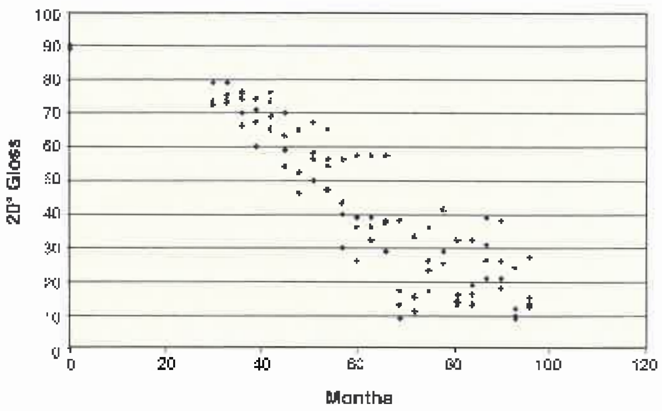


Figure 9—Trial 5: No spray—45°—Florida.

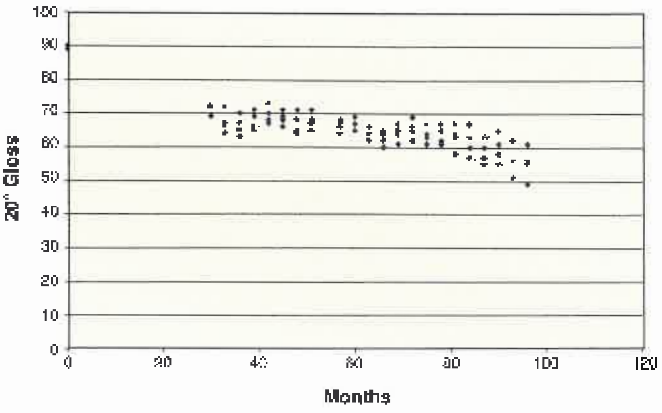


Figure 10—Trial 6: With spray—45°—Florida.

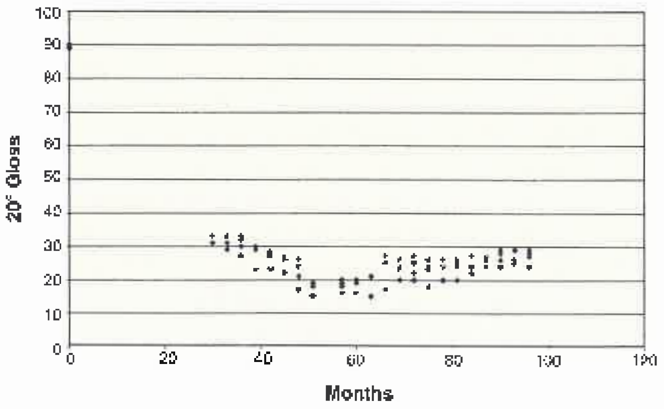


Figure 11—Trial 7: No spray—5°—Florida.

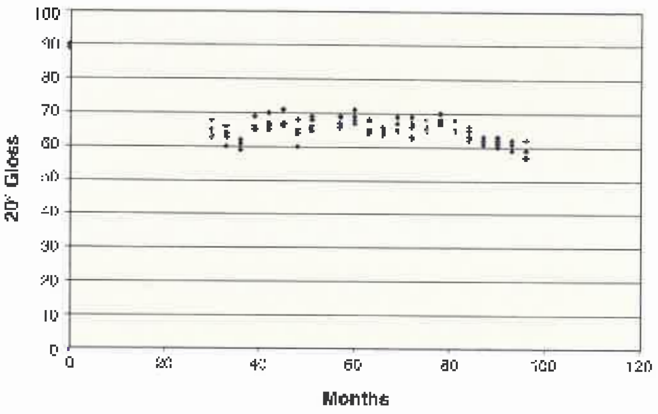
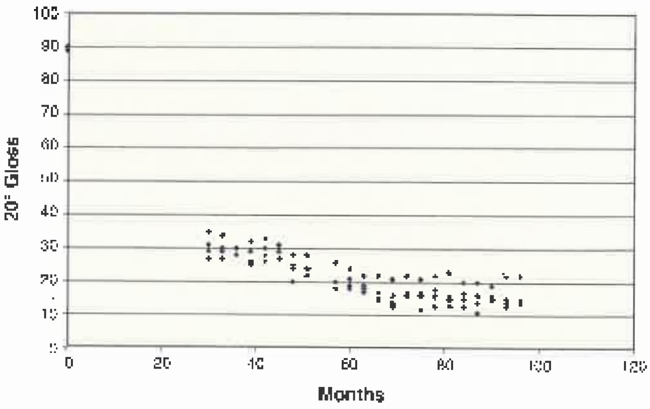


Figure 12—Trial 8: With spray—5°—Florida.



reason, 5° UV radiant exposure in southern Florida accumulates faster than the 45° UV radiant exposure in southern Florida (see *Figure* 4).

The Exposure Location Variable

In order to characterize the effect of exposure location in this DOE, four of the eight trials exposed specimens in southern Florida while the other four trials exposed specimens in desert Arizona. Trials shown in *Figure* 1 with the location variable set high (+) exposed specimens at Atlas Material Testing Technology's South Florida outdoor site located at 25° 47′ North latitude, 80° 50′ West longitude, while trials with the location variable set low (-) were exposed at Atlas Material Testing Technology's central Arizona outdoor site located at 33° 54′ North latitude, 112° 81′ West longitude. This represents another example of controlling a variable in a natural weathering DOE without introducing artificial effects. In this way, the DOE characterized the effect of changing the exposure location (and all covariables associated with these locations) on the degradation curves.

By changing exposure variables in this manner, the DOE obtained the following sets of weathering exposure information: four trials with water spray, four trials without water spray, four trials exposed at 5° angle, four trials exposed at 45° angle, four trials exposed in Florida, and four trials exposed in Arizona (for a total of 24 trials worth of data) by only actually performing eight trials. This power and efficiency of orthogonally balanced DOE trials represents one reason DOE approaches are especially suitable for weathering experiments. It is important to remember, however, that while researchers may control input variables for natural weathering DOEs, the natural environment may also affect study variables. Researchers must utilize considerable experience and skill to understand the interplay between effects caused by man and effects caused by nature in the environment within which the experiment is being performed.

MATERIALS AND DEPENDENT VARIABLES

Automotive Paint Systems

Within each exposure trial, the DOE exposed four "replicates" of commercially available automotive paint specimens. Each of the four replicates had the same formulation of acrylic melamine clear topcoat. Each of the four replicates had a different color basecoat: red, yellow, green, and blue. Each of the replicates came from a different manufacturing batch of specimens. By introducing some variation into the specimens via different color basecoats and manufacturing batches, the DOE captured information about the effect of this variation on the clearcoat performance and compared the effects of replicate variation (as experiment error) to the effects of the study variables (moisture spray, angle, and location). Additionally, the DOE captured information on the effects of the study variables across several different colors of paint system rather than limit interpretation of results to only a single color. The screening experiment publication fully describes the clearcoats exposed in this experiment.[3]

Figure 13—Main effects contrasts.

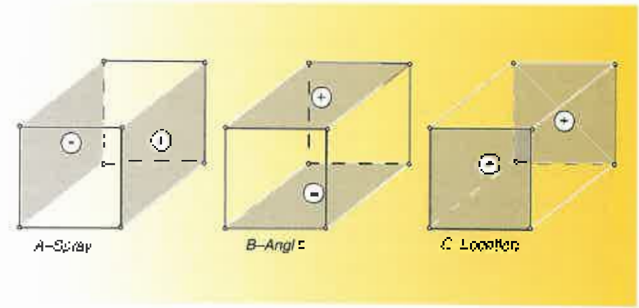


Figure 14—DOE Analysis: 45 Months, 20° Gloss

Trials	A-Spray	B-Angle	C-Location	AB	AC	BC	ABC	Y (AVG)	S²
1	–	–	–	+	+	+	–	74	0.92
2	+	–	–	–	–	+	+	45	82.67
3		+	–	–	+	–	+	71	4.67
4	+	+	–	+	–	–	–	62	45.67
5	–	–	+	+	–	–	+	69	4.33
6	+	–	+		–	–	–	25	4.92
7	–	+	+	–	–	+	–	68	5.67
8	+	+	+	+	+	+	+	29	3.67
SUM (+)	160	229	190	233	199	215	219		
SUM (–)	281	213	257	209	243	226	229		
AVG (+)	40	57	47	58	50	54	53		
AVG (–)	70	53	63	52	61	57	57		
Effect	–30	4	–16	6	–11	–3	–4		
Avg S_+^2	34.23	14.92	4.65	13.65	3.54	23.23	23.83		
Avg S_-^2	3.90	23.21	33.48	24.28	34.58	14.90	14.29		
F	8.79	1.56	7.21	1.79	9.76	1.56	1.67		

Raw Data

Rep 1	Rep 2	Rep 3	Rep 4
75	75	74	73
45	57	35	43
72	73	68	71
63	70	54	59
66	71	68	69
27	22	26	26
67	71	66	66
29	31	27	27

S_E^2 = 19.06 N = 32

S_E = 4.37 S_{eff} = 1.54

D.L. = +/– (t) (S_{eff}) 3.17989

df = (#obs/run–1) x #runs (trials) = 3 x 8 = 24

t24 = 2.06

D.L. F (12/12) = 2.69

Figure 15—DOE Analysis: 60 Months, 20° Gloss

Trial	A-Spray	B-Angle	C-Location	AB	AC	BC	ABC	Y (AVG)	S²
1	–	–	–	+	+	+	–	66	8.25
2	+			–	–	+	+	26	50.92
3	–	+	–	–	+		+	63	10.00
4	+	+	–	+		–	–	40	167.00
5	–	–	+	+	–	–	+	68	3.67
6	+	–	+	–	+	–	–	19	3.00
7		+	+	–	–	+	–	69	2.92
8	+	+	+	+	+	+	+	21	7.00
SUM (+)	104	192	175	194	168	181	177		
SUM (–)	266	178	195	176	202	189	193		
AVG (+)	26	48	44	48	42	45	44		
AVG (–)	66	45	49	44	50	47	48		
Effect	–40	3	–5	4.4	–8	–2	–4.1		
Avg S_+^2	56.98	46.73	4.15	46.48	7.06	17.27	17.90		
Avg S_-^2	6.21	16.46	59.04	16.71	56.13	15.92	45.29		
F	9.18	2.84	14.24	2.78	7.95	2.66	2.53		

Raw Data

Rep 1	Rep 2	Rep 3	Rep 4
67	70	64	64
29	34	18	22
64	67	60	61
39	57	26	36
67	69	65	69
19	16	20	19
68	71	67	69
21	24	18	19

S_E = 31.59 N = 32

S_E = 5.62 S_{eff} = 1.99

D.L. = +/– (t) (S_{eff}) 4.093764

df = (#obs/run–1) x #runs (trials) = 3 x 8 = 24

t24 = 2.06

D.L. F (12/12) = 2.69

Appearance Measurements

Gloss represents an important characteristic of automotive paint systems and the auto industry widely studies gloss weathering degradation of automotive coatings.[14,15] Technicians performed 20° gloss measurements on each replicate of each trial every three months in accordance with ASTM D 523-89.[16] Since the results and analysis did not show any analytical advantage by using delta gloss or percent gloss loss, this report presents actual measured gloss values. The same type of clear coating on the different replicates showed approximately the same initial values. Technicians measured gloss at the two different exposure locations using the same model gloss meters and identical measurement procedures including frequent calibrations during measurements.

RESULTS AND ANALYSIS

Figures 5 through 12 show the results of the eight trials in this weathering DOE as the degradation curves, through 96 months of exposure. Gloss measurements were not performed on the specimens until 30 months after the exposures started. Some of the curves show a portion of the function indicative of rate dependent degradation (slope) followed by a leveling off of the curve once some level of degradation had been achieved. Because of this characteristic of the degradation curves, analysis of the data at different points in time can drastically affect the results. For example, analyzing data after all the trial specimens have completely degraded will show no effects of the study variables. For this reason, the DOE included analysis at two points in the exposure period before the degraded condition had been reached in all the trials. Having the degradation curves to visually inspect, the 45- and 60-month intervals were chosen for analysis.

DOE is primarily a logic tool. The logic includes comparing or contrasting the set of trials with the specific factor of interest set low to the set of trials with the same factor set high. *Figure* 13, adapted from Montgomery,[12] illustrates this logic for this weathering DOE.[10] The analysis calculates the effect of factor A (spray) by determining an average of the four trials with no spray (low, A-), determining an average of the four trials with spray (high, A+), and finding the difference between these two averages. The analysis uses the same procedure to calculate the effect of factor B (angle), but, contrasts different sets of trials to determine the effect of angle. The analysis contrasts factor C (location) along a third axis of the experimental volume. In this manner, the analysis reveals information regarding the effects of each variable, as well as interactions in a robust manner from only eight trials in this experiment.

Figure 16—Main effects of spray, angle, location after 60 months.

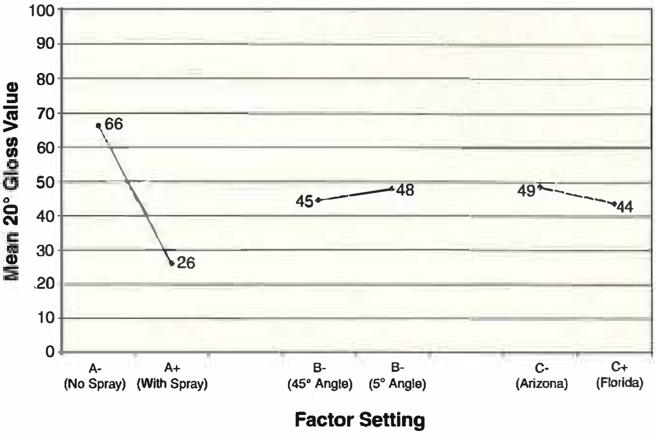
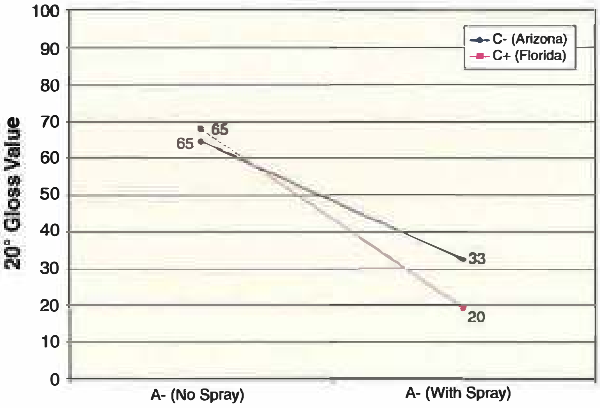


Figure 17—Interaction of spray and location after 60 months.



The mechanics of DOE analysis are fairly standardized and widely published. The Barrentine reference fully documents the analytical procedures used in this study.[9] The analysis tables in *Figure* 14 for 45 months and *Figure* 15 for 60 months follow Barrentine's approach very closely.

OBSERVATIONS

Observations at the 45-Month Interval

The analysis reveals several critical observations shown in *Figure* 14. Spray (A) had, by far, the largest effect on the gloss. Location (C) also showed a significant effect. Angle (B) showed only a marginal effect. Spray (A) interacted significantly with location (C). Spray did not affect gloss degradation in southern Florida as it did in Arizona. A similar interaction also appeared between spray (A) and angle (B). The analysis also indicates the possibility of a three-way interaction between spray (A), angle (B), and location (C) (however, the level of this effect appears very close to the decision limits for significance). Additionally, spray (A) and location (B), as well as their interaction, show a significant effect on the variation observed in the data.

Observations at the 60-Month Interval

Several observations can be made from the analysis shown in *Figure* 15. Spray (A) had, by far, the largest effect on the gloss. Location (C) showed only a marginal effect. The analysis also indicated the possibility of an interaction between spray and location. Additionally, spray (A) and location (C), as well as their interaction, show a significant effect on the variation observed in the data.

The results of the main effects analysis for 60 months are graphed in *Figure* 16, showing the effect of the spray, angle, and location factors studied in this experiment.

The results of the interaction effects for 60 months are graphed in *Figure* 17, showing the interaction between the spray (A) and location (B) factors in this experiment.

CONCLUSIONS AND CONSIDERATIONS

Natural weathering DOEs offer an efficient and robust approach to characterizing natural weathering material degradation.

Application of only eight daytime moisture sprays of one-minute duration showed significant and important effects on the degradation curves of the automotive paint systems exposed in both Arizona and Florida.

Application of water sprays dramatically accelerated gloss loss and the effect of these moisture sprays far outweighed the effects due to location and exposure angle.

The significant differences in radiant exposure due to different exposure angles did not appear to cause significant effects in this experiment since exposure angle did not show a significant effect on the results.

The significant differences in naturally occurring time of wetness due to different exposure angles did not appear to cause significant effects in this experiment since the exposure angle did not appear to have a significant effect on the results.

The moisture spray factor appeared to interact with the exposure location factor in this experiment.

One-factor-at-a-time (OFAT) experiments may not have characterized the interaction between the moisture spray factor and the exposure location factor.

Applying moisture sprays in artificial weathering methods may have dramatic effects on the results and conclusions. "Incorrect" simulation of the moisture factor in artificial weathering may impact results and conclusions from the tests. Simulating the interaction of the moisture factor and location factors observed in this study may prove especially difficult to simulate under highly artificial laboratory weathering test methods.

ACKNOWLEDGMENT

The author would like to thank the technicians at Atlas Weathering Services Group's DSET and EVTL facilities for the exposure testing and gloss measurements.

Refernces

(1) Pickett, J.E. and Umamaheswaran, V., "Highly Predictive Accelerated Weathering of Engineering Thermoplastics," SAE technical paper 2003-01-1192, Society of Automotive Engineers, March, 2003.

(2) Bauer, R., "Study Shows Differences in Weatherability of Universal Grades in White Paint," *PCI* (September 1997).

(3) "SAE J1960 Accelerated Exposure of Automotive Exterior Materials Using a Controlled Irradiance Water-Cooled Xenon Arc Apparatus," *2003 SAE Handbook, Vol. 1*, Society of Automotive Engineers, Inc., Warrendale, PA, 2003.

(4) Hardcastle, H.K. "Considerations for Relating Artificial Laboratory and Natural Outdoor Weathering Durability Testing," *Proc. Annual Technical Conference of The Society of Plastics Engineers (ANTEC)*, Chicago, 2004.

(5) "ASTM G90-94 Practice for Performing Accelerated Outdoor Weathering of Nonmetallic Materials Using Concentrated Natural Sunlight," *1994 Annual Book of ASTM Standards*, Vol. 14.02, American Society for Testing and Materials, West Conshohocken, PA, 1994.

(6) Nguyen, T., et al, "Relating Laboratory and Outdoor Exposure of Coatings: II. Effects of Relative Humidity on Photodegradation and the Apparent Quantum Yield of Acrylic-Melamine Coatings," J. Coat. Technol., 74, No. 932, 65 (2002).

(7) Misovski, T., Nichols, M.E., and Hardcastle, H.K., "The Influence of Water on the Weathering of Automotive Paint Systems," *Proc. 4th International Symposium on Service Life Prediction*, National Institute for Standards and Technology, Key Largo, FL, 2006.

(8) Pianka, E., *Evolutionary Ecology*, 2nd Ed., Harper & Row, New York, 1978.

(9) Barrentine, L.B., *An Introduction to Design of Experiments—A Simplified Approach*, ASQ Quality Press, Milwaukee, 1999.

(10) Hardcastle, H.K., "Applying Taguchi Designs to EMMAQUA Experiments," *Proc. 4th International Symposium on Weatherability*, Materials Life Society, Kanagawa University, Japan, 2000.

(11) Hardcastle, H.K., "Understanding the Effects of Weathering Variables on Plastics Using Fractional Factorial Experiments," *Proc. Annual Technical Conference of The Society of Plastics Engineers (ANTEC)*, Orlando, 2000.

(12) Montgomery, D.C., *Design and Analysis of Experiments*, 3rd Ed., John Wiley and Sons, New York, 1991.

(13) Hardcastle, H.K. "Characterizing the Effect of Weathering Variables Using Accelerated Fractional Factorial Experiments," in *Natural and Artificial Ageing of Polymers*, Reichert, T. (Ed.), Publication No.5, Gesellschaft fur Umweltsimulation, Germany, 2004.

(14) Bauer, D.R., "Chemical Criteria for Durable Automotive Topcoats," J. Coat. Technol., 66, No. 835, 57 (1994).

(15) Adamsons, K. "Chemical Depth Profiling of Automotive Coating Systems Using Slab Microtome Sectioning with IR/UV-VIS Spectroscopy and Optical Microscopy," J. Coat. Technol., 74, No. 924, 47 (2002).

(16) "Standard Test Method for Specular Gloss," ASTM D 523-89, *Annual Book of ASTM Standards*, Vol. 6.01, American Society for Testing and Materials, Philadelphia, 1998.