ATLAS
MATERIAL TESTING SOLUTIONS

SunSpots®

Material Testing Product and Technology News

Volume 36
Issue 78

Fall 2006

Artificial Weathering and Outdoor Exposure of Polyester Coatings

By M. Hoeflaak, B. de Ruiter, and J.H. Maas
©TNO Science and Industry, Eindhoven, The Netherlands

Abstract

The performance of 18 coil coatings was assessed by gloss measurements during different artificial weathering tests and outdoor exposures over 10 years. The data highlight the very different weathering behavior of polyester coatings compared to more durable non-polyester types, due to the specific sensitivity of polyester coatings to hydrolysis under wet and acid conditions.

TNO also examined correlations between various accelerated weathering tests and outdoor exposures. Only one accelerated test correlated well with any exterior exposure results, and only for certain coatings. A good correlation between various outdoor exposure tests shows, however, that the gloss retention data are highly accurate.

The test results lead to suggestions for improving the reliability of accelerated weathering tests.

Introduction

In 2001, TNO finished a large project on the performance of more than 30 different coil coated materials [1, 2, 3] that was sponsored by the Dutch Ministry of Economic Affairs and by the European Coil Coating Association. Initially, the project was focused on corrosion performance and the selection of reliable artificial corrosion tests, based on correlations with outdoor exposures. The outdoor exposures were continued up to 10 years.

Besides assessing the corrosion performance, gloss measurements were recorded, resulting in an enormous amount of valuable data on gloss retention after various artificial tests and up to 10 years of outdoor exposures. These data were further analyzed, with special attention to the different weathering behavior of polyester coil coatings and other, more durable coil coatings. Additionally, correlations were determined between various test methods, with respect to change in gloss retention.

Continued on page 4

Enhance your competitive edge with **Atlas' new consulting services.**
Page 3

In This Issue

AtlasShows

2006

HET
October 30–November 3
Utrecht, The Netherlands

IFAI
October 31–November 2
Atlanta, Georgia, USA

ICE
November 1–3
New Orleans, Louisiana, USA

ITCE
November 9–12
Cairo, Egypt

2007

SIAT 2007
January 17–20
Pune, India

TEXMAC INDIA
January 17–20
New Delhi, India

4th Annual Forced Degradation
January 22–24
Las Vegas, Nevada, USA

Additives 2007
January 22–24
San Antonio, Texas, USA

KNITTECH
February 2–5
Tiurpur, India

PHARMATECH
February 6–10
Mumbai, India

PACE
February 11–15
Dallas, Texas, USA

PLASTASIA
February 23–26
Bangalore, India

Lab Africa
March 14–16
Johannesburg, South Africa

FOCUS
May 3
Troy, Michigan, USA

ANTEC 2007
May 6–10
Cincinnati, Ohio, USA

European Coatings Show
May 8–10
Nuremberg, Germany

Chemistry
September 3–7
Moscow, Russia

ITMA
September 13–20
Munich, Germany

IFAI
October 3–5
Las Vegas, Nevada, USA

ICE 2007
October 3–5
Toronto, Canada

Eurofinish 2007
October 17–19
Gent, Belgium

Test Expo
October 24–26
Novi, Michigan, USA

K-Show
October 24–31
Duesseldorf, Germany

*For the latest on Atlas shows and presentations, visit **www.atlas-mts.com.***

AtlasSpeaks

2006

ICE 2006
November 1–3
New Orleans, Louisana, USA

Dr. Olivier Haillant will present "Scientific Evaluation of Test Methods to Assess the Durability of Organic Polymers."

Pittsburgh Society of Coatings Technology
November 13
Pittsburgh, Pennsylvania, USA

Matt McGreer will present "New Advancements in Irradiance Monitoring and Control."

Weathering Seminar at the 16th International Conference on Textile Coating and Laminating
Automotive Materials Association
November 28–29
Barcelona, Spain

Kurt Scott will present "Innovations to Measure Insitu, Critical Light and Temperature in Real-time, in Laboratory Weathering Devices."

Interaction of Modern Material to the Environment Conference
November 30
Vienna, Austria

Juergen Parr will present a paper regarding General Weathering and Aging.

4th International Symposium on Service Life Prediction
December 4
Key Largo, FL, USA

Kurt Scott will present "A New Approach to Characterizing Reciprocity in Xenon Arc."

2007

Symposium on International Automotive Technology (SIAT) 2007
Automotive Research Association of India
January 17–20
Pune, India

Cess van Teylingen will present "Lightfastness and Weathering Tests, From Material Selection to Final Product Testing."

Forced Degradation Studies
January 22–24
Las Vegas, Nevada, USA

Allen Zielnik will present a workshop on "Basic Instrumentation: Instumentation Considerations."

Symposium on Weathering of Plastics and Coatings in the Automotive Industry
SKZ–Southern German Plastics Institute
February 7–8
Festung Marienberg, Würzburg, Germany

Atlas speakers:
Burkhard Severon, Siggi Rössner, and Dr. Artur Schönlein

Atlas moderator:
Andreas Riedl

Gesellschaft fuer Umweltsimulation (GUS)
March 14–16
Pfinztal, Germany

Kelly Hardcastle will present a paper regarding Moisture and Weathering.

Atlas Announces New Consulting Group

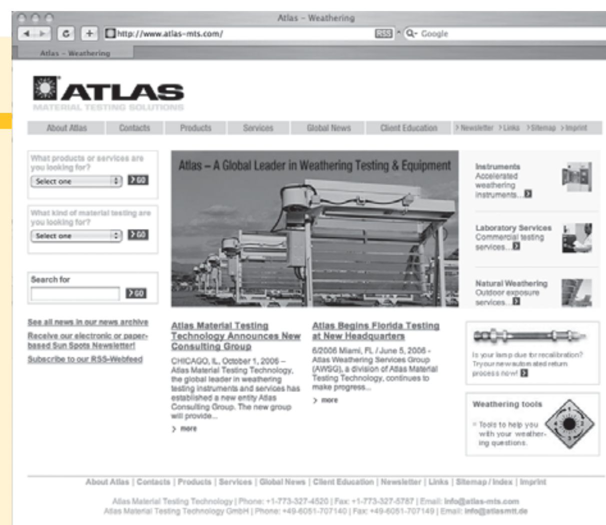
Atlas is excited to announce the establishment of a new entity, Atlas Consulting Group. The new group will provide consulting for the design, implementation, and evaluation of weathering test programs. It will offer training and education to improve testing practices, as well as offer development of customized test methods and analysis of product failure and service life prediction. Other services will include optimization of weathering processes within a client's organization and helping clients plan their own test labs and outdoor weathering testing facilities.

Atlas consultants will present solutions precisely tailored to a company's requirements and needs. They will work with companies to optimize resources and allow firms to shorten a product's time to market, enhance a competitive edge, and reduce risk of product failure and related product warranty costs.

"The new consulting group represents the next step to helping our clients reach their testing objectives. Our goal is to help clients improve the efficiency and quality of their weathering testing programs," states Andreas Riedl, Global Manager, Consulting Services. "We have a highly educated, experienced, and interdisciplinary staff who will work with our clients, offering extensive knowledge and expertise, providing customized services and programs specific to each of their products and needs."

For more information about our consulting services, please contact **Janina Groeninger, 49 (0) 6051 707 213** or **jgroeninger@atlasmtt.de.**

AtlasOnline



In response to customer feedback, Atlas has re-launched its website with a more user friendly design. The new site features several enhancements to streamline navigation, as well as more content and product information than ever before.

What's New?

The enhanced website has a new look and feel that better illustrates Atlas and our products and services. A clean, reader-friendly format with real-life application photos makes products and services more understandable and easier to access. In addition to the design, functionality has been enhanced:

- ✓ A **Careers section** has been added to broaden our reach for prospective employees. Current job openings will be listed online. Prospects will have the ability to apply online as well as submit their resume electronically.
- ✓ **Cross-links** have been added to a majority of the pages. These links will help users find all the information necessary to make informed decisions about Atlas products and services.
- ✓ The ability to **download information** has been added to our weathering instrument pages. Users can download software for specific instruments as well as current brochures.

Visit our new site today at **www.atlas-mts.com.** For more information contact Jamie Chesler at **jchesler@atlas-mts.com.**

Artificial Weathering, from page 1

Materials and Test Methods

Paint Systems

With two exceptions, all tested paint systems were stoving enamels for prefinished metal coil for outdoor building applications. The systems were applied on aluminium, hot dipped galvanized steel (HDG) or steel with an alu-zinc layer (Galvalume) on industrial coil coating lines in The Netherlands, by Euramax Coated Products, HunterDouglas Europe, and Corus Strip Products. After a suitable chemical pre-treatment, the metal substrates were coated with a thin layer of corrosion protective primer and a topcoat. The total layer thickness of the paint systems varied from 25 to 35 μm.

Table 1: Overview of Top-Coatings and Initial Gloss Values

PE Systems		Initial Gloss (%)	Non-PE Systems		Initial Gloss (%)
Code	Top Coating		Code	Top Coating	
PE 1	Polyester Stoving Enamel	31	PVDF 1	PVDF/Acrylic 80/20	27
PE 2	Polyester Stoving Enamel	24	PVDF 2	PVDF/Acrylic 70/30	20
PE 3	Polyester Stoving Enamel	66	PVDF 3	PVDF/Acrylic 80/20	21
PE 4	Polyester Powder Coating	54	PVDF 4	PVDF/Acrylic 80/20	28
PE 5	Polyester Stoving Enamel	34	PVDF 5	PVDF/Acrylic 80/20, Transparent Top Coating	30
PE 6	Silicon-Polyester Stoving Enamel	65	PVDF 6	PVDF/Acrylic 80/20, Transparent Top Coating	31
PE 7	Polyester-Melamine Stoving Enamel	40	PU 1	Polyurethane Stoving Enamel	33
			PU 2	Polyurethane, 2 Component, Ambient Curing	77
			PAPU 1	Polyurethane + Transparent Polyurethane Polyamide Top Coating	21
			PAPU 2	Polyurethane-Polyamide	30
			PAPU 3	Polyurethane-Polyamide	28

The two exceptions were a polyester powder coating with a layer thickness of 55–110 μm and a two component ambient curing coating system, consisting of a 15–30 μm epoxy primer and a 25–30 μm polyurethane top coating. A job coater in The Netherlands applied these two systems.

All top coatings were white or near white, with the exception of three non-polyester systems. To guarantee the objectiveness of the results, TNO received only a general description of the materials, without any information on details of paint systems and suppliers. For the analysis of the weathering data, the coating systems were divided in two main groups with respect to top coatings, a group of 7 systems with polyester top coatings and a group of 11 systems with non-polyester top coatings. A short description of the various top coatings, together with the initial gloss values, is given in Table 1.

Artificial Weathering Tests

The coatings were tested in three standard artificial weathering tests and in three combinations of artificial weathering tests and artificial corrosion tests, as specified below.

1 **WOM Xen** Weather-Ometer® test with xenon arc, according to DIN 53 231, black panel 65 °C, 102/18 cycle, during 1000 hours.

2 **WOM Carb** Weather-Ometer test with carbon arc, according to DIN 53 231, edition 1972, during 1000 hours.

3 **WOM NFT** Weather-Ometer test with xenon arc, according to NFT 30-049, during 1000 hours.

4 **QUV Proh** Combined test, consisting of 1 week QUV accelerated weathering test with UV-A lamps, alternated with 1 week Prohesion™ test, according to ASTM 5894, during 2000 hours (1000 hours QUV-A + 1000 hours Prohesion).

5 **WOM TCT** Combined test, consisting of 1 week Weather-Ometer test with xenon-arc (DIN 53 231) alternated with 1 week TNO corrosion test (TCT), according to the test cycle in the appendix, during 2000 hours (1000 hours WOM + 1000 hours TCT).

6 **WOMd TCT** Conditions were similar to test 5, but during the WOM test the xenon arc is switched off while temperature and humidity are not changed. Test duration: 2000 hours (1000 hours "dark WOM" test + 1000 hours TCT).

The combined Weather-Ometer corrosion tests were introduced to study the possible influence of UV degradation on the corrosion performance, but these tests also showed to provide valuable information on pure weathering performance. The last test with the xenon arc switched off during the weathering test was performed to get detailed information on the separate effects of UV radiation and the temperature/humidity cycle.

Outdoor Exposures

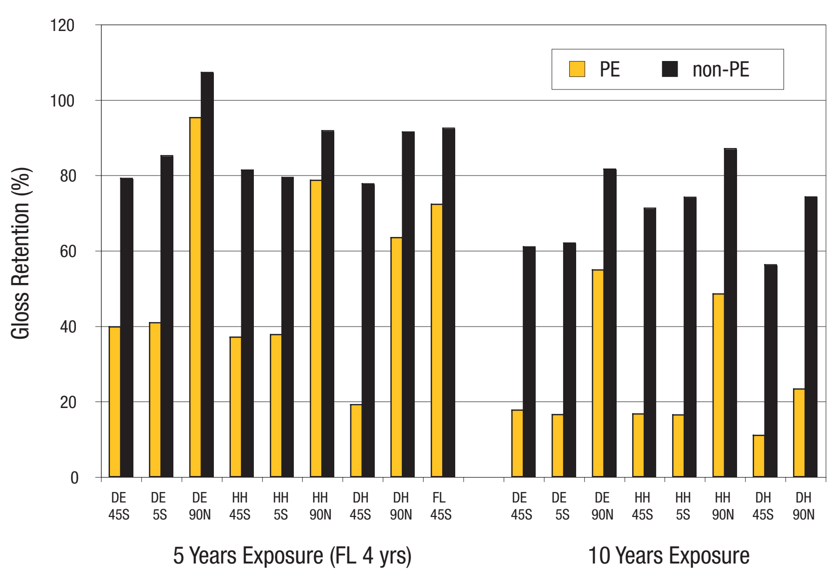
The outdoor exposures were performed at three locations in The Netherlands—Delft (DE), Hoek van Holland (HH), and Den Helder (DH)—and one in the United States—Miami (FL). Delft is a mild industrial/marine site 20 km inland; Hoek van Holland is a mild industrial/marine site 5 km from the north sea coast; and Den Helder is a severe marine site right on the north sea coast with a high salt content in the atmosphere and the influence of splashing seawater. All exposure sites are located in places with low atmospheric pollution. The exposure orientations are 45° south (45S), 5° south (5S), and 90° north (90N).

The combinations of test locations and orientations are:

- *DE 45° South-DE 5° South-DE 90° North*
- *DHH 45° South-HH 5° South-HH 90° North*
- *DH 45° South-DH 90° North*
- *FL 45° South*

The exposures in the Netherlands have been continued up

Figure 1: Average Gloss Retention After Outdoor Exposures



Continued on next page

Artificial Weathering, from previous page

Table 2: Weather Data of Miami, Florida and Hoek van Holland, The Netherlands

Weather Data	Miami	Hoek van Holland
Global Radiation Per Year	6500 MJ/m^2	3800 MJ/m^2
Average Relative Humidity	78%	87%
Average Temperature	23 °C	10 °C

According to the weather data for locations in the neighborhood, the data for Delft and Den Helder will not differ more than 10% from that of Hoek van Holland.

Figure 2: Average Gloss Retentions, 45° South, PE Systems

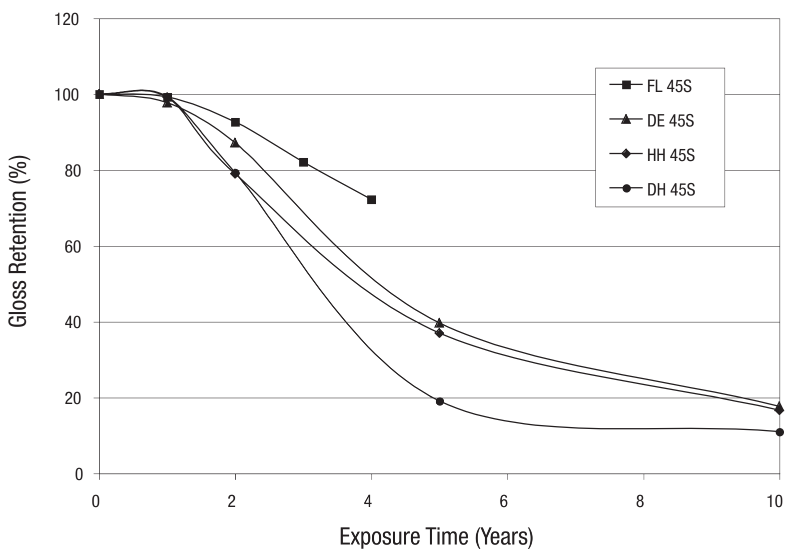
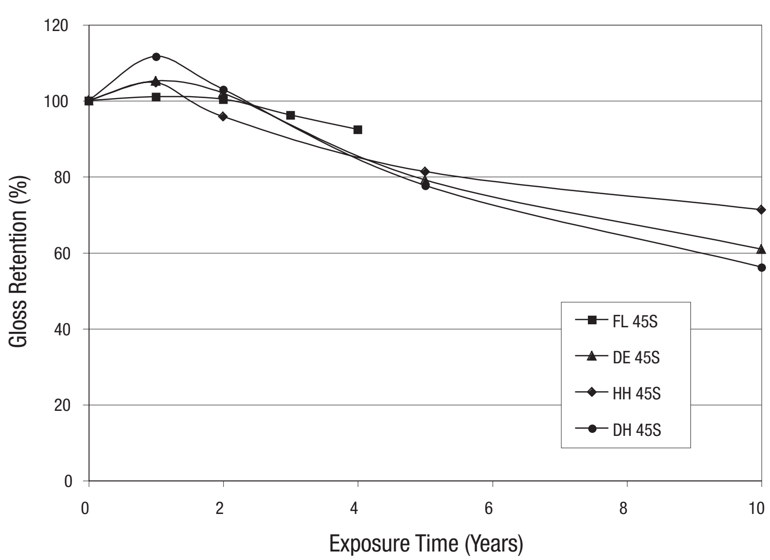


Figure 3: Average Gloss Retentions, 45° South, Non-PE Systems



to 10 years; the exposures in Florida were terminated after four years.

Characterization of Surface Degradation by Weathering

The surface degradation of the top coatings is characterized by gloss retention, defined as the gloss value after testing as a percentage of the initial gloss value before testing. The initial gloss values of the individual top coatings are included in Table 1. All gloss measurements were performed at 60° with the same instrument, according to ISO 2813. The gloss retentions of systems with identical topcoats were averaged because variations in substrates and primers had no significant influence.

Correlations Between Tests

The correlation coefficients (r) between the various tests were calculated, using the following formula:

$$r = \frac{n(\Sigma XY)-(\Sigma X)(\Sigma Y)}{\sqrt{[n\Sigma X^2-(\Sigma X)^2][n\Sigma Y^2-(\Sigma Y)^2]}}$$

r = the correlation coefficient,
n = the amount of tested paint systems,
X = the individual gloss retentions after test 1,
Y = the individual gloss retentions after test 2.

From statistical literature, it is common knowledge that values for correlation coefficients can give misleading results if not used together with so-called scatter plots. Scatter plots are figures showing one variable as a function of the other. For all correlation coefficients mentioned in this publication, scatter plots were used to verify that correlations were not caused by one or two outliers with extremely high or low gloss retentions.

For a reasonable correlation between various tests, an r-value of at least 0.7 is chosen. In the tables, the correlation coefficients *greater than 0.7* are divided in three groups:

r = 0.7–0.8
r = 0.8–0.9
r = 0.9–1.0

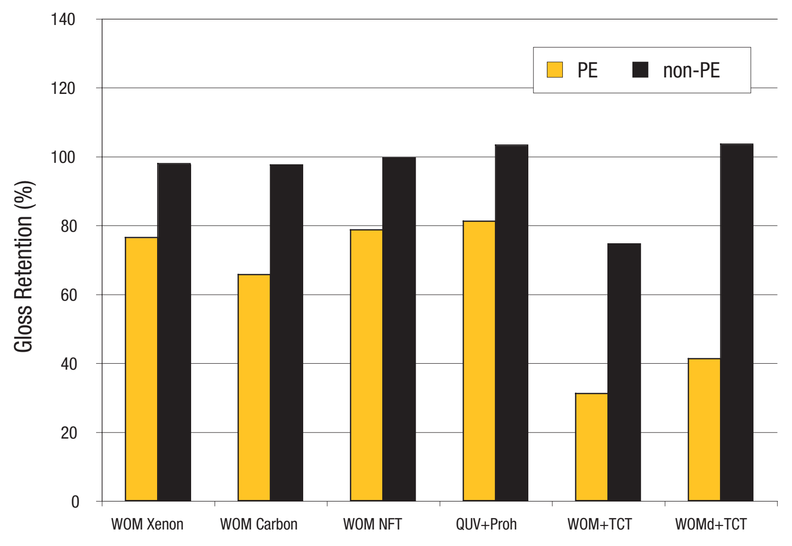
In the tables shown later in this article, the results of these groups are shown in grey shaded with increasing darkness.

Results and Discussion

Outdoor Exposure Tests

In Figure 1 the average gloss retentions of the polyester group and the non-polyester group are plotted after 5 and 10 years of outdoor exposures. The average gloss retention of >100% after 5 years, at 90° north exposure in Delft (DE 90N) shown in this figure may be somewhat surprising. However, it is a well-known phenomenon that various types of top coatings show an initial gloss increase after relatively short exposures in outdoor tests as well as in artificial tests. Several short exposures with these systems were repeated and produced the same results.

Figure 4: Average Gloss Retentions After Artificial Tests



After all exposures, the group of polyester systems show significantly lower average gloss retentions than the group of non-polyester systems. This is in line with the expectations because the non-polyester systems are all based on highly durable polymers like PVDF-acrylic, polyurethane, and polyurethane-polyamide.

Compared to the 90° north exposures, the 45° south and 5° south exposures have a much higher UV stress. This is reflected in the lower gloss retentions of the 45° south and 5° south exposures. For the degradation-susceptible polyesters, the effect of differences in UV stress is particularly strong. Considering the relatively low UV stress of the 90° north exposures, the low average gloss retention of the polyester group after 10 years at 90° north exposure in Den Helder is remarkable.

In Figures 2 and 3, the average gloss retentions of the 45° south exposures are plotted as a function of exposure time at different locations for the polyester group and the non-polyester group, respectively.

Table 3: Correlations Between the WOM-TCT Test and 45° South Exposure at Florida and 90° North Exposure at Den Helder, for Non-Polyesters

	WOM-TCT, 2000 ours r-value
2 Years Florida, 45° South	0.71
3 Years Florida, 45° South	0.79
4 Years Florida, 45° South	0.77
5 Years Den Helder, 90° North	0.65
10 Years Den Helder, 90° North	0.71

The weather data of the exposure sites at Florida (Miami) and Hoek van Holland [4] (Netherlands) are summarized in Table 2.

According to the weather data for locations in the neighborhood, the data for Delft and Den Helder will not differ more than 10% from that of Hoek van Holland.

Based on global radiation and temperature data, the lowest gloss retentions were expected for Florida. Higher values, at approximately the same level, were expected for the three Dutch sites. However, the gloss retentions of the polyester systems in Figure 2 are just the opposite of this expectation. The most probable explanation for this behavior is the susceptibility of the polyester systems to hydrolysis in wet conditions.

Florida is relatively dry in comparison to Hoek van Holland. The differences in humidity between Delft and Hoek van Holland are rather small. The extra low gloss retentions in Den Helder can be explained by the effects of splashing seawater, due to the location a few

Continued on next page

Artificial Weathering, from previous page

meters from the sea. Over the year, splashing seawater will result in a significantly longer time of wetness. This can also explain the remarkably low gloss retentions of the polyester group after 10 years of 90° north exposure at Den Helder (Figure 1).

The effect of the exposure sites on the average gloss retention, as illustrated in Figure 2, is also found for the individual polyester systems. The differences between Florida and Hoek van Holland may be larger than expected on the basis of the average relative humidities in Table 2. In The Netherlands, high relative humidities in combination with low temperatures result in rather long periods of surface wetting caused by dew. It seems quite likely that long periods of continuous surface wetness have more impact on hydrolysis than high relative humidities. Effects of atmospheric pollution on degradation were not expected because all exposure sites concerned are located in places with a relatively clean atmosphere.

The conclusion is that the degradation of the polyester systems strongly depends on the variations in relative humidity and time of wetness and much less on the intensity of solar radiation and the average temperature. For the group of non-polyester systems, the effect of the exposure site on the average gloss retention is negligible, as is illustrated in Figure 3. However, the durability of this group is much better than that of the polyester group, and even after 10 years of outdoor exposure, the average gloss retention is 56% or higher. The phenomenon of gloss retentions >100%, as shown in Figure 3 after 1 and 2 years exposure, has already been mentioned in this paper.

Table 4: Internal Correlations of Artificial Tests for Polyester Systems

	WOM-Xenon 1000 h	WOM-Carbon 1000 h	WOM-NFT 1000 h	QUV-Proh 2000 h	WOM-TCT 2000 h	WOMd-TCT 2000 h
WOM-Xenon 1000 h	1.00	0.87	0.76	0.98	-0.03	-0.14
WOM-Carbon 1000 h	0.87	1.00	0.94	0.86	0.08	-0.05
WOM-NFT 1000 h	0.76	0.94	1.00	0.73	0.30	0.17
QUV-Proh 1000 h	0.98	0.86	0.73	1.00	0.02	-0.08
WOM-TCT 2000 h	-0.03	0.08	0.30	0.02	1.00	0.99*
WOMd-TCT 2000 h	-0.14	-0.05	0.17	-0.08	0.99*	1.00

** High correlations caused by 1 system, PE 4.*

Table 5: Internal Correlations of Artificial Tests for Non-Polyester Systems

	WOM-Xenon 1000 h	WOM-Carbon 1000 h	WOM-NFT 1000 h	QUV-Proh 2000 h	WOM-TCT 2000 h	WOMd-TCT 2000 h
WOM-Xenon 1000 h	1.00	0.95	0.79	0.68	0.78	0.47
WOM-Carbon 1000 h	0.95	1.00	0.70	0.60	0.71	0.52
WOM-NFT 1000 h	0.79	0.70	1.00	0.92	0.69	0.68
QUV-Proh 1000 h	0.68	0.60	0.92	1.00	0.59	0.71
WOM-TCT 2000 h	0.78	0.71	0.69	0.59	1.00	0.46
WOMd-TCT 2000 h	0.47	0.52	0.68	0.71	0.46	1.00

Figure 5: Gloss Retention of Individual Polyesters After WOM Xenon, WOM+TCT and WOMd+TCT

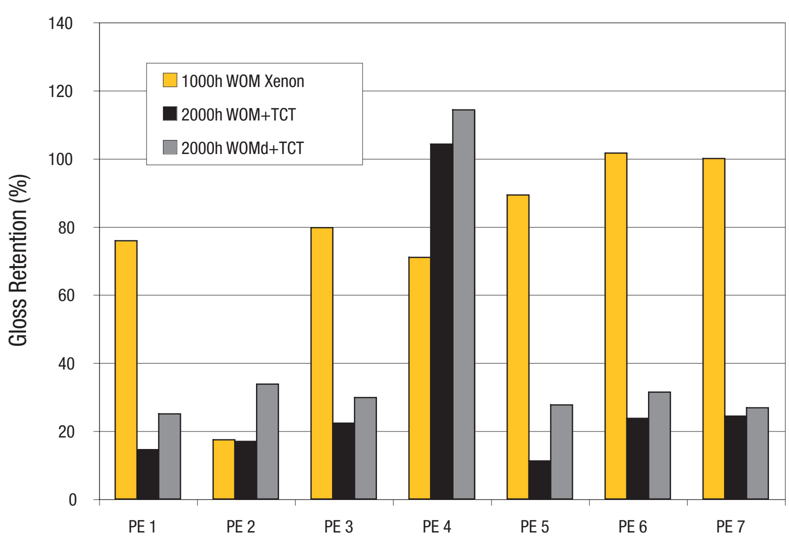


Table 6: Internal Correlations of Outdoor Exposure Tests for the Polyester Systems

	5y DE 45S	5y DE 5S	5y HH 45S	5y HH 5S	5y DH 45S	4y FL 45S	10y DE 45S	10y DE 5S	10y HH 45S	10y HH 5S	10y DH 45S
5y DE 45S	1.00	0.95	0.97	0.95	0.68	0.62	0.48	0.53	0.52	0.46	0.65
5y DE 5S	0.95	1.00	0.99	0.99	0.76	0.73	0.51	0.57	0.55	0.52	0.67
5y HH 45S	0.97	0.99	1.00	0.99	0.78	0.65	0.56	0.61	0.59	0.55	0.73
5y HH 5S	0.95	0.99	0.99	1.00	0.80	0.68	0.54	0.60	0.58	0.55	0.71
5y DH 45S	0.68	0.76	0.78	0.80	1.00	0.60	0.88	0.88	0.89	0.90	0.94
4y FL 45S	0.62	0.73	0.65	0.68	0.60	1.00	0.37	0.36	0.44	0.44	0.42
10y DE 45S	0.48	0.51	0.56	0.54	0.88	0.37	1.00	0.98	0.99	0.99	0.97
10y DE 5S	0.53	0.57	0.61	0.60	0.88	0.36	0.98	1.00	0.98	0.97	0.97
10y HH 45S	0.52	0.55	0.59	0.58	0.89	0.44	0.99	0.98	1.00	0.99	0.96
10y HH 5S	0.46	0.52	0.55	0.55	0.90	0.44	0.99	0.97	0.99	1.00	0.95
10y DH 45S	0.65	0.67	0.73	0.71	0.94	0.42	0.97	0.97	0.96	0.95	1.00

Table 7: Internal Correlations of Outdoor Exposure Tests for the Non-Polyester Systems

	5y DE 45S	5y DE 5S	5y HH 45S	5y HH 5S	5y DH 45S	4y FL 45S	10y DE 45S	10y DE 5S	10y HH 45S	10y HH 5S	10y DH 45S
5y DE 45S	1.00	0.98	0.98	0.98	0.93	0.86	0.78	0.89	0.84	0.89	0.76
5y DE 5S	0.98	1.00	0.98	0.98	0.95	0.86	0.81	0.92	0.89	0.92	0.79
5y HH 45S	0.98	0.98	1.00	0.99	0.90	0.81	0.72	0.86	0.81	0.86	0.70
5y HH 5S	0.98	0.98	0.99	1.00	0.92	0.79	0.73	0.88	0.81	0.87	0.73
5y DH 45S	0.93	0.95	0.90	0.92	1.00	0.79	0.91	0.99	0.95	0.97	0.92
4y FL 45S	0.86	0.86	0.81	0.79	0.79	1.00	0.72	0.74	0.77	0.76	0.64
10y DE 45S	0.78	0.81	0.72	0.73	0.91	0.72	1.00	0.93	0.95	0.91	0.97
10y DE 5S	0.89	0.92	0.86	0.88	0.99	0.74	0.93	1.00	0.97	0.99	0.94
10y HH 45S	0.84	0.89	0.81	0.81	0.95	0.77	0.95	0.97	1.00	0.98	0.94
10y HH 5S	0.89	0.92	0.86	0.87	0.97	0.76	0.91	0.99	0.98	1.00	0.92
10y DH 45S	0.76	0.79	0.70	0.73	0.92	0.64	0.97	0.94	0.94	0.92	1.00

Artificial Weathering Tests

In Figure 4 the average gloss retentions of the polyesters and the non-polyesters are plotted after 1000 hours for the single WOM tests and after 2000 hours for the combined WOM and corrosion tests. For all artificial tests the polyester systems showed significantly lower average gloss retentions than the non-polyester systems, which agrees with the outdoor exposure results. With exception of both combined WOM-TCT tests, the average

Continued on next page

Artificial Weathering, from previous page

Figure 6: Gloss Retention of Individual Non-Polyesters After WOM Xenon, WOM+TCT and WOMd+TCT

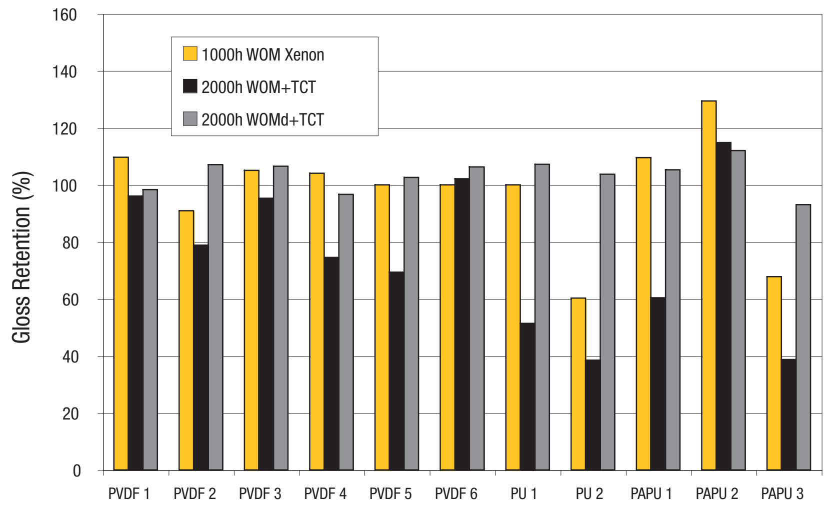
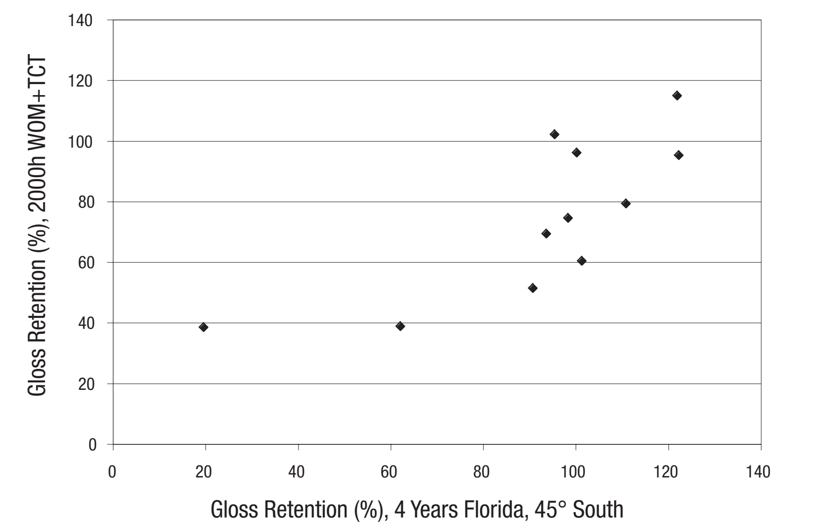


Figure 7: Correlation of WOM+TCT Test and 45° South Exposure at Florida, for Non-Polyesters (r = 0.77)



gloss retentions after the artificial tests are relatively high. For the non-polyester systems almost no decrease in average gloss retention was observed. For the polyester systems the average gloss retention levels are comparable with 5 years exposure in The Netherlands at 90° north and with 4 years exposure in Florida at 45° south (Figure 1). For polyesters and non-polyesters, the degradation after 1000 hours of standard artificial weathering is much less than after 5 years 45° south exposure in The Netherlands (Figure 1).

The low average gloss retentions of the polyesters after the combined WOM-TCT and WOMd-TCT tests form the most striking results shown in Figure 4. This is especially true for the WOMd-TCT test, in which there is no UV stress at all, because the xenon arc is switched off during the WOM part of the test. In this case, the low average gloss retention can only be explained by hydrolysis of the polyester systems. The TNO corrosion test (TCT) has longer continuous wet periods than the Prohesion™test, and the pH during the wet parts of the test is low (< pH 2), due to the dosage of sulphur dioxide (see test cycle details in the appendix). These results confirm that the susceptibility of hydrolysis plays an important role in the degradation of the polyester coatings.

For the non-polyesters the relatively low average gloss retention after 2000 hours in the WOM-TCT test is a remarkable result (Figure 4). The high average gloss retention after the WOMd-TCT test justifies the conclusion that the non-polyesters are not susceptible to the relatively wet and acidic conditions in the TCT test. However, after the 2000 hours WOM-TCT test, the average gloss retention is significantly lower than after 1000 hours of the single WOM-Xenon test, whereas the total UV stress in both tests was equal. This means that the wet and acidic conditions in the TCT test in combination with the UV stress in the standard WOM-Xenon test results in an extra acceleration of the degradation process of the non-polyester systems.

In Figure 5 the gloss retentions of the individual polyesters are plotted after the 1000 hours WOM-xenon, 2000 hours WOM-TCT, and 2000 hours WOMd-TCT tests. The general trend is that the combined WOM-TCT tests lead to much lower gloss retentions than just the WOM-Xenon test alone. A clear exception is PE 4, the polyester powder coating (Table 1), which seems to be insensitive to degradation by the relatively wet and acidic conditions in the TCT test. PE 2 already shows a very low gloss retention after the standard WOM-Xenon test.

In Figure 6 the gloss retentions of the individual non-polyester systems are plotted after the 1000 hours WOM-Xenon, 2000 hours WOM-TCT, and 2000 hours WOMd-TCT tests. In this case, the general trend is that the WOM-TCT combination gives the lowest gloss retentions, whereas the "dark" WOMd-TCT combination hardly affects the gloss retention. For only two top coatings, PU 2 and PAPU 3, the single WOM-Xenon test leads to significant gloss deterioration.

Correlations of Weathering Tests

Correlations have been determined between the changes in gloss retention in the various exposure tests. In addition to correlations between artificial weathering tests and outdoor exposure tests, internal correlations within both groups of tests were also determined. Details on the calculation of correlation coefficients are given on page 6.

Correlations Between Artificial Tests and Outdoor Exposures

After the artificial tests, the degradation of the non-polyesters hardly started, resulting in average gloss retentions near 100%. Consequently, it is meaningless to determine correlations between artificial tests and outdoor exposures. The only test that results in a significant decrease in gloss retention is the combined WOM-TCT test. The results of this test appear to have correlated reasonably well with 45° south exposure at Florida and with 90° north exposure at Den Helder. The correlation coefficients are summarized in Table 3.

Figure 8: Correlation of WOM+TCT Test and 90° North Exposure at Den Helder, for Non-Polyesters (r = 0.71)

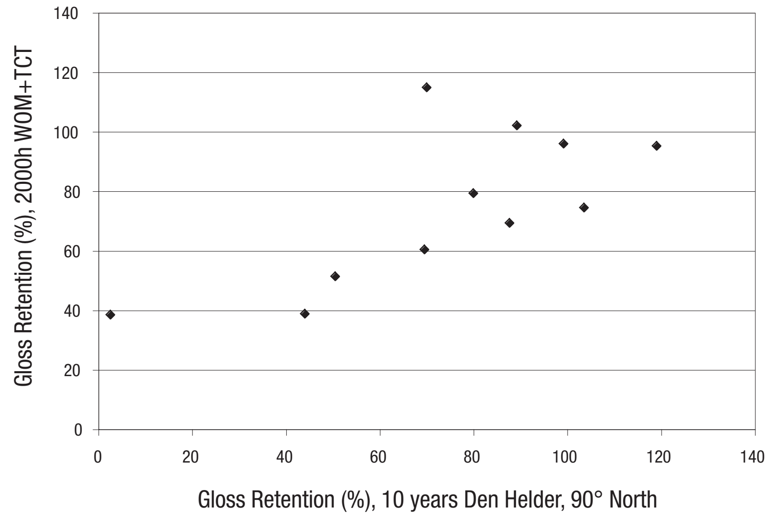
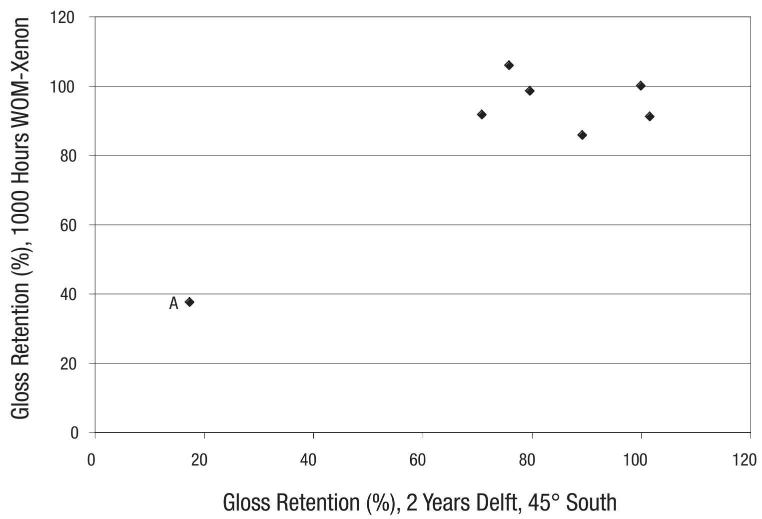


Figure 9: Correlation of WOM-Xenon Test and 45° South Exposure at Delft, for Polyesters (r = 0.85, without point A r = -0.22)



Figures 7 and 8 illustrate the correlations of the WOM-TCT test with 3 years at a 45° south exposure in Florida and with 5 years at a 90° north exposure in Den Helder. Obviously, the extra acceleration of the degradation process of the non-polyesters by the wet and acid conditions in the TCT gives a reasonable simulation of the conditions of 45° south exposure at Miami, Florida and 90° north exposure at Den Helder.

For the polyester systems the WOM-TCT and WOMd-TCT tests show no good correlations with any outdoor exposure test (all r-values < 0.30). This result may be expected because the strong effects of the wet and acid TCT test on most polyester systems are not found in outdoor exposures. The other artificial tests do seem to show some correlations with 1 or 2 years outdoor exposures (24 r-values of $r > 0.70$ in a matrix of 104 r-values). However, from scatter plots it appears that these correlations are mainly caused by only one relatively

Continued on next page

Artificial Weathering, from previous page

Figure 10: Correlation of Delft 5° South and Hoek van Holland 45° South Exposures for All Systems, PE + non-PE (r = 0.98)

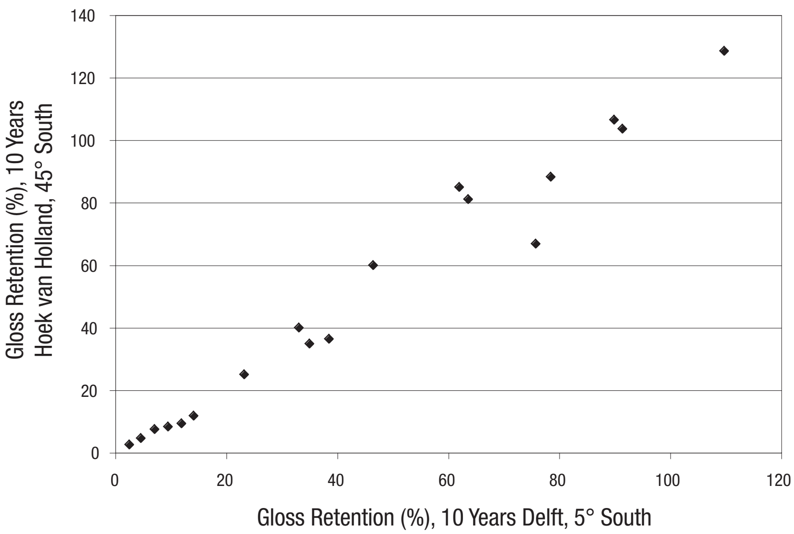
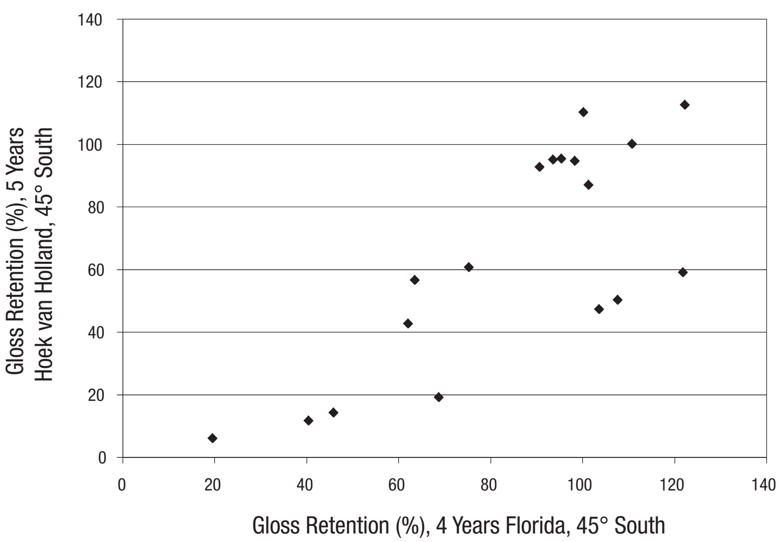


Figure 11: Correlation of Florida and Hoek van Holland, 45° South Exposures for All Systems, PE + non-PE (r = 0.78)



strongly degrading system, PE 2. If this system is omitted, only 4 correlation coefficients of 0.60–0.70 remain, the other correlation coefficients being all less than 0.60. An example of a correlation mainly caused by
1 system is given in Figure 9.

It is concluded that the gloss retention of the polyester coatings after outdoor exposure in The Netherlands and Florida (Miami) can not be predicted on the basis of 1000 hours (2000 hours for the combined tests) of weathering in the various artificial tests. These results indicate that for a reliable prediction of outdoor weathering of polyesters, the usual artificial tests must be improved considerably.

Internal Correlations of Artificial Tests

In Tables 4 and 5, the internal correlations of the artificial tests are summarized for the polyesters and non-polyesters, respectively.

From scatter plots it appears that the correlations in Tables 4 and 5 are not caused by 1 or 2 individual systems, with exception of the correlations between the WOM-TCT test and the WOMd-TCT test. The high correlation of 0.99 is caused by PE 4, the polyester powder coating that is not affected by the extreme conditions in the TCT test (see Figure 9). If this system is omitted, the correlation decreases to 0.22.

In Table 4 the four artificial tests without the two TCT combinations show high internal correlations, but almost no correlations with the two TCT combinations. This illustrates the exceptional effects of the wet and acid TCT test on the polyester systems. The exceptional effect of the WOM-TCT tests is not reflected in the internal correlations of the artificial tests for the non-polyester systems, as summarized in Table 5. In this table a sub-group with high internal correlations can be recognized, consisting of the three single WOM tests. The high internal correlations within some groups of artificial tests demonstrate that the accuracy of the test results is not questionable.

Internal Correlations of Outdoor Exposure Tests

In Tables 6 and 7, the internal correlations of the outdoor exposure tests are summarized for the polyesters and non-polyesters, respectively. The correlations are limited to the 45° south and 5° south exposures. The 90° north exposures are excluded because the UV stress is very low for this orientation, resulting in relatively low correlations with the other orientations.

From scatter plots it appears that the correlations in Tables 6 and 7 are not caused by 1 or 2 individual systems. For the Dutch sites, the correlations between Delft and Hoek van Holland and between the 45° south and 5° south exposures are high for both polyesters and non-polyesters. The correlations between exposure times of 5 and 10 years are considerably lower, especially for the polyester systems.

The correlations between 4 years Florida 45° south exposure and the exposures in The Netherlands are relatively low, especially for the polyester systems. The 4 years exposures at Florida correlate better with the 5 years exposures in The Netherlands than with the 10 years exposures. Two examples of scatter plots for all systems, polyesters and non-polyesters, are given in Figures 10 and 11. The high internal correlations within groups of outdoor exposure tests demonstrate the accuracy of the test results.

Conclusions

From the analysis of gloss retention data after artificial and natural weathering of groups of polyester and non-polyester coil coatings, the following conclusions are drawn:

- After all artificial and natural weathering tests the polyester coatings show significantly lower average gloss retentions than the non-polyester systems. Standard artificial weathering during 1000 hours is a much less severe test than 5 years 45° south exposure in The Netherlands, for both polyesters and non-polyesters.
- In comparison to the non-polyesters, the polyesters are extremely sensitive to hydrolysis in wet and acid conditions. As a result, the decrease in gloss retention of the polyesters during outdoor exposures depends strongly on the variations in relative humidity and time of wetness and much less on the intensity of the solar radiation and the average temperature. Gloss deterioration under Dutch conditions is therefore much faster than under Florida conditions.
- Six out of seven polyester coatings show a considerable decrease in gloss retention after an artificial test with relatively long wet periods and a low pH in absence of any UV stress. The non-polyesters are not affected by the test with wet and acid conditions without UV stress. However, if wet and acid conditions are combined with UV stress, the degradation of most non-polyesters is accelerated. This combined test is the only artificial test that results in a reasonable decrease in gloss retention of the non-polyester coatings. Moreover, this combined test correlates reasonably well with 45° south exposure at Miami, Florida and with 90° north exposure at Den Helder, The Netherlands.
- For the polyester coatings, all correlations between artificial tests and outdoor exposures are very low, with only a few exceptions. For a reliable prediction of outdoor weathering of polyester coatings, the usual artificial tests have to be improved considerably. The low correlations between artificial tests and outdoor exposures are not caused by inaccuracy of the test results. This is demonstrated by high internal correlations within groups of artificial tests and within groups of outdoor exposure tests.
- For the outdoor exposures in The Netherlands, the correlations between various locations and between 45° south and 5° south exposures are high for both polyesters

Continued on next page

Artificial Weathering, from previous page

and non-polyesters. The correlations between the exposure times of 5 and 10 years in The Netherlands and the correlations between 4 years Florida and all exposures in The Netherlands are low, especially for the polyester coatings.

Future Follow-Up Project

In the meantime, the outdoor exposures are continued and the analysis of gloss retention data can be extended with new results after 15 years.

Original test panels from all paint systems are still available for new tests. These panels have been stored under laboratory conditions during 15 years. Within a few months, Atlas and TNO will investigate if these original test panels have not changed with respect to gloss retention. If the results are positive, we will start a follow-up project, which is focused on the development of improved artificial test cycles. A main area of focus will be the optimization of wet/dry cycles and pH for hydrolysable and non-hydrolysable paint systems, supported by chemical surface analysis.

A major advantage in the follow-up project will be that results of new test cycles can be immediately correlated to outdoor exposures over 15 years at various locations and orientations.

New participants for the follow-up project are welcome. Please contact Atlas or TNO:
Gerard van Ling, gvl@atlasmtt.nl
Rinus Hoeflaak, rinus.hoeflaak@tno.nl

References

[1] H.J. Tiemens and M. Hoeflaak. “The performance level of some commercial coil-coated materials.” Construction and Building Materials Vol. 8, No. 4, 243–259, 1994.
[2] H.J. Tiemens. “The performance of coil-coated materials after 5 years of outdoor exposure in The Netherlands.” Construction and Building Materials Vol. 12, No. 1, 19–30, 1998.
[3] M. Hoeflaak and H.J. Tiemens. “Prediction of Durability of Coil-Coated Sheets.” ECCA Annual Congress, Technical Committee Meeting, Brussels, November 18–20, 2001.
[4] Information from Atlas Material Testing Technology GmbH.

Acknowledgments

Dutch Ministry of Economic Affairs
European Coil Coating Association
Euramax Coated Products
Hunter Douglas Europe
Corus Strip Products
Various suppliers of paints and pre-treatments
Atlas Material Testing Technology

Appendix: The Cyclic TNO Corrosion Test (TCT)

TNO has developed a test chamber for the execution of cyclic corrosion tests after it became clear that the classical test methods, like the salt fog test, do not correlate sufficiently with atmospheric corrosion. It was also clear that cyclic tests (often called “scab-corrosion tests”) produce corrosion products and types of defects that resemble the effects of atmospheric corrosion much more closely than the results of classic corrosion tests.

The apparatus developed allows a much tighter control of corrosion stress parameters, especially humidity, than found in most traditional test equipment. It also allows the variation of test conditions over a wide range to facilitate the study of the influence of different climatic factors on the corrosion process.

Details of the Test Cycle

A 24-hour wet/dry cycling period has been chosen so as not to disturb the natural water absorption/adsorption processes too much. The humidity/temperature cycle has been chosen to reflect more or less the Dutch atmospheric conditions, but with a shorter, more intense drying period. Further corrosion stresses are added by spraying the samples with simulated concentrated rainwater. The natural concentrations were increased 1000x. Gaseous pollutants, especially sulphur dioxide, result in a relatively low pH (< 2), add further corrosion stresses and increase the corrosion rates.

The 24-hour test cycle includes:

- 14 hours at 30 °C and 75 % RH
- 3 hours at 60 °C and 50 % RH, with a linearly decreasing RH from 75% to 50% during the first 30 minutes
- 7 hours at 30 °C and 96 % RH. During 4 periods of 30 minutes, in this 96 % RH interval, a fog of finely divided artificial rainwater is introduced into the test chamber.

Sulphur dioxide is added to maintain a constant concentration of 5 mg/m^3. Carbon dioxide is added to maintain a constant concentration of 0.4 % v/v. Accumulated salts are removed by washing during inspections.

Composition of Artificial Rainwater

Compound	g/l
$NaCl$	5.0188
KCl	0.4474
$CaCl_2.2H_2O$	2.2053
$MgCl_2.6H_2O$	2.5414
$Na_2CO_3.10H_2O$	0.5723
NH_4NO_3	4.0020
$Na_2SO_4.10H_2O$	7.1727

Compound	g/l
$CuCl_2.2H_2O$	0.0068
$FeCl_3$	0.1622
$NiCl_2.6H_2O$	0.0048
$NH_4F.HF$	0.0428
$NaHSO_4.H_2O$	2.1539
$(NH_4)_2SO_4$	1.6022

Atlas Congratulates Dr. Richard Fischer!

We are delighted to learn that Dr. Richard Fischer has been promoted to Corporate Scientist at 3M Company. The high honor is well deserved as Dr. Fischer has established himself as one of the most respected scientists in the field of weathering and materials durability. We are proud to say that many of us at Atlas have enjoyed a great professional partnership as well as friendship with Dr. Fischer over the many years of the strong relationship between our companies. Congratulations!

AtlasWeathering Services Group

Atlas Adds New High-Performance Spectrophotometer

Atlas Weathering Services Group continues to deliver the best technology has to offer with the addition of a high performance UV/Vis/NIR system PerkinElmer Lambda 950 Spectrophotometer.

The Lambda 950 is the optimal instrument for high precision measurements with the ability to measure wavelengths from 175 nm to 3300 nm. As part of the comprehensive evaluation service offered by Atlas, this new Spectrophotometer will be used for evaluating applications such as highly reflective and anti-reflective coatings, color correction coatings, and bandpass characteristics of UV, Vis, and NIR filters.

The PerkinElmer Lambda 950 Spectrophotometer is the latest upgrade to the Atlas Optics Lab that houses the most advanced weathering evaluation/ measurement equipment and expertise. Among the services offered are:

- Digital photography of specimen degradation
- Numerous visual assessment services for rating degradation phenomena
- Measurement of color and evaluation of other optical properties
- Spectrophotometric color measurement
- Gloss measurement
- Distinctness-of-Image (DOI) measurement
- Absolute or relative spectral measurements
- Haze, total transmittance and clarity measurements
- Emittance measurements
- Video Image Enhanced Evaluation of Weathering (VIEEW®)
- Window energy analysis, shading coefficient, and U-value analysis

For more information on the Lamdba 950 Spectrophotometer or services offered at the Atlas Optics Lab, please contact your customer service representative at **(800) 255-3738** or at **info@atlas-mts.com.** Visit the Atlas website at **www.atlas-mts.com.**

Change Your Address Book!

Atlas Weathering Services Group would like to remind you to change your contact information for our new headquarters. All Florida outdoor testing should be sent to our new headquarters located at:

South Florida Test Service, 16100 SW 216th Street, Miami, FL 33170

We are currently in the process of moving all active orders to our new headquarters. You can still reach us by phone at our Okeechobee Road location **(305) 824-3900** or at our new headquarters by dialing **(305) 245-3659.** We will continue to keep you updated on our progress.

For further information or to schedule a tour of the new facilities once they are completed, contact your client service representative at **(800) 255-3738** or visit our website at **www.atlas-mts.com.**

AtlasTest Instruments Group

Xenotest® Alpha and Xenotest® 150 S+ Enhanced with Additional Features

Atlas has made state-of-the-art enhancements to its xenon instruments Xenotest® Alpha—renamed Alpha+—and Xenotest®150 S+ to improve ease of use and instrument control.

The **Alpha+** is equipped with a convenient touch screen display so that weathering testing now can be programmed and performed with the touch of a button. The actual test state and the graphical progress of test parameters can be easily read off the full color display. With the PC interface RS 232, the USB slave port, and the SmartMedia™ card, data can be easily transferred. At the heart of the enhancements is a microprocessor control system with the latest generation of fiberoptic cables that allows an optimal data transfer between process control and system modules.

Another benefit of the new Alpha+ is the simplified menu-driven programming with 10 free programmable tests plus up to 10 additional pre-programmed standard tests, each with up to 12 test cycles. A rotating Xenosensiv® sensor measures irradiance and black standard temperature at the sample level in accordance with ISO/DIN standards while a stationary sensor measures the test chamber temperature and the relative humidity.

The **Xenotest 150 S+** offers an ideal combination of state-of-the-art technology, economical testing, optimum reproducibility, and good correlation to natural weathering. The large color touch screen and the simplified menu-driven programming ensure easy and convenient use. A dynamic memory offers 10 free programmable tests and additional pre-programmed standard tests. As with the Alpha+, the data management of the Xenotest 150 S+ can be easily done via SmartMedia™ Card, RS232, or USB slave port. Improvements of the new control system were a result of the latest generation of fiberoptic cables.

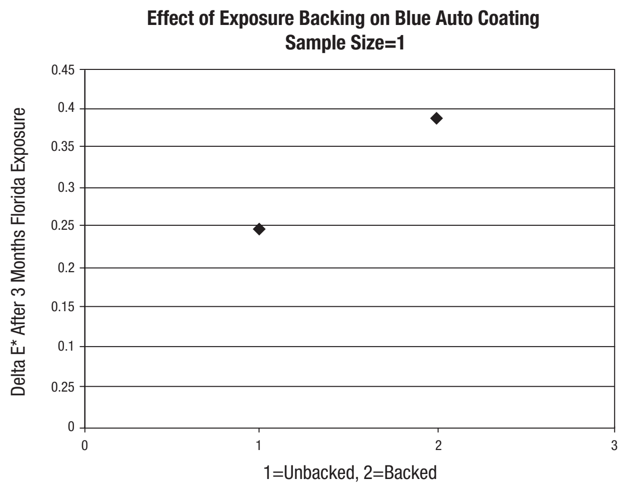
The easy-to-use touch screen display, the reliable sensor technology, and the multifunctional instrument features, such as an ultrasonic humidification and specimen spray system, prove both the Alpha and the 150 S+ as weathering testing instruments that meet global weathering and lightfastness test requirements. The Alpha+, with its more sophisticated technology and additional features, is ideal for test requirements of the plastics, coatings, and automotive industry. The Xenotest 150 S+ is ideal for textile lightfastness and weathering tests according to ISO 105-B02 or B04 and AATCC TM 169 and TM 16H-1998.

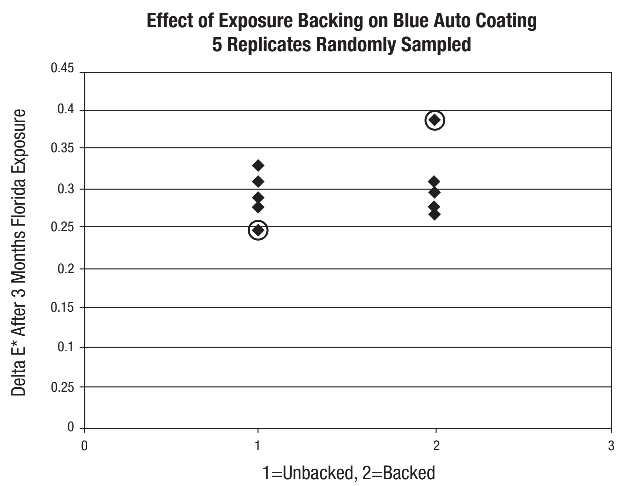
For further information, please contact your sales representative at **+49 6051 707 140** or **info@atlasmtt.de.** Visit the Atlas website at www.atlas-mts.com.

Weathering Experimenter's Toolbox: Replicates

By Henry K. Hardcastle III

The simple practice of including randomly selected replicates in a weathering exposure greatly increases the information value of the data. Consider the following weathering data of a commercially available blue automotive coating exposed to weather for three months in Florida.

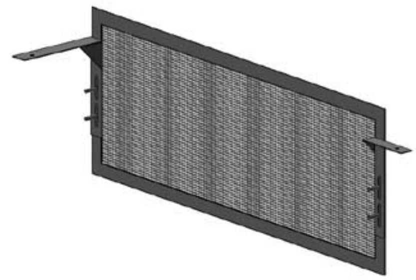




A simple comparison may lead to the interpretation that backed exposures lead to greater change. Adding additional replicates to this weathering study, however, may lead to a different interpretation.

Replicate exposures represent one of the most important tools for weathering researchers. Replicates may include random samples of a short production run, several production runs, or several years production runs, a single manufacturing line, a manufacturing plant or several plants. By tracking the levels of sampling (levels of production context), the weathering researcher may gain valuable insights into the causes of weathering variation due to production variations.

College Seniors Win Award for Redesign



A University of Illinois College of Engineering senior design group won the silver Lincoln Arc Welding Foundation award this year for its "Accelerated Weathering Machine Humidification Redesign for Reduced Water Damage" project. The James F. Lincoln Arc Welding Foundation offers annual awards to recognize and reward achievement by engineering and technology students in solving design, engineering, or arc welding fabrication problems. Professor Harrison Kim was the project leader and Atlas was the corporate sponsor.

As part of an ongoing cooperation between Atlas and U of I, the project was motivated by the need to reduce water damage to the films tested in weathering instruments. The team of students, Jason Chentorycki, Aaron Kirkpatrick, and Ines Hubler worked with Atlas to develop a simple and inexpensive in-line droplet catcher system. It is placed in the air stream which reduces large water particles in the chamber.

For more information, please contact Atlas at **info@atlas-mts.com.**

Atlas Client Education 2006–07

Atlas Client Education helps clients learn to design durability test programs to understand how weathering affects materials. Our education and training solutions will help you and your staff effectively master the skills and knowledge needed to develop long-lived products in shorted development cycles. Our programs are designed for all levels to ensure that everyone develops the skills required to understand the fundamentals of weathering and how to operate our instruments. For the latest schedules and locations, check the Atlas website, www.atlas-mts.com, or e-mail info@atlas-mts.com.

2006

Fundamentals of Weathering I

November 14
Oensingen, Switzerland

December 6
Paris, France

Fundamentals of Weathering II

November 15
Oensingen, Switzerland

December 7
Paris, France

SUNTEST Workshop

November 30
Oensingen, Switzerland

2007

Fundamentals of Weathering I

February 6
Boras, Sweden

February 8
Miami, Florida, USA

February 27
Regensburg, Germany

November 6
Europe
Location to be determined

Fundamentals of Weathering II

February 7
Boras, Sweden

February 9
Miami, Florida, USA

February 28
Regensburg, Germany

November 7
Europe
Location to be determined

Weather-Ometer® Workshops

February 5–6
Ci35/Ci65 Series

February 7
Ci4000/Ci5000

Miami, Florida, USA

For more information on courses in Europe, contact Atlas MTT GmbH, attention Bruno Bentjerodt, +49-6051-707-245 or clienteducation@atlasmtt.de.

For more information on courses in North America, contact Kerry Quilter at +1-773-327-4520 or kquilter@atlas-mts.com.

Or visit our website at www.atlas-mts.com.

Xenotest® Workshop

March 13–14
October 9–10
Linsengericht, Germany

SUNTEST Workshop

March 16
October 12
Linsengericht, Germany

Check out our newly re-designed website!
atlas-mts.com

To receive Sun Spots *electronically, please visit www.atlas-mts.com*

AtlasMaterial Testing Solutions

Atlas Material Testing Technology LLC
4114 North Ravenswood Avenue
Chicago, Illinois 60613, USA
Phone: +1-773-327-4520
Fax: +1-773-327-5787

Atlas Material Testing Technology GmbH
Vogelsbergstrasse 22
D-63589 Linsengericht/Altenhaßlau
Germany
Phone: +49-6051-707-140
Fax: +49-6051-707-149

K.H. Steuernagel Lichttechnik GmbH
Gerauer Straße 56a
64546 Mörfelden-Walldorf, Germany
Phone: +49-6105-91286
Fax: +49-6105-912880

Atlas Weathering Services Group
South Florida Test Service
16100 SW 216th Street
Miami, Florida 33170, USA
Phone: +1-305-824-3900
Fax: +1-305-362-6276

Note New Information < < <

DSET Laboratories
45601 North 47th Avenue
Phoenix, Arizona 85087, USA
Phone: +1-623-465-7356
Fax: +1-623-465-9409
Toll Free: 1-800-255-3738

KHS US Office
4114 North Ravenswood Avenue
Chicago, Illinois 60613, USA
Phone: +1-773-327-4520
Fax: +1-773-327-5787

Experience. The Atlas Difference.
www.atlas-mts.com

ATLAS
MATERIAL TESTING SOLUTIONS

ATLAS MATERIAL TESTING TECHNOLOGY LLC
4114 North Ravenswood Avenue
Chicago, Illinois 60613, USA