# Aesthetic Coatings for Steel Bridge Components Supplemental Study


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# WISCONSIN HIGHWAY RESEARCH PROGRAM

**PROJECT NO. 0092-11-07 AMENDED**

# AESTHETIC COATINGS FOR STEEL BRIDGE COMPONENTS

# SUPPLEMENTAL STUDY

**FINAL REPORT**

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SUBMITTED TO

THE WISCONSIN DEPARTMENT OF TRANSPORTATION

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**16. Abstract**
This supplementary study aims to determine the color and gloss retention performance of the top coats in the four best-performing coating systems from the original study, Aesthetic Coatings For Steel Bridge Components (project #0092-11-07), as well as four new colors that were not included in the original study. The colors carried over from the original study are black and blue, and the additional colors selected for this study are green, red, reddish brown and smoky topaz (or smoky yellow).

Color and gloss retention performance was evaluated by conducting Xenon Arc testing on sixty-four laboratory test samples. Each top coat/color sample was subjected to 1,260 cycles of Xenon Arc exposure, for a total period of 2,520 hours. Gloss retention index, color retention index and dry film thickness for each sample were measured according to the appropriate ASTM specifications.

Laboratory-accelerated UV radiation tests for steel top coats are not substitutes for real outdoor environmental exposures, but they are useful in predicting color and gloss retention over several years of service. Such tests are beneficial when multiple top coats and colors from different manufacturers are subjected to the same radiation exposures in a reasonably manageable time frame. A comparative evaluation of the performance of the top coats in the test program yielded information that can aid bridge owners to select the best performing top coat for their application.

Test results indicated that the black color from all of the selected manufacturers generally exhibited the most stability in retaining original color and gloss. The colors blue, green (except for Sherwin Williams) and smoky topaz exhibited acceptable retention characteristics, while reddish brown exhibited slightly higher loss, and red exhibited the greatest levels of loss. It was found that the selected PPG products in all colors performed better in terms of color and gloss retention.



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Coating systems, aesthetic, accelerated weathering test, gloss retention, color retention, steel bridge components, dry film thickness


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# Executive Summary

This report includes the results of a study that was initiated through an amendment to a previous Wisconsin Highway Research Program (WHRP) Project entitled, "Aesthetic Coatings for Steel Bridge Components." The WHRP Project ID for the first study was 0092-11-07. The first study has already been completed and a final report was submitted to WHRP in 2013 (1). The initial study included a comprehensive weathering, durability and UV exposure performance evaluation of 12 selected coating systems from different manufacturers with color black (Federal Color number 27038) top coats. It also included color and gloss retention evaluation of all of the top coats in the study for color blue (Federal Color number 15092). A comparative performance evaluation for color and gloss retention for colors black and blue was made in the initial study by conducting the Xenon Arc tests.

The primary objective of this amended study was to evaluate the color and gloss retention performance of four selected top coats in four additional colors. No durability evaluations were expected to be made for these top coats as their respective durability characteristics were identified and reported in the 2013 final report for the WHRP project #0092-11-07 (1). The top coats used in the amended study were selected as the best performing coating systems from the initial study. They included Sherwin Williams Acrolon 218 HS, Carboline Carbothane 133 LH, PPG Amercoat 450H, and Wasser MC-Luster 100. The selected additional colors included color green (Federal Color number 24260), color red (Federal Color number 11120), color reddish brown (Federal Color number 20152), and color smoky topaz (or smoky yellow, Federal Color number 10371). Color and gloss retention performance for the selected top coats and colors was evaluated by conducting Xenon Arc testing on sixty four laboratory test samples according to the specifications of ASTM G155-05, "Standard Practice for Operating Xenon Arc Light Exposure of Non-Metallic Materials" (2) and ASTM D6695-08, "Standard Practice for Xenon-Arc Exposures of Paint and Related Coatings" (3). Each top coat/color sample was subjected to 1,260 cycles of Xenon Arc exposure, for a total period of 2,520 hours. Gloss retention index, color retention index and dry film thickness for each sample were measured according to the appropriate ASTM specifications.

The test results indicated that the black color (Federal Color 27038) from all of the selected manufacturers generally exhibited the most stability in terms of retaining the original color and gloss. According to the test results, the greatest level of loss of color and gloss occurred in color red (Federal Color 11120) regardless of the choice of manufacturer. The colors blue, green (except for Sherwin Williams), and smoky topaz

exhibited acceptable color and gloss retention characteristics while the color reddish brown showed slightly higher loss of color and gloss. It was found that the selected PPG products in all colors performed better in terms of color and gloss retention. The better color and gloss retention performance by the selected PPG coating product may be associated with the use of dry colorants during its manufacturing process. It is recommended that additional performance verification be provided by manufacturers, through test results from independent sources, if the colors red and reddish brown are specified for steel highway bridge components.

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# 1.0 Introduction

This amended study was undertaken to evaluate the color and gloss retention characteristics of a series of top coats in colors other than colors black (Federal Color 27038) and blue (Federal color 15092) that were evaluated in the initial WHRP study #0092-11-07 (1). The color numbers are based on the color numbering system provided by the Federal Standard 595B (4). While the durability characteristics for twelve selected coating systems from different manufacturers were evaluated in the initial study, the amended study aimed to determine only the color and gloss retention performance of four top coats with four additional colors. The selected top coats were the best performing coatings in the initial study. They included Sherwin Williams Acrolon 218 HS, Carboline Carbothane 133 LH, PPG Amercoat 450H, and Wasser MC-Luster 100. The selected additional colors included color green (Federal Color number 24260), color red (Federal Color number 11120), color reddish brown (Federal Color number 20152), and color smoky topaz (or smoky yellow, Federal Color number 10371).

Since this report is prepared as an amended report to the initial study (1), the reader is referred to the 2013 final report for that study to gain background and technical information associated with the work under this amended study.

## 1.1 Problem Statement

Aesthetic concerns for coating systems can arise due to problems related to either durability or appearance. Durability problems, including cracking, peeling, blistering, and general degradation of coatings, are generally due to material or application shortcomings and can negatively affect both the protection of the underlying material as well as presenting an unpleasant appearance. On the other hand, a significant loss/change of color and gloss in the top coat of a coating system may have no negative effect on the protection of the underlying material but it can result in an unpleasant appearance that may not be acceptable.

A loss or change in the color and gloss for a top coat can result from exposures to sun radiation as well as exposures to harmful environments during the service life. It has been shown that color and gloss retention varies in top coats depending on the color (1). The initial coating study sponsored by the Wisconsin Department of Transportation (1), included testing and evaluation of top coats with colors black and blue. Accordingly, the Wisconsin Department of Transportation amended the initial study to evaluate the performance of four additional top coat colors: green, red, reddish brown, and smoky topaz. These colors were evaluated for the four best performing top coats from the initial study.

## 1.2 Objective

The objective of this study was to evaluate the performance of four selected top coats with four different colors in terms of color and gloss retention. The selected top coats showed the best performance during the initial coating study that was completed in 2013. Four colors were selected for each of the top coats. It was desired to obtain a comparative assessment of the performance of these top coats for the selected four colors from this amended study as well as those with colors black (Federal Color 27038) and blue (Federal Color 15092) from the initial study.

## 1.3 Scope of Work

The objective of this study was achieved by performing Xenon Arc exposure tests on a series of steel samples coated with the selected top coats and colors as required under this amended study. The color and gloss retention results from this and the initial study are summarized and presented in this report to offer a comparative evaluation of the selected coating systems with six different colors.

## 2.0 Laboratory Test Program

The laboratory test program under this amended study included color and gloss retention evaluation of the four best performing top coating materials from the initial study with four new colors. The selected top coats were Sherwin Williams Acrolon 218 HS, Carboline Carbothane 133 LH, PPG Amercoat 450H, and Wasser MC-Luster 100 and the selected new colors were green (Federal Color number 24260), red (Federal Color number 11120), reddish brown (Federal Color number 20152), and smoky topaz (Federal Color number 10371).

For each top coat and color, four 2-in. x 2-in. x 1/8-in. steel plate test samples were prepared. Accordingly, sixteen test samples were prepared for each top coat with a total of sixty four test samples for the test program. All of the test samples' surface preparation and coating application were completed following the same procedure and process used during the initial study. All test samples' surface preparation was based on complying with the specifications of SSPC SP-1 (4) followed by SSPC SP-10/NACE No. 2 (5). Coatings were applied to test samples following the manufacturers' recommendations and WisDOT guidelines. The coating application was made in a painting booth at the University of Wisconsin-Milwaukee's (UWM) Facilities Services.

The laboratory testing for all coated samples was conducted using the Xenon Arc testing chamber in the Coating Evaluation Laboratory at UWM, Figure 1. The test was based on the specifications of ASTM G155-05, "Standard Practice for Operating Xenon Arc Light Exposure of Non-Metallic Materials" (2) and ASTM D6695-08, "Standard Practice for Xenon-Arc Exposures of Paint and Related Coatings" (3). Due to the space limitation of the Xenon Arc testing chamber, only 32 coated samples could be tested at a time. Accordingly, two separate sets of complete exposure cycles were conducted with 32 samples included in each set. Each set of coated samples was subjected to 1,260 cycles of Xenon Arc and water spray exposures that consisted of a period of 2,520 hours. The same test procedure that was used during the initial study was followed in this study. A detailed description of the Xenon Arc testing procedure is presented in the final report for the initial study (1).

Color retention index, gloss retention index and dry film thickness for each coated sample were measured before, during (every third cycle of Xenon Arc exposure), and at the completion of the testing program. The color change evaluation was based on the specifications of ASTM D2244-09a: “Standard Practice for Calculation of Color Tolerances and Color Differences from Instrumentally Measured Color Coordinates” (6). For gloss change evaluation, the specifications of ASTM D523-05: “Standard Test Method for Specular Gloss” (7) were followed.


Figure 1 - Q-Sun, Xenon Arc Test Chamber

Both gloss and color retention index readings were measured and recorded using a BYK Gardner Spectro-Guide Sphere device, shown in Figure 2.


Figure 2 - BYK Spectro-Guide Sphere Device

Gloss is measured in terms of the level of light that is reflected off of a surface. The more surface light reflection, the larger the gloss index or a "G" value measured by the BYK Spectro-Guide device. The measurement of the gloss index is made at a 60° angle. The average value of four measurements taken at the corners of each test sample was used as the gloss index value for that test sample.

To assess changes in the colors of the coated samples, the CIELAB color indexing model, or color space, was used in this study. The model was developed by the "Commission Internationale de l'Eclairage" or "International Commission on Illumination" (CIE) in 1976 (8). The CIELAB system is a mathematical representation of all the colors in space as visible to the human eye. Three variables or coordinates of "$L^*$", "$a^*$", and "$b^*$" are used to indicate the level or range of lightness (where for black, $L^* = 0$ and for diffuse white, $L^* = 100$), green to red (where for green, there are -$a^*$ values and for red, there are +$a^*$ values), and blue to yellow (where for blue, there are -$b^*$

values and for yellow, there are +$b^*$ values), respectively. In most cases, the range of $a^*$ and $b^*$ is ± 100.

The $L^*$, $a^*$, and $b^*$ values for each coated sample were recorded initially and after every third Xenon Arc exposure cycle during this study. The BYK Spectro-Guide device was used to measure the $L^*$, $a^*$, and $b^*$ variables. Similar to the measurement of the gloss index, the average of four readings at the corners of each test sample was used as the $L^*$, $a^*$, and $b^*$ values for that test sample.

Under the CIELAB model, the overall difference in color is measured by $\Delta E_{ab}^*$ where it is determined by the relationship $\Delta E_{ab}^* = \sqrt{(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2}$. The parameters $\Delta L^*$, $\Delta a^*$, and $\Delta b^*$ are defined as differences between two subsequent measurements for $L^*$, $a^*$, and $b^*$, respectively. In this study, $\Delta E^*$ was calculated for each test sample by using the measured values of $L^*$, $a^*$, and $b^*$ from the control test samples, from before the start of the test program, and those from the panels after each third cycle of the exposure test.

Dry film thickness was measured for each coated sample according to the specifications of ASTM E376-06: "Standard Practice for Measuring Coating Thickness by Magnetic Field or Eddy Current (Electromagnetic) Examination Methods" (9). Dry film thickness for each test sample was taken at two opposite corners of the sample before, after every third Xenon Arc exposure cycle, and after the completion of the test program. The average value of the two readings was used as the dry film thickness for the test sample. The dry film thickness measurements were taken using the BYKO-Test MPOR eddy current gage, shown in Figure 3. Eddy current devices can measure variations in the impedance of an eddy current inducing coil caused by coating thickness variation (9).


Figure 3 - BYKO Eddy Current Dry Film Thickness Gage

## 3.0 Laboratory Test Results and Discussion

### 3.1 Introduction

Dry film thickness, color retention index, and gloss retention index for all coated samples in this amended study were measured and evaluated before, during, and after the completion of the Xenon Arc exposure cycles as described in the earlier sections of this report. These results, in conjunction with those from the initial study (1), offer a comprehensive evaluation of both durability and aesthetic performance of a selected number of coating systems in six different colors for application to steel structures. The initial study included results for durability and aesthetic performance evaluation for twelve coating systems in Federal colors black and blue. This amended study offers aesthetic performance evaluation for the four best performing top coats from the initial study in Federal colors red, reddish brown, smoky topaz, and green.

### 3.2 Evaluation of Dry Film Thickness

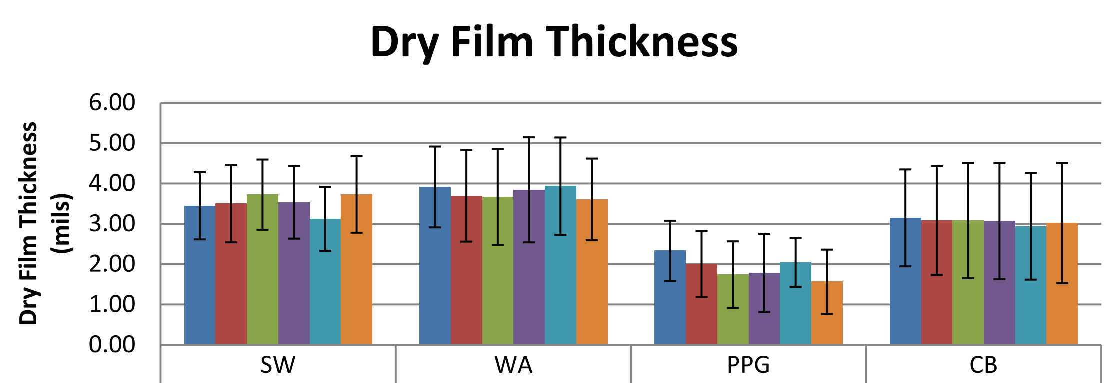
Coating thickness is one of the primary factors that can affect the level of protection that can be provided to a steel substrate against corrosion or other deterioration mechanisms. The color and gloss retention characteristics of a top coat can also be negatively affected if the top coat is installed too thin or if it loses its initial thickness due to exposure to its in-service environment.

Top coat thickness values for all coated samples subjected to Xenon Arc exposures in this study were measured before, during, and after the exposure cycles. The purpose of the top coat thickness measurements was to determine any coating thickness variations in the products by the different manufacturers included in this study. Table 1 shows the average measured values of coating thickness at different stages of the test from 16 test samples for coatings by the four manufacturers included in this study. It also shows the 95% confidence intervals for the measured values.

Table 1 - Average Dry Film Thickness and 95% Confidence Intervals

| Type | System | Cycles | | | | | |
|---|---|---|---|---|---|---|---|
| | | **Initial** | **3** | **6** | **9** | **12** | **15** |
| Av. Dry Film Thickness | SW | 3.44 | 3.50 | 3.72 | 3.53 | 3.12 | 3.73 |
| | WA | 3.91 | 3.69 | 3.66 | 3.84 | 3.93 | 3.60 |
| | PPG | 2.33 | 2.00 | 1.74 | 1.78 | 2.04 | 1.56 |
| | CB | 3.14 | 3.08 | 3.08 | 3.06 | 2.94 | 3.01 |
| 95% Confidence | SW | 0.83144 | 0.960787 | 0.869754 | 0.896725 | 0.793802 | 0.948418 |
| | WA | 1.00186 | 1.135561 | 1.186658 | 1.302074 | 1.205659 | 1.010595 |
| | PPG | 0.74422 | 0.81861 | 0.826112 | 0.968724 | 0.60572 | 0.798416 |
| | CB | 1.201071 | 1.347093 | 1.431252 | 1.437108 | 1.32276 | 1.490513 |

Average dry film thickness and the 95% confidence interval values at different stages of the test program for all of the top coats by the four manufacturers included in this amended study are also shown in Figure 4.




| | SW | WA | PPG | CB |
|---|---|---|---|---|
| Initial | 3.44 | 3.91 | 2.33 | 3.14 |
| 3 Cycles | 3.50 | 3.69 | 2.00 | 3.08 |
| 6 Cycles | 3.72 | 3.66 | 1.74 | 3.08 |
| 9 Cycles | 3.53 | 3.84 | 1.78 | 3.06 |
| 12 Cycles | 3.12 | 3.93 | 2.04 | 2.94 |
| 15 Cycles | 3.73 | 3.60 | 1.56 | 3.01 |

Figure 4 - Average Dry Film Thickness and 95% Confidence Intervals

An examination of the average dry film thickness values for SW, WA and CB top coats shows only a small reduction (less than 10%) in thickness from the initial stage to the completion of the exposure test. The thickness reduction for the PPG top coat was observed to be larger (exceeding 20%) than the observed values for the products by the other three manufacturers. Accordingly, there may be concerns that the greater thickness reduction for the PPG coating may have negative consequences on the long term performance of this product. However, it may be possible to address this concern by increasing the PPG's recommended top coat thickness at the initial installation to a higher level as recommended by the other manufacturers included in this study. Additional experimental evaluation will be required to verify that an increased coating thickness at the initial installation stage will result in a smaller thickness reduction for the PPG coating due to in-service environmental exposures.

It is important to note that even when the utmost care is taken during the application of a coating, it is unlikely that a perfectly uniform or a single specific coating thickness can be achieved for one or more test samples. The resulting variation in the thickness of coating at different points on a test sample can lead to a scattering of the measured values as indicated by the 95% confidence intervals in Table 1 and Figure 4.

Considering the 95% confidence intervals for the coatings by the four manufacturers in the study leads to a conclusion that while the coating thickness uniformity at the installation stage for all of the coatings was acceptable, the PPG product achieved a slightly more uniform coating thickness.

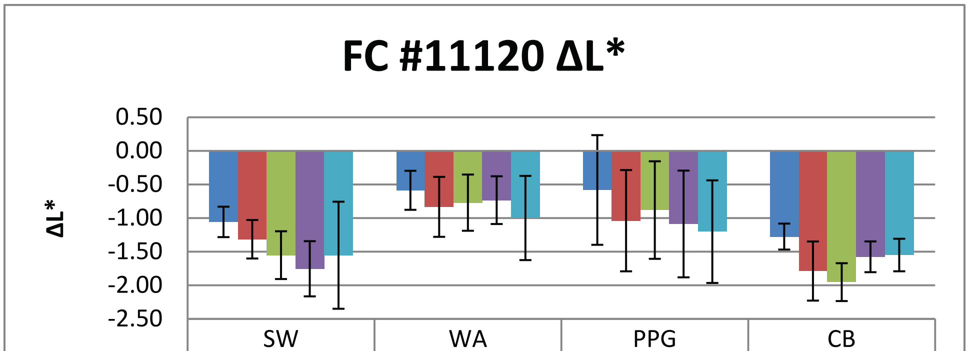
It should be noted that a small level of reduction in the dry film thickness of coating materials is expected due to the film drying effect and loss of flexibility when the coating is subjected to in-service environmental conditions. Furthermore, it is reasonable to expect some variations in the measured values of the film thickness when using the eddy current thickness gage on small test samples. This contributes to additional scatter in the measured coating thickness data. However, with an adequate coating thickness installed at the initial stage, a small thickness reduction should have only minimal or no detrimental effect on the overall performance of the coating.

Additional dry film thickness data for all test samples with associated coatings and colors are submitted as a part of this report in the form of a digital media.

**3.3 Evaluation of Color Retention**

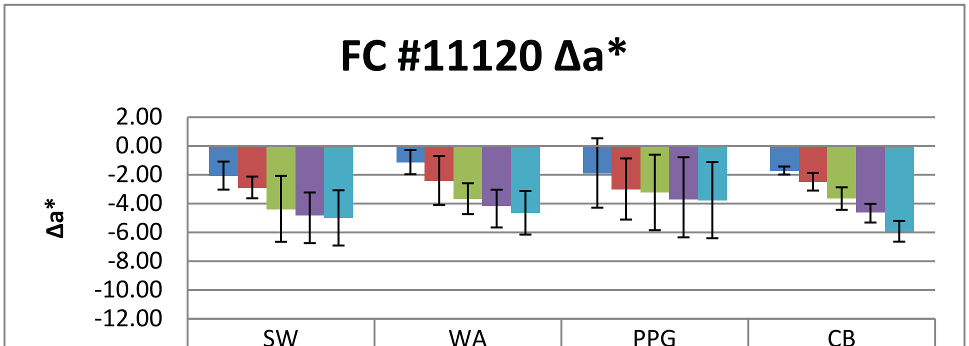
The aesthetic performance evaluation of the coatings and colors supplied by the four manufacturers in this study was made by considering the color and gloss retention characteristics of a series of coated test samples that were subjected to Xenon Arc exposure tests. As indicated earlier, all color and gloss index measurements and interpretations in this study were based on following the specifications of the CIELAB model. Accordingly, the values of "$L^*$", "$a^*$", and "$b^*$" were measured for all of the test samples before, during, and after the testing program using a Spectro-Guide sphere device, as shown in Figure 2. Charts were constructed to show changes in the measured values, from the control samples and after every three cycles of the Xenon Arc tests. In addition, an overall change in color ($\Delta E_{ab}^*$) was then computed and graphed for each product and color based on the measured values of "$L^*$", "$a^*$", and "$b^*$". The overall change in color graphs provided a more general indication of the overall color change for each product and color included in this study.

Generally, a consideration of changes in the values of "$L^*$", "$a^*$", and "$b^*$" can reveal color change information that is associated with only a part of the color spectrum. For example, a change in the values of "$L^*$" ($\Delta L^*$) indicates the darkening or whitening effect. Similarly, a change in the values of "$a^*$" ($\Delta a^*$), and "$b^*$" ($\Delta b^*$) can indicate a color transition between green and red and between blue and yellow, respectively. Accordingly, it will be more difficult to make an overall color change evaluation when the values of "$L^*$", "$a^*$", and "$b^*$" are considered independently. This may be demonstrated by examining Figures 5, 6, and 7. The figures show the mean values of ΔL*, Δa*, and Δb*, for color red (Federal Color 11120) based on the measurements of "L*", "a*", and "b*", respectively. The data in the figures was obtained prior to the Xenon Arc test on the control samples and after every three test cycles for the four manufacturers participating in the study: Sherwin William (SW), Wasser (WA), PPG, and Carboline (CB). The results shown in the figures are based on the calculated means of the measured values of "L*", "a*", and "b*" from the four corners of four test samples for each coating product and color. The figures also include the 95% confidence intervals for the measured values.



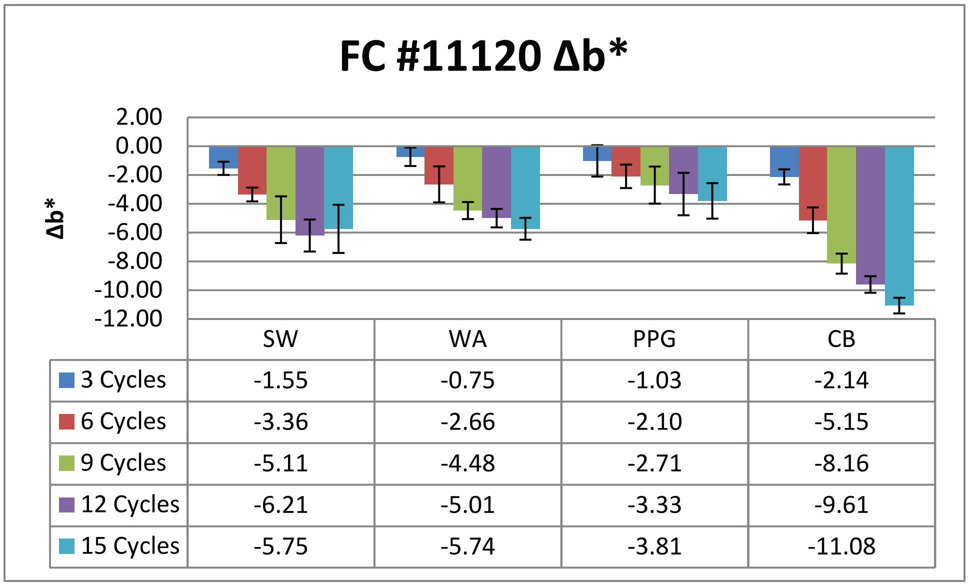

| | SW | WA | PPG | CB |
|---|---|---|---|---|
| 3 Cycles | -1.06 | -0.59 | -0.58 | -1.28 |
| 6 Cycles | -1.32 | -0.83 | -1.04 | -1.79 |
| 9 Cycles | -1.55 | -0.77 | -0.88 | -1.95 |
| 12 Cycles | -1.75 | -0.73 | -1.09 | -1.58 |
| 15 Cycles | -1.55 | -1.00 | -1.20 | -1.55 |

Figure 5 - Mean Values of Changes in L* (ΔL*) for Color Red (Federal Color # 11120)




| | SW | WA | PPG | CB |
|---|---|---|---|---|
| 3 Cycles | -2.07 | -1.13 | -1.88 | -1.71 |
| 6 Cycles | -2.89 | -2.40 | -3.00 | -2.49 |
| 9 Cycles | -4.37 | -3.67 | -3.24 | -3.66 |
| 12 Cycles | -4.83 | -4.15 | -3.70 | -4.60 |
| 15 Cycles | -5.00 | -4.65 | -3.77 | -5.93 |

Figure 6 - Mean Values of changes in a* (Δa*) for Color Red (Federal Color # 11120)



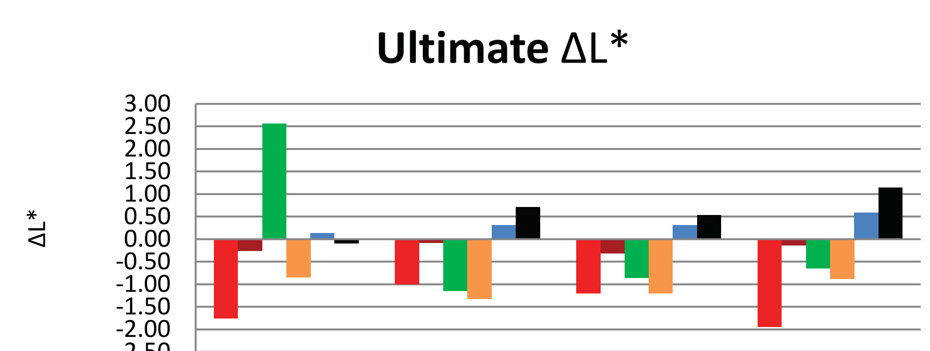

| | SW | WA | PPG | CB |
|---|---|---|---|---|
| 3 Cycles | -1.55 | -0.75 | -1.03 | -2.14 |
| 6 Cycles | -3.36 | -2.66 | -2.10 | -5.15 |
| 9 Cycles | -5.11 | -4.48 | -2.71 | -8.16 |
| 12 Cycles | -6.21 | -5.01 | -3.33 | -9.61 |
| 15 Cycles | -5.75 | -5.74 | -3.81 | -11.08 |

Figure 7 - Mean Values of Changes in $b^*$ ($\Delta b^*$) for Color Red (Federal Color # 11120)

An evaluation of Figure 5 shows that the test samples experienced a darkening effect as the Xenon Arc exposure cycles increased. This may be confirmed by a visual evaluation of color changes as shown in photographs of the test samples from different stages of the test program. Figures 6 and 7 show a color transition from red to green and from yellow to blue, respectively. A confirmation of these color transitions is more difficult when corresponding photographs from different stages of the test program are evaluated. Similar measurements were made and graphs constructed for other products and colors included in this study.

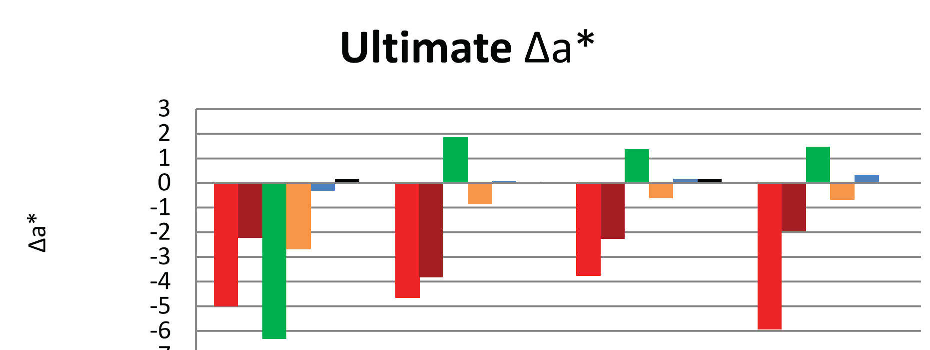
Figures 8, 9, and 10 show the mean values of changes in colors in terms of $\Delta L^*$, $\Delta a^*$, and $\Delta b^*$ for the control test panels and those at the completion of the Xenon Arc test program for the coatings and colors from the four manufacturers included in this study. These figures also include data for changes in color for the same coating materials, but with colors black and blue from the initial study (1). The results shown in the figures are based on the calculated means of the measured values of "$L^*$", "$a^*$", and "$b^*$" from the four corners of four test samples for each coating product and color. Accordingly, a comparative evaluation of the performance of the six selected colors may be made for the four best performing top coats based on the results of the initial study.

As shown in Figure 8, for all of the coating colors, except for black and blue, a darkening effect (a reduction in the $\Delta L^*$ values) was observed at the completion of the Xenon Arc test. An exception to this observation was for color green by Sherwin Williams. Figures 9 and 10 show a color transition from green to red and from blue to yellow, respectively.  The negative values in the figures indicate a transition toward colors green or blue or a reduction of color from red or yellow, respectively.



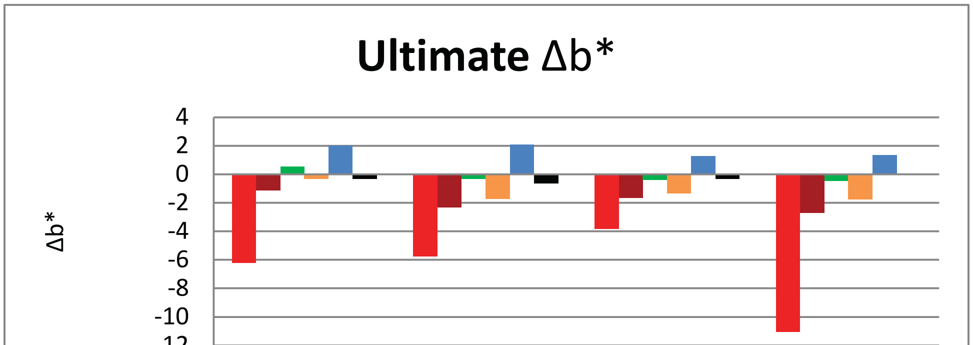

| | SW | WA | PPG | CB |
|---|---|---|---|---|
| FC #11120 | -1.75 | -1.00 | -1.20 | -1.95 |
| FC #20152 | -0.26 | -0.08 | -0.32 | -0.14 |
| FC #24260* | 2.57 | -1.15 | -0.86 | -0.65 |
| FC #10371* | -0.84 | -1.32 | -1.20 | -0.88 |
| FC #15092 | 0.14 | 0.32 | 0.31 | 0.59 |
| FC #27038 | -0.10 | 0.71 | 0.54 | 1.14 |

Figure 8 - Mean Values of Changes in the Dark to Light Transition in the Top Coat Colors Before and After the Xenon Arc Test




| | SW | WA | PPG | CB |
|---|---|---|---|---|
| FC #11120 | -5.00 | -4.65 | -3.77 | -5.93 |
| FC #20152 | -2.21 | -3.82 | -2.26 | -1.96 |
| FC #24260* | -6.31 | 1.86 | 1.36 | 1.46 |
| FC #10371* | -2.68 | -0.85 | -0.61 | -0.68 |
| FC #15092 | -0.32 | 0.08 | 0.17 | 0.31 |
| FC #27038 | 0.17 | -0.05 | 0.17 | -0.01 |

Figure 9 - Mean Values of Changes in the Green to Red Transition in the Top Coat Colors Before and After the Xenon Arc Test

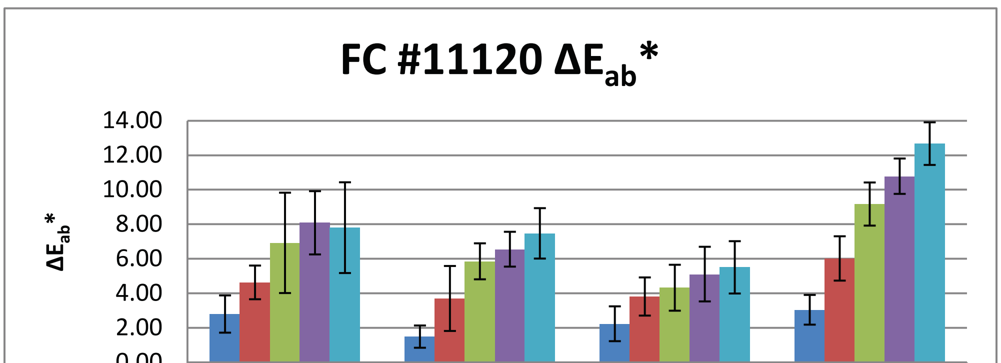



| | SW | WA | PPG | CB |
|---|---|---|---|---|
| FC #11120 | -6.21 | -5.74 | -3.81 | -11.08 |
| FC #20152 | -1.13 | -2.35 | -1.66 | -2.73 |
| FC #24260* | 0.57 | -0.35 | -0.39 | -0.44 |
| FC #10371* | -0.33 | -1.73 | -1.32 | -1.77 |
| FC #15092 | 2.02 | 2.08 | 1.28 | 1.34 |
| FC #27038 | -0.34 | -0.65 | -0.34 | 0.02 |

Figure 10 - Mean Values of Changes in the Blue to Yellow Transition in the Top Coat Colors Before and After the Xenon Arc Test

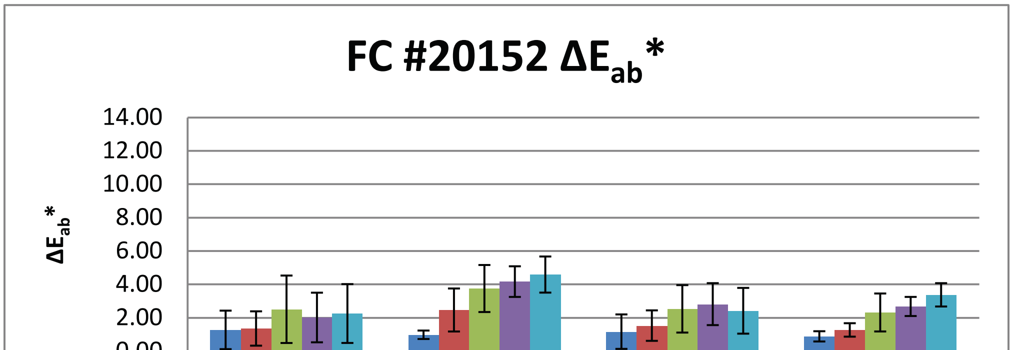
Figures 11, 12, 13, and 14 show the mean values of the $\Delta E_{ab}^{*}$ for the products by the four manufacturers after the completion of every three cycles of Xenon Arc test. These figures include results for colors red, reddish brown, green, and smoky topaz, respectively. Each mean value of the $\Delta E_{ab}^{*}$ was obtained by using the reference measurements on the four corners of the four control test samples from prior to the start of the Xenon Arc test. The figures also show 95% confidence intervals for the measured values. It can be seen in all of the figures that the overall color change increased for all products and colors with increasing exposure to Xenon Arc radiations. Among all of the colors tested in this study, the color red top coat exhibited the largest overall color change. While there were some variations in the extent of the overall color changes among the different manufacturers' products, they were not significant enough to warrant the selection of any manufacturer's product as superior. However, the PPG top coat, Amercoat 450H, for all of the selected four colors, performed slightly better in terms of color retention, while Sherwin Williams product, Acrolon 218 HS, exhibited a wider scatter in the measured color change index values.

The better performance of the PPG's Amercoat 450H in this study may be associated with the factory use of dry colorants instead of the commonly used liquid colorants by coating manufacturers. It is known that coatings with colors achieved by the use of dry and liquid colorants perform differently in terms of durability and color and gloss retention. A dry colorant utilizes dry pigments mixed in during the manufacturing process to achieve the desired color. Conversely, liquid colorants are developed by mixing a high concentration of colored pigments with a liquid vehicle (primarily glycol). The liquid pigments are then added to a manufactured base color to achieve the desired color. This is the most common method used by the coating manufacturers to obtain coating materials with desired colors. The presence of glycol causes the paint to be soft or lose adhesion, as the glycol mixture does not harden. The use of liquid pigments can also have a negative effect on UV stability and moisture resistance, as they commonly have a lower resin to pigment ratio. This is because pigment is added to develop the base color and then additional pigment is necessary to produce the final color. The higher the resin concentration, the stronger the pigment particles adhesion to the coating surface, thus improving resistance to exposure to both sunlight and moisture. The lower resin to pigment ratio paired with the presence of glycol in the liquid pigment, produce a lower exposure resistance in comparison to the use of dry colorants. Because of better durability and color and gloss retention, specifying the use of dry colorants during the coating manufacturing process is desirable but it may add to the cost of the coating material.



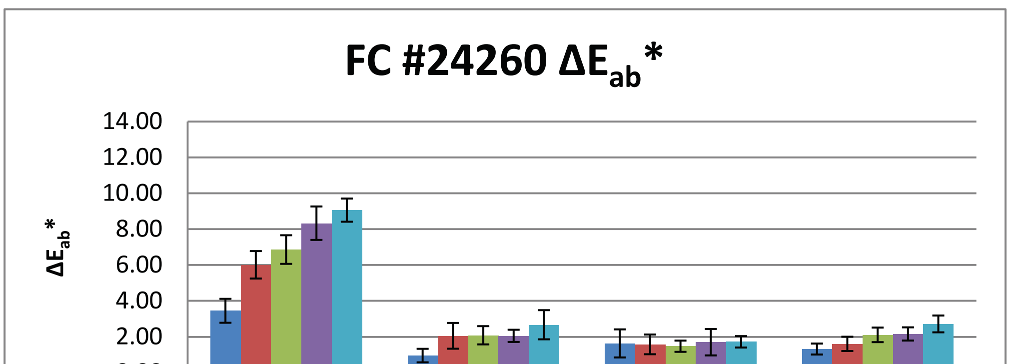

| | SW | WA | PPG | CB |
|---|---|---|---|---|
| 3 Cycles | 2.79 | 1.48 | 2.23 | 3.04 |
| 6 Cycles | 4.63 | 3.69 | 3.81 | 6.01 |
| 9 Cycles | 6.91 | 5.85 | 4.32 | 9.16 |
| 12 Cycles | 8.08 | 6.55 | 5.11 | 10.78 |
| 15 Cycles | 7.80 | 7.47 | 5.50 | 12.66 |

Figure 11 - Mean Values of Overall Changes in Color Red at Each Three Cycles of the Xenon Arc Test



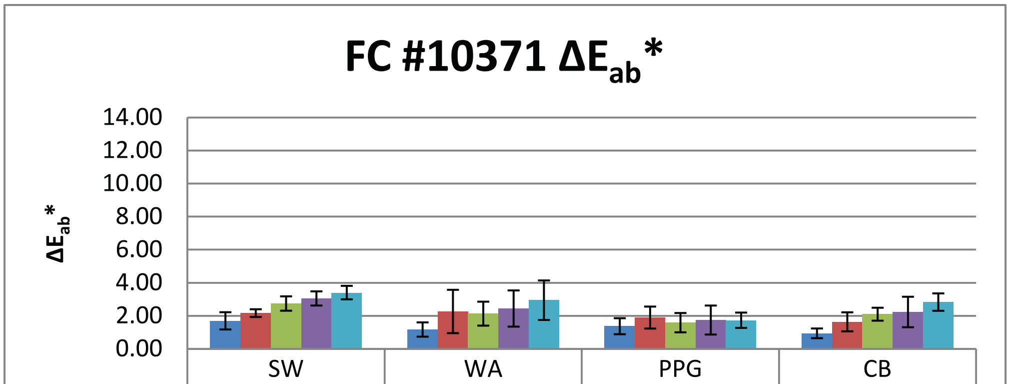

| | SW | WA | PPG | CB |
|---|---|---|---|---|
| 3 Cycles | 1.27 | 0.97 | 1.16 | 0.88 |
| 6 Cycles | 1.35 | 2.46 | 1.52 | 1.26 |
| 9 Cycles | 2.50 | 3.74 | 2.53 | 2.31 |
| 12 Cycles | 2.01 | 4.16 | 2.81 | 2.67 |
| 15 Cycles | 2.24 | 4.58 | 2.41 | 3.37 |

Figure 12 - Mean Values of Overall Changes in Color Reddish Brown at Each Three Cycles of the Xenon Arc Test




| | SW | WA | PPG | CB |
|---|---|---|---|---|
| 3 Cycles | 3.45 | 0.95 | 1.63 | 1.31 |
| 6 Cycles | 6.01 | 2.05 | 1.57 | 1.60 |
| 9 Cycles | 6.86 | 2.08 | 1.47 | 2.11 |
| 12 Cycles | 8.33 | 2.05 | 1.70 | 2.16 |
| 15 Cycles | 9.06 | 2.67 | 1.72 | 2.72 |

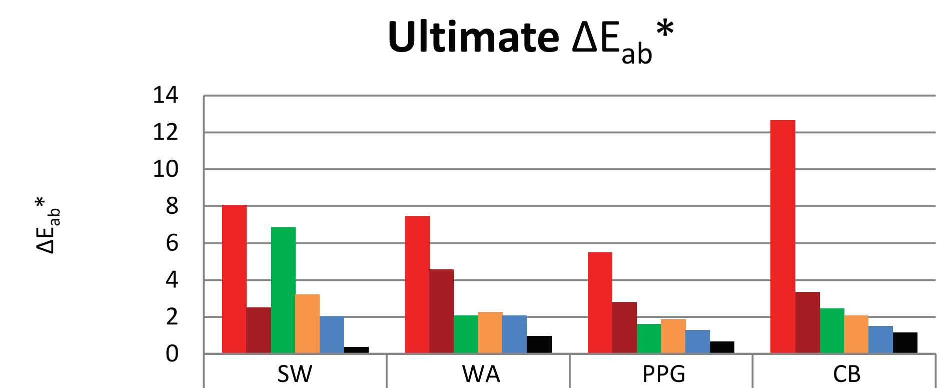
Figure 13 - Mean Values of Overall Changes in Color Green at Each Three Cycles of the Xenon Arc Test




| | SW | WA | PPG | CB |
|---|---|---|---|---|
| 3 Cycles | 1.69 | 1.16 | 1.36 | 0.93 |
| 6 Cycles | 2.16 | 2.26 | 1.89 | 1.63 |
| 9 Cycles | 2.74 | 2.12 | 1.58 | 2.09 |
| 12 Cycles | 3.04 | 2.43 | 1.74 | 2.22 |
| 15 Cycles | 3.40 | 2.94 | 1.73 | 2.82 |

Figure 14 - Mean Values of Overall Changes in Color Smoky Topaz at Each Three Cycles of the Xenon Arc Test

The ultimate overall change of color in coatings may be obtained by evaluating the difference in the $\Delta E_{ab}^{*}$ values for the control test samples and those at the completion of a test program. The results of such evaluation may be of the most value and benefit to bridge owners in determining the most suitable coating and color for a steel bridge component. Figure 15 shows the results of the ultimate overall color changes for the six coating colors by the four manufacturers included in this study. It should be noted that the color retention performance data for colors black and blue was obtained during the initial study (1) and it is included in the figure for a more complete comparative evaluation of the coating colors. It can be seen from the figure that color red in the coatings supplied by all of the participating manufacturers was associated with the largest color change. The black color (Federal Color 27038) from all of the selected manufacturers generally exhibited the most stability in terms of retaining the original color and gloss. Except for color green in the coating material by Sherwin Williams, all other colors and products were observed to yield comparable and acceptable results. The research team was unable to verify the resin to pigment ratio in the liquid colorants used for the coating colors by Sherwin Williams. However, it may be safe to assume that a lower resin to pigment ratio was the primary influencing factor for the somewhat poor color retention for most of the Sherwin Williams colors compared with those from other manufacturers in the study. The better color retention performance by the PPG coatings and colors may be associated with the use of dry colorants during the manufacturing process.




| | SW | WA | PPG | CB |
|---|---|---|---|---|
| FC #11120 | 8.08 | 7.47 | 5.50 | 12.66 |
| FC #20152 | 2.50 | 4.58 | 2.81 | 3.37 |
| FC #24260* | 6.86 | 2.08 | 1.63 | 2.46 |
| FC #10371* | 3.21 | 2.26 | 1.89 | 2.09 |
| FC #15092 | 2.05 | 2.09 | 1.31 | 1.50 |
| FC #27038 | 0.38 | 0.97 | 0.66 | 1.16 |

Figure 15 - Ultimate Changes in Overall Colors Based on Measuring $\Delta L^*$, $\Delta a^*$, and $\Delta b^*$ Before and After the Xenon Arc Test

While it may require a higher initial material cost, it could be beneficial to the bridge owners to specify the use of dry colorants during the manufacturing process for all colors.

Visual comparative evaluation of color change was made for all test samples before, during, and after the Xenon Arc tests. Photographs of all test samples were taken and digital copies were recorded prior to the start of the Xenon Arc tests. These photographs were used as the basis of comparison with those taken from the test samples at every three test cycles and those at the exposure test completion time. A desk top photography enclosure unit was used to allow taking digital photographs under the same lighting conditions. All photographs were taken throughout the test program under the same lighting conditions and same camera setting. Each test sample was placed on a plain white paper before taking its photograph. The white background paper was used to verify that the same lighting conditions and camera setting are producing the same color of the white background.

Additional test data related to color index measurements and color changes for all test samples with associated coatings and colors is submitted as a part of this report in the form of a digital media.

Figures 16, 17, 18, and 19 show typical photographs of coated test samples for colors red, reddish brown, smoky topaz, and green, respectively. Each figure includes, from left to right, photographs of control test samples, i.e. CB-2-0, and those from test cycles 3, 6, 9, 12, and cycle 15 which was at the test completion time. As it can be seen from the figures, a clear darkening of the coated test samples resulted for all coatings and colors, except for color green by Sherwin Williams, due to exposure to Xenon Arc radiation. This observation is in agreement with the results shown in Figure 8.

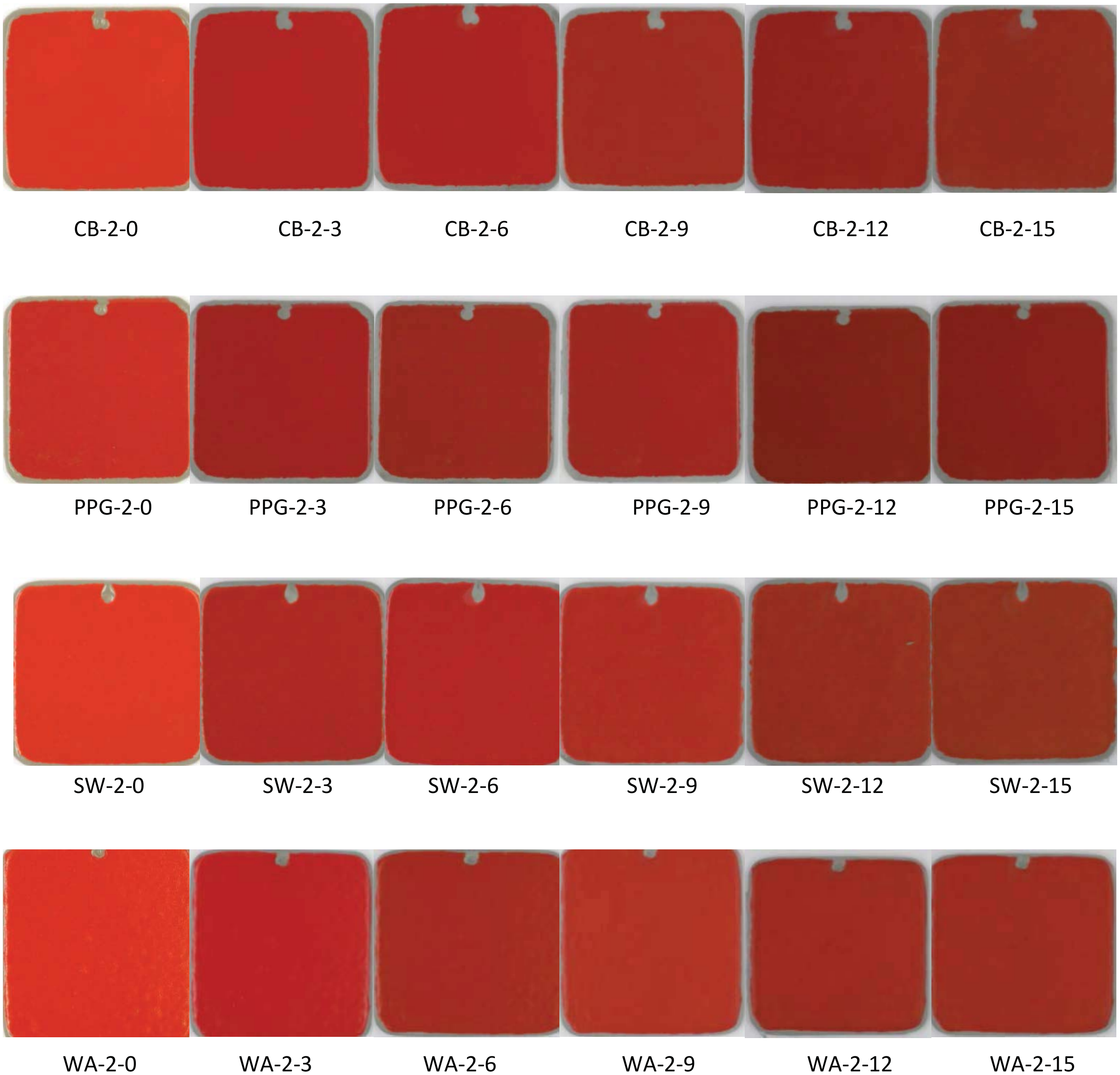



Figure 16 - Photographs of Coated Test Samples for Color Red for Coatings by Carboline (CB), PPG, Sherwin Williams (SW), and Wasser (WA)


Figure 17 - Photographs of Coated Test Samples for Color Reddish Brown for Coatings by Carboline (CB), PPG, Sherwin Williams (SW), and Wasser (WA)

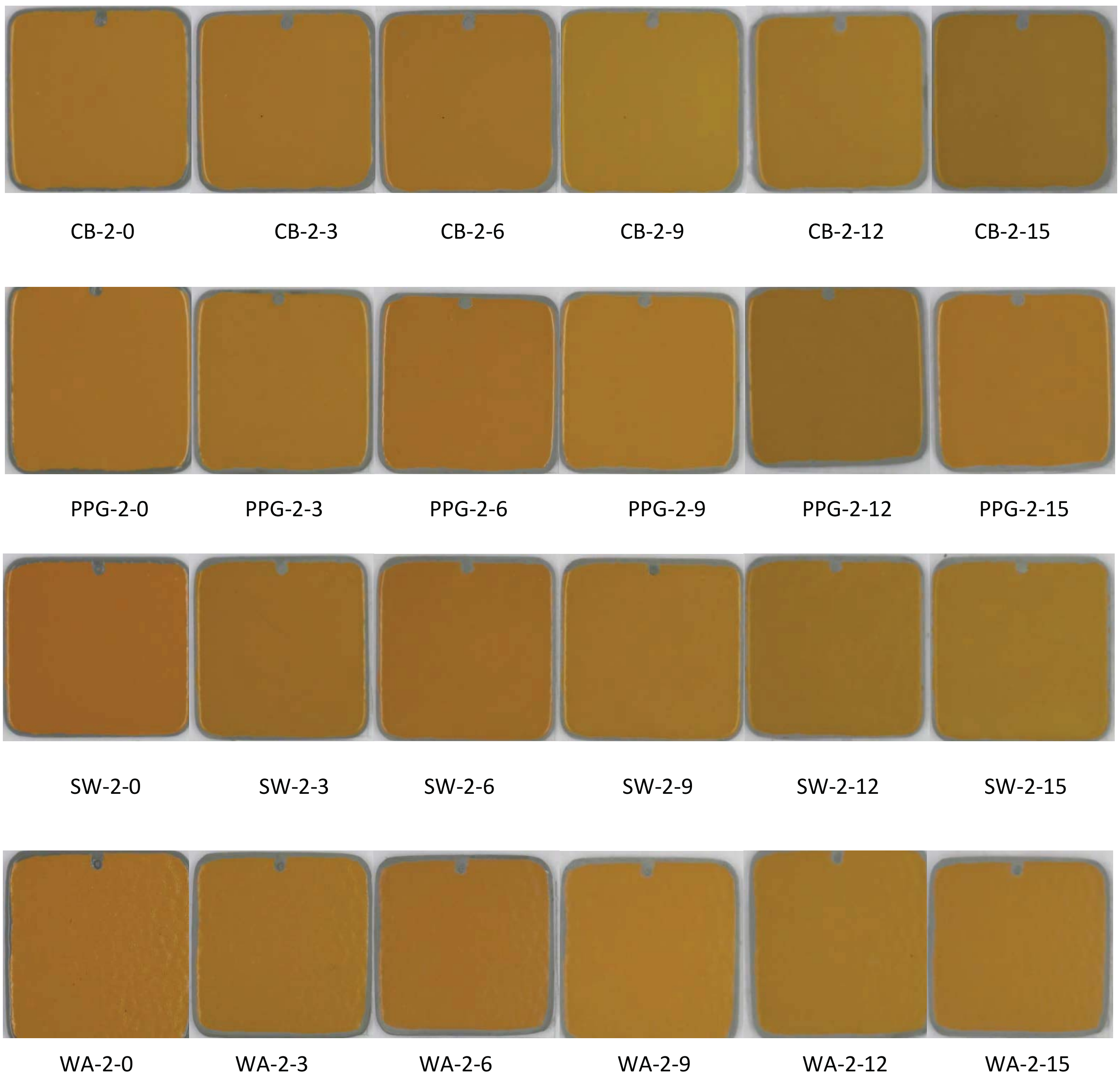



Figure 18 - Photographs of Coated Test Samples for Color Smoky Topaz for Coatings by Carboline (CB), PPG, Sherwin Williams (SW), and Wasser (WA)

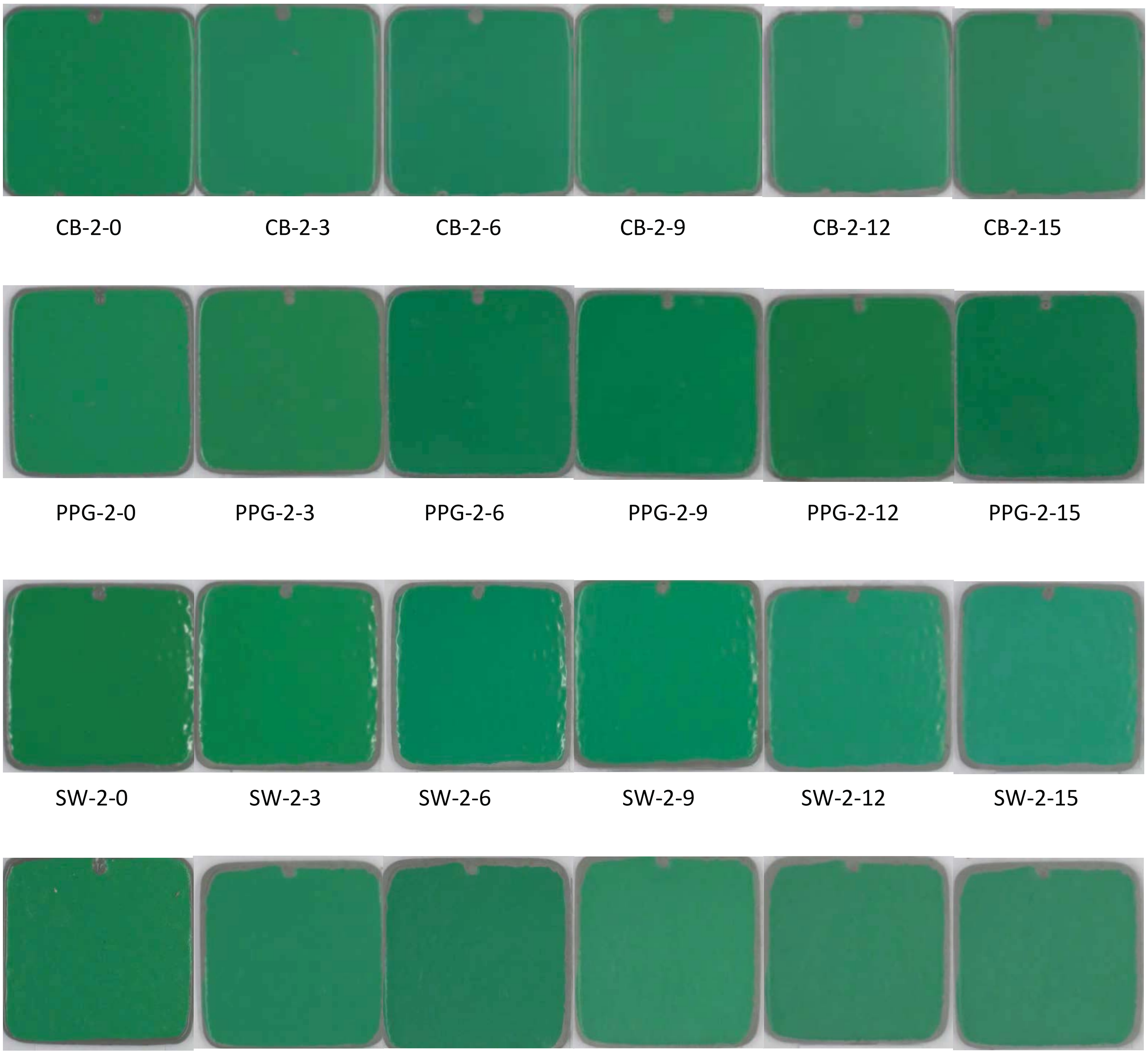



Figure 19 - Photographs of Coated Test Samples for Color Green for Coatings by Carboline (CB), PPG, Sherwin Williams (SW), and Wasser (WA)

Additional photographs for other test samples with associated coatings and colors are submitted as a part of this report in the form of a digital media.

### 3.4 Evaluation of Gloss Retention

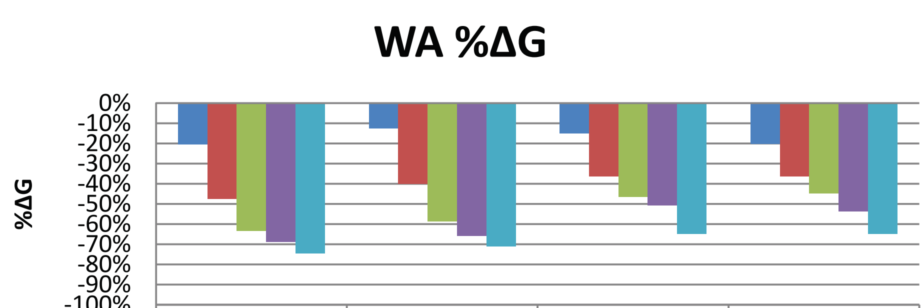
The measured initial mean gloss values (in control test samples), for the coatings and colors used in this study, ranged from 16.7 to 83.5. The initial mean gloss values for each manufacturer's product, regardless of the colors used, were 55.0 for Sherwin Williams, 19.4 for Wasser, 74.24 for PPG, and 40.11 for Carboline. These measured values indicated that the product with the highest gloss at the initial stage of the test was by PPG, followed by Sherwin Williams, Carboline, and Wasser. Accordingly, at different stages of the testing program, the percent change in gloss values from those in the control test samples was obtained to evaluate gloss retention performance.

Figures 20, 21, 22, and 23 show the percent change in gloss at every three cycles of the Xenon Arc test for colors red, reddish brown, green, and smoky topaz. The figures show gloss changes for manufacturers Sherwin Williams, Wasser, PPG, and Carboline, respectively. It can be seen that the extent of the loss of gloss is nearly the same for coatings with different colors produced by each manufacturer. However, it can be seen that there is a significantly better gloss retention performance by the PPG's coating materials used in this study. The average loss of gloss between the initial stage and completion of the test for the PPG coating materials was only 18.75 percent, while the loss for the coating materials by the other three manufacturers ranged from 61.25 to 68.75 percent. The better gloss retention performance of the PPG coating materials used in this study may be associated with the use of dry colorants during the manufacturing process as described earlier in this report.

Additional test data related to gloss index measurements and gloss changes for all test samples with associated coatings and colors is submitted as a part of this report in the form of a digital media.

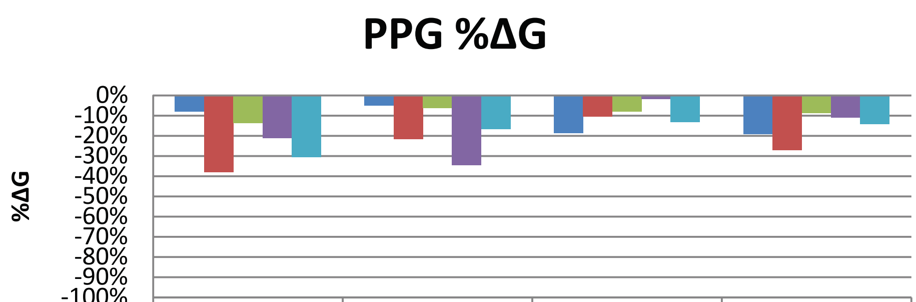

| | FC #11120 | FC #20152 | FC #24260 | FC #10371 |
|---|---|---|---|---|
| 3 Cycles | -0.04 | -0.09 | -0.11 | -0.24 |
| 6 Cycles | -0.21 | -0.18 | -0.04 | -0.14 |
| 9 Cycles | -0.41 | -0.36 | -0.22 | -0.30 |
| 12 Cycles | -0.64 | -0.36 | -0.22 | -0.28 |
| 15 Cycles | -0.81 | -0.57 | -0.57 | -0.52 |

Figure 20 - Percent Changes in Mean Gloss Values for Colors Red, Reddish Brown, Green, and Smoky Topaz During Xenon Arc Test for Sherwin Williams Coating Materials



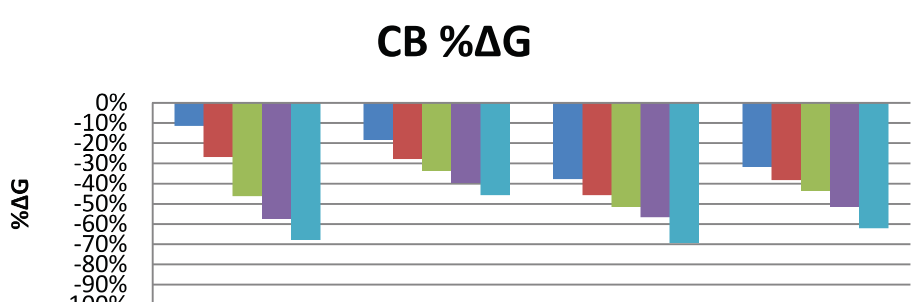

| | FC #11120 | FC #20152 | FC #24260 | FC #10371 |
|---|---|---|---|---|
| 3 Cycles | -0.20 | -0.13 | -0.15 | -0.20 |
| 6 Cycles | -0.48 | -0.40 | -0.36 | -0.36 |
| 9 Cycles | -0.64 | -0.59 | -0.47 | -0.45 |
| 12 Cycles | -0.69 | -0.66 | -0.51 | -0.54 |
| 15 Cycles | -0.74 | -0.71 | -0.65 | -0.65 |

Figure 21 - Percent Changes in Mean Gloss Values for Colors Red, Reddish Brown, Green, and Smoky Topaz During Xenon Arc Test for Wasser Coating Materials




| | FC #11120 | FC #20152 | FC #24260 | FC #10371 |
|---|---|---|---|---|
| 3 Cycles | -0.08 | -0.05 | -0.19 | -0.19 |
| 6 Cycles | -0.38 | -0.22 | -0.11 | -0.27 |
| 9 Cycles | -0.14 | -0.06 | -0.08 | -0.09 |
| 12 Cycles | -0.21 | -0.35 | -0.02 | -0.11 |
| 15 Cycles | -0.31 | -0.17 | -0.13 | -0.14 |

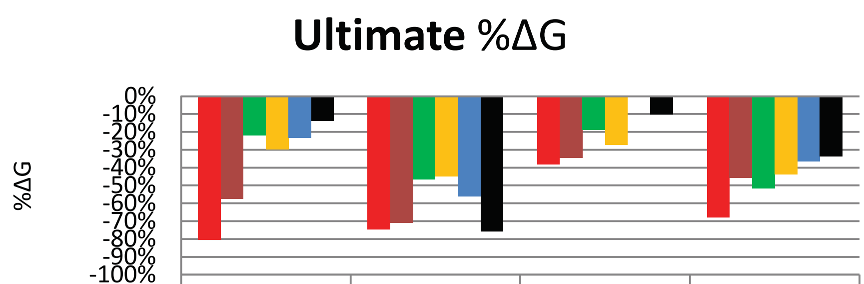
Figure 22 - Percent Changes in Mean Gloss Values for Colors Red, Reddish Brown, Green, and Smoky Topaz During Xenon Arc Test for PPG Coating Materials




| | FC #11120 | FC #20152 | FC #24260 | FC #10371 |
|---|---|---|---|---|
| 3 Cycles | -0.11 | -0.19 | -0.38 | -0.32 |
| 6 Cycles | -0.27 | -0.28 | -0.46 | -0.38 |
| 9 Cycles | -0.46 | -0.34 | -0.52 | -0.44 |
| 12 Cycles | -0.57 | -0.40 | -0.57 | -0.52 |
| 15 Cycles | -0.68 | -0.46 | -0.69 | -0.62 |

Figure 23 - Percent Changes in Mean Gloss Values for Colors Red, Reddish Brown, Green, and Smoky Topaz During Xenon Arc Test for Carboline Coating Materials

Figure 24 shows the ultimate percent change in mean gloss values for six colors, including colors black and blue from the initial study, for products by all of the manufacturers included in this study. It can be observed from the figure that there is a greater loss of gloss for colors red and reddish brown regardless of the manufacturer. It can also be noted that the loss of gloss in coating materials by PPG is significantly lower than that in the products by the other three manufacturers.




| | SW | WA | PPG | CB |
|---|---|---|---|---|
| FC #11120 | -0.81 | -0.74 | -0.38 | -0.68 |
| FC #20152 | -0.57 | -0.71 | -0.35 | -0.46 |
| FC #24260* | -0.22 | -0.47 | -0.19 | -0.52 |
| FC #10371* | -0.30 | -0.45 | -0.27 | -0.44 |
| FC #15092 | -0.23 | -0.56 | 0.00 | -0.36 |
| FC #27038 | -0.14 | -0.76 | -0.10 | -0.34 |

Figure 24 - Ultimate Percent Change in Mean Gloss Values for Colors Red, Reddish Brown, Green, Smoky Topaz, Blue, and Black Coating Materials

## 4.0 Summary, Recommendations, and Future Work

### 4.1 Summary

Laboratory accelerated UV radiation tests for steel top coats are not substitutes for real outdoor environmental exposures but may be used to predict how they can retain their color and gloss over several years of service. In particular, such tests can be beneficial when multiple top coats and colors from different manufacturers are subjected to the same radiation exposures in a reasonably manageable time frame. A comparative evaluation of the performance of the top coats in the test program will yield information that can aid bridge owners to select the best performing top coat for their application.

Coating selection, surface preparation, and application are equally important for acceptable performance of coating systems. At a minimum, it is important to follow manufacturers' recommendations and applicable specifications when coatings are used for aesthetics and for protecting steel railings in bridges. In addition, special provisions and specifications from bridge owners must be followed to enhance the effectiveness of a coating system.

It is known that different color pigments and the way they are mixed in coating materials during the manufacturing process can significantly affect the color and gloss retention performance of top coats exposed to various in-service environments. To address this issue, the Wisconsin Department of Transportation (WisDOT) and Wisconsin Highway Research Program (WHRP) initiated this work as a follow up study to an earlier project entitled, "Aesthetic Coatings for Steel Bridge Components." The WHRP Project ID for the first study was 0092-11-07. The first study completed an evaluation of the performance of a series of coating systems for both durability and aesthetics and a final report was submitted to WHRP in 2013 (1). The new study aimed to determine the color and gloss retention performance of the top coats in the four best performing coating systems from the first study with for four new colors that were not included in the earlier study.

The best performing coating systems from the initial study included: Sherwin Williams Acrolon 218 HS, Carboline Carbothane 133 LH, PPG Amercoat 450H, and Wasser MC-Luster 100. Top coat performance in terms of color and gloss retention for colors black (Federal Color 27038) and blue (Federal Color 15092) was evaluated in the initial study using the Xenon Arc exposure. Using these selected top coats, the new study included color and gloss retention evaluation for colors red (Federal Color number 11120), reddish brown (Federal Color number 20152), green (Federal Color number 24260), and smoky topaz (smoky yellow, Federal Color number 10371).

Color and gloss retention performance for the selected top coats and colors was evaluated by conducting a series of Xenon Arc tests on sixty four laboratory test samples according to appropriate ASTM specifications. Each top coat/color sample was subjected to 1,260 cycles of Xenon Arc exposure or a total period of 2,520 hours. Gloss retention index, color retention index and dry film thickness for each sample were measured according to the appropriate ASTM specifications.

The test results indicated that the black color (Federal Color 27038) top coats from all of the selected manufacturers generally exhibited the most stability in terms of retaining the original color and gloss. The greatest level of loss of color and gloss occurred in color red (Federal Color 11120) regardless of the choice of manufacturer. Colors blue, green (except for Sherwin Williams), and smoky topaz exhibited acceptable color and gloss retention characteristics while color reddish brown showed slightly higher loss of color and gloss. All colors in the study, except color green by Sherwin Williams, exhibited a darkening effect with increasing exposure to Xenon Arc radiation. The darkening effect is verified through observation of a reduction in the $\Delta L^*$ values at various stages of the test.

It was found that the selected PPG coating, in the four colors selected for this study, exhibited a higher initial gloss before the start of the Xenon Arc tests and performed better in terms of color and gloss retention. The better performance of the selected PPG product may be associated with the use of dry colorants used for this coating during its manufacturing process.

### 4.2 Recommendations

A series of recommendations are provided below for the selection of appropriate top coat materials and colors so an acceptable coating performance can be achieved during the service life.

I. The colors black and blue may be selected for bridge railings with more certainty regarding their color and gloss retention.

II. The color red, from all selected manufacturers in this study, exhibited more loss of color and gloss when subjected to the Xenon Arc radiation. Accordingly, it is recommended that the color red, from the manufacturers in this study, not be selected for top coat applications in bridge railings. The color reddish brown exhibited a somewhat better performance. If these colors are to be selected for bridge railings, it is recommended that additional performance verification be provided by manufacturers through test results from independent sources.

III. For all colors, it is recommended that the use of dry colorants be considered during the manufacturing process of the coating materials with desired colors. This may require a higher initial cost but could offer better color and gloss retention performance and durability during the service life of the coating.

**4.3 Future Work**

WisDOT could benefit from future studies that can address current shortcomings in existing coating systems and to identify more effective coating systems for bridge steel railings. The following recommended future studies could achieve the above stated benefits:

I. Investigate the color and gloss retention performance of coatings with dry colorants to achieve desired colors. Based on the observations from this study and communications with some of the manufacturers' representatives, it appears that the use of dry colorants during the manufacturing stage could result in a better color and gloss retention performance. To date, no studies have been performed to investigate the advantages of the use of dry colorants in coatings.

II. Investigate the performance of fluoropolymer top coats in duplex systems. The past WHRP coating studies have demonstrated excellent performances by duplex systems for resistance against corrosion and by fluoropolymer top coats for aesthetics. It seems that an ideal coating system may be achieved by using fluoropolymer top coats in duplex systems. To date, no studies have been performed for this system.

III. Investigate the performance of edge retentive epoxy mid-coating materials as well as stripe coating on member geometries with sharp edges and discontinuities to determine their performance effectiveness. It is known that sharp edges in coated structures generally will have a reduced dried film thickness (DFT) due to surface tension forces of the liquid coating materials during the drying process. This phenomenon is common in bridge railings due to the inherent geometrical shapes of the railings. Accordingly, some edges or areas of the structure may be more susceptible to premature coating failures.

IV. Perform realistic accelerated outdoor testing, at the site of selected Wisconsin bridges, on good performing coating systems from the past WHRP coating studies to correlated results with those from the past laboratory studies. Both small test samples and full size coated railing sections should be prepared and placed at the test sites for investigation. Exposure to the outdoor environment will introduce the effects of additional site-specific factors including true temperature variations, humidity, intrusive chemicals/particles in the air, UV, and others on structural elements that are coated with various coating systems. These factors cannot generally be included in the laboratory accelerated testing.

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