

FHWA BRIDGE COATING STUDY YIELDS PRELIMINARY TEST RESULTS

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ince the coatings industry changed in the 1970s from coating systems with lead-based primers to systems with zinc-based primers, the typical service life of a zinc-rich coating has been assessed to be about 30

years before a major touch-up is required. Typical concerns with zinc-rich systems include the cost of removing mill scale before coating application, the time and space required for shop application, and the logistics of moving heavy steel members from the shop to the field. A good alternative to addressing these cost

issues is to extend the service life of the existing coating system on steel before any maintenance or replacement is required of the existing coating system.¹

To search for inexpensive and durable coating systems, the FHWA Coatings and Corrosion Laboratory (CCL) at Turner-Fairbank Highway Research Center initiated the FHWA 100-year coating study. This in-house study was initiated in August 2009 under the U. S. Congress's mandated program on high-performance steel. The objective of this study is to identify and evaluate coating materials that can provide 100 years of virtually

Table 1: Selected Coating Systems

System Number	Category	Generic Coating Name	Acronym
1	Control: conventional 3-coat shop system	Inorganic zinc / epoxy / aliphatic polyurethane	IOZ/E/PU
2	Control: 3-coat organic zinc shop system	Zinc-rich epoxy / epoxy / aliphatic polyurethane	E/E/PU
3	3-Coat fluoro-topcoat system	Moisture-cured urethane-zinc / epoxy / fluorourethane	MCU/E/F
4	2-Coat fast dry coating	Zinc-rich epoxy / aliphatic polyurethane	E/PU
5	2-Coat polysiloxane	Inorganic zinc / polysiloxane	Zn/PS
6	Metallizing (conventional) + topcoat	Thermal sprayed zinc / linear epoxy	TSZ/LE
7	Organic zinc-rich epoxy (zinc flake) / linear epoxy	Experimental primer / topcoat	ZnE/LE
8	Calcium sulfonate alkyd	High-ratio, single-coat CSA	HRCSA

Test Panels and Test Conditions

Typically, for its in-house coating studies, FHWA uses conventional, rectangular-shaped, 4-inch x 6-inch test panels. For this study, in addition to using conventional panels, FHWA adopted a new test panel design to closely simulate the steel coated on highway bridges. The new panels are 18 inches x 18 inches, with a welding joint and two angle attachments. All 4-inch x 6-inch panels will be referred to as Type I; 18-inch x 18-inch panels will be referred to as Type II panels. Figure 1 shows a typical Type II panel with a v-notch (welding joint), a T-shaped angle attachment and a wide-angle attachment.

maintenance-free service life for the steel bridge structures at costs comparable to those of existing coatings. Coating systems were selected based on past experience and results from previous FHWA studies that had evaluated coating systems such as moisture-cured urethanes, waterborne acrylic and epoxy systems, two-coat zinc-rich rapid deployment systems, overcoating systems, and one-coat systems.²⁻⁶ This article presents an overview of the work plan as well as the first data sets collected through six 360-hour accelerated test cycles and one 6-month outdoor exposure test cycle. The article also describes design innovations in test panels and testing.

The corresponding dimensions of each component are also shown.

All Type I test panels were coated according to each manufacturer's recommendations for dry film thickness (DFT). The test surface of a Type II panel consisted of three areas of varying DFT values:

- (a) Area 1—Target DFT
- (b) Area 2—DFT is 20% less than the target DFT
- (c) Area 3—DFT is 20% more than the target DFT

Test results from these three DFT areas will help show how DFT areas thinner than target DFT and DFT areas

Experimental Procedure

Selected Coating Systems

Table 1 summarizes eight coating systems studied. Two 3-coat systems were used as controls; the remaining coating systems included another 3-coat system, four 2-coat systems, and a 1-coat system. The acronyms used for all the coating systems can also be seen in the far right column of Table 1. This article will use these acronyms to identify the coating systems. All the coating systems were applied to steel substrates prepared to SSPC-SP 5 (White Metal Blast).

Editor's Note: This article is based on a paper the authors will present at SSPC 2011 featuring GreenCOAT, the conference of SSPC: The Society for Protective Coatings. The conference will be held in Las Vegas, NV, January 31-February 3.

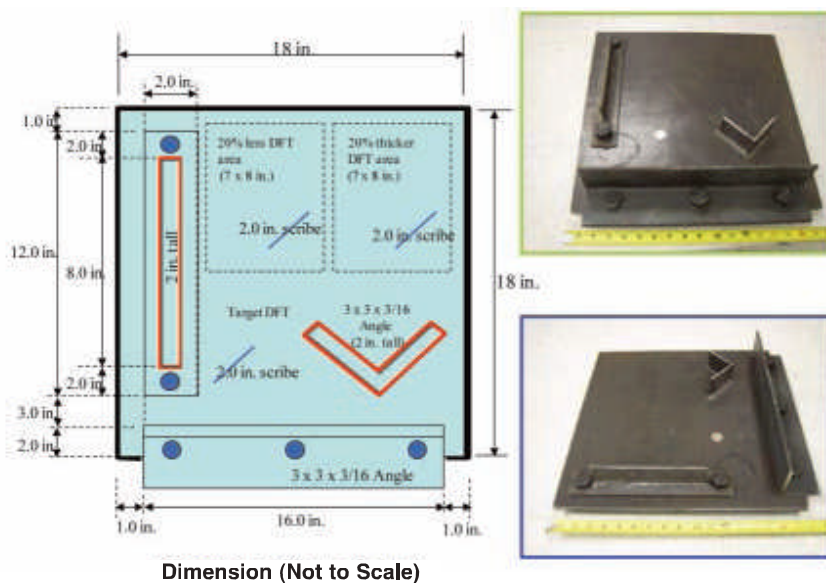


Fig. 1: Type II Test Panels

Initial Results from FHWA's Bridge Coating Study

Table 2: Type I Test Panels

Group	Number of Coating Systems	Accelerated Lab Test ^a	Outdoor Tests		Physical T	Total Number of Test Panels
		ALT	NW	NWS		
Uncoated steel			2 ^b	2 ^b		4
Control	2	10	5 ^c	5 ^c		24
Others	6	30	15 ^c	15 ^c		72
Subtotal	8	40	22 ^c	22 ^c	16	100

ALT – Accelerated Laboratory Testing; NW – Natural Weathering; NWS – Natural Weathering with Salt Spray

^a 3 scribed + 2 unscribed = 5 panels/coating system

^b 2 panels for periodic salt spray outdoor exposure and 2 panels for natural outdoor exposure (no salt spray), respectively

^c 2 scribed and 1 unscribed panels/coating system for periodic salt spray outdoor exposure and 1 scribed and 1 unscribed panels/coating system for natural outdoor exposure = total 5 panels/coating system

^d 2 unscribed panels/coating system

Table 3: Type II Test Panels

Group	Number of Coating Systems	NW	NWS	GGB*	Total
Uncoated steel		1	1	1	3
Control	2	2	2	2	6
Others	6	6	6	6	18
Subtotal	8	8	8	8	27

*GGB – Golden Gate Bridge

Table 4: Accelerated Lab Testing of Type I Panels

Item	Freeze Exposure (Hours)	UV-Condensation Exposure (Hours)	Prohesion Exposure (Hours)	Total Exposure (Hours)
Each Cycle	24	168	168	360
Target Duration (20 cycles)	480	3,360	3,360	7,200

thicker than target DFT compare to the target DFT area for the coating systems tested. Figure 1 also shows the physical locations of these test areas on the surface of the Type II test panel.

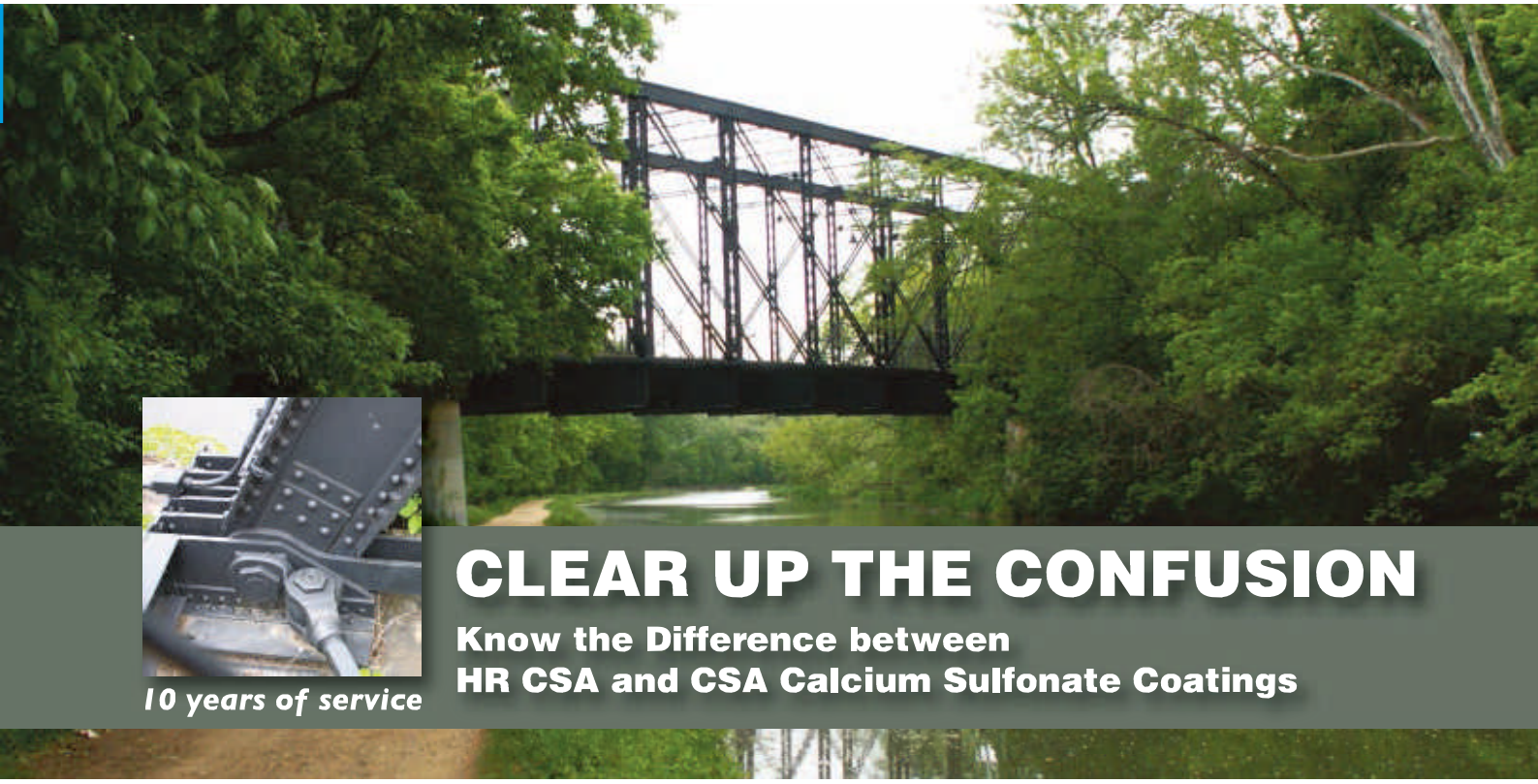
In all, 100 Type I and 27 Type II test panels were prepared for accelerated and outdoor testing, respectively. Tables 2 and 3 list the types and number of test panels. Outdoor exposure tests were arranged in the backyard of Turner-Fairbank Highway Research Center (TFHRC) with and without salt spray. Another outdoor test was conducted at Golden Gate Bridge (GGB) in San Francisco, California.

Each coating system was sprayed on 12 Type I panels. Five panels were tested in accelerated conditions, and five panels were tested outdoors in natural weathering and natural weathering with salt spray. None of the Type I panels were tested at the Golden Gate Bridge. The two remaining Type I panels were used exclusively for physical testing such as adhesion strength and Fourier Transform Infrared Spectroscopy analysis. Four uncoated steel panels were also deployed on the outdoor exposure racks, two on each exposure rack with and without salt spray.

For outdoor exposure testing on three racks—two for natural weathering (with and without salt spray) at TFHRC and one at GGB—3 Type II panels were coated with each coating system; 3 uncoated steel panels were also employed for each, making a total of 27 panels.

An independent coating laboratory prepared the test panels and delivered them to TFHRC. After their as-received condition was documented, half of the Type I test panels were scribed and the other half remained unscribed. DFT areas of all of the Type II test panels were scribed.

Three out of the 5 (Type I) panels for accelerated testing and 3 out of 5 (Type I) for outdoor testing were scribed



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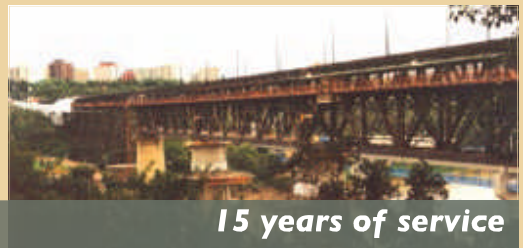
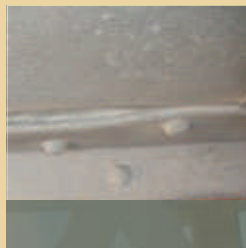
HR CSA coatings typically run 7,000 to 10,000 hrs ASTM B117 Salt Fog depending on film thickness. In a recent independent test run by a national authority HR CSA went 6820 hours under an ASTM D5894 protocol with a freeze thaw cycle. The test was terminated and the HR CSA showed no signs of failure.

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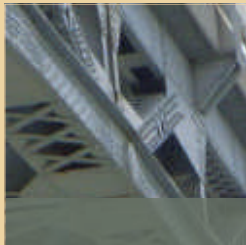


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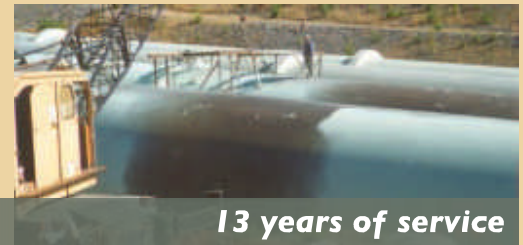
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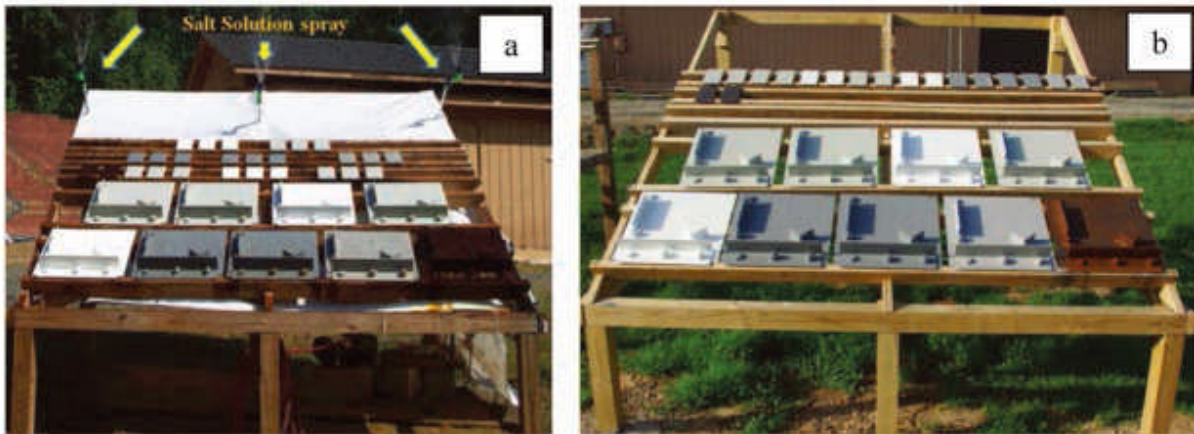


Fig. 2: (a) Natural weathering with salt rack and (b) natural weathering rack

according to ASTM Method D 1654. Using a mechanical scriber, researchers made a 2-inch long, diagonal scribe on each panel.

All test areas of Type II test panels were scribed (Fig. 1). A mechanical scribing tool used for Type I panels was not suited for the large size test panels; hence, the Type II test areas were scribed using a high-speed Dremel tool with a rotary bit. C-clamps were used to support a metallic guide, along which the scribing was done using the Dremel bit.

The exposure conditions used in the 100-year study are summarized in Tables 2 and 3.

Accelerated Testing

Table 4 summarizes the test conditions for accelerated testing and the total number of cycles. Each accelerated laboratory test cycle was carried out for 360 hours and a total of 20 cycles will be carried out. Upon completion of every 360-hour cycle, the panels are examined for their performance. A detailed description of each 360-hour test cycle is shown below.

1. Freeze: 24 hours
Temperature: -23 C (-10 F)
2. UV/Condensation: 168 hours (7 days)
Test cycle: 4 hours
UV/4-hour condensation cycle
UV lamp: UVA-340
UV temperature: 60 C (140 F)
Condensation temperature: 40 C (104 F)

3. Prohesion (Cyclic Salt-Fog, ASTM G85): 168 hours (7 days)

Test cycle: 1-hour wet/1-hour dry

Wet cycle: A Harrison Mixture of 0.35 wt% ammonium sulfate and 0.5 wt% sodium chloride was used. Fog was introduced at ambient temperature.

Dry cycle: Air was preheated to 35 C (95 F) and then was purged to the test chamber.

Natural Weathering with and without Salt Spray

Type I and Type II test panels were deployed on wooden racks inclined at 30 degrees facing south. Figures 2(a) and 2(b) show the test panels deployed initially in the back yard at Turner Fairbank Highway Research Center in Mclean, Virginia.

A 15 wt% sodium chloride solution was sprayed onto these test panels every 24 hours by an automatic salt spray system. This system was built in-house. It works with a timing switch turning on an electro-mechanical pump every 24 hours to spray these test panels for a short period (15 seconds) with the salt solution. After a week of salt spray, due to excessive salt deposit buildup, the

salt solution was changed from 15 wt% sodium chloride to the Harrison mixture (0.35 wt% ammonium sulfate and 0.5 wt% sodium chloride). Test panels are evaluated every 6 months for coating performance.

Golden Gate Bridge

The outdoor exposure test conditions at Golden Gate Bridge can be considered harsh because of the severe fog, which also contains airborne chlorides. Figure 3 shows Type II panels deployed near the south abutment at the Golden Gate Bridge. Test panels are evaluated every 6 months for coating performance.

Initial Coating Characterization and Performance Monitoring

Coating systems in this study were characterized through Fourier



Fig. 3: Type II panels deployed at the Golden Gate Bridge

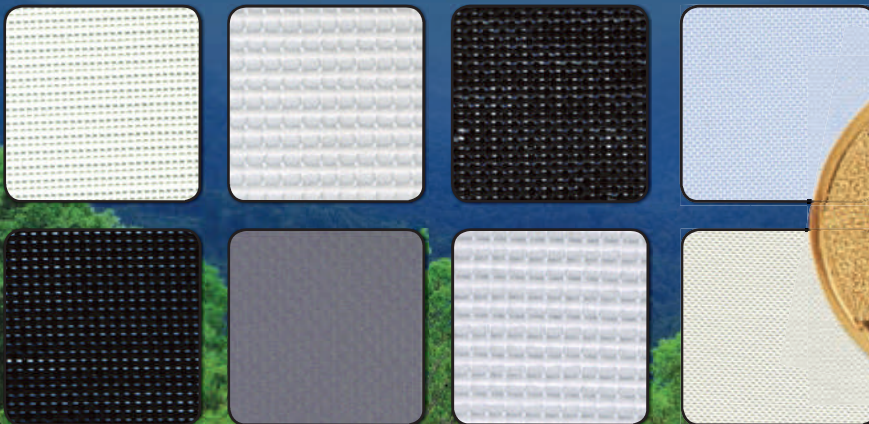


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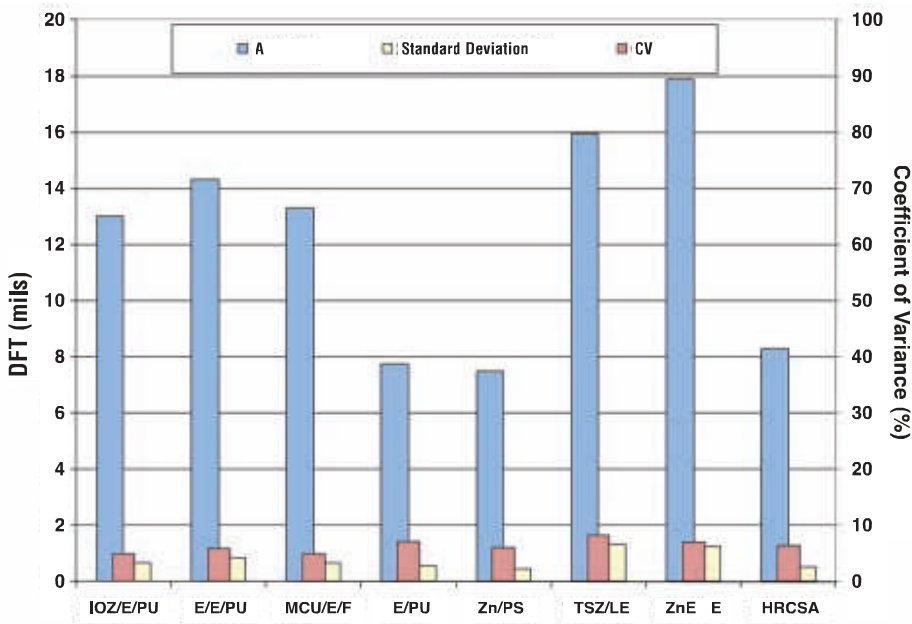


Fig. 4: Mean DFT values (Type I panels)

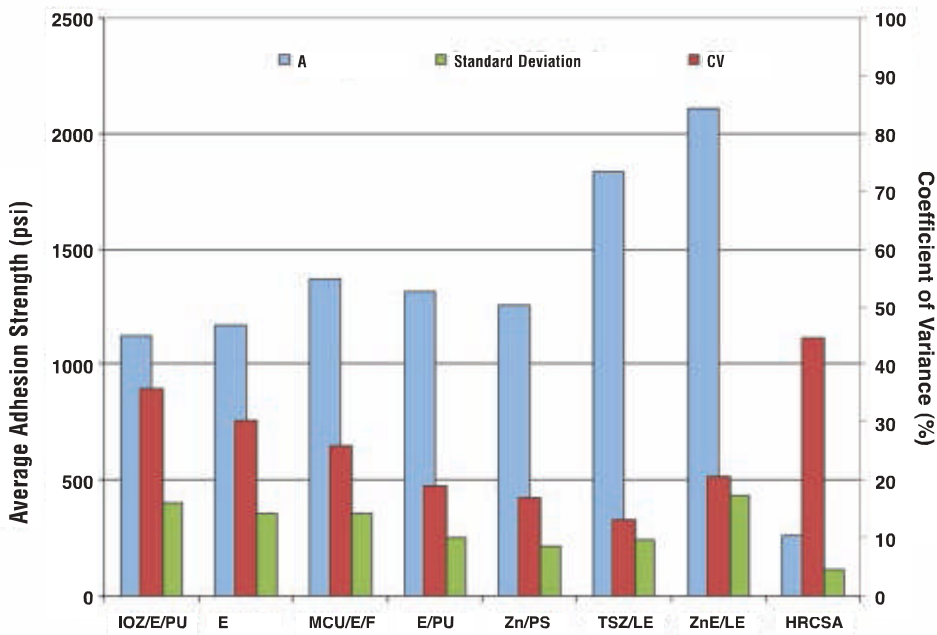


Fig. 5: Mean adhesion strength values (Type I panels)

Transform Infrared (FTIR) Spectroscopy and pull-off adhesion.⁷ The tests were performed on two extra panels for each coating system. The adhesion tests were conducted with a hydraulic pull-off adhesion tester, and the nominal adhesion strength of a coating system was calculated by averaging six readings from two panels.

DFT and the number of holidays were measured on individual panels using SSPC-Paint Application Specification No. 2 and ASTM D5162^{8,9} before the panels were exposed to accelerated or outdoor testing. Digital photographs were also taken before testing to document their as-received conditions. A low voltage holiday detector was used for the hol-

iday measurement. Electrochemical Impedance Spectroscopy (EIS) was used to determine initial impedance properties of selected test panels and monitor their subsequent changes upon exposure. The gloss and color of each panel were measured by methods described in ASTM D523 and D2244, respectively.^{10,11}

During the tests, test panels were evaluated periodically by monitoring changes in the number of holidays and physical condition. Measurements were made after every 360 hours of laboratory testing and after every six months for outdoor exposure testing. Digital photographs were taken to document progressive changes of individual panels. Growth of rust creepage at the scribe was monitored according to ASTM D7087.¹²

Preliminary Test Results

This section presents initial coating characterization results and preliminary test results from accelerated testing and outdoor exposures pertaining to color and gloss, DFT, pull-off adhesion, surface appearance, holidays, and creepage. Some supplementary photographs are included.

DFT

Figure 4 shows the mean DFT, standard deviation, and coefficient of variance (CV) of each coating system. DFT varied significantly, from 7.5 mils to 17.8 mils, depending on the coating system. None of the mean DFTs were less than 7 mils, and three systems (E/PU, Zn/PS, and HRCSA) were between 7 and 10 mils. All three-coat systems (IOZ/E/PU, E/E/PU, and MCU/E/F) had mean DFTs between 10 mils and 15 mils. The remaining two-coat systems (TSZ/LE and ZnE/LE) had DFTs exceeding 15 mils. Variation of DFT data, in terms of CV and standard deviation, was the highest for the last group of coating systems.

Pull-Off Adhesion

Initial mean adhesion values and their variability are shown in Fig. 5. ZnE/LE exhibited the highest adhesion strength of 3160 psi (CV 20%) while HRCSA demonstrated the lowest adhesion strength of 259 psi (CV 44%). All remaining three-coat and two-coat systems except TSZ/LE showed adhesion strengths from 1,000 to 1,500 psi (CV 15–25%). TSZ/LE had the second highest adhesion strength of 1,834 psi (CV 13%). The two control coating systems had adhesion strengths of 1,119 and 1,173 psi respectively (CV 30 and 35%).

Holidays

Figure 6 shows the cumulative (preliminary) number of holidays detected during the accelerated laboratory testing. When excessive holidays were detected, discrete defect spots could not be identified, and an arbitrary number of 100 was entered in the data sheet. Excessive numbers of holidays were observed on the surface of the TSZ/LE coating system. Initial assessment of this coating system showed no holidays on the surface. However, one of the panels demonstrated more than 20 holidays after 1,080 hours of testing, and the number of holidays increased excessively after two accelerated cycles that followed (after 1,440 and 1,800 hours of testing). These surface defects were then followed by excessive blistering and cracking of the surface of the coating system.

The rest of the three-coat, two-coat, and one-coat systems demonstrated either zero or minimal coating defects on the surface after 2,160 hours of accelerated testing.

Test panels coated with the Zn/PS coating system had initial defects to begin with on the low DFT area of Type II panels. After outdoor exposure of six months, none of the test areas on the Type II panels had developed any new holidays. All Type II test panels

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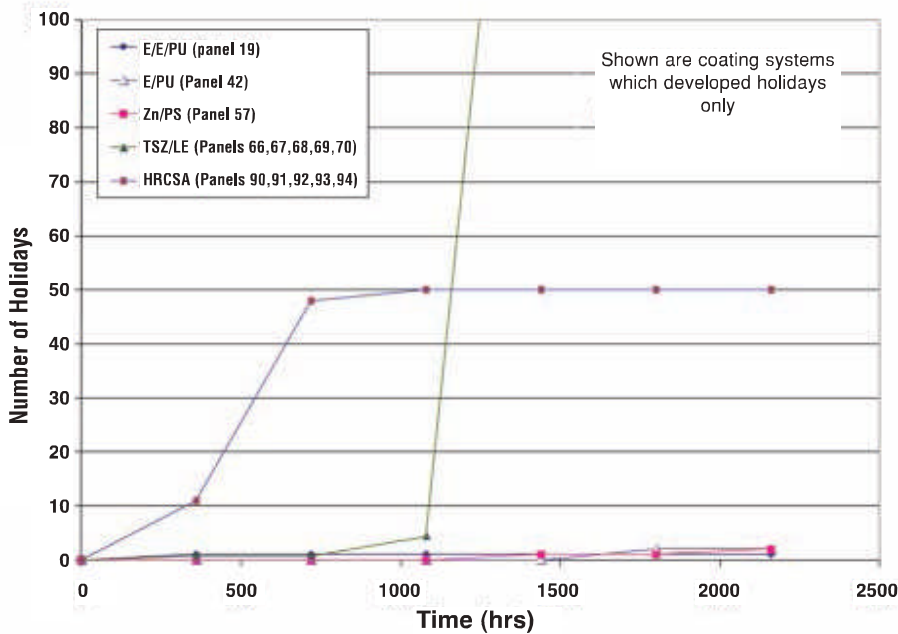


Fig. 6: Cumulative holiday development during accelerated testing

had coating defects in areas such as nuts, bolts, the underside of the T-attachment, and the wide angle attachment. These areas appeared to have developed rusting in areas of improper coating application. They will be carefully monitored over time for coating degradation and rusting.

Rust Creepage

Figure 7 shows rust creepage data for eight coating systems after 2,160 hours of accelerated testing. MCU/E/F (2.0

mm) and E/E/PU (1.42 mm) have shown more than 1.0 mm creepage at 2,160 hours. HRCSA, IOZ/E/PU, E/PU and Zn/PS showed creepage growth of less than 1 mm. Based on the creepage values at the end of 2,160 hours of accelerated testing; the coating systems can be ranked in the following order of highest to lowest rust creepage:

MCU/E/F > E/E/PU > E/PU > Zn/PS > HRCSA > IOZ/E/PU

It is interesting to note that the inorganic zinc three-coat control has the best per-

formance for rust creepage, followed by the HRCSA. The latter coating system has performed well in earlier studies,⁵ and a similar trend is being observed here up to 2,160 hours of accelerated testing.

The surface of the TSZ/LE coating system at 2,160 hours of accelerated testing indicated surface blistering and peeling off of the coating system all over the surface for both scribed and unscribed panels.

After six months of outdoor exposure at TFHRC in natural weathering with salt spray, two of the Type I panels coated with ZnE/LE coating system developed severe rust creepage of 7.6 mm. On a high DFT area of ZnE/LE on Type II panels, high rust creepage (11.8 mm) developed. The high DFT area of the three-coat control IOZ/E/PU was the only other coating system that showed moderate creepage of 1.9 mm after six months of exposure in natural weathering with salt spray.

Surface Deterioration

Figures 8 through 10 show selected Type I test panels representing coating systems with the best (HRCSA), moderate (E/PU), and worst (TSZ/LE) performance during the accelerated laboratory testing at 0; 1,080; and 2,160 hours. Similarly, Figs. 11

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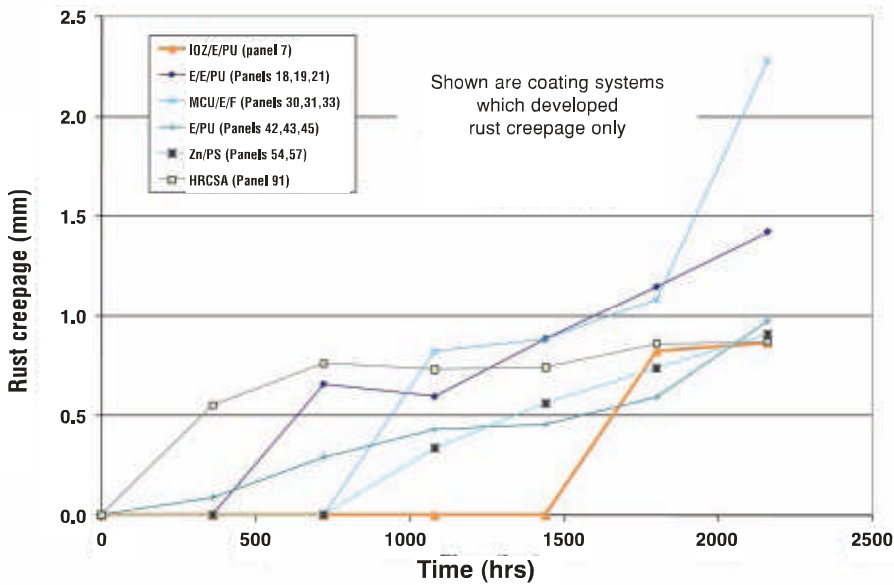


Fig. 7: Rust-creepage growth with time accelerated testing

a
els that showed the best (HRCSA) and worst (ZnE/LE) surface deterioration after six months of exposure in natural weathering with salt spray.

The three-coat inorganic zinc control (IOZ/E/PU) had the best surface retention properties in terms of holidays, rusting, and blistering. However, this is expected of a control coating system. The next best performing coating system among the candidate coating systems was identified as the HRCSA. The E/PU had a moderate development of holidays and rust creepage growth. The

- TSZ/LE coating system had the worst surface deterioration, as indicated by the development of holidays, surface blistering, and coating peel-off.

The visual observation of surface changes was followed up with digital microscopy of the surface of the test panels. Digital microscopy of the TSZ/LE coating system showed the

phases of its progressive deterioration. Certain areas still had blisters intact while some areas had half-peeled off coating or detachment of the coating from the surface. White residual zinc oxide was forming on the surface in the areas where coating had peeled off.

Digital microscopy at 1,440 hrs of accelerated testing yielded another important experimental observation. The surface of the ZnE/LE coating system demonstrated micro-cracks all over the surface of the coating system. Cracks appeared to have spread across the coating surface. The central points at which these micro-cracks originated seemed to be a few microns in size, and the cracks themselves were a few hundred microns in size. However, the surface of these test panels did not demonstrate any holidays, indicating that the

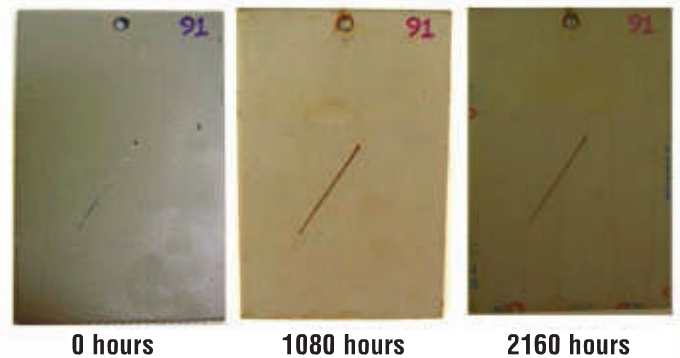



Fig. 8: Progressive changes of HRCSA (1-coat system)




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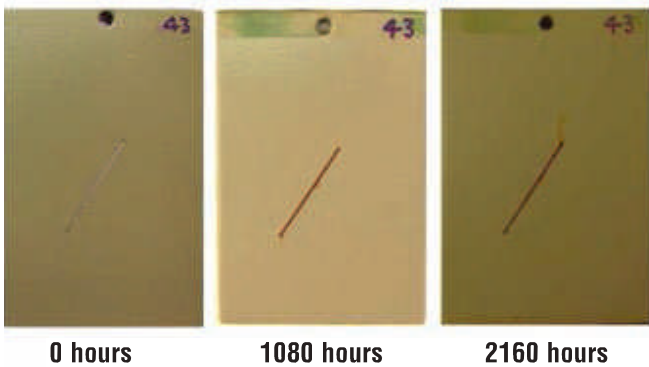


Fig. 9: Progressive changes of E/PU (2-coat system)

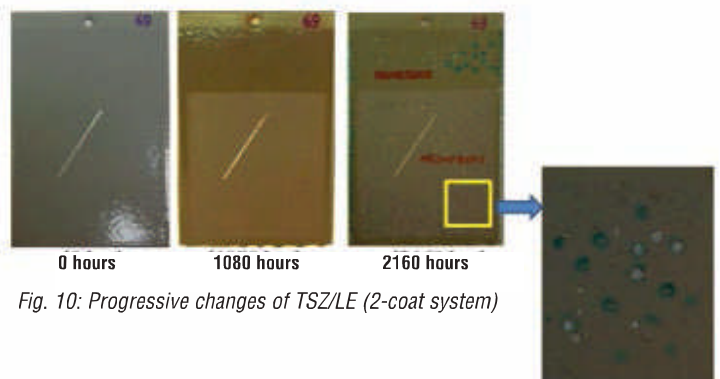


Fig. 10: Progressive changes of TSZ/LE (2-coat system)

cracks did not develop through the coating thickness and may have originated only on the surface. The density of the cracks seemed to increase as the time of accelerated testing increased.

Comparison of digital microscopy images before and after exposure indicated that these crack-originating locations were on the panel surface before testing. However, the cracks that propagated from these locations have

appeared after accelerated testing. During outdoor exposure testing, except for ZnE/LE, none of the Type I panels and the Type II panel test areas developed holidays or rust creepage at the scribe. Figures 11 and 12 show the Type II test panels for the HRCSA and ZnE/LE coating systems.

Summary of Preliminary Findings

In this study, a new test panel was

designed, and 27 of the new panels were used. They include welding joints and angle attachments. On the new design, three DFT areas of varying thickness were selected to simulate field conditions. Based on the initial coating characterization—six accelerated test cycles and one 6-month outdoor exposure cycle—some preliminary findings are summarized below.

1. Two three-coat systems were cho-



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Fig. 11: Progressive changes of HRCSA

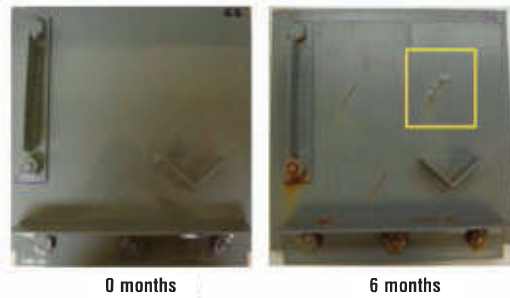


Fig. 12: Progressive changes of ZnE/LE

sen as the controls, and another three-coat system, four two-coat systems, and one one-coat system were selected as candidate coating systems.

2. Adhesion strength of the three-coat systems was comparable to that of the three-coat systems, but four times higher than the adhesion strength of the one-coat system.

3. The TSZ/LE coating system developed the highest number of defects during accelerated testing up to 2,160 hours, but no holidays developed on the surface after outdoor testing. The defect formation was progressively followed by blisters and by the coating peeling from the surface.

4. MCU/E/F developed the highest amount of rust creepage (almost twice) in comparison to the rest of the coating systems in accelerated testing. As was expected, the inorganic three-coat control (IOZ/E/PU) had the lowest creepage, followed by the HRCSA.

5. In outdoor exposure testing, ZnE/LE developed severe rust creepage on both Type I and Type II panels.

6. During accelerated testing, ZnE/LE developed micro cracks on the surface.

7. All coating systems developed no new holidays and surface deterioration after the first outdoor exposure cycle at the TFHRC and the Golden Gate Bridge.

[Note below received close to press time—Ed.]

Note: Due to unexpected premature failures of certain coating systems, the FHWA 100-year coating study has been terminated in December 2010.

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Initial Results from FHWA's Bridge Coating Study

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