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Rail Base Corrosion and Cracking Prevention: Phase 2

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13. ABSTRACT (Maximum 200 words)
EWI was engaged by the Federal Railroad Administration to research rail treatments to prevent rail base corrosion in corrosive environments. A coating system was selected in Phase 1 and recommended for field trials. In Phase 2, four railroads sponsored the acquisition of coated rail sets and three installed them in-track. The coating suffered from adhesion loss and premature failure. The potential cause for failure was identified by the coating supplier. An additional set of four coating systems was tested in Phase 2B, using both accelerated laboratory exposure and ambient outdoor exposure. The laboratory tests included standard industry exposure tests. The outdoor exposure testing included salt applications. Based on the results of these tests, EWI is recommending a new coating for field trials.

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METRIC/ENGLISH CONVERSION FACTORS

ENGLISH TO METRIC

LENGTH (APPROXIMATE)

1 inch (in)	=	2.5 centimeters (cm)
1 foot (ft)	=	30 centimeters (cm)
1 yard (yd)	=	0.9 meter (m)
1 mile (mi)	=	1.6 kilometers (km)

AREA (APPROXIMATE)

1 square inch (sq in, in^2)	=	6.5 square centimeters (cm^2)
1 square foot (sq ft, ft^2)	=	0.09 square meter (m^2)
1 square yard (sq yd, yd^2)	=	0.8 square meter (m^2)
1 square mile (sq mi, mi^2)	=	2.6 square kilometers (km^2)
1 acre = 0.4 hectare (he)	=	4,000 square meters (m^2)

MASS - WEIGHT (APPROXIMATE)

1 ounce (oz)	=	28 grams (gm)
1 pound (lb)	=	0.45 kilogram (kg)
1 short ton = 2,000 pounds (lb)	=	0.9 tonne (t)

VOLUME (APPROXIMATE)

1 teaspoon (tsp)	=	5 milliliters (ml)
1 tablespoon (tbsp)	=	15 milliliters (ml)
1 fluid ounce (fl oz)	=	30 milliliters (ml)
1 cup (c)	=	0.24 liter (l)
1 pint (pt)	=	0.47 liter (l)
1 quart (qt)	=	0.96 liter (l)
1 gallon (gal)	=	3.8 liters (l)
1 cubic foot (cu ft, ft^3)	=	0.03 cubic meter (m^3)
1 cubic yard (cu yd, yd^3)	=	0.76 cubic meter (m^3)

TEMPERATURE (EXACT)

[(x-32)(5/9)] °F = y °C

METRIC TO ENGLISH

LENGTH (APPROXIMATE)

1 millimeter (mm)	=	0.04 inch (in)
1 centimeter (cm)	=	0.4 inch (in)
1 meter (m)	=	3.3 feet (ft)
1 meter (m)	=	1.1 yards (yd)
1 kilometer (km)	=	0.6 mile (mi)

AREA (APPROXIMATE)

1 square centimeter (cm^2)	=	0.16 square inch (sq in, in^2)
1 square meter (m^2)	=	1.2 square yards (sq yd, yd^2)
1 square kilometer (km^2)	=	0.4 square mile (sq mi, mi^2)
10,000 square meters (m^2)	=	1 hectare (ha) = 2.5 acres

MASS - WEIGHT (APPROXIMATE)

1 gram (gm)	=	0.036 ounce (oz)
1 kilogram (kg)	=	2.2 pounds (lb)
1 tonne (t)	=	1,000 kilograms (kg)
	=	1.1 short tons

VOLUME (APPROXIMATE)

1 milliliter (ml)	=	0.03 fluid ounce (fl oz)
1 liter (l)	=	2.1 pints (pt)
1 liter (l)	=	1.06 quarts (qt)
1 liter (l)	=	0.26 gallon (gal)
1 cubic meter (m^3)	=	36 cubic feet (cu ft, ft^3)
1 cubic meter (m^3)	=	1.3 cubic yards (cu yd, yd^3)

TEMPERATURE (EXACT)

[(9/5) y + 32] °C = x °F

QUICK INCH - CENTIMETER LENGTH CONVERSION

Inches	0	1	2	3	4	5
Centimeters	0 1 2 3 4 5	6 7 8	9 10	11	12	13
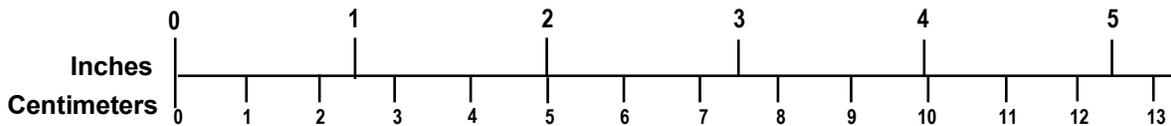
QUICK FAHRENHEIT - CELSIUS TEMPERATURE CONVERSIO
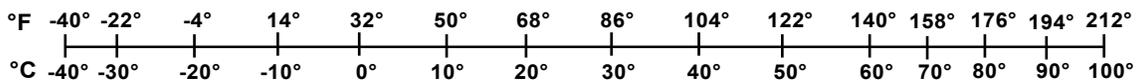
°F	-40°	-22°	-4°	14°	32°	50°	68°	86°	104°	122°	140°	158°	176°	194°	212°
°C	-40°	-30°	-20°	-10°	0°	10°	20°	30°	40°	50°	60°	70°	80°	90°	100°

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Contents

Illustration

Tables

Executive Summary

In Phase 1, EWI was engaged by the Federal Railroad Administration (FRA) to research rail treatments to prevent rail base corrosion in corrosive environments. A coating system was identified in Phase 1 and recommended for field trials [11].

FRA initiated a Phase 2 project with EWI in March 2014 to place treated rails into the field for observation under true running conditions. This project concluded in April 2017. Four railroads sponsored the acquisition of coated rail sets and three installed them in-track with both electrified and non-electrified rail. The four railroad initially participating were Amtrak, Long Island Rail Road (LIRR), Port Authority Trans-Hudson (PATH), and Norfolk Southern Corporation (NS). The railroads provided rail segments and tie plates for treatment and covered the cost of installation and monitoring. Subsequently, Amtrak was not able to place its rail segments in-track due to shared usage constraints.

Several rail segments and tie plate sets were coated with EonCoat® and placed into field service by three railroads. The coating did not perform to expectations due to loss of adhesion. The railroads regularly inspect track for corrosion. In some locations, rail may be replaced annually. Several of the Phase 2 coated rails originally installed in March 2017 were still in service. Thus, the coating does appear to provide some additional protection despite the adhesion problems.

Based on the poor adhesion performance of the EonCoat® product, EWI searched for alternatives and found four new coating systems for laboratory and outdoor exposure testing. The laboratory tests included standard industry exposure tests. The outdoor exposure testing included salt applications. Of the four coatings, Precision Coatings, Inc.'s PCI-5000 performed the best in both laboratory and outdoor exposure testing. It is suggested that the PCI-5000 coating be considered for field trials in track.

1. Introduction

In Phase 1 of this program, EWI was engaged by the Federal Railroad Administration (FRA) to examine rail treatments for their potential to passivate rail steel towards corrosion by using anti-corrosion conversion chemistries. One of those approaches appeared quite promising. The results of that work were presented at the American Railroad Engineering Maintenance-of-Way Association annual conference in 2013 and was covered in detail in Phase 1[11].

FRA initiated a Phase 2 project with EWI in March 2014 to place treated rails into the field for observation under true running conditions. This project concluded in April 2017. Four railroads sponsored the acquisition of coated rail sets and three installed them in-track with both electrified and non-electrified rail. The four participating railroads were Amtrak, Long Island Rail Road (LIRR), Port Authority Trans-Hudson (PATH), and Norfolk Southern Corporation (NS). The railroads provided rail segments and tie plates for treatment and covered the cost of installation and monitoring (subsequently, Amtrak was not able to place its rail segments in-track due to shared usage constraints).

This report details the installation and monitoring of the rail segments. Further, it summarizes subsequent laboratory testing of four additional coating systems.

1.1 Background

Rail base corrosion is a cause of premature rail failure in highly corrosive environments. Examples of highly corrosive environments are passenger boarding platforms and at-grade crossings that are deiced, as well as tunnels, underpasses, and locations near saltwater bodies. Thus, both passenger and freight rail lines can be compromised by rail base corrosion. Reducing or mitigating rail corrosion will improve the safety of rail operations and the reliability of its infrastructure.

Rail base corrosion has been observed by rail operators in areas where water is periodically present at the base of the rail. The Transit Cooperative Research Program (TCRP) and Transportation Technology Center, Inc.'s (TTCI) review of this behavior found that the most severe corrosion was reported in tunnels in the New York City area [12]. Some corrosion was invasive and found to advance as much as 1/4 in. upward from the area where the rail base crosses tie plates. There is the possibility that the edge of the corroded area could act as a stress concentrator that would allow fatigue crack to initiate and propagate up the rail [13] [14]. Furthermore, the effects of corrosive antagonists can be amplified by mechanical abuse and fatigue, exposure to road deicing materials, and electrical currents transmitted through the rail base and tie plate path to earth ground.

There is significant interest from railroad operators such as Amtrak, LIRR, and PATH in extending the life of rails in tunnels or wet areas by minimizing or eliminating the issue of rail corrosion and the associated fatigue cracking. There are many locations throughout the country with similar corrosive environmental conditions where condensing or dripping water causes rails to corrode. Class 1 railroads, or others operating non-electrified rail, also seek a cure for rail base corrosion. Treatment of the rail bottom surface has the potential to be effective in limiting the progression of rail corrosion, which leads to increasing rail life, reliability, and overall rail safety [1] [9].

Reducing or mitigating rail corrosion will improve the safety of rail operations and the reliability of its infrastructure. The coatings that have been studied are applicable to new rail and possibly to installed rail as a remedial measure. This study has found that treated rail can be installed following established procedures. It may also be beneficial to use treated rail and tie plates in combination on electrified railroad tracks.

1.2 Objectives

The objectives of the work discuss in this report are:

- Phase 2 – Manage the coating, installation, and monitoring of the treated rail segments and tie plates using the EonCoat® coating system.

- Phase 2B – Implement additional laboratory testing on four additional coating systems, and evaluate and compare their potential for use in the rail corrosion protection application.

1.3 Overall Approach

EWI provided overall program management of the technical portion of the work and coordinated the program with the railroads.

EWI conducted field experiments using EonCoat, LLC (EC) coated rails. These rails were installed on selected track segments on LIRR, PATH, and NS. Amtrak was interested in participating in this research, but was unable to overcome logistics issues associated with installing rail on shared track. Amtrak's coated rails remained in yard storage.

The participating railroads provided rail stock, tie plates, most of the transportation, installation, and monitoring cost of the treated rails. The rail segments and tie plates were treated at the EC facility and shipped back to the railroads. The participating railroads provided photos documenting the performance of the coatings over a period of about 1 year.

EWI conducted post-field test research (Phase 2B) using a new set of coatings at its facility in Ohio and at a nearby testing laboratory. This testing included new coatings from EonCoat®, Rutgers University, and two coatings from Precision Coatings, Inc. (PCI). Testing included outside exposure tests and laboratory corrosion testing to industry standards.

1.4 Scope

The scope of this report includes the coated rail segment field trials and the additional laboratory work that FRA commissioned following the field trials. After about 1 year of field trials, additional laboratory screening was warranted based on issues with adhesion and corrosion witnessed in the field. EWI then developed a laboratory test protocol to examine four additional coating systems provided by EC, Rutgers, and PCI. A Contract Modification Agreement for additional work listed as Phase 2B of the program was put in place to address these new concerns.

The overall program approach and scope for the entire project are summarized in the Work Breakdown Structure (Figure 1).

3

1.5 Organization of the Report

The report provides a detailed review of all the project activities. Section 2 covers field testing of the EonCoat® product on rails installed in multiple railroad locations. Section 3 reports on the detailed laboratory testing that EWI conducted subsequent to the EonCoat® field trails. This testing included a new version of EonCoat® and other materials designed to prevent corrosion. Section 4 summarizes the results of the project and provides recommendations for additional research.
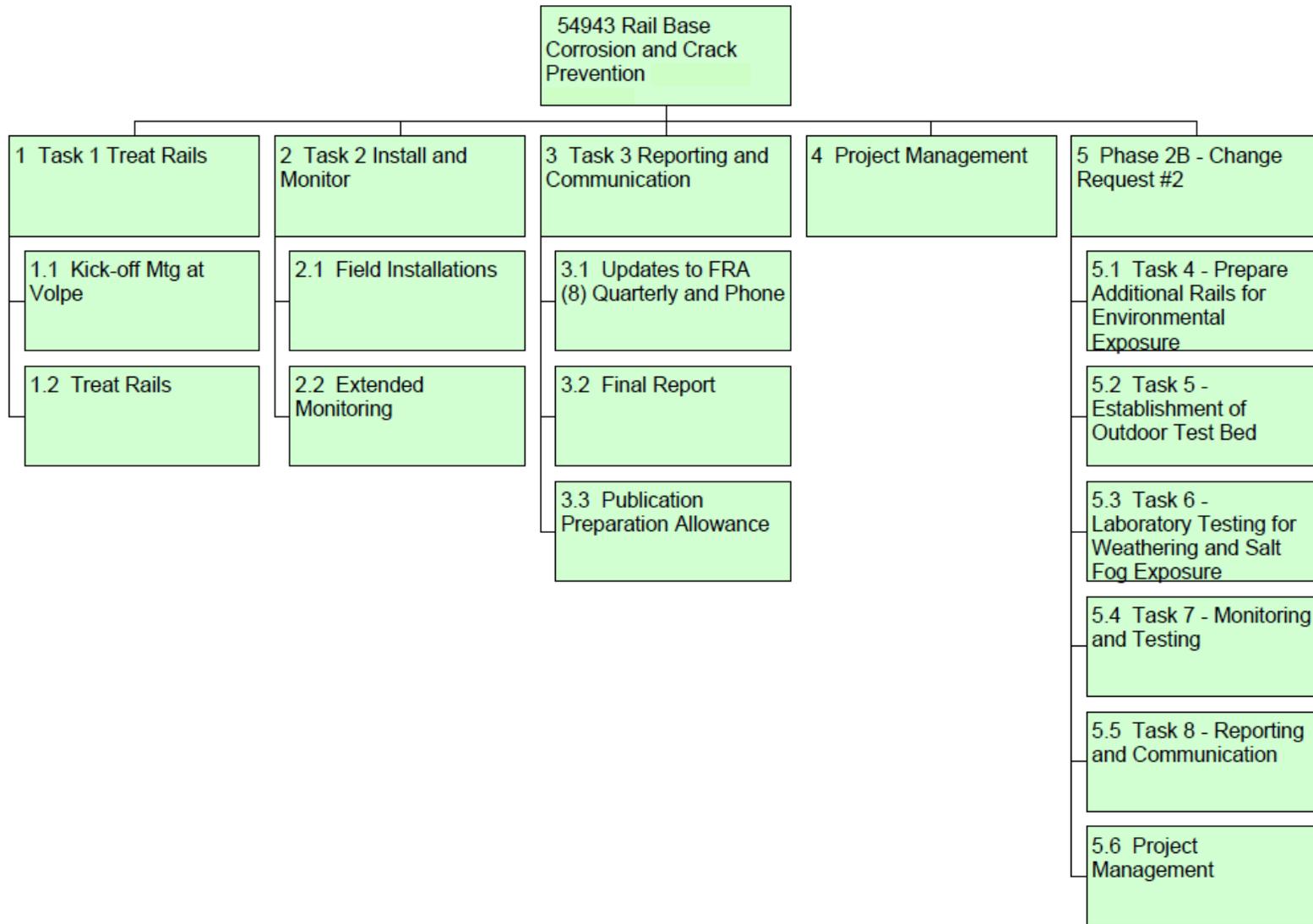
Figure 1. Work Breakdown Structure

2. Phase 2 – Field Testing of Rails Treated with EonCoat®

Based on the results of Phase 1, the recommendation was made to engage participants from the rail industry to support field installations of rails coated with the EC product.

In Phase 2, several rail segments and tie plates provided by the participating railroads were coated with EonCoat® before field installations. These rail segments were 115# (LIRR), 132# (NS), or 136# (LIRR, PATH, Amtrak) and about 40-ft long. Sufficient tie plates for the installed length were also provided for coating. In all, 14 rail segments were treated along with tie plates needed for installation. The cost share and commitment for the program was substantial. Over half of the program cost was in the form of cost share from the railroads. EC provided all coating services for the field trials.

2.1 Experimental Coating Procedures

EC prepared the rails by grit blasting to remove loose rust and/or provide a blast profile of their choosing, usually a gray blast. EonCoat® coatings are two-part systems that admix in the nozzle. They do not require a primer. The coating is applied in multiple, overlapping coats built to produce a total thickness of 20–30 mils. Only the EonCoat® coating was used in the Phase 2 field trials.

Amtrak supplied two rails, LIRR supplied five, PATH supplied six, and NS supplied one, as shown in Table 1. However, Amtrak information is not included in Table 1 because they were unable to install the coated rails due to logistics issues. All participating railroads but one had the specimens treated at the EC facility and returned for field installation. The NS rail segments and tie plates were treated at EWI by EC personnel. This procedure demonstrated the possibility of applying the coating system in the field, although it is likely not practical to apply the coating in-track. Figure 2 shows the completed rail segments and tie plates. The blasting and coating preparations take approximately 2–3 hours. The rail heads and portions of each end were masked. The ends were masked back about 1 foot to allow for drilling/bolting or welding in the field.

Most of the rails were installed in the locations indicated in Figure 3 and Figure 5 by mid-December 2015. Two of the PATH rails were not installed in Tunnel E until May 2015.

2.2 Phase 2 – Installation of Treated Rail Segments by Railroads

In Phase 2, the railroads installed their rails as time permitted. Most rails were in service by December 2014. LIRR installed its five rails by that time. PATH installed three of their rails by December 2014 and two more by May 2015. One of their rails remained unused. NS installed its one rail in November 2014. Amtrak was unable to install either of its two rails because of complications arising from having shared track.

All rails, except the NS rail which used spikes, were fixed with E-clips. For the most part, rails were bolted and attached to wooden ties. The LeFrak installation was the exception, being welded and on concrete ties. All rails, except the NS rail, were electrified.

The disposition of rails and locations is summarized in Table 1. Figure 3 through Figure 5 show the installation on each railroad.

Figure 2. Rail Segments and Tie Plates Treated with EonCoat® at the EWI Facility

Table 1. Installation of Rails by the Railroads

Railroad	Installation No.	Installation Date	ID Location Mile Marker, Track No., or Intersection	Briefly Describe Surrounding Environment, Ballast and Drainage Condition, Corrosion Issue, or Concern
Summary of Installations for Corrosion Control Coating Field Trials
LIRR	1	11/18/2014	Jamaica Station Jay/Hall Int. Trk-2 Open Track	Open station with ballasted track with corrosion issue
	2	11/30/2014	Atlantic Brook 1 Int., Trk 6 Tunnel	Tunneled station with ballasted track with overhead leak and corrosion issue
	3	12/4/2014	Ronkonkoma Station KO-2, Trk 2 Open Track	Open station with ballasted track with corrosion issue
	4	12/4/2014	Port Washington Station, Trk 2, Open Track	Open station with ballasted track with corrosion issue
	5	12/12/2014	Forest Hills LeFrak Over Build, Trk 3, Under Structure	Ballasted track (80 mph MAS) with overhead leak and corrosion issue
PATH	1	12/1/2014	Tunnel Section A-3	Tunnel installation with ballasted track
	2	12/1/2014	Tunnel Section A-3	Considerable moisture accumulation
	3	12/1/2014	Tunnel Section A-3	Loose, piled fill
	4	5/15/2015	Tunnel Section E-4	
	5	5/15/2015	Tunnel Section E-5	
NS	1	11/21/2014	Lambert Yard, Trk 19	Highly corrosive coal yard track at Lambert's Point, Norfolk, VA. These tracks are exposed to leachate from standing coal cars, saltwater, and occasional flooding

Figure 3. Installations by LIRR
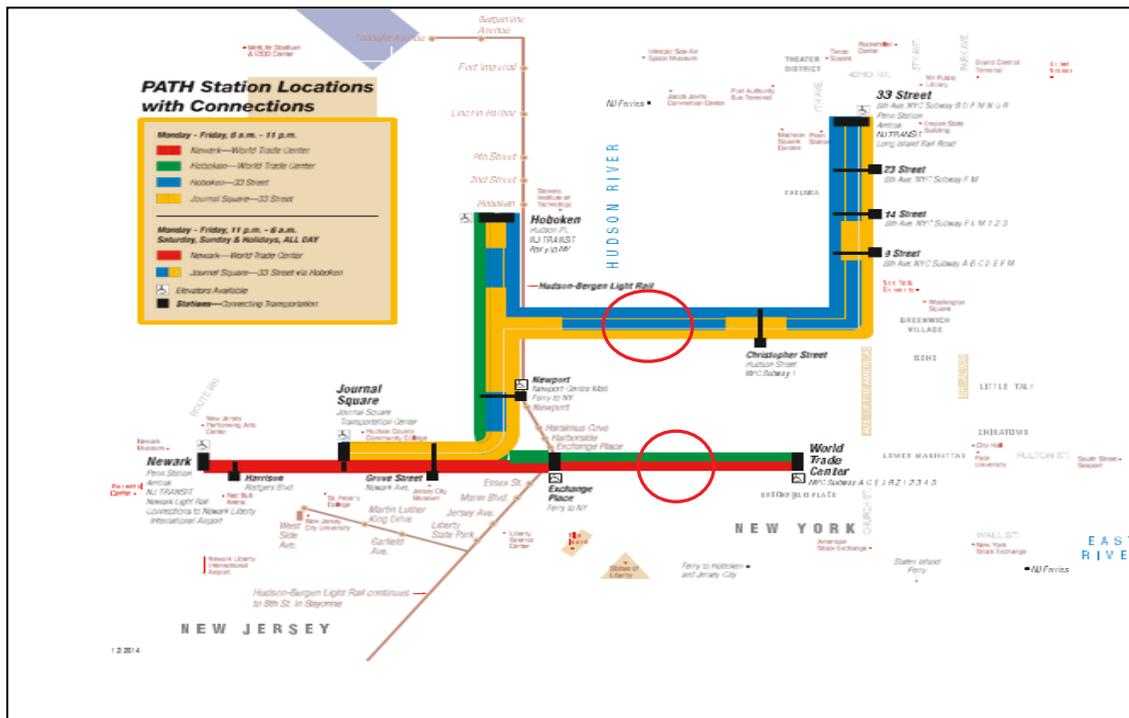
Figure 4. Installations by PATH

Figure 5. Installation by NS

2.3 Results from the Field Installations

By late summer and early fall of 2015, almost 10 months after installation, reports came back regarding premature failure of the coating. This was observed by all the railroads regardless of location. This indicated a systematic problem, given that the installations represented diverse locations, exposures, track usage, and electrically live or dead rail (Table 1). A pictorial review of the in-track installations by the railroads is given in Figure 6 through Figure 8. These photographs represent 6–10 months in service, depending on location, for example:

- At ground return the corrosion rate is about 30 percent higher than that at other locations.

- At LeFrack Overbuild which carries both diesel and electric locomotives estimated coating losses was 50 percent higher than other locations.

- Lambert Yard is likely the most aggressive environment. Seepage from coal cars is quite acidic.

Figure 6. LIRR (Clockwise: UL – Port Washington, UR – Jamaica Station, LR – Atlantic Terminal, LL – LeFrack Overbuild)

11

Figure 7. PATH (Clockwise: UL – Tunnel A, UR – Tunnel E, LR – Tunnel E – Other, LL – Uninstalled Rail in Crib)

Figure 8. NS Lambert Yard (Clockwise: UL – as Installed, UR, LR, LL – About 8 Months)

13

2.4   EC Investigation

All the participating railroads reported that damage to the coating may have occurred during installation. They also reported that chipping and spalling are common on the rails themselves. Where coating is being lost, there is evidence of incipient corrosion. However, the tie plates appear to be holding up very well and generally did not display mechanical damage to the coatings. In consultation with EC, it was determined that adhesion to rail steel was the culprit. EC ran many tests and isolated at least one issue as stemming from the inclusion of bubbles (likely hydrogen) at the interfacial surface of the coating and the steel. The combination of the steel chemistries and the size of the specimen being coated may have influenced coating adhesion on the rails.

2.4.1   Formation of Hydrogen Gas

EonCoat® is a two-part system that protects the steel by creating a reaction to produce a passivating conversion layer that provides the corrosion protection. The reaction with the surface can produce hydrogen gas. While it is reacting with the surface, it is also crosslinking to harden. If the coating hardens faster than the surface reaction, it is possible that forming hydrogen gas can be trapped in the coating as it hardens. This foamy contact layer, in turn, would lead to a weak interfacial layer and adhesion failure.

2.4.2   Possible Influence of Rail and Tie Plate Chemistries

The differences in chemistry between rail steel and tie plate steel may also be a factor in adhesion. Rail steel has a relatively higher carbon content, having >0.7% carbon, compared with tie plates having 0.2–0.3 percent [3]. Rail steel also contains approximately 0.25 percent chromium and approximately the same amount of nickel. Carbon, chromium, and nickel can result in lower adhesion. Rails are roll formed while tie plates are often stamped [9]. The difference in processing can produce a different surface grain structure and chemistry. This may influence adhesion as well. Therefore, both chemistry and processing can influence surface adhesion, with the adhesion of rail steel being inherently more difficult than adhesion to tie plates.

2.4.3   Influence of Coated Article Size

Considerable salt fog testing was performed in Phase 1. The test panels used in Phase 1 were small compared with a full stick of rail, being only 4×12 inches. Salt fog testing of those panels produced exceptional results even after 5,000 hours (see Figure 9 taken from the Phase 1 work). There was no exposure to excessive moisture or UV, as would be found in an outdoor setting. Overall, there was no evidence of significant loss of adhesion.

Smaller plates, and even tie plates, can be coated faster than a large rail, simply because of sample size. There would be less overall time between coats. One of the observations from the field testing was the tie plates seemed to retain coating much better than the rails, suggesting better adhesion (Figure 6 through Figure 8). Therefore, it is possible the combination of size, surface chemistry, surface morphology, and coating time may have worked against good coating adhesion on the rails, while providing better mechanical performance on the tie plates. Taken in concert with the formation of bubbles and a foamy region near the steel surface, these linked concepts suggested that the causes for poor adhesion had been identified.
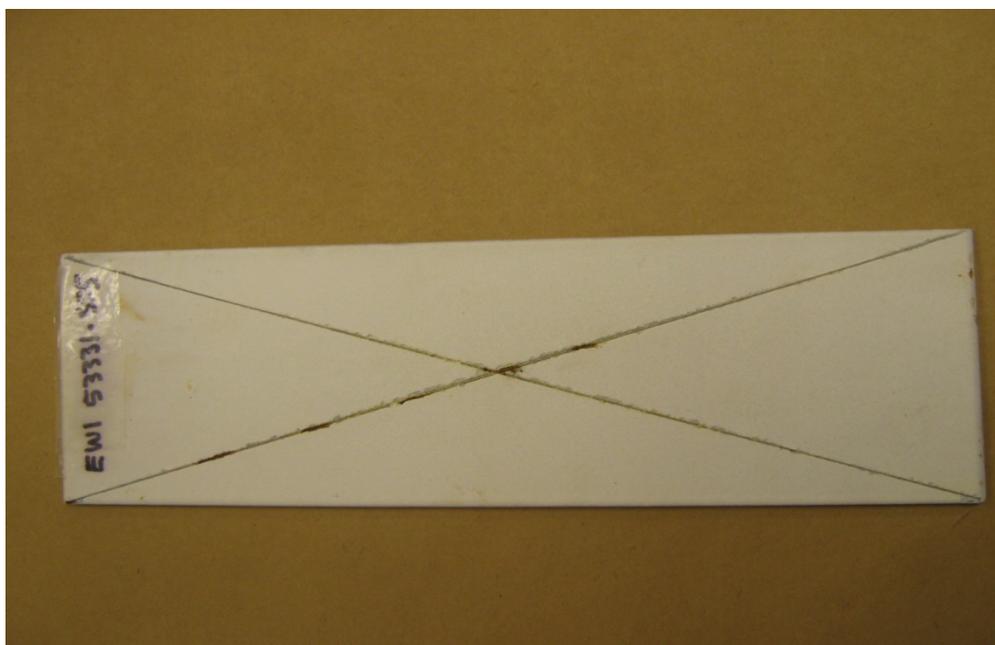
Figure 9. Salt Fog Specimen of EonCoat® After 5,000 Hours Salt Fog Exposure (ASTM B117)

2.4.4 Reformulation of EonCoat®

In developing a new coating for better protection against corrosion, EC made formulation changes to balance the steel reaction speed with the coating curing speed such that gas formation would be retarded or eliminated. This goal was achieved as indicated in the micrographs of the interfacial regions shown in Figure 10. The new formulation was identified as EonCoat® V.
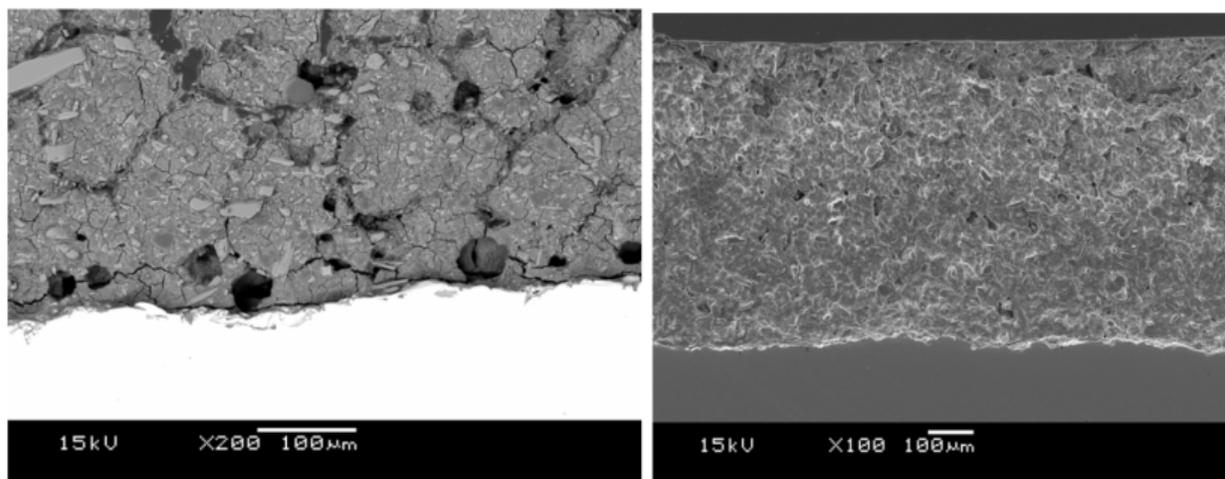
Figure 10. Micrographs of Original EonCoat® (left) and Modified EonCoat® V (right)

2.4.5 Voltammetry Studies on EonCoat® and EonCoat® V

EC also performed extensive voltammetry studies on the two coating types applied to steel. A sample voltammogram is shown in Figure 11 for EonCoat® V, EonCoat®, and stainless steel.
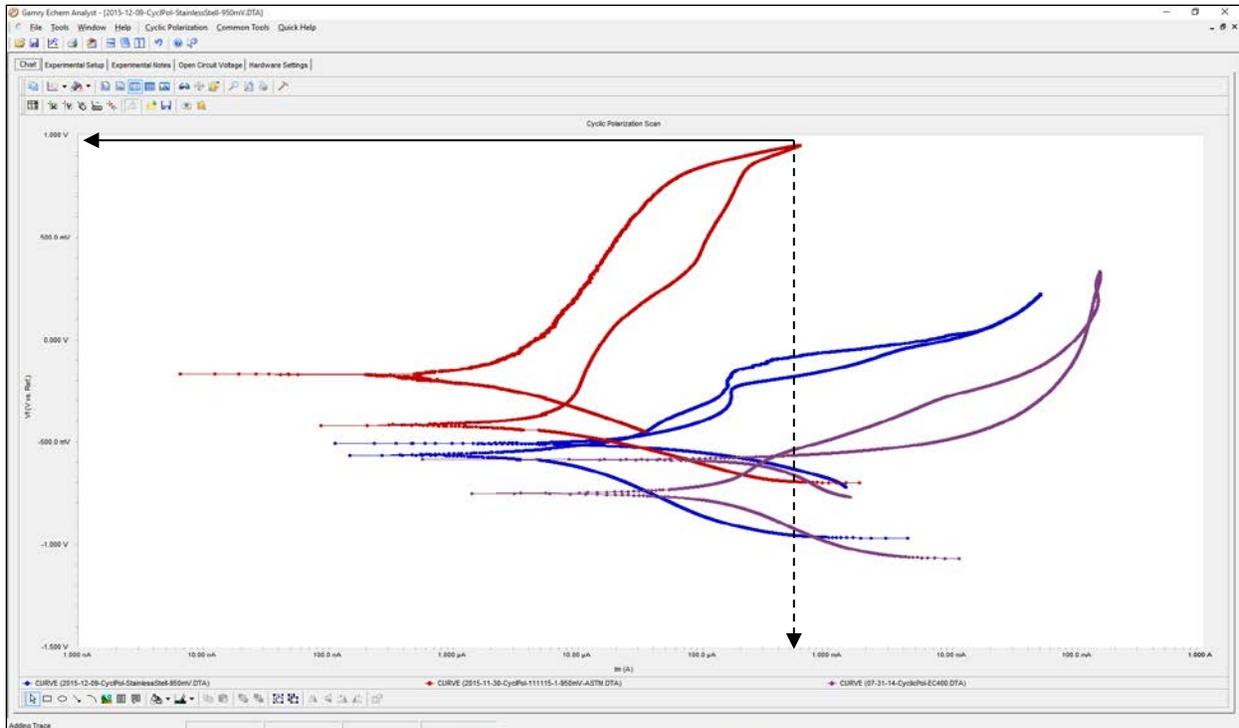
**Figure 11. Cyclic Voltammetry Curves for EonCoat® V (red),
EonCoat ® (blue), and Stainless Steel (violet)**

Interpreting these plots can be complex [10]. In this plot, the Y-axis is impressed voltage and the X-axis is the resulting current from that impressed voltage. The voltage scale is linear and represents a swept range of -1 to +1 V. The current scale is logarithmic and runs from 1 nanoamp (left) to 1 amp (right), or nine decades.

The voltage is swept from negative to positive and back to negative. On the advancing positive cycle, the peak voltage represents the threshold potential for corrosion and pitting (solid black line). The resulting current at that point (dashed line) gives an indication of corrosion rate. A higher voltage threshold is good because it indicates a higher resistance to corrosion onset. A lower current at the impressed voltage is good because it indicates less charge flow, therefore, a lower corrosion rate.

The red curve (EonCoat® V) depicts the highly desirable property of having very low leakage current (rate) at relatively high impressed voltage (threshold). The blue curve is for the original field-tested EonCoat® while the violet curve is for stainless steel. Both EonCoat® versions show cyclic voltammetry behavior that is superior to that for stainless steel. From the current scale (logarithmic), it is seen that EonCoat® V has a corrosion rate about three orders of magnitude *lower* than stainless steel, i.e., 1,000× slower. The threshold voltage is just shy of +1 V, which exceeds that for stainless steel. However, that advantage is not realized if the coating does not adhere to rail steel.

2.5 Possible Role of Electrification

Mechanical adhesion is not the only consideration for coating longevity in service. There are two possible contributing factors to coating performance stemming from use on electrified rail.

One is a resultant impressed voltage that causes pitting corrosion, i.e., the coating perceives an impressed voltage >1V. The other is physical loss of the coating caused by a phenomenon called cathodic disbonding.

2.5.1 Onset of Pitting Corrosion

The results from the cyclic voltammetry discussed above are impressive. However, they also reveal that an impressed voltage of more than +1 V can initiate corrosion. Because the current is fairly low, the corrosion rate might be quite slow, but it would be present.

In electrified rail, there are dozens of leakage points between the return rail and true ground [15]. In consulting with the railroads, it was reported that leakage currents can result in upwards of 70 V of potential between a return DC rail and true ground [2]. Rails are not truly grounded, they only act as a DC return. They are floating above true ground, insulated nominally by the wooden or concrete ties. The worst corrosion is noticed on DC lines while AC lines show a much lower rate. With DC, the impressed potential is constant. With AC, the positive portion of the cycle leads to corrosion while the negative portion of the cycle can impart "healing."

2.5.2 Cathodic Disbonding

There is a phenomenon in coatings on charged surfaces called cathodic disbonding. It stems from electrolysis of water at a charged surface. Moisture can always penetrate a coating at some rate and deposit at the coating-surface interface. Water vapor is more insidious than genuine liquid water because the water molecules as a gas are more diffusive through the coating. When water reaches the surface, and if there is sufficient charge, it will electrolyze to form hydrogen gas. This gas will build pressure behind the intact coating, but can ultimately pop it off the surface as the pressure builds. It is possible that no coating can protect cathodically charged steel indefinitely because of the physical disruption of the coating caused by cathodic disbonding. Here again, performance of any coating on an AC rail may be substantially better than on a DC rail because reverse reactions can take place.

2.5.3 Limitations in Testing Under Power

During this study, it was not possible to reproduce electrification in service other than by having rails placed into service. There is no safe way to duplicate the +750 VDC electrical system and also simulate the many ground leakage paths that exist along an installed rail. The cyclic voltammetry tests come closest to providing indication of resistance to effects from electrification, but they cannot reproduce the actual conditions in the field.

2.6 Ultimate Result of In-Field Phase 2 Testing

The railroads regularly inspect track for corrosion. In severe corrosion locations, rail may be replaced annually. At the time of this report, several of the Phase 2 rails are still in service. Since some of these rails are still in service after more than 2 years of field installation, it appears that the coating does provide added protection for the rail.

2.7 Response to the Phase 2 Results

The findings from the EC investigation were presented to the partner railroads in February 2016. Based on these results, FRA and EWI recommended to the railroads that additional field tests be

undertaken with the reformulated EonCoat® V coating. However, because of concerns regarding the true improved performance of the reformulated coating and the general concern over whether any coating would be effective on electrified rail, the railroads requested additional testing prior to making commitment to reintroduce a new coating in the field.

It was agreed by all parties that additional testing should be undertaken in a laboratory prior to reintroduction of test rails in the field. This led to the introduction of Phase 2B that involved corrosion studies on four new coatings, including the reformulated EonCoat® V.

3. Phase 2B – Additional Laboratory Testing and Outdoor Exposures

Through a project extension, FRA authorized EWI to begin additional investigations of candidate coatings. Four coatings were selected for additional trials: EonCoat® V, an experimental coating from Rutgers University, Precision Coatings, Inc.'s PCI-3000, and Precision Coatings, Inc.'s PCI-5000.

3.1 Phase 2B – Experimental

Additional laboratory tests were added to this program in Phase 2B. Two parallel test profiles were developed, as explained in Sections 3.1.1 and 3.1.2.

The additional laboratory testing took two forms. Det Norske Veritas (DNV) was contracted to perform weathering and salt fog testing on coated 3×6-in. test plaques. EWI established an outdoor test bed using coated 4-foot rail segments and each with three coated tie plates.

All the test specimens were coated by the suppliers using supplied grit-blasted plates or grit-blasted rails. The Rutgers coating was applied over the supplied blasted surface. The PCI coatings were applied over an SSPC SP-6 blasted surface (~ 2 mils depth). A build primer is then applied, followed by a top coat. Both layers are 3–5 mils in dry film thickness. EonCoat® V was applied over the blasted surface, which is similar to the SSPC SP-6.

3.1.1 DNV Accelerated Corrosion Testing

Coated test plates were provided to DNV for testing. For each coating type, one test plate had a scribe-to-metal down the center line of one face. The test protocol provided by DNV was as follows:

- Cyclic testing per American Society for Testing and Materials (ASTM) D5894 for 1,008 hours (3 cycles = 6 weeks).

- ASTM D5894 combines 168 hours of ASTM D4587 UV Weathering with 168 hours of ASTM G85 Annex A5 "Prohesion" cyclic salt spray. This provides a robust, multi-faceted weathering exposure very commonly used for paints and coatings on buildings and equipment. The protocol consists of 168 hours of UV Weathering with cyclic UV and condensing humidity, and 168 hours of cyclic salt fog/drying with 0.05 percent salt concentration in the electrolyte. Each cycle of D5894 is thus, 336 hours in duration.

- Evaluation was performed using ASTM D1654 [6] [7] [8] [15].

3.1.2 EWI Outdoor Exposure Testing

EWI established an outdoor test bed (Figure 12 and Figure 13) that consisted of coated 4-foot rail segments, each resting on three coated tie plates. The tie plates were covered by rocks and dirt piled up against the rail web. Rock salt was placed on each center tie mound and on one end mound for PCI-3000. These were left exposed to open air and weather for 6 months. Every month, the rails were inspected and photographed (the Rutgers entry was not available until later in the exposure cycle).
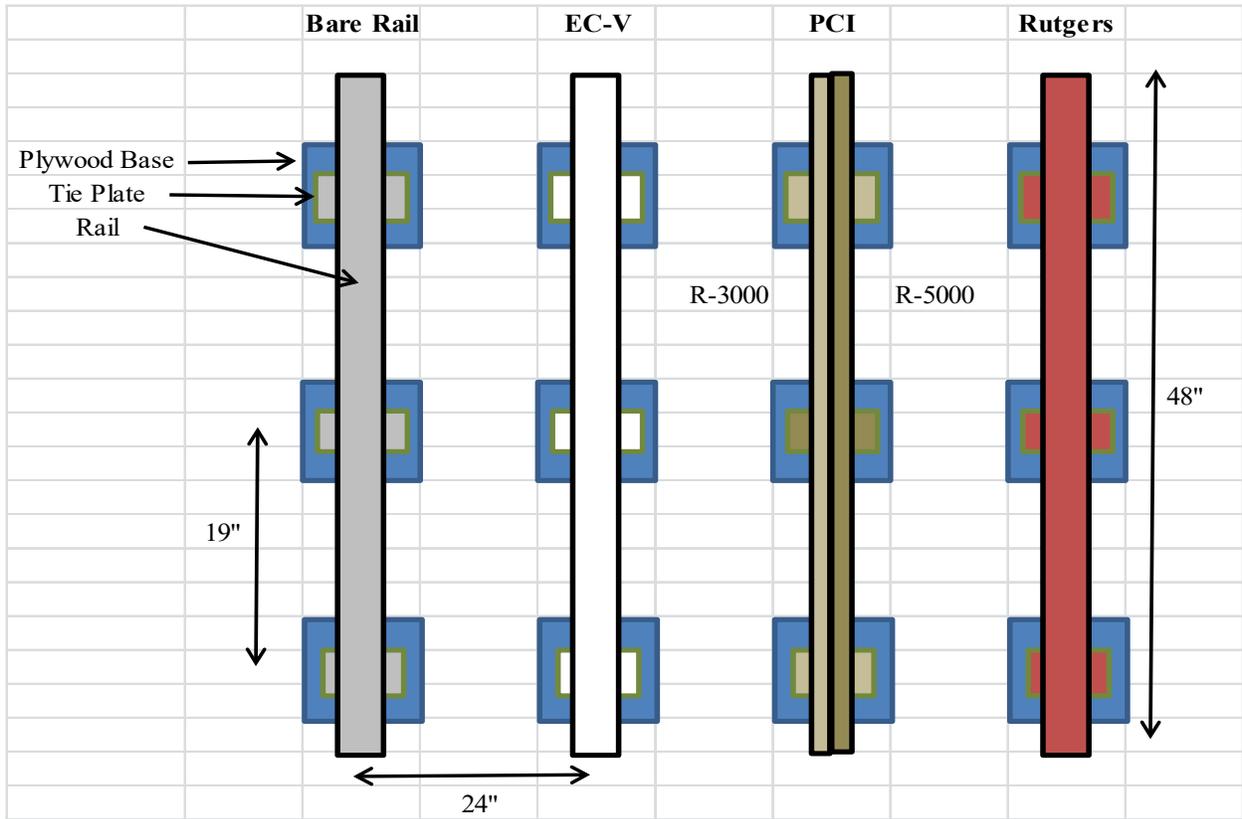
Figure 12. Disposition of EWI Outdoor Rail Exposures for Phase 2B

Figure 13. Test Bed Established for Phase 2B (Rutgers Rail Not Present)

3.2 Results of Phase 2B

The following sections detail the results of the laboratory testing undertaken during Phase 2B of this project.

3.2.1 Results of DNV Accelerated Corrosion Testing

The DNV test cycle is a very aggressive test protocol. The inclusion of scribed plates provides known defects in the protective system and allows aggressive incursion into the metal. The desired results would show minimal rusting in the scribe region and would also show minimal incursion underneath the coating. Ideally, there is no blistering or lifting. The results of the DNV testing are summarized in Table 2 and in Figure 14 through Figure 29.

Table 2. Summary of Accelerated Corrosion Testing

Panel Coating	Panel Number	Scribe Rating IAW ASTM D1654	Red Rust Rating IAW ASTM D610	Blister Rating IAW ASTM D714
EonCoat V	1 - scribed	6 - Poor adhesion	8 - Good	Many - Poor
	2		6 - Fair	Many - Poor
	3		6 - Fair	Many - Poor
	4		9 - Very good	Many - Poor
Rutgers	5 - scribed	8 - Good	1 - Poor	Few - Good
	6		1 - Poor	Few - Good
	7		1- Poor	Few - Good
	8		1 - Poor	Few - Good
PCI-3000	9 - scribed	9 - Very good	10 - Excellent	Few - Good
	10		7 – Fair/Good	Very few - Better
PCI-5000	11- scribed	8 - Good	10 - Excellent	Few - Good
	12		10 - Excellent	Few - Good

3.2.1.1 EonCoat® V

Figure 14 and Figure 15 show the before and after pictorial record from the DNV exposures. There are penetrations to metal on the plates that were initially undamaged. On the scribed plate, there is obvious pulling back of the coating from the scribe region, however, there is still rust protection outside the region. That is a trait of the EonCoat® V system. It converts the surface, not just coats it, so there is additional resistance to corrosion with time in regions where coating has been lost physically.

In examining Figure 16 through Figure 19, it can be seen that micro-cracking is developing along with incipient adhesion loss. While this performance is better than the original EonCoat® coating, it suggests the longer-term protection might be compromised.
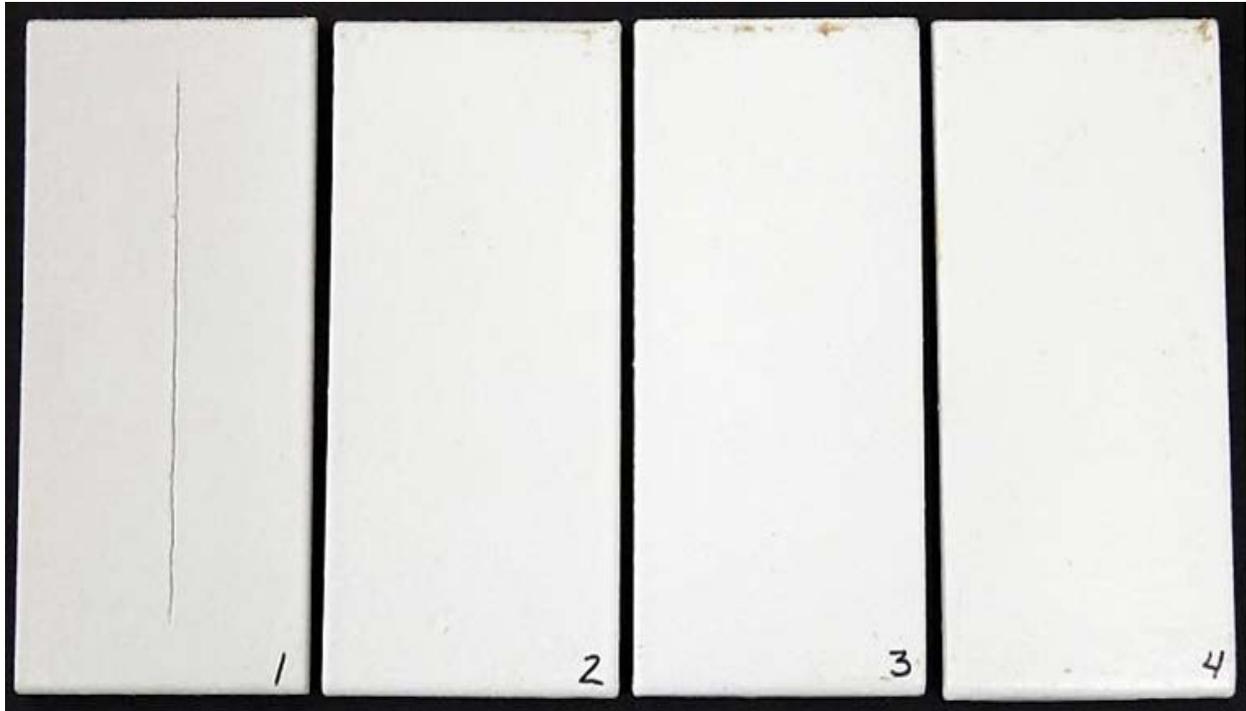
Figure 14. EonCoat® V – Macro of Panels Before Testing
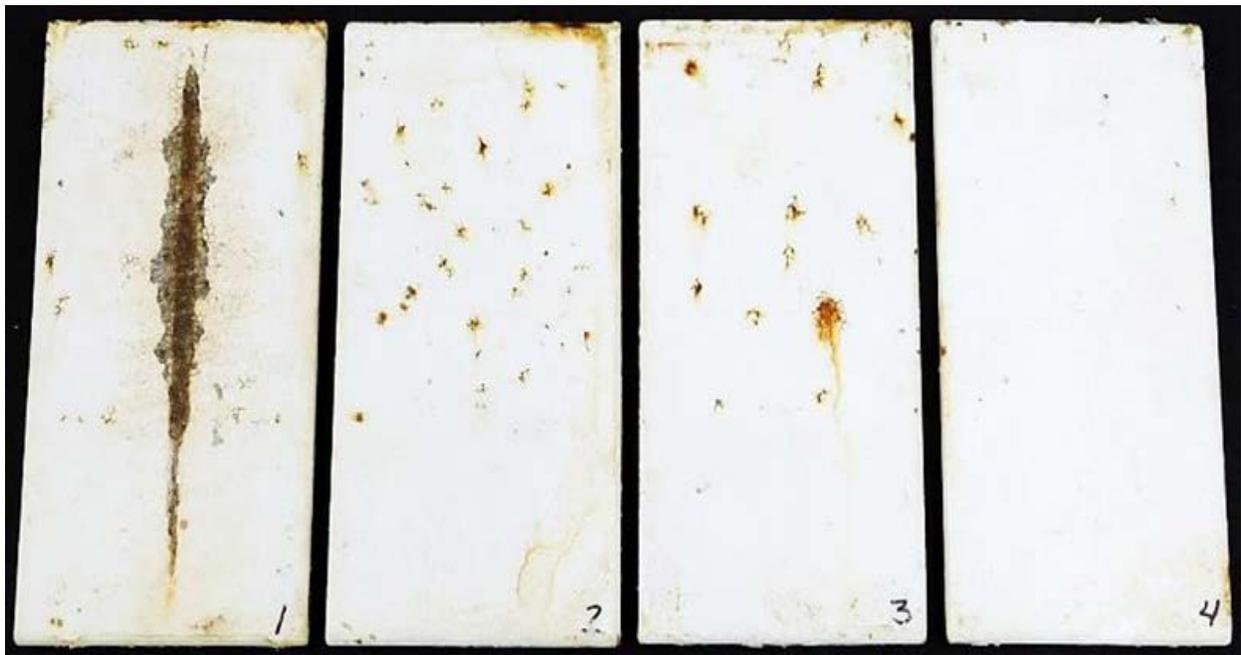
Figure 15. EonCoat® V – Macro of Panels After Testing

Figure 16. EonCoat® V – Scribe Region Into Field (2× Magnification)
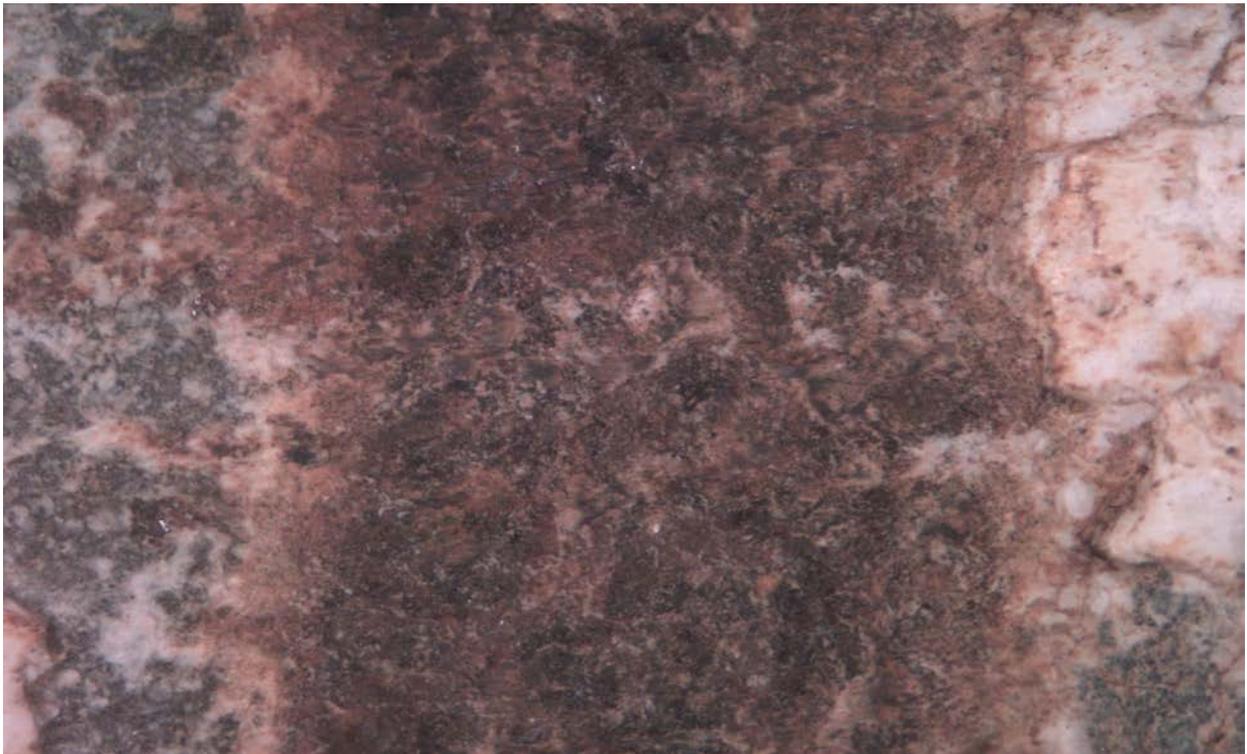
Figure 17. EonCoat® V – Scribe (4× Magnification)

Figure 18. EonCoat® V – Blister (2× Magnification)
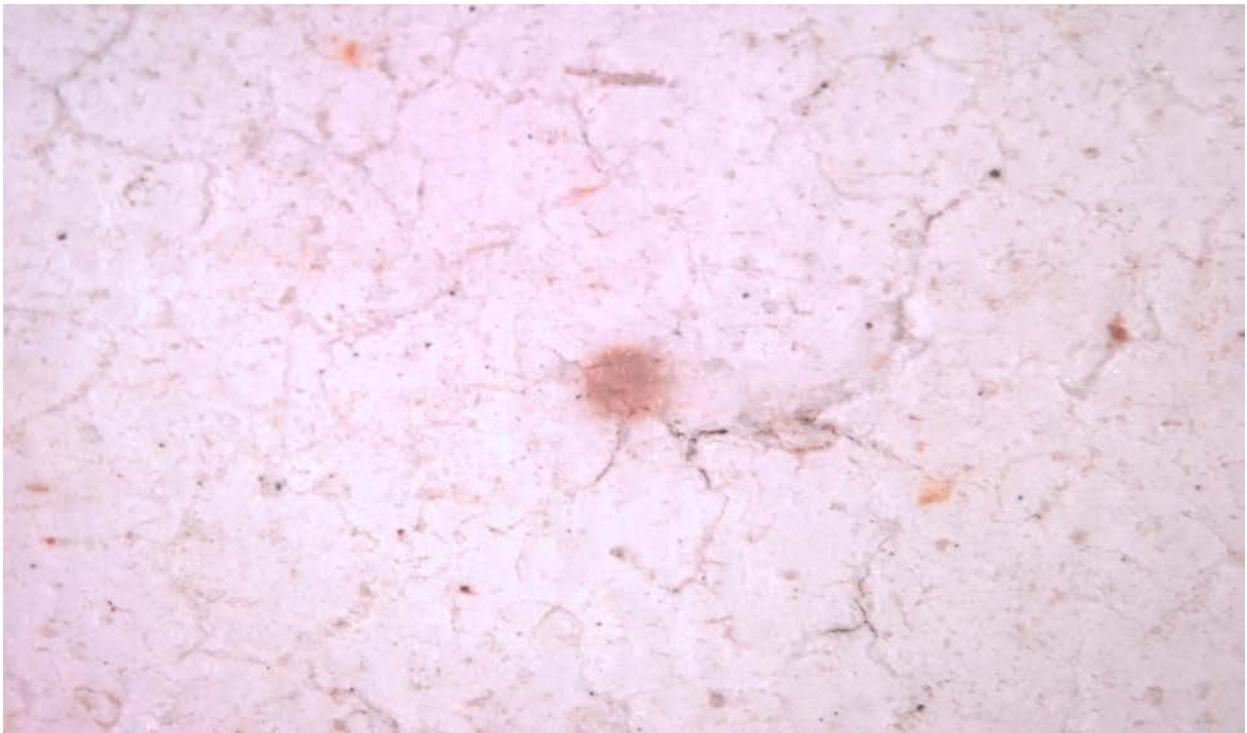
Figure 19. EonCoat® V – Developing Blister into Field (2× Magnification)

3.2.1.2 Rutgers Coating

This is an experimental coating and not commercially available. Figure 20 through Figure 23 show that the coating has remained substantially intact. However, moisture and possibly salt have transgressed its protection to reach the surface and begin corrosion. In Figure 23, the development of a blister is evident.
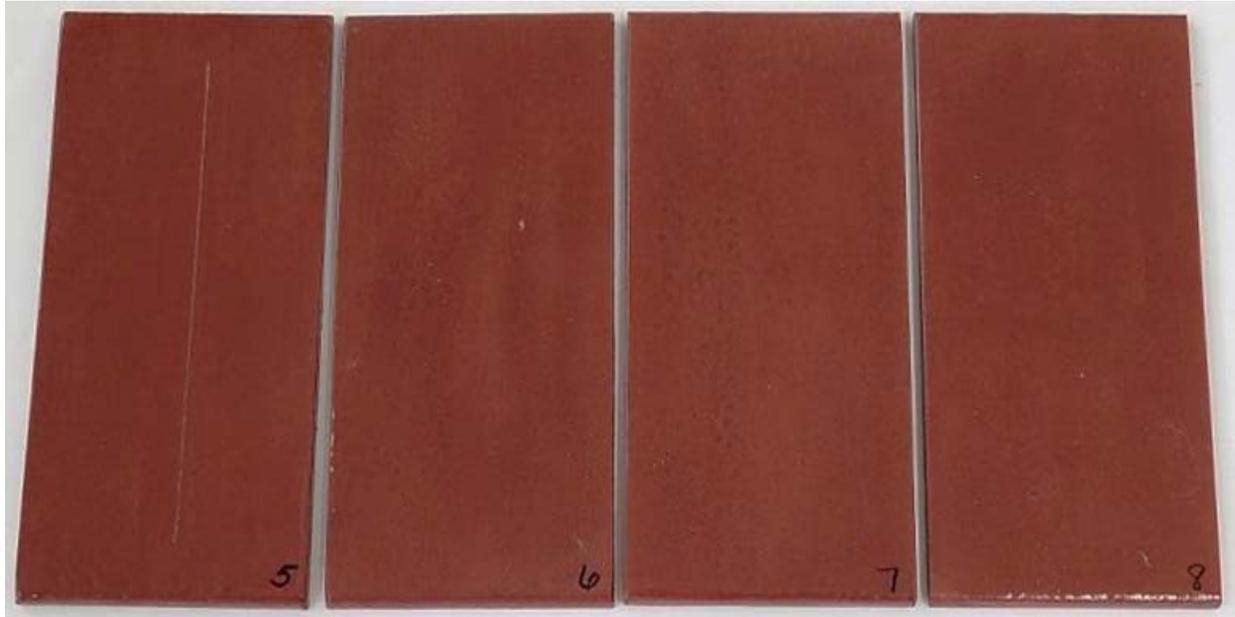
Figure 20. Rutgers Coating – Macro of Panels Before Testing

Figure 21. Rutgers Coating – Macro of Panels After Testing

Figure 22. Rutgers Coating – Scribe (4× Magnification)
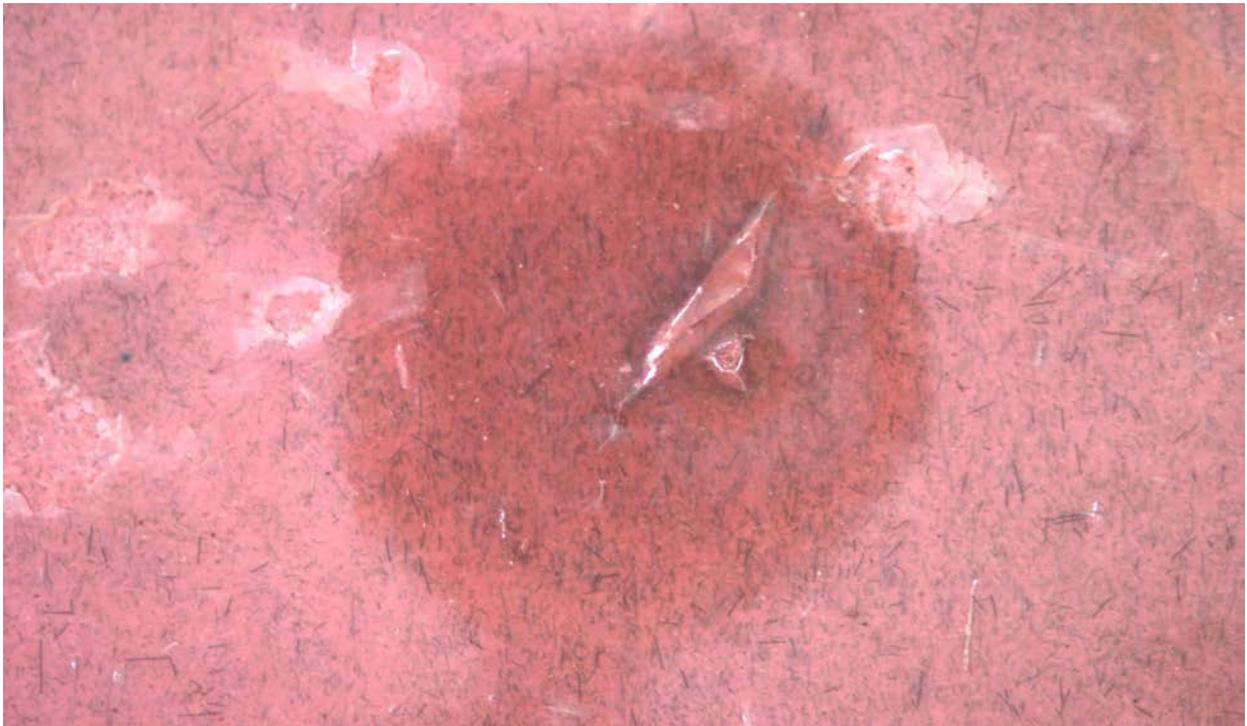
Figure 23. Rutgers Coating – Blister (2× Magnification)

3.2.1.3 PCI Coatings

Both the PCI-3000 and PCI-5000 coatings performed well, with the PCI-5000 appearing to perform better of the two (and the best of the set of four) coatings. The plate coated with PCI-5000 had good resistance to blistering and peeling in the scribe region. All the coatings showed incursion from the edges, which is common in this type of testing. However, the PCI coatings showed good resistance to creeping corrosion from the edges, much as they had done in the scribe region. Based on the results of this testing (Figure 24 through Figure 29), the PCI-5000 coating is a good candidate for field testing.
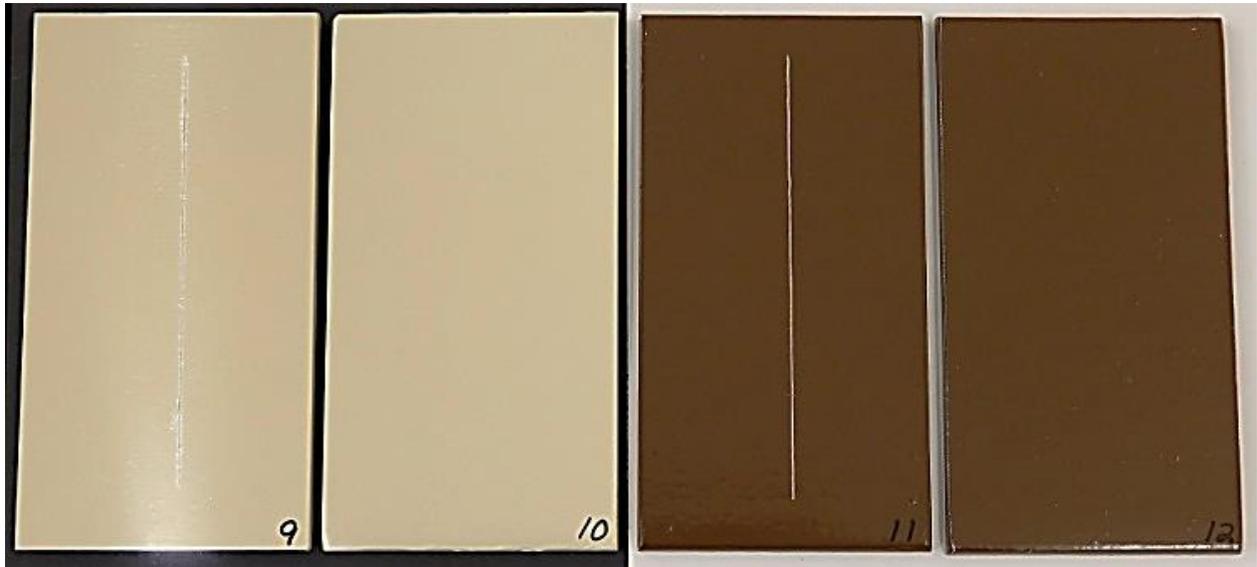
Figure 24. PCI-3000 (left) and PCI-5000 (right) Panels Before Testing
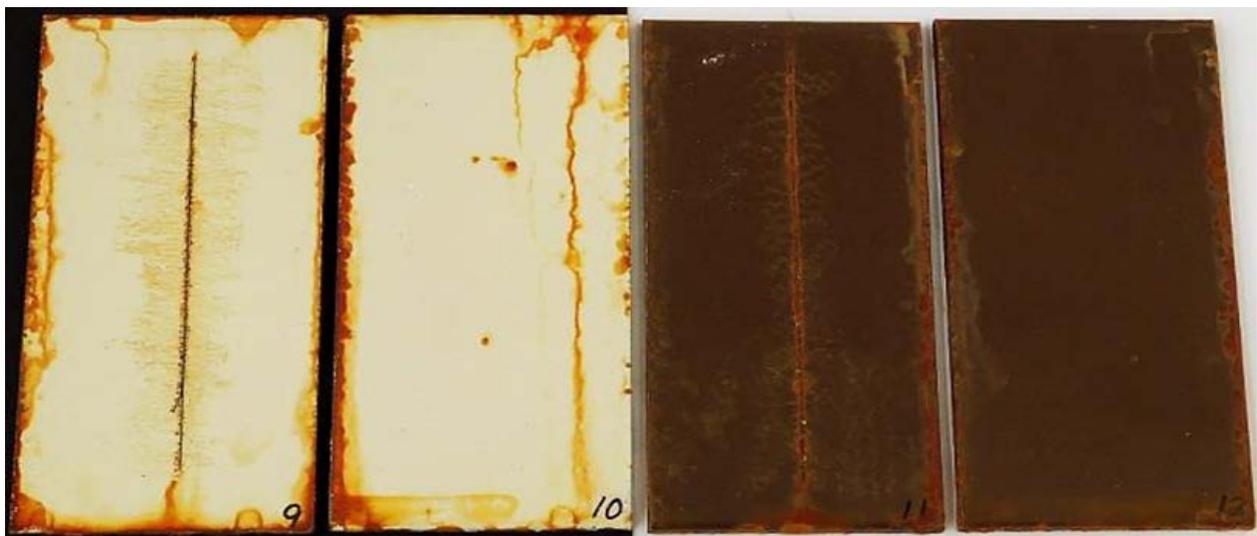
Figure 25. PCI-3000 (left) and PCI-5000 (right) After Testing

27

Figure 26. PCI-3000 – Scribe (2× Magnification)

Figure 27. PCI-3000 – Edge into Field (2× Magnification)

Figure 28. PCI-5000 – Scribe (2× Magnification)
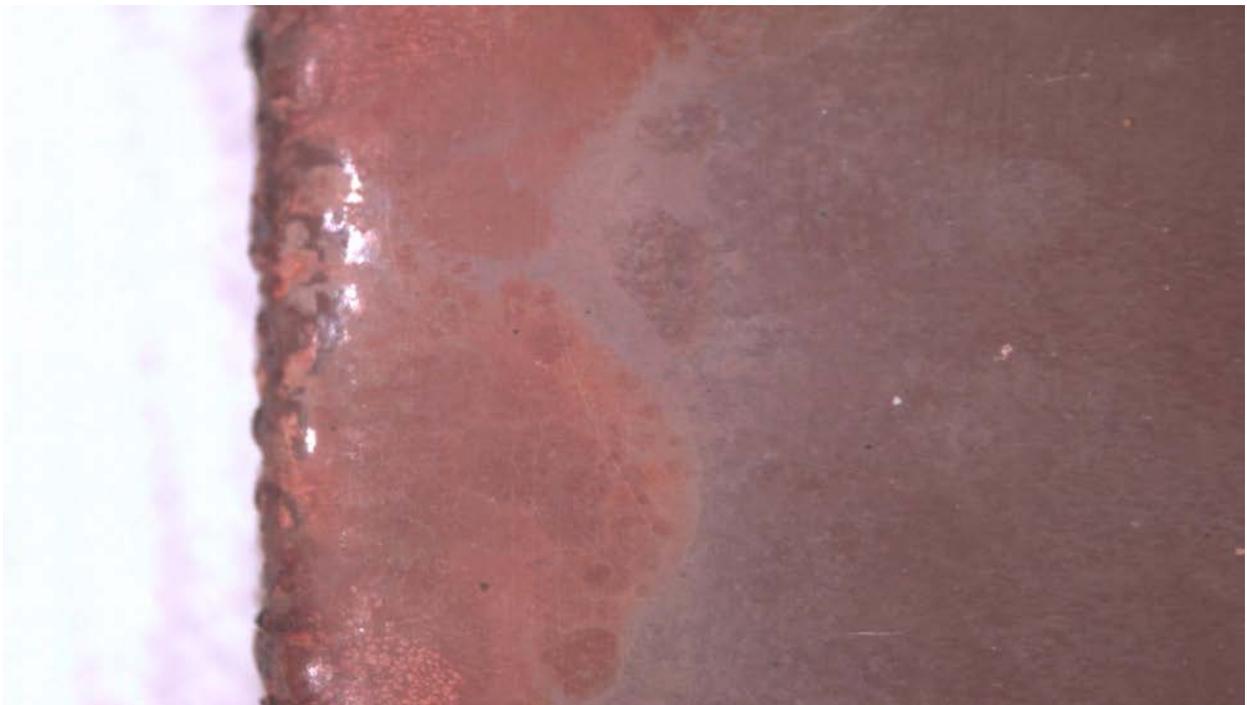
Figure 29. PCI-5000 – Edge into Field (2× Magnification)

3.2.2 Results of the EWI Outdoor Exposure Testing

This type of outdoor testing was designed to look at the effects of pervasive exposure to weather conditions. The test was in place from September 2016 to March 2017. Testing occurred on the grounds of the EWI facility in Columbus, OH. There was no electrification and, obviously, no rail traffic. The rails were unearthed, washed, and photographed about monthly. They were then reseated and the mounds of dirt, rocks, and added salt were replenished. This step provided further environmental stressing and was suggested by LIRR. It allowed moisture to congregate along the rail even under otherwise dry weather conditions.

An untreated (bare) rail specimen is included in this test. Figure 30 through Figure 35 focus on the salted regions of the exposures. Normally, the center tie plate-rail interfaces of the installations (Figure 6 through Figure 7) were the ones that had salt. The theory was that salt would percolate down through the pile with rain water.

It is almost surprising how fast bare rail succumbs to rail base corrosion. In Figure 30, the lower left picture shows 6 months of exposure in the wet and salty environment. There is deep pitting in the contact region. Also, this took place in the absence of electrification which would undoubtedly increase the rate of attack. In light of that, all the coatings showed at least some benefit compared with untreated rail.

The EonCoat® V coating held up fairly well (Figure 31). However, at the end of the 6-month exposure, it was beginning to show the same types of penetration and incursion that were seen in the DNV exposure sequence. This was evident not only at the rail-tie plate interface, but also in the built-up regions where dirt-gravel-salt had been piled up against the web.

Rutgers did not coat the base of their rail. The Rutgers experimental coating (Figure 32) showed substantial deterioration in the rail-tie plate interface after only 3-months exposure—it was not available for testing outdoors until the fourth month. This too paralleled the relative results from the DNV testing.

PCI also did not coat the base of the rail, although they did apply primer to it. PCI provided two coatings on the same rail. One side was coated with PCI-3000 (tan) and the other was coated with PCI-5000 (brown). They also provided two PCI-3000-coated tie plates and one PCI-5000-coated tie plate. Therefore, one of the PCI-3000-coated tie plates on one end also had salt in the mounded region.

The PCI-3000 system did moderately well, but the interfacial rail-tie plate region did not hold up as well as the PCI-5000 system (Figure 33 and Figure 34). Having the bottom of the rail untreated enabled more advanced corrosion on the PCI-3000 system, but did not attack the PCI-5000 system within the same time frame. This is an encouraging result since it suggests the PCI-5000 coating may be inherently more resistant to corrosion. As shown in Figure 34, the rail base has developed severe corrosion even though the coated tie plate is in very good condition. These results also paralleled those found in the DNV testing.

Figure 35 shows the 6-month end result for the four coatings. Since these results parallel the predictions based on the DNV testing, it appears the DNV testing protocol is useful for predicting long-term performance and for screening purposes. It also shows the PCI-5000 system provides the most corrosion resistance of the four systems under the conditions presented.

Figure 30. Bare Rail (Clockwise: UL – Start, UR – 2 Months, LR – 4 Months, LL – 6 Months)

Figure 31. EonCoat® V (Clockwise: UL – Start, UR – 2 Months, LR – 4 Months, LL – 6 Months)
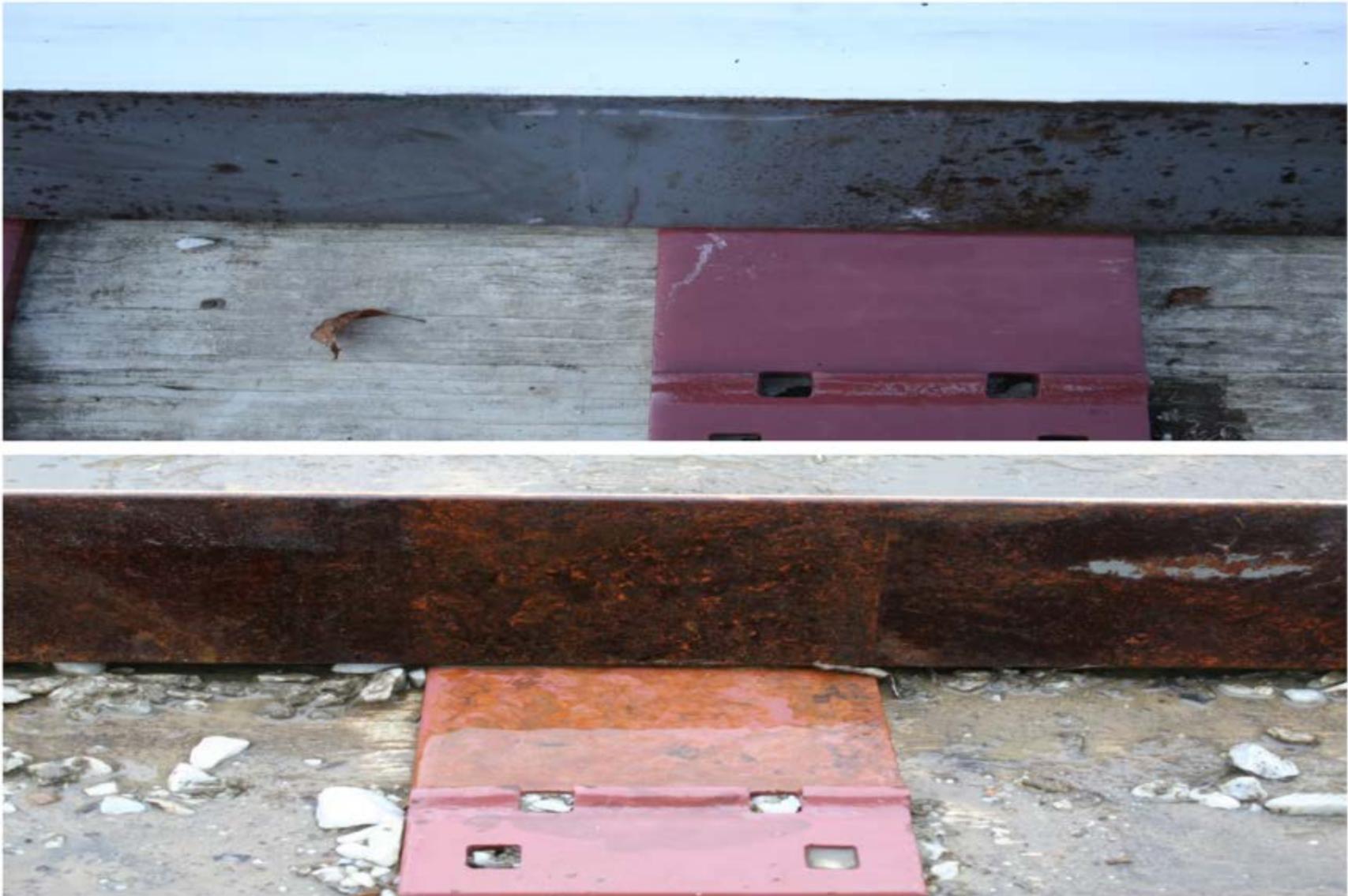
Figure 32. Rutgers Coating (Top – Start, Bottom – 3 Months)

Figure 33. PCI – 3000 (Clockwise: UL – Start, UR – 2 Months, LR – 4 Months, LL – 6 Months)

Figure 34. PCI – 5000 (Clockwise: UL – Start, UR – 2 Months, LR – 4 Months, LL – 6 Months)

35

Figure 35. Six Months (Clockwise: UL – EonCoat® V, UR – Rutgers 3 Months, LR – PCI-3000, LL – PCI-5000)

4. Conclusion

Rail base corrosion represents a significant safety concern for passenger and freight rail operating on tracks in highly corrosive environments, such as locations near platforms, in tunnels, under overpasses, or on rail lines operated near bodies of saltwater. Untreated rail, even in the absence of electrification, succumbs to environmental corrosion attack very soon after installation. These regions are not easily accessible for inspection, which is of great concern to the rail industry. Having some form of corrosion protection between the rail base and the tie plate would be useful.

In Phase 2, several rail and tie plate sets were coated with EonCoat® and placed into field service by three railroads. Most of these service tracks have electrified rail. Results from the field indicated the coating displayed poor adhesion properties and thus led to the review of four new coating systems for their applicability in rail base corrosion prevention. However, several of the Phase 2 coated rail are still in service, suggesting a benefit was provided by having the coating.

In Phase 2B, both laboratory testing and outdoor exposure testing were undertaken and neither involved electrification. The outdoor testing over 6 months substantially paralleled the results and conclusions drawn from the laboratory testing which required about 8 weeks. One of the coatings, Precision Coatings, Inc.'s PCI-5000 performed the best in both laboratory and outdoor exposure testing.

4.1 Recommendations for Future Work

The PCI-5000 system is shown to provide the best performance of the four new treatments tested in both the laboratory and outdoor test bed at EWI. A limited field trial, similar to the type outlined for Phase 2 in this program, should be undertaken. There is currently no safe, simple method known to evaluate the coating's performance on electrified rail in a way that mimics the actual field environment. Concerns over the effects of electrification are real and understandable. However, it would be useful to conduct field trials on electrified rail—on AC-fed lines and on DC-fed lines—to measure the overall effectiveness of the coating.

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Abbreviations and Acronyms

ASTM	American Society for Testing and Materials
DNV	Det Norske Veritas
EC	EonCoat, LLC
FRA	Federal Railroad Administration
Volpe	John A. Volpe National Transportation Systems Center
LIRR	Long Island Rail Road
NS	Norfolk Southern Corporation
PATH	Port Authority Trans-Hudson
PCI	Precision Coatings, Inc.
PCI-3000	Precision Coatings, Inc. Reflect® 3000
PCI-5000	Precision Coatings, Inc. Reflect® 5000
TCRD	Transit Cooperative Research Program
TTCI	Transportation Technology Center, Inc.