U.S. Department of Transportation
Federal Highway Administration

Turner-Fairbank
Highway Research Center

Current Research at FHWA Coatings and Corrosion Laboratory

Office of Research, Development, and Technology
Federal Highway Administration (FHWA) Coatings and Corrosion Lab
Current Activities—2022

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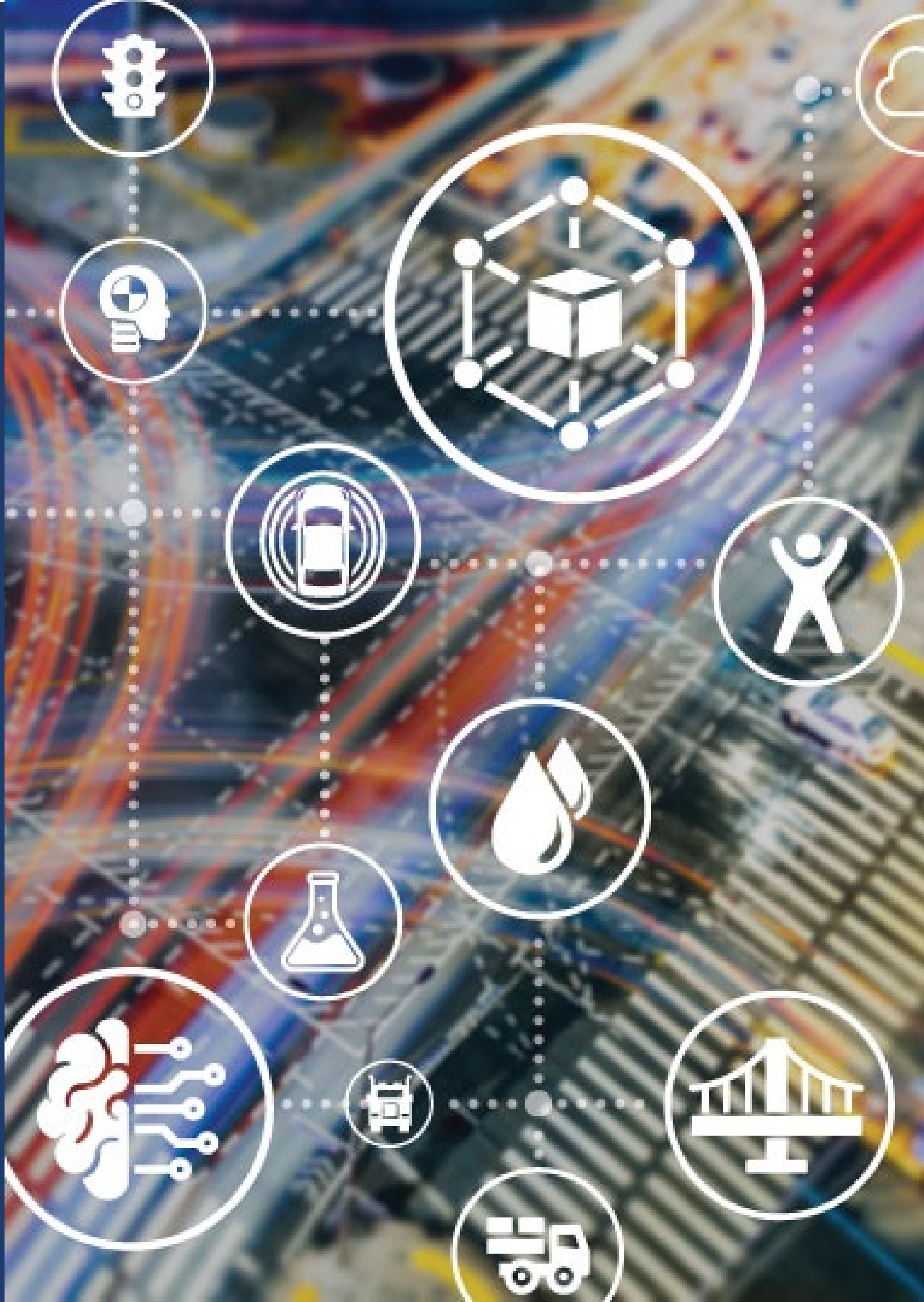

Outline

- Coatings and Corrosion Laboratory (CCL) expertise, mission, and research disciplines.
- CCL current research projects:
  - Corrosion performance of metalized coatings over contaminated steel substrate.
  - Performance of coating systems used for preventive maintenance.
  - Stress corrosion cracking of stainless steel in contact with chloride ions at low level.
  - Corrosion performance of alternative strand materials.
- CCL outreach.

Turner-Fairbank Highway Research Center Expertise

- Structural design and performance.
- Pavement design and evaluation.
- Safety design and operations.
- Human factors analytics.
- Connected vehicle technologies.
- Intelligent transportation systems.

Source: FHWA.

Laboratories

Safety

Federal Outdoor Impact Laboratory (FOIL)

Geometric Design Laboratory

Human Factors Laboratory

Safety Training Analysis Center (STAC)

Operations

Saxton Transportation Operations Laboratory (STOL)

Infrastructure

Aggregate and Petrography Laboratory

Asphalt Binder and Mixture Laboratory

Chemistry Laboratory

Coatings and Corrosion Laboratory

Concrete Laboratory

Geotechnical Laboratory

J. Sterling Jones Hydraulics Research Laboratory

Nondestructive Evaluation (NDE) Laboratory

Pavement Testing Facility

Structures Laboratory

Source: FHWA.

CCL Mission and Goals

1. Conduct research to discover innovative solutions for the most critical materials-related problems that affect durability and serviceability of transportation infrastructure.

2. Focus on research that can yield field-applicable results within 2–3 yr.

3. Make the Nation's infrastructure safer and last longer by providing useful research products to stakeholders (e.g., State and local highway agencies, industries, and academia).

Corrosion Modeling and Simulation

Data sources:

- Construction documents.
- Field assessment.
- Laboratory testing.

→

Modeling corrosion:

- Chloride ingress.
- Corrosion initiation and propagation.
- Corrosion damage to steel and concrete.

CCL Research Program

Data sources:

- Field assessment.
- Laboratory testing.
- Modeling and simulation.

Data science

Infrastructure management:

- Service life prediction.
- Preservation strategy.
- Life cycle cost analysis.

Source: FHWA.

CCL Current and Recently Completed Research Projects

U.S. Department of Transportation
Federal Highway Administration

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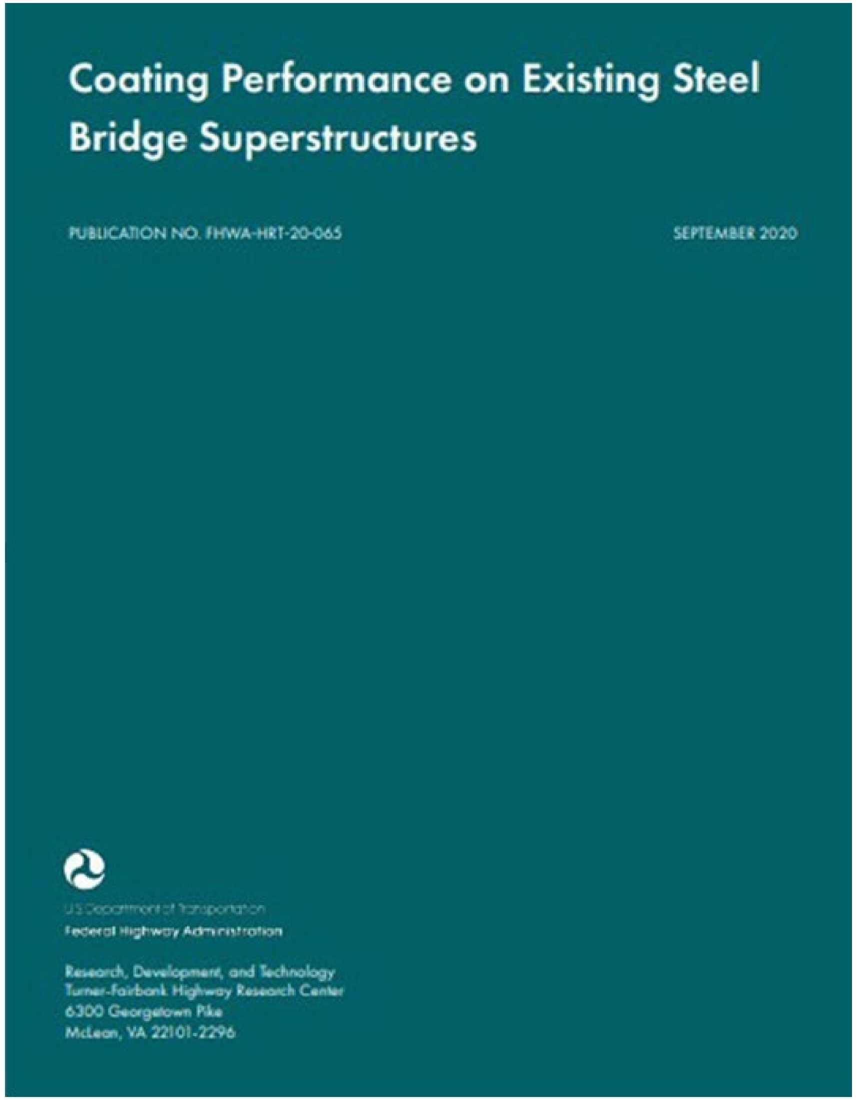
Recently Completed Research Projects

- Protective coatings:
  - Report on industry-recognized corrosion prevention worker certifications effectiveness evaluation (Congressionally mandated study) (Becker and Kogler 2019).
  - Coating performance on existing steel bridge superstructures (coating performance over chloride-contaminated substrates) (Liu and Runion 2020).
  - Innovative coating removal techniques for coated bridge steel (laser versus grit-blasting coating removal performance evaluation) (Fitz-Gerald et al. 2019).
- Steel corrosion:
  - Report on best practices guidance for corrosion control and mitigation (Congressionally mandated study of FHWA corrosion guidance to industry) (Ault and Becker 2019).
  - Laboratory evaluation of corrosion resistance of metallic dowel bars (Lee 2018).
  - Laboratory evaluation of corrosion resistance of metallic rebar (Lee 2018).
  - Sulfate threshold for corrosion initiation in post-tensioning strand (Lee 2020).

Coating Performance on Existing Steel Bridge Superstructures


Coating Performance on Existing Steel Bridge Superstructures

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U.S. Department of Transportation
Federal Highway Administration

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Source: FHWA. (Liu and Runion 2020)

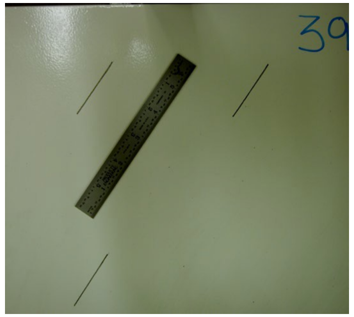
Coating Performance on Existing Steel Bridge Superstructures

- Evaluated four coatings over intentionally contaminated surfaces:
  - A three-coat system with an inorganic zinc-rich primer.
  - A three-coat system with an organic zinc-rich primer.
  - A two-coat system with zinc-rich primer with carbon nanotubes and urethane topcoat.
  - A one-coat system of high-ratio calcium sulfonate alkyd.
- Developed substrates with three levels of chloride contamination:
  - Control: less than 1-µg/cm^2.
  - –20-µg/cm^2.
  - –60-µg/cm^2.

Outdoor Exposure Testing

Typically multiyear

All photos source: FHWA.



Scribes in coating.

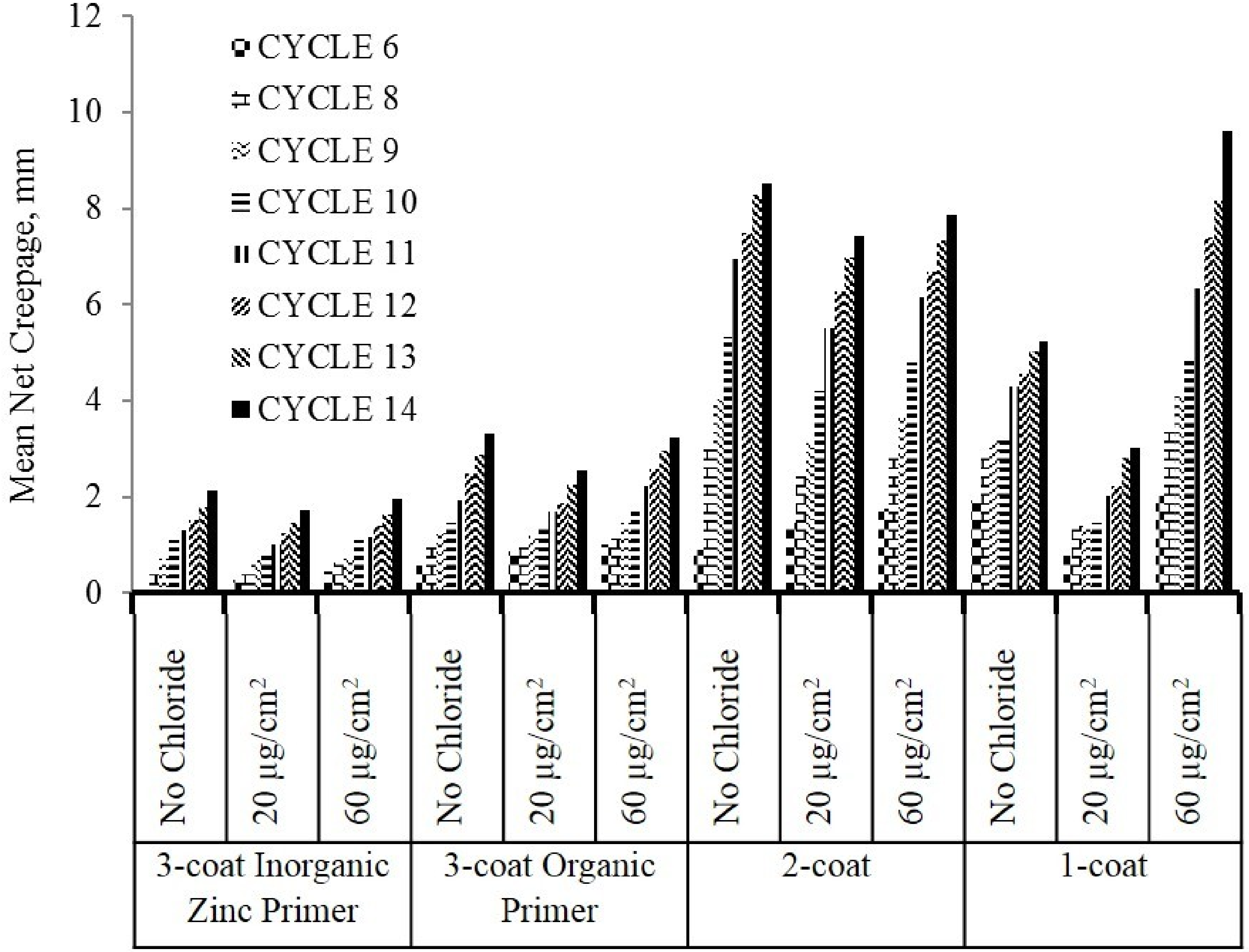
Accelerated Lab Testing (ALT)

Salt fog chambers

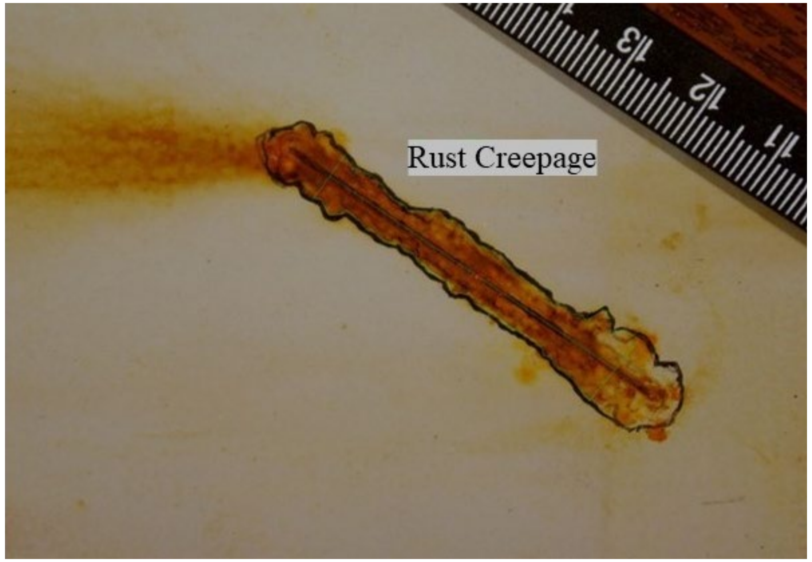
UV chamber

All photos source: FHWA.

ALT



Rust creepage development on ALT panels



Rust creepage measurement

All photos source: FHWA.

Coating Performance—Conclusions

- The three-coat systems showed better tolerance of chloride than the two- and one-coat systems. The three-coat system with inorganic zinc primer had the best tolerance of chloride.
- The inorganic zinc primer performed slightly better than the organic zinc primer with chloride contamination levels up to 60-µg/cm^2.
- Spraying saltwater did not affect the performance of the three-coat systems. The two-coat panels subjected to saltwater spray developed significant rust creepage, whereas the panels exposed to water spray did not exhibit noticeable creepage.
- Outdoor weathering simulates the natural exposure conditions experienced by steel bridges in service. However, the testing time should be significantly longer than ALT.

Current Research Projects

- Protective coatings:
  - Corrosion performance of metalized coatings over contaminated steel substrate (metalizing/galvanizing performance over chloride-contaminated substrate).
  - Performance of coating systems used for preventive maintenance.
- Steel corrosion:
  - Stress corrosion cracking of stainless steels (SSs) in contact with chloride ions at low temperature (stress corrosion cracking of SS rebars).
  - Corrosion performance of alternative strand materials.
  - Expansive synthesis on post-tensioned (PT) tendon corrosion issues.

Corrosion Performance of Metalized Coatings Over Contaminated Steel Substrate

Corrosion Performance of Metalized Coatings Over Contaminated Steel Substrate

- Evaluated the performance of thermal spray coatings on contaminated steel substrates.
- Evaluated three coating types (i.e., zinc, aluminum, and zinc/aluminum (85 percent zinc and 15 percent aluminum)) over four levels of chloride contamination: 0-, 20-, 60-, and 100-µg/cm^2.
- Coated the specimens with a top sealer.
- Stripe coated the edges with the seal coating.

Metallization

Thermal spray operation

Panel coated with top sealer

All photos source: FHWA.

Metalized Coatings—Testing

Outdoor exposure

Panels in salt-fog chamber

All photos source: FHWA.

Metalized Coatings—Testing

Aluminum coated

Aluminum coated

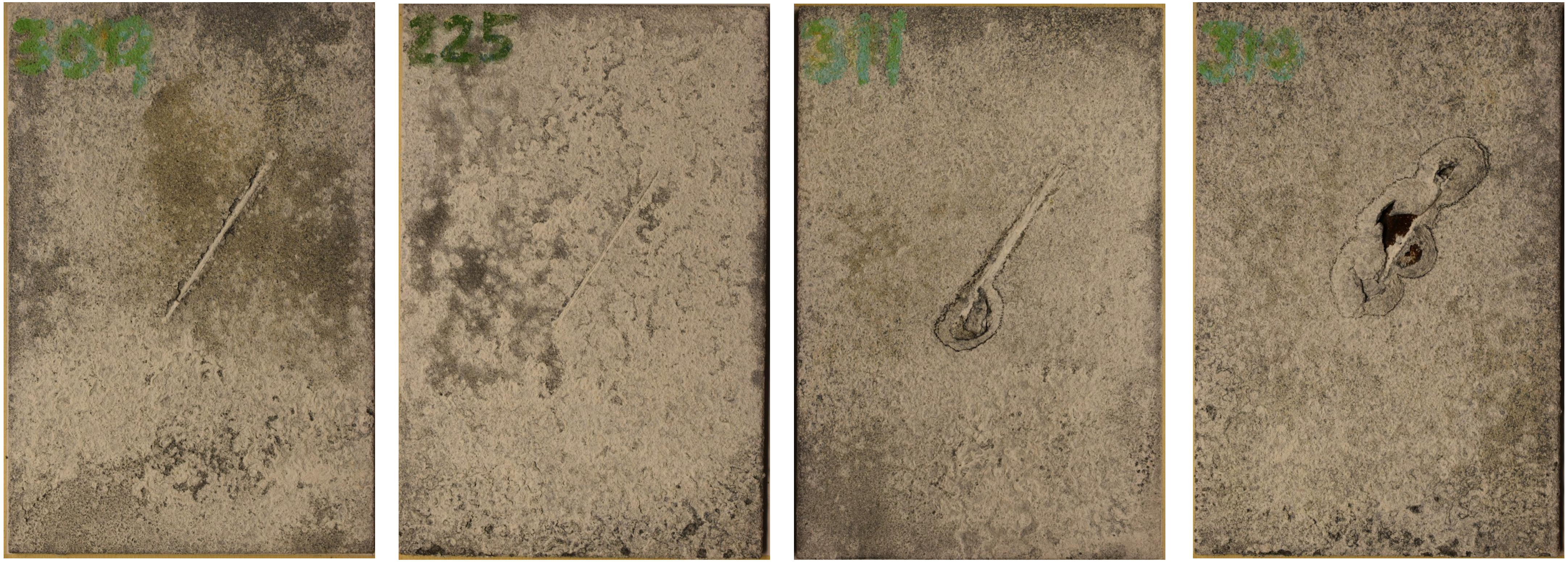
Zinc coated

Aluminum-zinc coated

Coated panels after 10 ALT cycles

All photos source: FHWA.

Metalized Coatings—Testing



Aluminum-zinc coated panels showing coating failure after 10 ALT cycles

All photos source: FHWA.

Performance of Coatings Used for Preventive Maintenance

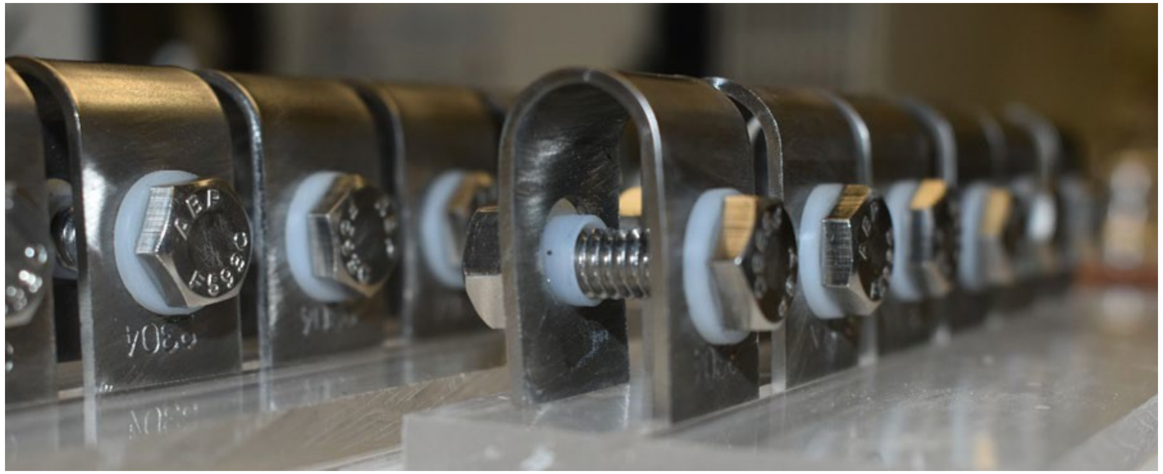
Performance of Coatings Used for Preventive Maintenance

- Investigate new and advanced coating materials for preventive maintenance and condition-based preservations.
- Research surface cleaning methods that are field-deployable for preventive maintenance coating applications.
- Explore maintenance coating application in the field (e.g., thermal spray, brush/roll).
- Explore the long-term performance of duplex coating systems.

Stress Corrosion Cracking of SS in Contact With Chloride Ions at Low Level

SS U-Bend Specimens

- Studied stress corrosion cracking (SCC) in several SS specimens under corrosive atmospheric conditions.
- Achieved stress in U-bend specimens by deformation.

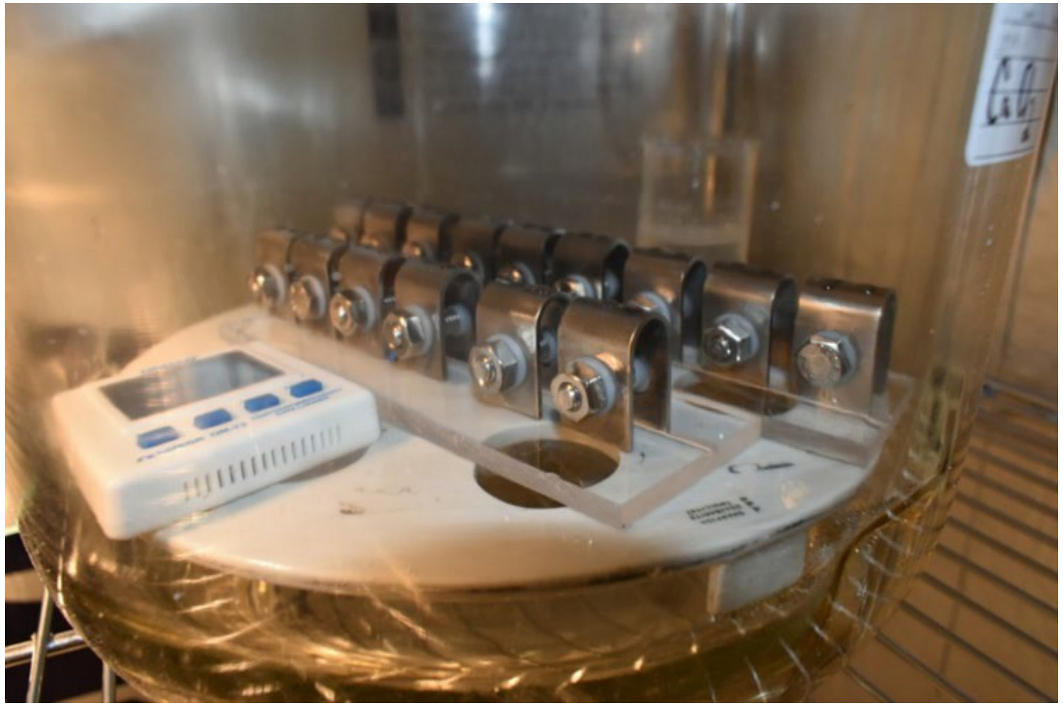


Source: FHWA.

Exposure Conditions

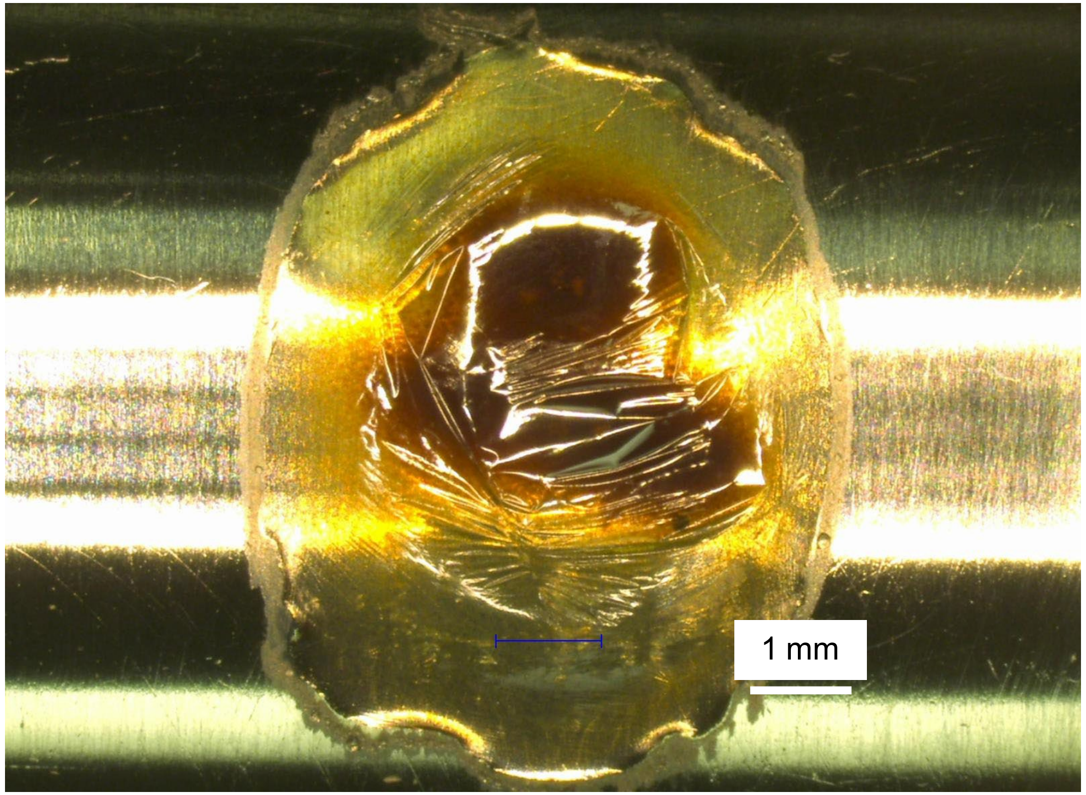
- SS specimens used were duplex 2205 and 2304, XM-28, 316LN, and 304L.
- Intent was to simulate initially high pH concrete pore solution and deicing salts.
- SS may develop localized corrosion at locations of concentrated chloride ions at relatively low temperature (around 50 °C /122 °F).
- Specimens were constantly exposed to salts (i.e., calcium chloride, magnesium chloride, and sodium chloride) in evaporative (i.e., including deliquescent) conditions.

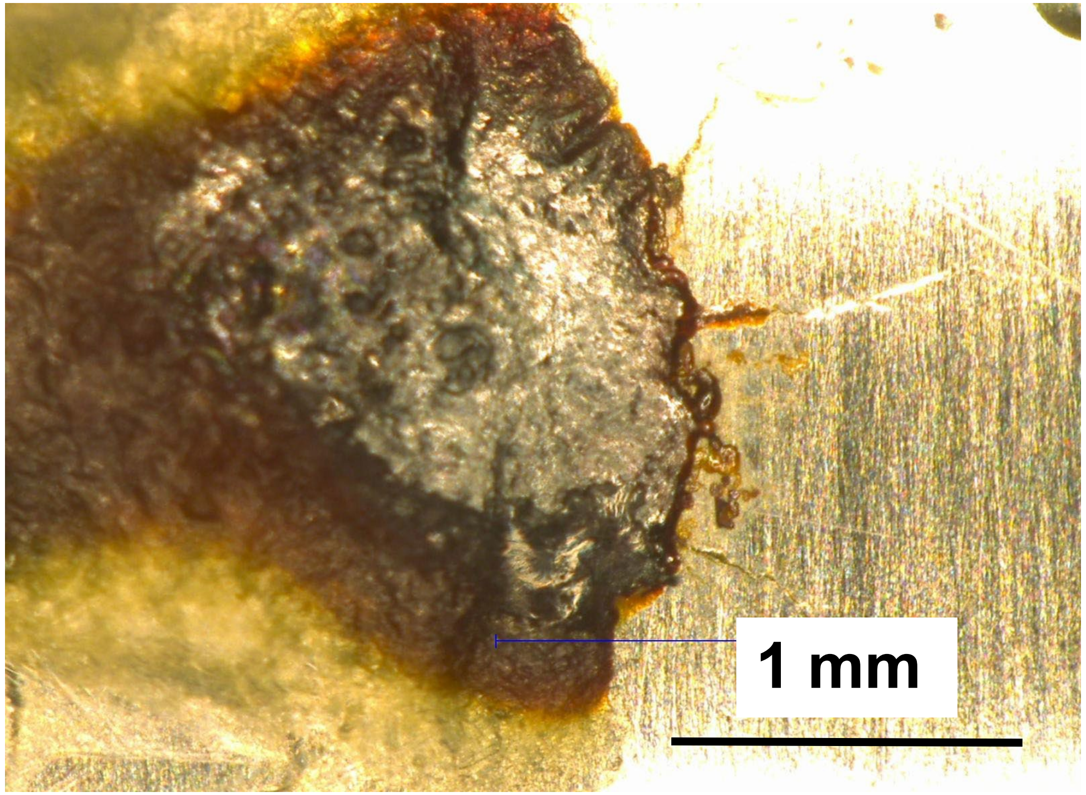
SS U-Bends in Test Chamber



All photos source: FHWA.

Droplets and Corrosion





All photos source: FHWA.

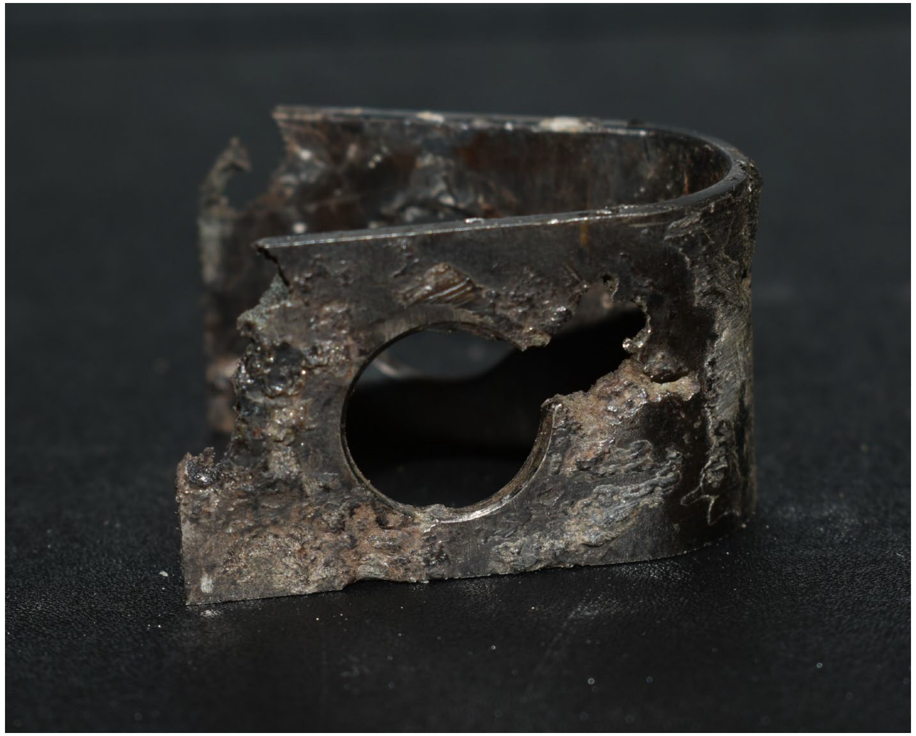
SCC Developed in U-Bend Samples


SCC in 316LN SS due to magnesium chloride


SCC in 304L SS due to calcium chloride

All photos source: FHWA.

Localized Corrosion in XM-28 SS

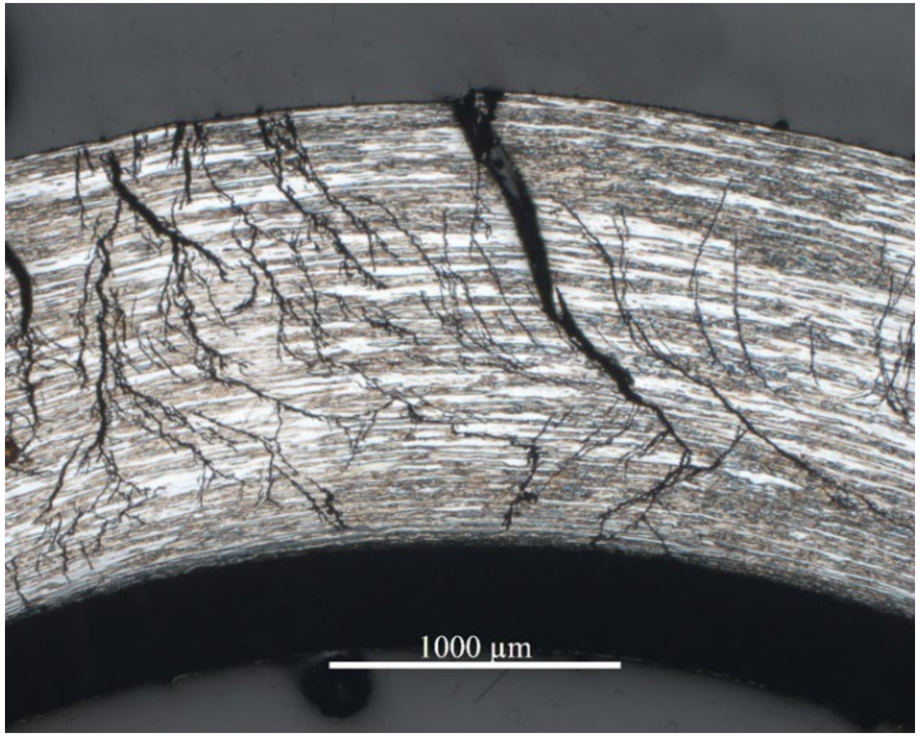


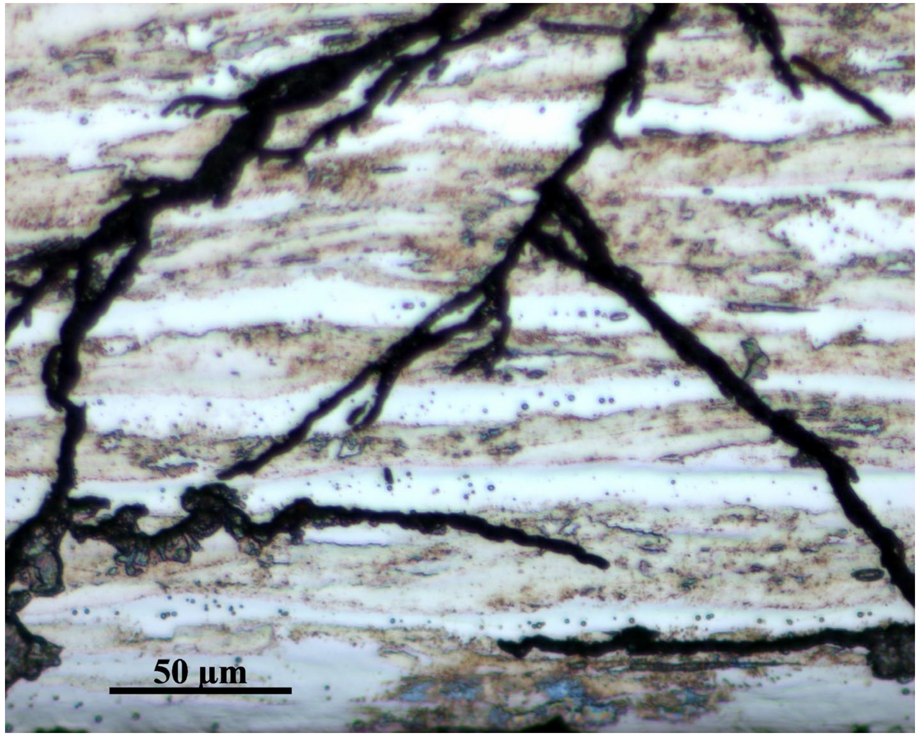
XM-28 in magnesium chloride

XM-28 in sodium chloride

All photos source: FHWA.

SCC in 316LN SS

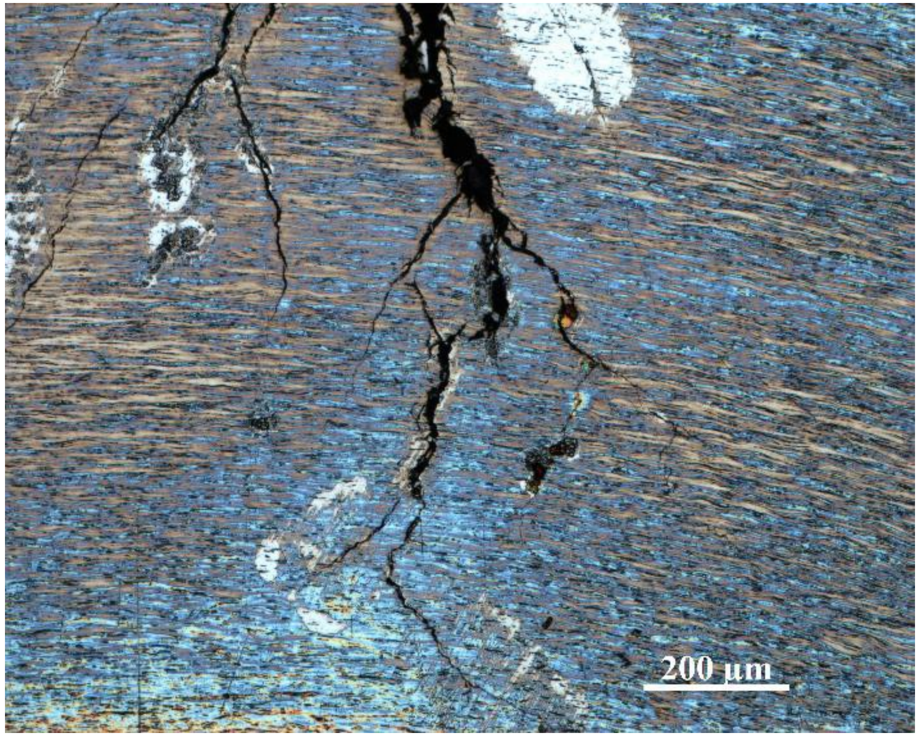


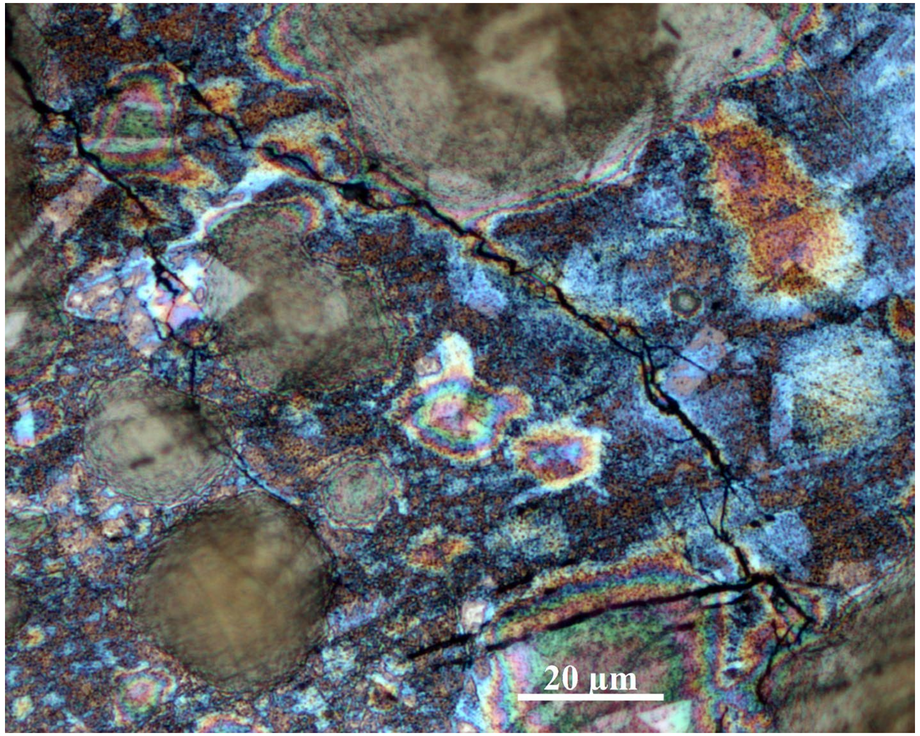


All photos source: FHWA.

SCC in 316LN SS due to magnesium chloride

SCC in 304L SS

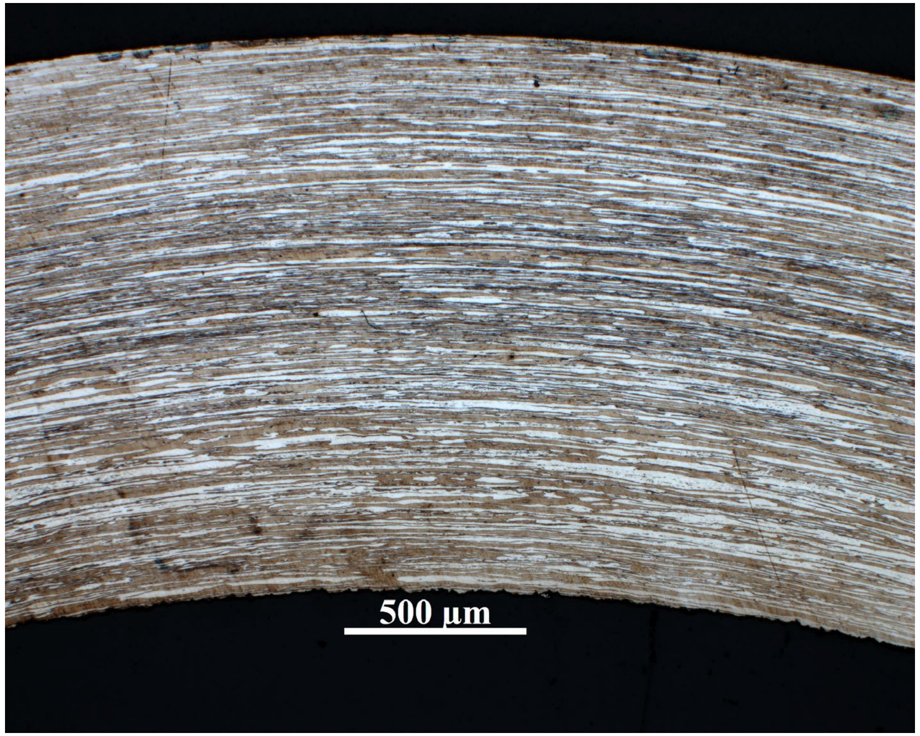


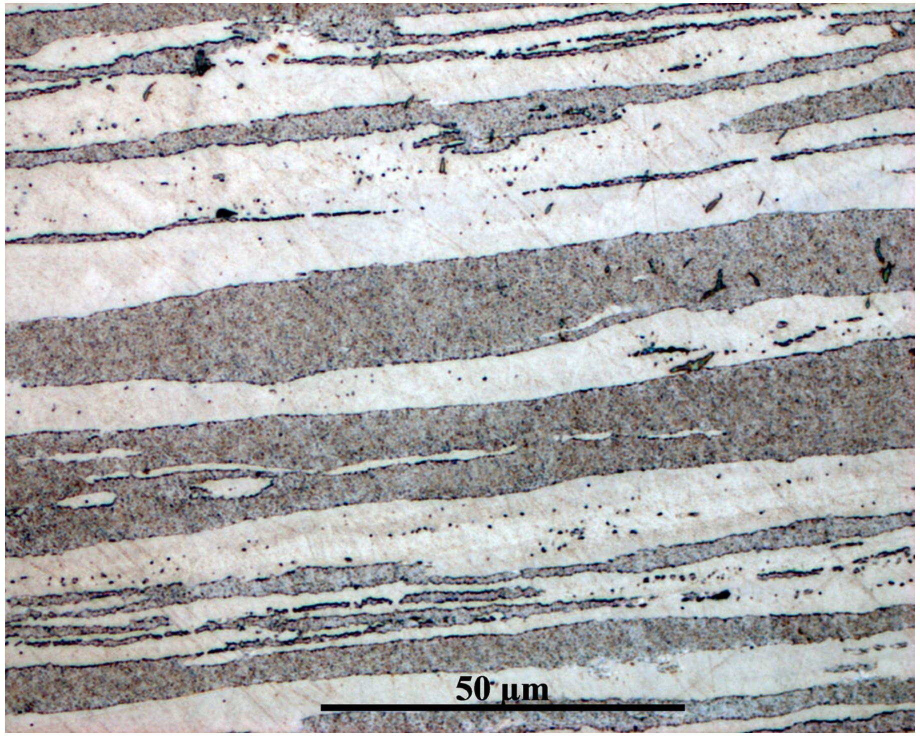


All photos source: FHWA.

SCC in 304L SS due to magnesium chloride

No SCC in 2304 SS

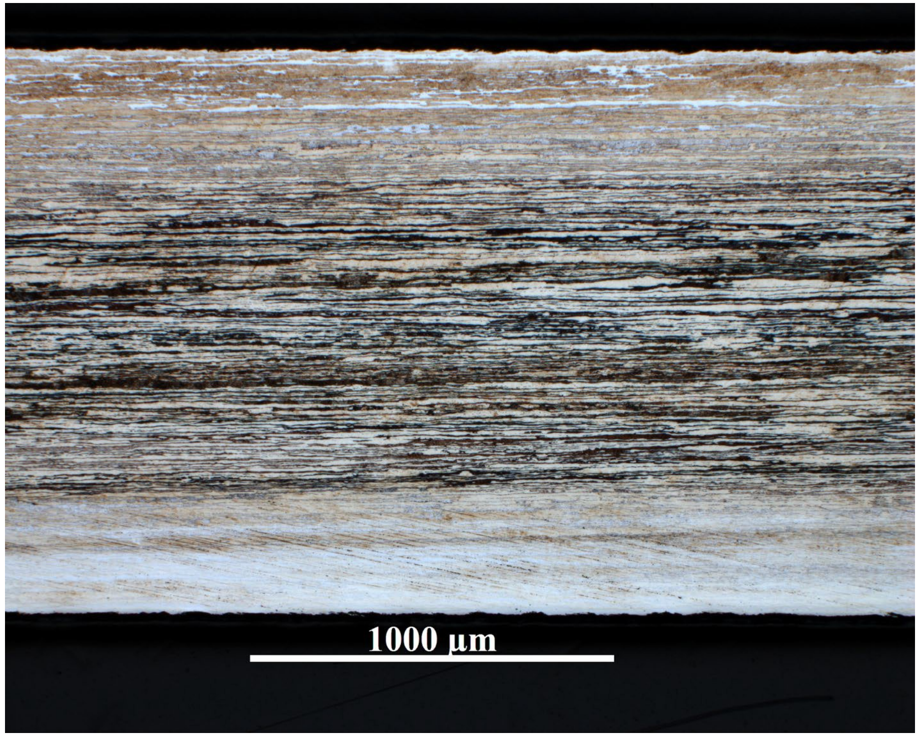


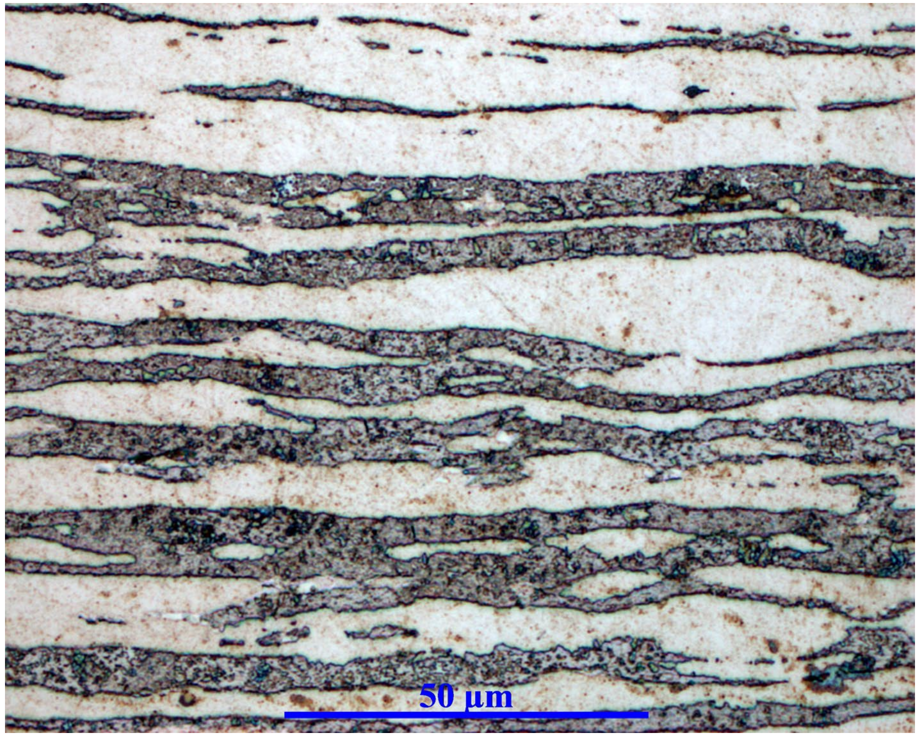


All photos source: FHWA.

Microscopic image showing grains of the 2304 SS

No SCC in 2205 SS





All photos source: FHWA.

Microscopic image showing grains of the 2205 SS

Corrosion Performance of Alternative Strand Materials

PT Tendon Corrosion Problems

Background:

- The observed (PT) strand corrosion problems were linked to water (or a moist environment) and grout voids.
- Other factors included sufficient amounts of chloride and sulfate ions, carbonation of grout and bleed water, segregated grout, and cracks in the grout.
- The tendons are always buried in grout/ducts (i.e., grouted external tendons) or in grout/ducts/concrete (i.e., grouted internal tendons). Corrosion damage often cannot be detected before it is too late.
- More corrosion-resistant materials are needed for new construction, and effective corrosion control methods are desirable for existing tendons.

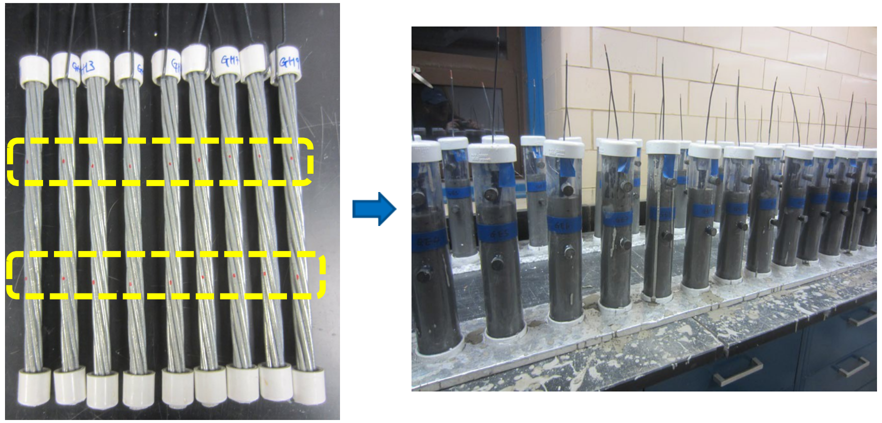
Laboratory Evaluations of Alternative Systems for Corrosion Control of PT Tendons in Prestressed Concrete Bridges

Objectives:

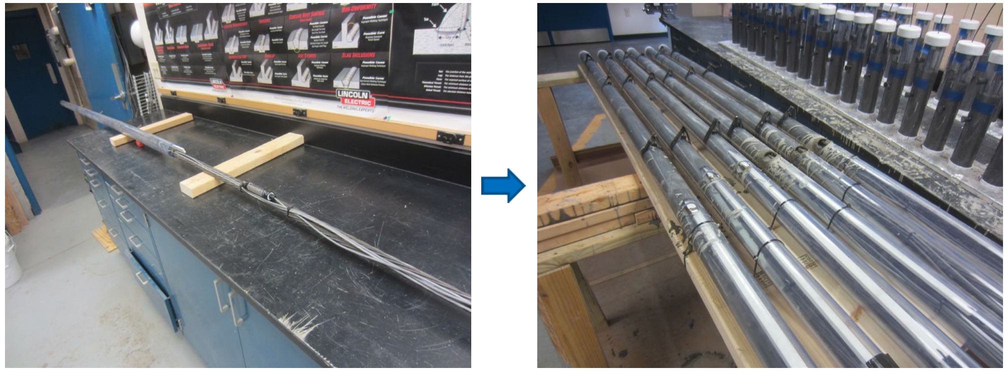
- Conduct an accelerated corrosion testing to quantify corrosion resistance of various metallic strand materials exposed to chloride (0.08, 0.2, 0.4, 0.8, 2.0 percent) and sulfate (0, 0.1, 0.2, 0.4, 0.8, 1.5, 3.0 percent) ions:
  - An A416 bare strand.
  - A hot-dip galvanized strand—ASTM A475-03 (ASTM International 2020a).
  - A 95 percent Zinc/5 percent Aluminum coating strand—(Close to ASTM B750, which covers GALFAN®) (ASTM International n.d.a).
  - An epoxy-coated strand (flow-filled type, no grit)—ASTM A882/A882M-04a (withdrawn 2019; no replacement) (ASTM International n.d.b).
  - A 2205 duplex SS strand—ASTM A1114 (ASTM International 2020b).
- Evaluate the effectiveness of the impregnation method, drying air, and inert gas method to suppress ongoing PT tendon corrosion problems.

PT Tendon—Laboratory Experiments

Corrosion resistance testing in simulated pore water and bleed water



Corrosion resistance testing in real grout



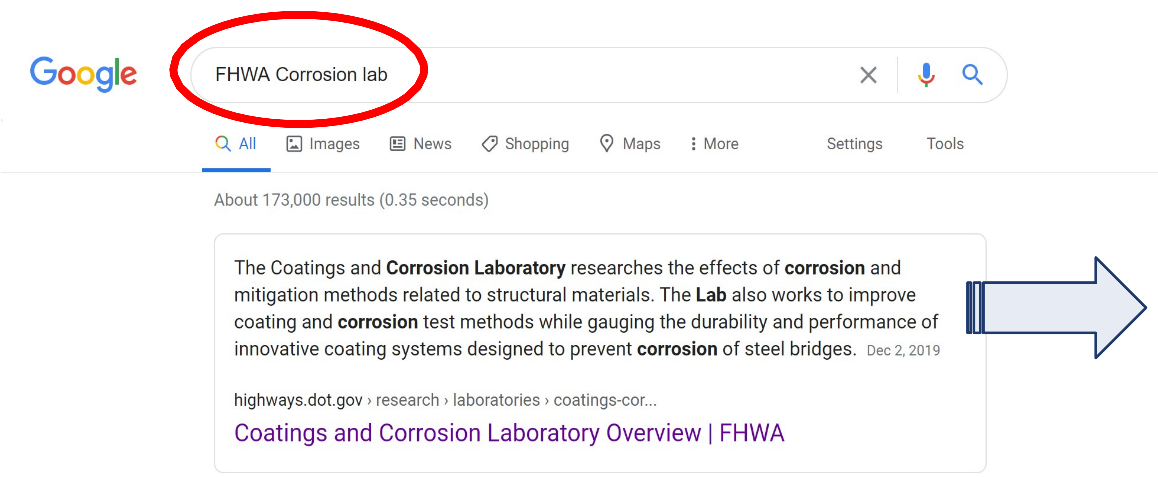
Evaluation of corrosion mitigation methods

All photos source: FHWA.

CCL Web Page

https://highways.dot.gov/research/laboratories/coatings-corrosion-laboratory/publications

Google Search: FHWA Corrosion Lab



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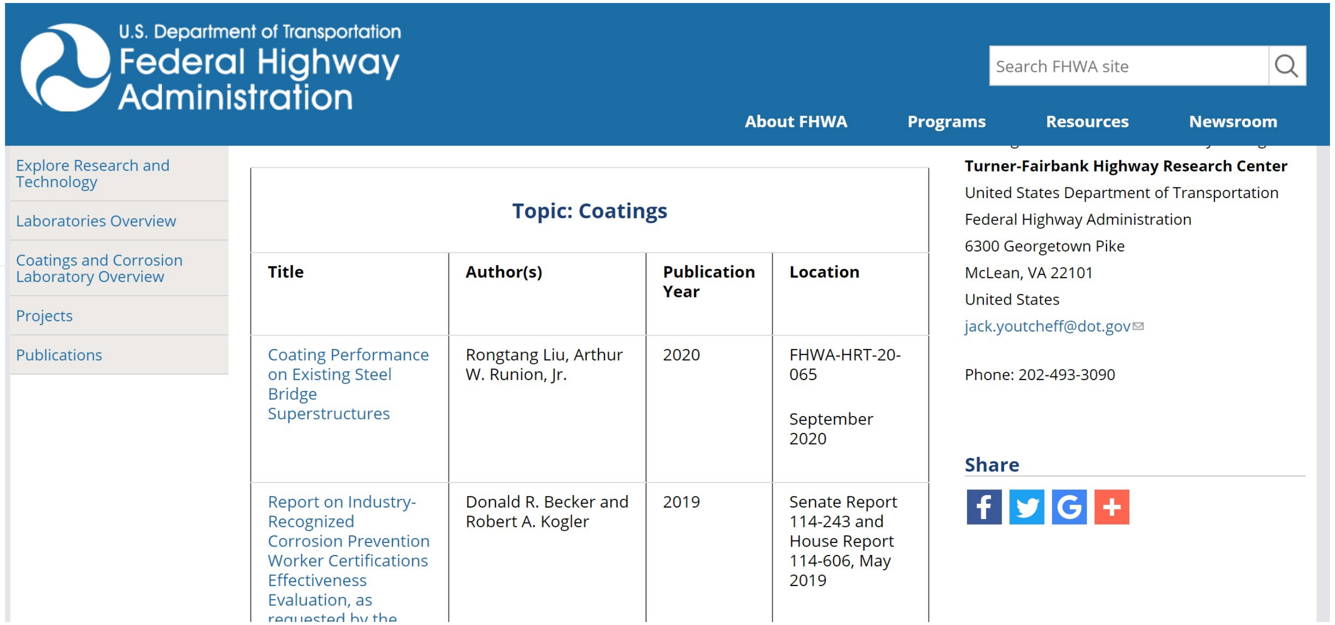

Source: FHWA.

(Federal Highway Administration. n.d.)

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