U.S. Department of Transportation
Federal Highway Administration

Turner-Fairbank Highway Research Center

Federal Highway Administration (FHWA) Coatings and Corrosion Laboratory (CCL): Ongoing Research on Corrosion

Office of Infrastructure Research and Development
FHWA CCL
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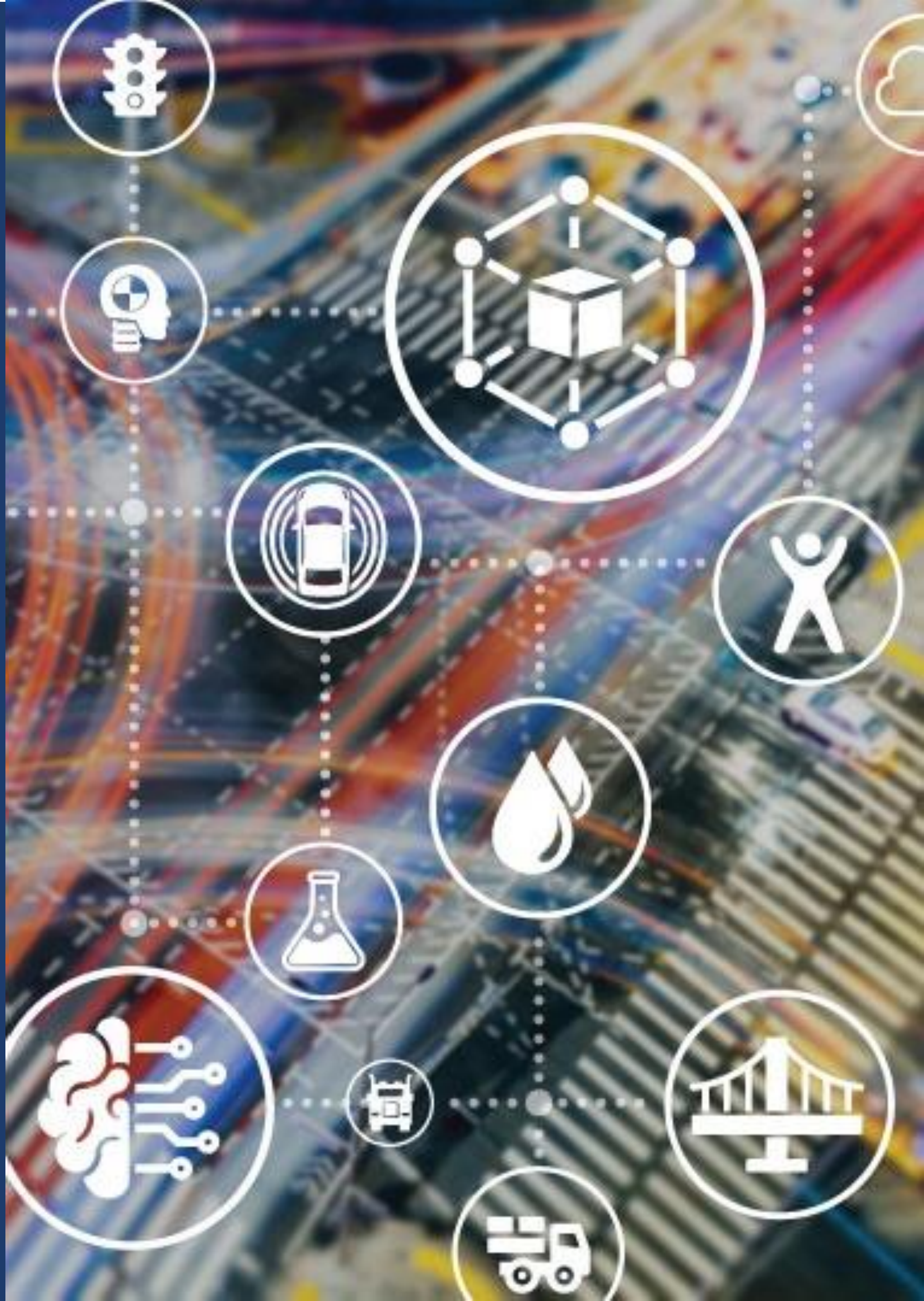
Frank Jalinoos
Coatings and corrosion lab manager
Long-Term Infrastructure Performance Team



Outline

- CCL expertise, mission, and research disciplines.
- Stress corrosion cracking (SCC) of stainless steel (SS) in contact with chloride ions:
  - Phase I—SCC in U-bend specimens.
  - Phase Ⅱ—SCC of SS embedded in chloride-contaminated concrete slabs.
  - Phase Ⅲ—long-term performance of SS rebars.

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 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.

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).

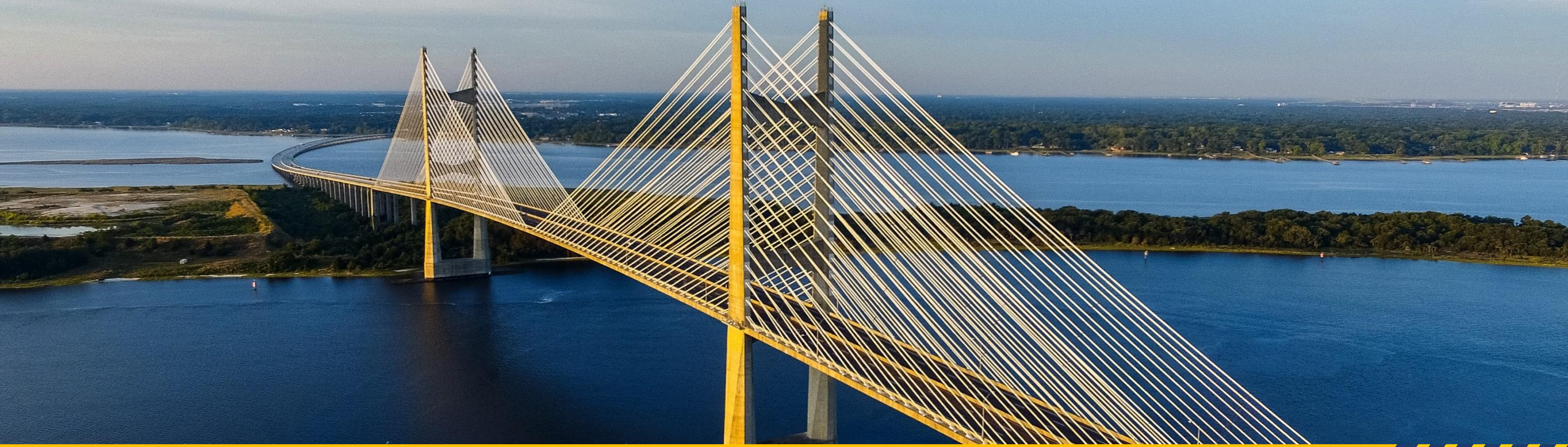
Corrosion Modeling and Simulation

Data sources:

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

Modeling corrosion:

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



Source: FHWA.

CCL Current Corrosion Research Projects

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Recently Completed Corrosion Research Projects

- Report on best practices guidance for corrosion control and mitigation (a congressionally mandated study of Federal Highway Administration (FHWA) corrosion guidance to industry) (Ault and Becker 2019).
- Laboratory evaluation of corrosion resistance of metallic dowel bars (Lee 2018b).
- Laboratory evaluation of corrosion resistance of metallic rebar (Lee 2018a).

Current Corrosion Research Projects

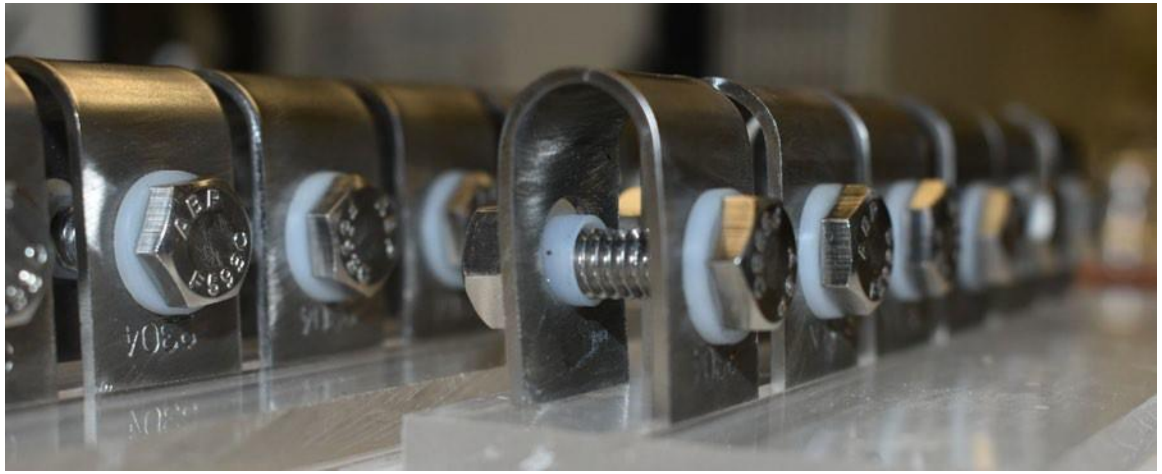
- Stress corrosion cracking (SCC) of stainless steel (SS) in contact with chloride ions (SCC of SS rebars).

- Corrosion performance of alternative strand materials.

Stress Corrosion Cracking (SCC) of Stainless Steel (SS) in Contact With Chloride Ions

Phase I—SS U-Bend Specimens

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

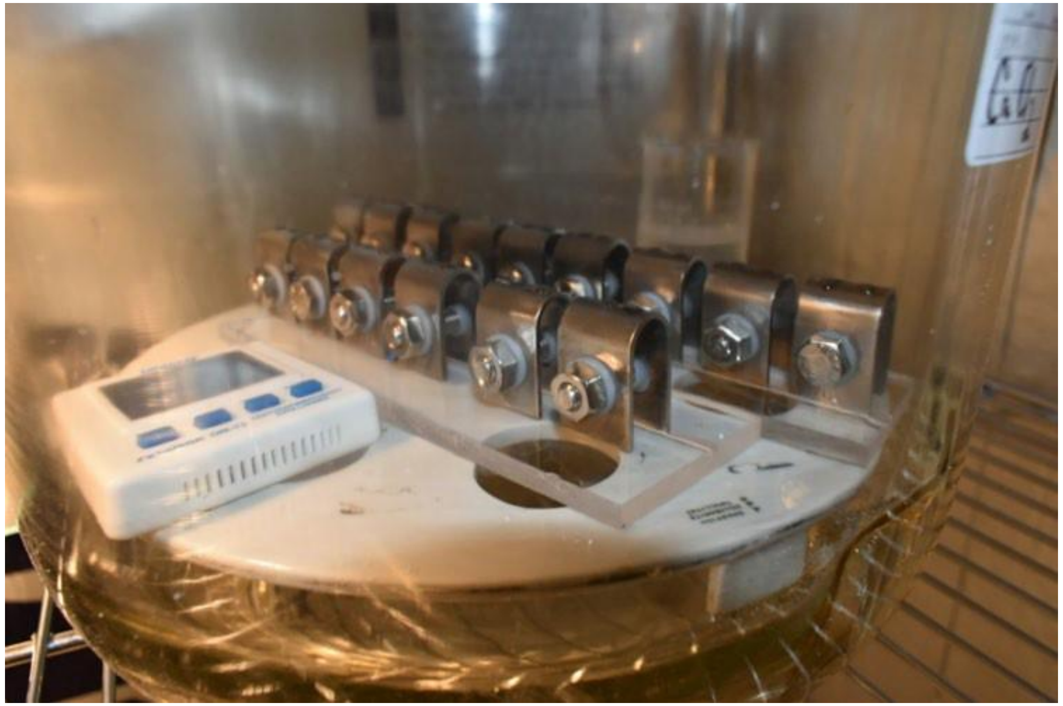


Source: FHWA.

Exposure Conditions in Phase I

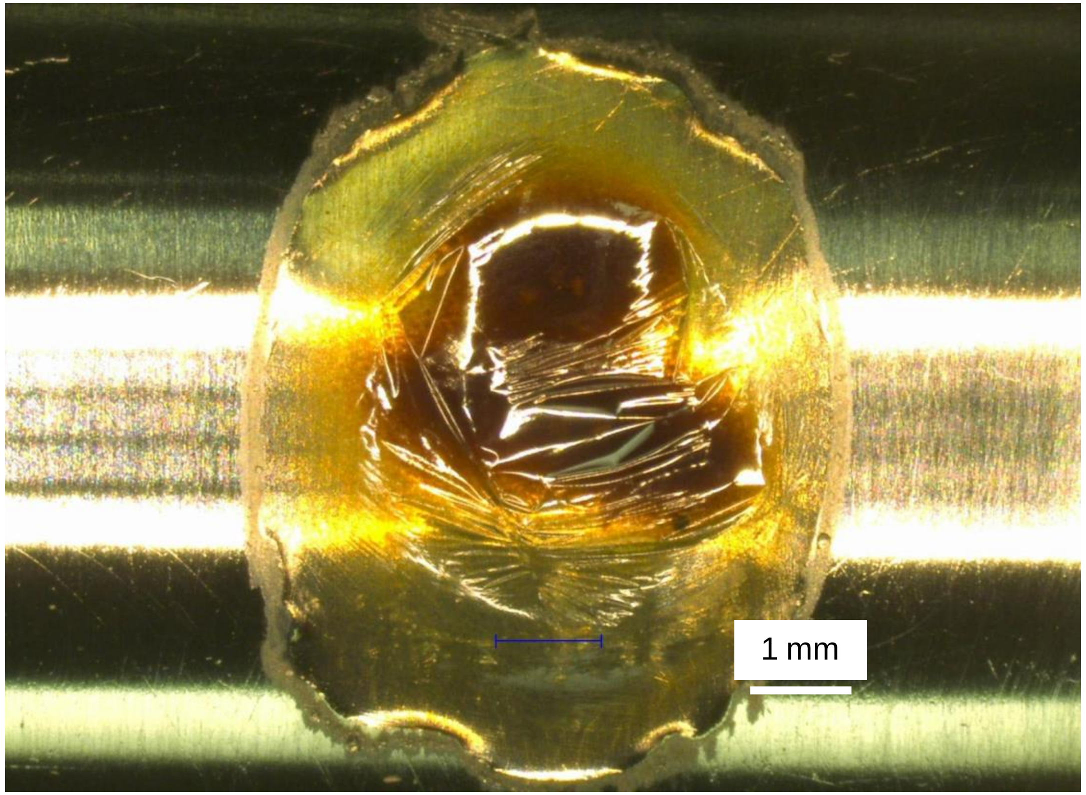
- SS specimens used were duplex 2205 and 2304, XM-28, 316LN, and 304L.
- Intent was to simulate initially high pH concrete pore solution and deicing salts.
- SS may develop localized corrosion at locations of concentrated chloride ions at relatively low temperature (around 50 ℃/122 ℉).
- Specimens were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

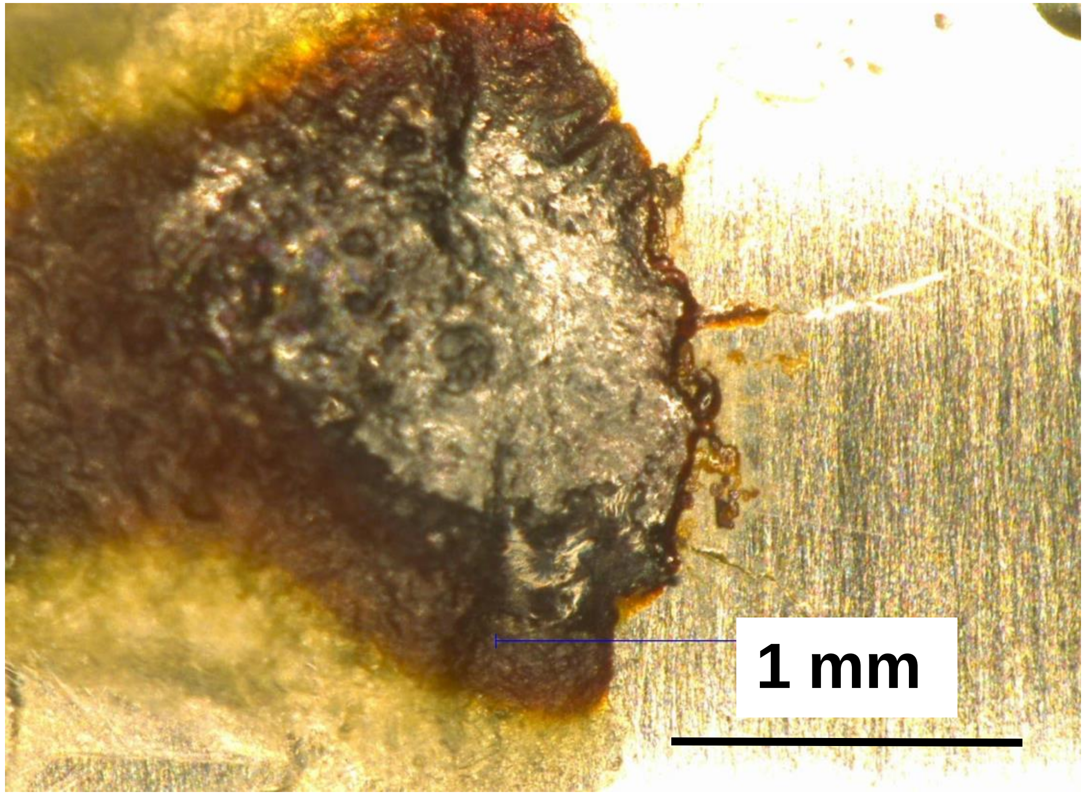
SS U-Bends in Test Chamber



All photos source: FHWA.

Droplets and Corrosion





All photos source: FHWA.

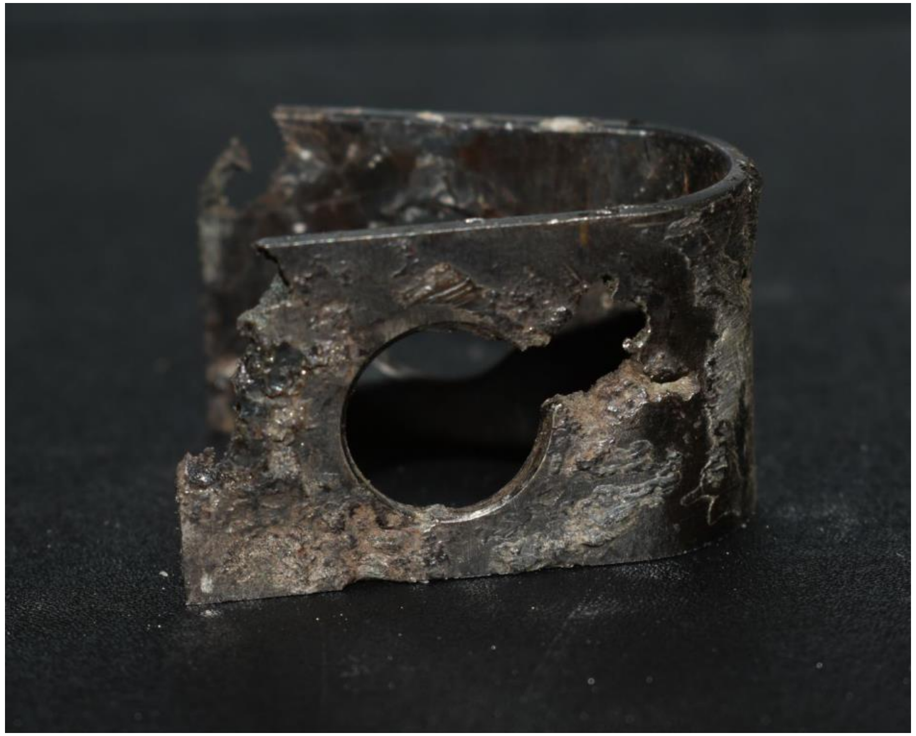
SCC Developed in U-Bend Samples

All photos source: FHWA.

SCC in 316LN SS due to magnesium chloride.

SCC in 304L SS due to calcium chloride.

Localized Corrosion in XM-28 SS

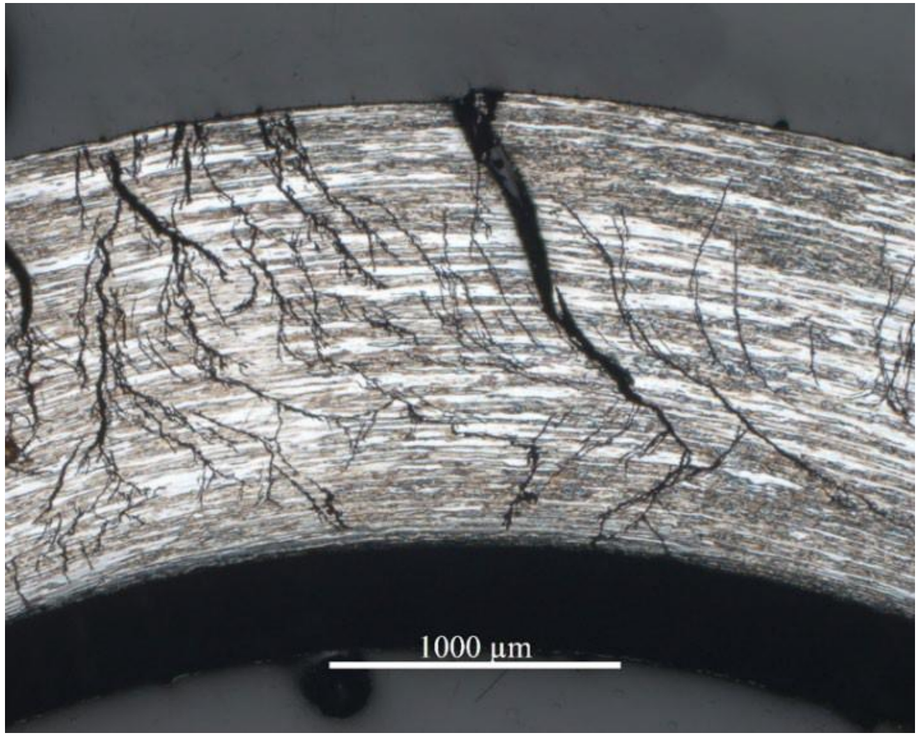


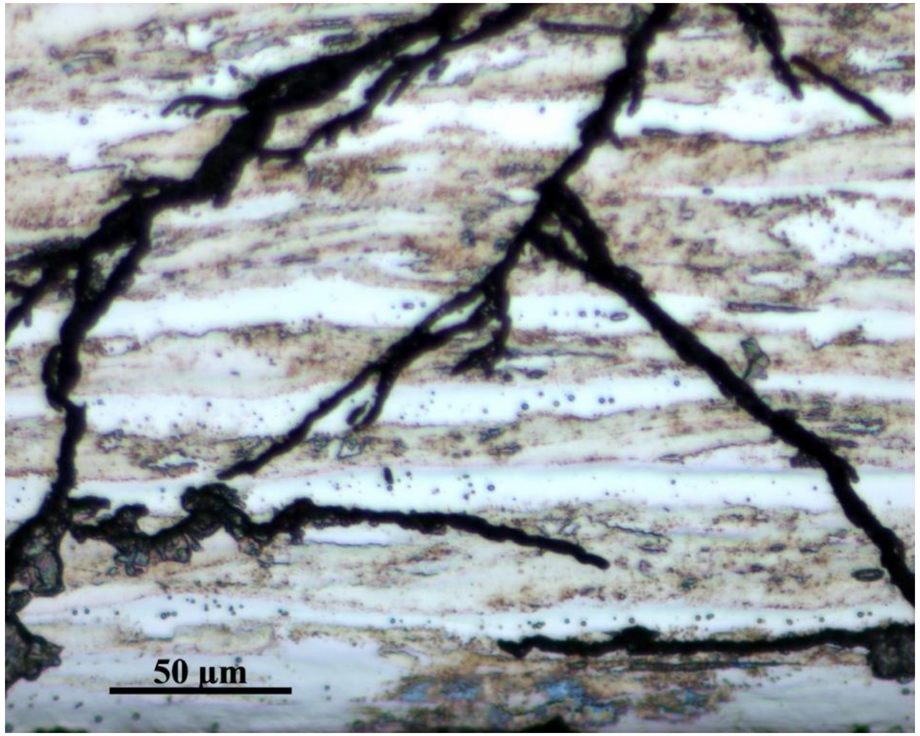
All photos source: FHWA.

XM-28 in magnesium chloride.

XM-28 in sodium chloride.

SCC in 316LN SS

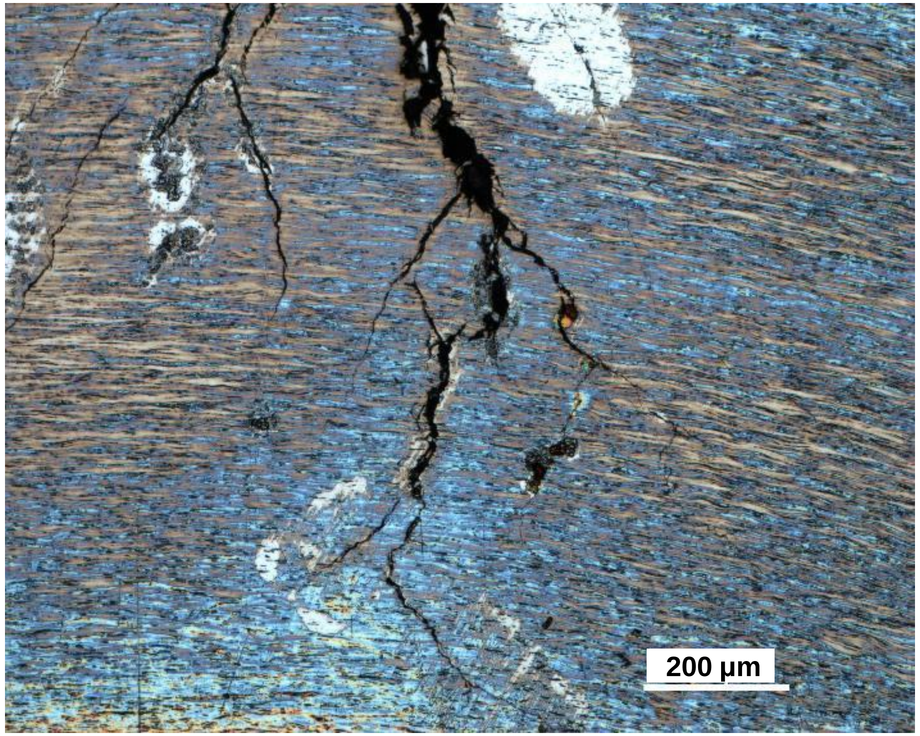


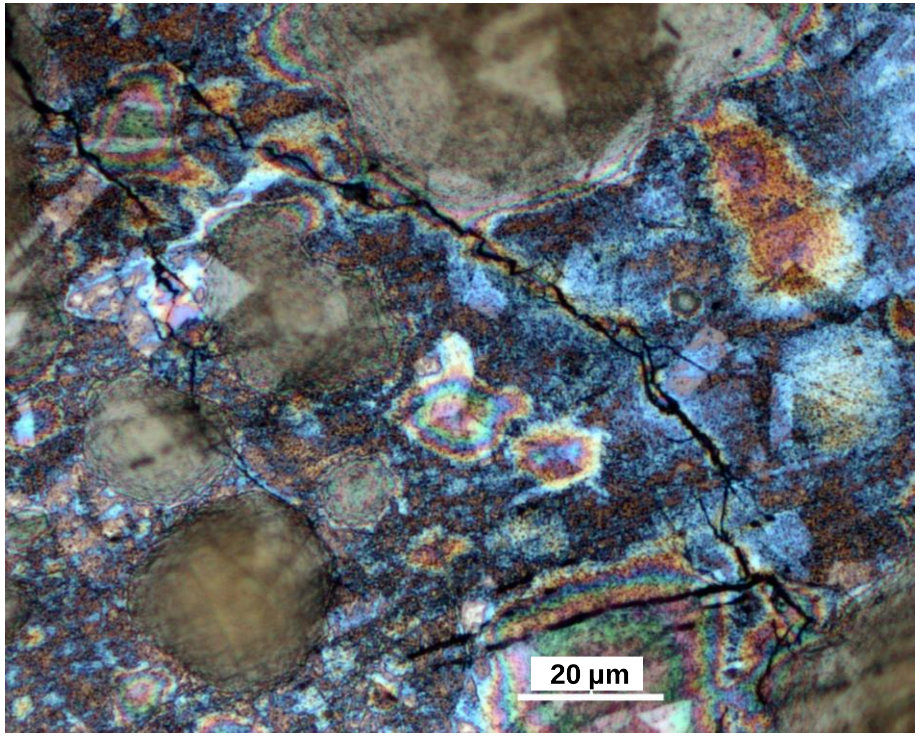


All photos source: FHWA.

SCC in 316LN SS due to magnesium chloride.

SCC in 304L SS

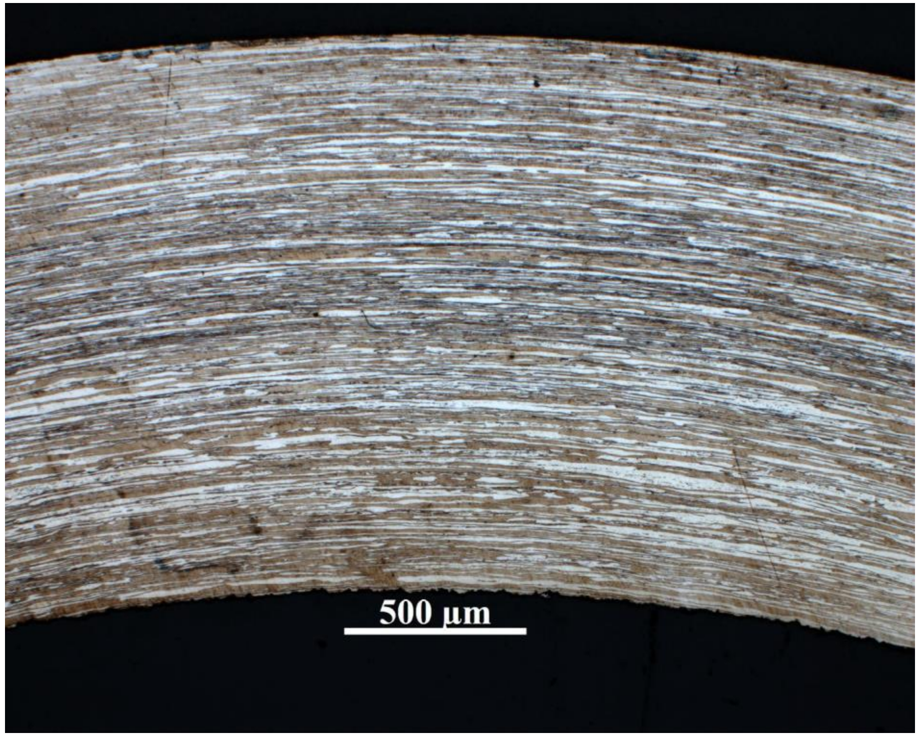


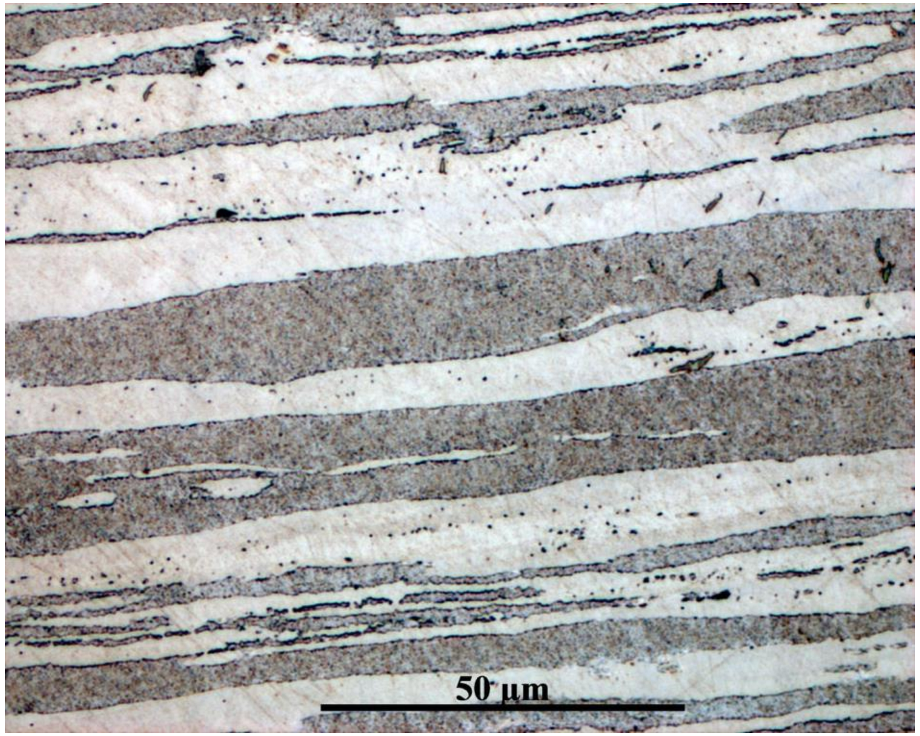


All photos source: FHWA.

SCC in 304L SS due to magnesium chloride.

No SCC in 2304 SS

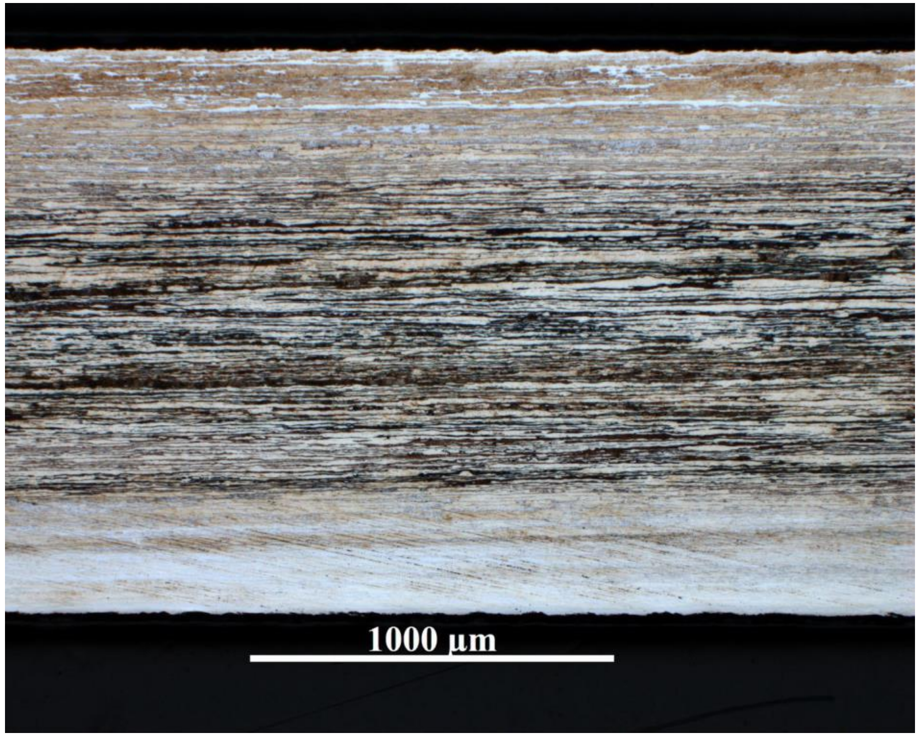


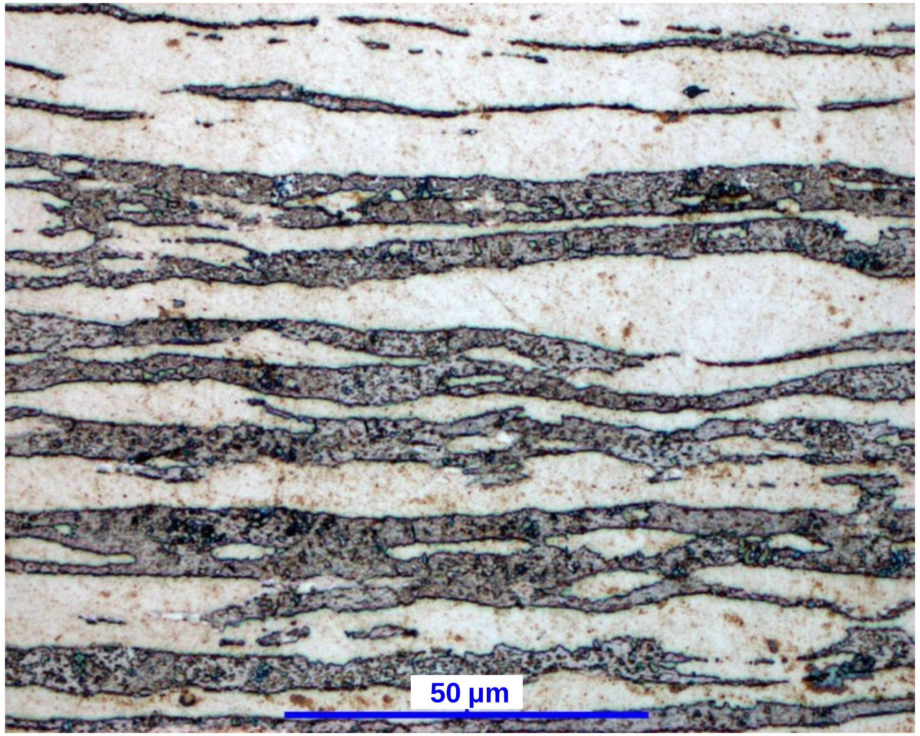


All photos source: FHWA.

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.

Phase Ⅱ—SCC of SS Embedded in Chloride-Contaminated Concrete Slabs

SCC in SS

- SCC is of great concern in SS exposed to aggressive environments. The stresses that cause SCC are tensile in nature.
- SCC is not the result of stress concentration at surface flaws caused by corrosion reactions.
- Residual stresses and tensile stresses often cause SCC (e.g., rebar hooks, welds, tendons, bars, and fasteners).
- Temperature and chloride ions are critical for SCC in SS.
- Crack propagation results from the interaction of mechanical stress and corrosion reactions.

SS Reinforcement

The austenitic SS are also considered to be the most weldable of the high-alloy steels and can be welded by all fusion and resistance welding processes:

1. 304L (unified numbering system (UNS) S30403): an austenitic SS with a minimum of 18-percent chromium and 8-percent nickel, and the carbon maximum is 0.030 percent (ASM International 1990).
2. 316LN (UNS S31653): a nitrogen-alloyed austenitic SS with molybdenum (Mo) addition. Due to a lower carbon content, 316LN loses some of its strength. It is alloyed with nitrogen to compensate for the loss of strength (ASM International 1990).
3. XM-28 (UNS S24100): a high-manganese, low-nickel austenitic SS, strengthened by extra nitrogen present in solid solution (ASM International 1990).

SS Reinforcement (Continued)

Duplex (austenitic ferritic) SS—better resistance to stress corrosion cracking:

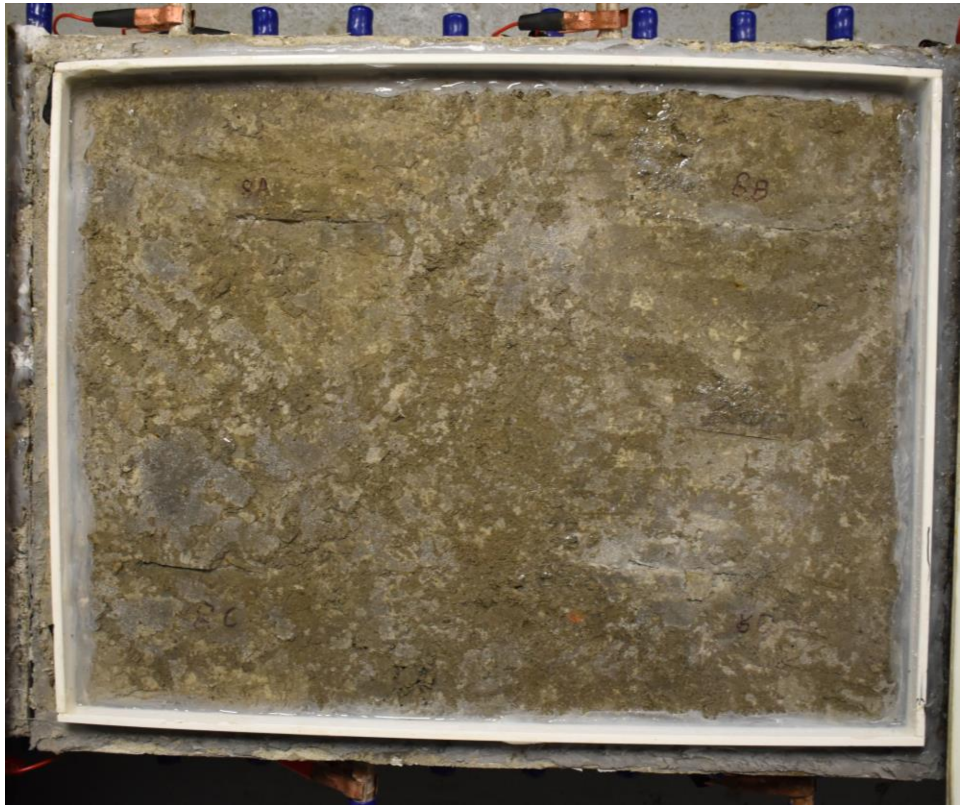
- Alloy 2304 (UNS S32304): usually called a lean duplex SS with 23-percent chromium and 4-percent nickel with no Mo content (ASM International 1990).
- 2205 duplex (UNS S32205): a duplex SS containing high chromium, molybdenum, and nitrogen contents (ASM International 1990).

Steel Specimens

Source: FHWA.

Residual stress is induced in SS hooks by plastic deformation.

Ponding



Source: FHWA.

Brine solutions:

- Sodium chloride (NaCl).
- Calcium chloride ($CaCl_2$).
- Magnesium chloride ($MgCl_2$).

Ponding concrete slab with brine solutions.

Exposure Conditions in Phase Ⅱ

Source: FHWA.

Ponding and heating cycles:

- Ponding: 4 d.
- Heating: 3 d.

Image caption:

- Left: Specimens were heated to 50 ℃ /122 ℉ with lamps in an insulated box.
- Right: measuring corrosion after removal of insulated boxes.

Corrosion Measurements

Source: FHWA.

Polarization resistance measurement with a potentiostat.

Corrosion measurements:

- Half-cell potential of top hooks.
- Macrocell corrosion current.
- Polarization resistance.
- Electrochemical impedance spectroscopy.

Phase Ⅲ—Long-Term Performance of SS Rebars

SS rebars in concrete slabs:

Rebar size: #5 bars.

SS types: (ASM International 1990)

- XM28.
- 316LN.
- 2205.
- 2304.

Control: mild steel black bar. (ASM International 1990)

Slab dimension: 3 ft by 4 ft by 1 ft.

Concrete mix:

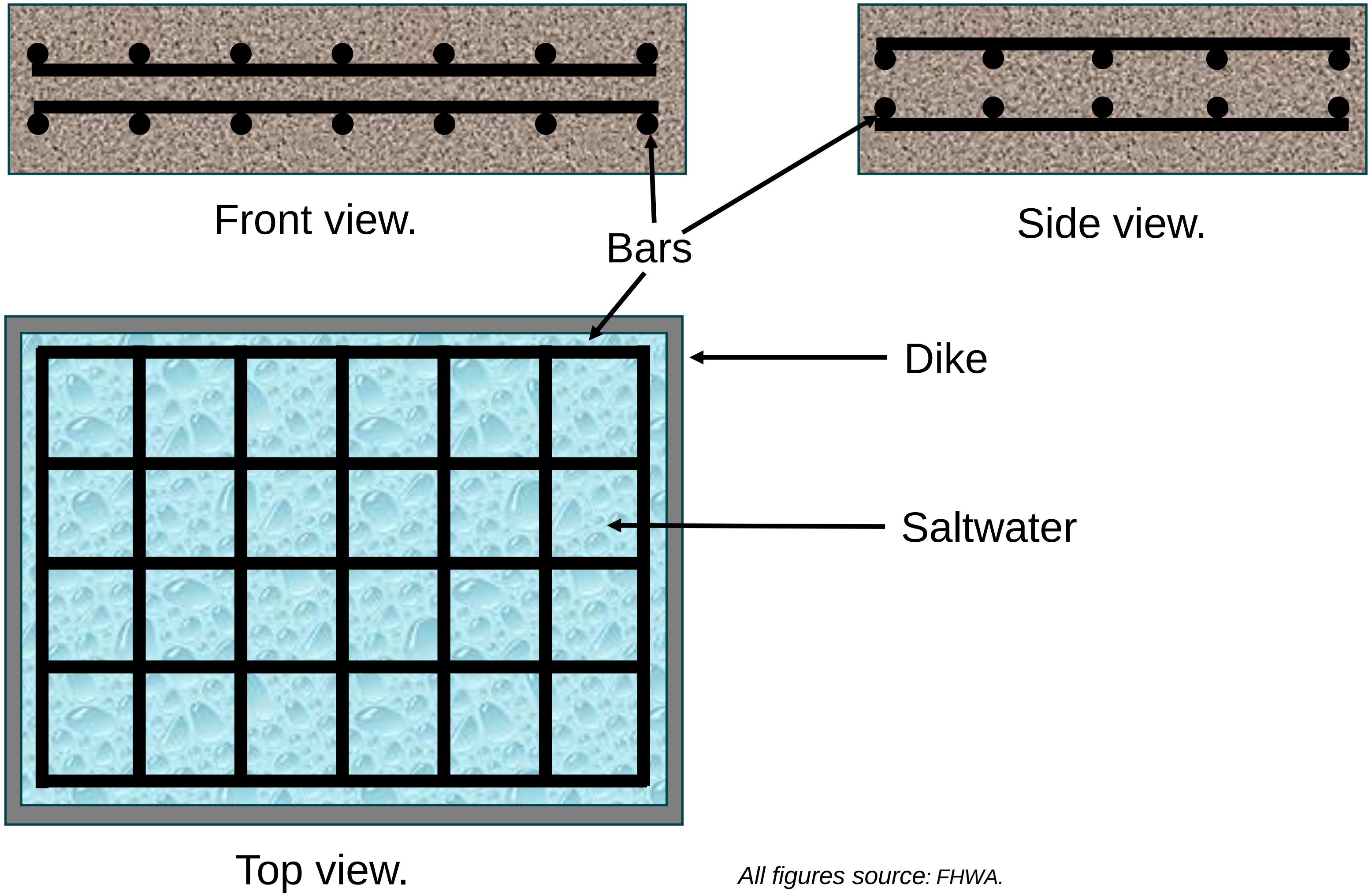
- Regular.
- Light-weight aggregate concrete.

Concrete clear cover:

- Top: 2 inches.
- Bottom: 2.5 inches.

Saltwater concentration: 15-percent NaCl.

Long-Term Performance of SS Rebars (Continued)

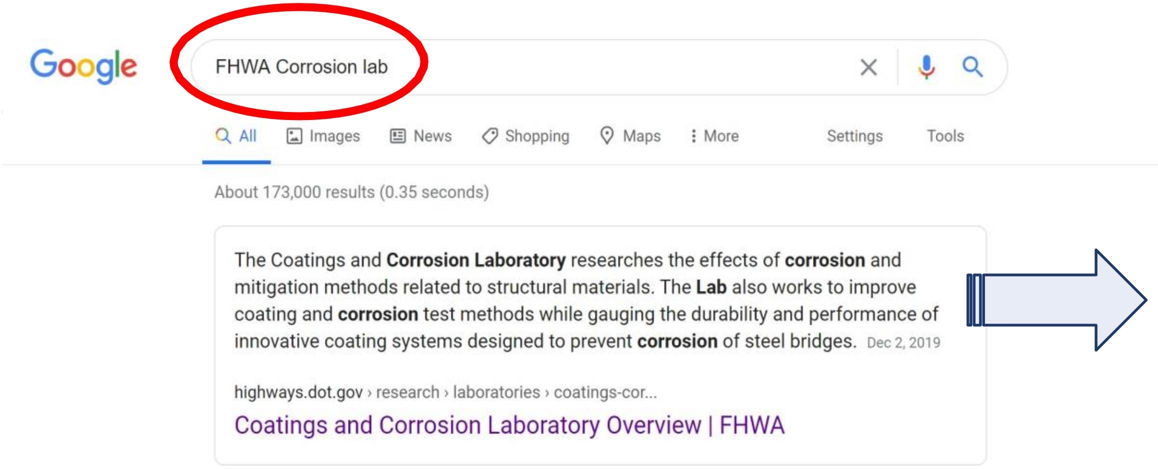


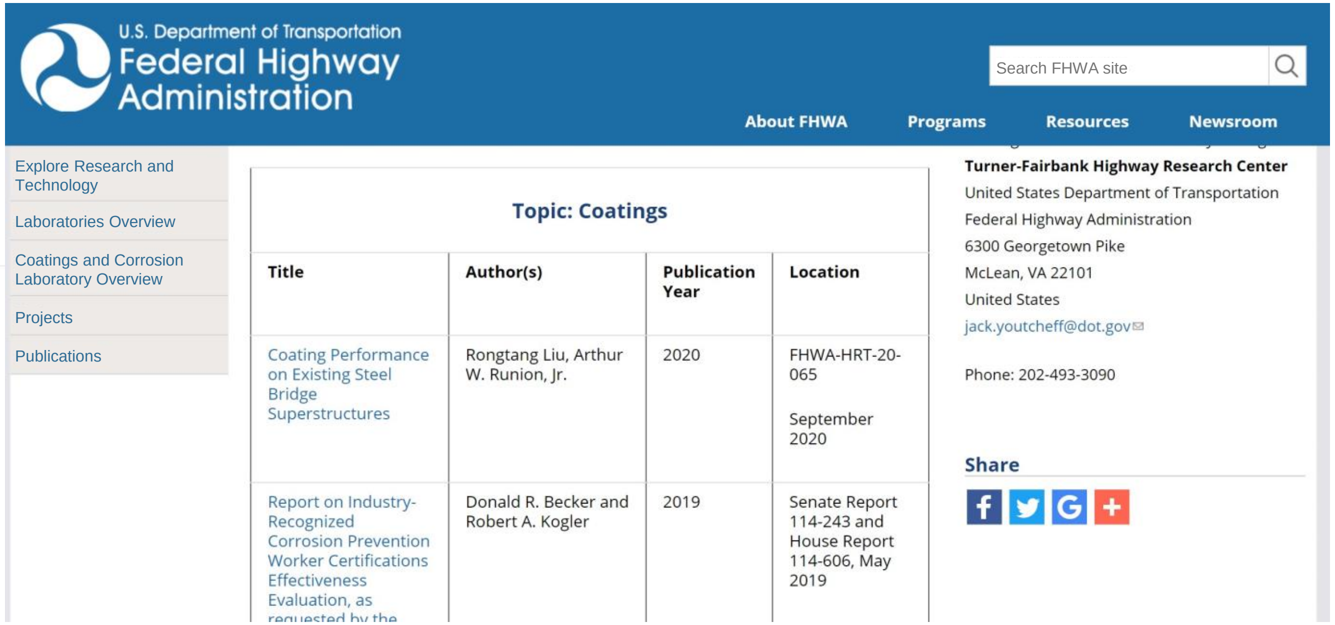
All figures source: FHWA.

CCL Web Page

https://highways.dot.gov/research/laboratories/coatings-corrosion-laboratory/publications (FHWA n.d.)

Google® search: “FHWA Corrosion Lab”





Source: FHWA (FHWA n.d.).

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References

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Contact

Frank Jalinoos

frank.jalinoos@dot.gov

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