CONCRETE REINFORCEMENT – CORROSION RESISTANT ALTERNATIVES

Florida Atlantic University
Department of Ocean Engineering
Overview of Factors Affecting Durability of Concrete Bridge Structures

Material Factors
1. Cement/Grout
2. Admixtures
3. Aggregates
4. Type of Reinforcement
5. Material Variability
6. Duct

Environmental Factors
1. Temperature
2. Chlorides
3. Carbonation
4. Relative Humidity
5. Wet-Dry

Design/Construction Factors
1. Applicable Standards
2. Mix Design
3. Cover
4. Joints/Connections
5. Quality Control
The Case for Corrosion Resistant Reinforcement

Time to Surface Cracking

Propagation Period (ECR)

~ 5 y

Uncertainty

~ 5 y

Initiation Time
(CC)

Corrosion Initiation Time (Black Bar and ECR)

Black Steel

Cumulative Corrosion Damage

Time
The Case for Corrosion Resistant Alloys As Reinforcement

CS: Passive in concrete/cement pore water but with low Cl- tolerance

STAINLESS STEELS
- Alloys w/ >12w/0 Cr.
- More tenacious passive film than carbon steel (lower critical current density).
**Project Objective and Concerns**

**Objective:** Characterize the performance of different corrosion resistant reinforcements in exposures relevant to northern and coastal bridge applications.

**Susceptibility to Localized Corrosion**

1. Pitting.
2. Crevice Corrosion.

**Concerns in Addition to Cl:**

1. Carbonation.
2. Storage/Atm. Corrosion.
4. End Connections (Clad).
5. Torch Cuts/Welds.
6. Penetrations.
7. Product Variability.
Candidate Alloys

- Type 304 SS
- Type 316 SS
- Type 2205 SS
- Type 2201 SS
- Type 3Cr12 SS
- Clad Type 316 SS
  1. Stelax*
  2. SMI*

- MMFX-II*+
- Black Bar

Note: Default testing condition is with bars as-received.
* Testing in the surface abraded and surface damaged conditions.
+ Testing in the pickled condition.
Project Tasks

Short-Term Experiments:

- AST-1 Wet-Dry Exposure
- AST-2 A Potentiostatic Tests
- AST-2 B Potentiodynamic Polarization Scans
- Atmospheric Exposures

Long-Term Experiments:

- Reinforced Concrete Slab Exposures
AST-1 Wet-Dry Experiments
(Modeled after Previous FHWA/WJE Program)

- Multiple 152 mm long #5 rebar specimens in as-received condition (selected materials bent, abraded, surface damaged, and pickled).
- Repetitive 1.75 hrs wet – 4.25 hrs dry cycle (four cycles per day) in simulated pore water (pH~13.2).
- Incrementally increasing NaCl concentration with time.
- Total exposure duration 84 days.

![Graph showing NaCl concentration over time](image-url)

![Exposed specimens](image-url)
AST-1 Data Correlation

Corrosion Rate (RP), mpy

0.01  0.1  1  10  100

Corrosion Rate (WL), mpy

0.01  0.1  1  10  100

- Black Bar
- 316 ss
- 2205 ss
- 2201 ss
- 2201 P ss
- MMFX
- Stelax
Corrosion Rate versus Time for Straight Bars: AST-1
AST-2 Specimen and Test Cell

- Electrical Connection
- Exposed Circumferential Surface
- Epoxy

Dimensions in inches:
- 0.625
- 1.20
- 2.0
- 4.0

SCE
Specimen
Counter Electrode Mesh
AST-2 Potentiodynamic Polarization Experiments

- Anodic scans performed on individual candidate specimens in saturated Ca(OH)_2 with various chloride concentrations.

![Graph showing polarization experiments](image-url)
AST-2B Potentiodynamic Polarization Scan Results

Critical Pitting Potential, V (SCE)

NaCl Concentration, weight percent
Distributed Nature of the Critical Pitting Potential

![Graph showing distributed nature of critical pitting potential for different alloys](image)

- 2201 SS
- 2201P SS
- MMFX
- 3Cr12
- 304 SS
Corrosion Resistance Reinforcement As an Alternative to Conventional Structural Steel for Corrosive Applications – AST-2 (Electrochemical Testing)

A. Triplicate specimens in SPW+\([\text{Cl}^-]_{\text{low}}\) at RT and constant potential. Monitor applied current. Incrementally increase \([\text{Cl}^-]\). Retrieve bars once critical chloride concentration is reached.

B. Repeat (A) at pH = 9.

C. Repeat (A) and (B) at 40°C.

D. Correlate w/ results from 1) WJE test program, 2) AST-1, and 3) LLT.

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AST-2 Rationale

Critical Cl⁻ Concentration

Increasing Cl⁻

Current Density

Potential, mV SCE
Test Yard Exposure of Deck Slabs
Potential Data, Black Bar Set 1
Potential Data, Set 1 Straight Bars

Potential (mV ref SCE)

Exposure Time, days

Current Density Data, Set 1 Straight Bars
Potential Data, Set 2 Cracked Concrete
Potential-Current Density Format

Potential – Current Density Trend

Current Density, µA/cm²

Potential, V (SCE)
Present Project Status

- Approximately 3 years into a six year effort.
- Atmospheric exposures to be initiated.
- AST-1 and -2A exposures to be completed.
- AST-2B exposures completed.
- Slab monitoring to continue.
- Correlations between accelerated, short-term exposures and long-term concrete slab exposures to be developed.
- Life cycle modeling as a function of HPMR type and exposure severity to be developed.