Corrosion Issues in Repair

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Outline

• Introduction
• Corrosion mechanisms
  – Methods to reduce corrosion
• Epoxy-coated bars
• Repair and corrosion
  – The ring anode
Why is corrosion important?

$\$
Corrosion can be stopped!

• Use alternate deicing methods
  – Heated structures, alternate chemicals
• Provide bars immune to corrosion
  – Titanium or Type 316 stainless steel
• Provide active cathodic protection throughout
  – And staff to maintain it
• Prevent contact between concrete and chloride
  – Impermeable coatings
Slowing down the process

- Reduce ingress
- Increase threshold
- Reduce reaction rates
- Provide alternate reactions
## High Performance Concrete

### HPC Mix Proportions (Wacker Drive)

<table>
<thead>
<tr>
<th>Material</th>
<th>Amount</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cement – Type I/II</td>
<td>525 lb/yd³</td>
</tr>
<tr>
<td>Fly ash– Class F</td>
<td>53 lb/yd³ (10%)</td>
</tr>
<tr>
<td>Silica Fume</td>
<td>27 lb/yd³ (5%)</td>
</tr>
<tr>
<td>GGBFS</td>
<td>79 lb/yd³ (15%)</td>
</tr>
<tr>
<td>Limestone</td>
<td>1800 lb/yd³</td>
</tr>
<tr>
<td>Sand</td>
<td>1140 lb/yd³</td>
</tr>
<tr>
<td>Water</td>
<td>30.5 gal (w/cm= 0.37)</td>
</tr>
<tr>
<td>Other Admixtures</td>
<td>Varied</td>
</tr>
</tbody>
</table>

**Other Admixtures** (HRWR, Mid-range, AEA)

- Strict Specifications Req’d
Sealers

Surface sealers:
- Linseed oil
- Epoxies
- Urethanes
- Silanes/Siloxane

...
Increased Chloride Threshold

• Corrosion-resistant rebar
  – Stainless
  – Galvanized
  – Epoxy-coated (?)
  – Non-metallic

• Corrosion inhibitors
Cathodic protection

• Impressed current (active)
• Sacrificial anode (passive)
Limitations of various systems

• Cost
• Maintenance
• Cracking
• Long-term performance
• Lack of field data
CORROSION MECHANISMS
Rebar in Fresh Concrete

pH >13

Passive film develops on the bar surface
Corrosion Battery

ANODE
Fe $\rightarrow$ Fe$^{2+}$ + 2e$^-$

CATHODE
Cu$^{2+}$ + 2e$^-$ $\rightarrow$ Cu
Corrosion

Anode

Fe $\rightarrow$ Fe$^{2+}$ + 2e$^-$

Cathode

H$_2$O + $\frac{1}{2}$O$_2$ + 2e$^-$ $\rightarrow$ 2OH$^-$

Electrical Connection

• between anode and cathode

Ionic path

• To prevent buildup of charged ions
Anode

Fe $\rightarrow$ Fe$^{2+}$ + 2e$^{-}$

- Concrete permeability
  - w/c, pozzolans, chemical additions
  - Membrane, silane
- Chloride threshold
  - Inhibitor
  - Change metal (stainless)
- Reduce reactive surface
  - Coatings
- Reduce corrosion rate
  - Dry out concrete
- Force opposite reaction
  - Cathodic protection
Cathode

\[ \text{Cathode} \]

\[ \text{H}_2\text{O} + \frac{1}{2}\text{O}_2 + 2\text{e}^- \rightarrow 2\text{OH}^- \]

- Reduce area of reactive surface
  - Coatings
- Dry concrete
- Reduce oxygen
- Reduce cathode effectiveness
  - Inhibitors
Electrical continuity

- Disconnect anode and cathode
- Electrical separation of bars
  - Coatings
  - Electrical separation
Ionic Path

- Make pathway between anode and cathode more difficult
  - High resistivity concrete
  - Low moisture content
EPOXY-COATED BARS
Use

• 2nd most common strategy
  – Following increased concrete cover
• 65,000 bridges in the US alone
• USA, Canada, Middle East, Japan, and India

700,000,000 sq ft of bridge deck
Research and Performance

• Over 200 research papers
• Widespread use by DOT’s and Counties
Black bar in bridge deck

**Salts**

**ANODE:** $\text{Fe} \rightarrow \text{Fe}^{++} + 2e^-$

**CATHODE:** $\frac{1}{2} \text{H}_2\text{O} + \frac{1}{4} \text{O}_2 + e^- \rightarrow \text{OH}^-$

**No Reduction**

Electron Flow

Charge balance through electrolyte

Plain reinforcing
Epoxy-coated bar

**Salts**

**ANODE:** $\text{Fe} \rightarrow \text{Fe}^{2+} + 2e^-$

**CATHODE:** $\frac{1}{2} \text{H}_2\text{O} + \frac{1}{4} \text{O}_2 + e^- \rightarrow \text{OH}^-$

98+% Reduction

Electron Flow

Charge balance through electrolyte
Epoxy-coated bars

Anode
- Reduces anode area
- Increases threshold*

Cathode
- Reduces cathodic area

Electrical Connection
- Electrical path between anode and cathode

Ionic path
- Makes ionic pathway longer

Reduced corrosion
FIELD PERFORMANCE
Bridge 2930, West Virginia, 2009

Black Bars, 1st repair 1993

Epoxy-coated bars
Oregon Piles

4 – 5 mil - inadequate surface profile

9 – 10 mil - adequate surface profile

- Anchor profile
- Delay after blasting
- Backside contamination
- Chloride contamination
- Coating thickness
- Holidays
- Flexibility
- Cathodic debonding
- Repair of jobsite damage
- Vibrators
Performance vs. Cost

Performance

1 2 4 8 12

Black
Galvanized
Epoxy

Stainless

5 – 15% increase in bridge cost
CONCRETE REPAIR
Repair outline

• Stopping the cycle of corrosion and repair
• Corrosion
• Ring anode
• Methods to stop ring anode and future reduce corrosion
Water Analogy Newly Constructed
Water Analogy – Before Repair

High Chloride

ANODE

CATHODE

e- e- e- e-
Water Analogy – Before Repair

ANODE

CATHODE

High Chloride
Water Analogy – After Repair

Low Chloride

RING ANODE
Reducing Ring Anode

**Anode**
- Dry the concrete
- Provide cathodic protection
- Migrating inhibitors **

**Cathode**
- Dry the concrete
- Coated bars or bar coatings (2 coats)
- Cathodic inhibitors
- Provide local cathodic protection

**Corrosion**

**Electrical Connection**
- ???

**Ionic path**
- Use high electrical resistivity concrete in patch
Summary

• We can stop corrosion, but cannot afford it
• Corrosion is a battery
  – anode
  – cathode
  – electrical connection
  – ionic path
• Epoxy-coated bars work on all mechanisms of corrosion
• In repair, ring anodes need to be considered and mitigated
• Multiple methods need to be used to reduce future deterioration
Questions?