PERFORMANCE OF BRIDGE DECKS CONTAINING EPOXY-COATED REINFORCING BARS

Concrete Bridge Conference
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What we have learned

• Field
• Specifications
• Manufacturing
Epoxy Bar Use

- 2nd most common strategy to prevent reinforcement corrosion
  - After increased cover
- USA, Canada, Middle East, Japan, and India

- 700,000,000 ft$^2$ of decks
  - 65,000 bridges in the US alone
  - ~600,000 ton/yr
  - 10 - 15% of all rebar
Standard Specifications

• ASTM A775/A775M
  – Standard Specification for Epoxy-Coated Steel Reinforcing Bars
• ASTM A934/A934M
  – Standard Specification for Epoxy-Coated Prefabricated Steel Reinforcing Bars
• ASTM D3963/D3963
  – Standard Specification for Fabrication and Jobsite Handling of Epoxy-Coated Steel Reinforcing Bars
• ASTM A884/A884M
  – Standard Specification for Epoxy-Coated Steel Wire and Welded Wire Fabric for Reinforcement
• AASHTO M284
  – Standard Specification for Epoxy-Coated Reinforcing Bars
• AASHTO M317
  – Standard Specification for Epoxy-Coated Reinforcing Bars: Handling Requirements for Fabrication and Job Site
# ASTM A775
## Manufacturing specifications

<table>
<thead>
<tr>
<th>Criteria</th>
<th>1980’s</th>
<th>2007</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bar anchor profile</td>
<td>-</td>
<td>1.5-4 mil</td>
</tr>
<tr>
<td>Coating delay after blasting</td>
<td>&lt; 8 hours</td>
<td>&lt; 3 hours</td>
</tr>
<tr>
<td>Coating thickness</td>
<td>90 percent within 5-12 mil</td>
<td>7-12 mil (Nos. 3-5)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>7-16 mil (Nos. 6-18)</td>
</tr>
<tr>
<td>Coating continuity</td>
<td>&lt; 2 holidays per foot</td>
<td>&lt; 1 holiday per foot</td>
</tr>
<tr>
<td>Coating flexibility</td>
<td>120 degree bend</td>
<td>180 degree bend</td>
</tr>
<tr>
<td>Cathodic disbondment test</td>
<td>-</td>
<td>Yes</td>
</tr>
<tr>
<td>Criteria</td>
<td>1980’s</td>
<td>2007</td>
</tr>
<tr>
<td>--------------------------</td>
<td>---------------------------------------------</td>
<td>-------------------------------------------</td>
</tr>
<tr>
<td>Permissible damage</td>
<td>No patch for damage &lt; 0.1 in²</td>
<td>All damages must be patched</td>
</tr>
<tr>
<td></td>
<td>Maximum damage level 2 percent</td>
<td>Maximum damage level 1 percent</td>
</tr>
<tr>
<td>External storage protection</td>
<td>-</td>
<td>Yes, if &gt; 2 months</td>
</tr>
</tbody>
</table>
FIELD PERFORMANCE
Research and Performance

• Over 200 research papers
• Approx 50% of all decks in 2008
Poor concrete and poor bars

• 1986, spalls observed in Florida
  – Typically 1 x 1 ft spalls in tidal zone
• Poor concrete and poor bars
  – Bars left beside ocean
  – Highly salt contaminated concrete
  – Only 25 mm (1 in.) of cover.
  – Poor quality concrete
• Four bridges
  – 1973 to 1978
• Overall condition
  – good to very good, with no or modest levels of corrosion activity.
• Corrosion constrained joints over piers
• Amount of delamination in all decks is very low
## Delaminations in 1996 and 2006

<table>
<thead>
<tr>
<th>Bridge</th>
<th>Total Delaminated Area 1996</th>
<th>Total Delaminated Area 2006</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(ft²)</td>
<td>(%)</td>
</tr>
<tr>
<td>19015</td>
<td>0</td>
<td>0.0%</td>
</tr>
<tr>
<td>27062</td>
<td>2</td>
<td>0.0%</td>
</tr>
<tr>
<td>27812</td>
<td>0</td>
<td>0.0%</td>
</tr>
<tr>
<td>27815</td>
<td>0</td>
<td>0.0%</td>
</tr>
</tbody>
</table>

<<10%
New York State Department of Transportation 2009

- Used extensive statistical analysis of all state bridge inspection data
- Pool of 17,000 structures
  - “structural decks with epoxy-coated rebars perform significantly better than those with uncoated rebars, especially in the later years.”
2009 West Virginia Study
Lawler and Krauss

- Detailed study of six bridges built 1974 – 1976
  - Deck area: 62,000 sq ft
- After 34 -36 years
  - Total delamination: 22.7 sq ft
  - Chloride levels above threshold
- Black Bar performance
  - Repaired in 1993 with overlays
Bridge 2930, West Virginia

Epoxy-coated bars

Black Bars
Effect of coating thickness

Thickness (mil)
Effect of chloride level

Chloride (% by wt. concrete)

- Epoxy-coated: active corrosion
- Uncoated: active corrosion
- Epoxy-coated: no active corrosion
- Uncoated: no active corrosion

Cumulative distribution
Effect of time

- Epoxy-coated: no active corrosion
- Epoxy-coated: active corrosion
- Uncoated: no active corrosion
- Uncoated: active corrosion

Cumulative distribution

Time (years)
Conclusions from WV bridges 33 – 35 years old

• Good to excellent condition (33 – 35 years)
• Black bar decks were overlaid or otherwise rehabilitated at 18 to 21 years
• No delaminations where both mats epoxy-coated reinforcing steel
  – High chloride contents in the concrete
• Factors:
  – high chloride
  – low coating thickness
  – extended exposure to chloride concentrations above the black bar chloride threshold
EXAMPLES OF RECENT USE
Woodrow Wilson Bridge, Virginia/Maryland

Bridge of Honor, Ohio

I-35 Minneapolis, Minnesota

Biloxi Bay Bridge, Mississippi
WHAT WE HAVE LEARNT ABOUT CORROSION MECHANISMS
Black bars

Salts

ANODE: Fe → 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

Plain reinforcing
Epoxy-Coated Bars - Top mat only with deliberate damage

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

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

**60-93% Reduction**

**Salts**

**Charge balance through electrolyte**
Epoxy-Coated Bars - Both mats with deliberate damage
What has been learnt

• The cathodic reaction is important
  – Use ECR on both top and bottom mats coated to reduce cathodic area
  – Most agencies are now doing this
  – But some are not...

• Even damaged bars perform considerably better than black bars
MANUFACTURING AND QC PROCESS
Plant Certification Program

- CRSI in 1991
- ...capable of producing epoxy-coated steel reinforcing bars in accordance with industry standards and recommendations.
- Almost all plants are certified
- Required by 21 DOT’s
FIELD HANDLING
Understand the material

• Improper handling on ANY MATERIAL may reduce its performance
• Any material can be misused or misapplied
Improper handling

- Dragging
- Lifting using chains
- Flexing bundles while lifting
- Using non-approved patching material
- Leaving uncovered in storage for more than 30 days
- Using uncoated bar supports
- Using uncoated tie wire
- Flame cutting
- Using unprotected concrete vibrator
COST/PERFORMANCE CONSIDERATIONS
Performance vs. Cost

Performance

- Black
- Epoxy
- Galvanized ASTM A1035

Cost

- Stainless
clad
- Stainless
- SS316

Years

100
75
50
25
0

1 2 4 8 12
SUMMARY AND CONCLUSIONS
Conclusions

• ECR used in 65,000 bridge structures
  – Still excellent performance

• 2\textsuperscript{nd} most common strategy to prevent reinforcement corrosion

• Many favorable field and laboratory studies
  – Even Gen 1 product provided substantial increases in design life

• Cost/performance better than other materials
Materials have changed

• Improved manufacturing specifications
  – ASTM A775
• Improved manufacturing
  – CRSI certification
• Improved field handling
  – ASTM D3963
• Improved concrete technology
• Improved design
  – Both mats using epoxy-coated bars
EPOXY INTEREST GROUP

www.epoxyinterestgroup.org