Recent DOT Studies on the Long-Term Performance of Epoxy-coated Reinforcing Steel

ABCD - 24th ANNUAL BRIDGE CONFERENCE
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Epoxy Bar Use

- 850,000,000 ft$^2$ of decks
  - >70,000 bridges in the US alone
  - ~600,000 ton/yr. or 10 - 15% of all rebar in NA
- USA, Canada, Middle East, Japan, and India
Woodrow Wilson Bridge, Virginia/Maryland

I-35 Minneapolis, Minnesota

Bridge of Honor, Ohio

Biloxi Bay Bridge, Mississippi
MICHIGAN DOT STUDY (2010)
Background

- Estimate the service life of bridge decks containing black reinforcing steel and epoxy-coated reinforcing steel
- Time to reach a poor condition.
  - Rating of 4 or less in the Bridge Safety Inspection Report
Markov analysis

• Transition matrices
  – describe the probability that a bridge element will change to another condition state.

• Convert to a deterioration rate

7 → 5% → 6 → 3% → 5

95% → 97%
Data

• Deck surface ratings from 2004 to 2010
• 1,790 bridge decks
  – 766 contained epoxy-coated reinforcing steel
  – 1,024 contained black reinforcing steel.
Predicted distress

![Graph showing distress rating over deck age for decks with black bar and decks with epoxy-coated bar. The graph illustrates a downward trend in distress rating with increasing deck age, with distinct points indicating critical levels of distress.]
Estimated time to reach rating of 4

<table>
<thead>
<tr>
<th>Black</th>
<th>Epoxy-coated</th>
</tr>
</thead>
<tbody>
<tr>
<td>35 years</td>
<td>70 years</td>
</tr>
</tbody>
</table>

Performance of epoxy-coated bars showing substantial improvement over uncoated bars
NYDOT STUDY (2009)
2009 Bridge Element Deterioration Rates

• Statistical analysis of 17,000 structures
  – NYSDOT bridge inspection database
• Markov chains and Weibull-based approaches
• Data going back to 1981

Agrawal, A.K. and Kawaguchi, A.;
The City College of New York
Weibul Analysis

• Uses statistical distribution of rating vs bridge age
Distribution of rating 4 vs age
Weibul – coated vs uncoated
# Life prediction

<table>
<thead>
<tr>
<th>Rating</th>
<th>Black</th>
<th>Epoxy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Analysis</td>
<td>Markov</td>
<td>Markov</td>
</tr>
<tr>
<td></td>
<td>Weibull</td>
<td>Weibull</td>
</tr>
<tr>
<td>7 to 5</td>
<td>32</td>
<td>38</td>
</tr>
<tr>
<td></td>
<td>31.5</td>
<td>37.6</td>
</tr>
<tr>
<td>7 to 4</td>
<td>49</td>
<td>62</td>
</tr>
<tr>
<td></td>
<td>43</td>
<td>60</td>
</tr>
</tbody>
</table>
Conclusions

• Structural decks with epoxy-coated reinforcement perform significantly better than those with uncoated reinforcement, especially in the later years.
KU STUDIES FOR KDOT

Draper, Darwin, Browning, Locke, Evaluation of Multiple Corrosion Protection Systems for Reinforced Concrete Bridge Deck
Program

• Chloride to cause corrosion (threshold)
• Rate of corrosion
• Field chloride levels

• Materials
  – Uncoated steel
    • With and without corrosion inhibitors
  – Epoxy-coated steel
    – With and without corrosion inhibitors
  – Type 2205 stainless steel
Test specimen types

96 week period, using two test cycles.
15 percent sodium chloride salt solution
## Measured Corrosion Thresholds

<table>
<thead>
<tr>
<th>System</th>
<th>Threshold (lb/yd³)</th>
<th>Relative threshold</th>
</tr>
</thead>
<tbody>
<tr>
<td>Uncoated</td>
<td>1.58</td>
<td>1</td>
</tr>
<tr>
<td>Epoxy Coated</td>
<td>7.28</td>
<td>4.6</td>
</tr>
<tr>
<td>Inhibitors</td>
<td>0.83 - 3.05</td>
<td>0.52 – 1.9</td>
</tr>
<tr>
<td>Inhibitors and ECR</td>
<td>1.69 - 9.85</td>
<td>1.1 – 6.2</td>
</tr>
<tr>
<td>Type 2205</td>
<td>26.4</td>
<td>16.7</td>
</tr>
</tbody>
</table>
# Rate of Crack Propagation in Concrete Specimens

<table>
<thead>
<tr>
<th>Material</th>
<th>Propagation (years)</th>
<th>Relative rate</th>
</tr>
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<tbody>
<tr>
<td>Uncoated reinforcing</td>
<td>7</td>
<td>1</td>
</tr>
<tr>
<td>Epoxy-coated reinforcing</td>
<td>25</td>
<td>3.6</td>
</tr>
<tr>
<td>Corrosion inhibitor</td>
<td>7 - 27</td>
<td>1 - 3.9</td>
</tr>
<tr>
<td>Corrosion inhibitor &amp; epoxy-coated reinforcing</td>
<td>25 - 46</td>
<td>3.9 - 6.6</td>
</tr>
<tr>
<td>Type 2205 stainless-steel</td>
<td>359</td>
<td>51</td>
</tr>
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Chloride Data at cracks
3 in. depth, AADT > 7500

\[ C(t) = 0.0316t + 0.746 \]

Where \( t \) = time (months)
\( C(t) \) = chloride content (lb/yd\(^3\))
### Estimated performance – cracked concrete

<table>
<thead>
<tr>
<th>Material Description</th>
<th>Initiation (years)</th>
</tr>
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<tbody>
<tr>
<td>Uncoated reinforcing</td>
<td>2</td>
</tr>
<tr>
<td>Epoxy-coated reinforcing</td>
<td>20</td>
</tr>
<tr>
<td>Corrosion inhibitor</td>
<td>1 - 4</td>
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<tr>
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Estimated performance cracked concrete

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<thead>
<tr>
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<th>Initiation (years)</th>
<th>Propagation (years)</th>
<th>Time to first repair (years)</th>
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<tbody>
<tr>
<td>Uncoated reinforcing</td>
<td>2</td>
<td>7</td>
<td>14</td>
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<tr>
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<td>20</td>
<td>25</td>
<td>50</td>
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<td>432</td>
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Time to repair = initiation + propagation + 5 years
Economic Analysis

• Net present value (NPV)
  – Concrete and reinforcing costs
  – Repair costs and repair life
  – Discount rate (4%)
    • High discount rates reduce long term costs
Initial Cost

What can we afford today?

- Uncoated: $189
- Epoxy: $196
- Stainless: $319
Life-cycle cost

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<th>Material</th>
<th>Cost/sq yd</th>
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Comparison:
- Uncoated: $189
- Epoxy: $196
- Stainless: $319
Conclusions from Kansas Study

• Uncoated reinforcement exhibits the highest corrosion rates
• Epoxy coated bars have higher corrosion threshold and lower corrosion rate than uncoated bars
• LCA shows Type 2205 stainless steel is $82/sq yd than epoxy-coated reinforcement
Laboratory

• 12 different bar types from 11 sources
  – Epoxy-coated*
  – Dual-clad*
  – Galvanized*
  – Low carbon chromium
  – Steel alloys
  – Stainless clad
  – 2205 Stainless steel

Defects added 0.15, 0.5, 1.0%
Preliminary Findings

• Use of fusion-bonded coated bars in both mats offered the best corrosion resistance
  – epoxy, and dual coated
• Alloyed bars did not provide adequate corrosion resistance
  – A1035 low carbon-chrome
  – Duracorr
  – 3CR12
Preliminary Findings (con’t)

• Solid stainless and stainless clad bars exhibited very good corrosion performance
• Galvanized bars may be used in moderately corrosive environments

Final report due 2013?
WV STUDIES
West Virginia 2009 – 34 yo deck

Black reinforcement – substantial corrosion damage

Epoxy-coated reinforcement – no corrosion damage
SUMMARY
Conclusions

• Field research (NY, MI, WV) shows long lives of decks with epoxy-coated reinforcing steel
• Laboratory data (KU, FHWA) showing epoxy and stainless performing well
• Cost analysis shows epoxy-coated reinforcing provides lowest lifecycle costs (KU)
Celebrating 40 years of improved materials and manufacturing of epoxy-coated reinforcing steel

www.epoxyinterestgroup.org