Optimizing Performance of Concrete Structures with Zinc Coated Reinforcing Steel

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Outline

• The Corrosion Problem
• Batch Galvanized
• Mitigation Solutions
• Zinc in Concrete
• Continuous Galvanized
• Research and Current Projects
• Next Steps
International Zinc Association

- Trade association that represents the interests of the zinc industry
Corrosion

• Affects
  – Roads, bridges, buildings, airplanes, machinery, automobiles

• $2.2 trillion -> corrosion costs worldwide

• $660 billion -> possible savings

• 3.3% US GDP -> corrosion mitigation

• Zinc provides the best corrosion protection
The USA Bridge Problem

- 604,000 bridges across the USA
  - 48% state owned
- 2/3 built 26+ years ago
- 50-80% maintenance funds for bridge decks
- 25-30% of corrosion could be eliminated
  - If proper materials are used and maintained
Galvanized Reinforcing Steel

Built in 1995  Built in 1990
Batch Galvanized Bridges

Boca Chica Bridge, Florida
Tappan Zee Bridge, New York
Curtis Road Bridge, Michigan
Athens Road Bridge, Pennsylvania
Corrosion of Black Bar

- Initially – Cosmetic Staining
- Later – Structural Weakening
Corrosion of Black Bar

Fe
FeO
Fe$_3$O$_4$
Fe$_2$O$_3$
Fe(OH)$_2$
Fe(OH)$_3$
Fe(OH)$_3$ • 3 H$_2$O

Volume (cm$^3$)
Corrosion of Black Bar

- In concrete, steel corrosion can cause major deterioration
- Corrosive elements, diffuse through the concrete matrix to reach rebar
Corrosion Model

- Stress level at which concrete cracks
- Concrete Cracks
- Concrete Spalls
- Uncoated Rebar
- Galvanized Rebar
- Cl\(^-\) concentration when uncoated rebar starts to corrode
- Cl\(^-\) concentration when galvanized rebar starts to corrode
- 2 – 4X Cl\(^-\)

Protection
Zinc Protection

\[ Zn \rightarrow Zn^{++} + 2e^- \]
\[ 2e^- + H_2O + 1/2 O_2 \rightarrow 2(OH)^- \]
Zinc in Concrete

• Passivated by formation of a layer of adherent crystals
  – Calcium Hydroxyzincate (CHZ)
• Reaction begins upon contact with wet cement solution
  – Ceases once concrete hardens
• Surface film stabilizes the zinc
  – Second level of barrier protection
Migration of Zinc

Migration of zinc-rich corrosion products away from the bar/matrix interface and well into the cement matrix.

Partial dissolution of the galvanized coating and zinc corrosion product migrating into the cement matrix.
Bond Strength in Concrete

Graph showing the bond strength in concrete over months of curing for three studies (A, B, and C). The graph compares stress in pounds per square inch between black and galvanized materials.

Source: University of California
Load-Slip Characteristics

Reduced slip for galvanized bars

- Epoxy
- Black
- Galvanized
Zinc Protection

- Passivation Reaction Product (CHZ)
- Barrier Coating
- Cathodic Protection
- High Chloride Threshold (2-4x black steel)
- Corrosion Product Migration
  - Concrete Matrix Densification
  - No stress generated at rebar surface
- Low pH Tolerance (Carbonation protection)
Batch Galvanized Coating

ASTM A767 Standard Specification for Zinc-Coated (Galvanized) Steel Bars for Concrete Reinforcement
Batch Galvanized Process

1. Caustic Cleaning
2. Rinsing
3. Pickling
4. Rinsing
5. Flux Solution
6. Galvanizing
7. Molten Zinc Bath
8. Cooling and Cleaning
9. Inspection
Continuous Galvanized Coating

Pure Zinc Layer

Thin Fe$_{2}$Al$_{5-x}$Zn$_x$ Layer

ASTM A1094 - Standard Specification for Continuous Hot-Dip Galvanized Steel Bars for Concrete Reinforcement
Improved Corrosion Resistance

- Pure Zinc corrodes at a slower rate than Iron-Zinc Intermettalic
- Less zinc consumed to form CHZ passivation layer
- Less zinc required to provide corrosion resistance

<table>
<thead>
<tr>
<th>Coating Type</th>
<th>Average Depth of Loss to Passivation (um)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Annealed (Intermettalic)</td>
<td>1.18</td>
</tr>
<tr>
<td>Pure Zinc</td>
<td>0.45</td>
</tr>
</tbody>
</table>
How does the 50 µm In-Line coating corrosion resistance compare to the 85µm General Galvanized coating? Results of potentiodynamic polarization tests

Zn (eta) phase current density = 2.38 A/cm² (—— line)
Zeta (Zn-Fe) phase current density = 3.98 A/cm² (--- line)
Therefore Zn 1.7 times more corrosion resistant than Zn-Fe in the concrete corrosion cell
Continuous Galvanized Rebar

- Durable, Flexible Coating
  - Fabricate after coating

- Pure Zinc
  - Improved corrosion resistance

- Low cost
  - Less material, shipping, weight, etc.
USA trademark application 85882085 made by IZA

ASTM A1055 - pending
Standard Specification for Zinc and Epoxy Dual-Coated Steel Reinforcing Bars
Duplex Bar Formability
Continuous Galvanized Process

**Surface preparation**
- Black, uncoated rebar from mill
- Shot Blasting
- Spray-On Flux

**Pre-heat**

**Galvanizing**
- Induction Heater
- Zinc / zinc alloy trough
- Air knife
- Galvanized rebar
Rollers into Induction Heater
From Heater to Zinc Bath
Zinc Bath
Bath through Air Knife to Quench
Continuously Galvanized
Quality Assurance
Installing Galvanized Rebar

Same as Black rebar:
• Overlap links
• Handling procedures
• Field Bending Possible

Optional:
• Touch-up field cut ends
Route 66 Bridge
University of Waterloo

• Tomb stone samples
  – Sound
  – Transverse & Longitudinal Cracks

• Cyclical ponding
  – 21% chloride brine

• No visible corrosion
Corrosion Current - Sound

Average $i_{corr}$ Sound beam

Time (Days)

$i_{corr}$ (A/m²)

C1  C2  C3  BLACK  HDG
Corrosion Current - Transverse

Average $i_{\text{corr}}$ Transversely cracked

Time (Days)

Corrosion Current - Transverse

Average $i_{\text{corr}}$ Transversely cracked

Time (Days)
Corrosion Current - Longitudinal

Average $i_{\text{corr}}$ Longitudinally cracked

![Graph showing corrosion current over time for different conditions.](image-url)
Shenzhen Metro Line No. 11, Shenzhen, China

- Currently under construction
- Opening later this year
- Fastest Metro line in Shenzhen with speeds of 120 km/h
- Galvanized rebar is being produced by Xiamen Newsteel
G7 Beijing–Ürümqi Expressway

Connects the cities of Beijing, China, and Ürümqi, Xinjiang. When complete, it will be 2,540 km (1,580 mi) in length. Galvanized rebar is being produced by Xiamen New Steel
Comparison versus Black Bar

FHWA, 2012
*estimated
USA Production

• AZZ Galvanizing
  – Fall 2016
  – Oklahoma

• South Atlantic Reinforcing
  – Air Wipe Method
Continuous Galvanized Rebar

Low Cost
Tough
Corrosion Resistant
Formable

For more Information and Samples contact:
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