Continuous Galvanized Reinforcement

10/26/21
In July of 2020, GalvaBar® was acquired from AZZ Inc. (the largest Galvanizer in the world) by Commercial Metals Company (one of the major steel producers in North America)
41 States
Bahamas & Bermuda

New Placed AK, ID, MI, MD, MA, NH

New DOT Approvals: WA, NM, CO, NJTA, WV, SC, RI & NY (A1055)
ASTM A1094 is Continuously Galvanized Reinforcement

Continuous Galvanizing process yields consistent, formable zinc coating

Fabricated after processing. Fabrication with no special equipment

Thicker pure zinc coating increases corrosion initiation threshold

Inventoryed at reduced competitive cost with logistical “last mile” advantages
Processing Comparison

How A1094 Continuous Galvanized Rebar is made
Processing
Applicable Global Performance Standard(s)

**Designation: A767/A767M**
Standard Specification for Zinc-Coated (Galvanized) Steel Bars for Concrete Reinforcement
- Coating minimum thickness for Class I = (150 μm) 5.9 Mil and Class II = (86 μm) 3.4 Mil
- Substrates = A996, A706, A615

**Designation: A1094/A1094M**
Standard Specification for Continuous Hot-Dip Galvanized Steel Bars for Concrete Reinforcement
- Coating minimum thickness (50 μm) 2 Mil
- Substrates = A1035, A996, A722, A706, A615

**Designation: A1055/A1055M**
Standard Specification for Zinc and Epoxy Dual-Coated Steel Reinforcing Bars
- Type I = metallized coated substrate thickness > (150 μm) 5.9 Mil
- Type II = 1094 coated substrate minimum thickness (50 μm) 2 Mil
Applicable Global Performance Standard(s)

Reference: AASHTO M 111
Standard Specification for Zinc (Hot-Dip Galvanized) Coatings on Iron and Steel Products
- Fabricated reinforcing steel bar assemblies are covered by the present specification.
- The batch galvanizing of separate reinforcing steel bars shall be in accordance with ASTM A767.
- The continuous galvanizing of reinforcing bars shall be in accordance with ASTM A1094.

Reference: ACI 439 4R
Steel Reinforcement – Material Properties and US Availability
- No special requirements for the design of galvanized reinforced concrete beyond those that apply to conventional reinforced concrete.

Reference: CRSI MSP
Manual Standard Practice
- The manual states to apply the same bend diameter criteria as conventional reinforcing steel bar.
Composition and Materials

Cross Section Comparison of Coating

**ASTM A767** - 129μm min.

- Eta (100% Zn) 70 DPN
- Zeta (94% Zn, 6% Fe) 180 DPN
- Delta 90% Zn, 10% Fe) 245 DPN
- Gamma 75% Zn, 25% Fe) 250 DPN
- Steel (100% Fe) 159 DPN

10-40μm Zinc layer

129-150μm Intermetallic Zinc-Iron

Ternary Layer Fe$_2$Al$_5$-XZn$_X$

**ASTM A1094** - 50μm min.

- 50μm min Pure Zinc Coating

Source: University of South Wells Canberra (Thicker Pure Zinc Layer)
Environmental Considerations

Sustainability and Resiliency Features

24th most abundant chemical element mineral in earth's crust

What is Zinc?

Zinc and steel are both 100% recyclable. 35% of the world's Zinc supply is from recycled sources

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Environmental Comparisons

A1094 vs A767

• **Innovative process/ technology**
  - Efficient use of pure zinc
  - Pure Zinc “0” lead CGG alloy
  - Lower embodied energy
  - No Hazardous Waste

• **Reduced logistics**

• **Fabricates like uncoated**
  - Changes on the fly
  - No embrittlement concerns

• **Historical Process**
  - Heavier Zinc-Iron Coating
  - Oxidized zinc/ Higher lead
  - Inefficient energy usage
  - Large Quantity Waste Generator

• **Extra logistics**

• **Special bend diameters**
  - No field adjustments/ Go back
  - Higher potential for embrittlement
## Procurement

### Comparative Analysis: Project Lead Time and Embodied Energy

<table>
<thead>
<tr>
<th>Mill (Raw)</th>
<th>Fab Shop</th>
<th>Galvanizer</th>
<th>Fab Shop</th>
<th>Jobsite</th>
</tr>
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<tr>
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<td><img src="image8" alt="Image" /></td>
<td><img src="image9" alt="Image" /></td>
</tr>
</tbody>
</table>

© Commercial Metals Company
Fabrication

Processed prior to fabrication and available in current supply chain

Form tight bend radii without coating flaking or peeling

Uniform thickness (~ 70 μm) complete circularity of pure zinc coating

ASTM A780 is the repair standard for galvanized rebar using a Zinc-Rich Paint:

Only the cut ends need touch-up repair and occasional minor field touch up because of zinc’s cathodic protection ability
Fabrication
Features and Benefits
Performance (Exceptional Bond Strength)

Pull-out Tests (6-Types of Reinforcing Bars)

Stress vs. Crack Width Plots for Corrosion-Resistant Bars

Source: University of Akron/Ohio DOT (Larger Reduction of Bridge Deck Cracking)
Installation

Same as “Conventional Steel” rebar

- Same Splice/Lap/Coupling Connections
- Same Handling Procedures
- No Damaged Material to Touchup
- No Weather Restrictions
- No UV Light Degradation
Case Study 1: Transportation - Bridges

A1094 provides solutions to combat corrosion on bridges (old and new)

Project: Buffalo Creek (Buchanan County)
Location: Independence, Iowa
Information: Iowa DOT
Application: Bridge Superstructure/ Deck
Completed: 2018
Case Study 2: Transportation – Bridges

A1094 delivers corrosion sustainability & resiliency solutions for P3 project(s)

**Project:** Cherokee County (I-85)
**Location:** SCDOT Blacksburg, SC
**Contractor:** Lane Construction
**Application:** Bridge Deck
**Completed:** 2021
Case Study 3: Precast Bridge and Rail

A1094 is specified for critical asset corrosion protection and integrated delivery methods

Project: Middlebury Rail Tunnel
Location: Middlebury VT
Information: VTrans
Application: Infrastructure
Fabrication: Dimension
Completed: 2021
Case Study 4: Grand Island, VT Drawbridge

A1094 is specified for critical asset corrosion protection and integrated delivery methods

Project: North Hero Draw Bridge  
Location: Grand Island, VT  
Information: VTrans  
Application: Infrastructure  
Fabrication: Harris Rebar  
Completed: 2022?
Case Study 4: Infrastructure Energy Power Station

- Galvanized Rebar is specified exclusively for corrosion protection for all infrastructure in Bermuda.
- Galvanized Rebar is applied universally for corrosion protection for all vertical reinforced concrete construction in Bermuda.
- With limited freshwater, concrete is mixed with saltwater introducing extreme chloride exposure at the beginning of service life.
Case Study 5: Infrastructure Energy Power Station

A1094 is specified exclusively for corrosion protection of critical infrastructure asset(s)

Project: BELCO
Location: Bermuda
Information: Power Plant
Application: Foundation
Completed: 2020
Continuous Galvanized Rebar Initiatives
Comparing ASTM A1094 with alternative materials and methods

- Comprehensive Corrosion Performance for (RC) systems
  - Dr. Castaneda, Texas A&M/ Tran-SET

- Thicker Pure Zinc Layer
  - Dr. Yeomans, Galvanized rebar concrete researcher

- Larger Reduction of Bridge Deck Cracking
  - Dr. Patnaik, University of Akron/ Ohio DOT

- Equal or Better Corrosion Performance of Reinforcing Bar
  - Dr. Darwin, University of Kansas/ Oklahoma DOT
Tran-SET Galvanized Rebar Models

Source: Texas A&M (Center for Infrastructure Renewal) National Corrosion and Materials Reliability Laboratory

- Less Voluminous Zinc corrosion products
- More homogeneous coating
- Resourceful use of Zinc
- Improvements in protection

A1094

Anode (active zone)

\[
\begin{align*}
Fe & \rightarrow Fe^{2+} + 2e^- \\
Fe^{2+} + 2Cl^- & \rightarrow FeCl_2 \\
FeCl_2 + 2H_2O & \rightarrow Fe(OH)_2 + 2H^+ + 2Cl^- \\
\end{align*}
\]

Cathode (passive layer)

\[
\begin{align*}
2H_2O + O_2 + 4e^- & \rightarrow 4OH^- \\
\end{align*}
\]

Anode

\[
\begin{align*}
Zn & \rightarrow Zn^{2+} + 2e^- \\
Zn + 2H_2O & \rightarrow Zn(OH)_2 + H_2 (g) \\
2H^+ + 2e^- & \rightarrow H_2 \\
\end{align*}
\]

Diffusion of aggressive species
Sacrificial and barrier protection
Migration of corrosion products into concrete

Less Voluminous Zinc corrosion products
More homogeneous coating
Resourceful use of Zinc
Improvements in protection
Tran-SET Continuous Immersion Test for A767

Source: Texas A&M (Center for Infrastructure Renewal) National Corrosion and Materials Reliability Laboratory

≈ 3600
Tran-SET Continuous Immersion Test for A1094

Source: Texas A&M (Center for Infrastructure Renewal) National Corrosion and Materials Reliability Laboratory
The EUROSTRUCT 2021 Study
Uniform and local corrosion characterization and modeling (EIS Spectra Evolution)

- 3.5 wt. % NaCl chloride-induced process to generate corrosion at the surface to analyze the pitting attack.
- 20-month test to simulate cross-sectional loss for 615, 767 and 1094 configurations.

- These images show the pit colony intrusion at the surfaces to provide a cumulative report for long-term exposure.
- The pit colony locations illustrate the section losses in this Fig.
Figure 3.8: Rapid Macrocell Test.

Average corrosion potentials of A767 and A1094 galvanized reinforcement vs. time.

Table 3.1 Rapid Macrocell Test: Macrocell Losses Based on Total Area at End of Testing (um)

<table>
<thead>
<tr>
<th>Reinforcing Type</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
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<tbody>
<tr>
<td>A767 - ND</td>
<td>709.70</td>
<td>687.20</td>
<td>797.50</td>
<td>350.60</td>
<td>388.10</td>
<td>3,068.70</td>
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<tr>
<td>A1094 - ND</td>
<td>2.09</td>
<td>2.03</td>
<td>5.56</td>
<td>2.03</td>
<td>2.08</td>
<td>6.25</td>
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</tbody>
</table>

Table 3.3 Rapid Macrocell Test: Total Corrosion Losses Based on Total Area from LPR measurements (um)

<table>
<thead>
<tr>
<th>Reinforcing Type</th>
<th>Corrosion Loss</th>
<th>Average Loss</th>
<th>Std. Dev.</th>
</tr>
</thead>
<tbody>
<tr>
<td>A767 - ND</td>
<td>709.70, 687.20, 797.50, 350.60, 388.10, 3,068.70</td>
<td>1,000.30, 1,029.50</td>
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<tr>
<td>A1094 - ND</td>
<td>2.09, 2.03, 5.56, 2.03, 2.08, 6.25</td>
<td>3.34, 2.00</td>
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</table>

Source: University of Kansas/ Oklahoma DOT (Equal or Better Corrosion Performance of Reinforcing Bar)
### 100-year Design Life Analysis

A steel reinforcement density of 64.9 lb/SY is used, based on the average quantity of steel used in bridge decks constructed in Oklahoma.

#### 8-in. Deck, 2.5-in. Cover

<table>
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<tr>
<th>Reinforcing Type</th>
<th>Time to Repair, Years</th>
<th>Total Present Cost, $/SY</th>
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<tbody>
<tr>
<td></td>
<td>1</td>
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<tr>
<td>Conv-A</td>
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<tr>
<td>ECR</td>
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<td>85</td>
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<tr>
<td>ECR-UV-1000</td>
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<tr>
<td>A767</td>
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<td>100</td>
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<tr>
<td>A1094</td>
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#### 8.5-in. Deck, 3.0-in. Cover

<table>
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<th>Total Present Cost, $/SY</th>
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<tr>
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Source: University of Kansas/ Oklahoma DOT (Equal or Better Corrosion Performance of Reinforcing Bar)
Research Summary

1. A1094 & A767 are interchangeable in all tests conducted
2. Relieves Stress and Reduces Chlorides Ion Concentration
3. Slower Corrosion Rate with a Longer Service Life
4. Major Improvement in Corrosion Resistance in Concrete
5. Better Mechanistic Performance of A1094 in Concrete
Conclusion

Thank YOU NESMEA/ NEAUPG!

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