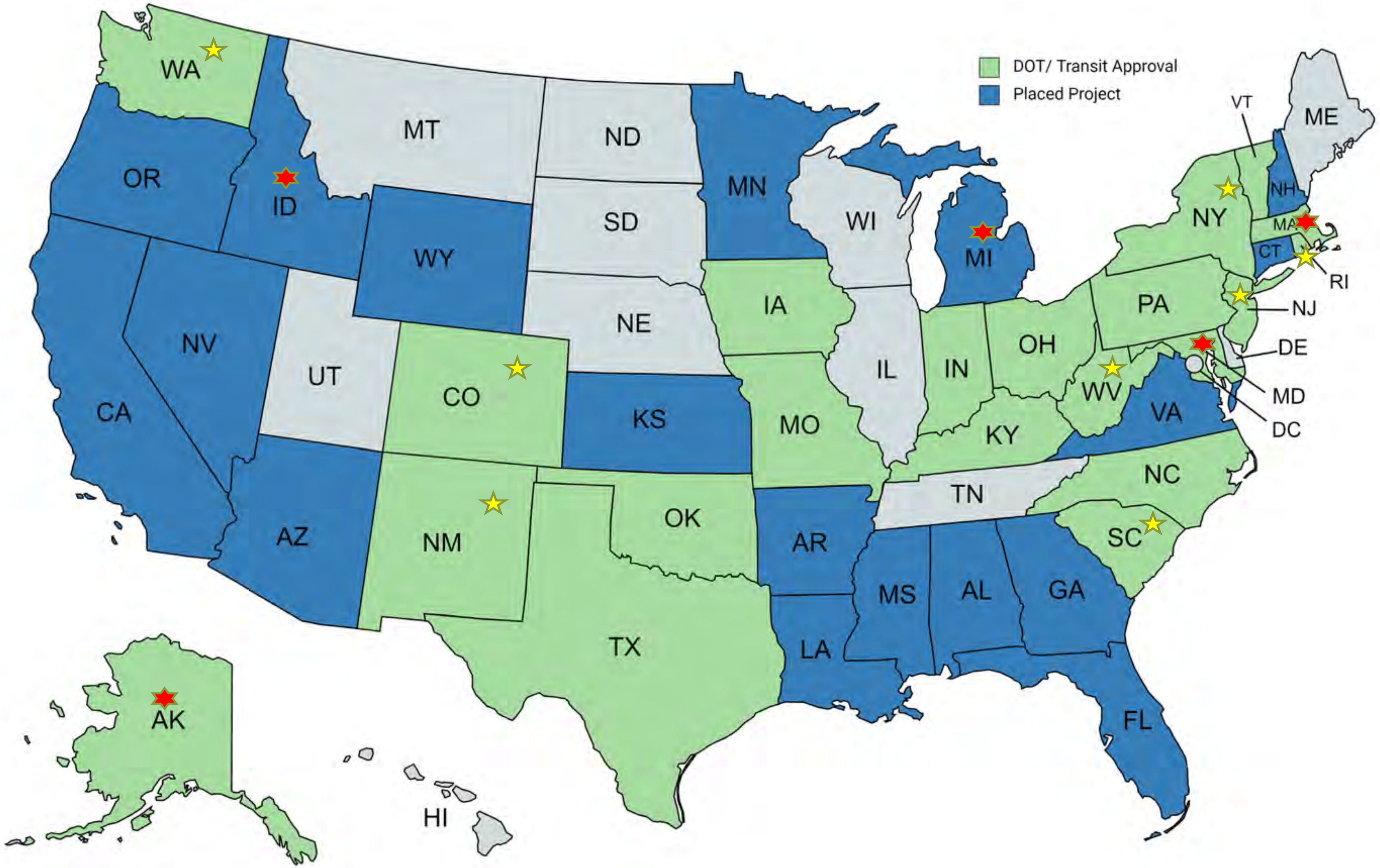
NESMEA/ NEAUPG

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)



GALVABAR®

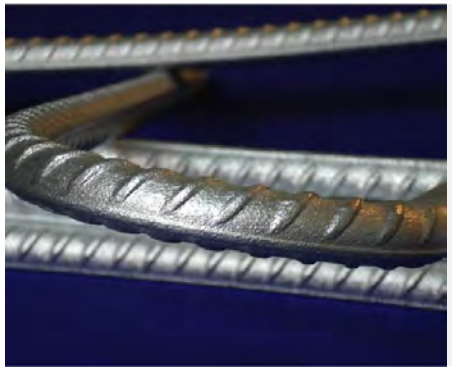
41 States
Bahamas & Bermuda

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



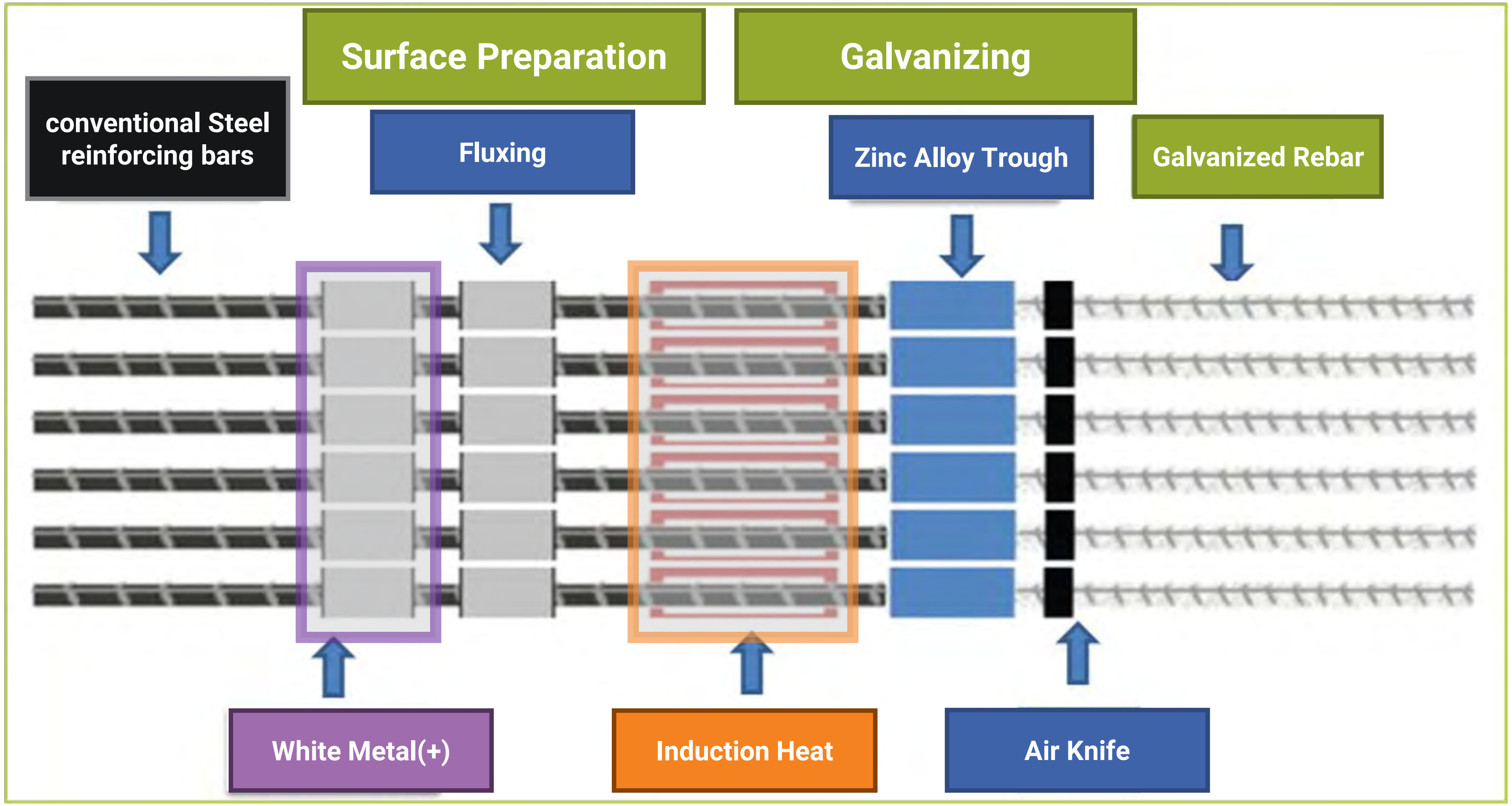
Fabricated after processing. Fabrication with no special equipment

Thicker pure zinc coating increases corrosion initiation threshold

Inventoried 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

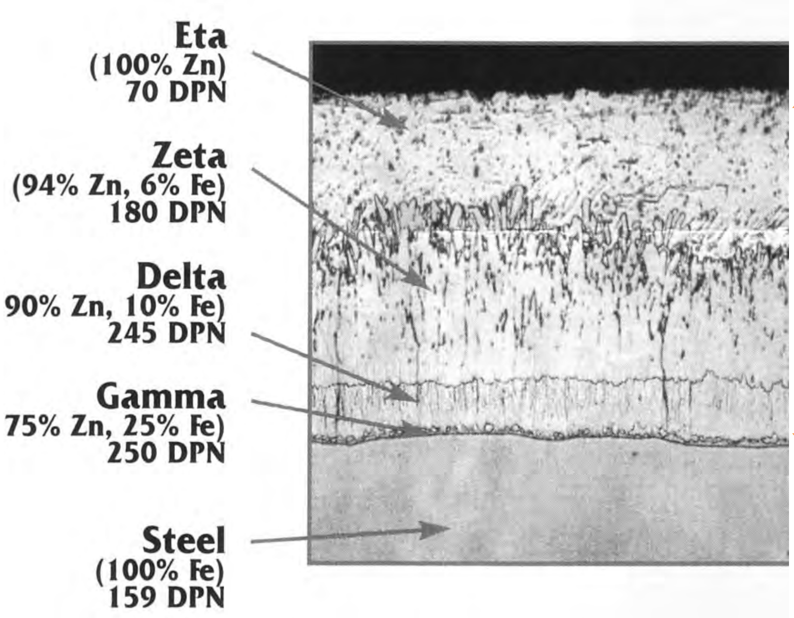
- The manual states to apply the same bend diameter criteria as conventional reinforcing steel bar.

Composition and Materials

Cross Section Comparison of Coating

ASTM A767 - 129µm min.

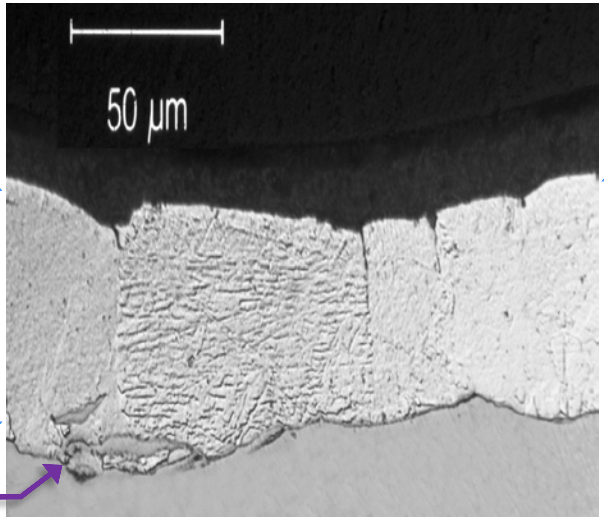
ASTM A1094 - 50µm min.



10-40µm Zinc layer

129-150µm Intermetallic Zinc-Iron

Hot-Dip Galvanized



50µm min Pure Zinc **Coating**

Ternary Layer $Fe_2Al_5\text{-}XZn_x$

Continuously Galvanized

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

○ 24th Most Abundant ○○ Ore Mineral ○○○ Ingots ○○○○ Recycling ○○○○○ Practices

Environmental Comparisons

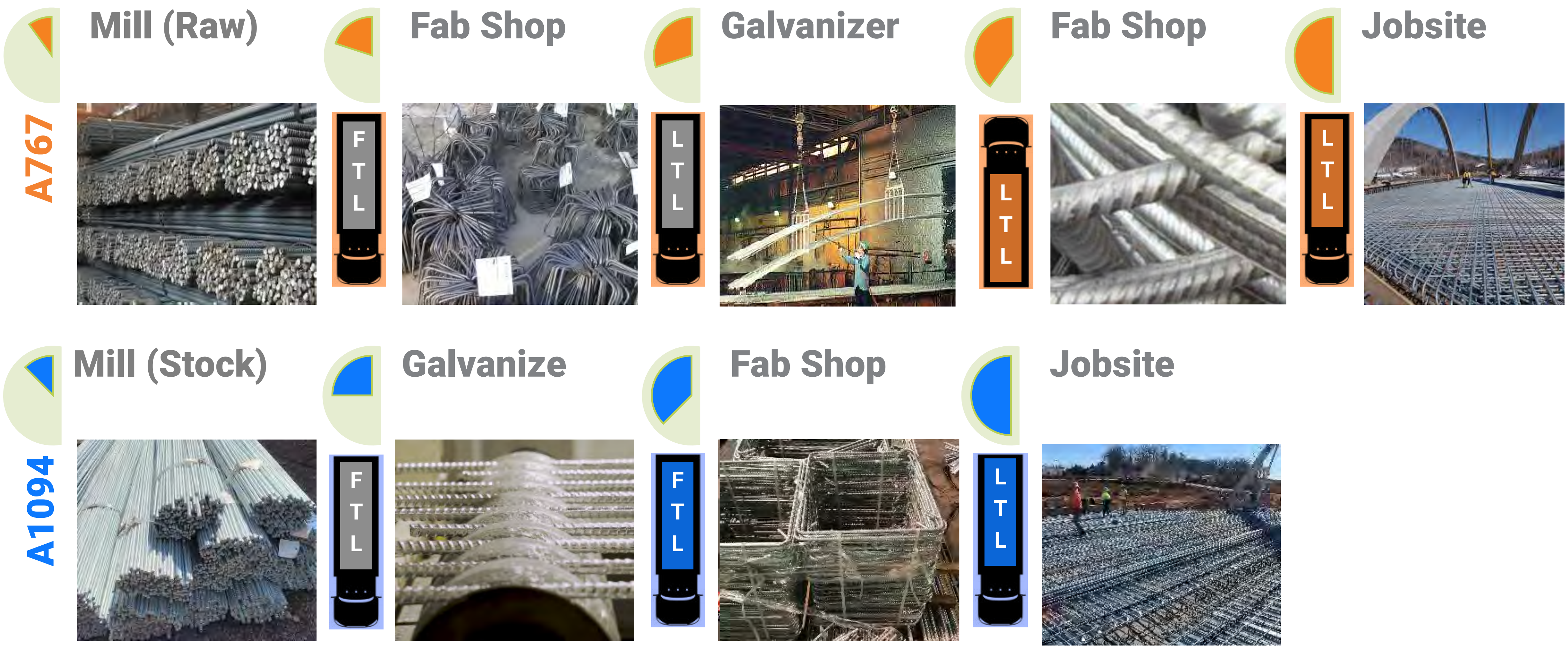
A1094 vs A767

- **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



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:

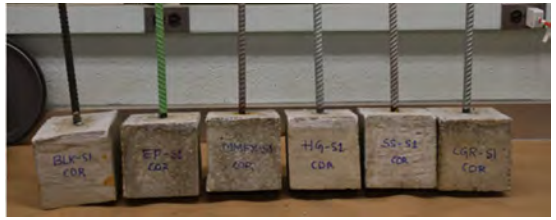
Only the cut ends need touch-up repair and occasional minor field touch up because of zinc's cathodic protection ability

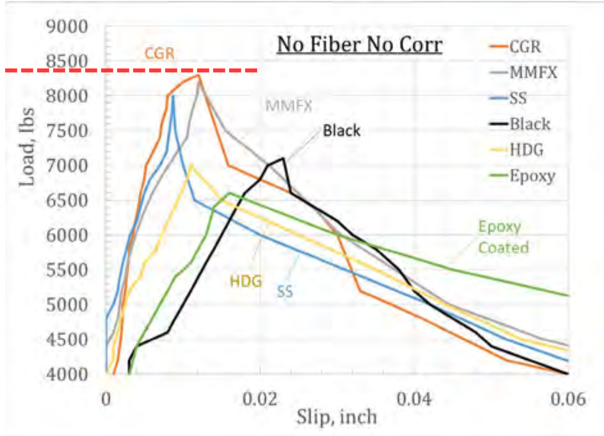
Fabrication

Features and Benefits

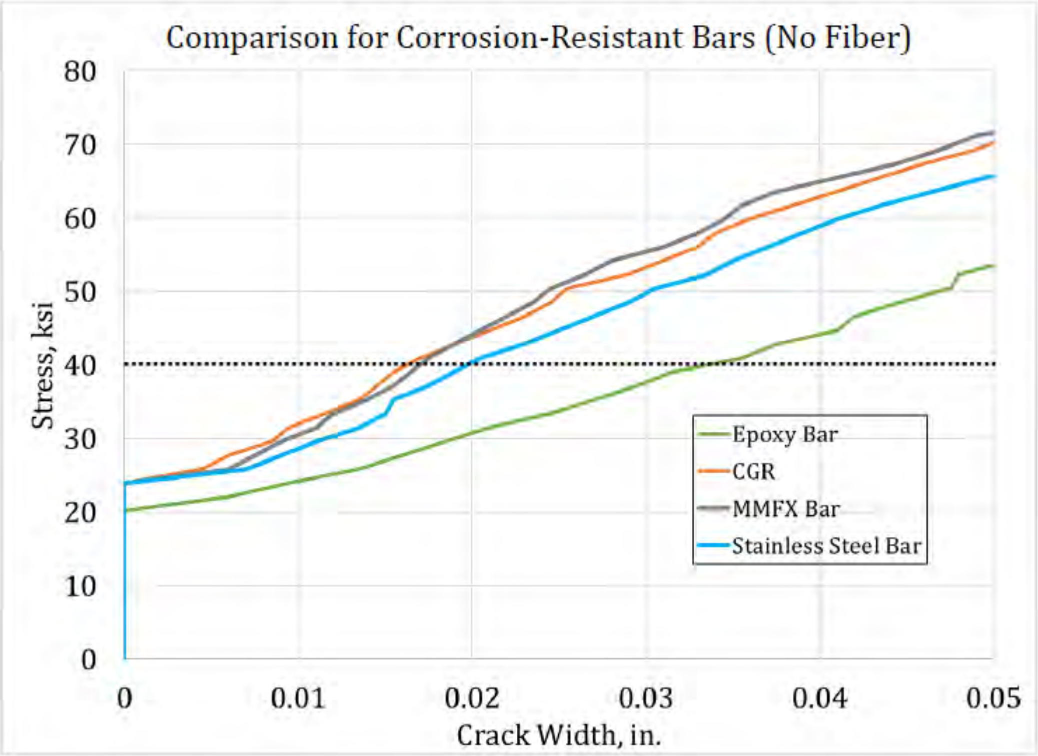
Performance (Exceptional Bond Strength)

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

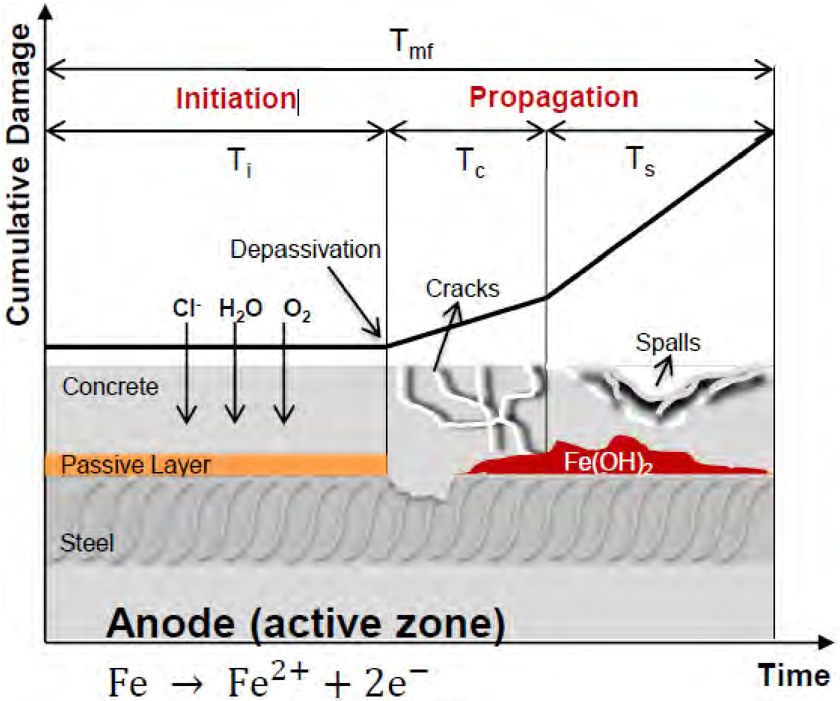
UNSW CANBERRA

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



Anode (active zone)

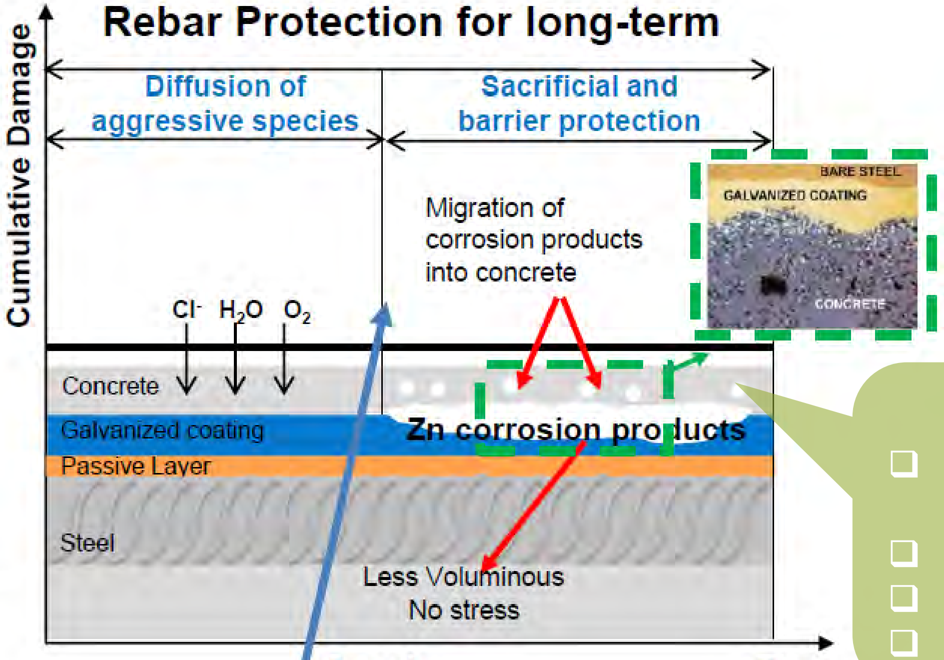
$$Fe \rightarrow Fe^{2+} + 2e^{-}$$

$$Fe^{2+} + 2Cl^{-} \rightarrow FeCl_2$$

$$FeCl_2 + 2H_2O \rightarrow Fe(OH)_2 + 2H^{+} + 2Cl^{-}$$

Cathode (passive layer)

$$2H_2O + O_2 + 4e^{-} \rightarrow 4OH^{-}$$



Anode

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

$$Zn + 2H_2O \rightarrow Zn(OH)_2 + H_2(g)\uparrow$$

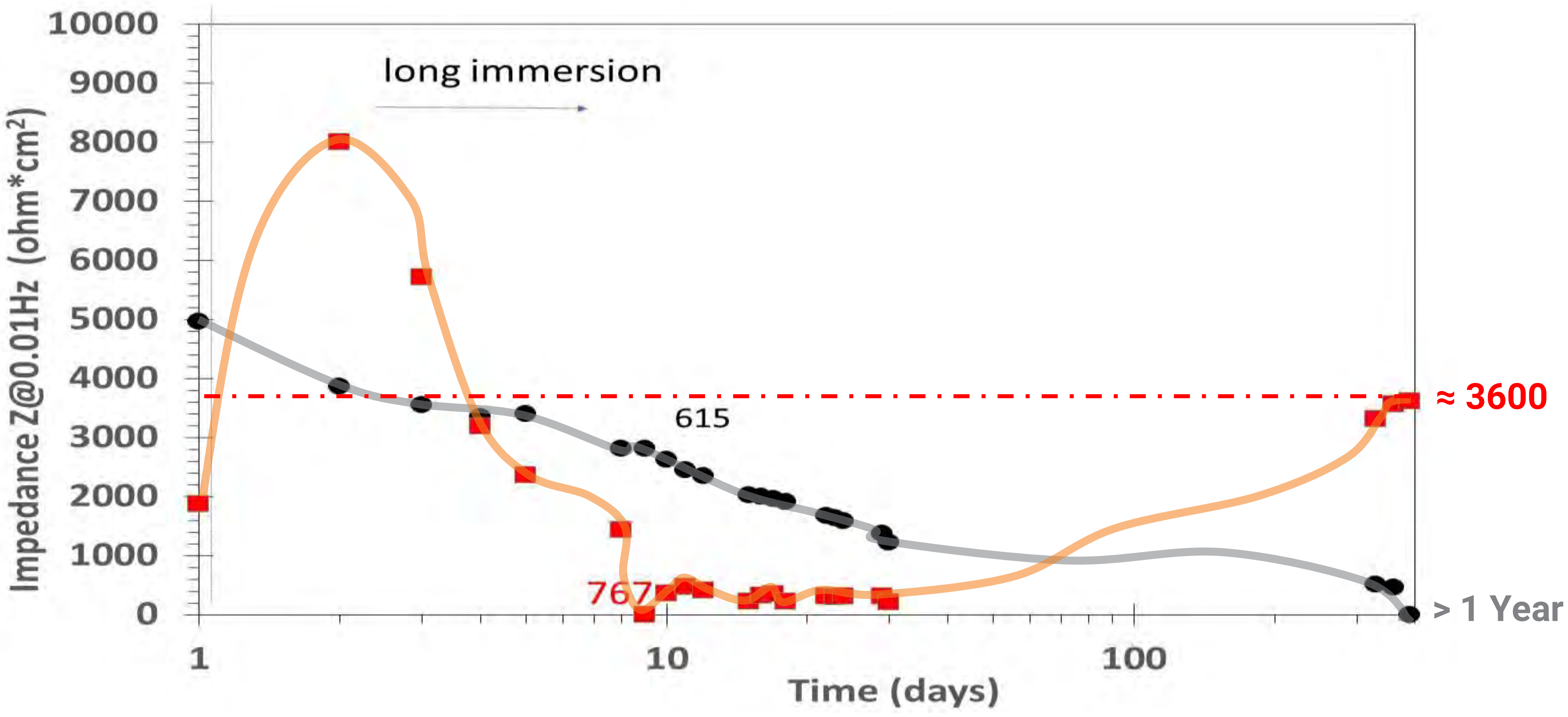
Cathode

$$2H^{+} + 2e^{-} \rightarrow H_2$$

A1094

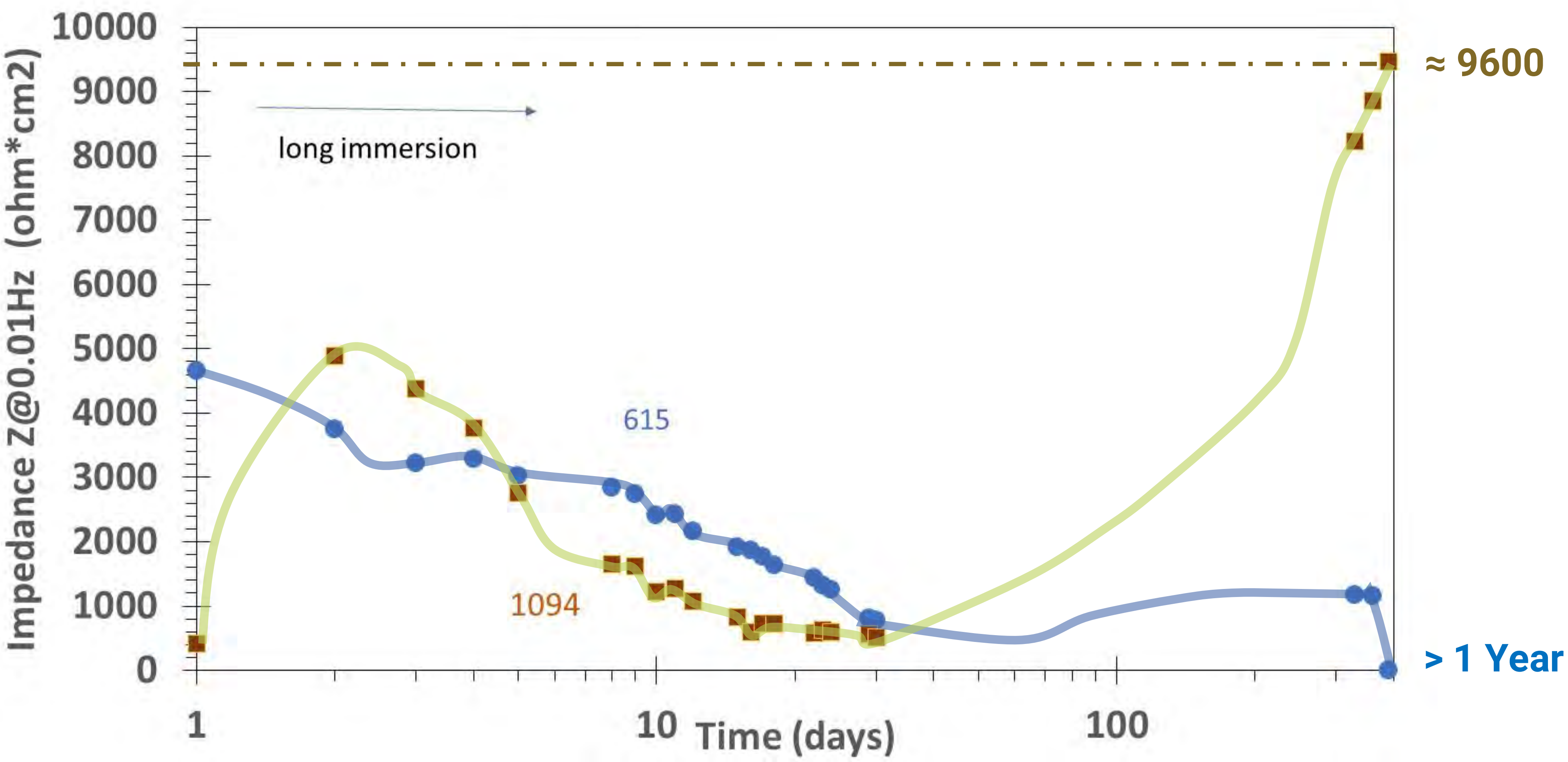
- ❑ Less Voluminous Zinc corrosion products
- ❑ More homogeneous coating
- ❑ Resourceful use of Zinc
- ❑ Improvements in protection

Tran-SET Continuous Immersion Test for A767



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

Tran-SET Continuous Immersion Test for A1094



The EUROSTRUCT 2021 Study

Uniform and local corrosion characterization and modeling (EIS Spectra Evolution)

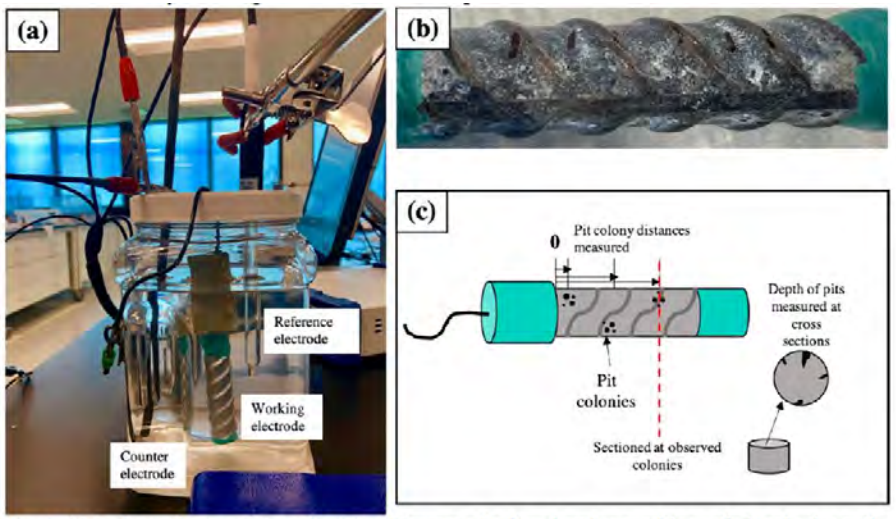
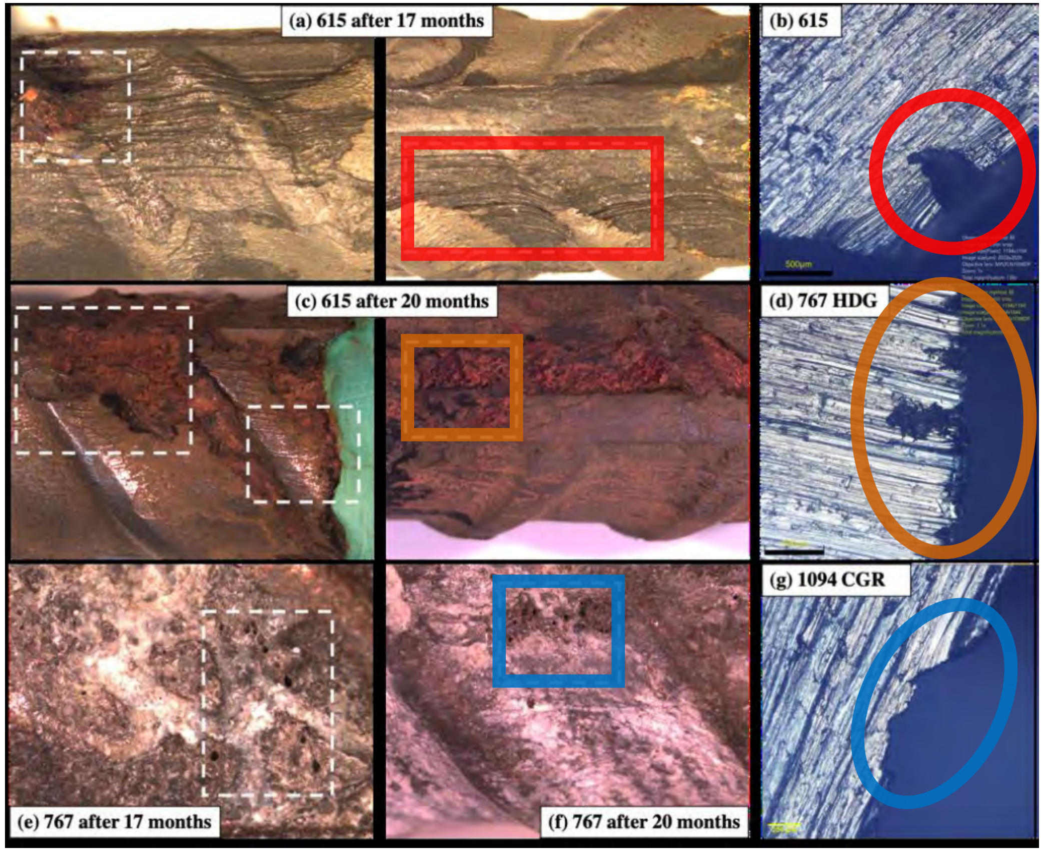


Fig. 1. (a) 3-electrode experimental set-up, (b)removed rebar showing markings of pit colonies and (c) schematic showing procedure employed to obtain pit distribution.

- ✓ 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.

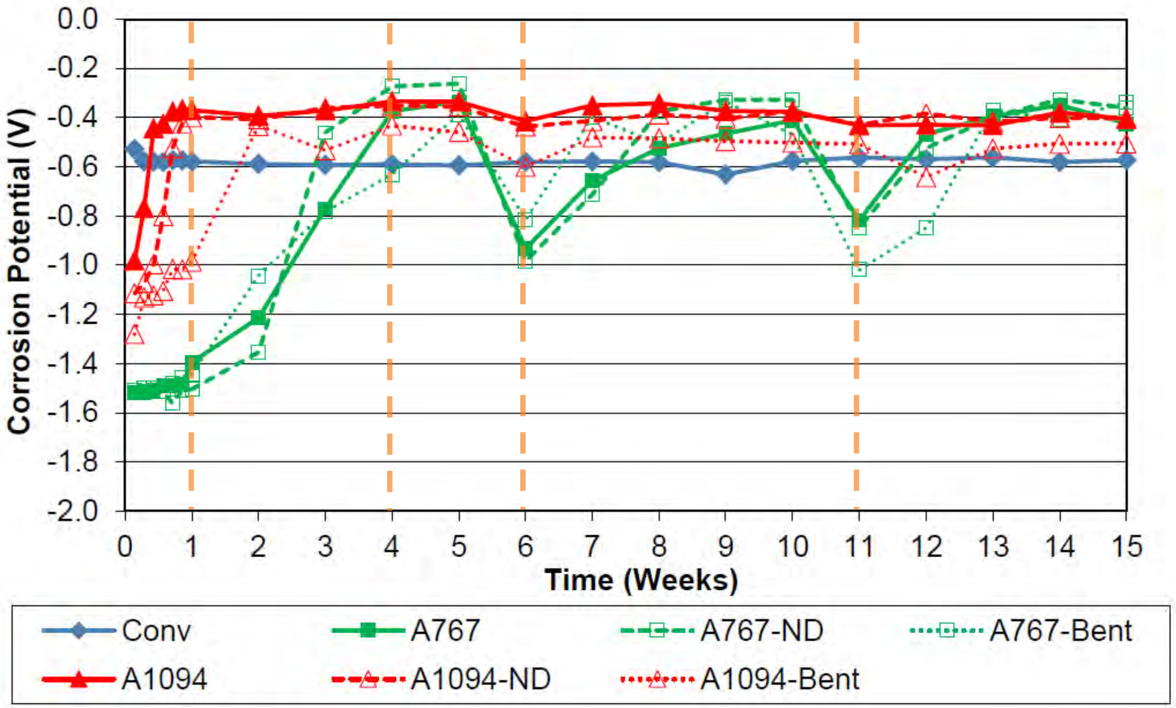
- ➢ These images show the pit colony intrusion at the surfaces to provide a cumulative report for long-term exposure.
- ➢ The pit colony locations illustrate the section losses in this Fig.



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

Figure 3.8: Rapid Macrocell Test.

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



Kansas University Study – Oklahoma DOT

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

Reinforcing Type	Corrosion Loss						Average Loss	Std. Dev.
	1	2	3	4	5	6		
A767 - ND	709.70	687.20	797.50	350.60	388.10	3,068.70	1,000.30	1,029.50
A1094 - ND	2.09	2.03	5.56	2.03	2.08	6.25	3.34	2.00

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

Kansas University Study – Oklahoma DOT

8-in. Deck, 2.5-in. Cover						
Reinforcing Type	Time to Repair, Years					Total Present Cost, $/SY
	1	2	3	4	5	
Conv-A	22	44	66	88		$929
ECR	43	85				$512
ECR-UV-1000	17	59				$724
A767	50	100				$473
A1094	50	100				$461

8.5-in. Deck, 3.0-in. Cover						
Reinforcing Type	Time to Repair, Years					Total Present Cost, $/SY
	1	2	3	4	5	
Conv-A	26	52	77			$779
ECR	56					$373
ECR-UV-1000	19	75				$679
A767	62					$367
A1094	62					$356

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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GALVABAR®