Galvanized Reinforcing Steel

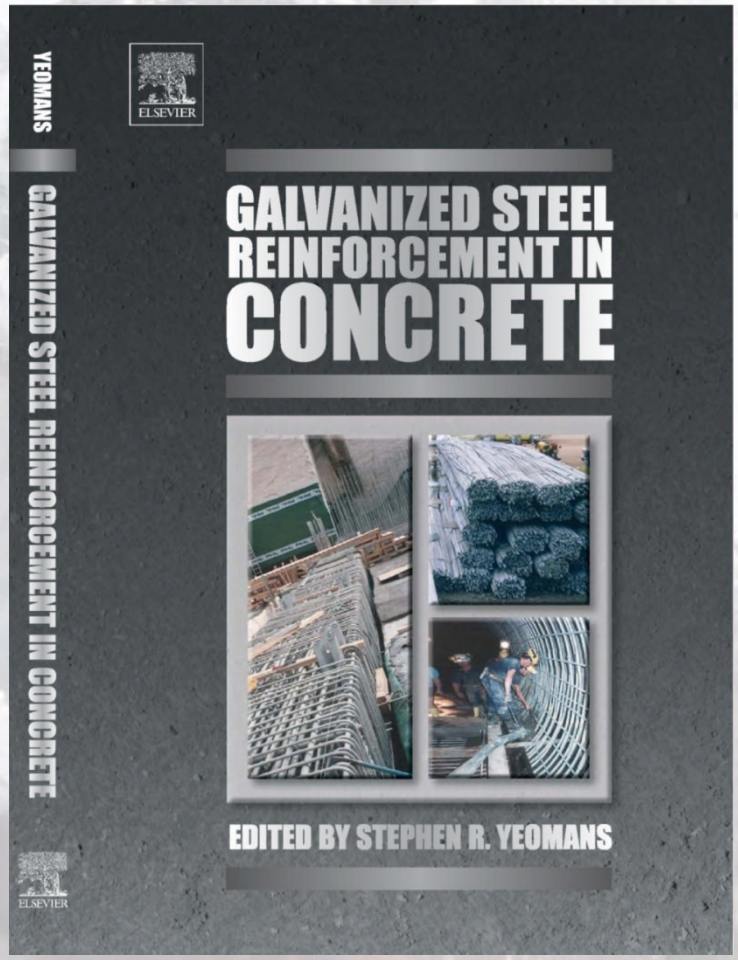
Questions and Answers

ACI Pittsburgh, 2010

Carl Maki – South Atlantic Galvanizing

SOUTH ATLANTIC
REINFORCING

Resources



International Zinc Association

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ZINC

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....Essential for Life

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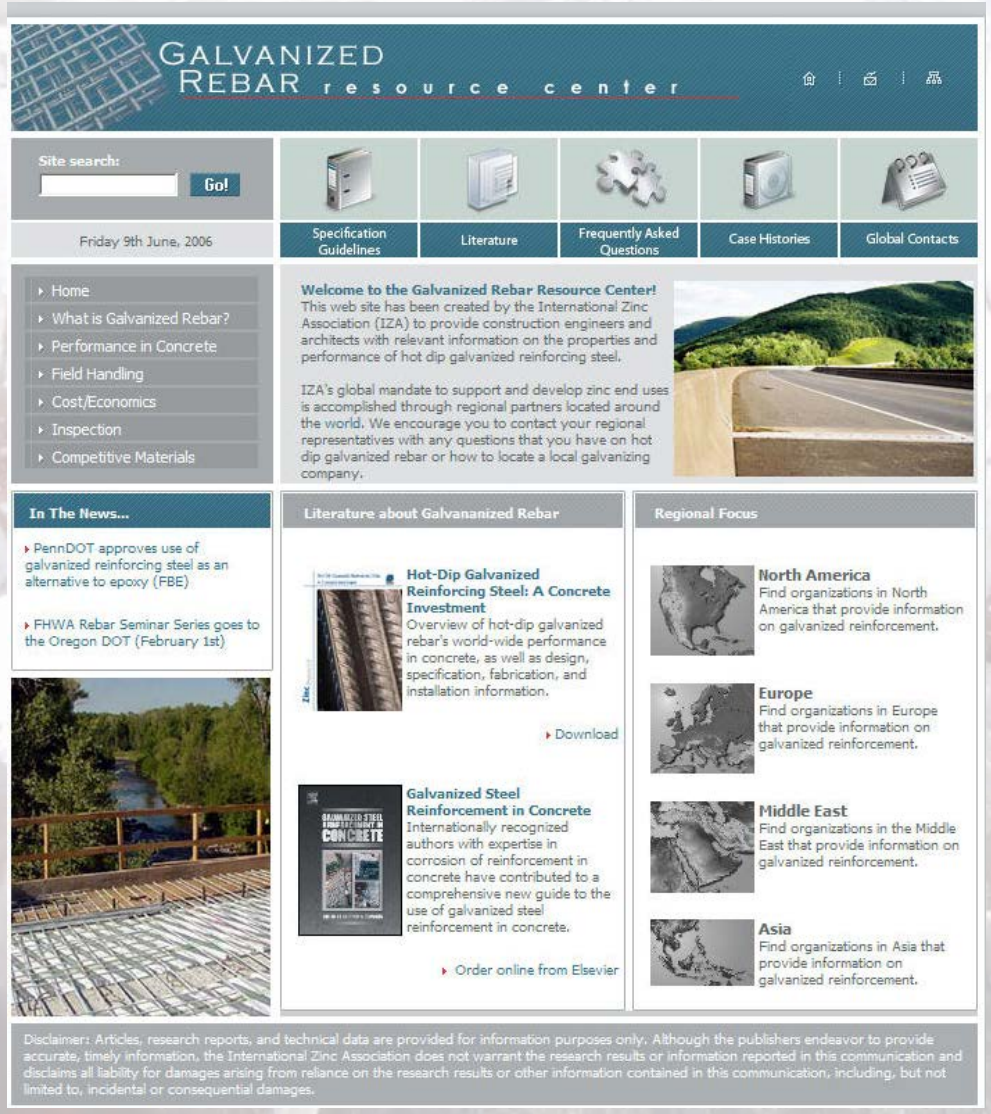
www.galvanizedrebar.com



Why use galvanized reinforcement in concrete construction?

To provide a safeguard against reinforcement corrosion and the resultant damage to the concrete

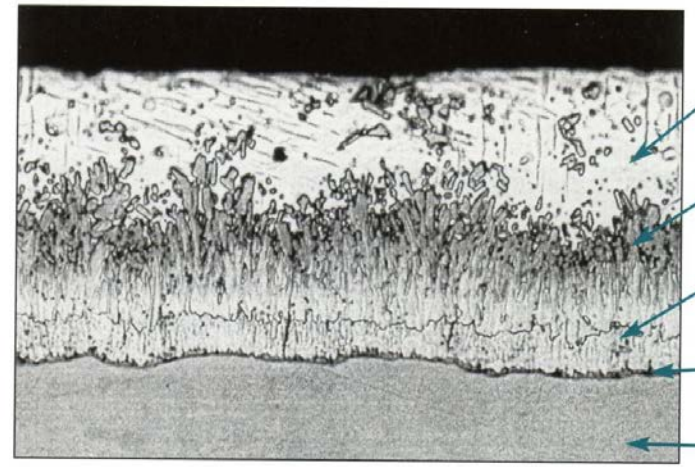
What are the important differences between galvanizing and other coatings for reinforcing steel?

HDG is a tough coating

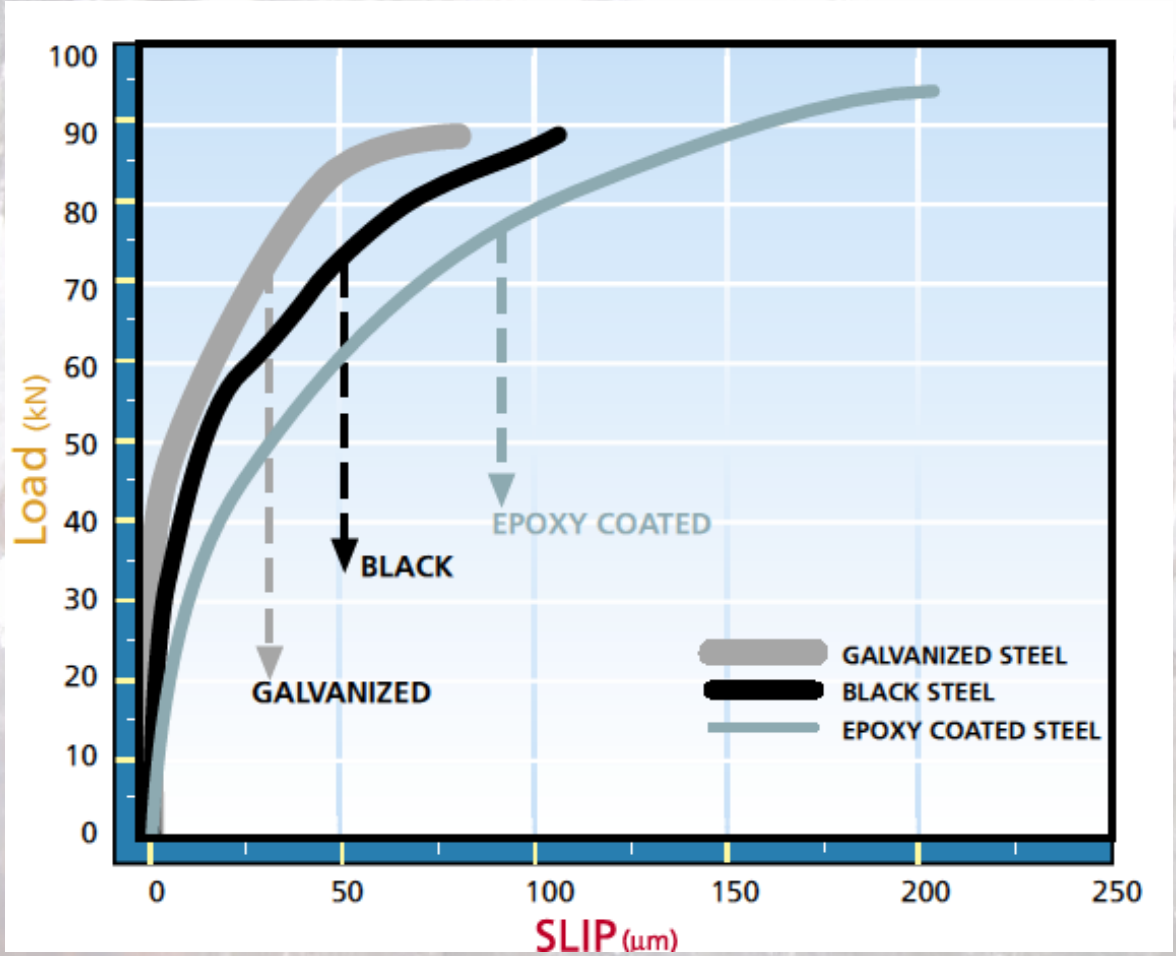
- Stands up to rough handling and job site abuse without being compromised
- No special handling required
- Cathodic protection of any damaged areas

HDG is Metallurgically Bonded

- A ductile coating with alloy layers harder than the base steel (250DPN)
- Cathodic protection of any damaged areas



Galvanized Reinforcing Exhibits Superior Bond Strength



Installation is the same as uncoated rebar

- Overlap links are same as black
- Handle the same as black
- Installed under the same weather conditions as black
- No sensitivity to UV light
- No touchup (except field-cut ends)

Installing HDG Rebar

How long have galvanized reinforcing steels been used in concrete?


Reportedly used in early as 1900’s on bridgework in Bermuda

Bermuda is a harsh environment

- No place more than 1 KM from ocean
- Local aggregate is high chlorides
- High humidity, steady winds
- Extremely limited fresh water
  - Primarily use stored rainwater
  - A very few wells with restricted withdrawel
  - Has at times been common to use salt water

The Bermuda Case Study

RBYC Wharf

Bermuda now specifies HDG for 100% of concrete construction

By mid 1970's significant tonnage of reinforcing bar was being galvanized in the US

- Primarily for Bridges
- Primarily in snow belt states
- Many of these bridges today still show no signs of corrosion

Bridge survey data: 1975-2002

Location	Build	Inspect	Chlorides (kg/m^3)	Zinc coating (microns)
Boca Chica Bridge , FL	1972	1975	1.17	130
		1991	1.21	102
		1999	1.93	170
Tioga Bridge, PA	1974	1981	0.35	150
		1991	0.64	224
		2001	1.34	198
Curtis Road Bridge, MI	1976	2002	4.13	155
Spring Street Bridge, VT	1971	2002	2.50	191
Evanston Interchange, WY	1975	2002	1.53	236

Route 66 bridge deck, Kittanning PA

- **The recent refurbishment of this bridge, built in 1973, provided a unique opportunity to assess the performance of galvanized rebar used in the deck after more than 30 years of service.**
- **The deck remains in excellent condition, but PennDOT wanted to replace the post and beam medial barrier with a concrete Jersey barrier.**
- **This required removing the entire mid-section of the deck and exposing the galvanized**

What Happened?

- 1979 FHWA Report very critical of HDG
  - Designated an ‘experimental’ coating
  - Very limited matching funds
- 1983 Report Withdrawn
  - Damage was done
- Some Agencies in US returned to Galvanizing
  - New York Thruway
  - Ohio Turnpike
- HDG Remains an unknown to many Engineers

How HDG Protects Rebar

- High Chloride Threshold (2 - 4X black steel)
- Protective Reaction Product (CaHZn)
- Low pH Tolerance (Carbonation)
- Cathodic Protection
- Corrosion Product Migration
  - Concrete Matrix Densification
  - Lower Unit Stress Generation
  - Good bond strength

Zinc Corrosion Products are Less Dense

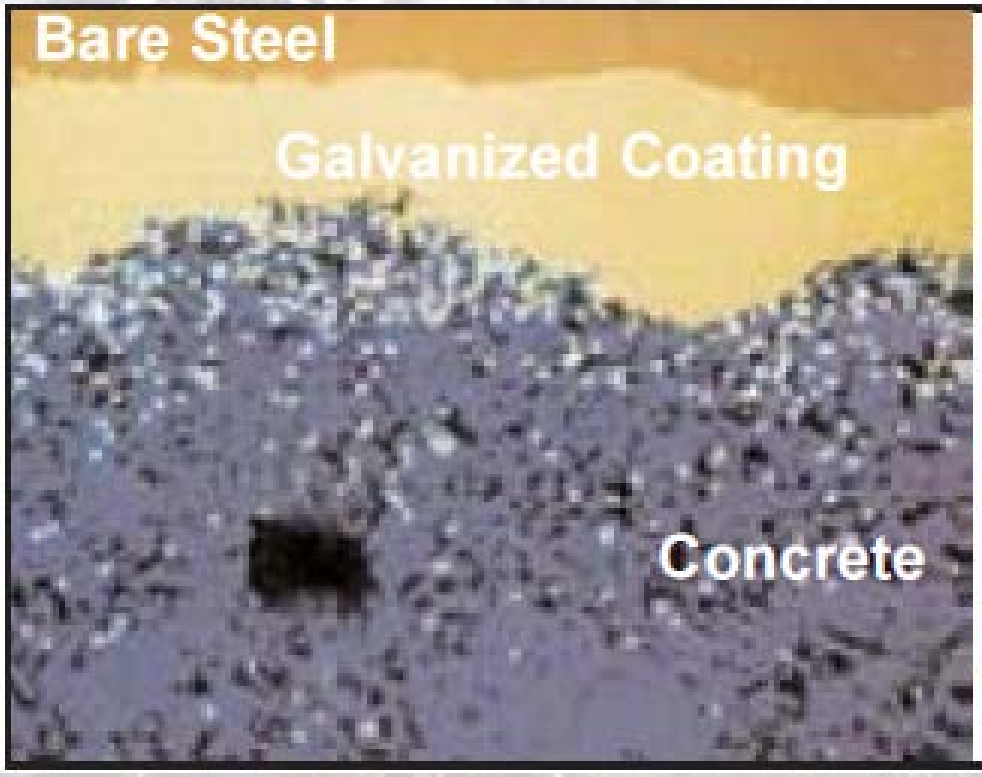
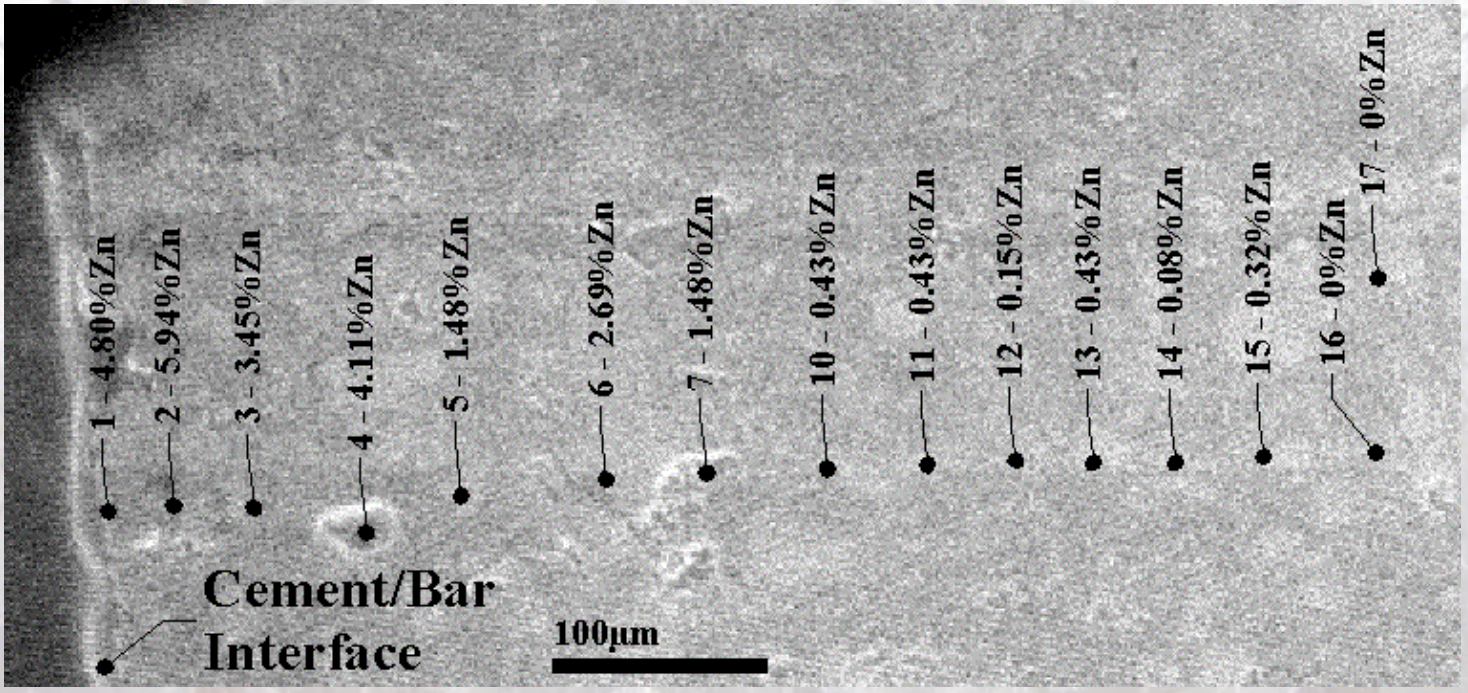


Figure 4: Elemental map of galvanized rebar.
The corrosion products of galvanized rebar are less dense and do not build up pressure to cause concrete spalling (unlike the dense corrosion products of bare steel). The zinc corrosion products (depicted left, in white), migrate away from the galvanized coating and disperse into the concrete matrix.

Diffusivity of Corrosion Products



Zinc concentration as a function of depth into the cement paste for non-chromated specimen

The commencement of corrosion activity at the zinc / concrete interface is the activation of the sacrificial protection mode

- Limited expansive pressure
- Localized densification which may inhibit the attack
- Zinc has the ability to re-passivate

Are there different design requirements when galvanized bar is to be used reinforced concrete ?

Design values similar to uncoated bar

- Splice and lap lengths are the same as for black steel
- Bond and load transfer values are the same as for black steel
- When coupled to black steel, the connection point should be deeply embedded in the concrete or the connection should be isolated thru use of vinyl tape or other non-conductors.

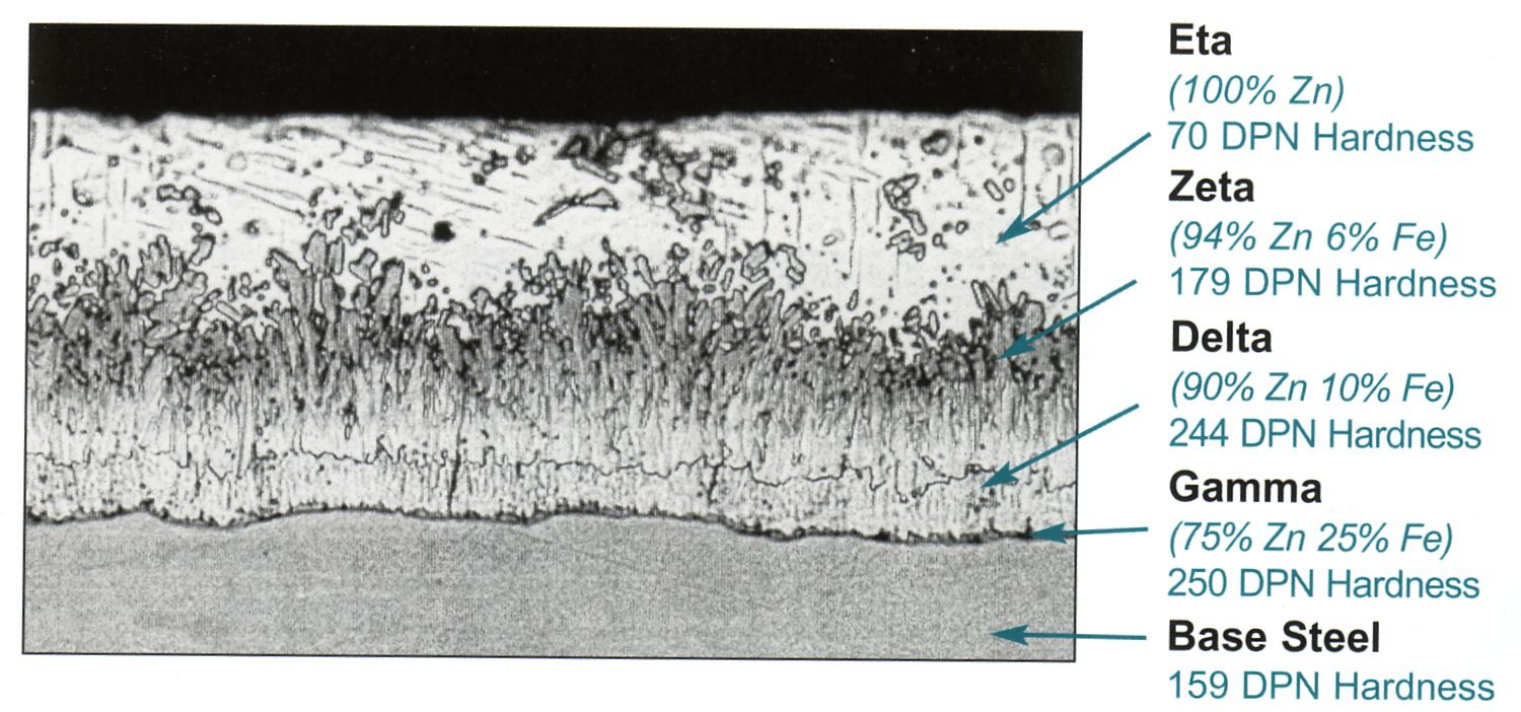
What is the cost of galvanizing?

What is the cost of galvanizing?

- Expect to pay 25% to 50% premium over the cost of black bar
  - Cost is affected by size and configuration of job
  - Local galvanizing capabilities
  - Specified coating weight

When specifying galvanizing, why is it necessary to specify *hot dip* galvanizing?

Only Hot Dip Galvanizing has this type of metallurgical bond to the steel



Electroplating, Thermal Spray and Zinc Rich Paint are not the same

What types of steel reinforcement can be safely galvanized?

All types of reinforcing steel, including newer high strength grades can be safely galvanized

- Laboratory testing shows that galvanizing does not significantly alter the tensile properties of the steel bar
  - Excessive cold working (i.e. bending and re-bending) should be avoided before galvanizing
  - If there is a specific concern, a simple retest after galvanizing can be performed

IMR TEST LABS
A Division of Ithaca Materials Research & Testing Incorporated

What Standards should be used when galvanizing reinforcing steels?

- **United States**: ASTM A767, Zinc-coated (galvanized) steel bars for concrete reinforcement
- **Canada**: CAN/CSA G164, Hot dip galvanizing of irregularly shaped articles
- **United Kingdom**: BS ISO 14657, Zinc coated steel for the reinforcement of concrete
- **France**: NF A35-025, Hot-dip galvanized bars and coils for reinforced concrete
- **ISO**: ISO 14657, Zinc-coated steel for the reinforcement of concrete

What coating thickness should be specified when galvanizing reinforcing steel?

- All of these standards call for a coating thickness of 85-87 microns on bar larger than 6mm.
- In addition, A767 has a ‘Class I’ coating with a thickness of 140 microns.
  - Cost for ‘Class 1’ is significantly higher
- A767 also calls for chromate post treatment

Why are chromates used to treat galvanized reinforcement?

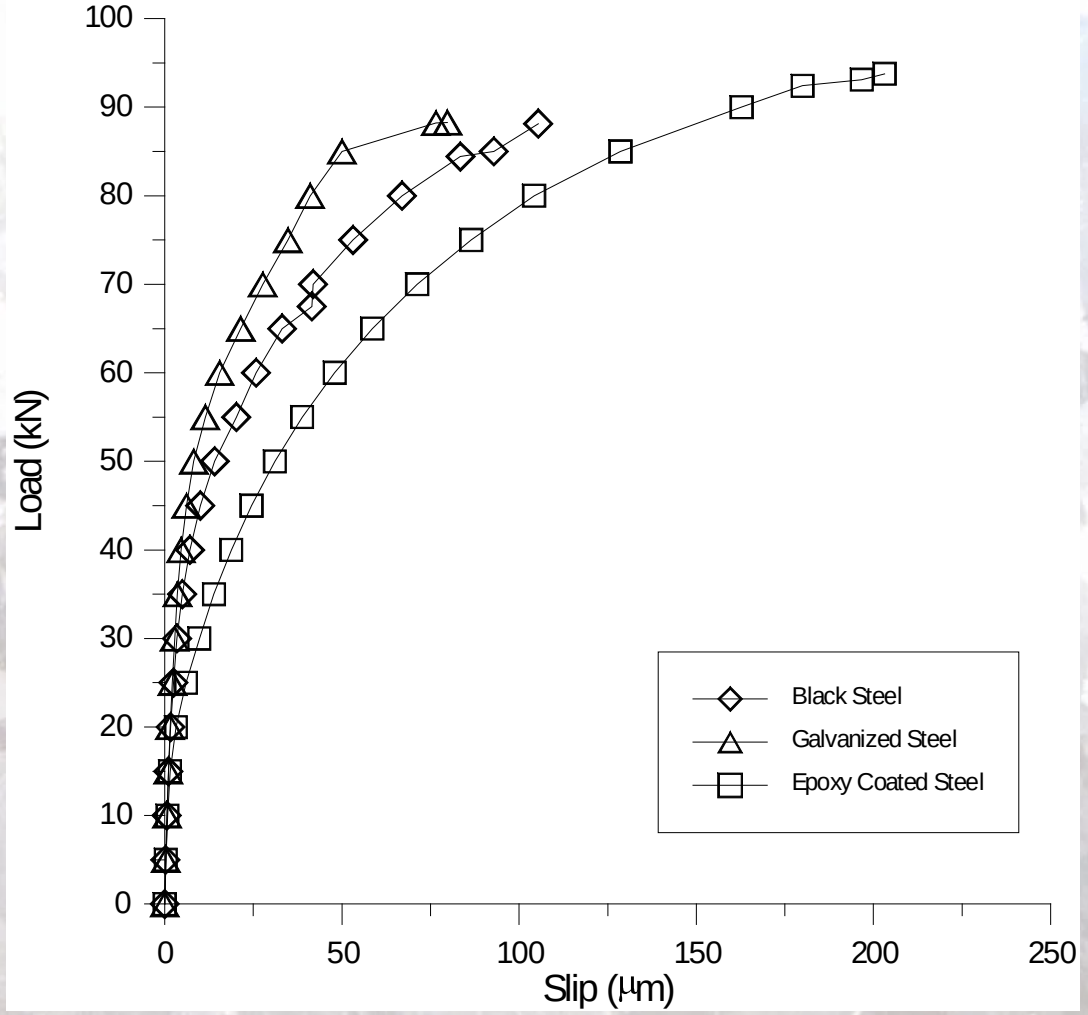
- When freshly galvanized steel comes in contact with wet cement, a reaction occurs at the zinc surface which passivates the coating by the precipitation of a protective layer of calcium hydroxy-zincate (CHZ).
  - This reaction ceases within a couple of hours
  - A by-product of this reaction is the liberation of hydrogen and it has been suggested that the presence of the resulting gas micro-pores in the concrete matrix may reduce the bond capacity of the reinforcement itself.

Is this detrimental and will concrete bond adequately to galvanized reinforcement?

Bond

After 28 days, galvanized bar develops a bond to the concrete which is superior to black bar

The basis of this is the formation of the protective surface layer of calcium hydroxyzincate. This layer is not only tightly adhered to the zinc surface it also interacts with the adjacent cement matrix effectively creating a bridge between the bar and the matrix.



Effect of surface condition on the initial corrosion of galvanized reinforcing steel embedded in concrete

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Published in Corrosion Science 2008

University of Waterloo

Program Objective

- Measure initial corrosion rates of hdg rebar with different surface conditions (chromated, non-chromated, weathered and alloyed) in different concretes (OPC, silica fume and slag)
- Confirm diffusivity of zinc corrosion products
- Determine if hydrogen evolution during corrosion reaction creates any porosity in surrounding concrete

Current Density vs Time in OPC

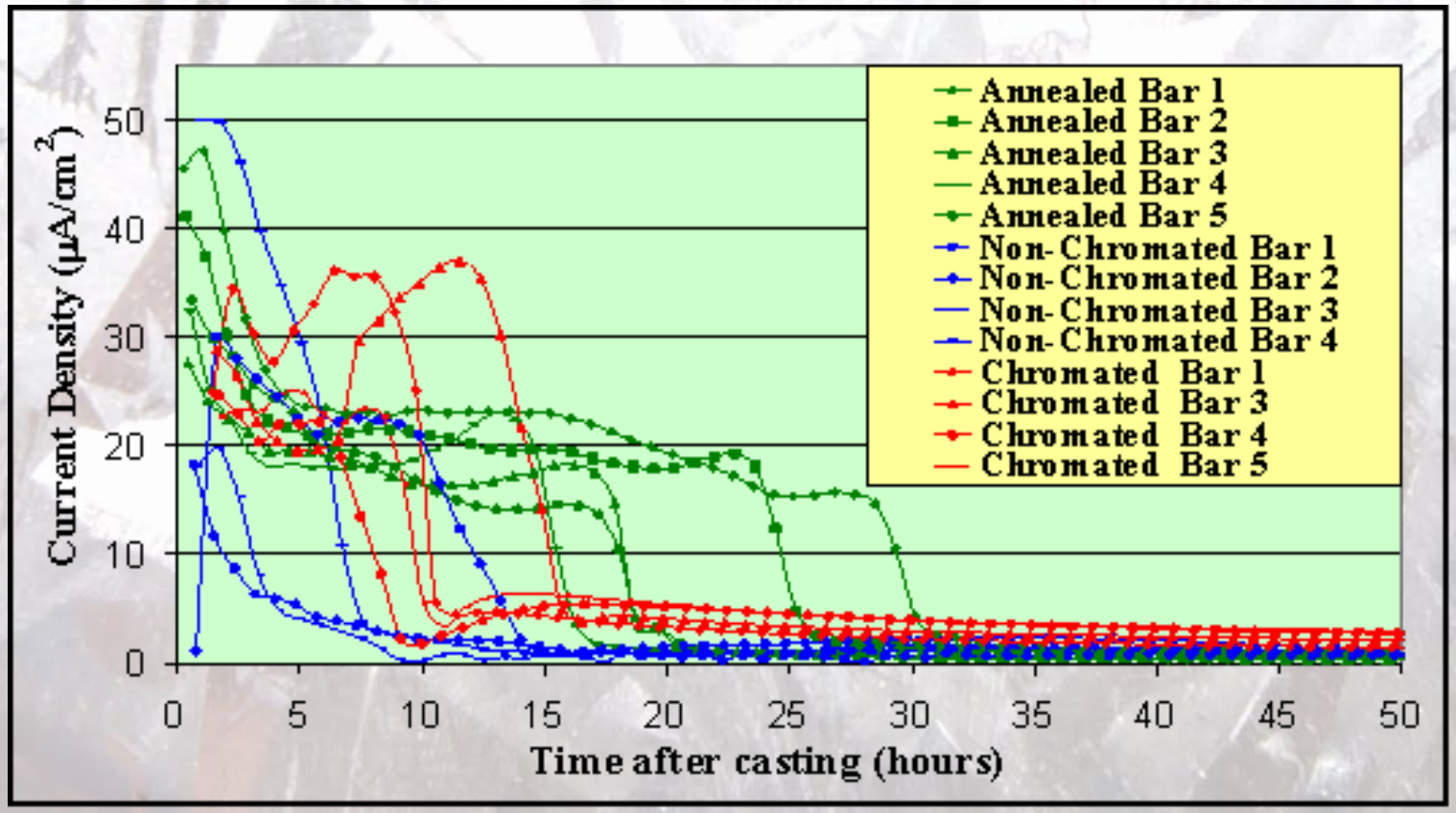
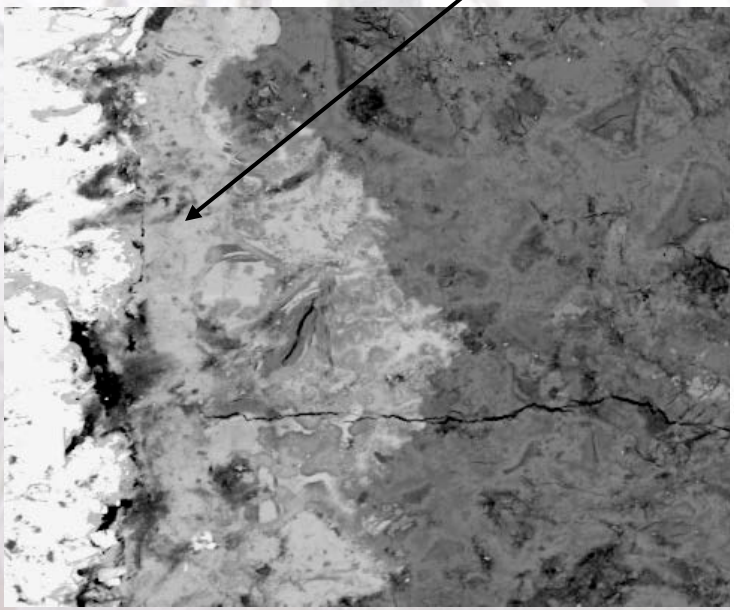


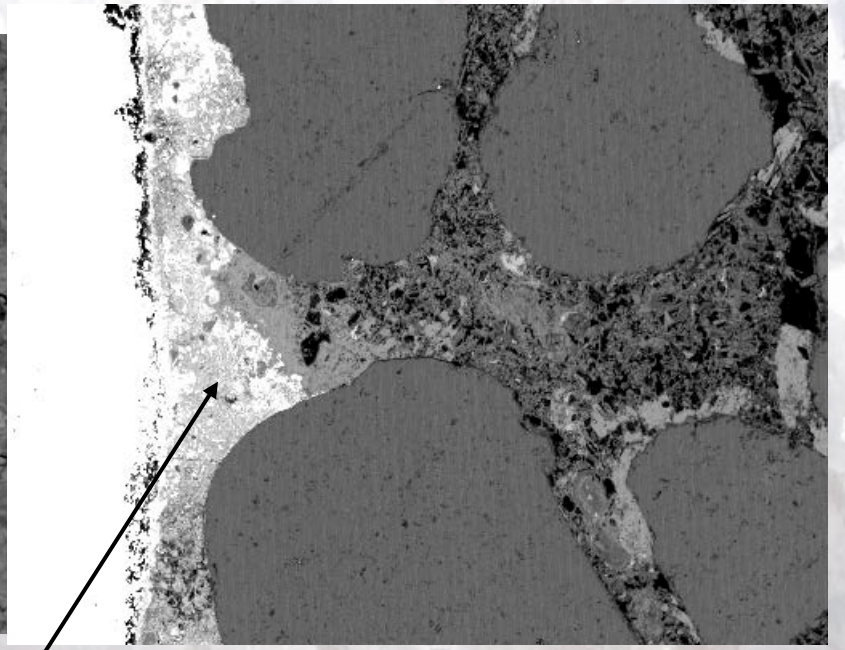
Figure 9. Corrosion of bars in OPC concrete

Migration of Zinc into Cement Mortar Matrix

Showing partial dissolution of the galvanized coating (left) and plume of zinc-rich corrosion product (centre) migrating into the cement matrix (right).



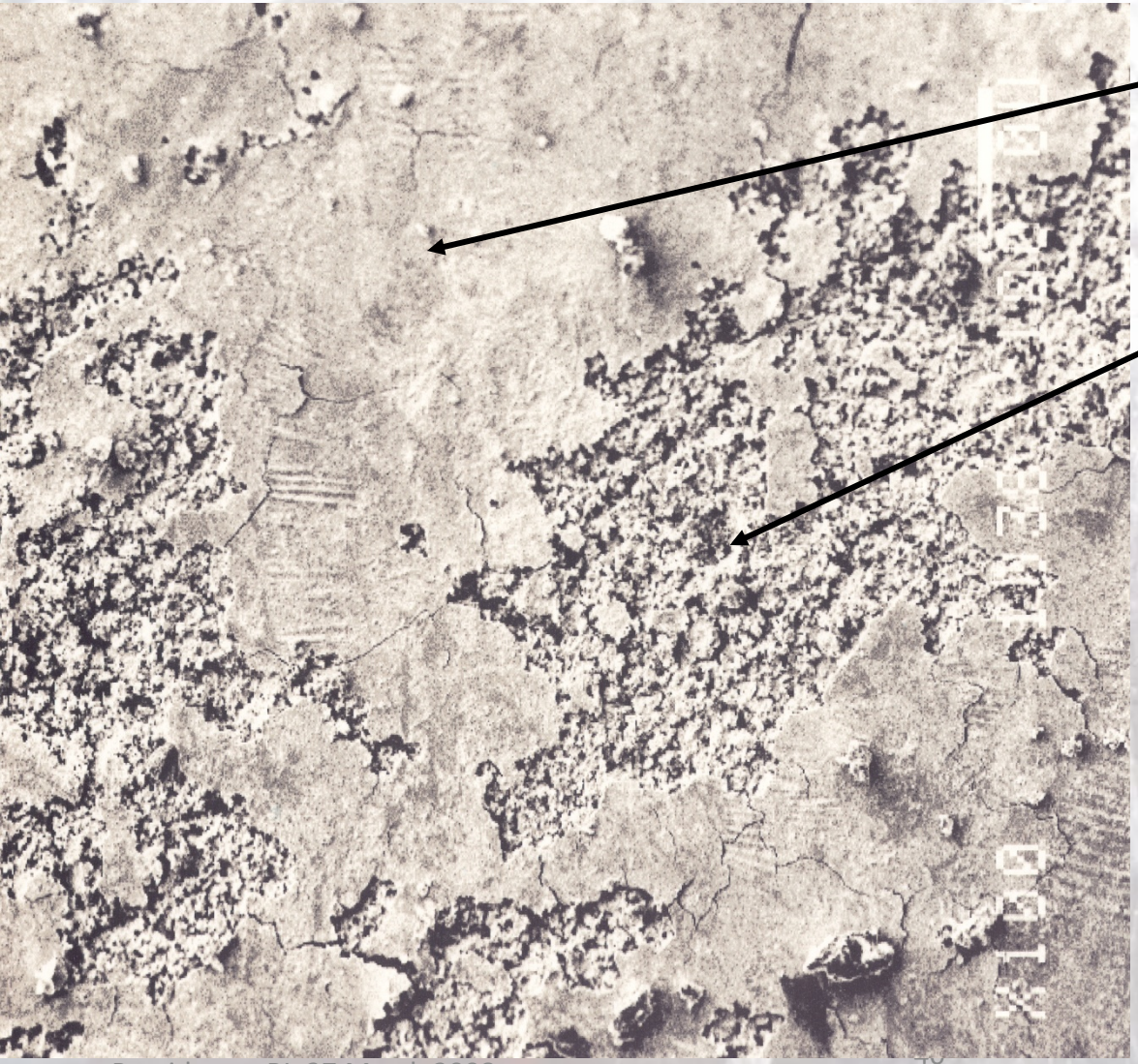
1000x



100x

Migration of zinc-rich corrosion products away from the bar/matrix interface and well into the cement matrix. Large particles are fine sand. (100x)

SEM of interfacial zone



Dense interfacial zone adjacent to the zinc alloy surface.

Local region of failure of interfacial zone due to firm adhesion to bar and showing cement matrix beyond.

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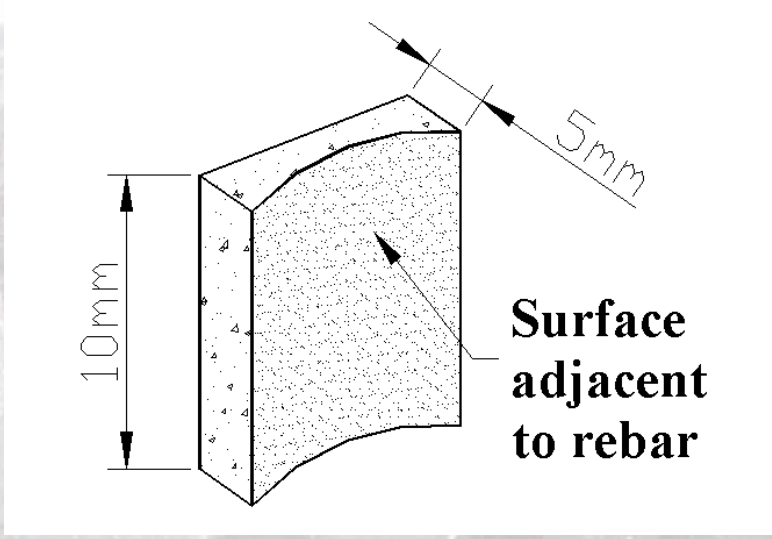
Mercury Intrusion Porosimetry

- After 9 days of hydration, diffusion of corrosion products into the cement may be compensating the effect of hydrogen evolution
- No detectable difference

Cement Type	Rebar type	Average intrusion volume %
OPC	Black steel	22.7±1.5
	Non-Chromated HDG	19.7±1.2
	Chromated HDG	20.7±2.1
Silica Fume Cement	Non-Chromated HDG	13.7±0.6
	Chromated HDG	13.3±0.6
Slag cement	Non-Chromated HDG	15.7±0.6
	Chromated HDG	15.3±1.2



UNIVERSITY OF Waterloo

FAU FLORIDA ATLANTIC UNIVERSITY

Towards Achieving the 100 Year Old Bridge Using Galvanized Rebar

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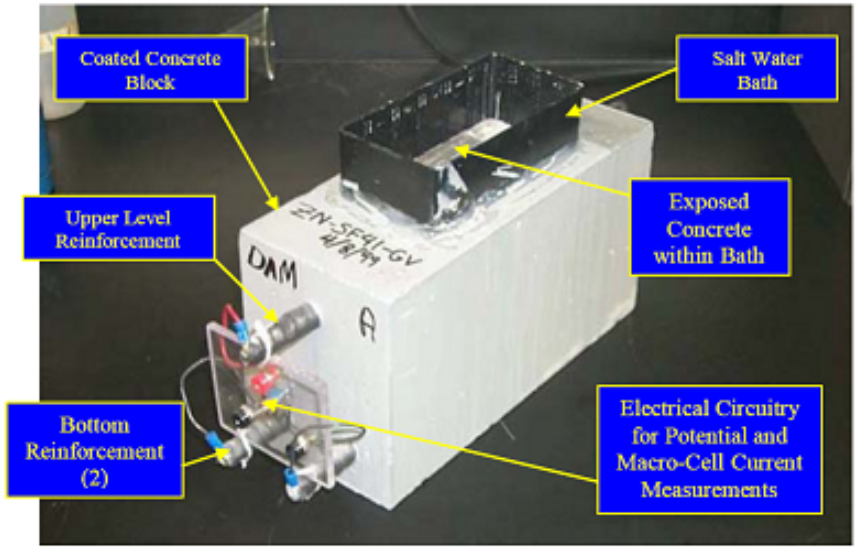
Experimental

- G109 Specimens with galvanized rebar, black rebar and GF bar and various variables have been exposed ~ 9 years
- The G109 specimens located indoors at room temperature.
- 4 concrete mix: 1) Portland Type II cement with no admixtures, 2) FA – Type II cement with admixed fly ash, 3) SF – Type II cement with admixed silica fume, 4) CN – Type II cement with admixed calcium nitrite

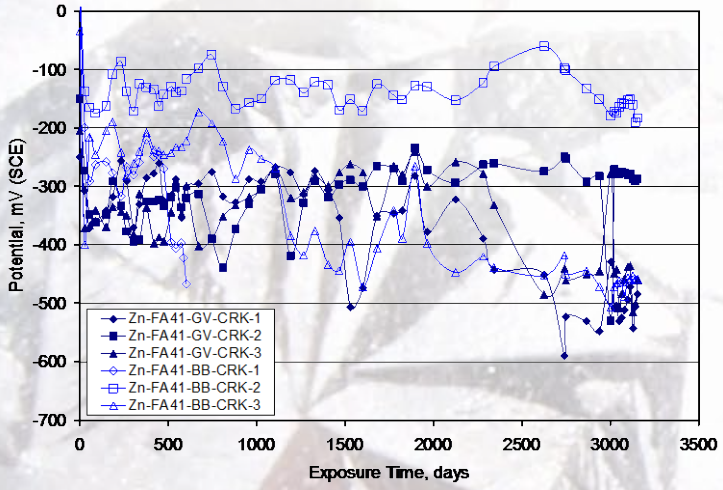
GF is Zn based coating with a typical composition of Zn-4.9Al-0.1 misch metal bath, and has been recently characterized in [5].

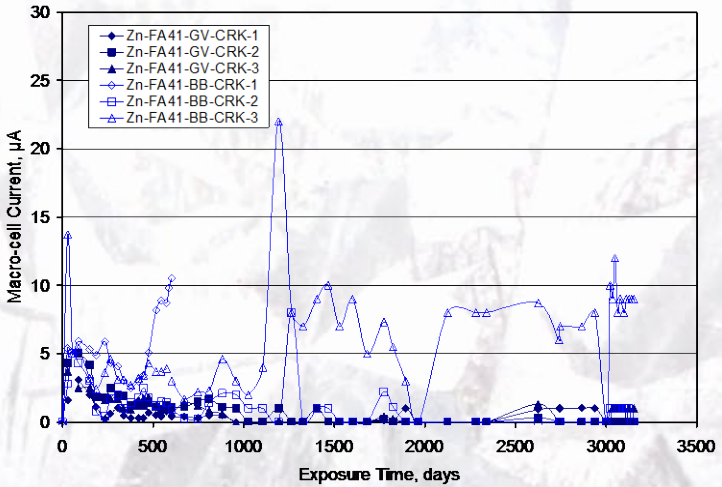


Specimen variables

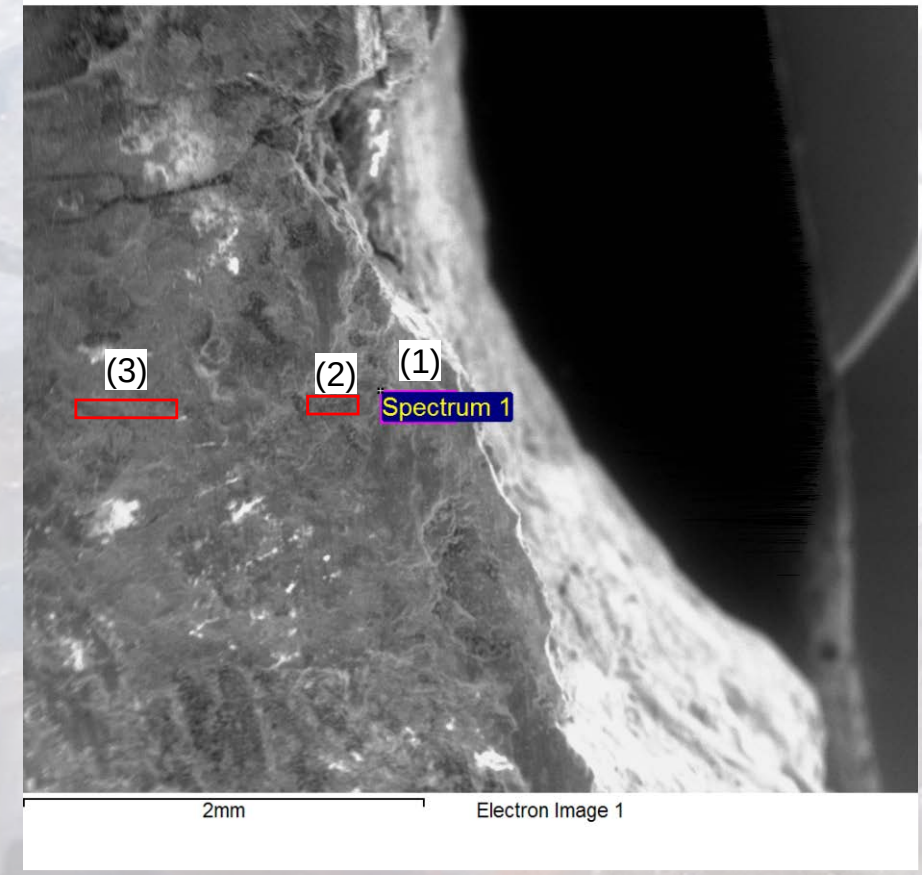
Bar Type	Black Bar
	Galvanized Bar
	Galfan Bar
Concrete Condition	Uncracked Concrete
	Cracked Concrete
Bar Condition	Straight, Undamaged
	Damaged
	Bent
Concrete Mix	No admixture
	Admixed with Fly Ash
	Admixed with Silica Fume
	Admixed with Calcium Nitrite

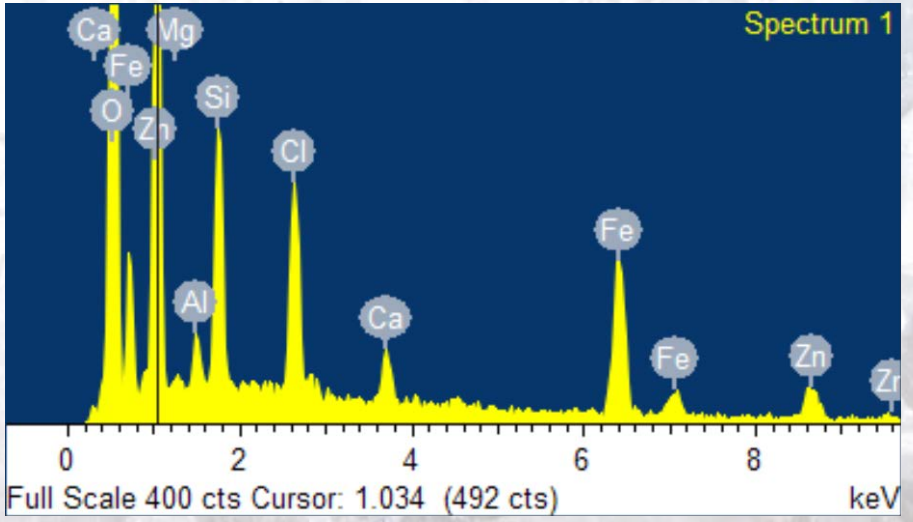
FA Concrete Specimens and CRK





E-SEM picture and EDS analysis in the vicinity of the rebar trace. For specimen FA-41-GV-CRK-1





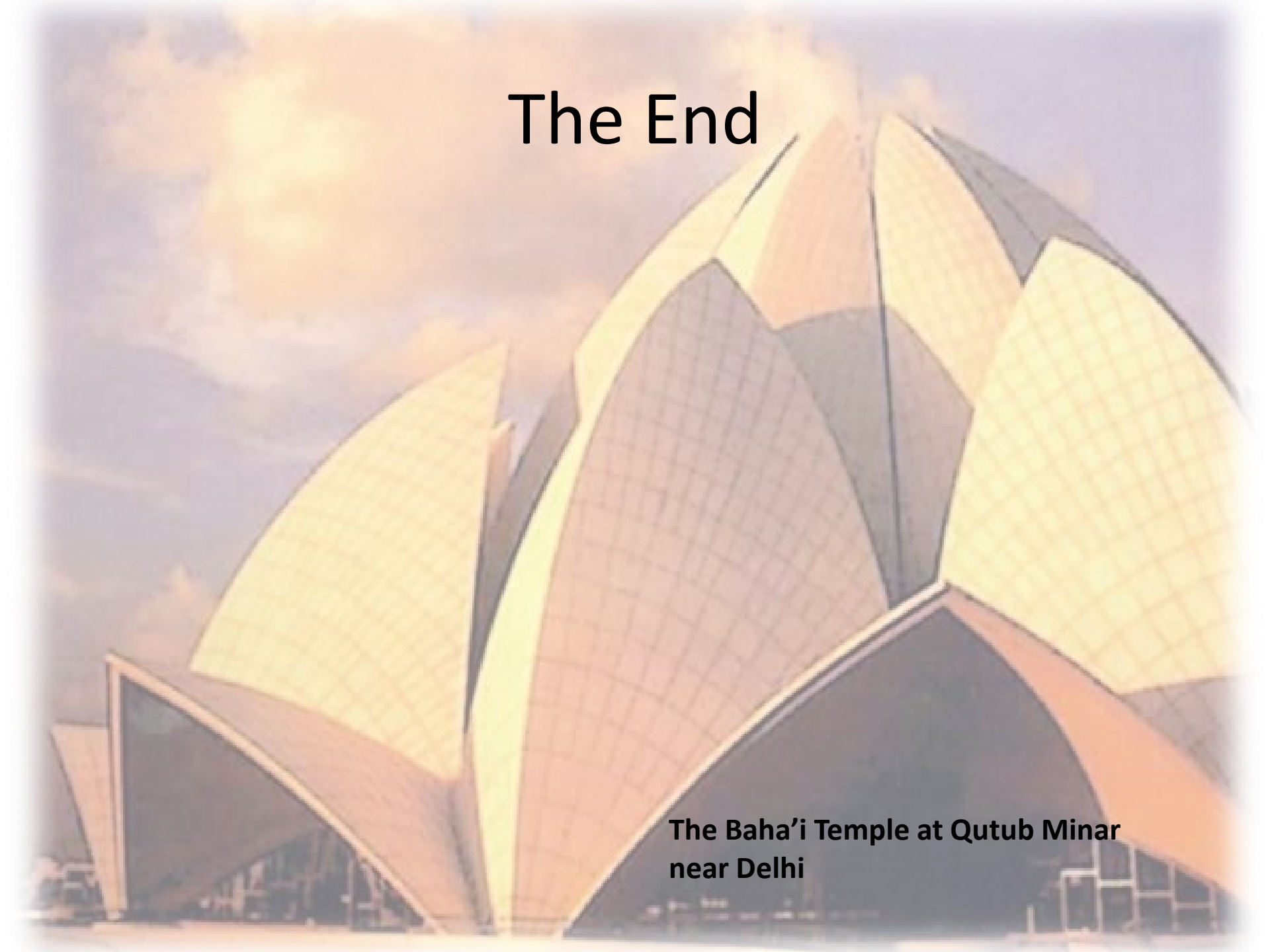
Zn in area (1) 21.41 wt%, (2) 7.2 wt%, (3) 6.26 wt%

FA41 GV-CRK, Cross section

Going Forward

- **Provide accurate, up to date information to the design community**
- **We need to tell the storey of the many galvanized reinforcing successes**
  - **There are many 40 and even 50 year old structures that clearly exhibit the benefits of galvanized reinforcing**
- **Underwrite and support continued research**

The End



The Baha'i Temple at Qutub Minar near Delhi

Elongation vs. Tensile of cold work bars after galvanizing