

aci Spring 2018 | Salt Lake City

The Concrete Convention  
and Exposition

**MASTER<sup>®</sup>**  
**BUILDERS**  
SOLUTIONS



## Reinforcement Corrosion, No Perfect Solution

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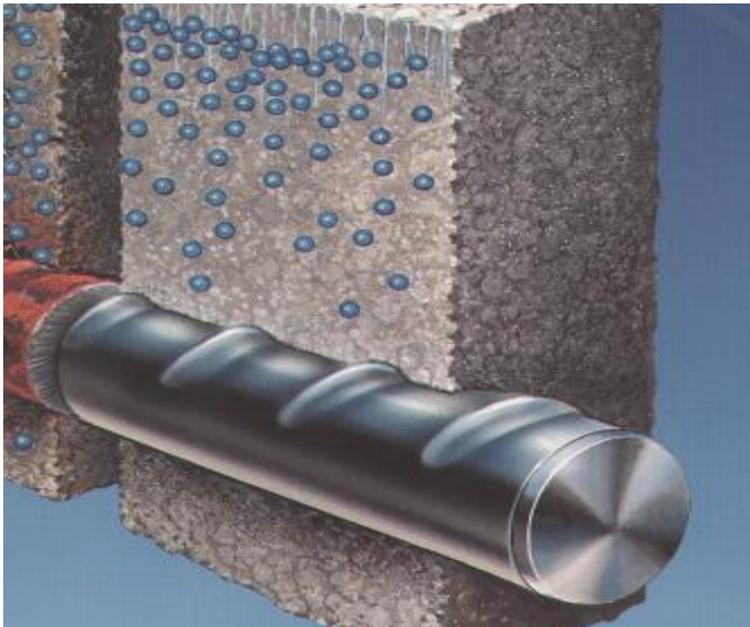


 **BASF**

The Chemical Company

# Concrete & Reinforcement Steel

## *A Strong Connection*



### Steel strengthens concrete

- » Concrete itself cannot withstand high tensile strengths
  - Usage of steel reinforcement to provide world's most widely used building composite

### Concrete protects steel

- » A dense layer of cover concrete acts as a barrier to the atmosphere
- » Alkalinity released during hydration sustains a stable oxide film on the surface
- » Additionally a lime rich layer forms on the steel surface, assisting passivation

# Corrosion of Steel in Concrete

*A huge cost to society...*

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CaCl<sub>2</sub> Grout Lowe's Motor Speedway Bridge Concord, North Carolina --

May 20, 2000



Rebar detailing and installation  
de la Concorde overpass in Laval  
Canada — Sept. 30, 2006

## Key Facts:

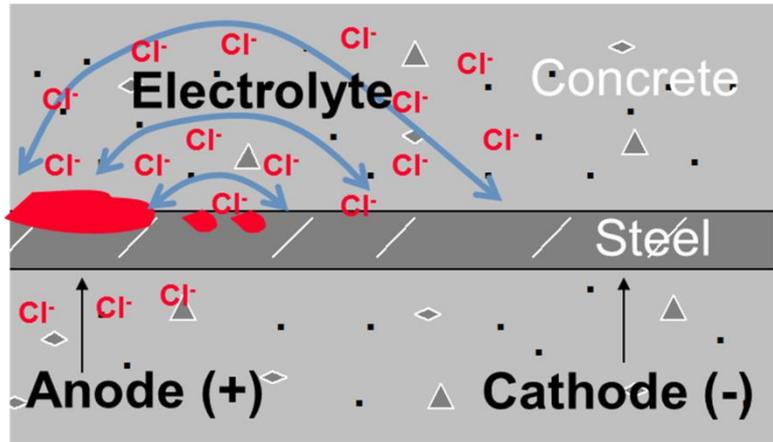
- » All steel reinforced concrete worldwide is at risk due to corrosion
- » Global cost of corrosion 1 - 5% of GNP
- » Global market size of corrosion mitigation in steel reinforced concrete = \$1 ¼ B (1 Bn€)
- » As long as we reinforce concrete with steel, it will rust.



**Natural laws: Concrete cracks – steel corrodes**

# Corrosion of Steel in Concrete

## *Electrochemical Process and Materials Science*

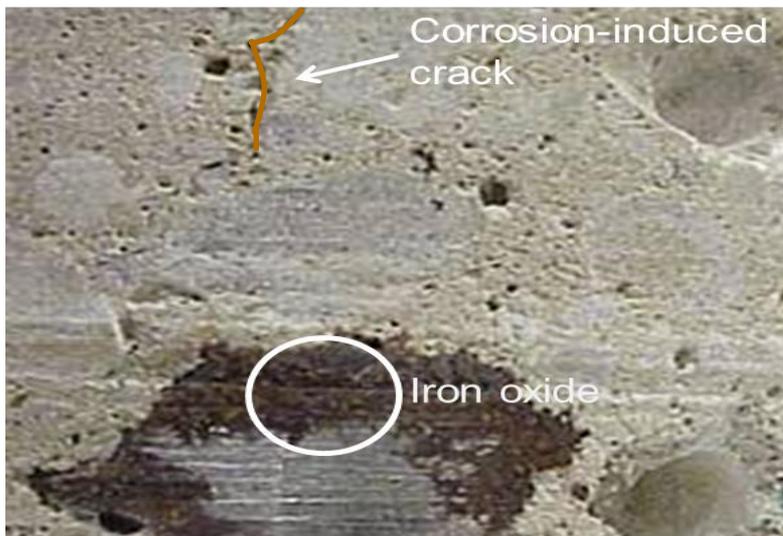


## Passivation layer can be breached

- » Halide ions  $>$   $\sim 330$  ppm
- » pH value  $<$   $\sim 10$
- » In combination with Oxygen, Temperature, resistivity etc...

## Steel corrosion is the problem

- » Conversion to iron oxide which occupies 4-10 times the volume
- » Internal pressure builds up, results in cracking and spalling of concrete
- » Loss of strength, weakening of the concrete faster deterioration, up to failure



# Corrosion:

There is no perfect Solution. We are still Learning.

## Why does Corrosion Occur?



## What Can We Do?



# RUST

THE SEASONAL APOCALYPSE  
HAS ARRIVED

ARE YOU PREPARED?

# Corrosion Management

*Essential element of sustainable strategy*

## Sustainability

### Corrosion Management of Concrete Construction

#### Economy



Provide return  
on investments

#### Environment

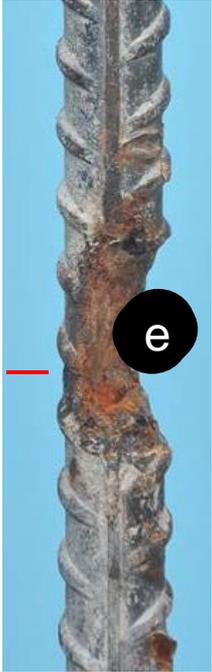


Protects  
resources

#### Social Responsibility



Saves Lives



## Anode

- Concrete Permeability
  - W/CM, Pozzolans, Chemical Additions
  - Membrane, Silane
- Corrosion Threshold
  - Inhibitor
  - Change Metal (i.e. Stainless)
- Reduce Reactive Surface
  - Coatings
- Reduce Corrosion Rate
  - Dry Out Concrete
- Force Opposite Reaction
  - Cathodic Protection

## Cathode

- Reduce Area of Reactive Surface
  - Coatings
- Dry Concrete
- Reduce Oxygen
- Reduce Cathode Effectiveness
  - Inhibitors
- Cathodic Protection



# RUST

## Electrical Continuity

- Disconnect Anode & Cathode
- Electrical Separation of Bars
  - Coatings

## Ionic Path

- Higher Resistivity
  - Lower W/CM
  - Dry Concrete
  - SCM



# Corrosion Prevention/Mitigation Strategies

## “Breaking the Chain”

### Mechanical/Physical

- Remove/Replace
- Barrier
- Chloride Extraction
- Alternative Materials

### Electrical

- Cathodic Protection

### Chemical

- Admixtures
- Surface Applied Corrosion Inhibitors





# Non-Corrosive Reinforcement

- Stainless steel, FRP bar and specialty alloys
- Galvanized steel
- Epoxy coated steel
- Fiber reinforced polymer



## PRO

- Permanent
- Eliminates Corrosion

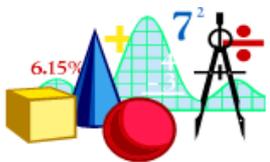
## CON

- EXPENSIVE
- Design may be different
- Compatibility with conventional reinforcing?
- Pinholes on Epoxy Coated
- Bond on galvanized & epoxy & FRP



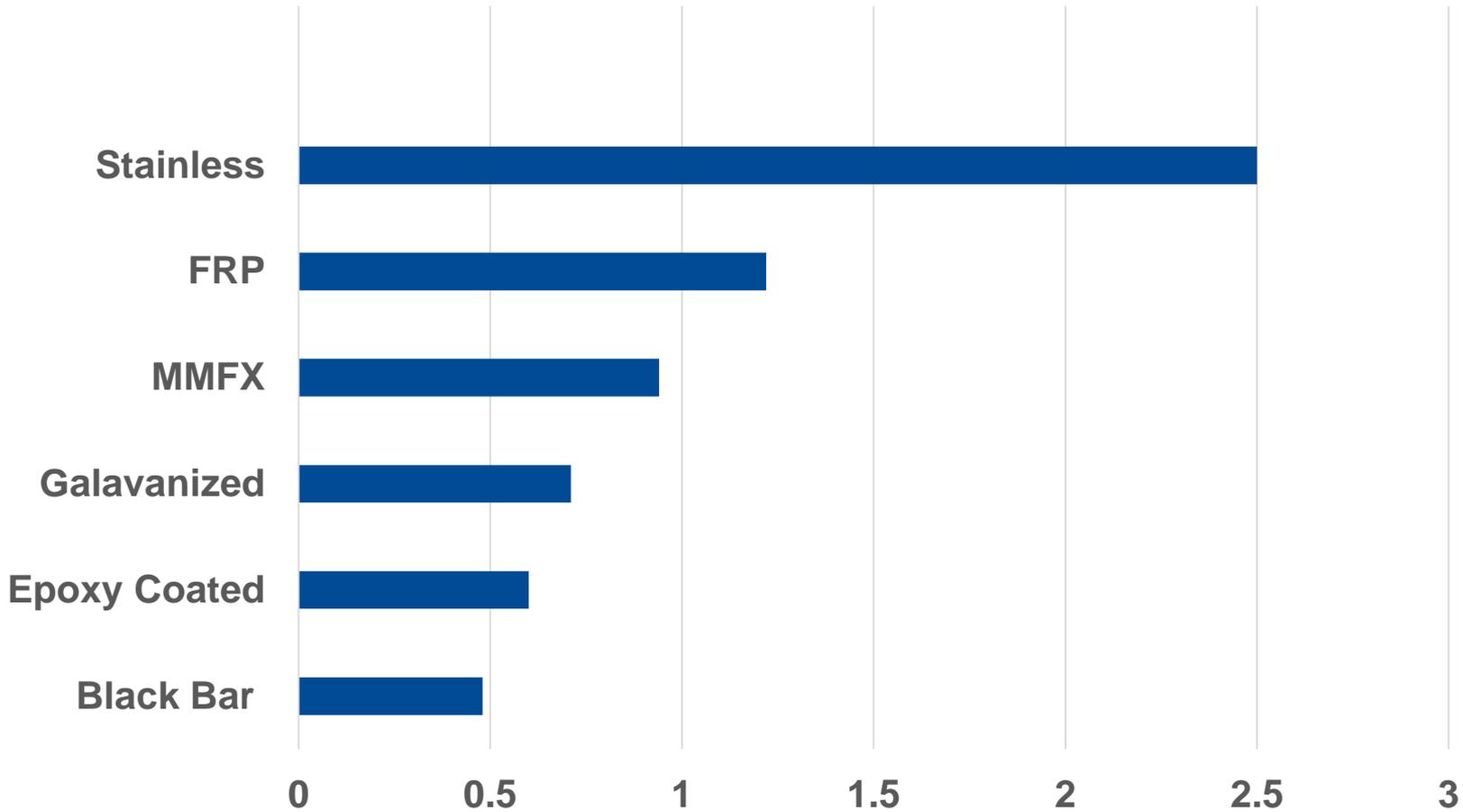
Stainless  
Galvanized  
Epoxy Coated Bar  
FRP

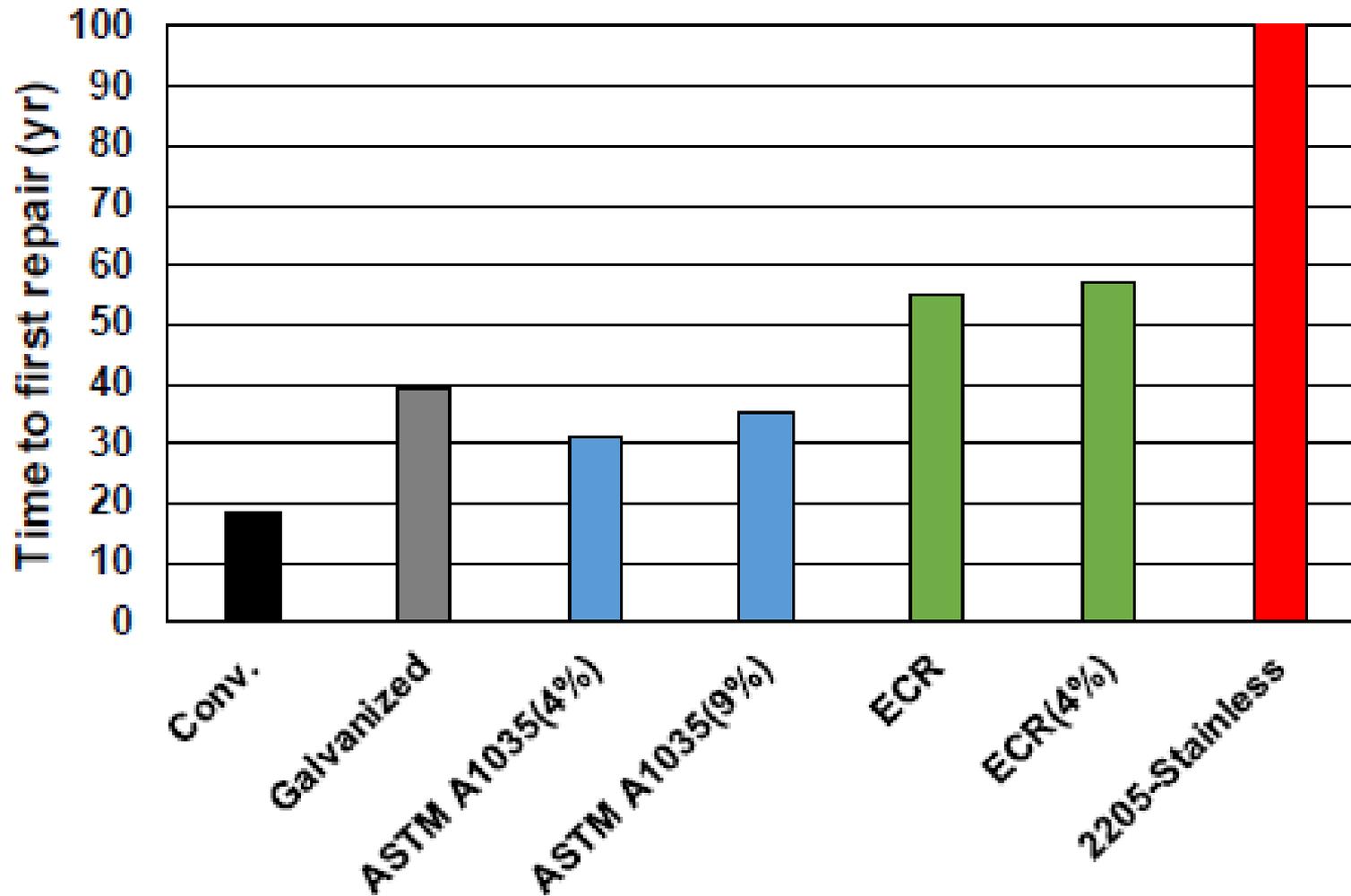
Bar  
Fabric  
Sheet



Design phase

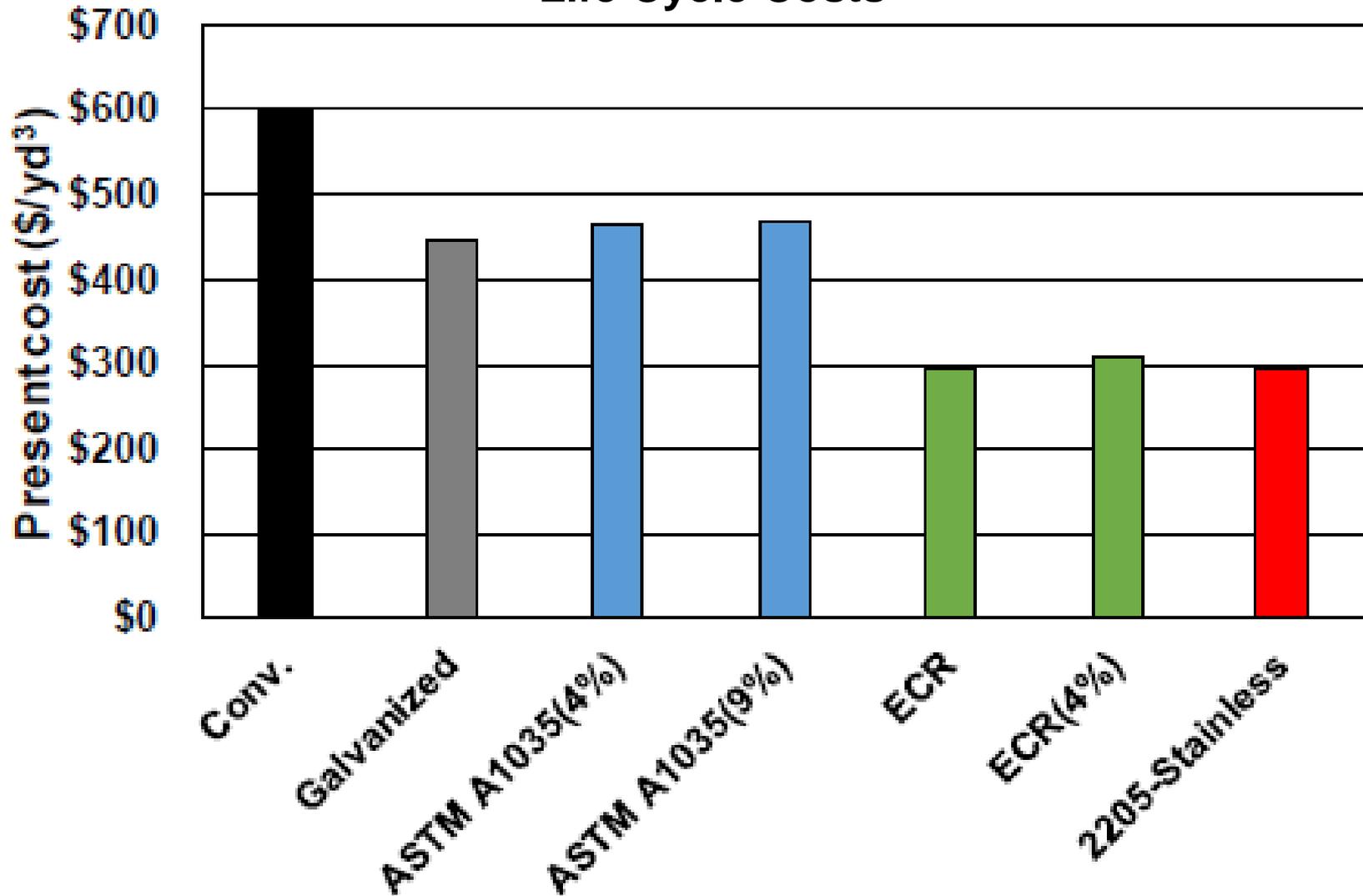
## Alternative Reinforcement Relative Costs





ACI Webinar D. Darwin Corrosion Protection Systems for Reinforcing Steel  
 Feb. 6, 2018

# Life Cycle Costs



ACI Webinar D. Darwin Corrosion Protection Systems for Reinforcing Steel  
Feb. 6, 2018

# Admixtures

- Adsorbed layer formers
- Oxidizing inhibitors
- Passivators
- Conversion layer formers
- Scavengers



## PRO

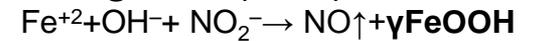
- Preventative
- Usage history
- Rebar Contact

## CON

- May leach
- Dosage Verification
- Dispersion Verification
- Concentration Dependency
- Consumption during inhibition?
- Proprietary



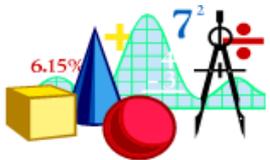
Inorganic (Nitrite)



Organic

Anode and Cathode effects

Coat steel & decrease permeability



## Design phase

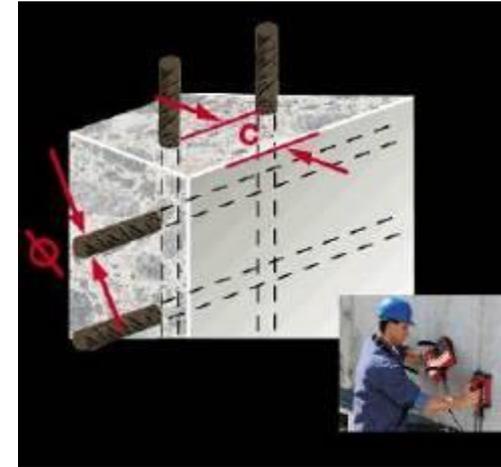


## PRO

- Renewable
- Inexpensive
- Possible to Enhance Appearance

## CON

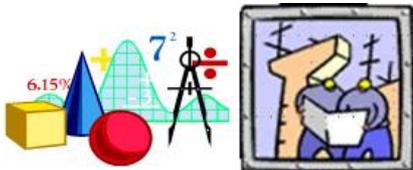
- Consumable (coatings)
- Section thickness increase (cover)
- Load increase
- Defects may magnify issues
- Detail and Inspection Intensive



Wall Coating Products

Structural Repair

Surface Repair





## PRO

- Aesthetic Appearance
- Relatively Inexpensive
- Recoatable & Repairable

## CON

- May Need Dry Substrate
- Surface Preparation
- Maintenance
- Abrasion & CTE
- Snow Removal
- Impermeable Trap Moisture



Deck Membrane Products

**Construction, Maintenance, Repair Phases**

## Reinforcement Coatings

**E** Epoxy  
**E** Cement/epoxy hybrid  
**E** Cement latex  
**E** Zinc based

PROTECTION

### PRO

- Field application
- Low cost
- Mature technology
- Some claim bonding agents

### CON

- Pinholes & Under-bar
- Bond to Concrete Window?
- Continuity of Coating
- Hardening Depending on Environment
- Incipient Anode



Rebar/Corrosion Protection



Repair Phase

# Penetrating Sealers

**E** Silane  
**E** Siloxane  
**E** Siliconate  
**E** Others



## PRO

- Renewable
- Inexpensive
- No Appearance
- Easy to apply
- Hydrophobization

## CON

- Consumable
- Maintenance
- Effectiveness Monitoring
- High Hydrostatic
- Crack Bridging
- Solvent?
- Overspray



Maintenance & Repair Phases

Water Repellents

# SACI

- Amino alcohol
- Amino carboxylate
- Silicate
- Aminofunctional silanes
- Nitrites



## PRO

- Renewable
- Inexpensive
- No Appearance
- Easy to apply

## CON

- Inhibition, not solving
- Effectiveness monitoring
- Penetration
- Residue
- Volatility
- Many technologies
- Life cycle
- Product compatibility



# Galvanic Anodes



- “Hockey Pucks”
- Hydrogel
- Arc Spray
- Imbedded mesh
- Hybrid

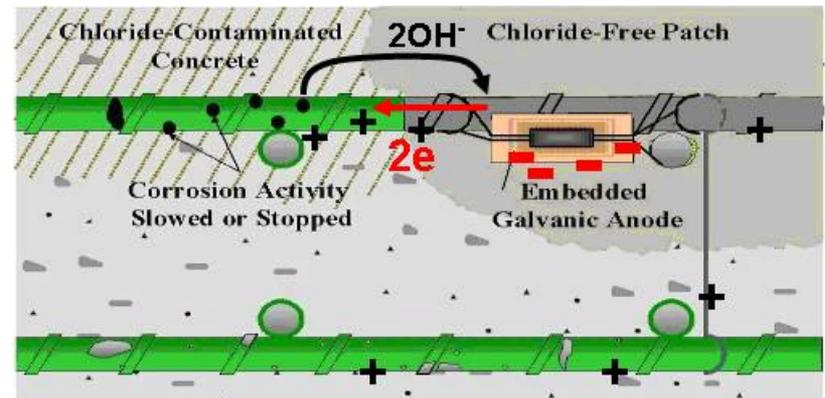
- Point source or general protection
- Follow corrosion activity (i.e. RH-Temp)
- Effectiveness monitoring
- Ring / incipient anode
- Self powered

## CON

- Consumable
- Passivation?
- Excavation
- Oxidation buildup



Construction & Repair Phases



# Impressed Current



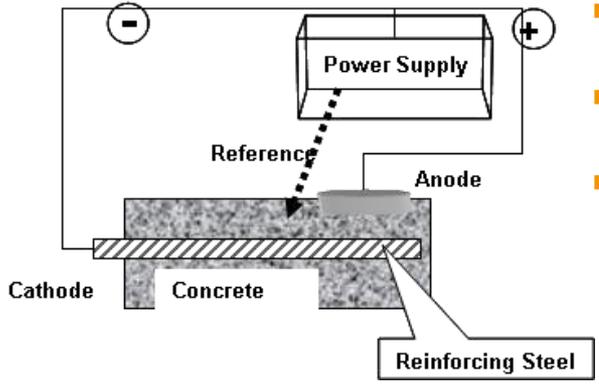
- ICCP
  - Discrete Anodes
  - Strip Systems
  - Coatings
  - Mortar Systems
- Electrochemical Chloride Extraction
- Realkalization
- Electrochemical moisture extraction

## PRO

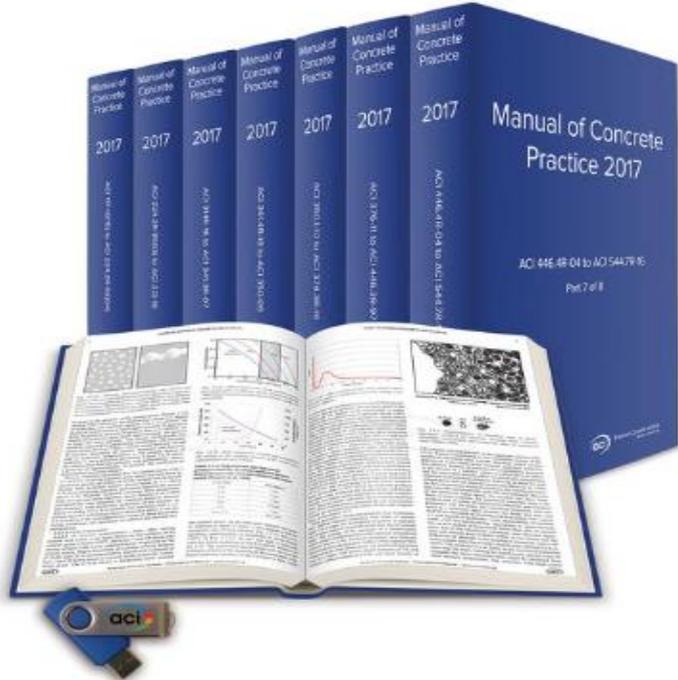
- ICCP Proven to Prevent
- Usage History
- Various Systems

## CON

- Expensive
- Design and maintenance critical
- Reinforcement continuity
- Anode acidification
- May cause AAR
- H<sub>2</sub> Generation?
- Appearance?



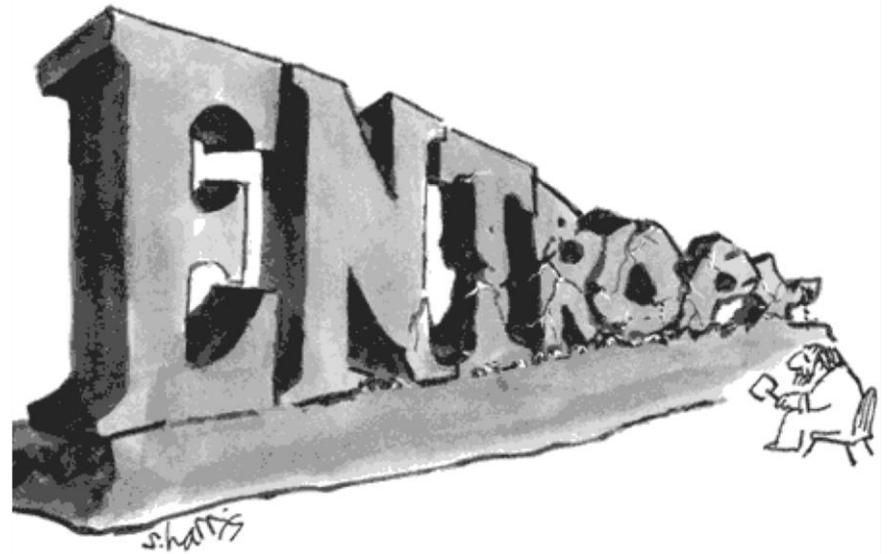
Design, Construction, & Repair Phases



## Good Trade Practices

- DDAS with design
- Low W/CM
- Satisfactory Material Quality
- Enough Binder for Strength
- Consistency for Consolidation
- Enough Cover
- Sufficiently Cured...

**Keep the Water Out!**



**It's not so much about letting it go as submitting to the inevitable**

## Concrete Maintenance

- Verify
- Inspect
- Fix cracks
- Keep the Water Out!

Don't Delay, Problems **GROW**



# Questions ?

# THANK YOU!

Fred Goodwin FACI, FICRI, FASTM  
Head Corrosion Competency Center  
BASF Construction Chemicals, EB-N